Building Capacity of the California Wetland Program Plan to Protect and Restore Vernal Pools

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Introduction

The California Wetland Program Plan (WPP[1]) seeks to strengthen protection for wetlands in many ways, including building capacity to track the net benefits of wetland policies and programs by employing aspects of the State's Wetlands and Riparian Area Monitoring Plan (WRAMP). The WRAMP framework was initially developed by the California Wetland Monitoring Workgroup (CWMW) of the California Water Quality Monitoring Council (WQMC). The framework recommends the application of systematic and standardized methods to support aquatic resource mapping, wetland condition assessment, public data access to support mitigation planning, and project performance tracking.

This U.S. Environmental Protection Agency (EPA) Wetland Program Development Grant focused on developing foundational environmental datasets that support a regional approach to protect and restore vernal pool habitats in California's Central Valley by applying the California Rapid Assessment Method for streams and wetlands (CRAM). The outputs provide a landscape context for wetland project evaluations and ecological condition tracking tools that can support project planning and performance tracking as outlined in the 401 Certification Program's *State Wetland Definition and Procedures for Discharges of Dredged or Fill Material to Waters of the State* (or Procedures, SWRCB Rev. April 2021).

WRAMP adopted the U.S. EPA's recommended three-tier monitoring and assessment framework (Levels of Assessment):

- **Level 1 assessments** rely on geospatial (map-based) inventories and analytics of wetlands, rivers, streams, and riparian areas, plus related projects that have a direct effect on the distribution, abundance, diversity, and condition of these habitats. Level 1 data can serve as the basis for landscape and watershed profiles of wetland and stream systems, and as sample frames for surveys of condition for Level 2 and Level 3 assessments.
- **Level 2 assessments** are rapid, field-based assessments of the overall condition or functional capacity of wetlands/streams and/or their likely stressors. Level 2 results can be used to cost-effectively survey the overall condition of wetlands and streams across a broad range of scales, from individual wetlands/streams to watersheds, regions, and statewide. In California, the California Rapid Assessment Method for streams and wetlands (CRAM) is the baseline for level 2 data collection. Other level 2 assessments exist and may also be used when needed.
- **Level 3 assessments** are usually intensive site-specific measures of specific resources. Plant species composition, nesting bird surveys, spawning success, water quality chemistry, and groundwater recharge rates are examples of level 3 data types. Types of level 3 assessments will vary from site to site.

[1] California Wetland Program Plan 2017-2022 link

The California EcoAtlas (www.ecoatlas.org) is a web-based tool that integrates data across the three levels of information in the WRAMP framework. It provides a public access point for data visualization and summarizes standardized geospatial data and stream and wetland ecology monitoring information to support local, regional, and state resources planning and assessment.

This project updated the Level-1 aquatic resources inventory map of vernal pools in the Central Valley, employed Level-2 CRAM to survey and characterize the overall ecological conditions of vernal pool systems across the region, and developed an initial habitat development curve (HDC) for project performance tracking. The outputs from these tasks have been integrated into EcoAtlas:

- The updated map of vernal pool habitats has been integrated into a recently updated version of the California Aquatic Resources Inventory (CARI) and uploaded to EcoAtlas as the base map of surface waters. CARI streams and wetlands can be explored and summarized using the Landscape Profile tool in EcoAtlas.
- The probability based ambient survey resulted in cumulative distribution function estimates (CDF) of the overall ecological conditions of vernal pool systems across the Central Valley based on CRAM Index and Attribute Scores. The CDF(s) can be accessed through the Landscape Profile tool. EcoAtlas users can zoom into a project site that has been assessed using CRAM and see the project's CRAM scores overlaid onto the regional CDF curve. This allows users to compare project scores relative to ambient conditions for the Central Valley region as a whole.
- The HDC for vernal pool projects has been integrated into EcoAtlas's Project Tracker module along with existing HDCs for estuarine and depressional wetlands. EcoAtlas users can see a project's CRAM scores overlaid on the HDC to evaluate project performance over time compared to the expected development scores.

The publication of the project's CDFs and HDCs on EcoAtlas enables users to interactively summarize the abundance, diversity, and condition of vernal pool ecosystems for any selected area within the Central Valley region.

The report sections below describe the updates to the vernal pool habitat map, the development of the ambient baseline ecological condition survey of vernal pool systems within the Central Valley, and the development and results of the habitat development curve. A fictional project example shows how CRAM and the vernal pool complex CDFs and HDCs can help project proponents and the regulatory agencies think critically about project designs (using CRAM Attributes and Metrics as a standard measure), evaluate project conditions within a regional landscape context, and monitor project performance over time to ensure that project goals are met.

Update to the Vernal Pool Habitat Map and Change Analysis

Carol W. Witham and Bob Holland originally mapped vernal pool habitat in the California Central Valley using standardized mapping methods in 2005, and later updated the mapping in 2012. In this project, using these same standardized methods, they remapped vernal pool habitats using updated 2018 aerial imagery, and compared vernal pool habitat abundance, distribution, and diversity between 2005 and 2018 (Witham, 2021). This mapping, along with her wide range of studies, is an example of how Carol Witham has been integral to improving the understanding and conservation of vernal pool ecosystems in California. The mapping includes extant pools, extirpated pools, land conversion types, and preserved areas. A comparison of the historical (2005) and updated (2018) geospatial datasets characterized and quantified changes in vernal pool habitat abundance, distribution and diversity over 13 years (Witham, 2021).

Between 2005 and 2018, a total of 76,023 acres of vernal pool habitat was lost, about 9% of the total acreage. The majority of loss was due to agricultural conversions, particularly for orchards, with nearly 7% of the total loss due to urbanization/industrial conversion. Madera, San Joaquin, and Merced Counties had the greatest losses in acreage. Losses were partly offset by the creation of 2,135 acres of mitigation bank vernal pool habitat and the inclusion of 3,406 acres of habitat that were missed in earlier mapping efforts.

The vernal pool habitat Geographic Information System (GIS) mapping and accompanying geodatabase can be used as a base layer for analyzing various attributes related to vernal pool conservation and impacts. The data can be combined and analyzed with other existing data to identify elements such as: (1) areas of highest overall conservation value; (2) the most rare or particularly vulnerable vernal pool habitat types in need of conservation; and (3) the success of and trends in conserving vernal pool habitat.

The updated ArcGIS geodatabase and a copy of the report are available on SFEI-ASC’s Data Center (https://www.sfei.org/data/changes-distribution-great-valley-vernal-pool-habitats-2005-2018#sthash.4UE36SGK.dpbs).

Ambient Baseline Survey using CRAM

The primary outputs of a probabilistic baseline survey employing CRAM and the EPA’s Generalized Random Tessellation Stratified (GRTS) survey design and analysis methodology are CDF estimate plots and tables. A CDF curve estimates the proportion of the surveyed area (in this case vernal pool habitat in the Central Valley) that is less than or equal to any given CRAM Index or Attribute score with a known level of confidence. CDFs based on CRAM provide resource managers a standardized way to evaluate and compare wetland projects to local watershed or regional ecological conditions by allowing them to place project condition scores on the CDF curves and see if the project is (for example) above or below the 50th percentile score of wetlands in the watershed or region.

CDFs do not represent the condition of any specific site but provide a landscape level (or regional context) for comparing individual sites to the overall ambient conditions. CDF outputs are both tabular and graphical, and can be summarized using the standard CRAM condition classes to characterize the proportions of vernal pool habitat in poor, fair, and good conditions. In this section we present the ambient baseline condition results from the 2020-2021 CRAM vernal pool systems survey of the Central Valley.

Methods

The survey extent (or sample frame) employed Carol Witham and Bob Holland's 2012 GIS map of vernal pool habitats in the Central Valley[2]. They mapped areas where vernal pool systems (or complexes) and individual vernal pools are likely to be found, and used their best professional judgment to estimate the density and percent cover of vernal pool systems within each of the mapped polygonal areas. The target population for the ambient ecological condition survey (employing CRAM) was specific vernal pool complexes. Large individual vernal pools required a different CRAM module, so the 2012 sample frame was modified to remove mapped individual vernal pools, and thus these individual pools are not included within the resulting CDF within this project. Areas that were classified as extirpated (vernal pool habitat that had been lost since the original 2005 mapping effort) were also removed from the sample frame.

CRAM is a standardized, statewide Level-2 field observation method that assesses the overall condition of streams and wetlands. To date there are eight different wetland types (including vernal pool systems) for which field methods have been developed. CRAM provides numerical scores to estimate the overall condition of a wetland, or the potential of a wetland and its adjacent riparian area to provide the ecological services expected given its type, condition, and environmental setting. CRAM scores are based on visible indicators of physical and biological form and structure relative to statewide reference conditions. This project employed the CRAM Vernal Pool Systems module to assess vernal pools across the Central Valley. For more information about CRAM and the specific field methods, see the CRAM User's Manual (v6.1) and the CRAM Vernal Pool Systems Field Book (v6.2) at https://www.cramwetlands.org/documents#field+books+and+sops).

With the goal of assessing at least 50 sites, a total of 400 candidate sites were randomly selected in an unstratified, equal probability sample draw employing the U.S. EPA's GRTS Survey Design and Analysis methods and *spsurvey* package in R (Diaz-Ramos et al. 1995, Stevens and Olsen 2004, Kincaid 2020, Kincaid and Olsen 2020). The project's field consultants

[2] Vernal pool mapping for Changes in the Distribution of Great Valley Vernal Pool Habitats from 2005 to 2018 are available for download.

