Multi-Benefit Recharge Project Methodology for Inclusion in Groundwater Sustainability Plans

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Executive Summary

As Groundwater Sustainability Agencies (GSAs) plan for projects and management actions (PMAs) to achieve groundwater sustainability, multi-benefit recharge projects emerge as promising tools to maximize benefits to numerous groundwater and environmental water uses and users. The multi-benefit groundwater recharge project (Project) described in this technical memorandum is spearheaded by The Nature Conservancy (TNC) and builds on its successful BirdReturns program and a pilot program implemented in Colusa County in partnership with the Colusa Groundwater Authority (CGA). The main goals of the Project described in this guidance document are to simultaneously:

(1) recharge groundwater supplies, and
(2) create temporary habitat for migratory shorebirds along the Pacific Flyway.

This guidance document summarizes considerations and planning that may go into designing, selecting, implementing, and monitoring a Project in the context of groundwater sustainability plan (GSP) development for GSAs. Multi-benefit recharge projects should be customized to the specific settings and needs of each GSA in order to reach GSP sustainability goals and designed, selected, and implemented to maximize desired benefits.

The following is an outline of the five primary sections of this guidance document:

Section 1. Introduction.
Introduction to how multi-benefit groundwater recharge projects can be integrated as a PMA in GSPs.

Section 2. Designing and selecting multi-benefit groundwater recharge projects.
Guidelines and suggestions for designing multi-benefit recharge projects and selecting sites for implementation.

Section 3. Implementing and monitoring multiple benefits.
Guidelines and suggestions for implementing and monitoring projects and quantifying recharge and environmental benefits.

Section 4. Integrating multi-benefit recharge into GSPs.
Sample outline and language that GSAs can use to describe these multi-benefit groundwater recharge projects in the PMA chapter of their GSPs.

Section 5. Case study example: TNC-Colusa Groundwater Authority multi-benefit recharge in Colusa County.
A working example of a multi-benefit recharge project based on work completed between 2019-2021.

1 Introduction

1.1 Groundwater recharge as a tool to achieve sustainability

In 2014, SGMA was signed into California law, supplying a framework for sustainable management of California's groundwater basins and subbasins. SGMA enables local management of groundwater resources, requiring that local agencies achieve and maintain sustainable groundwater conditions for the many and diverse beneficial users of groundwater. Groundwater sustainability is key to the future vitality of urban, domestic, agricultural, and environmental groundwater uses across California.

GSAs have the authority to develop, adopt, and implement a GSP for the subbasin they manage. Ultimately, GSAs must plan to achieve groundwater sustainability within 20 years of implementing their GSPs. While the precise criteria that define sustainability are described in each GSP, groundwater sustainability generally results from a long-term balance between inflows to and outflows from the groundwater system, and culminates in the absence of adverse, undesirable results of chronic lowering of groundwater levels and reduction of groundwater storage.

1.2 Projects and management actions (PMAs)

Among the required elements of a GSP, GSAs must identify PMAs that will help to achieve and maintain groundwater sustainability in the subbasin, as defined in the GSP. Effective PMAs are developed as integral components within the overall sustainable groundwater management strategy, helping GSAs to achieve specific, target "measurable objectives" and "interim milestones," and to avoid specific "minimum thresholds" on the path to sustainability.

"Projects", as considered as a PMA, generally refer to structural features, programs, and activities that supplement and expand available water supplies. Common project types include:

- **Direct groundwater recharge projects**, such as winter and off-season flooding of farmland (e.g., on-farm managed aquifer recharge), recharge basins, and injection wells.
- **In-lieu groundwater recharge projects**, including projects that enhance the use of existing surface water supply (through existing or expanded conveyance and distribution infrastructure), and projects that bring in new surface water supply (e.g., treated wastewater reuse, produced water from oil and gas production, supply partnerships, pipelines, and water rights).

"Management Actions" are typically programs, policies, or economic incentives designed to reduce consumptive use, starting first with non-beneficial consumptive uses (e.g., evaporation from soil surfaces from irrigation) and moving forward beneficial consumptive uses if necessary.

1.3 Multi-benefit groundwater recharge as a PMA

Direct groundwater recharge projects are important tools for achieving groundwater sustainability, allowing GSAs to directly recharge aquifers to the benefit of all groundwater users. When groundwater recharge projects are strategically designed and operated to achieve multiple objectives, such as seasonal habitat formation, even greater benefits can be achieved for numerous groundwater and surface water users.

Multi-benefit groundwater recharge projects achieve broader benefits for numerous groundwater and surface water users without sacrificing important aquifer recharge benefits. The multi-benefit groundwater recharge approach described in this document builds on the successful BirdReturns program, with a specific focus on strategic flooding of agricultural fields with the goals of (1) recharging groundwater supplies while (2) simultaneously creating late summer/early fall and/or spring habitat for migratory shorebirds.

Multi-benefit groundwater recharge projects dovetail with the overall aims of SGMA, providing groundwater recharge to support long-term groundwater sustainability for all beneficial groundwater users, while also providing direct, near-term benefits of shallow flooding to create migratory shorebird habitat, especially during critical migration periods along the Pacific Flyway. A landmark study in the journal *Science* on staggering population declines in North American avifauna since 1970 found that shorebirds have declined precipitously and consistently, with 69% of shorebirds species declining and an overall 37% drop in species abundance over the last half century (Rosenberg et al, 2019), underscoring the critical need for short-term wetland habitat in the Pacific Flyway during shorebird migration periods. Significant funding opportunities are increasingly available for multi-benefit projects that enhance environmental habitat, furthering the appeal of these projects.

Sections 0 and 0 of this document describe the process that GSAs may follow to design, select, implement, and monitor their own multi-benefit groundwater recharge projects. Much of this process is scalable and customizable to the specific setting and needs of each GSA. Following these suggestions, Section 0 offers a suggested outline for how GSAs can document and report their multi-benefit groundwater recharge projects in their GSPs. Finally, lessons learned from the 2019-2020 implementation of a multi-benefit groundwater recharge program in Colusa County are described in Section 0.

2 Designing and selecting multi-benefit groundwater recharge projects

Multi-benefit recharge projects should be designed, selected, and implemented to maximize project benefits (Figure 1), and customized to the specific settings and needs of each GSA in order to reach the GSP sustainability goals. Multi-benefit groundwater recharge projects that simultaneously supply groundwater recharge and migratory bird habitat are just one type of multi-benefit recharge project and are the focus of this guidance document.

GSAs may use the following general process to design and select multi-benefit recharge projects and estimate the costs and benefits of the selected projects:

1. Generate a ranked list of candidate sites via a geospatial analysis of the project area(s) (Section 2.1);
2. Using the candidate site attributes and an assumed project size (i.e., number of sites and total flooded area), estimate project benefits and costs (Section 2.2);
3. Compare the estimated project benefits and costs to the specific needs and settings of the GSA (Section 2.3) and adjust the project size by including more or fewer fields from the ranked list and recalculate the project benefits and costs using the new average field attributes until the project benefits, costs, or cost-benefit ratio meet the needs of the GSA in order to help reach sustainability goals; and
4. Conduct outreach to growers to solicit willing participants with suitable fields and surface water availability (Section 2.4).

