Hydrology | Hydraulics | Geomorphology | Design | Field Services

TECHNICAL MEMORANDUM

Date:	September 21, 2023
To:	Lewis Bair (RD108); Barry O'Regan and Holly Dawley (KSN); Julie Rentner and Mike Davis (River Partners)
From:	Chris Campbell, Noelle Patterson, Kiernan Kelty, and Luke Tillmann
Project:	21-1028 Floodplains Reimagined
Subject:	Juvenile Salmon Rearing Habitat Restoration Opportunities Within the Sacramento River Corridor

1 INTRODUCTION

The Floodplains Reimagined initiative is exploring multi-benefit opportunities within the Sacramento Valley that include improving floodplain habitats for juvenile salmonids. This technical memorandum summarizes a technical assistance to identify seasonal pools that may serve as rearing habitat for juvenile salmonids in the Sacramento River corridor between Hamilton City and Colusa. These pools very in shape and size and may take the form of oxbow lakes, relic channels, scour holes, local depressional points, and agricultural fields that activate at high flows and later become disconnected from the mainstem river as flood waters recede. Depending on surface and subsurface connectivity, these in-corridor pools can disconnect from the mainstem channel and dry out, causing juvenile fish mortality and stranding risk. This analysis used both aerial imagery and analysis of a calibrated 1D model of the Sacramento River to quantify pool activation/deactivation flows and stages and to identify, quantify, and rank pools based on their likelihood of occurrence and their potential to create a stranding impact on fish. The results of this analysis, plus a description of the approach, are described below.

While not all pools in the river corridor necessarily create fish stranding risk, identifying and quantifying pools allows the opportunity to further investigate these features for their potential habitat benefits or risks. At the Willow Bend site of the Sacramento River, for example, an experimental project combined fish stranding mitigation with juvenile rearing benefits. Willow Bend was historically an in-corridor farming site where relic agricultural berms had created a fish stranding hazard with documented entrapment. An experimental solution with agency participation was implemented to alleviate fish stranding hazards through construction of a permanent connection from Willow Bend to the main channel to maintain juvenile rearing opportunities by sustaining the duration of shallow inundated floodplain habitat whilst allowing for volitional egress by slowly metering outflows via the experimental structure. This project provides an example of a type of habitat enhancement that could be used to reconnect disconnected

2544 Industrial Blvd, West Sacramento, CA 95691 USA
T/F 916.231.6052
www.cbecoeng.com

pools. Figure 1 presents aerial images of the Willow Bend Preserve in its first flood season post construction, through several dates of a flood recession in January 2023.

2 METHODS AND RESULTS

2.1 TASK 1: AERIAL IMAGERY DATA COLLECTION AND ANALYSIS

2.1.1 METHODS

cbec obtained high-resolution aerial imagery collected from fixed-wing aircraft between Hamilton City and Colusa during the receding limb of a flood event. The images were taken on four separate midday flights across nine days, with flights occurring on 1/17, 1/20, 1/22, and 1/25 (Figure 2). Sacramento River flows at Ord Ferry are estimated to have receded from 43,271 cfs down to 11,526 cfs across the image collection period (Figure 3). An image set was intended to be collected at higher river flows but there was too much low fog cover. In total, twenty-six photos were taken on each flight in a straight-line sequence from north to south, at an altitude of 12,000 feet above ground (1:24000) with a resolution of approximately 1 inch, with 60% overlap between each photo to facilitate accurate imagery mosaicking and orthorectification (alignment and placement of photos within a coordinate system).

Images were mosaicked and partially georectified using Agisoft software, which employs a process for image mosaicking called Structure for Motion (SfM). Once images were mosaicked into one continuous image, ground control points were added within Agisoft to spatially tie the image to the UTM coordinate system. This process was completed in ArcGIS using image raster georectification using the 2020 NAIP aerial imagery as the reference.

2.1.1.1 ASSUMPTIONS AND UNCERTAINTIES

- Image orthorectification is most accurate where photos overlap, and some error may occur along the edges of images. However, the river corridor in the center of the finished images has generally high accuracy confirmed by comparison with 2020 NAIP imagery.
- Image flyovers captured the second half of a storm event receding limb. Peak flow from before imagery capture likely affected the wetted areas observed in the flyover images, and associated flow rates at each point in time should be considered approximate.

2.1.2 RESULTS

Four mosaicked, orthorectified image rasters will be delivered in .TIFF format, and an example floodplain image panel is shown in Figure 2. The rasters are in the following coordinate reference system: NAD83 / UTM Zone 10N Meters. The images approximately align with corresponding flow rates on the Sacramento River, as pictured in Figure 3.

2.2 TASK 2: CALIBRATED HYDRODYNAMIC MODEL ANALYSIS

2.2.1 METHODS

The existing calibrated one-dimensional (1D)/two-dimensional (2D) hydrodynamic model based on the TUFLOW software platform as prepared for Floodplains Reimagined (cbec, 2023) was paired with cbec's Ecological Inundation Potential (EcoFIP) tool (cbec, 2022) to identify and quantify all pools in the

Sacramento River corridor between Hamilton City and Colusa. First, the hydrodynamic model representing the leveed Sacramento River corridor (represented in 1D) between Hamilton City and the Tisdale Bypass and its flood weir connections to and including the Butte Basin (represented in 2D) was run at stepped flows from 10,000 to 80,000 cfs to determine the inundated area of the river corridor. Flows above 80,000 cfs were not simulated as those conditions activate the three overflow relief weirs and are indicative of Sacramento Valley wide flooding conditions. Next, individual stranding pools were identified in EcoFIP at the earliest point of disconnection based on water surface elevations from the 1D model and organized by their deactivation flow. Size limitations were set so that stranding locations required a minimum depth of 0.5 ft and minimum surface area of 0.5 acres. The stranding pool volume, surface area, distance to the mainstem channel, and soil infiltration rate were calculated for each stranding location at its largest potential size. These metrics were factored into a ranking to prioritize locations with the highest potential for stranding risk at each deactivation flow rate. The overlap of pools with public or private conservation easement land was also calculated, considering both partial overlap and complete overlap of pools within designated land areas.

A suite of inundation metrics was also calculated for each pool, based on the pool's deactivation flow rate and its location within the basin (since flow patterns differ across the basin depending on overflow weir controls). Metrics were calculated using average daily flow records from 1997-2021, for October 1 – June 1 each year (the season most relevant for rearing salmonids). Inundation metrics include: 1) average frequency of inundation events per season, 2) average duration of each inundation event, and 3) cumulative seasonal duration of inundation events. For duration metrics, the inundation periods represent time during which flows are above the activation level of a given pool, and do not represent the period when flows have receded but pools may still be wetted. Figure 4 illustrates the calculation window of inundation metrics across a sample of water years.

Limiting soil infiltration rates on the Sacramento River floodplain were determined from USDA data from the USDA's Soil Survey Geographic Database (SSURGO 2023). The limiting infiltration rate (lowest value) was selected from available USDA data, under the assumption that the least permeable soil layer will control drawdown rates of pooled water on the floodplain. Infiltration rates are reported in inches/hour.

Initial outputs for pool locations were validated for accuracy using flood recession aerial imagery. A subset of pools were validated with results from 2D hydraulic modeling. When pools appeared to be misidentified by EcoFIP as either nonexistent or incorrectly classed by their deactivation flow rate, these pools were either removed or their deactivation flow rate was changed. Altogether, 11 pools were corrected based on visual quality control.

2.2.1.1 ASSUMPTIONS AND UNCERTAINTIES

- Many pools are in densely vegetated areas, so visual confirmation of pools using aerial imagery was difficult in some cases.
- LiDAR was resampled to 10 ft, which may affect the connectivity analysis within EcoFIP.
- LiDAR is known to retain areas obscured by vegetation and may not accurately reflect bare earth elevations, potentially affecting EcoFIP results.

- Field verification will be needed to confirm pool locations and metrics calculated from this preliminary study.
- Pools identified in the river corridor as part of this study are not assumed to be fish stranding hazards, but results from this study may be used to guide investigation into potential stranding effects.

2.2.2 RESULTS

Results for pools on the Sacramento River corridor are included as attachments in shapefile format. In total, 355 pools were identified that met the minimum depth and surface area size requirements and were validated against aerial imagery. Files are organized by pool activation/deactivation flow rate, with about 10 to 40 individual pools included in each shapefile. An overview of all pools, colored by their deactivation flow rate, is shown in Figure 5.

Each pool has the following associated metrics with metric summaries for each activation flow rate presented in Figure 4:

1. Pool activation/deactivation flow rate (cfs)
2. Pool surface area (acres)
3. Pool volume (ft^3)
4. Pool distance to the river centerline (shortest linear distance, ft)
5. Limiting infiltration rate (in/hour)
6. Average annual inundation events (count)
7. Average inundation duration per event (days)
8. Average cumulative inundation per season (days)

Pools were also prioritized according to metrics 2-5 and summarized by metric 1 to illustrate one potential method of identifying pools with the greatest potential stranding impact. The prioritization strategy is described by the following equation:

$$ranking\ value = (2 * surface\ area + 2 * volume + 1 * (1/distance) + 1 * infiltration\ rate)/6$$

This preliminary ranking method was calculated with double weight given to pool surface area and volume, with the expectation that larger pools have risk of trapping a greater number of fish. Linear distance to the river was incorporated with inverse values, so that shorter distances are associated with higher stranding hazard and rank. Infiltration was incorporated so that higher infiltration rates are associated with higher stranding risk, because this could lead to faster dewatering of pools before the chance of reactivation with the channel. A shapefile of priority pools is included separately that includes the top two ranked pools in each flow deactivation category. Priority pools for habitat restoration may change as the prioritization method is refined based on direct field observations or further validation of results.

Figure 6 presented below presents a selection of pool metrics calculated across the entire basin. As the bottom-left panel shows with the total number of pools, most pools activate/deactivate at 45,000 cfs, and most pools occur within the range of 20,000 – 60,000 cfs. There are 355 pools total across all deactivation flow rates.

