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Floodplains Reimagined: Juvenile salmon floodplain habitat suitability criteria and application to baseline conditions

Memorandum

Provided to the Floodplains Reimagined Program Team
Prepared by Alison A. Whipple (San Francisco Estuary Institute), in collaboration with Jesse Rowles and Chris Campbell (cbec, inc.)

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Overview

The loss of functional floodplain habitat in California's Central Valley has substantially contributed to species declines and ecosystem change. Through voluntary collaborative partnerships with private landowners, sovereign tribal entities, government, and non-government representatives, the Floodplains Reimagined Program ("Program" herein) seeks to increase connectivity of flood bypasses and agricultural fields with the Sacramento River to affect certain floodplain conditions such as frequency and duration of inundation. The intention is to improve ecological floodplain functions in support of juvenile rearing Chinook salmon and Pacific Flyway birds, while also considering flood benefits, agriculture, recreation, and indigenous cultural values. The first phase of the Program involved the establishment of priorities and objectives for the Program and related methods, criteria, and metrics used to quantify the objectives. This memorandum presents juvenile salmon habitat criteria for managed floodplains, selected to evaluate objectives addressing increasing hydrologic connectivity and juvenile floodplain rearing habitat availability.

The criteria are simplifications of highly complex physical and biological processes and interactions and are applied within a modeling context. The selection of criteria is also complicated by the fact that the application is to highly modified floodplains that currently primarily serve as flood bypasses and agriculture, where the science from naturally functioning floodplain science is important but not always enough. In addition, such criteria may be relatively more important within highly managed floodplain environments compared to process-based restoration of more naturally functioning floodplains, where there is less concern about carefully managing habitat conditions. The suitability analysis provides approximations of potential benefits to juvenile salmon, given the criteria, assumptions, and simplifications of the approach described herein. The criteria are intended to be used to estimate current conditions and compare relative changes as a result of hydrologic and hydrodynamic changes due to one or more proposed actions to increase hydrologic connectivity within the highly modified floodplain environments in the Program's footprint. They do not represent an absolute measure of available habitat as the modeling and evaluation effort is limited to those factors that can be readily evaluated using hydrodynamic modeling output.

Rationale

Naturally functioning floodplain environments are some of the most diverse and productive systems globally (Amoros and Bornette, 2002; Tockner and Stanford, 2002; Ward et al., 1999). These transition zones are defined by spatially and temporally dynamic mosaics of aquatic and terrestrial habitats. Floodplains are broadly recognized for their integral connection to the river's flow regime, hydrologic and geomorphic processes that move sediment and organic matter and maintain a dynamic mosaic of habitats, nutrient cycling, food web support, and spawning and rearing habitat for fish (Opperman et al., 2017). Research from systems around the world demonstrate the high value of floodplains for fish (e.g., Balcombe et al., 2007; Bayley, 1991; Bellmore et al., 2013; Gorski et al., 2011; Pratt et al., 2023). Substantial human modifications to rivers and their floodplains globally have resulted in ecosystem degradation and species loss, prompting calls for reconnection of rivers and their floodplains (Dudgeon et al., 2006; Tockner and Stanford, 2002). In the Central Valley of California, the once vast wetlands within the flood basins along the Sacramento River were part of a complex and dynamic river-wetland corridor (The Bay Institute, 1998; Whipple et al., 2012), which helped support Central Valley salmon populations. Aligned with global patterns, the loss of approximately 95% of historical floodplain wetland habitats in the Central Valley (The Bay Institute, 1998) has profoundly changed the complex interaction of physical and ecological processes and habitat conditions to which native species are adapted, with loss of floodplain habitat considered as a key contributor to declines in salmon populations (NMFS, 2014; Waples et al., 2009). Research over the last several decades has pointed to potential growth and life history diversification benefits of rearing juvenile salmon in slower-moving and warmer waters of inundated Central Valley flood bypasses and agricultural lands, likely mimicking some functions of former floodplain processes (Goertler et al., 2018; Jeffres et al., 2008; Katz et al., 2017; Sommer et al., 2001; Takata et al., 2017). Efforts such as the Floodplains Reimagined Program seek to improve conditions and key functions that are likely to support Central Valley salmon populations, among other benefits. A habitat quantification approach, such as described here, can provide a means to assess key characteristics of suitable floodplain conditions for rearing juvenile salmon.

Criteria Development Process

The criteria recommendations presented in this memo represent the outcomes of a series of Salmon Ad-Hoc Committee meetings. The recommendations were subsequently approved by the Advisory Committee and Steering Committee. Initial criteria were developed based on review of criteria applied in similar prior efforts. In addition, only criteria that could be evaluated from the hydrodynamic model were included for consideration. Criteria were further refined by the Program team through exploration of initial model results and sensitivity testing. Three Ad-Hoc meetings were held in 2022 and 2023, involving representatives from fisheries agencies, NGOs, consultants, as well as land owners, all of whom were also part of the Advisory or Steering Committees. Feedback centered on defining what conditions related to each of the criteria should be considered suitable.