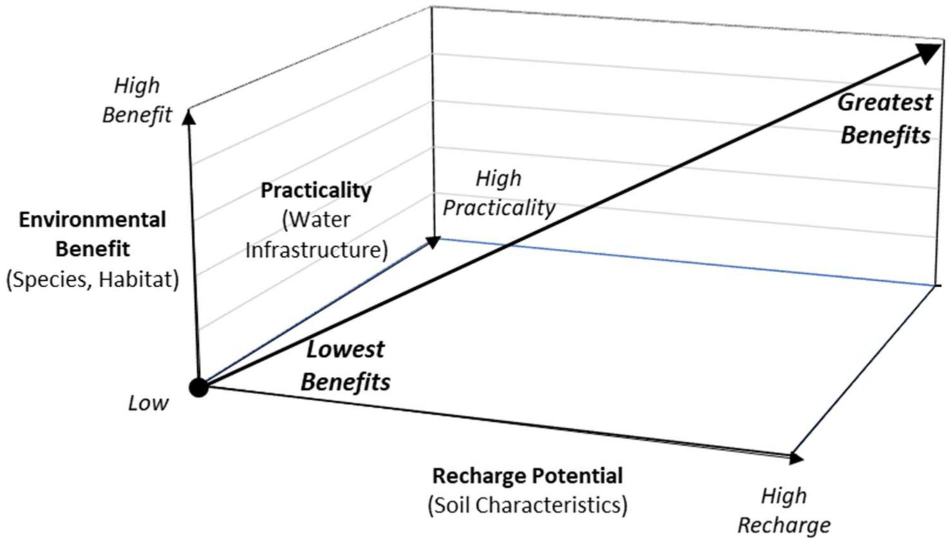

Figure 1. Conceptualization of the primary benefits and objectives from project design, selection and implementation. Successful projects will realize the greatest benefit from high groundwater recharge, high environmental benefit, and high implementation practicality.

2.1 Identifying project sites

GSAs should consider the following criteria when selecting sites to be considered for project implementation:

- Soil types conducive to recharge as categorized by the UC Davis Soil Agricultural Groundwater Banking Index (SAGBI). Historical land use may often be a better indicator of where recharge can occur most optimally;
- Annual row crop fields that are open and free of tall vegetation (after remaining vegetation is tilled into the soil post-harvest) where water spreading will provide open, flooded habitat where shorebirds can see predators;
- Crop types that can tolerate waterlogged conditions;
- Available surface water rights with appropriate timing and uses for on-farm groundwater recharge and/or habitat creation purposes;
- Relatively flat topography to allow water ponding;
- An agronomic cycle that allows for flooding during peak migration of shorebirds in late summer-early fall (July 15-October 1) or late winter-mid spring (March 15-April 30);
- Fields with underlying aquifers that have had greater losses of groundwater over the period from 2009-2019 than other potential sites, thus in more need of recharge for groundwater sustainability;
- Fields that have historically been used to cultivate crops characterized by low nitrogen loading, or that have low potential for nutrient leaching into the aquifer (see Section 0);
- Fields located within areas identified as disadvantaged communities (see Section 0); and
- Fields outside of identified exclusion zones, including airports (to avoid higher number of birds in proximity to planes) and urban areas (for mosquito vector control).
- Larger fields should be prioritized for better bird habitat, more cost-effective monitoring, and lower administrative costs per unit of habitat area and recharge volume benefit.

In order to efficiently identify sites that meet the requirements listed above, the GSA should perform a geospatial analysis of fields using the Multi-Benefit Recharge Mapping Tool. This web tool can help GSAs identify suitable locations to flood agricultural fields to achieve multi-benefit recharge goals: recharging groundwater supplies while creating habitat for migratory shorebirds. GSAs can use this tool to view individual factors relevant for siting projects and can see how these factors overlap within their area of interest. Locations that meet all criteria are ideal locations to implement multi-benefit recharge projects.

The geospatial analysis should result in a ranked list of candidate project fields, which may be used along with the candidate field attributes and GSP sustainability goals to design the project and estimate project benefits and costs (Section 2.2).

2.2 Estimating multi-benefit recharge benefits and costs

GSAs will need to estimate the benefits (Table 2-1) and economic costs (Table 2-2) of multi-benefit recharge projects in order to select and design projects for the specific settings and needs of the GSA. These estimated costs and benefits will vary based on the overall size of the project (e.g., number of sites and total flooded area), see Section 2.3 below, and the attributes of the assumed project fields from the ranked list of candidate fields (Section 2.1).

GSAs will need to make certain assumptions or estimates about the number of fields that will be available for a project. When calculating the average candidate field attributes for an assumed project size, GSAs should consider and evaluate field attributes across a larger area, recognizing that only a small fraction of eligible fields will ultimately participate. Farmer interest in participation can vary across different areas depending on water availability, water reliability, outreach, local interests, and compensation (if applicable). GSAs can estimate the percent enrollment in a Project through outreach and feedback at grower meetings, polling, or other means.

Once the project area has been estimated, project benefits to groundwater recharge can be estimated by multiplying the total area by an estimated recharge (or infiltration) rate. The recharge rate may be based on local infiltration data, if available, or can be estimated based on soil characteristics and the SAGBI ratings of the project area. Table 2-3 summarizes the relationship between infiltration rates and SAGBI rating components at five sites studied in Colusa County in 2019 and 2020. Infiltration rates at these sites range from 0.2 to 1.2 inches per day, depending on site conditions and soil characteristics. As shown in Figure 2, the SAGBI deep percolation component correlates with calculated infiltration rates,[1] and may be a useful proxy for estimating recharge rates at new project sites. SAGBI ratings may also be useful for evaluating relative recharge potential across larger potential study areas. Figure 3 summarizes the relationship between the average SAGBI deep percolation component for the entire service area of eight different irrigation districts across California, and average deep percolation rates quantified from multi-year district-wide water budgets. While conditions vary between districts, SAGBI ratings may help to shed light on typical ranges or relative rankings of recharge potential across candidate sites in each GSA’s unique setting.

The estimated area of habitat that will be generated by the project can be estimated as the planned project area that will be flooded each year, assuming that all flooded area will provide viable habitat.

Table 2-1. Descriptions of multi-benefit recharge project benefits and recommended methods for estimating annual benefits.

Benefit Category	**Description**	**Recommended method and considerations for estimating benefit**
Recharge	Estimated groundwater recharge volume generated by the project	• Estimate a recharge rate, in feet per day, for the project area. Use area-weighted SAGBI ratings or other available data for the project area, as available, to estimate the recharge rate. • Multiply the recharge rate by both the planned project annual area, in acres, and the planned project annual duration, in days, to calculate total estimated annual recharge in acre-feet.
Habitat	Estimated area of habitat generated by the project	• Habitat area generated should be estimated as equal to the planned project annual area.

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[1] Pearson correlation significant at the 0.05 level (two-tailed test, N=5).

Table 2-2. Descriptions and examples of multi-benefit project costs.