Figure 7 below presents inundation metrics for pools whose flow patterns are represented by the USGS gage on the Sacramento River at Ord Ferry. Flows in this region are similar to the rest of the study area with the exception of the furthest south reach near the town of Colusa, where the Colusa weir overtops at 30,000 cfs and therefore limits sustained higher flows downstream. For the given example (in front of the M&T overflow relief weir), inundation frequency occurs between 2-12 times per season, and the average inundation event lasts between 3-6 days. Although inundation events at the lowest deactivation rates have the shortest event durations, they also occur most frequently and therefore have the highest cumulative seasonal duration, at nearly 40 days of seasonal inundation. Inundation metrics and plots are provided for the remaining regions of the study area in the appendices.

Figure 8 presents an overview of pool overlap with public and private easement land in the river corridor, quantified as pool surface area in units of acres. The left panel shows overlap area among pools that fall completely within public or easement land, and the right panel shows all overlap including partial pool overlap. Hundreds of acres of pools intersect with public or easement land across the basin, especially when considering pools with partial overlap.

3 SUMMARY AND RECOMMENDATIONS

About 350 pools were identified within the Sacramento River corridor, across a range of sizes, location, and activation/deactivation flow rates. Flood flows occur often enough in most sections of the study area that pools are activated (and subsequently deactivated) on a frequent basis, between 2 to 12 times per year on average. This represents both an opportunity for juvenile salmonid floodplain rearing habitat and the potential for fish stranding risk where pools may have insufficient outlet to the main channel as flood flows recede. The presented analysis represents a broad approach to identifying pools within the Sacramento River corridor using static water levels at stepped flow rates to determine pool connectivity to the main river channel. This approach is helpful as an initial assessment tool, but further analysis is required to determine specific habitat benefits or risks of individual pools. Pool ranking by size and other metrics presented here provides the first step towards assessment of priority pools that may be explored in further detail. Additional assessment can include more advanced modeling techniques applied in a targeted approach, such as 2D modeling using high resolution LiDAR to determine the direction of flow and outlet characteristics as pools deactivate during flood recessions. Additional steps may include field monitoring of fish presence or potential stranding during flooding events. These methods can inform whether certain sites or types of pools in the river corridor should be considered for habitat enhancement projects. Overlap with public or private easement land provides an additional method to prioritize pools within the river corridor for potential habitat enhancement. The following steps are recommended as options to build on this initial assessment:

- Use priority pools provided from this analysis to assess if pools represent rearing habitat benefits or potential stranding risk that can be addressed with floodplain enhancement actions. Methods to achieve this can include:
  - Field monitoring for fish presence during flooding events
  - Procurement of high-resolution LiDAR in the river corridor to aid in further modeling

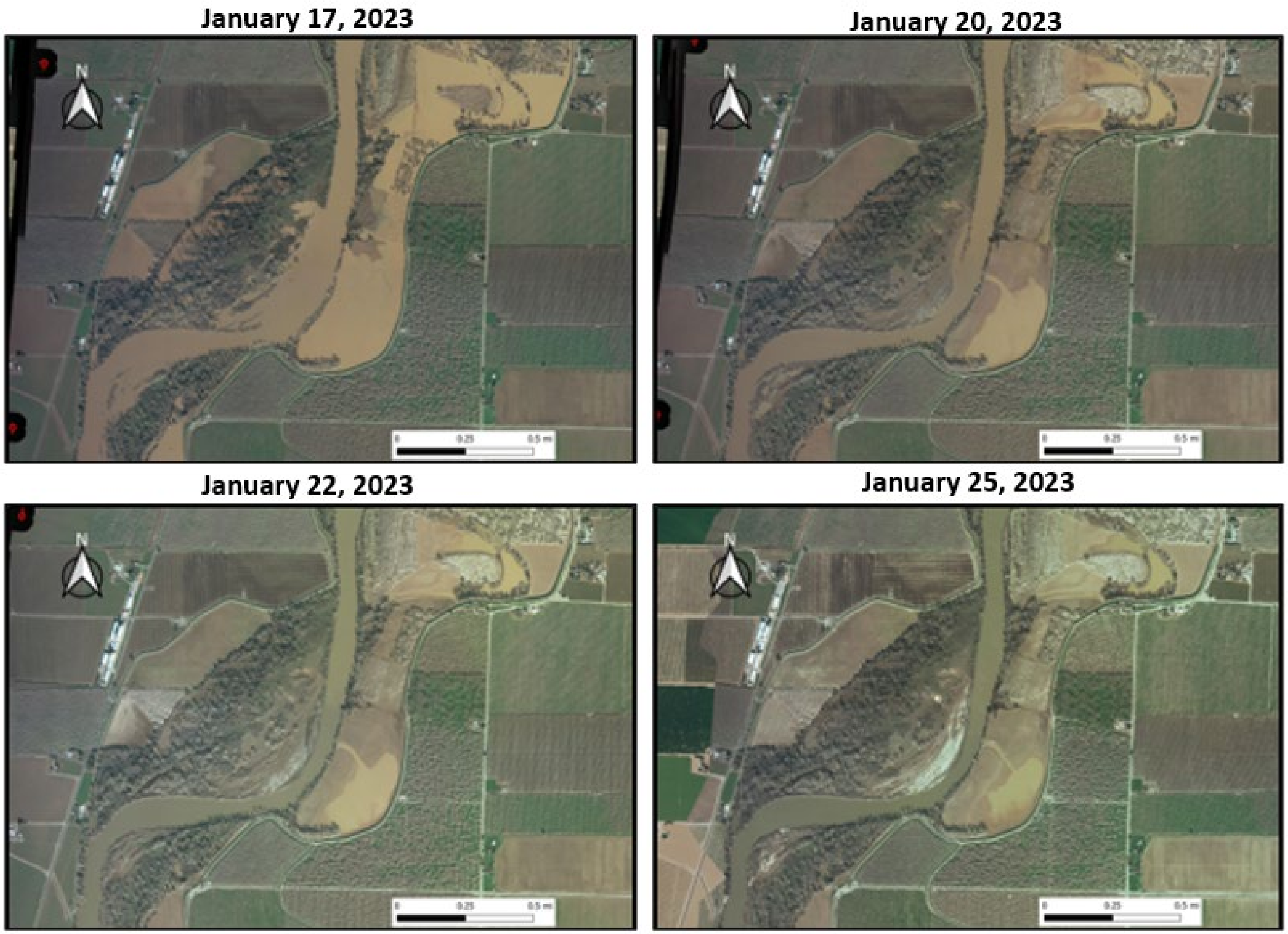
        - Note: it is our understanding that this is in-progress by the Yurok Tribe from funding with the US Bureau of Reclamation to support CVPIA efforts
    - Application of 2D hydrodynamic modeling throughout the study area
        - Note: it is our understanding the US Bureau of Reclamation intends to build an SRH-2D model for the Sacramento River corridor from Cleark Creek downstream to Wilkins Slough to fill the gap between the SRH-2D models that exist upstream and downstream of this reach (but it may not be at a resolution to resolve individual pool connection/disconnection)
    - Additional aerial flyovers during flood recession events to provide further model validation
    - Consider pools that overlap with public or private easement land (based on provided shapefiles) and identify priority sites for potential habitat enhancement
- Use the initial assessment framework outlined this study to develop a refined pool identification and prioritization scheme and robust habitat formulation and evaluation framework leveraging additional EcoFIP functionality

4 REFERENCES

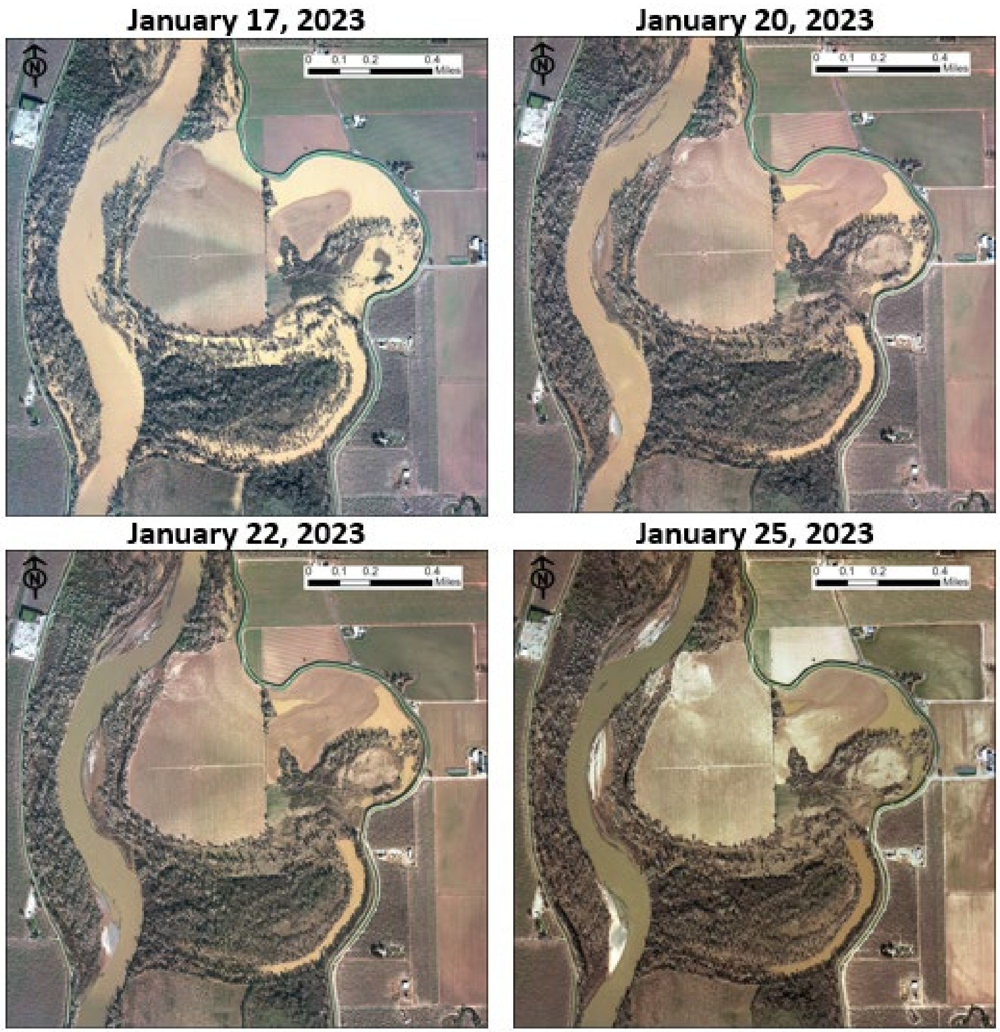
cbec. 2023. IN PROGRESS. Exploration of Floodplain Reactivation at a Landscape Scale within the Sacramento Valley: Baseline Hydrodynamic Model Development for the Butte Basin, Colusa Basin, and Sutter Bypass.

cbec. 2022. Ecological Floodplain Inundation Potential and Managed Aquifer Recharge Upper San Joaquin River Pilot Study.