Juvenile Salmon Habitat Suitability Criteria

The Program recommends the criteria listed in Table 1 to quantify juvenile salmon floodplain rearing habitat suitability within the context of Program goals, assumptions, and limitations. While many factors affect suitability, criteria were selected based on physical habitat criteria that could be evaluated from the hydrodynamic modeling output, were relevant for comparing different scenarios, and were considered to be most limiting. These include timing, duration, depth, velocity, connectivity, and land cover. The criteria, their conditions, and associated suitability values were kept as simple as possible for a number of reasons, including that simplicity would facilitate the interpretation of results, not add specificity beyond what is needed or appropriate given scientific understanding and model uncertainty, and reflect the intended use of the criteria as a screening tool to evaluate overall relative benefits across different management or land use scenarios. Suitability values associated with each of the criteria were limited to just three values: 1 (good condition), 0.66 (suboptimal), or 0 (not suitable). These therefore represent general bins of quality and should not be interpreted to mean that a given condition with a suitability score of 1 is exactly 50% better than one with a score of 0.66.

Table 1. *Juvenile habitat suitability criteria recommended for comparing management action scenario outcomes within the Floodplains Reimagined Program.*

Criteria	Key source(s)	Condition	Value
Timing	Whipple et al. (2019)	November 1 - June 30	1
Duration	DWR and USBR (2012); Górski et al. (2013)	≥ 14 days	1
		< 14 days	0.66
Depth	Ad-Hoc feedback; DWR and USBR (2012); KSN, Inc. (2021)	> 0.9 ft	1
		0.6 - 0.9 ft	0.66
Velocity	DWR and USBR (2012); Whipple et al. (2019)	≤ 1.5 ft/s	1
Connectivity	Ad-Hoc feedback	Naturally inundated areas: hydraulically connected (with water depths > 0.3 ft) to upstream/downstream waterways	1
		Managed fields: Considered connected when field perimeter berms overtop and disconnected when all structures are disconnected or depth drops below 0.6 ft. Two types of connectivity occur within this definition:	
		1) Field berm overtopping (initiates connectivity event)	1
		2) Managed inundation, with flow over outlet structure (or possible management action of leaky outlet	0.66

		structure), where field depth is at least 0.6 ft. Assumes that boards are pulled at 0.6 ft depth to allow egress.	
Land cover	Ad-Hoc feedback	Riparian / Wetlands / Open water	1
		Rice / Other Agriculture	0.66

The approach to apply these criteria is consistent with the science-based hydrospatial analysis approach used by the Program across the suitability criteria analyses. This approach has precedence in prior floodplain habitat evaluation and restoration efforts, and it follows the hydrospatial analysis approach developed by Whipple (2018) and adapted for the Central Valley Habitat Exchange Chinook salmon habitat quantification tool (Whipple et al., 2019). It estimates suitability based on physical criteria that are applied in a spatially- and temporally-resolved way, such that suitable habitat can be evaluated over space and time and summed to a total available floodplain habitat measured as suitable "acre-days" (area summed over time). Additionally, when calculating across multiple years or other divisions such as flood events, variability in conditions can be assessed (e.g., variability related to wet and dry years or small versus large flood events). When applied to restoration, management, or climate change scenarios, for example, the hydrospatial analysis approach allows users to determine the relative impact of such changes on expected habitat in a temporally- and spatially-explicit way.

The approach uses concepts typical for evaluating suitable habitat from hydrodynamic modeling, which includes the use of habitat suitability criteria to assign index scores to estimates of physical parameters from hydrodynamic modeling outputs (e.g., depth). In this approach, these criteria are applied on a cell-by-cell basis on a daily time step. The index scores or habitat suitability indices (HSI) for each parameter are then combined together for a global habitat suitability value (gHSI). For a single cell on one day, this calculation can be generalized to:

$$HSI_{global} = (criteria_1 HSI) * (criteria_2 HSI) * \ldots$$

In the case of this application, the calculation equates to:

$$HSI_{global} = HSI_{timing} * HSI_{duration} * \sqrt{HSI_{depth} * HSI_{velocity}} * HSI_{connectivity} * HSI_{cover}$$

Grids of cell suitability can then be summarized over the model domain or specified areas for total WUA on day t (units of area):

$$WUA_t = (raster\ cell\ area) * \sum_{n=1}^{n} gHSI_n$$

where *n* is the total number of cells. To summarize over time, the sum of daily WUA for a period of time is calculated (units of acre-days):

$$WUA_{days} = \sum_{t=1}^{t} WUA_t$$

where *t* is the total number of days in the analysis period.