Cost Category	Examples
Project costs: costs that can be best estimated as fixed project costs	• Project administration • Developing outreach materials
Site costs: costs that can be best estimated and scaled per project site.	• Grower outreach and workshopping • Monitoring equipment purchase and installation • Monitoring data processing and quality control • Contract administration
Per-acre costs: costs that can be best estimated and scaled per total project acreage.	• Site compliance and water depth monitoring • Grower financial incentives

In order to estimate total annual costs for each category in Table 2-2, the initial costs (e.g., developing outreach materials, and purchasing and installing monitoring equipment) should be annualized over the planned duration of the project and combined with estimated ongoing costs (e.g., outreach, monitoring data processing, grower financial incentives).

Table 2-3. Summary of infiltration parameters at five sites studied in Colusa County.

Site Infiltration and SAGBI Ratings		Site 1	Site 2	Site 3	Site 4	Site 5
Calculated Steady-State Saturated Infiltration Rate (inches/day)		0.2	1.2	0.3	1.0	0.6
SAGBI Rating		62	77	73	78	60
SAGBI Rating Components	Deep Percolation	35	60	54	62	55
	Root Zone Residence Time	71	70	68	71	49
	Chemical Limitations	100	100	100	100	100
	Topographic Limitations	100	100	100	100	100
	Surface Condition	60	54	48	57	56

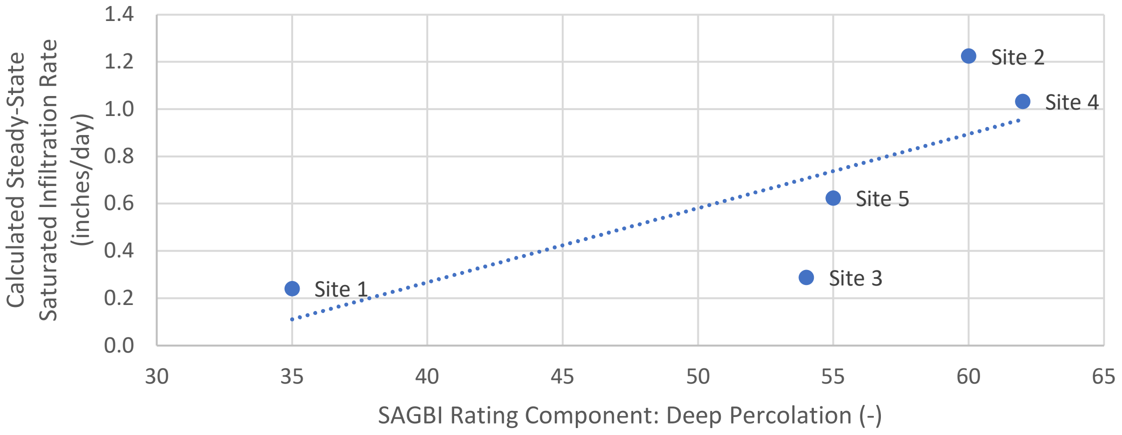

Figure 2. Relationship between the SAGBI Deep Percolation Component and the Saturated Infiltration Rate in inches per day at project sites studied in Colusa County.

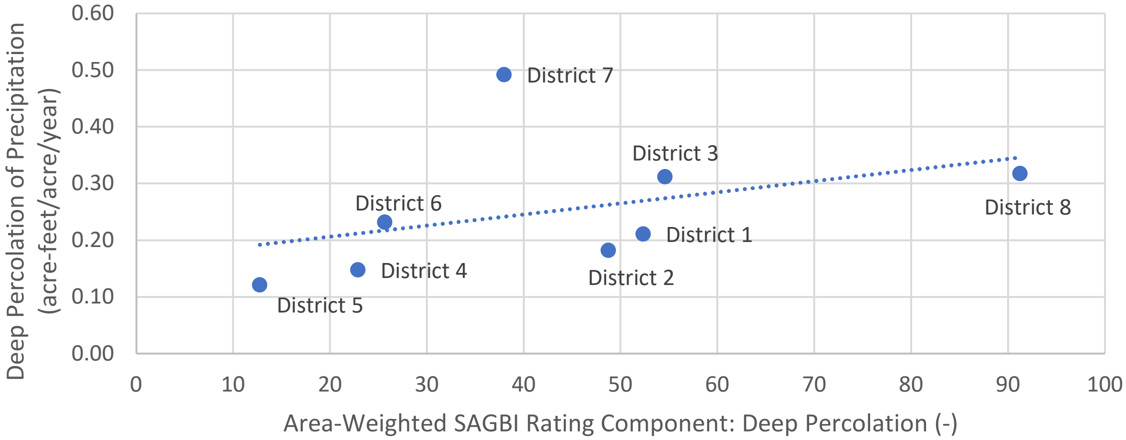

Figure 3. Relationship between the SAGBI Deep Percolation Component and Deep Percolation of Precipitation for eight different irrigation and water districts across California.

2.3 Selecting multi-benefit recharge projects to match GSP sustainability goals

The ultimate goal in designing and selecting sites for multi-benefit recharge projects is to enable the GSA to reach GSP sustainability targets while providing multiple benefits. To meet this goal, GSAs will need to select and design projects that provide a specific benefit or cost/benefit ratio. Using the attributes from the ranked list of candidate fields (Section 2.1) and estimated unit costs and benefits (Section 2.2), GSAs may adjust the estimated project size (i.e., number of sites and total area), thereby adjusting (1) the average field attributes as more or fewer fields are included in the project and (2) the estimated costs and benefits as the project size and field attributes change, until the target benefit or cost/benefit ratio is reached.

2.3.1 Estimating multi-benefit recharge productivity

Due to their multi-beneficial nature, the benefits and return on investment (ROI) of these projects are not easily compared to other recharge projects where the non-recharge benefits are different or non-existent. GSAs may wish to assign some value to these habitat benefits in addition to the groundwater recharge benefit. To simplify comparison of the ROI across various types of recharge projects, a simple recharge productivity metric, such as the following, can be calculated for different project types:

$$RP = \frac{(C \times h_A + r_V)}{Cost}$$

where RP is the recharge productivity metric, h_A is the estimated project habitat area, r_V is the estimated project recharge volume, cost is the estimated total project cost, and C is a coefficient representing the relative value of an acre of habitat compared to value of an acre-foot of recharge. The value of C can be refined by GSAs to reflect local interests and needs. For example, if one acre of habitat is considered to be equivalent in value to two acre-feet of recharge, then C is 0.5, or if one acre of habitat and one acre-foot of recharge are considered to be of equal value then C is 1. RP can then be used to prioritize and select different types of multi-benefit recharge projects.

Lastly, we recognize that GSAs may have more than one option for recharging groundwater supplies. Relatively speaking, by their nature, multi-benefit recharge projects are often one of the least expensive means for recharging groundwater resources, as compared to other means for securing additional water supplies (Figure 4).

Figure 4. Water supply cost comparison, with the cost per unit of water increasing left to right.

2.3.2 Minimizing potential water quality concerns

Among other considerations, GSAs should review and select candidate sites with the goal of minimizing any potential water quality concerns associated with recharge. Historical crop types and any available information on nutrient loading should be considered when selecting candidate sites. Specifically, GSAs should prioritize fields that have historically been used to cultivate crops characterized by low nitrogen loading. GSAs may also consider repeating recharge projects on the same fields to minimize the risk of nutrient loading, as nutrients would be leached to a greater extent each time flooding occurs. It is also important to consider monitoring water quality from soil and water samples to monitor potential water quality effects, especially in areas that may impact disadvantaged communities and domestic wells.