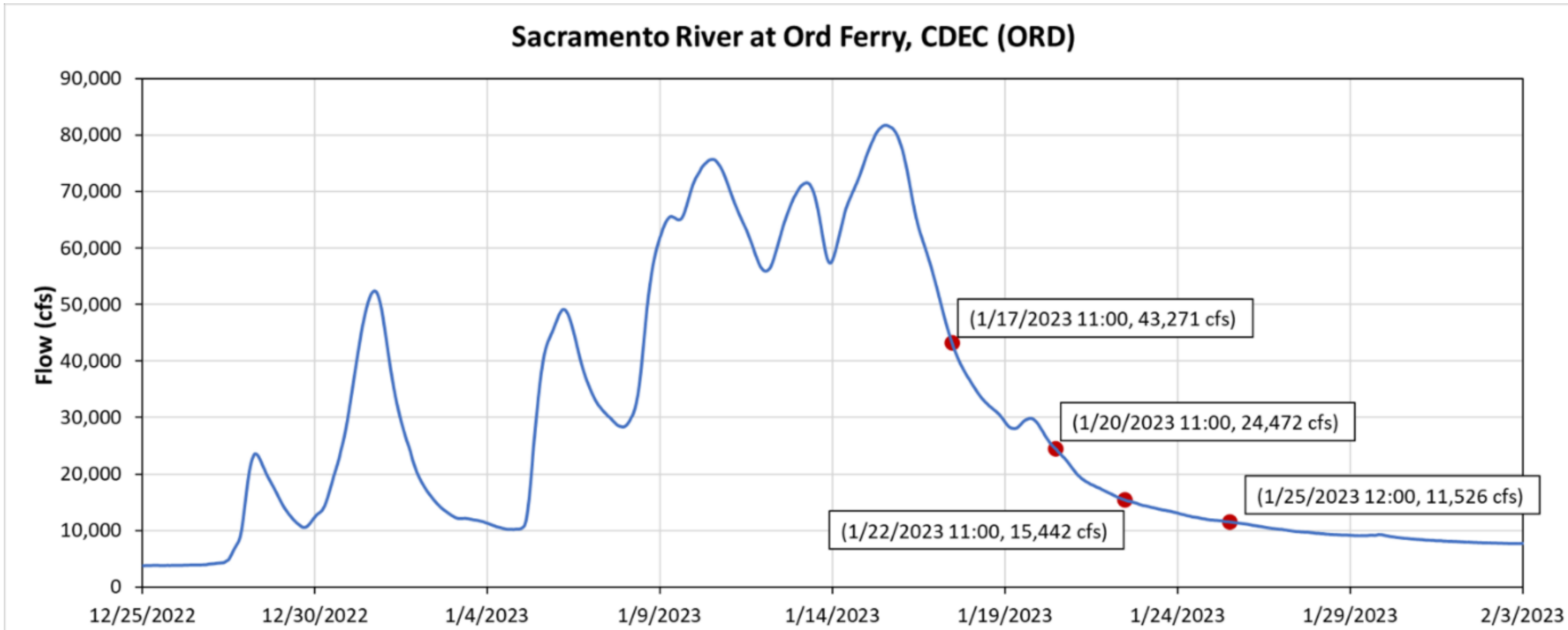
SSURGO. Accessed 2023. (USDA) Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at https://websoilsurvey.nrcs.usda.gov/. Accessed 2023.



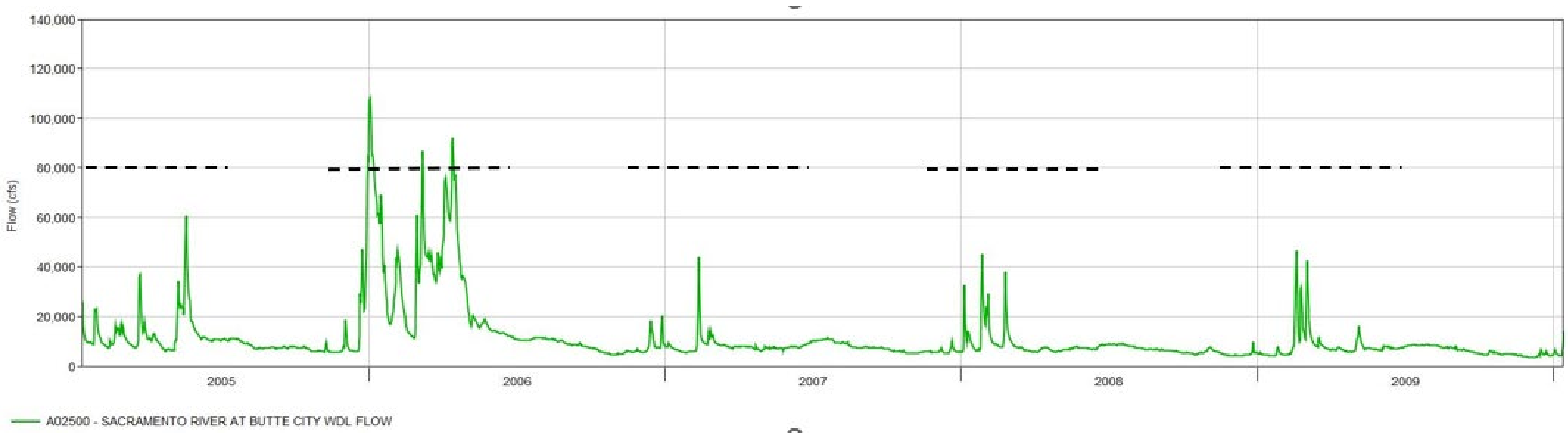
Notes: Aerial photos of Willow Bend in the Sacramento River corridor, across four dates of a flood recession in winter 2023.	cbec eco engineering	*Floodplains Reimagined* **Aerial Images of Willow Bend**	
		Project No. 21-1028	Created By: NKP	**Figure 1**



Notes: Example images from orthomosaicked, georectified aerial photos of the Sacramento River corridor.	cbec eco engineering	*Floodplains Reimagined* **Aerial images of the Sacramento River corridor**	
		Project No. 21-1028	Created By: NKP
			Figure 2



Notes: Air photo flyover dates and times and the corresponding flow rate of the Sacramento River at Ord Ferry.	cbec eco engineering	*Floodplains Reimagined* **Air photo flyover dates and Sacramento River flow**		
		Project No. 21-1028	Created By: NKP	**Figure 3**



Notes: Example flow on the Sac. River at Butte City showing the process for detecting peak flows each year between Oct 1 – Jun 1 (dotted lines). The threshold at 80,000 cfs is shown as an example	cbec eco engineering	*Floodplains Reimagined* **Illustration of peak flow detection process**		
		Project No. 21-1028	Created By: NKP	**Figure 4**

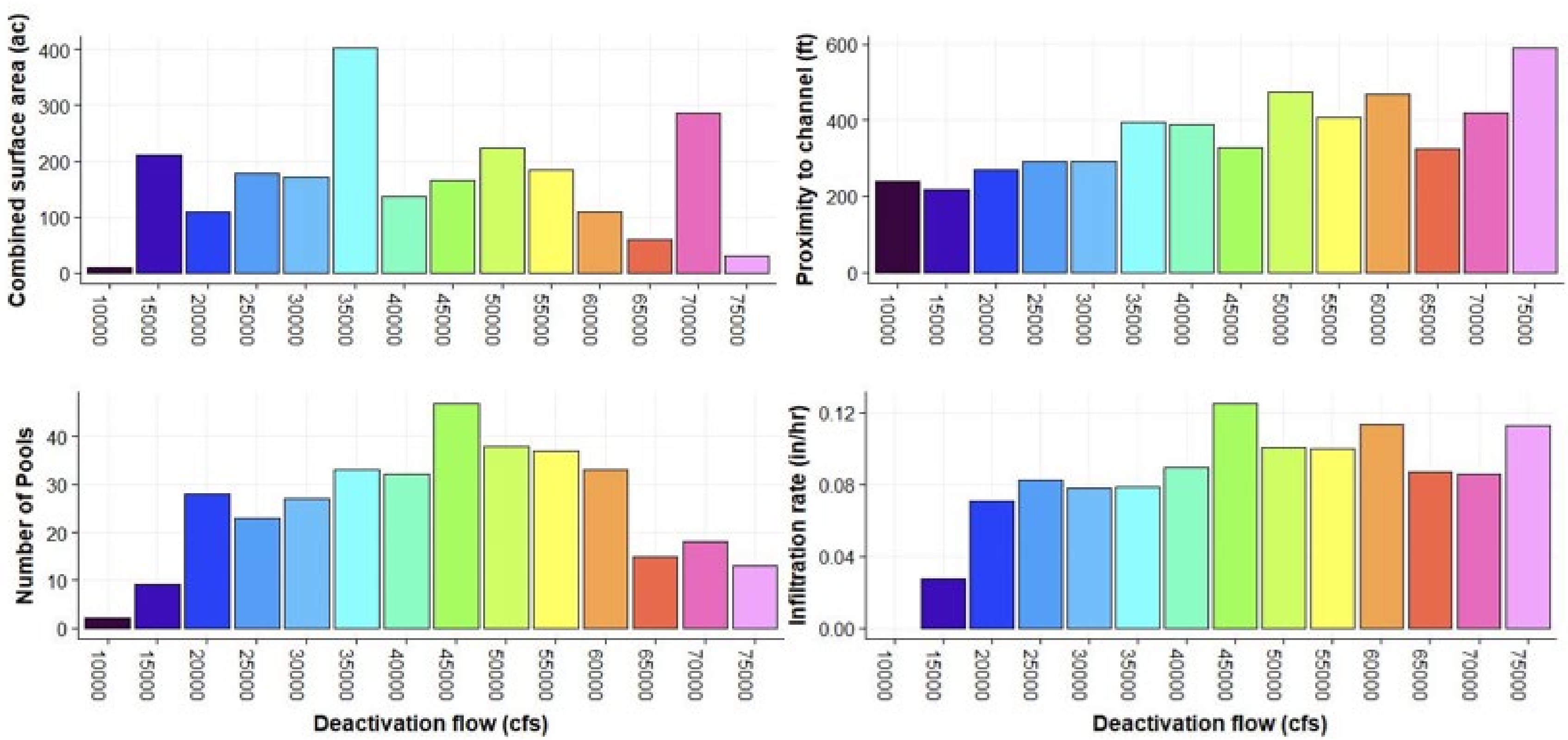
Notes: Overview of all pools identified in the river corridor, categorized by deactivation flow rate.