(Vollmar Natural Lands Consulting, VNLC) reviewed all 400 sites in a stepwise manner[3] by first evaluating if the target site had any vernal pool complex features that were visible in recent National Agriculture Imagery Program (NAIP) aerial imagery. If the target site did have features visible, they contacted the landowner to get permission to visit the site and verify the existence of at least one vernal pool complex whose southernmost extent was within the target 300m square (with the target sample draw point in the middle). With those constraints, the field teams successfully accessed and completed 51 CRAM assessments across the Central Valley (see Appendix A, Table A.1).

Results

CDF estimate plots and tables, with 95% upper and lower confidence levels (CL), are the outputs of the GRTS survey analysis. CRAM Index and component Attribute Score CDF curves are shown in Figure 1 and provide a visual representation of the proportions (or percent) of vernal pool habitat in the Central Valley with any specific condition score or lower with 95% CLs (in blue). On the CDF, the x-axis represents ecological condition scores (CRAM Index and Attribute Scores range from 25-100). The y-axis indicates the estimated proportions of vernal pool habitat area in the Central Valley. The two vertical lines at scores of 50 and 75 indicate the ranges of CRAM's three standard condition classes of poor (25-50), fair (51-75), and good (76-100) ecological conditions.

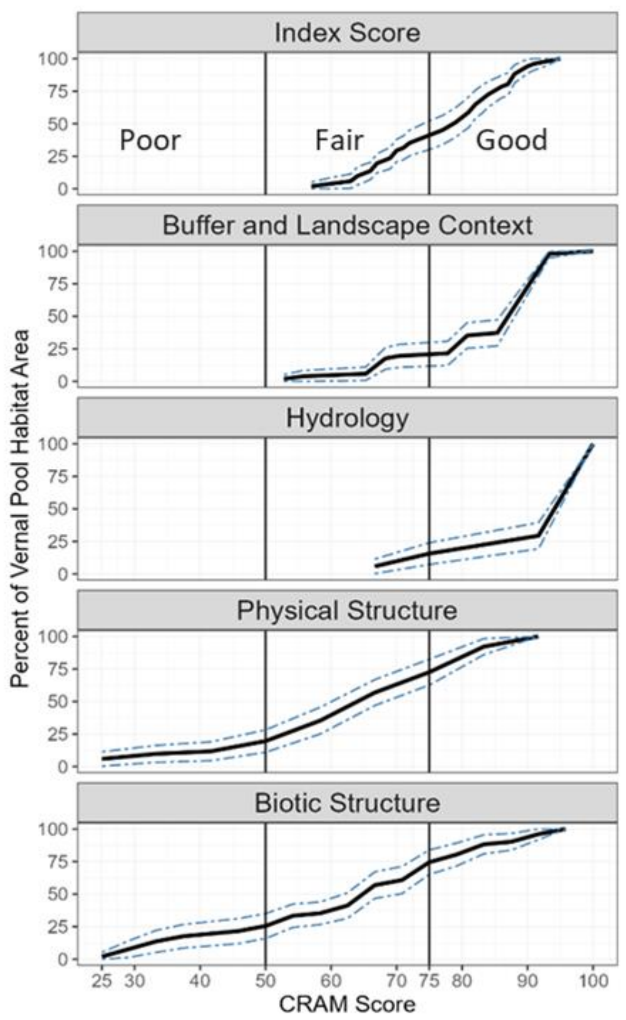

Figure 1. CDF estimate curves and 95% confidence limits with vertical lines indicating CRAM standard condition classes of poor, fair, and good ecological conditions.

At the overall CRAM Index Score level, vernal pool systems in the Central Valley are in good to fair condition, with over half of the vernal pool systems in good condition (59% with 95% CLs between 48 and 70%), and less than half of the vernal pool systems in fair condition (41% with 95% CLs between 30 and 52%). These estimates can be seen in the uppermost Index Score plot in Figure 1 by reading the curves along the fair/good vertical

[3] Please refer to the Vernal Pool GRTS Survey Design, Sample Draw, and Site Evaluation Process document for more information.

line (where CRAM Score = 75) from the top down to the mean CDF curve (black solid line) and two upper and lower 95% CL curves (in blue).

The uppermost Index Score bar in the bar charts presented in Figure 2 also shows the proportions of vernal pool complexes in good and fair condition, but without the CLs. The tabular CDF outputs from the *spsurvey* analyses in R are presented in Appendix A (CDF percentile summaries (Tables A.2 and A.3) and a weblink to download the much larger CDF estimate results used to develop the CDF curves presented in Figure 1.

Drilling down to the Attribute level, the ambient survey found less variation in CRAM scores for the Buffer and Landscape Context and the Hydrology Attributes compared to the Physical Structure and Biotic Structure Attribute scores. This is evident in Figure 1, which shows the Buffer and Landscape Context and Hydrology curves shifted to the right compared to the other two Attributes. The initial shallow slopes of these two curves, and their sharp increase in slope at much higher scores, indicate that a large proportion of vernal pool habitat area within the Central Valley region has high CRAM Buffer and Landscape Context and Hydrology scores. This observation makes sense since most of the vernal pool systems assessed in the ambient survey were naturally occurring pools located in open landscapes that are largely undeveloped or grazing lands, and therefore generally have good Buffer and Landscape Context and Hydrology.

The overall Physical Structure and Biotic Structure of vernal pool habitat areas in the Central Valley varied widely, with about half of the vernal pool resources in fair condition and the other half of the resources split between the poor and good condition classes (see Figures 1, 2, and Appendix A Table A.3).

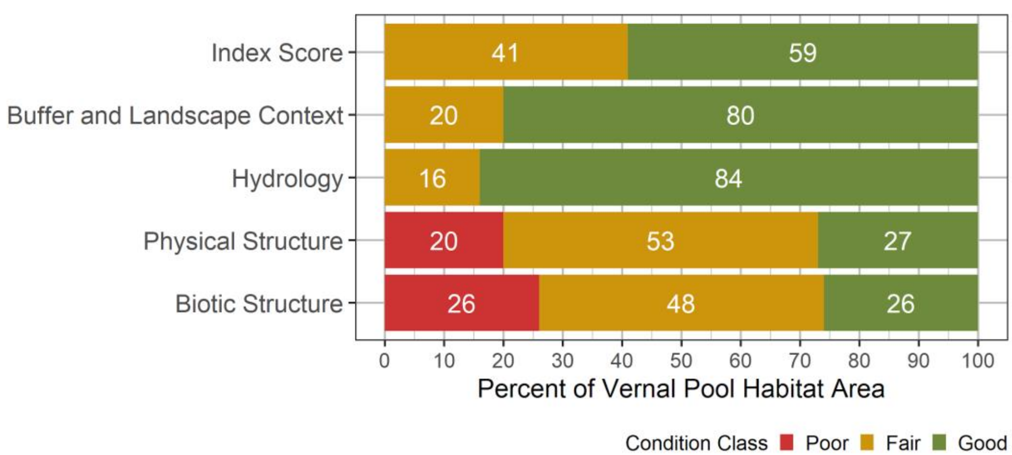

Figure 2. Bar charts showing the percent of vernal pool system resources in the Central Valley in poor (scores between 25-50), fair (51-75), and good (76-100) ecological condition.

Habitat Development Curve

Habitat development curves (HDCs) developed using CRAM can be used to evaluate the expected rate of improvement in the overall ecological condition of a wetland project based on the number of years since project completion. Wetland mitigation or restoration project practitioners can use CRAM to assess the overall ecological conditions of their project wetlands and plot the scores on the HDC curve to evaluate if the wetlands are aligned with the expected rate of natural ecological development. If scores are below the curve, additional actions could be implemented to improve low-performing wetland functions.

HDCs can also be used to forecast the expected ecological condition that a project will likely achieve at a future date after the project is completed, or to estimate the number of years that it might take for a project wetland to reach reference condition. Finally, HDCs can be used to establish project performance targets (e.g. a project's CRAM Index Score must be on or above the curve by Year 5, or on a trajectory to intercept the curve within a reasonable length of time (CWMW, 2019)).

To date, CRAM HDCs have been developed for estuarine and depressional wetlands in California[4], and have been integrated into EcoAtlas's Project Tracker to support project monitoring and performance evaluations. The development of the HDC for vernal pool systems represents an additional tool to help manage and protect vernal pools in the Central Valley.

How are HDCs developed?

The WRAMP approach to developing a CRAM HDC includes assessing wetland mitigation or restoration projects of different ages to characterize a variety of developmental stages over time, as well as assessing minimally impacted wetlands that represent reference conditions. Ideally, the overall ecological conditions of specific project wetlands could be assessed over many years, with that data used to develop the curve. However, monitoring projects for 30+ years to develop an expected performance curve is not feasible. Therefore, HDCs are developed using multiple project wetlands of differing ages to represent the expected rate of improvement for any given wetland type. In doing so, it is important that the curve incorporates wetland projects from across the full time range, to adequately characterize the rate of improvement in ecological conditions without significant time gaps that might introduce additional uncertainty to the curve.

A major finding of previous efforts to develop wetland HDCs was that the dataset must only include wetlands of known age that have been subject to natural developmental processes, that is, minimally perturbed by catastrophic natural events or by human intervention. Not knowing the age of the wetlands can greatly decrease the precision of the HDC by artificially spreading data along the time axis. Human intervention such as irrigation or seeding/planting since project

[4] Developmental Trajectory for California Tidal Marsh Restoration and Mitigation Projects displays the Estuarine HDC, while Depressional Wetland Habitat Development Curve displays the Depressional HDC.

completion can either slow or accelerate their development. And wetlands that have been managed for a specific purpose, or managed for a specific developmental state do not represent natural development.