2.3.3 Prioritizing recharge near disadvantaged communities and domestic groundwater users

GSAs may also consider reviewing and selecting candidate sites to prioritize groundwater recharge in areas identified as disadvantaged communities and in areas with higher concentrations of domestic groundwater wells. In subbasins where groundwater levels have declined, this prioritization can help to alleviate the adverse impacts of diminished groundwater supply that may be felt by disadvantaged communities and domestic groundwater users. Demonstration of project benefits to these communities is also a critical component considered in many applications for grant funding.

2.4 Conduct outreach to growers within project area

Outreach to the local farming community is a critical component to educate stakeholders about groundwater sustainability needs and to find willing grower partners and suitable multi-benefit recharge sites. GSAs should develop an outreach plan and work closely with local agencies and Resource Conservation Districts to engage community members and diverse stakeholders using the following methods:

- Convene workshops to educate potential stakeholders and participants.
    - Invite local farmers, members of water and reclamation districts in the basin, Native American tribes, environmental justice organizations via mail or electronic communications to attend a workshop
    - Conduct workshop with community members to introduce the project, and provide education about multi-benefit, on-farm recharge and required methodology and covering program requirements, water flow measurement, criteria for suitable fields, timing, field preparation and any grower incentives.
- Publicly announce the pending program

    - Send a program description that describes the project and timeline and includes project area map via electronic mail to stakeholders.
    - Post program announcement on GSA and water district websites
    - Reach out to local growers via email and phone calls
- Outreach and network through local farming associations and agencies
    - Work with local Resource Conservation Districts and the Farm Bureau to engage with farmers
- Solicit applications, depending on the GSA's project requirements
    - Set up an online application form and/or accept applications by mail
- Targeted outreach
    - Using the Multi-Benefit Recharge Mapping Tool to pinpoint ideal site locations and reach out to farmers in those areas.
    - Contact individual landowners/growers where the GSA's planning has indicated the program can be implemented

2.5 Mosquito and vector control concerns

For projects carried out in late summer-early fall, it is important to establish early communication with Vector Control Districts, so they are aware flooding for multiple benefits will be occurring. Mosquitoes are a concern during this season, and fields within a three-mile radius of towns should be excluded to keep flooded habitat away from populated areas. A three-mile exclusion zone is included in the Multi-Benefit Recharge Mapping Tool. Once recharge sites have been chosen, GSAs need to inform Vector Control Districts of the precise timings and locations where water spreading will be happening on the landscape. Grower participants need to know that the Vector Control Districts will be informed.

3. Implementing and monitoring multi-benefit groundwater recharge projects

Multi-benefit groundwater recharge projects can be designed and selected by GSAs to maximize conceptual benefits and to meet the GSP sustainability goals. However, the actual benefits of multi-benefit recharge projects are only realized after the planning phase through implementation and monitoring. In the implementation and monitoring phase, actual benefits to groundwater recharge and the environment are quantified using field-collected data and best practices for relating those data to specific benefits. The following sections recommend methodologies for implementing and monitoring multi-benefit projects, and methods for quantifying the specific benefits achieved by these projects once sites have been selected for implementation and growers have been identified for participation.

After identifying potential candidate sites (covered in Section 0), GSAs can begin contracting and coordinating with program participants to implement on-farm, multi-benefit groundwater recharge. The primary phases of project implementation and monitoring include Field preparation (Section 3.1), flooding and monitoring (Section 3.2), and quantification of benefits (Sections 3.3-3.4).

3.1 Field preparation

Specific field conditions are required for effective project implementation to recharge groundwater and create high-quality temporary wetland habitat that shorebirds can use on long migrations. Depending on post-harvest or native field conditions, some field preparation may be required to create these ideal conditions. Shorebirds need open, shallow water or mud flats largely free of vegetation where they can spot predators and easily probe in the mud for invertebrates.

3.2 Optimal field conditions

To maximize habitat value for shorebirds specific habitat conditions are required. Growers can create these conditions using mechanical treatments that chop standing vegetation followed by discing, chiseling, rolling, or stomping. These practices create open field habitat with minimal vegetation standing or laying on the surface. where birds can access mud for foraging and have a clear of predators. Incorporating plant residue facilitates the production of soil invertebrates and leads to better foraging conditions than bailing and removing it. A uniformly smooth surface is not required. Furrows, clods, and mounds are acceptable as they create a range of different water depths once the fields are flooded. This is advantageous because different shorebird species have different water depth preferences.

To support continuous field flooding and reduce outflow, fields also should be modified with berms as needed (see Section 3.4.2.2). Sample images of field conditions are shown below, with Figures 5-7 showing good conditions suitable for bird habitat, and Figures 8-10 showing unsuitable, poor conditions.

Figure 5. Ideal bird habitat with mudflat-like conditions.

Figure 6. Great shallow flooded habitat, attracting lots of birds.

Figure 7. Good field conditions with clumps that are good for smaller birds.

Figure 8. Unsuitable, poor field conditions with too much standing crop stubble and water that is too deep for shorebirds.

Figure 9. Unsuitable, poor field conditions with too much standing stubble and water that is too deep for shorebirds.

Figure 10. Unsuitable, poor field conditions with too much undecomposed vegetation. Thick, matted vegetation makes it difficult for birds to forage.

Field preparation may also be required to support monitoring. Parameters that are typically monitored include:

- Surface water inflows (to quantify the volume of water that floods the field, and that is available for recharge and habitat formation)

- Precipitation (to quantify the volume of water that falls directly onto the field, and that is also available for recharge and habitat formation)
- Surface water outflows, if applicable (to quantify the volume of water that leaves the field without evaporating or providing recharge)
- Standing water levels (to track and quantify the depth of flooding, and changes in the volume of flooding and to confirm water depth is no higher than four inches to provide functional habitat for wildlife)
- Groundwater depths (to track changes in groundwater levels in or near the field)
- Bird presence (monitored to confirm habitat quality)

Other parameters may also be useful to monitor and track but are not required for project implementation. For example, collecting and testing soil and water samples is beneficial for understanding and reporting project impacts on water quality. However, monitoring these parameters can be expensive and time-consuming, and is not critical to project implementation.

Monitoring equipment or methodologies that can be used to track key parameters are described in Section 3.4 below.

3.3 Flooding and monitoring

During the project period (generally July 15-October 1 and/or March 15-April 30), participating growers flood their fields continuously and maintain depths no higher than four inches for four to six weeks to deliver temporary wetland habitat for migrating shorebirds and recharge groundwater. Existing diversions and conveyance infrastructure are used to supply surface water to fields.

Coordination with participating growers to monitor the various parameters identified above is recommended. Participating growers may be expected to record any changes in parameters within the field, such as surface water inflows and outflows in an irrigation log, surface water depths, and bird presence. To provide the benefit of temporary habitat for migratory shorebirds, it is critical that water depths remain shallow. If the water depth exceeds four inches (4”), most shorebird species will not use the habitat (see section 3.5 for more detail). GSAs may be expected to monitor precipitation, groundwater levels at wells in or near the field, and may also help with tracking habitat formation. However, GSAs and participants can distribute the monitoring and record-keeping tasks as they choose.