cbec eco engineering

Floodplains Reimagined

Overview of all pools identified in the river corridor

Project No. 21-1028 | Created By: NKP | **Figure 5**



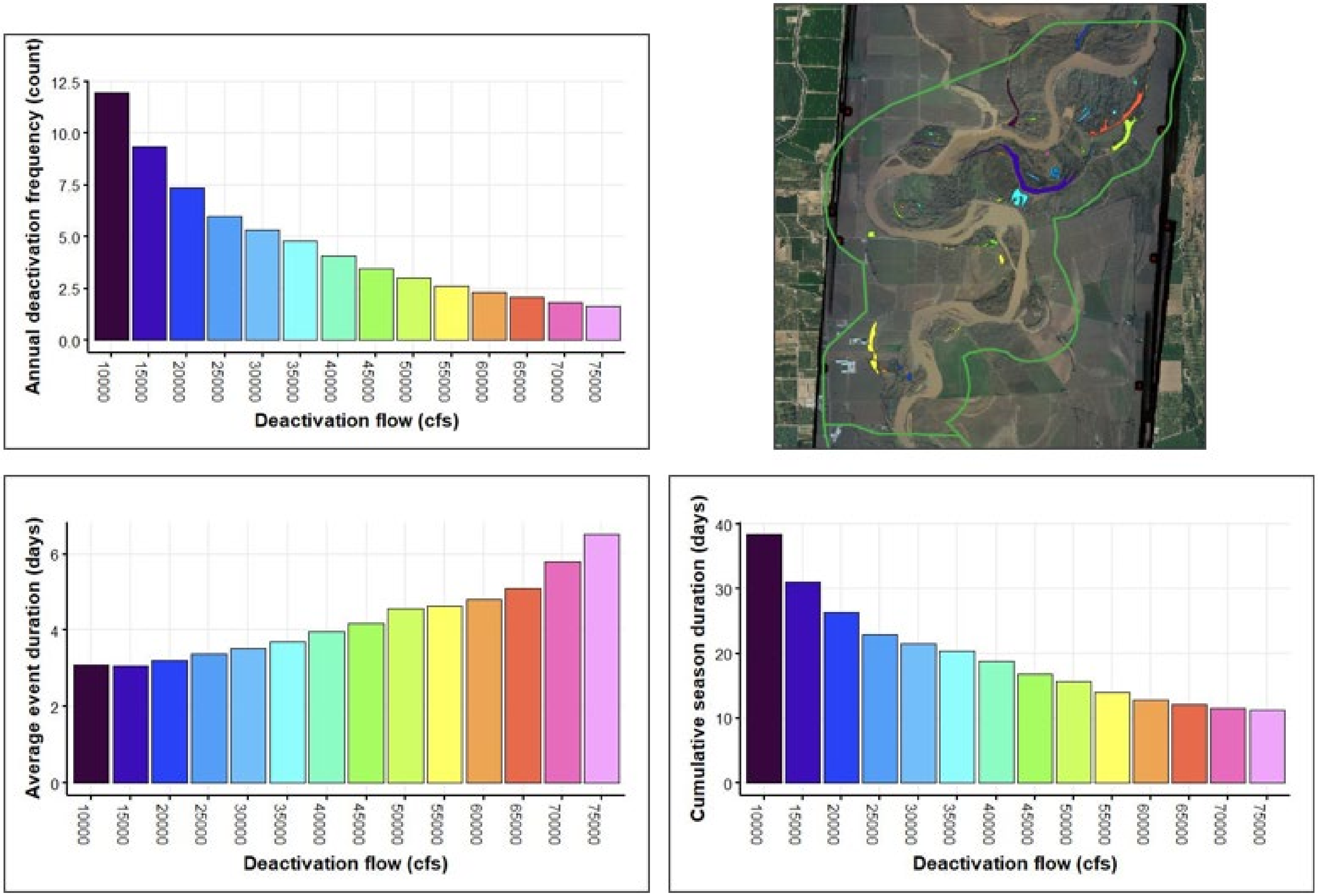
Notes: Select pool metrics for all locations, organized by deactivation flow rate.

Floodplains Reimagined

Select pool metrics across all deactivation flow rates

Project No. 21-1028 | Created By: NKP

Figure 6



Notes: Streamflow based on the Sac. River at Ord Ferry gage. The modeling region is lined in green on the map, and pools shown on the map colored with the deactivation flow rate.