CRAM assessment data from numerous project wetlands are collected and each wetland is carefully evaluated to determine age, environmental setting, and any management practices or recent enhancement actions that might alter the natural development processes. If any of the wetlands or CRAM scores are determined to be affected due to any unusual circumstances (such as recent wildfire or beaver activity nearby), the reason is documented, and the data point is removed from the HDC dataset. A best-fit, second-order polynomial curve is overlaid on the remaining scatter of data points (CRAM Score versus wetland age), which becomes the HDC.

In addition to project sites, HDCs are anchored in time by reference wetland sites that represent the intended endpoint condition score for wetland projects of that type. Reference sites are identified as natural, old, undisturbed/unmodified wetlands that have not experienced anthropogenic modification. These sites represent wetland conditions in absence of stressors or intense management. In addition to being plotted on the curve, the reference sites are also used to develop a reference range, or the upper and lower CRAM condition scores calculated from the reference site dataset as the mean score +/- one standard deviation from the mean.

Methods

Data Gathering

The first steps toward developing the HDC for the Central Valley were to: (1) compile existing vernal pool system CRAM assessments from existing projects or other wetlands of a known age within the Central Valley region; and (2) develop a list of new candidate vernal pool projects that could be assessed to provide additional data to build the HDC.

All pre-existing vernal pool systems CRAM assessment data from the Central Valley region were compiled from the eCRAM database and other sources and evaluated for use in developing the HDC. A total of 30 pre-existing candidate CRAM assessments (completed between 2011 and 2016) were evaluated. CRAM assessments completed prior to 2020 used earlier versions of the Vernal Pool Systems module (version 5.0.2, version 6.0, and version 6.1). To bring the historical data up to date with the current CRAM Vernal Pool Systems module (version 6.2; CWMW 2020) each of the assessments were carefully reviewed and updated to Version 6.2.

Various means were used to develop the list of candidate projects with vernal pools of a known age where new CRAM assessments could be completed. Candidate projects were identified based upon previous experience, projects with previous CRAM assessment data, communication with local vernal pool experts, investigation of the RIBITS mitigation bank database, and online searches for projects. A total of 91 candidate projects were identified. Information about each project site, including project location, dates of construction, type of project (e.g. enhancement, restoration, creation), and ownership, was compiled. Details about the project age (specifically the construction end date, or the last date when on-the-ground actions in the pools ceased), what the specific work entailed (e.g., pool creation, seeding, inoculation, etc), the timing of these actions, and confirmation that no later actions had occurred that might affect the condition of the pool complex were of vital importance. After evaluation, 32 projects were dropped from further consideration because of lack of available information.

For the remaining 59 projects, the team created a database to record project information, and a geodatabase in ArcGIS to map their locations.

Next, the candidate projects for new assessments were prioritized using the following guidance:

- Geography: distribute the assessments across the full geographic extent of the Central Valley by ensuring representation among the seven vernal pool ecoregions.
- Wetland Age: ensure that the full range of project ages are represented based upon documented project completion dates.
- Revisit projects with existing CRAM data, to allow for multiple assessments of a single vernal pool complex through time.
- Confidence in the project details, and confidence that the project field teams would have a reasonable chance of gaining owner permissions to access the vernal pool complexes on the project sites.

New CRAM Assessments

Using the project prioritization guidance, a subset of candidate projects were identified, access permissions were requested from the landowners, and permission to access 23 project sites was granted.

A questionnaire was developed to ask the project owners (or managers) to verify and add to previously collected information about the type of project, specific project actions, construction completion date, any management actions that may have occurred after the project completion dates that may have “reset” the project. This information was used in further evaluating and confirming the environmental setting, wetland age, management status, and other details for specific CRAM scores in the preliminary draft HDC.

The VNLC field teams successfully completed 40 new CRAM assessments in the spring seasons of 2020 and 2021, including both project sites and unmodified reference sites with the Central Valley. Field teams used the CRAM Vernal Pool Systems module, version 6.2 (CWMW, 2020). Practitioners replicated the previous Assessment Area (AA) at sites where previous CRAM data existed, carefully checking the boundary to ensure that it still met the CRAM guidance. Practitioners established a new AA in a representative vernal pool complex following the CRAM guidance at sites with no existing data. They also ensured that the AAs were placed in a portion of the project site with a known completion date and known project actions.

All field results were uploaded to the eCRAM database, and field photographs and scanned field datasheets were transferred to SFEI. The new CRAM assessment data was downloaded from the eCRAM database, and added to the previously compiled CRAM data from existing assessments.

Data Analysis

A preliminary draft HDC CRAM Index Score plot was created from the full set of 90 candidate CRAM assessments (56 wetland mitigation or restoration project vernal pool wetland assessments and 34 reference site assessments) including the existing data that was reviewed and updated to Version 6.2 and the new CRAM assessments completed under this grant. The wide range of CRAM scores across time indicated that each candidate assessment needed to be further vetted.

Reference sites were further vetted and subset by employing the following process[5]:

- Compile all available CRAM assessment data for vernal pool systems in the Central Valley, and calculate the 90th percentile Index Score from this dataset. In this case, the 90th percentile Index Score was 88.
- Ensure the 90th percentile score is clearly within the 'good' CRAM condition class based on CRAM's standard condition class tertiles and accuracy of CRAM as described in the CRAM Data Quality Assurance Plan (CWMW, 2018). The lowest score in the good condition class for the Index Score is 76, plus the 90% accuracy for CRAM Index Score is 5 CRAM points, which equals 81. Thus the 90th percentile Index Score of 88 from the vernal pool dataset is clearly within the "good" condition class.
- From the set of candidate reference site assessments from natural, old, undisturbed/unmodified wetlands that have not experienced anthropogenic modification, select sites that have a CRAM Index Score of the 90th percentile or higher.

Fourteen of the 34 candidate sites met these criteria and were used to calculate the mean reference condition score and one standard deviation range for the HDC.

Candidate project assessments were further vetted using field notes, photos, the questionnaire, and discussions with VNLC staff and Carol Witham to better understand any outliers. Based on this best professional judgment, data points that did not fit the HDC criteria were removed. For example, one site had recent beaver activity, which caused excessive flooding of the vernal pool AA due to a new beaver dam on the adjacent stream. A number of other sites had management constraints (they could not be managed with grazing due to proximity of urban areas, and thus had depressed condition scores).

After removing these anomalous project sites, a second-order polynomial trendline was fitted to the remaining data to create the HDC, with the reference sites anchoring the curve at 30 years. Although the reference sites are known to be much older than 30 years, the team decided to plot them at this age because the vernal pool experts consulted in this project hypothesized that vernal pool project condition would rapidly increase (e.g. within the first 10-15 years) and then

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[5] This methodology follows and improves upon that of the Depressional Wetland HDC (Pearce, *et al.*, 2016).

would stabilize. In addition, they hypothesized that there would be a fair amount of variability in reference site scores due to the wide variety of pool types and environmental settings within the Central Valley. The team explored plotting the reference data at different ages (e.g. at 40 years, 50 years, 75 years, 100 years), but each age that was explored showed no change in when the curve crossed the reference condition score of 90 and no improvement in the fit of the curve (R squared value). The team determined that no additional benefit would be gained by plotting the reference data at an older age, as compared to plotting it at 30 years of age.

Results

The final HDC dataset included 49 CRAM assessments, 35 from 18 unique vernal pool projects and 14 from reference sites (Appendix B Tables B.1 and B.2). The project sites were distributed across the Central Valley with spatial representation from each of the 7 vernal pool ecoregions. The number of AAs in each ecoregion ranged from one in each of the San Joaquin Valley and Livermore ecoregions, to 14 in the Southeastern Sacramento Valley ecoregion. The project data represent pools of a variety of ages, with pools as young as three years to as old as 27 years. The very old, unmodified, natural reference site pools anchor the right side of the HDC, with that data plotted at 30 years. Reference condition scores and their reference ranges are presented in Table 1.

Table 1. Reference CRAM Index and Attribute Scores and reference ranges for vernal pool complexes in the Central Valley. * exceeds maximum CRAM score of 100

Indicator	Reference Condition Score (Mean)	Standard Deviation (Reference Range)
Index Score	90	2 (88-92)
Buffer and Landscape Context	92	6 (85-98)
Hydrology	96	7 (90-103*)
Physical Structure	82	8 (74-90)
Biotic Structure	88	7 (81-96)

Figure 3 presents the CRAM Index score HDC illustrating the expected rate of improvement in condition for vernal pool systems in the Central Valley. The curve shows a constant rate of expected improvement in condition, with a slight slowing in the rate after approximately age 15. The HDC shows that vernal pool systems are likely to mature to be within the reference range (88-92) within approximately 23 years after construction, and may reach the reference condition of a CRAM Index score of 90 in approximately 30 years after construction. However, there are examples of projects that are only 10 years post-construction that have already achieved reference condition. It is also interesting to note the wide range of scores that exist in projects younger than five years. The variety in condition observed across all ages within the curve is likely due to the inclusion of both creation and enhancement projects within the dataset.