3.4 Quantifying groundwater recharge

Groundwater recharge occurs because of deep percolation of surface water applied to fields during the implementation of projects. While the volume of deep percolation from projects can be estimated or quantified through a number of methods, current best practices recommend the use of a field-scale water budget approach for localized implementation.

3.4.1 Field-scale water budget approach

A field-scale water budget is calculated as a mass balance of all water that flows into or out of a field (Figure 11). The main inflows to a field generally include precipitation and surface inflows, primarily of surface water applied for irrigation or flooding for multi-benefit projects. The main outflows from a field include evapotranspiration, surface outflows (e.g., tailwater and runoff), and deep percolation. Some water may also be stored on the land surface (i.e., surface storage) or in the soil (i.e., root zone storage), with changes in storage following imbalances between inflows and outflows.

Using a field-scale water budget, the volume of deep percolation that contributes to groundwater recharge can be quantified in several ways, depending on the time scale and data availability. Over the course of a season or an implementation period, deep percolation can be calculated from a field-scale mass balance as the difference between all other inflows and outflows, in which all other components of the mass balance are measured, calculated, or estimated based on available data and local conditions. On a shorter daily time-step, deep percolation can also be estimated as a function of soil water content (i.e., root zone storage).

Recommended procedures for monitoring and quantifying all water budget components, including deep percolation, are summarized in the sections that follow.

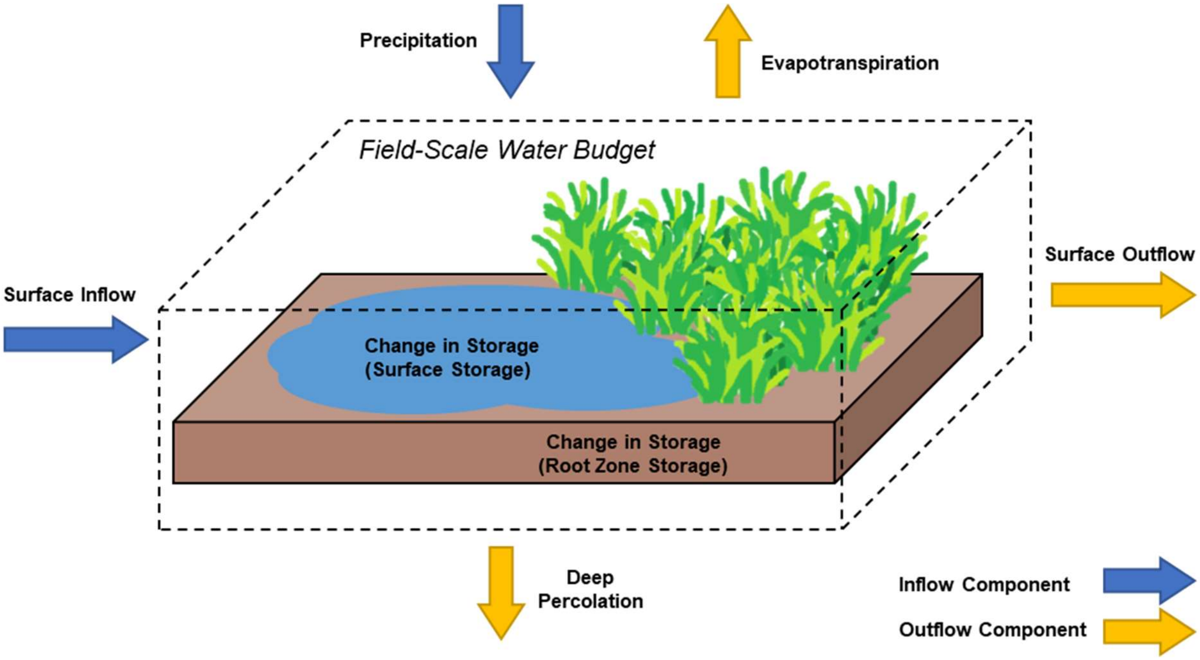

Figure 11. Field-scale mass balance water budget schematic. The dashed lines show the spatial domain of the water budget. The fluxes into or out of the domain are indicated by arrows. Blue arrows represent inflows; yellow arrows represent outflows. Within the domain, there can be a change in storage in the ponded water at the surface or within the root zone. Inflows have to equal outflows plus changes in storage, where increases in storage are positive and vice versa.

3.4.1.1 Inflows

Inflows to fields enrolled in multi-benefit projects generally include precipitation and surface water inflows that are used to flood fields. Typical methods for quantifying these inflows are described below.

3.4.1.2 Precipitation

Precipitation in individual fields can be monitored with rain gauge dataloggers installed in or near the field. Precipitation data from nearby weather stations and/or remote sensing may also be used, but with lower accuracy. However, the accuracy of weather stations and remotely sensed data may be sufficient during the project implementation period in late summer and early fall, when there is typically little precipitation.

Over larger areas, precipitation can also be estimated using spatially interpolated precipitation data sources, such as the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM is operated by the PRISM Climate Group, a division of the Northwest Alliance for Computational Science & Engineering (NACSE) at Oregon State University and reports daily and monthly weather data for locations throughout the United States through a publicly available online system. More information about the modeling approaches and available spatial precipitation data are available online at: https://prism.oregonstate.edu/.

3.4.1.3 Surface inflows

Surface inflows to fields can be either directly measured or calculated from measured values. In fields directly served by metered lift pumps or metered gates, the volume of surface inflows to the field can be directly measured or calculated from totalized measurements. Typical accuracies of pipe flow measurements range from 1-12 percent. In fields that are indirectly supplied with surface water, surface inflows may need to be calculated from upstream and downstream flow measurements, or through theoretical or empirical equations relating available data to field surface inflows. For example, fields served from canals measured using weirs, or fields served from canals that deliver water to multiple locations downstream of a measurement device may require site-specific calculations to quantify surface inflows to a specific field. Low-cost in-field measurements can also be made by setting up flashboards at the measurement location and correlating the “runup” of an unsubmerged weir overflow on a flat weir stick to the flow rate using standardized equations (USBR, 2001). Typical accuracies of “runup” or indirect flow measurements may exceed 10 percent, depending on site conditions and the accuracy of measurement data.

To monitor surface inflows, participants may record flow data, maintain irrigation logs, and maintain logs of any other parameters required to calculate field deliveries, depending on the unique conditions of their field. GSAs or other agencies may also consider using mobile flow monitoring equipment to measure or verify surface inflows to fields.

3.4.2 Outflows

Outflows from fields generally include evapotranspiration from plants and flooded land surfaces, surface outflows of tailwater and runoff, and deep percolation of water to the underlying groundwater system. Typical methods for quantifying evapotranspiration and surface outflows are described below. The quantification of deep percolation is described below in Section 3.6.

3.4.2.1 Evapotranspiration

Evapotranspiration (ET) encompasses the combined evaporation and transpiration from a field. ET primarily occurs from the flooded land surface.