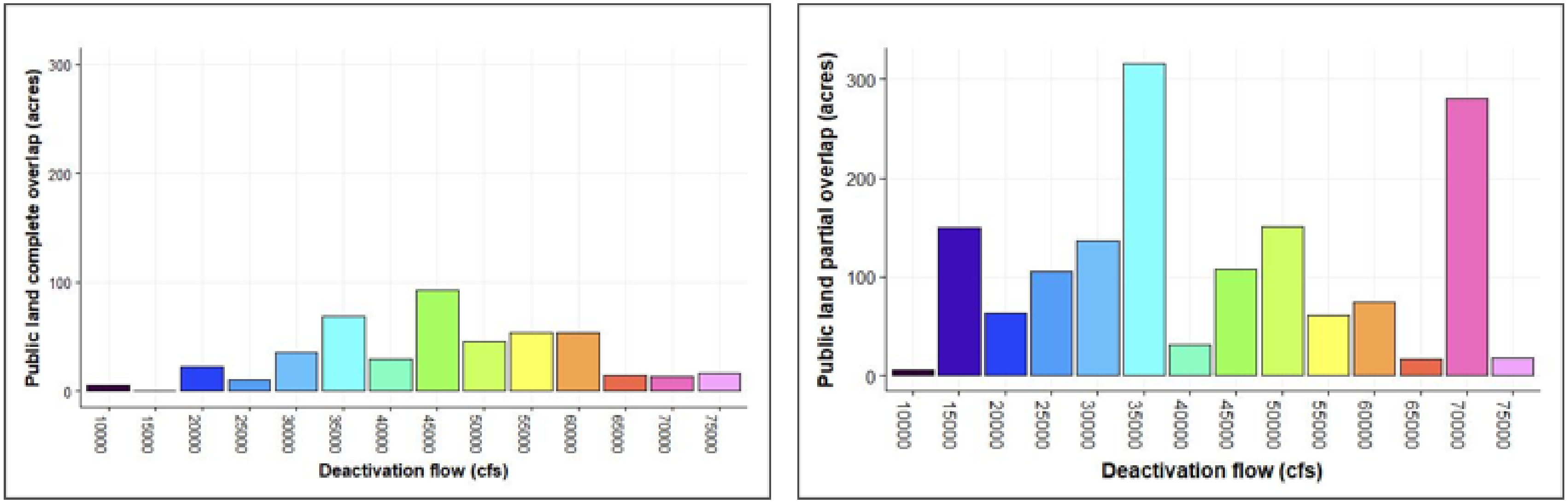
Floodplains Reimagined

Inundation metrics for a select location in the river corridor

Project No. 21-1028

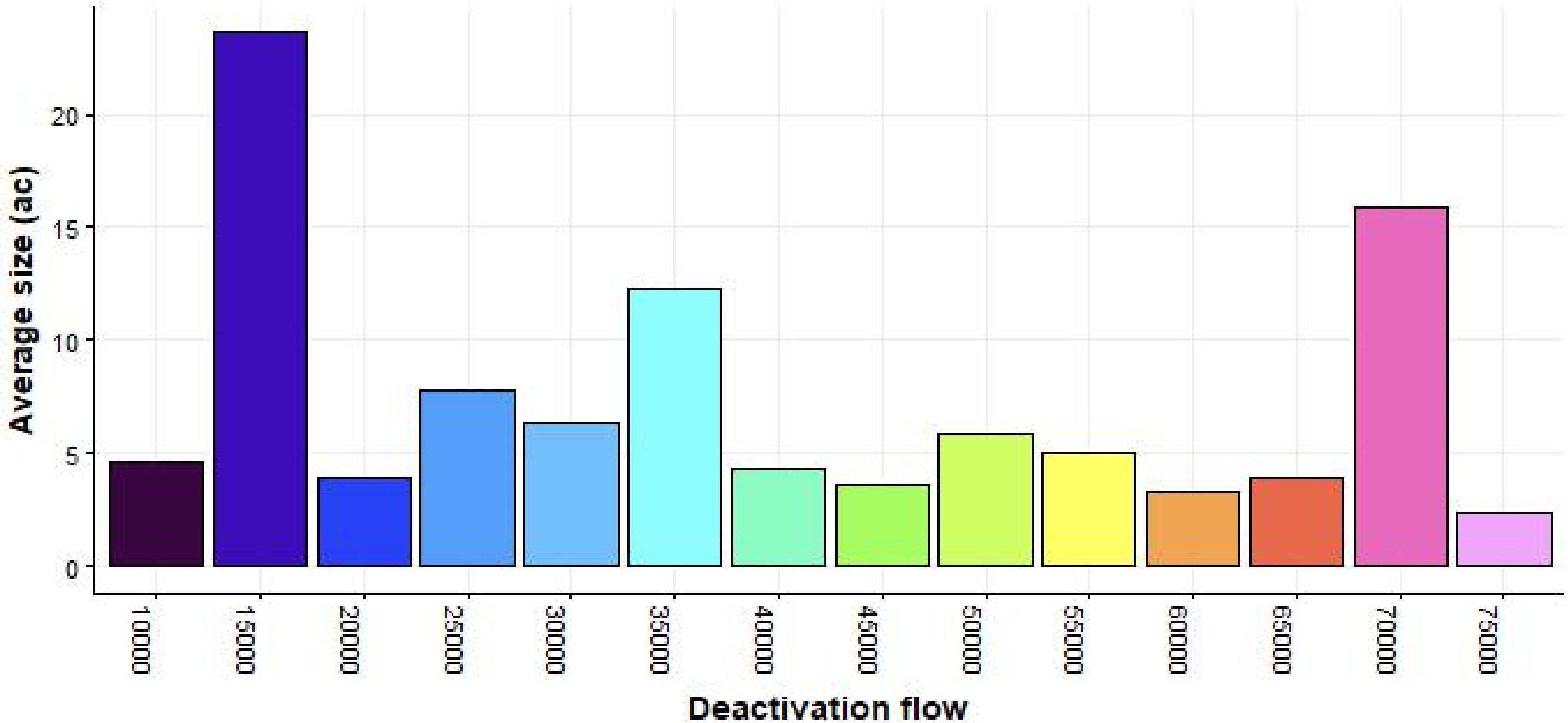
Created By: NKP

Figure 7

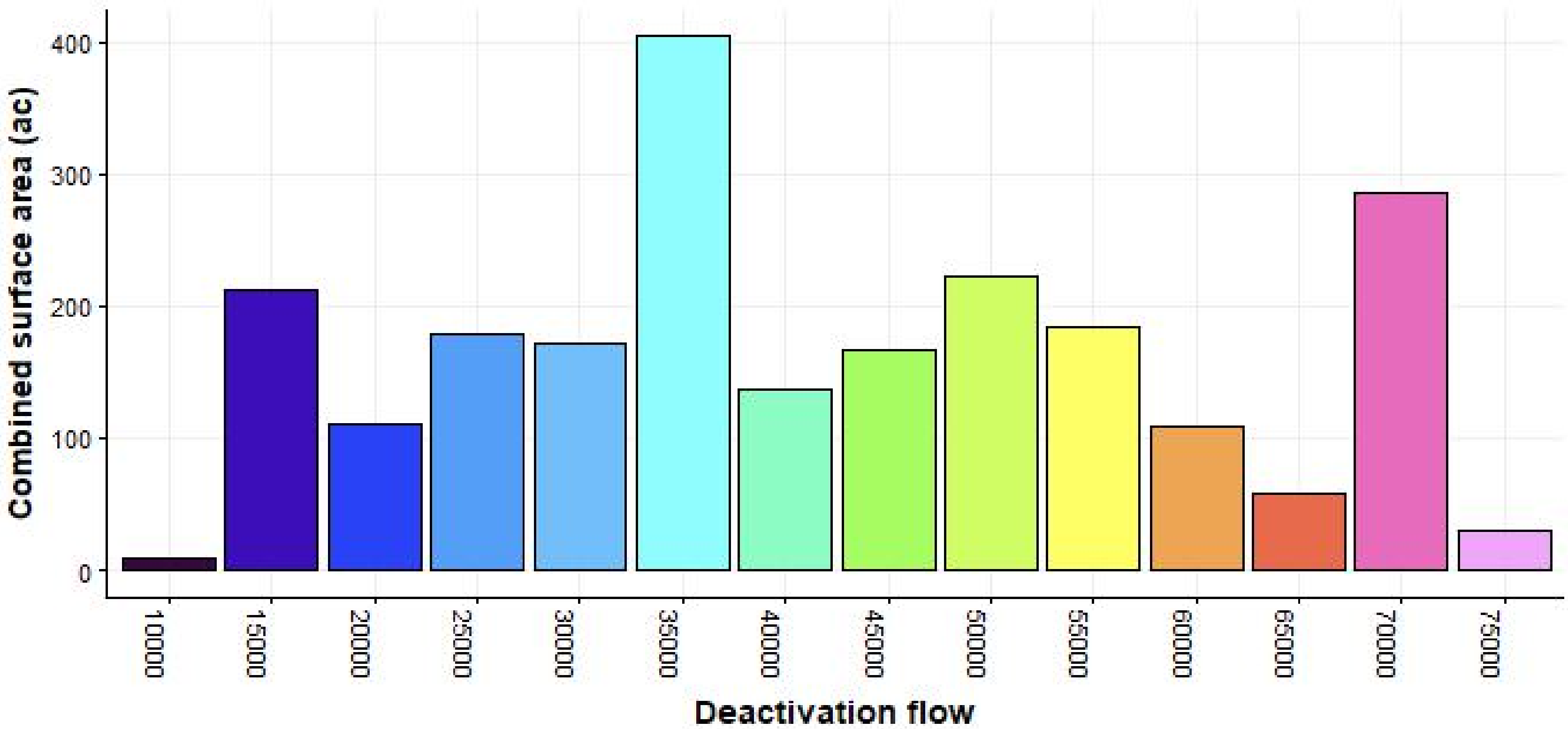


Notes: Overlap of pools with public land or private easement land, in units of acres. Values are calculated for both partial overlap of pools with public/easement land, and complete overlap.	cbec eco engineering	*Floodplains Reimagined* **Overlap of pools with public land or private easement land** Project No. 21-1028 · Created By: NKP · **Figure 8**

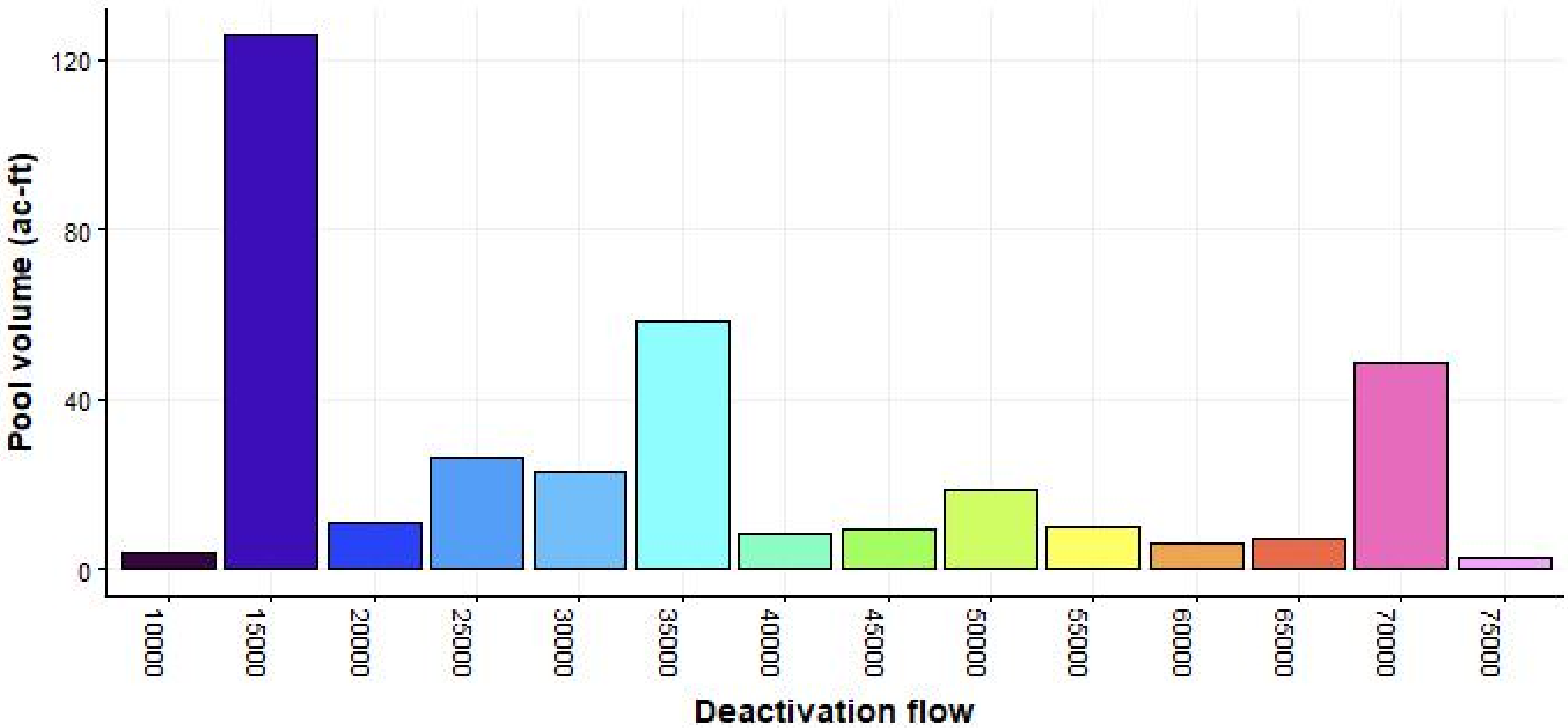
Appendix A
Pool characteristic metrics



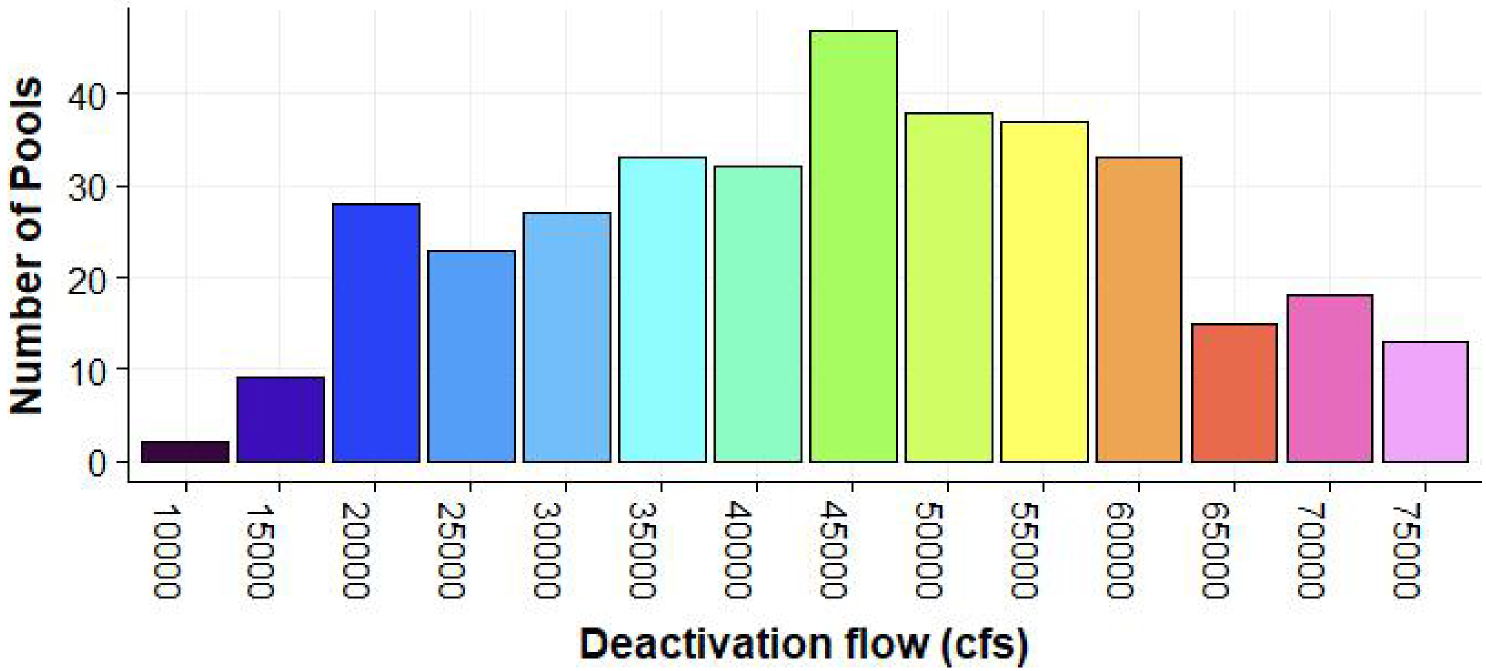
Notes: Average pool surface area per deactivation flow.	cbec eco engineering	*Floodplains Reimagined* **Average pool surface area**	
		Project No. 21-1028	Created By: NKP	**Figure A1**