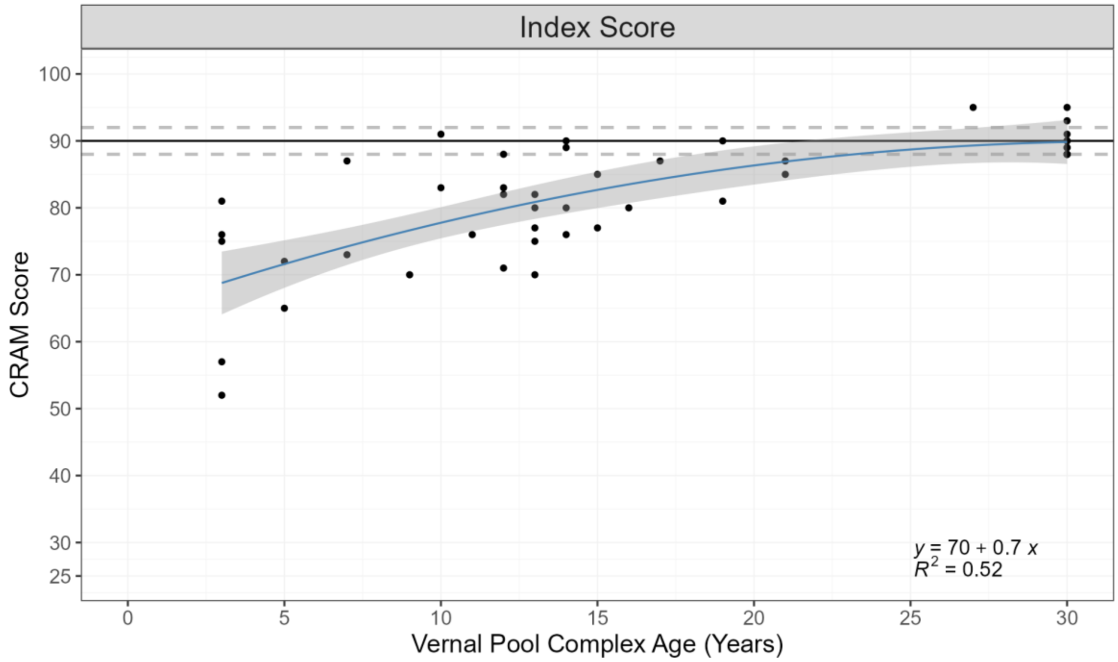

Figure 3. Habitat Development Curve for vernal pool systems in the Central Valley based on the overall CRAM Index score. The black and dashed gray horizontal lines indicate the mean reference condition score of 90 and reference range (+/- 2 points, 88-92).

Figure 4 presents the HDCs for the four underlying CRAM Attribute scores. These curves show the different rates of improvement that are expected for each individual Attribute. The Buffer and Landscape Context Attribute HDC has a very shallow slope, with less than 10 points of improvement expected between the construction completion date and 30 years later. The data supporting the curve show that this group of projects either has good landscape setting and buffer, scoring as a 92, or has slightly lower condition setting or buffer, scoring in the 60s to 80s. In some cases, project managers do not have any control over the surrounding areas, which may or may not provide buffer to their project. Additionally, this Attribute is typically not expected to change significantly over time; improvements in buffer condition can be costly (e.g. adding additional aquatic area, removing adjacent land uses and replacing with buffer land uses, or improving the condition of the buffer), while decreases in condition (e.g. fewer adjacent aquatic areas, less buffer or worse condition buffer) typically do not occur within or immediately adjacent to the project sites.

The Hydrology Attribute curve has a slight upward trajectory, despite having a number of project sites of various ages with a score of 100. Similar to the Buffer and Landscape Context curve, this curve only has approximately 10 points of improvement expected over the 30 years. The Hydrology Attribute evaluates the degree of departure from the natural hydrologic conditions, and so a vernal pool project's hydrology is not expected to naturally change much after construction. Instead, scores will improve only if there are improvements in the land cover of the contributing watershed such as the removal of features that are altering the hydroperiod, and/or removal of adjacent levees or berms that are restricting the hydrologic connectivity of the pool complex.

The Physical Structure Attribute curve is nearly linear, with an upward trend, and approximately 20 points of expected improvement. It suggests that the physical structure of young projects are expected to steadily improve over time and typically start out in fair condition.

The Biotic Structure Attribute curve shows a very pronounced and relatively rapid increase in condition for project sites in the first 10-15 years after construction. Some young projects can have high Biotic Structure Attribute scores in the 70s and 80s, likely because they are existing vernal pool complexes that were enhanced or restored. This attribute curve most closely matches the Index Score HDC, and has the highest R squared value of the four Attribute curves.

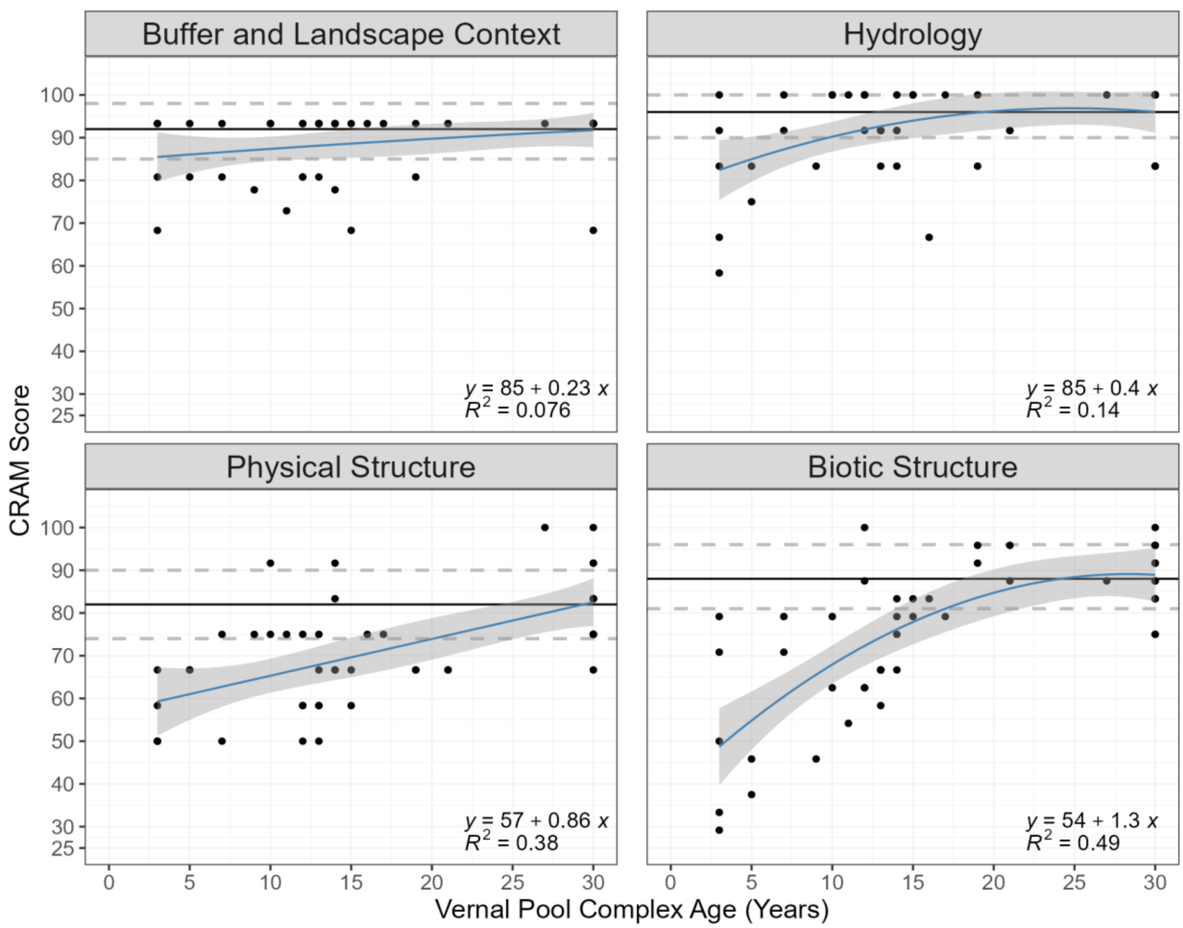

Figure 4. Habitat Development Curves for vernal pool systems in the Central Valley based upon the underlying CRAM Attribute scores: Buffer and Landscape Context (top left), Hydrology (top right), Physical Structure (bottom left), and Biotic Structure (bottom right). The solid black and dashed gray horizontal lines indicate the mean reference condition scores and reference ranges as listed in Table 1.

Discussion

The trajectory of the Index Score HDC matches the hypotheses proposed by the vernal pool experts before the project began. That is, vernal pool condition increases relatively rapidly, reaching reference condition in a much faster period of time than depressional wetlands (50-60 years to reach reference condition) or estuarine wetlands (100 years to reach reference condition).

Also as expected, there is variation in the condition of vernal pools of any given age. This is likely due to multiple factors. First, these projects span the full geography of the Central Valley, with pools indifferent ecoregions, climatic zones with different annual precipitation, different geologic units, landforms, and different underlying impermeable layers (hardpan, claypan, bedrock). These physical and climatic differences likely account for some of the observed variation. In addition, these projects also have variable management, land use history, and landscape position. This variation includes grazing intensity and timing, historical ripping and discing of the landscape for agricultural purposes, and proximity to urban areas, which place different kinds of stress on vernal pool systems.

The types of projects included within the HDC also likely contribute to variation in condition. Projects include new pool creation in areas that did not previously have vernal pools, creation of new pools within existing vernal pool landscapes, restoration of degraded existing pools, and enhancement of existing pools. Projects also include restoration, compensatory mitigation, and mitigation banks, which likely had different reasons for conducting the project, with different actions and levels of intensity of actions. Older compensatory mitigation projects sometimes created the highest density of pools possible within a project footprint, so as to maximize the acres of mitigation. Enhancement projects occur within existing vernal pools, and typically are aiming to increase the condition of a single aspect of the pool, such as cover of native plant species. These two project strategies will likely have very different trajectories and end conditions.