The most widely used method for calculating ET is the “crop coefficient – reference crop ET” methodology, following standardized conventions established by the Food and Agriculture Organization of the United Nations (FAO) Irrigation and Drainage Paper 56 (FAO-56) (Allen, et al., 1998), and by the American Society of Civil Engineers (ASCE, 2016). In this methodology, evapotranspiration of a reference field surface (reference ET or ET_o) is first calculated based on local weather and climate conditions specific to the study area and analysis period. Then, reference ET is adjusted to estimate ET for other fields using specific crop coefficient values that are unique to the field surface and crop conditions:

$$ET = Reference\ ET\ \times Crop\ Coefficient$$

In California, ET calculations typically use ET_o, the reference ET of a clipped cool season grass reference crop (ASCE-EWRI, 2005). Daily ET_o values for specific local climate and weather conditions are available from local California Irrigation Management Information System (CIMIS) weather stations across California.

Crop coefficients are widely available from technical literature for a variety of crops, field conditions, and locales. For shallow open water surfaces, such as those expected in Projects, ASCE has identified a standard crop coefficient of 1.05 (for open water less than 2 meters in depth) or 1.1 (for temperate wetlands with short vegetation) (ASCE, 2016).

In addition to ET calculations based on reference ET and crop coefficients, there are also a number of accepted ground-based methods and remote sending approaches for calculating local ET values for specific fields.

The eddy covariance method, for example, is a ground-based approach that correlates direct measurements of wind speed and water vapor density fluxes to compute a local energy balance and estimate ET. Additional information about the eddy covariance method can be found throughout technical literature published over the last several decades (Baldocchi, 2003; Shaw and Snyder, 2003; ASCE, 2016). Simplified ground-based systems, such as surface renewal technology, are also available that use lower-cost sensors with weather station or satellite data to estimate local ET.

Remote sensing approaches use aerial or satellite imagery with visible, near infrared, and thermal infrared bands to calculate the surface energy balance and estimate ET over an area of interest. Common remote sensing approaches include the Mapping Evapo-Transpiration at High Resolution with Internalized Calibration (METRIC) approach (Allen et al. 2007, Allen et al. 2014) and the Surface Energy Balance Algorithm for Land (SEBAL) approach (Bastiaanssen, et al. 2005). Remote sensing approaches have several advantages in that they are relatively low-cost and scalable to accommodate analyses of large study areas. However, the time scale of remote sensing approaches is limited by the availability and return period of satellite imagery. Over the short duration of project implementation, the availability of remotely sensed ET estimates may be somewhat limiting. However, some newer ET models relying on a variety of different remotely sensed products (e.g. IrriWatch) provide daily ET data at a 10 meter by 10 meter resolution. The benefits and costs of remote sensing approaches should be considered by GSAs interested in pursuing these methods.

3.4.2.2. Surface outflows

Similar to surface inflows, surface outflows from fields are either directly measured or calculated from monitoring data at field outflow locations. Depending on field infrastructure and preparation prior to flooding, surface outflows may be reduced or eliminated through the placement of berms. Surface outflows can also be controlled through measurement structures that allow direct monitoring and measurement. Outflows from flooded fields that occur through flashboard or weir structures allow surface outflows to be calculated from water level measurements using standard weir equations or using the "runup" of an unsubmerged weir overflow on a flat weir stick to the flow rate using standardized equations (USBR, 2001).

To monitor surface outflows, participants may record flow data or water level data and maintain logs of any other parameters required to calculate outflows, depending on the unique conditions of their field. Pressure transducers and dataloggers may be used to automatically monitor water levels, or participants may install wooden stakes to manually monitor water depths.

3.5 Changes in storage

Changes in storage occur when there is an imbalance in the total volume of inflows and outflows. Changes in storage include changes in surface storage as fields are flooded and drained, and changes in root zone storage as water infiltrates into the upper portion of the soil. Methods for quantifying each are described below.

3.5.1 Root zone storage

The root zone is comprised of the upper portion of the soil where water extraction by roots occurs, above the depth at which water infiltrates to the groundwater system. The depth to the bottom of the root zone varies by crop, but typically extends up to seven feet (ASCE, 2016).

The root zone depth in a specific field can be approximated from technical literature identifying root depths for specific crops, such as Keller and Bliesner (2001) and ASCE (2016), with consideration and refinement for local conditions. The root zone depth can also be iteratively determined from a field-scale water budget, gradually adjusting the root zone depth to match calculated water levels with observed water levels.

The change in storage in the root zone can be estimated based on soil properties and simplifying assumptions about the soil moisture at the start and end of the annual project implementation period. Soil maps and soil characteristics are publicly available from the Natural Resources Conservation Service (NRCS) Web Soil Survey[2]. Over larger areas with multiple soil types, volume-weighted (area-weighted and depth-weighted) average soil characteristics can be calculated and used.

Without soil moisture data, and depending on irrigation practices leading up to flooding, the initial root zone soil moisture can be estimated as the median water content between the soil-specific field capacity and permanent wilting point. At the end of the flooding period, after the field is drained, the final root zone soil moisture can be estimated as field capacity.

3.5.2 Surface Storage

The change in surface storage, or average ponded water depth, can be calculated from measured and observed changes in water surface levels at points throughout the project field. Over the annual

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[2] Natural Resources Conservation Service (NRCS), USDA. Web Soil Survey. https://websoilsurvey.nrcs.usda.gov/

project implementation period, the total change in surface storage is typically zero, provided that the surface of a field is dry and free of ponded water at the start and end of the project.

3.6 Solving for Recharge

Throughout implementation, consistent monitoring or calculation of all inflows and outflows is important to understanding the field-scale water budget. But ultimately, the volume of groundwater recharge benefit to the subbasin is the most critical water budget result for GSP annual reports and periodic evaluations.

As described above, groundwater recharge is quantified as the deep percolation of surface water applied during project implementation. Using a field-scale water budget, deep percolation can be calculated as the difference between all other inflows and outflows, per the equation below, with each other inflow and outflow quantified according to the methods described above.

$$Deep\ Percolation\ (Recharge) = Precipitation +\ Surface\ Inflow - Evapotranspiration - Surface\ Outflow - Change\ in\ Storage^{3}$$

Groundwater recharge can also be monitored and verified through groundwater level measurements at groundwater wells adjacent or near to fields implementing recharge projects. For instance, groundwater level measurements collected before, during, and after implementation can potentially help verify that net recharge is occurring; especially in well-positioned wells with continuous monitoring.

3.7 Uncertainty

When calculated based on other water budget inflows and outflows, the volume of groundwater recharge carries an uncertainty that is a function of the uncertainty in all other measurements. If accurate, direct measurements can be made for all inflows and outflows from a field, the uncertainty of recharge volumes will be relatively low. Conversely, if major inflows and outflows require indirect estimates and assumptions that carry high uncertainty, the uncertainty of recharge volumes will be higher.

While the uncertainty of each inflow and outflow will vary based on field conditions and measurement devices, typical uncertainties associated with each water budget component are summarized in Table 3-1.

The uncertainty of deep percolation (i.e., recharge) can then be calculated from these other uncertainties, for example following the process described by Clemmens and Burt (1997).

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[3] Change in storage is equal to the sum of change in surface storage (initial surface storage – final surface storage) and change in root zone storage (initial root zone storage – final root zone storage).