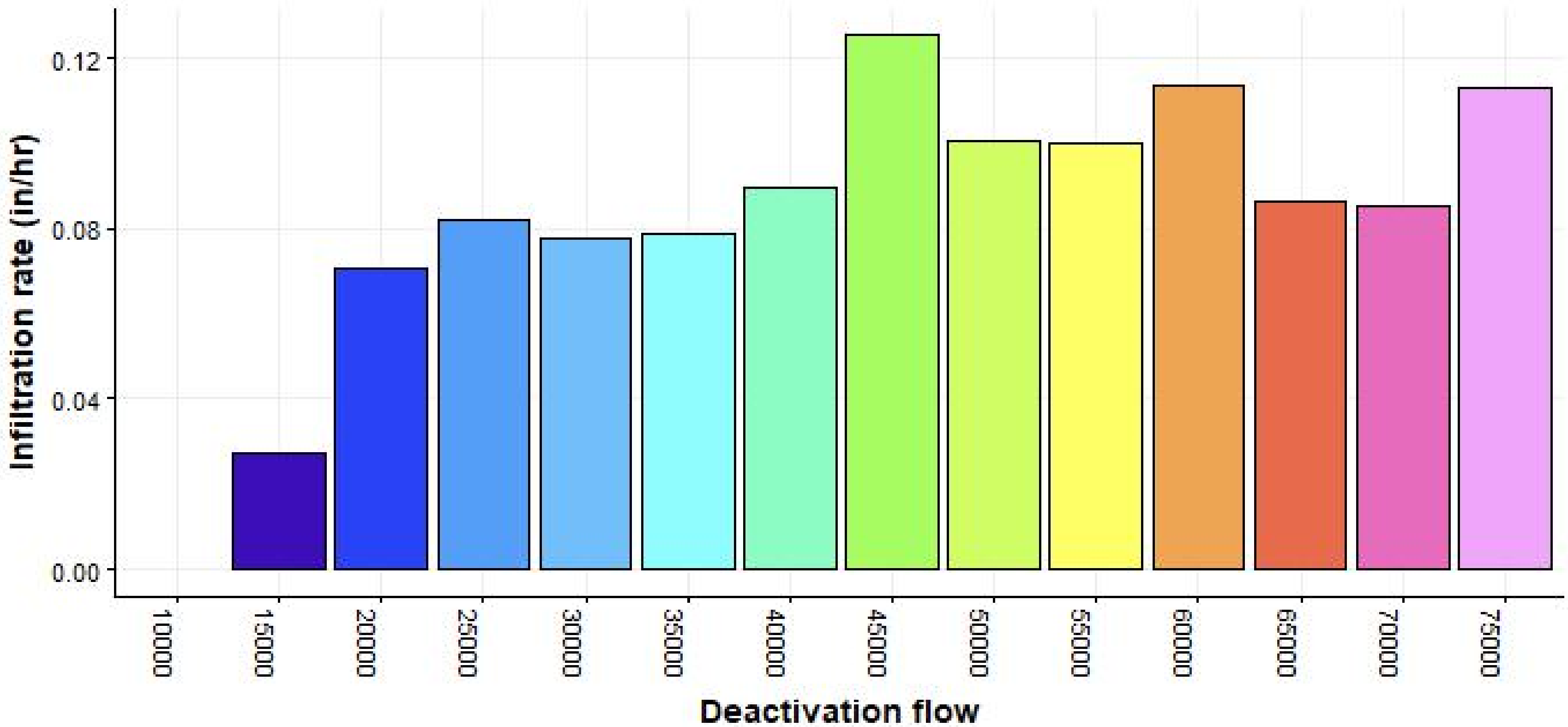
Notes: Combined pool surface area across all pools in each deactivation flow	cbec eco engineering	*Floodplains Reimagined* **Total pool surface area**
	Project No. 21-1028 / Created By: NKP	**Figure A2**



Notes: Average pool surface area per deactivation flow	cbec eco engineering	*Floodplains Reimagined* **Average pool volume**
	Project No. 21-1028 / Created By: NKP	**Figure A3**



Notes: Average pool surface area per deactivation flow, in acres.	cbec eco engineering	*Floodplains Reimagined* **Number of pools in each deactivation flow**
		Project No. 21-1028 / Created By: NKP / **Figure A4**



Notes: Average pool infiltration rate of the underlaying soil, in in/hr.