Timing

The timing criterion is drawn from the Habitat Quantification Tool criteria, defining a window from November 1 through June 30 to receive a suitability value of 1 (Whipple et al., 2019). This was established to encompass the time window where fish from different salmon runs are present in the greatest numbers (NMFS, 2014; Williams, 2006). However, though natural flood events that occur late in the season can generate important floodplain habitat, the late spring period may be outside the desired window for managed inundation. Timing could be refined further, depending on desired levels of inclusivity and specificity. This criterion did not receive substantial feedback from advisors.

Duration

The duration criteria were established based on a compilation of sources, precedents from prior efforts, and a desire to keep values relatively simple (Cal Marsh and Farm Ventures, 2020; DWR and USBR, 2012; Whipple et al., 2019). A 14-day threshold was used where shorter durations receive a suitability value of 0.66 and 14 days and longer receive a suitability value of 1. Generally, the preference for longer duration inundation relates to the time to support zooplankton production as food and to give higher credit to less ephemeral habitat, allowing for meaningful rearing opportunities. Sources suggest that anywhere from a week to three weeks allows for the development of high prey densities (e.g., Górski et al., 2013), so the 14-day threshold between suboptimal (0.66) and good conditions (1) is an intermediate value. This was preferred by advisors over a more conservative longer duration requirement.

Depth

Water depth affects foraging behavior and predator avoidance. Depths below 0.6 ft were considered to be too shallow for juvenile fish. Depths between 0.6 and 0.9 ft receive a suitability value of 0.66, and anything deeper receives a value of 1. The criteria to represent depth were adjusted substantially over the development period. Feedback in the November 2022 Ad-Hoc meeting resulted in the addition of a non-optimal category of 0.6 - 0.9 ft, which would include the 10 inch managed depth of agricultural fields. In this meeting, it was suggested that the initially proposed upper depth maximum of 6.6 ft be removed to simplify interpretation as consensus could not be reached on an appropriate threshold. Use of a 2 ft threshold, above which suitability values would be reduced to suboptimal (0.66), was also explored, with precedents in other efforts, such as the Yolo Bypass 2012 Implementation Plan (DWR and USBR, 2012).

In the March 2023 Advisory Committee Meeting, some questioned the exclusion of a maximum depth threshold, and supported reducing suitability for depths of six feet or greater. Others made the point that suitability for deeper depths is not well understood for floodplain environments. These diverging viewpoints demonstrate that suitability for deeper depths remains a substantial area of uncertainty, which warrants revisiting in future phases, considering in the interpretation of results (see subsequent sections), and investigating through further research.

Velocity

The criteria for velocity use a single threshold value of 1.5 ft/s, where higher velocities are not considered suitable. This value was selected based on similar prior efforts. The Habitat Quantification Tool (Whipple et al., 2019) and Yolo 2012 Implementation Plan (DWR and USBR, 2012) both used similar values (1.5 ft/s and 1.3 ft/s, respectively). The Sutter Bypass Management Plan (KSN, Inc., 2021) also assigned optimal conditions to velocities below 1.8 ft/s (with lower suitability values up to 4.0 ft/s). Feedback during the Ad-Hoc and Advisory Committee meeting suggested that this was an acceptable condition to use for velocity.

Connectivity

While the concept of hydraulic connectivity is relatively straightforward, evaluating it within the constraints of the model is challenging and requires assumptions (see section below). First, any unmanaged inundated area that was hydraulically connected to waterways receives a value of 1. For managed fields, only field perimeter berm overtopping (as occurs during a flood event) can trigger connectivity, so berm overtopping conditions mean that the field is assigned a value of 1. Once berm overtopping stops and the field drains via an outlet structure, connectivity is assigned a suboptimal value (0.66) until the minimum depth threshold of 0.6 ft is reached (note that under baseline conditions, fields are managed at 10 inches, so this condition is likely to only occur under potential alternative scenarios considered in future phases of Floodplains Reimagined). These assignments reflect general consensus around the concept that natural hydraulic connectivity is preferred to that through infrastructure, given limits on passage efficiency. Discussions for this criterion also addressed whether short periods of disconnection (ponding) should be considered suitable, and there was preference to only consider areas maintaining connection at all times. The need for further exploration of hydraulic connectivity across the landscape, through various canals to the main river channel, was a core area of feedback, and should be explored in future phases of the work (see following sections).