Table 3-1. Typical Uncertainties of Field-Scale Water Budget Components

Water Budget Component	Typical Estimated Uncertainty (%)	Description
Surface Inflow	1-12%	Typical range of accuracy from meters to minimum delivery accuracy requirements of delivery and diversion measurement devices per SBx7-7 and SB88
Precipitation	2-20%	Typical range of accuracy from field-level rain gauges to extrapolation of local weather station data
Surface Outflow	1-20%	Typical range of accuracy from meters to estimated outflow relationships
Evapotranspiration	20%	Clemmens and Burt, 1997; typical accuracy of calculation based on CIMIS reference ET_o and free water surface evaporation coefficient.
Change in Storage	15-25%	Estimated accuracy of change in storage calculation based on field-scale water budget calibration to observed water levels.
Deep Percolation	5-30%	Typical range of calculated accuracy from field-scale water budget results (fields ranging from 56 to 125 acres)

Other factors of uncertainty to consider when quantifying recharge are:

- Deep percolation does not immediately recharge the groundwater system. There is a time lag between when deep percolation occurs through the root zone and when that water reaches the saturated groundwater system.
- Subsurface inflows and outflows can occur through the groundwater system. While deep percolation may supply water to the groundwater system, that water may migrate away from the field along groundwater gradients.

3.8 Proximity to groundwater pumping capture zones

If the main goal of groundwater recharge is to quickly alleviate reductions in groundwater levels and storage due to unsustainable groundwater pumping, the benefits of recharge will be felt more quickly if recharge sites are located in closer proximity to the pumping capture zones. If recharge occurs in highly transmissive aquifers nearby streams, it is possible that the recharge water would be quickly discharged to the stream. This *may* mitigate impacts to GDEs or streamflow depletion, but not the impacts to groundwater levels or storage.

3.9 Quantifying environmental benefits

Recent bioenergetic analyses suggest that shorebirds face habitat shortfalls in the Central Valley during two distinct time periods: late summer/early fall (July-September), and spring (mid-March-April). These are thus the windows of time that should be targeted for creation of additional habitat. Habitat that is created in between these two periods of habitat shortfall is also likely to provide some benefits, but in most years, there is already a sufficient amount of shorebird habitat on the landscape such that this intervening time period should not be prioritized for additional habitat creation.

It is critical that flooded fields be appropriately managed so that they are suitable as foraging and resting habitat for the birds. Shorebirds typically walk on the bottom of flooded areas when foraging, as opposed to swimming like many other waterbirds. As a consequence, they require shallow depths to access prey items (typically invertebrates) often obtained by probing in the mud. From a field management standpoint, it is thus important that flooding be less than 4 inches, ideally with some areas that are considerably shallower than this. Varying depths less than 4 inches are beneficial because they provide habitat for the full suite of shorebird species including some which are small and have very short legs and often utilize shoreline habitats when feeding. For these reasons TNC has required fields to be at least 75 percent flooded in areal extent, no more than 4 inches deep, and have rice stubble or other vegetative material substantially incorporated into the soil. Incorporation of vegetation allows easier access for foraging, but the sites need not have smooth mud flats, and some microtopography is beneficial in that it adds variation in depth.

Although previous research has suggested that flooded fields be situated in close proximity to other flooded areas, recent analyses suggest that this is not the case with flooded rice fields in the Sacramento Valley. Individual flooded fields should be 75 acres or more in size, however, so that they are large enough to attract the birds.

In terms of quantifying benefits, a sufficient metric could be acre-days of habitat during the appropriate time window, at the appropriate depth, with appropriate field conditions. This translates to:

> *acre-days of habitat created in the project period (July 15-Oct. 1 and/or March 15-April 30), that is less than 4 inches deep, at least 75 percent ponded, with most of the vegetative material incorporated into the soil.*

4. Outline of a multi-benefit PMA for inclusion in GSPs

This section provides an annotated outline summarizing the content that GSAs may wish to include in their GSPs to describe their multi-benefit groundwater recharge PMAs. A detailed description of the Colusa multi-benefit groundwater recharge project, with an emphasis on lessons learned, is provided in Section 0.

4.1 Overview

- Introduce general plan to implement multi-benefit groundwater recharge with partnering growers in the GSA.
- Introduce relevant details specific to the GSA's particular program, such as whether you are offering financial compensation to participating growers who will implement multi-benefit groundwater recharge through normal farming operations.
- Note that the proposed program will result in field flooding for on-farm recharge, with multiple benefits to:
    - The underlying aquifer (groundwater recharge to support groundwater sustainability, under SGMA)
    - Critical, temporary, flooded habitat for waterbirds migrating along the Pacific Flyway
    - Other beneficial groundwater users in the subbasin

4.2 Implementation

- Frame the general program implementation strategy and timeline
- The proposed program will:
    - Identify fields with soil and cropping conditions conducive to groundwater recharge
    - Coordinate with growers to implement on-farm, multi-benefit groundwater recharge
    - Flood and maintain shallow surface water in fields of participating growers
    - If applicable, note that the program will pay for field preparation, irrigation, and water costs

4.3 Construction activities

- The program will be conducted on existing agricultural fields with existing flood irrigation system infrastructure
- Note any additional engineering work that will be needed, as applicable:
    - Surveying of participating fields
    - Installing monitoring equipment in the field, to monitor applied water and any other inflows/outflows
    - Installing monitoring equipment in adjacent wells, to monitor groundwater depth

4.4 Water source

- Surface water will be delivered during program implementation in either July 15-Oct. 1 and/or March 15-April 30.
- Note that existing infrastructure and diversions will be used.
- If applicable, note any other water sources that may be available (e.g., ephemeral flood flows)

4.5 Conditions and constraints on operation

- Describe the availability, timing, and potential quantity of surface water supply in the GSA:
    - during the July 15-October 1 and/or March 15-April 30 implementation periods

    - reliability over time (historical reliability, expected future reliability)
- Describes areas within the GSA's boundary where the potential program is best suited for implementation
    - Assess interest from growers who cultivate the appropriate row crops in project applications
    - Field suitability for groundwater recharge based on criteria listed in Section 2.1.
- Goal of minimizing water quality concern by selecting fields with suitable crops and low nitrogen loading, and potential for monitoring water quality impacts to disadvantaged communities, tribes, and domestic wells

4.6 Permitting processes and agencies with regulatory control

- GSAs will need to identify water rights, file necessary permits, and go through any necessary environmental review processes
- Coordinate with the following entities, depending on how the program will be implemented:
    - State Water Resources Control Board for water rights
    - Regional Water Quality Control Board for water quality impacts
    - Bureau of Reclamation, if using CVP water
- Other regulatory considerations, if applicable:
    - Environmental review (CEQA)

4.7 Project operations and monitoring

- For each field identified for potential program participation, describe how the GSA and potential farmer will complete the following activities prior to implementation:
    - install or modify field inflow and outflow monitoring equipment, as applicable, for calculating the quantity of groundwater recharge,
    - prepare fields to manage and incorporate vegetation, depending on field conditions and crop history,
    - collect soil and water samples to monitor pre-wetting water quality if the GSA is monitoring recharged groundwater quality
    - install calibrated wooden stakes to monitor:
        - water depths
        - bird presence
- During the program
    - Participating growers will spread water on the fields and maintain a shallow depth of 4 inches maximum on the fields for 4-6 weeks.
    - Participating growers will record:
        - changes in water flow in an irrigation log
        - flooding depth
        - bird presence
    - If applicable, GSAs may monitor changes in groundwater depth, water quality, and precipitation at select sites throughout their jurisdiction in addition to on or nearby implementation sites.