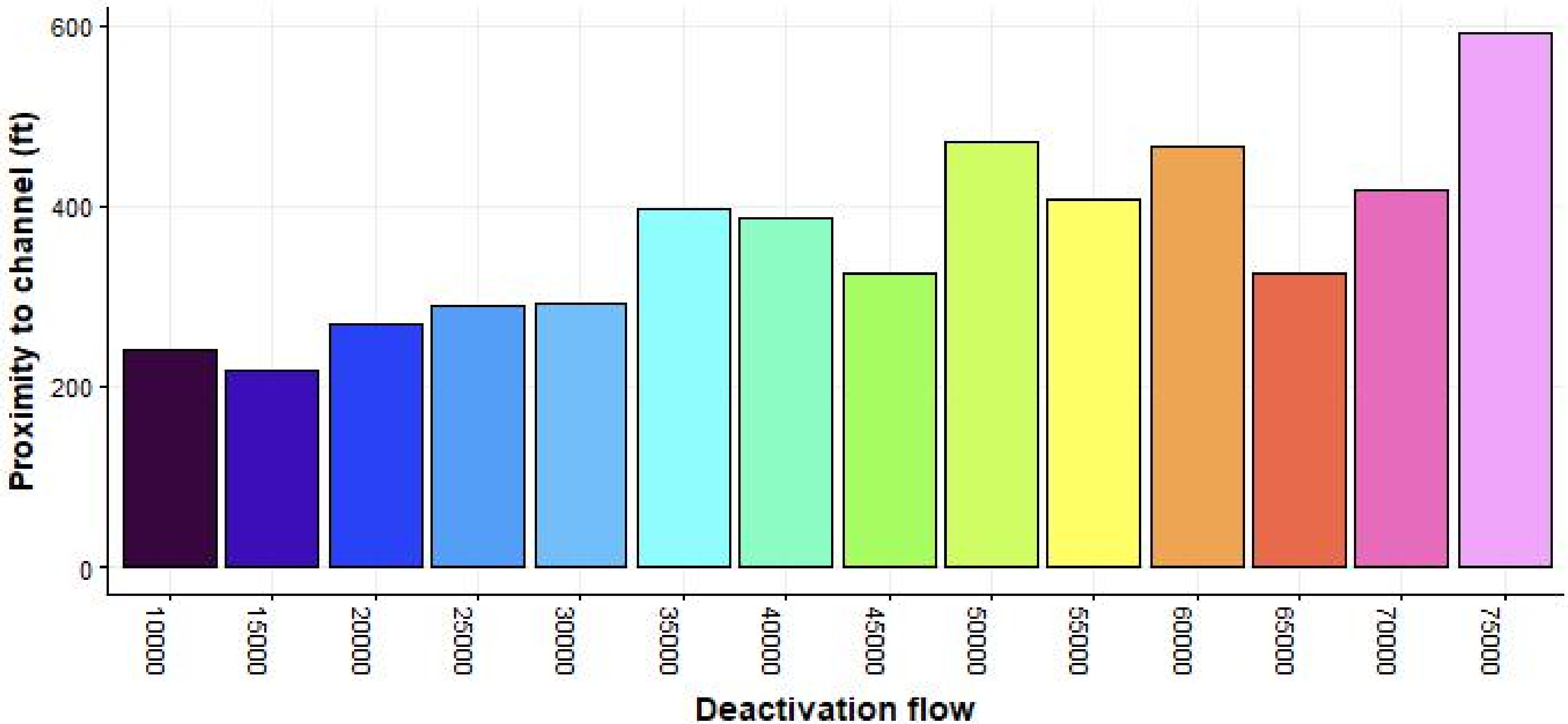
cbec eco engineering

Floodplains Reimagined

Average pool infiltration rate

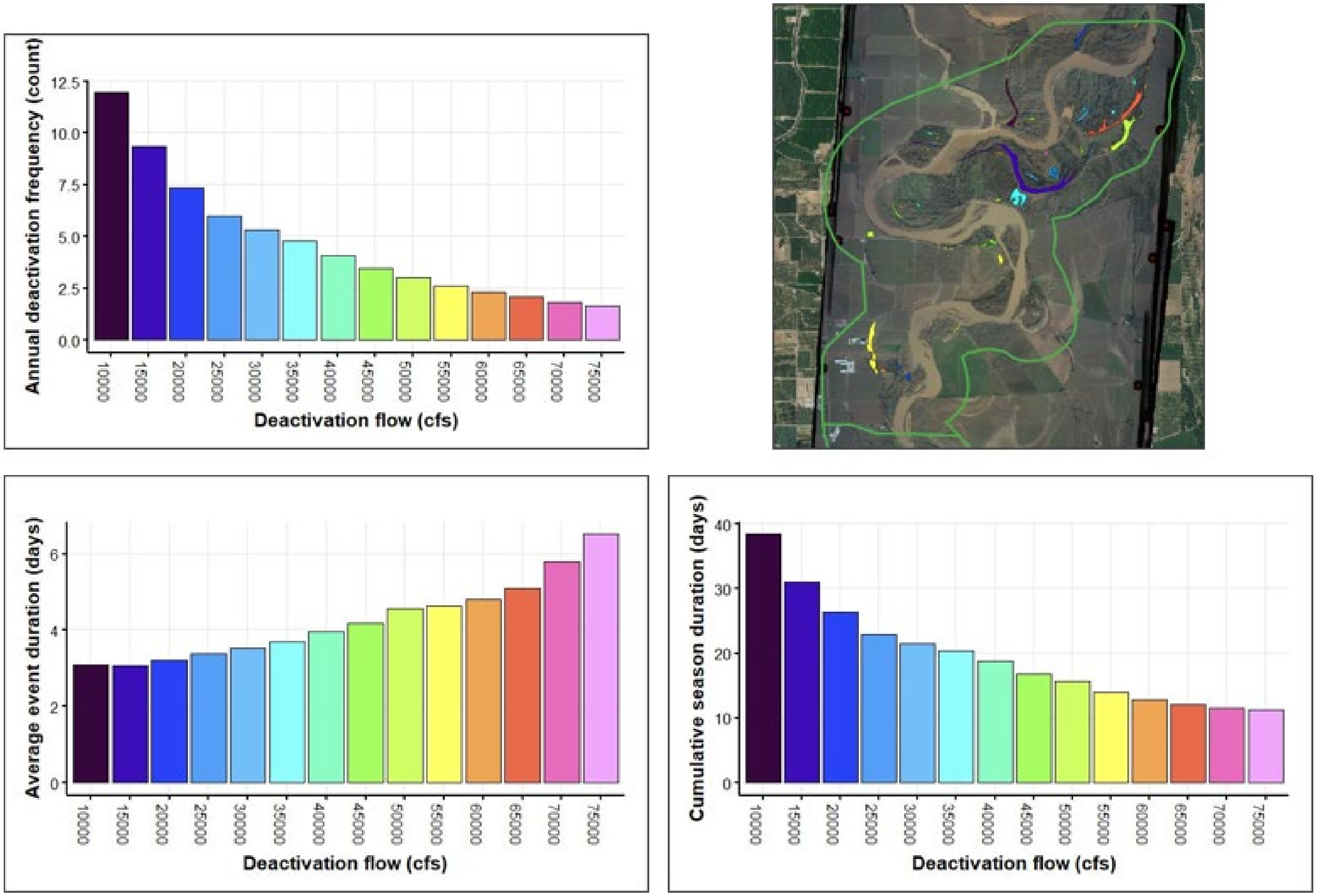
Project No. 21-1028 | Created By: NKP

Figure A5

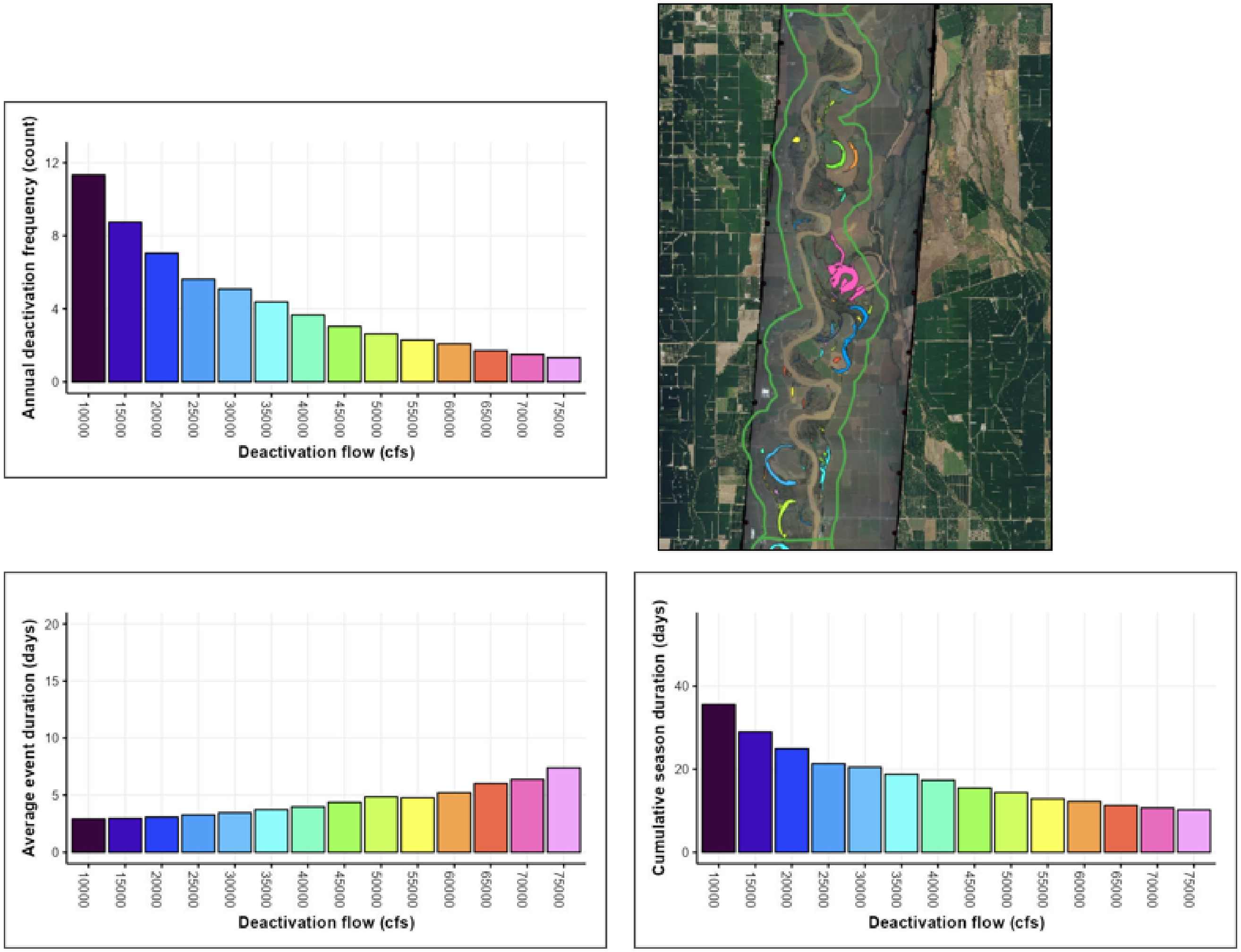


Notes: Average proximity from pools to the main channel, calculated as minimum linear distance.	cbec eco engineering	*Floodplains Reimagined* **Average proximity from pools to the main channel**
	Project No. 21-1028 / Created By: NKP	**Figure A6**

Appendix B
Pool inundation metrics



Notes: Streamflow based on the Sac. River at Ord Ferry streamflow gage. The modeling region is lined in green, and inundation metrics represent the pools shown on the map colored with the corresponding deactivation flow rate.	cbec eco engineering	*Floodplains Reimagined* **Inundation metrics for pools near the Ord Ferry streamflow gage**		
		Project No. 21-1028	Created By: NKP	**Figure B1**



Notes: Streamflow based on the Sac. River at Ord Ferry streamflow gage. The modeling region is lined in green, and inundation metrics represent the pools shown on the map colored with the corresponding deactivation flow rate.