Land cover

The cover criteria assign either good condition or sub-optimal values to all land cover types. The criteria make the basic distinction between natural and managed land cover types to give a higher weight to natural types. This is because habitat complexity associated with natural cover types is generally considered to offer a wide range of habitat conditions and be supportive overall of ecosystem functions, but also the inherent challenge of managing for specific ecological conditions when not all variables are well known or easily controlled. In the November 2022 Ad-Hoc meeting, the point was raised that cover criteria may not be very useful, and that turbidity may be more of a determinant of habitat quality (though this parameter is not modeled). Discussion of the substantial uncertainty and question of the value of including a land cover criterion continued in the February 2023 Ad-Hoc meeting and the March 2023 Advisory Committee meeting. It was also noted that greater refinement of land cover types could also be warranted as some crops or agricultural practices may not be conducive at all for salmon rearing habitat.

Other criteria

Additionally, criteria of inundation frequency and floodplain conditions were initially considered, but subsequently removed. Inundation frequency was deemed unnecessary given too many nuances (e.g., dependencies on timing, antecedent conditions) and that this did not seem to be a determining factor for rearing habitat suitability. Floodplain conditions - whether an area was natural or unmanaged versus managed - was considered to be addressed by land cover and connectivity criteria.

Assumptions and Uncertainties

Over the course of developing the criteria, discussions with advisors made it clear that the assumptions and uncertainties associated with the approach and the criteria were equally important as the criteria themselves. These qualifications arise both in terms of the overall approach, as well as the science and understanding supporting specific values used. Many assumptions and uncertainties could be addressed through additional exploration and discussion in future phases of this Program as well as in new scientific studies and monitoring efforts.

An overarching assumption inherent to the habitat suitability assessment approach is that increased extent and access of suitable floodplain rearing habitat will actually benefit juvenile fish and confer population-level benefits to salmon. Good outcomes for fish are interpreted as those that support reproductive success, where greater growth and/or lower in-river mortality confer higher return rates from the ocean, leading to higher reproductive success. Within this assumption is the idea that juveniles are able to access the area (or that the area will not be counted unless it is accessible) and that the process of accessing the habitat doesn't affect mortality (or at least additional mortality is compensated by better growth of survivors). With the focus on floodplain habitat, modeling and analysis centers on comparison of management scenarios within the floodplain and does not compare the relative benefits between floodplain and in-river habitats. Also, the approach is developed for application in highly modified floodplain environments and does not capture the many complex processes and interactions that ultimately support salmonid populations in naturally functioning floodplains. Additionally, the focus on juvenile rearing habitat means that other factors, such as stranding potential, and impacts to other life stages, such as adult migration, are not accounted for.

A substantial area of uncertainty lies within the assignment of suitability criteria within a modeling context. Much of the science concerning habitat suitability, such as depth and velocity tolerances and preferences, comes out of literature on in-stream conditions as opposed to floodplain environments. Assignment of criteria and suitability values also drew on precedents set by other floodplain habitat and floodplain modeling applications, which may not align with the goals and priorities of the Floodplains Reimagined Program. There is a general lack of observational data on the habitat preferences of juvenile salmonids on floodplains, and particularly agricultural fields. Various simplifications in the model also introduce uncertainty. The necessary "hydroflattened" field units for modeling purposes means that much of the small-scale complexity in natural environments that is likely important to fish is not considered in this analysis. There are also assumptions about ingress and egress opportunities during berm overtopping events and structure connections that cannot be evaluated in greater detail due to the resolution of the model. Another area of uncertainty is that, limited by variables that are part of the hydrodynamic modeling, the analysis does not include other potentially important factors affecting habitat suitability, such as temperature, turbidity, contaminants and toxins, and microhabitat conditions.

More specific assumptions and uncertainties are provided in the following bullets associated with specific criteria:

- **Depth:** The criteria assume that there is no negative effect on juvenile salmon of increasing water depth. However, there was a divergence of viewpoint by participants in the Ad-Hoc Group and Advisory Committee around whether a maximum depth should be included for habitat considered to be in "good condition". While habitat suitability studies for juvenile salmon tend to include upper depth limits, some thought that these limits may be less relevant in floodplain environments. Others felt that it made sense to be conservative and include a lower value for deeper inundation. Another consideration is that the depth range considered suboptimal (0.6 - 0.9 ft) includes the 10 inch managed depth that the model assumes fields are held to during winter non-flood conditions (though fields under these conditions are also not likely to be connected, and therefore likely do not meet connectivity suitability criteria).
- **Cover:** The criteria assume that habitat complexity (e.g., variable depth) and availability of refugia (from predators and high flow velocities) on natural land cover types generally provide more opportunities for higher quality habitat relative to highly managed agriculture. It is also an expression of the understanding that increased management complexity associated with managed floodplains and agriculture translates to greater challenges to provide suitable habitat (more opportunities for things to go wrong). It is difficult to know the relative difference in benefits between natural and agricultural cover types. Another consideration is that turbidity (which is not able to be modeled in this effort) may be a more important determinant of suitability and negate the relevance of distinguishing between different land cover types. Overall, there is considerable uncertainty and divergence of viewpoint around whether natural land cover is substantially better than agriculture in inundated managed floodplain environments and warrants distinction in this analysis.
- **Connectivity:** Meaningful connectivity evaluation is important because additional floodplain habitat is not valuable to salmon if they cannot volitionally and safely enter and exit fields and navigate channel complexities or infrastructure to re-enter the river corridor to continue migration downstream. Connectivity of a given cell is assessed as to whether it is hydraulically connected to a nearby waterway (meeting the 0.3 ft depth threshold). However, though these channels ultimately connect to the primary river corridors, the distance, how convoluted (e.g., highly impacted by management infrastructure) that connection might be, and the habitat quality of that connection is not considered in the analysis. Furthermore, whether connectivity pathways within the landscape are primarily serving ingress or egress functions is not assessed, so it is not possible to separately track whether a location is connected for ingress, egress, or both. Results from this analysis therefore contain substantial uncertainty when it comes to how readily accessible a location is for juvenile salmon. Within a managed agricultural field, the