The creation, restoration and enhancement of vernal pool systems is relatively new, with the majority of “older” projects occurring in the 1990s. As vernal pool projects have become more common and more experience has been gained, many lessons have been learned about how to most effectively create and restore vernal pools so that they function, are resilient, and have the best possible condition. The dataset includes pools with ages spanning the past 27 years, capturing the varying levels of experience and “sophistication” of restoration and creation during this time period. The style, level of detail, and use of science during project design and construction has changed. This is evident in details such as the depth of pools, the steepness of side slopes, the density of pools, and the use of inoculation. We suggest that some of the variation in CRAM condition scores is a reflection of the change in project style or “sophistication”, with greater consideration of details such as hydrologic functioning and ecological complexity in the more recent projects.

Data collection for this project occurred in the 2020 and 2021 spring seasons, during a statewide drought. Precipitation levels were high enough to support the pools, though they were below average. We hypothesize that drought conditions affected the condition of the pools during these assessments, particularly for the Biotic Structure Attribute. Drier conditions tend to cause a reduced bloom in the pools, with a lower diversity of species, reduced total vegetative cover, and reduced complexity in the spatial patterns of the vegetation. This hypothesis is supported by field observations made by VNLC staff and other vernal pool experts, as well as the repeat assessments from the handful of sites that were completed during “normal” precipitation years. For example, assessments completed at the Madera Caltrans project site had Biotic Structure Attribute scores of 75.00 in 2016 and 62.50 in 2021. As no other element or management action had changed, this example illustrates the effect of the ongoing drought on the system.

In the future, new data could be added to the initial Central Valley vernal pool systems HDC to refine the curve. For example, data from a larger number of projects could be included, or data from specific, under-represented ages could be added (e.g. the very young projects from 1-5 years or data from older projects as they continue to mature). In addition, new data from old, unimpacted natural pool systems could be added to improve the estimate of reference condition. This project utilized data that already existed (e.g. older CRAM assessments, data from the CDF where appropriate) and new assessments from areas that were known or estimated (based upon best professional judgment) to be of reference quality. This data certainly is not complete, and may not be fully representing the best of vernal pool wetland conditions that exist within the Central Valley.

Project Example using the Vernal Pool CDF and HDC

The vernal pool CDF and HDC are part of the WRAMP framework, which employs standardized monitoring methods, digital geospatial aquatic resource data, and other state and federal environmental information to support project proponents, designers, regulators, scientists, consultants and managers in planning, implementing, and evaluating wetland restoration and mitigation projects. Here we use a fictional example project to demonstrate how these tools can be used in a project. It is important to understand that the example project is fictional, and does not represent actual vernal pool systems nor an actual project.

In this example, we consider a development project that is building a small tract of houses in the Central Valley. The new houses will be built in an area of existing vernal pool landscape and will cause unavoidable permanent impacts to a small number of vernal pool systems. The developer is proposing compensatory mitigation to offset the impact, by implementing a project to increase the density of vernal pools in a nearby existing vernal pool landscape (that is visible in the CARI mapping) that has a low density of pools.

Project Planning

The developer begins project planning by viewing the CDF for vernal pools in the Central Valley on EcoAtlas. They see that the 50th percentile for vernal pool systems has a CRAM Index score of 79. They know that in order to have their project contribute to the increase in overall condition of pools in the Central Valley, their project must have a final CRAM Index score that is above the 50th percentile. They also review the CDFs for each of the four CRAM Attributes, and see that the 50th percentile CRAM scores are lower for the Physical Structure and Biotic Structure Attributes, compared to the Landscape and Buffer and the Hydrology Attributes. They decide that the mitigation project should place extra focus on these two Attributes, so their actions will have more benefit to the vernal pool population in the Central Valley. They input the initial project information into Project Tracker (ptrack.ecoatlas.org) including mapping the wetland extents for the vernal pool systems that will be lost and gained at both the impacted and mitigation project sites. At this stage, both project sites are marked as being in the "planning" phase.

Next, the developer conducts baseline CRAM assessments of the vernal pool systems at both the impact and mitigation project sites:

- The impact site vernal pools are assessed to determine the condition of vernal pool resources that will be permanently lost.
- The mitigation site vernal pools are assessed to determine existing baseline conditions, and to evaluate the potential conditions that might be expected for the new pools that are constructed in this location.

Scores for assessments at the impact and the mitigation sites are plotted on the CDF (Figure 5). Current condition of pools at the impact site is fair, with these pools having an overall CRAM Index Score of 63 (5th percentile for the Central Valley). The current condition of existing vernal pools at the mitigation site is also fair, with an overall CRAM Index Score of 73 (40th percentile for the Central Valley).

The pre-project CRAM assessments and use of regional CDFs allow the developer and the regulators to evaluate overall wetland conditions at the impact and mitigation sites in a regional (or landscape) context, and the CRAM assessments can be one ecological condition assessment to help determine mitigation ratios (USACE 2021[6]). It should be noted, however, that CRAM is only one aspect of the ecological data that can be used in the USACE 404 or the state's 401 certification permit process.

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[6] USACE 12501-SPD Regulatory Program Standard Operating Procedure for Determination of Mitigation Ratios can be downloaded from:
https://www.spd.usace.army.mil/Portals/13/docs/regulatory/qmsref/ratio/12501-SPD.pdf

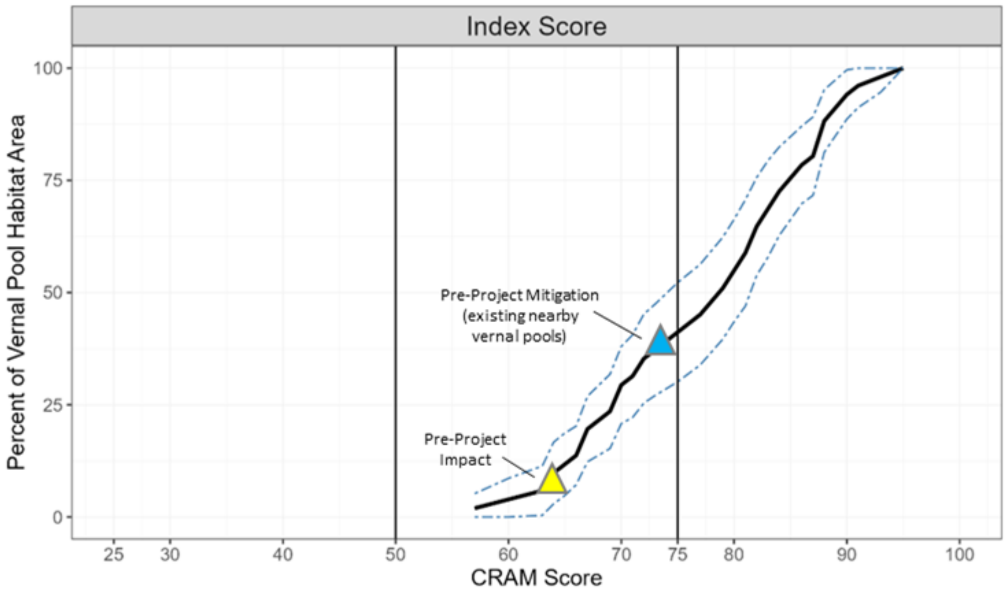

Figure 5. Pre-project CRAM Index scores for the impact (63) and the existing nearby mitigation site (73) vernal pool systems plotted on the Central Valley vernal pool system CDF.

During the permitting process, the regulators and the developer decide to modify the initial project mitigation proposal so as to enhance existing pools in addition to creating new vernal pools to increase the density of vernal pools in the complex. The developer predicts the Year 1 CRAM scores, informed by the project's designs, and plots the predicted scores on the HDC. Together, the developer and regulators review and discuss the project designs and potential ecological lift the project will provide, including how predicted post-project CRAM scores were estimated. They also discuss the frequency of CRAM monitoring that will be used to evaluate and track the mitigation project's performance once the project is completed, and use the HDC to estimate the length of time that the project will likely take to reach reference condition. The project designs are updated using the CRAM Vernal Pool Systems module's Metric evaluation guidance. This guidance helps the designers consider and discuss elements of complexity and resilience that can be included within the design, especially in the Physical and Biotic Structure Attributes. For instance, vernal pool systems are more complex and have better overall condition if they are part of a system with a diversity of pool and swale sizes and depths, and the pools have a variety of slopes and depths within them, and are dominated by a variety community of vernal pool endemic plant species.

Project Performance Tracking

After the project is constructed, the developer begins the monitoring program, which includes CRAM assessments at Years 1, 2, 5, and 10. Two Assessment Areas (AAs) are designated for the created pool area, while a single AA is designated for the nearby enhanced existing pools (for simplicity, we do not discuss this AA any further). The Year 1 assessments (timestep 1, or T1) are plotted on the CDF (Figure 6); AA#1 has an overall CRAM Index Score of 77 (yellow dot), and AA#2 has an overall CRAM Index Score of 80 (orange dot) placing them in the 45th and 53th percentiles, respectively. The Year 1 scores are also plotted on the HDC and show that both AAs are plotting above the curve, meaning that those pools are on track to eventually reach reference condition absent any significant changes to the system (Figure 7).