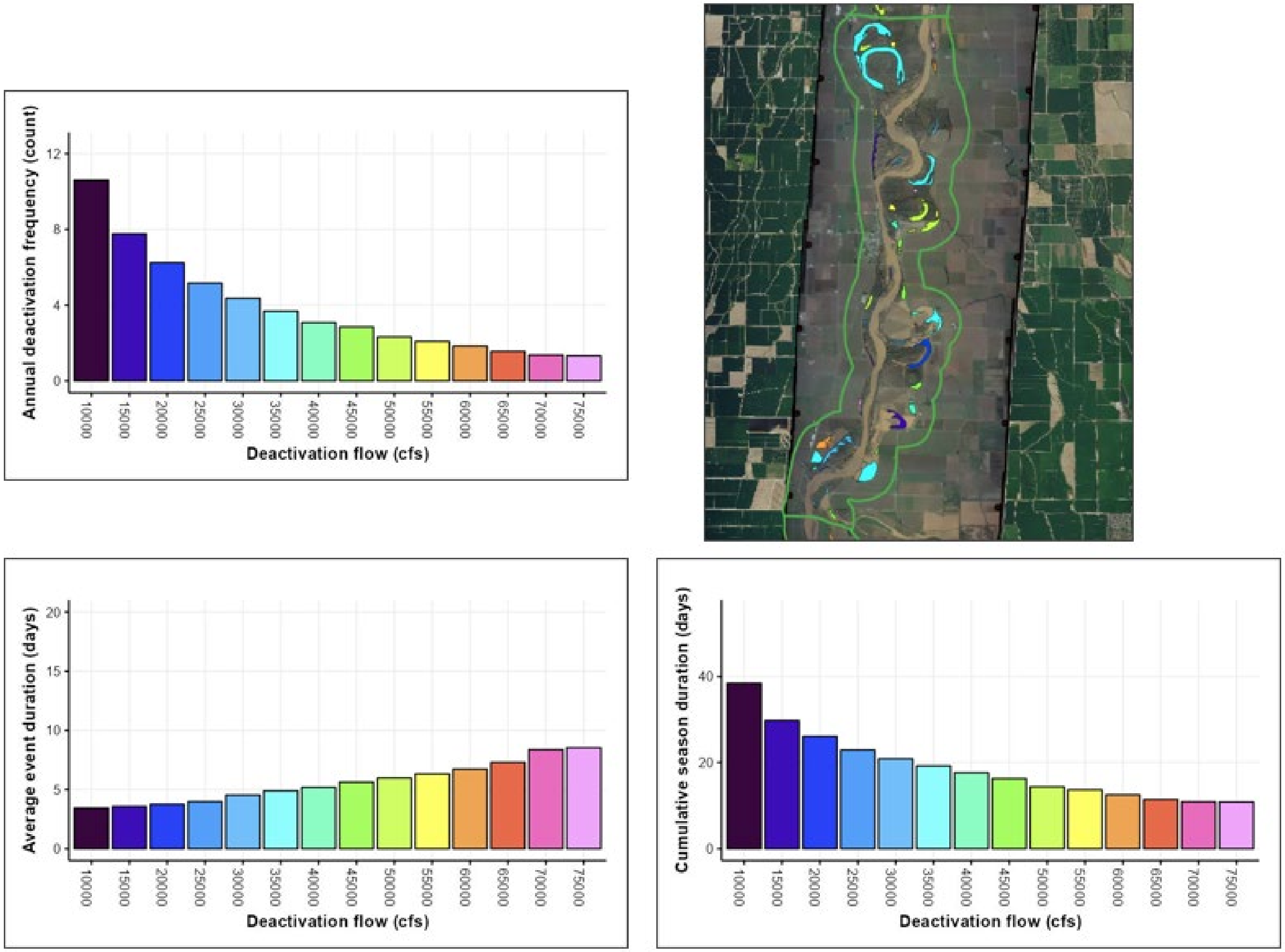
Floodplains Reimagined

Inundation metrics for pools near the Butte City USGS gage

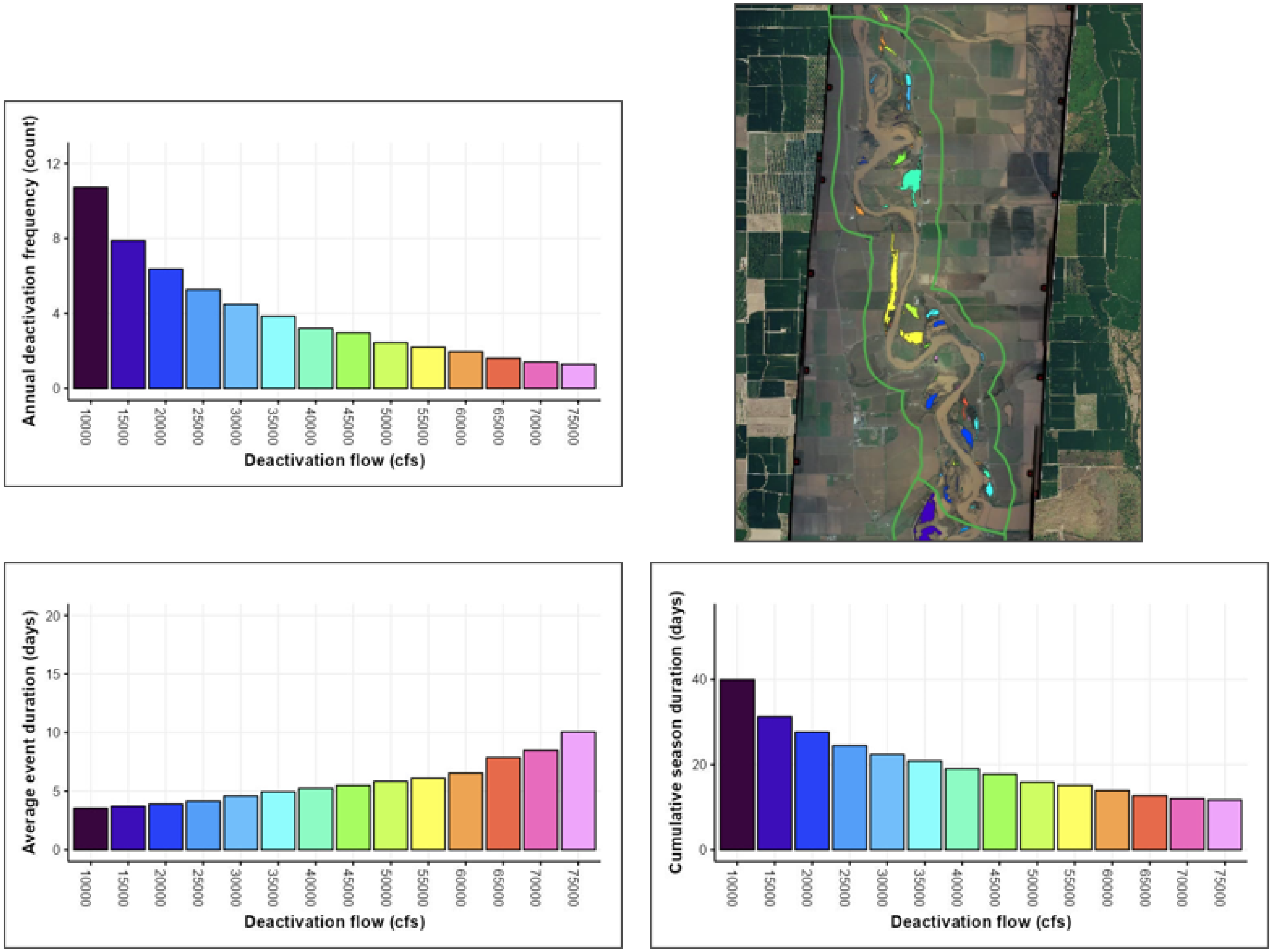
Figure B2

Project No. 21-1028

Created By: NKP



Notes: Streamflow based on the Sac. River at Ord Ferry streamflow gage. The modeling region is lined in green, and inundation metrics represent the pools shown on the map colored with the corresponding deactivation flow rate.	cbec eco engineering	*Floodplains Reimagined* **Inundation metrics for pools near Moulton Weir**		
		Project No. 21-1028	Created By: NKP	**Figure B3**



Notes: Streamflow based on the Sac. River at Ord Ferry streamflow gage. The modeling region is lined in green, and inundation metrics represent the pools shown on the map colored with the corresponding deactivation flow rate.

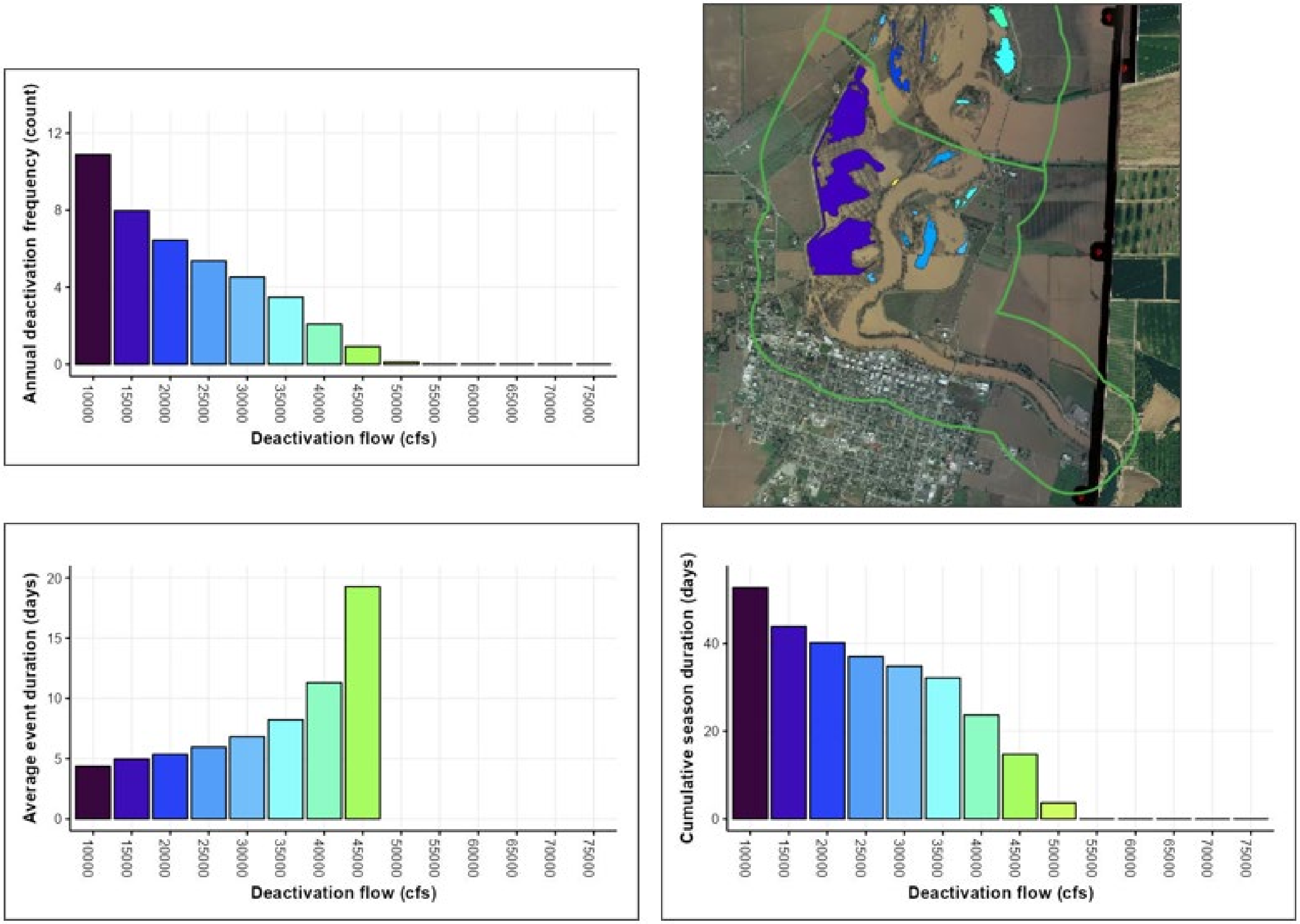
Floodplains Reimagined

Inundation metrics for pools near Colusa Weir

Project No. 21-1028

Created By: NKP

Figure B4



Notes: Streamflow based on the Sac. River at Ord Ferry streamflow gage. The modeling region is lined in green, and inundation metrics represent the pools shown on the map colored with the corresponding deactivation flow rate.	cbec eco engineering	*Floodplains Reimagined* **Inundation metrics for pools near the Colusa City USGS gage**		
		Project No. 21-1028	Created By: NKP	**Figure B5**