criteria assume that berm overtopping allows volitional passage to occur on and off the field under those conditions. Addressing some of the associated uncertainties through greater model resolution in terms of, for example, local flow direction and magnitude, is beyond the scope of the hydrodynamic modeling. The likely greater limitations to volitional egress through outlet structures (as well as for other management alternatives such as through leaky boards) is reflected in the suboptimal (0.66) assignment. This generalized assignment does not account for the considerable variability in connection quality at a local level, which is beyond the resolution of the model. The modeling of suitability criteria must also make assumptions regarding management, including that infrastructure management occurs to support fish entering and exiting (e.g., boards pulled to prevent stranding).

Baseline Results

The application of the juvenile salmon rearing habitat criteria to baseline hydrodynamic modeling results across five different water year types suggests that the suitability-weighted acre-days of habitat follows water year type variability, where more habitat is available in the wetter years (e.g., 2019) versus drier years (e.g., 2013 and 2015; Figure 1). Year to year variability is substantial, with coefficients of variability for Sutter of 41% and Butte of 33%. The average acre-days across the years is roughly half of the wetted area that is considered connected to the channel network by the model (Sutter: 55.8%, Butte: 52.0%). This suggests that, while the Butte subregion offers approximately four times as much suitable habitat as the Sutter subregion on average (2.31 million acre-days versus 0.68 million acre-days), this is largely due to the differences in connected wetted area.

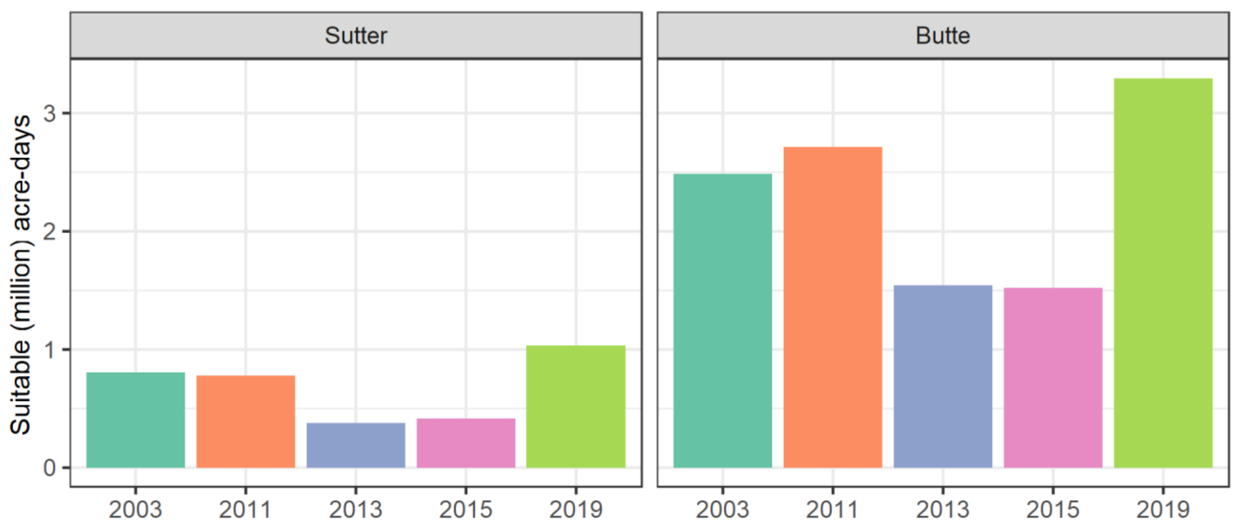

Figure 1. *Suitability-weighted juvenile salmon rearing habitat in millions of acre-days across the three subregions of the study area for each of the modeled water years.*