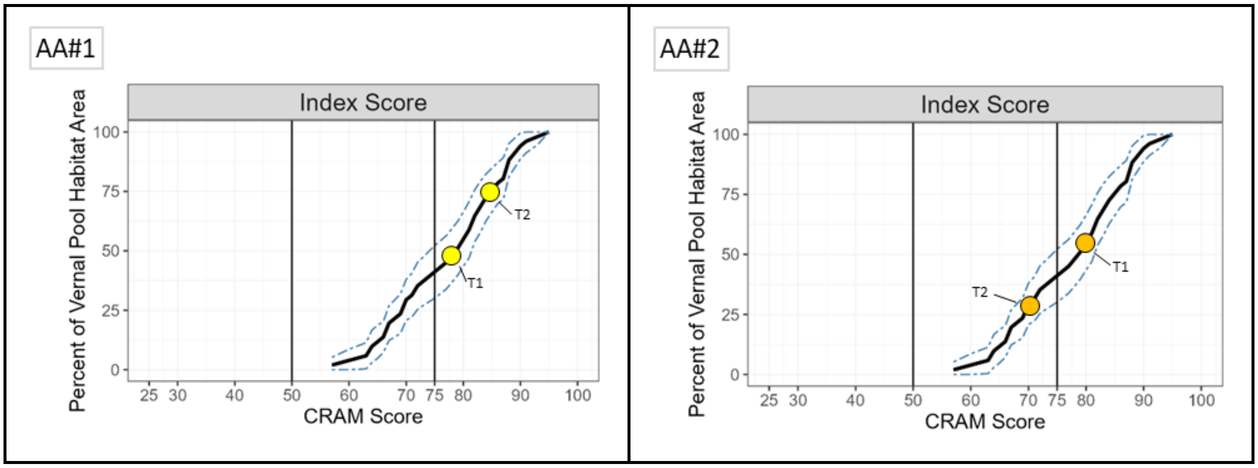

Figure 6. Fictional project example showing the CRAM Index Score CDF for vernal pools in the Central Valley and the CRAM scores from AA#1 in yellow (left) and AA#2 in orange (right) for Year 1 (timestep 1, or T1) and Year 10 (timestep 2, or T2) following the construction end date.

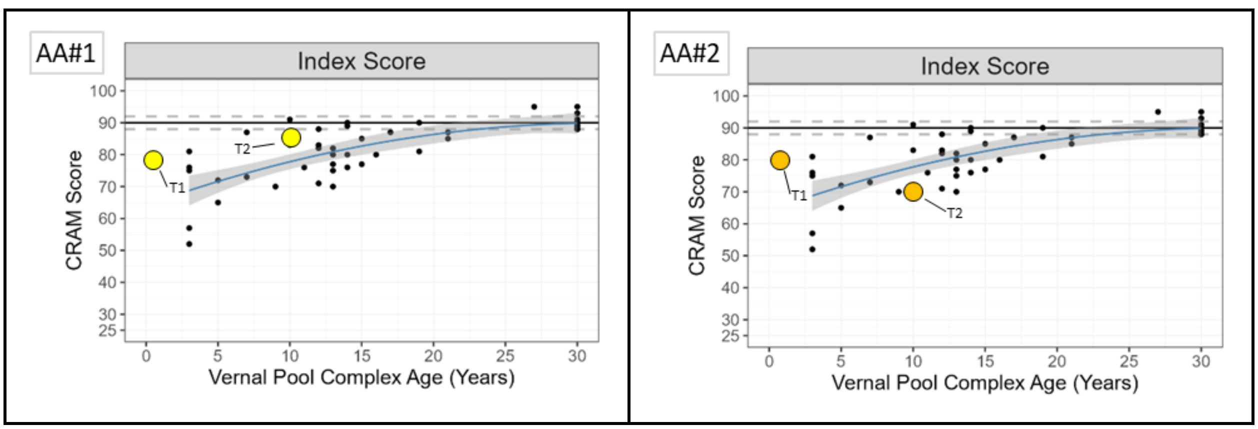

Figure 7. Fictional project example showing the HDC and CRAM Index scores for AA#1 (left, in yellow) and AA#2 (right, in orange) for Year 1 (timestep 1, or T1) and Year 10 (timestep 2, or T2).

Assessments were completed again in Years 2 and 5, and the project sites showed improvement in their condition (not shown in the figures above). However, Years 8 and 9 were very wet water years, and areas of the project site, including in AA#2, experienced disturbance and erosion.

The Year 10 CRAM assessment scores were plotted on the Central Valley CDF and HDC (see Figures 6 and 7 above, timestep 2, or T2). AA#1 has improved in condition so that the overall CRAM Index Score is now 85, placing it in the 75th percentile of vernal pools systems in the Central Valley region as seen on the CDF, and continues to plot on or above the HDC curve. However, AA#2 experienced significant erosion, which caused failed hydrology of the pools.

The overall Index Score is now 70, placing it in the 28th percentile, and it is now plotting below the HDC curve. This degraded condition triggers a further look at the CRAM Attribute scores to support implementing corrective adaptive management actions to address the erosion and hydrology issues at the degraded AA. The CRAM Attributes and underlying Metric scores are a useful resource for evaluating core ecological functions that are under-performing at a site.

The developer voluntarily decides to continue to monitor the two AAs to ensure that AA#1 reaches reference condition (estimated to occur by Year 15 following its current trajectory), and to ensure that the adaptive management actions in AA#2 are successful. Successful adaptive management actions would increase the overall ecological condition of the created vernal pool system so that the Index score is again plotting on or above the HDC.

Summary

This project applied WRAMP's Level-1 and 2 assessment methods to develop foundational environmental datasets that support a regional approach to protect and restore vernal pool habitats in California's Central Valley. These datasets include an updated Level-1 aquatic resources inventory ArcGIS map of vernal pool habitat in the Central Valley using recent 2018 NAIP imagery, a Level-2 probability based ambient survey and resulting CDF employing CRAM that characterized the overall ecological conditions of vernal pool systems in the Central Valley, and an HDC for project performance tracking also employing CRAM. The vernal pool habitat map and CRAM assessment data and resulting CDF and HDC have been integrated into EcoAtlas to provide interactive public access to the basemap and CRAM tools and to support vernal pool habitat management, and project planning and performance tracking.

This report also includes a fictional example of how resource managers and mitigation project planners might use the CRAM-based planning and tracking tools across the project's lifecycle to evaluate project designs, and track project performance within its broader regional watershed (or landscape) context. This example is a simple illustration of how the WRAMP approach can be applied to projects in a watershed context. The CRAM methodology helps project proponents and the regulatory agencies think critically about the project designs to ensure that the project wetlands are the highest condition possible and the most resilient to disturbances and stressors. Employing CRAM, CDFs, and HDCs allows resource managers to evaluate and compare project wetlands to others across time and space, and appropriately monitor and track the project to ensure the project goals are met.

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Appendix A - Ambient Survey Tables

Weblink to access the CDF estimate results: https://www.sfei.org/node/7782 The downloadable Excel filed includes the vernal pool complex CDF estimates for the Central Valley (Index and Attribute Scores as presented in Figure 1) as well as other CDF results for other wetland types and regions available in EcoAtlas' Landscape Profile tool (under the Condition profile).

Table A.1. CRAM Scores for the 51 vernal pool complex AAs (assessed 2020 - 2021) for the ambient survey in the Central Valley.

Site ID	Site Name	AARowID	Visit Date	Longitude	Latitude	Index Score	Landscape and Buffer Attribute	Hydrology Attribute	Physical Structure Attribute	Biotic Structure Attribute
VP002	02 - TNC	7537	5/12/2020	-120.4413	37.4040	87	80.79	91.67	83.33	91.67
VP004	4 Sheridan	8037	4/29/2021	-121.3700	38.9943	67	55.79	100.00	58.33	54.17
VP008	8 Muzzy Ranch	8068	4/14/2021	-121.8974	38.2731	86	93.29	100.00	66.67	83.33
VP009	9 Grissom Ranch	8099	4/6/2021	-120.6842	37.2346	83	93.29	100.00	58.33	79.17
VP010	10	7526	5/5/2020	-119.1904	36.1933	66	93.29	66.67	66.67	37.50
VP012	12 - Stillwater Plains	7527	5/21/2020	-122.2620	40.5110	84	93.29	91.67	75.00	75.00
VP015	15 Dry Creek Ranch	8098	4/27/2021	-121.0779	38.3239	91	93.29	100.00	75.00	95.83
VP018	18 - Ichord Ranch	7562	5/7/2020	-120.3701	37.3425	70	93.29	100.00	58.33	29.17
VP027	27 Luther, Sacramento	8097	4/26/2021	-121.1918	38.3599	64	65.29	75.00	50.00	66.67
VP046	46 Bulldog Acquisitions	8048	4/9/2021	-119.8341	36.9779	64	68.29	100.00	33.33	54.17
VP047	47 Solano County Water Agency	8063	4/13/2021	-121.7790	38.2359	72	93.29	100.00	58.33	37.50
VP057	57 - Ronnie Richards Ranch	7564	5/8/2020	-120.2363	37.2549	82	93.29	100.00	75.00	58.33
VP061	061 - Chance Ranch	7535	3/30/2020	-120.4258	37.4756	86	93.29	100.00	83.33	66.67
VP066	066 - Robinson Ranch	7539	3/30/2020	-120.4385	37.4445	88	93.29	100.00	83.33	75.00

Table A.1. (continued) CRAM Scores for the 51 vernal pool complex AAs (assessed 2020 - 2021) for the ambient survey in the Central Valley.