When examined over time, daily values of suitability-weighted acres largely follow the patterns of the annual hydrograph (Figure 2), with brief periods of high peaks associated with the flood peaks and longer periods of recession (Figure 3). The daily suitability also illustrates how closely the variability follows connected wetted area, suggesting that this is a primary factor affecting overall juvenile salmon rearing suitability for this approach and analysis. While the time series for a given year for each of the subregions have similar patterns, they are also fairly different. For example, the large peak for Butte in 2011 is not substantially greater for Sutter than the first peak of the season. The daily time series also shows that suitable habitat is not only greater in magnitude for Butte relative to Sutter on a given day, but suitable habitat occurs both earlier and later in the season across all water years.

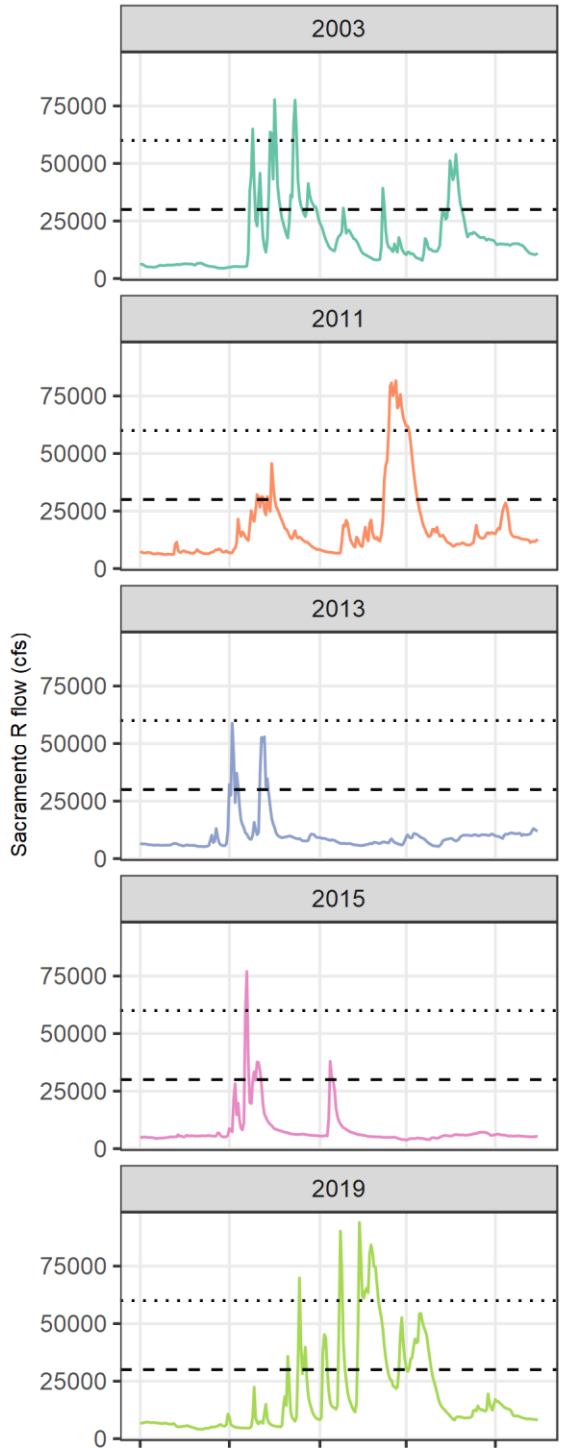

Figure 2. *Daily hydrograph for the each of the five modeled water years. Flow (cfs) is modeled flow near the Butte City streamgage. Horizontal lines represent Moulton weir activation (dotted line, ~60,000 cfs) and Colusa weir activation (dashed line, ~30,000 cfs).*

Next Steps

The criteria presented in this memo are recommended for use in comparing management scenarios going forward in future phases of the Floodplains Reimagined Program. Given concerns around several areas of key uncertainties, particularly depth, land cover, and connectivity, the Program team and technical advisors recommend additional model sensitivity testing and focused literature synthesis, as well as careful presentation and interpretation of results. Additional research would help address underlying scientific uncertainties and help refine criteria. The following points describe next steps in terms of further exploration of options to address uncertainties within the modeling context and in terms of scientific research and monitoring opportunities.