Site ID	Site Name	AARowID	Visit Date	Longitude	Latitude	Index Score	Landscape and Buffer Attribute	Hydrology Attribute	Physical Structure Attribute	Biotic Structure Attribute
VP070	70 - Ichord Ranch	7560	5/7/2020	-120.5749	37.7284	76	85.38	100.00	50.00	66.67
VP082	82 - Ichord Ranch	7565	5/7/2020	-120.3932	37.3582	80	93.29	100.00	83.33	41.67
VP098	098 - Flying M Ranch	7536	4/1/2020	-120.3141	37.3683	82	93.29	100.00	66.67	66.67
VP109	109 - Richards Ranch	7538	3/31/2020	-120.2187	37.3226	82	93.29	100.00	66.67	66.67
VP130	130 - TNC	7540	5/12/2020	-120.4268	37.4001	88	93.29	100.00	75.00	83.33
VP134	134 Scott Armstrong, Stanislaus	8100	4/7/2021	-120.5261	37.6932	72	80.79	75.00	58.33	75.00
VP139	139 - Chance Ranch	7541	5/7/2020	-121.0389	38.3946	90	93.29	100.00	75.00	91.67
VP140	140 - Stillwater Plains	7548	5/21/2020	-122.2642	40.5185	79	93.29	91.67	50.00	79.17
VP155	155 Waegell, Sacramento	8038	4/26/2021	-121.2792	38.4928	69	52.79	75.00	75.00	75.00
VP162	162 - Flying M Ranch	7545	4/1/2020	-120.3173	37.3883	81	93.29	100.00	66.67	62.50
VP173	173	7561	5/18/2020	-120.2437	37.3442	79	93.29	100.00	91.67	29.17
VP175	175	7546	5/5/2020	-120.8184	38.1884	75	77.79	66.67	91.67	62.50
VP185	185b - Drayer Ranch	7563	5/8/2020	-120.1522	37.2186	63	80.79	100.00	25.00	45.83
VP188	188 - Vina Plains Preserve	7547	5/19/2020	-122.0018	39.8969	88	93.29	100.00	66.67	91.67
VP195	195 Jane Craeger, Fresno	8102	4/6/2021	-119.5693	36.8789	65	68.29	100.00	58.33	33.33
VP196	196 Moore Ranch	8101	4/26/2021	-121.3557	38.8531	86	93.29	91.67	83.33	75.00

Table A.1. (continued) CRAM Scores for the 51 vernal pool complex AAs (assessed 2020 - 2021) for the ambient survey in the Central Valley.

Site ID	Site Name	AARowID	Visit Date	Longitude	Latitude	Index Score	Landscape and Buffer Attribute	Hydrology Attribute	Physical Structure Attribute	Biotic Structure Attribute
VP198	198 Double A Ranches, Stanislaus	8126	4/7/2021	-120.5836	37.7128	83	100.00	100.00	66.67	66.67
VP203	203 - Chance Ranch	7543	5/7/2020	-121.0321	38.3925	95	93.29	100.00	91.67	95.83
VP210	210 - Flying M Ranch	7542	4/1/2020	-120.3633	37.3643	93	93.29	100.00	91.67	87.50
VP222	222 - McKinney Ranch	7559	4/1/2020	-119.9217	36.9764	70	80.79	100.00	50.00	50.00
VP227	227 Table Mountain Substation	8045	5/10/2021	-121.6644	39.5541	71	70.42	66.67	75.00	70.83
VP247	247 Gill Ranch	8103	5/7/2021	-121.1188	38.4254	77	68.29	100.00	75.00	66.67
VP276	276 KB Homes, City of Lincoln	8036	4/29/2021	-121.2880	38.8637	57	68.29	75.00	58.33	25.00
VP286	286 - McKinney Ranch	7557	4/1/2020	-119.9385	36.9705	60	80.79	100.00	25.00	33.33
VP287	287	7556	5/29/2020	-121.8042	38.2788	80	93.29	91.67	66.67	66.67
VP291	291 North Table Mountain Ecological Reserve	8043	5/10/2021	-121.5740	39.5869	88	93.29	100.00	83.33	75.00
VP301	301 - Richards Ranch	7544	3/31/2020	-120.2327	37.3095	70	93.29	100.00	33.33	54.17
VP316	316 - Vina Plains	7549	5/19/2020	-121.9849	39.9116	79	68.29	100.00	66.67	79.17
VP317	317 - Chance Ranch	7550	3/30/2020	-120.3713	37.4883	74	93.29	91.67	83.33	29.17
VP322	322 - Flying M Ranch	7553	4/1/2020	-120.3132	37.3511	81	93.29	100.00	66.67	62.50
VP324	324 Twelve Bridges	8047	4/29/2021	-121.2992	38.8459	67	80.79	75.00	58.33	54.17
VP335	335 - Gridley Mitigation Bank	7555	5/29/2020	-121.8008	38.2975	67	93.29	100.00	25.00	50.00

Table A.1. (continued) CRAM Scores for the 51 vernal pool complex AAs (assessed 2020 - 2021) for the ambient survey in the Central Valley.

Site ID	Site Name	AARowID	Visit Date	Longitude	Latitude	Index Score	Landscape and Buffer Attribute	Hydrology Attribute	Physical Structure Attribute	Biotic Structure Attribute
VP338	338 - Flying M Ranch	7554	4/1/2020	-120.3496	37.4029	90	93.29	100.00	83.33	83.33
VP339	339 Upper Bidwell Park	8035	5/25/2021	-121.7933	39.7759	73	93.29	100.00	66.67	33.33
VP347	347 - TNC Valensin	7551	5/7/2020	-121.3102	38.3567	84	80.79	100.00	83.33	70.83
VP370	370 - UC Merced Reserve East	7558	5/12/2020	-120.4056	37.3692	90	93.29	100.00	83.33	83.33
VP380	380 - Stillwater Plains	7552	5/21/2020	-122.2628	40.5084	69	68.29	91.67	41.67	75.00

Table A.2. CDF estimates of the proportions (percentile statistics or Pct) of vernal pool complex habitat (as an area resource) in the Central Valley, CA by CRAM indicator (Index or Attribute Scores) and ecological condition score (CRAM Score) with number of responses (N Resp.), Standard Error (StdError), and Lower and Upper 95% Confidence Bounds (or limits, LCB95Pct and UCB95Pct).

CRAM Indicator	Statistic	N Resp.	CRAM Score	StdError	LCB95Pct	UCB95Pct
Index Score	5Pct	2	62		57	64
Index Score	10Pct	5	64		59	67
Index Score	25Pct	12	69		67	71
Index Score	50Pct	23	79		74	81
Index Score	75Pct	37	85		82	88
Index Score	90Pct	45	89		87	92
Index Score	95Pct	48	90		88	95
Index Score	**Mean**	**51**	**78**	**1**	**76**	**80**
Index Score	**Variance**	**51**	**90**	**10**	**69**	**110**
Index Score	**Std. Deviation**	**51**	**9**	**1**	**8**	**11**
Buffer and Landscape Context	5Pct	2	61		53	66
Buffer and Landscape Context	10Pct	3	66		61	68
Buffer and Landscape Context	25Pct	11	79		68	81
Buffer and Landscape Context	50Pct	19	87		86	88
Buffer and Landscape Context	75Pct	19	90		89	92
Buffer and Landscape Context	90Pct	19	92		91	100
Buffer and Landscape Context	95Pct	19	93		92	100
Buffer and Landscape Context	**Mean**	**51**	**86**	**1**	**83**	**88**
Buffer and Landscape Context	**Variance**	**51**	**131**	**23**	**87**	**175**
Buffer and Landscape Context	**Std. Deviation**	**51**	**11**	**1**	**10**	**13**
Hydrology	5Pct	3	67		67	71
Hydrology	10Pct	3	70		67	75
Hydrology	25Pct	8	86		76	92
Hydrology	50Pct	15	94		93	95
Hydrology	75Pct	15	97		96	98
Hydrology	90Pct	15	99		98	100
Hydrology	95Pct	15	99		98	100
Hydrology	**Mean**	**51**	**94**	**1**	**92**	**97**
Hydrology	**Variance**	**51**	**105**	**24**	**59**	**152**
Hydrology	**Std. Deviation**	**51**	**10**	**1**	**8**	**13**

Table A.2. (continued) CDF estimates of the proportions (percentile statistics or Pct) of vernal pool complex habitat (as an area resource) in the Central Valley, CA by CRAM indicator (Index or Attribute Scores) and ecological condition score (CRAM Score) with number of responses (N Resp.), Standard Error (StdError), and Lower and Upper 95% Confidence Bounds (or limits, LCB95Pct and UCB95Pct).

CRAM Indicator	Statistic	N Resp.	CRAM Score	StdError	LCB95Pct	UCB95Pct
Physical Structure	5Pct	3	25		25	36
Physical Structure	10Pct	5	34		25	47
Physical Structure	25Pct	10	53		47	57
Physical Structure	50Pct	18	64		60	68
Physical Structure	75Pct	37	76		71	80
Physical Structure	90Pct	37	82		78	92
Physical Structure	95Pct	47	86		82	92
Physical Structure	**Mean**	**51**	**66**	**2**	**63**	**70**
Physical Structure	**Variance**	**51**	**305**	**51**	**204**	**405**
Physical Structure	**Std. Deviation**	**51**	**17**	**1**	**15**	**20**
Biotic Structure	5Pct	1	27		25	29
Biotic Structure	10Pct	4	31		26	36
Biotic Structure	25Pct	11	49		35	57
Biotic Structure	50Pct	21	65		62	70
Biotic Structure	75Pct	38	75		72	81
Biotic Structure	90Pct	45	87		80	93
Biotic Structure	95Pct	46	91		84	96
Biotic Structure	**Mean**	**51**	**64**	**2**	**60**	**68**
Biotic Structure	**Variance**	**51**	**374**	**51**	**275**	**474**
Biotic Structure	**Std. Deviation**	**51**	**19**	**1**	**17**	**22**

Table A.3. CDF condition class estimates (Estimate.P) of the proportion of vernal pool complex habitat area in the Central Valley, CA in good, fair, or poor condition as assessed using CRAM and its standard condition classes. Poor ecological condition is characterized as having CRAM Index or Attribute Scores of 25-50, fair 51-75, and good 76-100. As above, number of responses (N Resp.), Standard Error (StdError), and Lower and Upper 95% Confidence Bounds (or limits, LCB95Pct and UCB95Pct) are included in the *spsurvey* outputs.