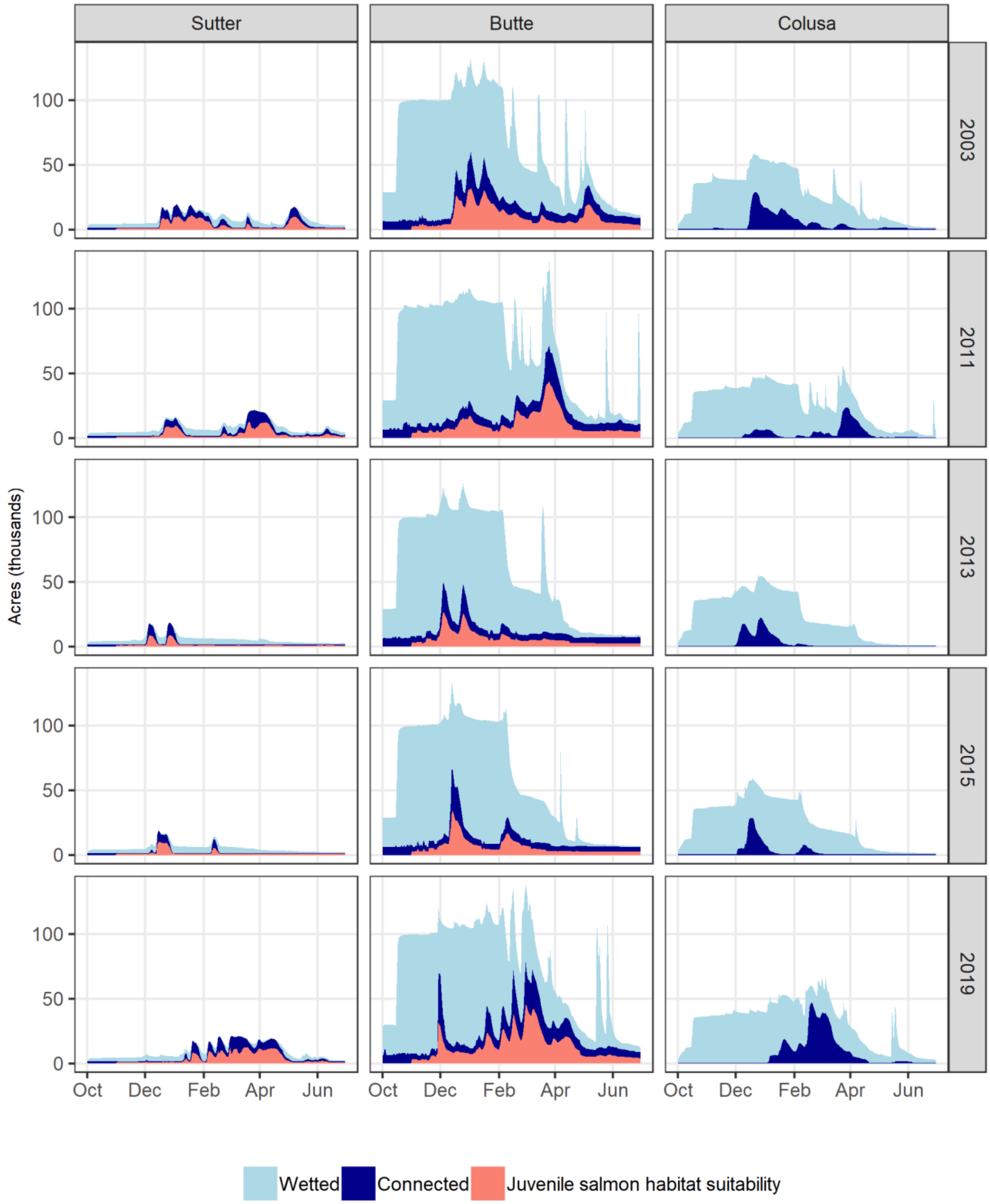

Figure 3. *Daily time series of suitability-weighted juvenile salmon rearing habitat area (orange) relative to connected wetted (dark blue) and total wetted (light blue) area, shown for the wet season of the five modeled water years.*

For future phases of the Program, further exploration of criteria values and how they are expressed within the model is warranted. Specifically, more in-depth connectivity analysis would reduce uncertainty around whether suitable habitat is actually available as juvenile rearing habitat. This includes examining how areas are connected to the river channel upstream and downstream (including distance and complexity). Current work conducted by others to examine connectivity as it relates to distance to river may be possible to apply to this analysis in the future. Though initial exploration of the modeling output suggested that few ponded areas disconnect to create areas of fish stranding potential, revisiting possible inclusion of evaluating stranding potential is suggested for future phases of work. Additional connectivity evaluation for other life history stages, namely adult migration, is also recommended (e.g., adequate depths for safe passage through floodplain in-channel infrastructure). Finally, as management actions and scenarios are developed, refinement of criteria associated with certain types of actions would help address concerns such as that connectivity through managed structures like leaky boards may not be as effective as other types of connections. Additional discussions with technical advisors concerning criteria for land cover (or whether land cover should be considered by the analysis) and an upper limit of suitable depth, informed by sensitivity testing and any new floodplain-focused evidence from the literature, could help address concerns and refine criteria such that all can support.

For reporting results comparing scenarios, the Program team and technical advisors recommend reporting the results from each criteria separately as well as the overall habitat suitability assessment, in order to aid the interpretation of results. For example, given concerns around the assignment of non-optimal suitability for rice and other agriculture, being able to see the relative impact of the land cover criteria on the results will support interpretation. For depth criteria, especially if criteria remain as they are with no upper depth limit, results should be post-processed so that the contribution of deeper (e.g., over six feet) depths to the total suitable habitat can be broken out.

Further field-based research and monitoring tailored to address key uncertainties in physical habitat suitability criteria and their application to the modeling output would help boost confidence in the scenario analysis results and build greater trust overall in the process. Given that much of the juvenile salmon physical habitat suitability criteria draw on studies conducted in streams (as opposed to floodplains), studies focused on evaluating depth and cover type preferences within floodplains would support the establishment of appropriate suitability criteria with the purpose of comparing floodplain management scenarios. Such studies could also lend themselves to exploring whether variables measurable in hydrodynamic modeling output (e.g., depth, velocity, duration) can serve as reasonable proxies for factors, such as water age/residence time and turbidity, that are known to be important determinants of habitat suitability. To address uncertainties concerning connectivity, focused studies examining the ability of juvenile salmon to pass through various floodplain infrastructure (e.g., outlet weir, leaky boards) would greatly inform the criteria, analysis, and development and implementation of appropriate management actions. A second type of study to inform this approach would be to design a study to validate the hydrospatial habitat suitability approach. This would involve monitoring juvenile fish presence across a wide range of within-floodplain conditions (both managed and unmanaged) to see whether modeling predictions of more and less suitable habitat are borne out in the data showing where fish are actually present within floodplain environments. If conducted over a range of water year and flood types, it would also help improve understanding around the influence of hydrology on floodplain outcomes (and point to the potential benefits that are achievable through floodplain management for a given water year or flood type).

Summary

Approach:

- Weighted suitable habitat area (suitable acre-days) for floodplain rearing juvenile salmon is based on criteria related to timing, duration, depth, velocity, connectivity, and land cover.
- Criteria were established based on a compilation of sources, precedents from prior efforts, best professional judgement, and a desire to keep evaluation and interpretation relatively simple.
- The hydrospatial analysis approach evaluates hydrodynamic modeling output using multiple physical habitat criteria and applies them in a spatially- and temporally-resolved way.
- Applied criteria result in approximations of potential benefits to rearing juvenile salmon and are intended for comparing relative differences in benefit across scenarios.

Assumptions and uncertainties:

- Whether and to what extent deeper depths of inundation affect juvenile salmon floodplain rearing habitat suitability is not well understood. The Ad-Hoc and Advisory Committee meetings resulted in a divergence of viewpoints around whether to include a maximum depth threshold or to reduce suitability for deeper depths.
- Connectivity is an essential criterion, as it allows access of fish to a given area of habitat. It is assumed that accessing the habitat does not involve harm greater than the benefits. For this phase of the project, connectivity is evaluated in terms of whether there is connection to a nearby channel. A key area of future work is to enable the evaluation of the full path of connection between a given habitat area and the main river channel.
- Land cover criteria distinguish between natural and managed conditions, and it is assumed the habitat complexity and availability of refugia on natural cover types provide higher quality habitat relative to managed agriculture. Land cover criteria could be refined through more specific land cover types. Some divergence of viewpoints was noted in Ad-Hoc and Advisory Committee meetings as to whether land cover criteria were meaningful enough when factors like turbidity may be more important (but not something that can be evaluated using hydrodynamic modeling output).
- Overall, there is a general assumption of transferability of science from other environments (e.g., in-stream conditions), which further investigations could help test.
- Additional factors not represented in the model (e.g., turbidity, toxins from pesticides) are not considered by the approach.
- Impacts to other life stages, such as adult migration, and fish species are not addressed.

Baseline results:

- Both annual and daily suitability-weighted habitat availability is highly dependent on flow, with wetter years and higher flows generally associated with greater habitat.

- The Butte subregion has the highest absolute suitability-weighted habitat availability, though all three subregions are similar when results are normalized by wetted and connected area.
- Connectivity is a primary driver of variability in habitat availability.

Next steps:

- Evaluate fish use and/or preferences for depth and cover type within Central Valley managed floodplains to support or refine suitability criteria with the purpose of comparing management scenarios.
- Evaluate connectivity beyond adjacent channels and floodplain infrastructure and how they affect fish access, movement, and survival, and include in suitability criteria.
- Evaluate and monitor managed field operations for fish access/egress passage.
- Consider the relevance of criteria and potential revisions within the context of management actions considered by the Program.

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