CRAM Indicator	Condition Class	N Resp.	Estimate.P	StdError.P	LCB95Pct.P	UCB95Pct.P
Index Score	Good	30	59	6	48	70
Index Score	Fair	21	41	6	30	52
Buffer and Landscape Context	Good	41	80	4	72	89
Buffer and Landscape Context	Fair	10	20	4	11	28
Hydrology	Good	43	84	4	76	93
Hydrology	Fair	8	16	4	7	24
Physical Structure	Good	14	27	5	18	37
Physical Structure	Fair	27	53	6	41	65
Physical Structure	Poor	10	20	4	11	28
Biotic Structure	Good	13	26	5	16	35
Biotic Structure	Fair	25	48	6	38	60
Biotic Structure	Poor	13	26	5	16	35

Appendix B - Habitat Development Curve Tables

Table B.1. CRAM Scores for the 35 project sites used to develop the HDC.

Project Type indicates the kind of mitigation/restoration activities: R = restoration (or re-creation), C = creation (where no pools were historically present) P = preservation of historically natural pools. Age indicates the estimated age of the pools when they were assessed (in years).

Project Type	Unique location	Site ID	Site Name	AA RowID	Visit Date	Pool Year	Age	Index Score	Landscape and Buffer Attribute	Hydrology Attribute	Physical Structure Attribute	Biotic Structure Attribute
R	12A	HDC 12	12 Byron Vernal Pools Restoration	8033	5/13/2021	2012	9	70	77.79	83.33	75.00	45.83
C	15A	HDC 15	15 Cottonwood Creek	7989	4/13/2021	2018	3	57	80.79	66.67	50.00	29.17
R	2C	HDC 2	2 Elsie Gridley, Phase 1	7992	4/13/2021	2005	16	80	93.29	66.67	75.00	83.33
R	2D	287	287	7556	5/29/2020	2006	14	80	93.29	91.67	66.67	66.67
R	2A	HDC 2	2 Elsie Gridley, Phase 3, AA	8111	4/13/2021	2018	3	76	93.29	91.67	50.00	70.83
R	2B	HDC 2	2 Elsie Gridley, Phase 3, AA	8113	4/13/2021	2018	3	75	93.29	100.00	58.33	50.00
C	8A	HDC 8	8 Foothill Park	7986	5/4/2021	1994	27	95	93.29	100.00	100.00	87.50
C	8B		8 Foothill Park	8645	5/11/2011	1994	17	87	93.29	100.00	75.00	79.16
C	26A	HDC 26	26 Gill Ranch AA	7998	4/27/2021	2006	15	85	93.29	100.00	66.67	79.17
C	26B	HDC 26	26 Gill Ranch AA	7999	4/27/2021	2007	14	90	93.29	100.00	83.33	83.33
C	26C	HDC 26	26 Gill Ranch AA	8000	4/27/2021	2009	12	82	80.79	100.00	58.33	87.50
C	17A	HDC 17	17 Lazy K Ranch HSR AA	8031	4/9/2021	2016	5	65	80.79	75.00	66.67	37.50
C	17B	HDC 17	17 Lazy K Ranch HSR AA	8032	4/9/2021	2008	13	70	80.79	83.33	50.00	66.67
C	1A		Madera Caltrans 77-86	5629	4/13/2016	2009	7	73	80.79	91.67	50.00	70.83
C	1A	HDC 1	1 Madera Caltrans AA	8005	4/19/2021	2009	12	71	80.79	91.67	50.00	62.50
C/R	1B		Madera Caltrans 48-55	5631	4/13/2016	2009	7	87	93.29	100.00	75.00	79.16
C/R	1B	HDC 1	Madera Caltrans AA	8007	4/19/2021	2009	12	83	93.29	100.00	75.00	62.50
R	22A	HDC 22	22 Markham Ravine	7995	4/23/2021	2018	3	81	93.29	83.33	66.67	79.17
C	25A	HDC 25	25 Meridian Ranch	8034	5/4/2021	2010	11	76	72.88	100.00	75.00	54.17
C	3A	Mont_c	Montezuma Created Pools	5621	5/13/2016	2003	13	75	93.29	91.66	58.33	58.33
R	9B	VPS-1	VPS-1	8631	4/24/2013	2000	13	82	93.29	91.67	75.00	66.66
R	9B	HDC 9	9 Moore Ranch AA	8002	4/26/2021	2000	21	87	93.29	91.67	66.67	95.83
R	9A	VPS-2	VPS-2	8632	4/24/2013	2000	13	77	93.29	91.67	58.33	66.67

Table B.1. (continued) CRAM Scores for the 35 project sites used to develop the HDC.

Project Type indicates the kind of mitigation/restoration activities: R = restoration (or re-creation), C = creation (where no pools were historically present) P = preservation of historically natural pools. Age indicates the estimated age of the pools when they were assessed (in years).

Project Type	Unique location	Site ID	Site Name	AA RowID	Visit Date	Pool Year	Age	Index Score	Landscape and Buffer Attribute	Hydrology Attribute	Physical Structure Attribute	Biotic Structure Attribute
R	9A	HDC 9	9 Moore Ranch AA	8003	4/26/2021	2000	21	85	93.29	91.67	66.67	87.50
R	9C	VPS-3	VPS-3	8646	4/24/2013	2000	13	80	93.29	91.67	66.67	66.67
C	19A	HDC 19	19 Noonan Ranch	7990	4/14/2021	2018	3	52	68.29	58.33	50.00	33.33
R	7B	RSAA-2	RSAA-2	8643	5/16/2011	1997	14	89	93.29	91.66	91.66	79.16
R	7B		Rancho Seco Created Pools	5623	5/11/2016	1997	19	90	93.29	100.00	66.67	95.83
R	7C	HDC 7	7 Rancho Seco AA	7993	6/3/2021	2011	10	91	93.29	100.00	91.66	79.16
C	21A	HDC 21	21 Reason Farms	7988	5/11/2021	2006	15	77	68.29	100.00	58.33	83.33
R	14A	SP-1	SP-1	8629	2/28/2012	2002	10	83	93.30	100.00	75.00	62.50
R	14A		Stillwater Created Pools	5624	5/12/2016	2002	14	76	77.79	83.33	66.67	75.00
R	14A	HDC 14	14 Stillwater Plains	8046	5/10/2021	2002	19	81	80.79	83.33	66.67	91.66
C	27A	HDC 27	27 Van Vleck Ranch	8001	5/7/2021	2009	12	88	93.29	100.00	58.33	100.00
C	18A	HDC 18	18 Yosemite Lake	7997	4/13/2021	2016	5	72	93.29	83.33	66.67	45.83

Table B.2. CRAM Scores for the 14 reference sites used to develop the reference ranges for the HDC.

Project Type indicates the kind of mitigation/restoration activities: P = preservation of historically natural pools. Age indicates the estimated age of the pools when they were assessed (in years). Even though the reference site pools are considered historically undisturbed by anthropogenic influences, we set the Age to 30 years for inclusion in the HDC.

Project Type	Unique location	Site ID	Site Name	AA RowID	Visit Date	Pool Year	Age	Index Score	Landscape and Buffer Attribute	Hydrology Attribute	Physical Structure Attribute	Biotic Structure Attribute
P		139	139 - Chance Ranch	7541	5/7/2020	1900	30	90	93.29	100.00	75.00	91.67
P		203	203 - Chance Ranch	7543	5/7/2020	1900	30	95	93.29	100.00	91.67	95.83
P		CDF 15	15 Dry Creek Ranch	8098	4/27/2021	1900	30	91	93.29	100.00	75.00	95.83
P		210	210 - Flying M Ranch	7542	4/1/2020	1900	30	93	93.29	100.00	91.67	87.50
P		338	338 - Flying M Ranch	7554	4/1/2020	1900	30	90	93.29	100.00	83.33	83.33
P	3B	Mont_n	Montezuma Natural Pools	5620	5/13/2016	1900	30	88	93.29	83.33	75.00	100.00
P	3B	SF VP RN-01	Montezuma Preserve Pools	7884	5/18/2011	1900	30	89	93.29	83.33	83.33	95.83
P		CDF 291	291 North Table Mountain Ecological Reserve	8043	5/10/2021	1900	30	88	93.29	100.00	83.33	75.00
P	7A	RSAA-n	Rancho Seco Natural Pools	5622	5/11/2016	1900	30	88	93.29	83.33	83.33	91.67
P		066	066 - Robinson Ranch	7539	3/30/2020	1900	30	88	93.29	100.00	83.33	75.00
P	14B	1	Stillwater Plains	7891	2/29/2012	1900	30	89	68.30	100.00	100.00	87.50
P		130	130 - TNC	7540	5/12/2020	1900	30	88	93.29	100.00	75.00	83.33
P		370	370 - UC Merced Reserve East	7558	5/12/2020	1900	30	90	93.29	100.00	83.33	83.33
P		188	188 - Vina Plains Preserve	7547	5/19/2020	1900	30	88	93.29	100.00	66.67	91.67