4.8 Project benefits and costs

- Describe anticipated benefits:
    - Groundwater recharge to support subbasin groundwater sustainability
        - Expected volume of recharged water per year of operation

        - Average volume of recharged water per year (if not expected to operate every year)
            - Note or quantify the typical reliability of surface water
        - Note any expected changes over time (e.g., if implemented gradually, and expected to expand to more areas over time)
    - Anticipated acres of flooded habitat to support waterbirds migrating along the Pacific Flyway
    - Note other benefits, as applicable
- Describe anticipated program costs:
    - Summarize actual cost estimates, or typical costs per unit area enrolled in program
    - Describe funding sources, as applicable

5. Description of Colusa County multi-benefit demonstration project

Between 2019 and 2021, TNC and the Colusa Groundwater Authority (CGA) have partnered to design and implement an on-farm, multi-benefit groundwater recharge pilot demonstration program (Program) in disadvantaged communities in Colusa County. The Program, which was partially funded by a Department of Water Resources Sustainable Groundwater Management grant, is designed to strategically flood agricultural fields with the goals of recharging groundwater supplies while simultaneously creating critical habitat for shorebirds migrating along the Pacific Flyway. Implementation of the Program in Colusa County has demonstrated great potential for recharging groundwater and creating temporary habitat for migratory shorebirds as part of normal farming operations, without hindering agricultural production. Growers receive financial compensation for participation in the Program, as well as potential agronomic benefits from flood irrigation in early fall.

The following discussion provides lessons learned from the Program and provides an example of the content and level of detail GSAs may wish to include in their GSP.

5.1 Design and site selection

5.1.1 Identifying project sites

TNC completed a complex geospatial analysis of fields in the Program area to efficiently identify potential implementation sites that met the multi-benefit groundwater recharge criteria (see Section 2.1) and created a web map similar to the Multi-Benefit Recharge Mapping Tool for identifying these potential sites.

Moderately poor to excellent SAGBI ratings were used to evaluate recharge potential and prioritize individual fields. Findings from the Program, however, indicate SAGBI alone may not provide sufficient indication of potential recharge. Although the fields in the 2020 Program had very similar soil types, all with moderately good to good SAGBI ratings, results showed total recharge estimates varied greatly between sites, suggesting SAGBI ratings may not be the best predictor of recharge rates at small scales. Consideration of historic land use along with soil type is likely to be a good indicator of groundwater recharge potential.

5.1.2 Conduct outreach to growers within project area

The biggest challenge in site selection proved to be finding farmers who had suitable fields and water available during the program periods and were willing to engage in an innovative practice. TNC and CGA held an in-person grower workshop in February 2020 in Colusa, a virtual workshop in February 2021, and conducted extensive individual, targeted grower outreach and networking through CGA's contacts, CGA board members, local water districts, and previous participants in TNC's BirdReturns program. The majority of growers who participated in the Program had previously participated in other habitat programs.

Participation in the 2020 Program was lower than expected as the 2020 and 2021 Program was carried out during a pandemic, which limited in-person meetings and presentations, and during water curtailments due to drought conditions. The 2020-2021 drought underscored the need for groundwater recharge and for using available water for multiple uses. As this multi-benefit recharge approach becomes more well-established and familiar, and the urgency around groundwater replenishment increases, farmers are likely to be more motivated to participate. Early, frequent, and extensive outreach and education about multi-benefit practices through local community members, Resource Conservation Districts, county farm bureaus, and GSAs are essential for success.

Table 5-1. 2021 implementation timeline for the Colusa County Program.

Timeline Activity	Start	End
Grower outreach	March	Mid-August
Growers apply to participate	April	Mid-August
Sites are selected	June	September
Site preparation	July	September
Project implementation	Mid-July	October 1
Financial Incentive Payment	October	December

5.1.3 Water source

Existing diversions and conveyance infrastructure were used to supply surface water for the Program, which came from Sacramento River Settlement Contracts. Settlement contractors in the Colusa Subbasin receive Sacramento River supplies diverted at the Red Bluff Pumping Plant and Fish Screen into the Tehama-Colusa Canal and delivered through the Glenn-Colusa Irrigation District and Colusa County Water Authority, or are delivered through on-site infrastructure at individual farms.

5.1.4 Permitting process

Because the Program was designed as a small-scale, pilot program testing various methodologies, the CGA filed a CEQA Notice of Exemption with the County of Colusa. The Program did not need to obtain underground storage permits from the State Water Resources Control Board because federal water was used. The Bureau of Reclamation does not currently require a permit for groundwater recharge.

5.2 Implementation and monitoring

In 2019-2020, the Program was implemented at four (4) sites in Colusa County to test and refine the methodologies as described above in Sections 2 and 3.

5.2.1 Field preparation

Prior to spreading water, participating growers completed field preparations to enhance flooded habitat and recharge potential according to recommendations described in Section 3.1. This methodology has been extensively tested by TNC and partner organizations Point Blue Conservation Science and Audubon California over the last seven years of implementing habitat programs on California farm fields.

5.2.2 Soil and water monitoring

Groundwater recharge can impact water quality. For this Program, we collected 10-year crop histories with online application forms to evaluate the nitrogen loading potential of each field. We reviewed crop histories with partner researchers from the University of California, Davis Watershed Sciences Department (UCD), who are working with TNC to monitor water quality impacts of this Program as well as to develop a numerical groundwater model for this Program. Soil and water samples were collected at each Program site before and after the 30-day flooding period, which are being analyzed by UCD to ascertain water quality impacts. This is important, particularly because this Program is demonstrating a tool for sustainable groundwater management in disadvantaged communities, which are often at higher risk for water quality concerns.

5.2.3 Equipment installation

Flow rate and groundwater level monitoring equipment was installed at Program sites to facilitate project monitoring before field flooding began. Engineers developed a unique survey plan for each site, and installed pressure transducers and dataloggers (Figure 12) at all inflow and outflow points and in wells (Figure 13) adjacent to or within participating fields. Rain gauges with dataloggers were installed at each site (Figure 14). Wooden stakes were installed to manually monitor water depths and as specified survey locations for water birds (Figure 15).

Figure 12. Pressure transducers with data loggers ready for installation.

Figure 13. Installing a pressure transducer in a well head.

Figure 14. Rain gauge installed at Program site.

Figure 15. Water depth stake with two-inch color bands installed at Program site.

5.2.4 Field flooding

After site preparation, participating growers applied water to their fields and maintained water depths no higher than 4 inches. The best recharge results occurred when water was initially applied at a high rate and then adjusted to a constant rate until the end of monitoring. This approach resulted in a fairly consistent surface water level throughout the implementation period. At other sites, water was applied slowly or inconsistently, resulting in fluctuating surface water levels or dry areas of the field, and then water was shut off prior to the end of monitoring, resulting in a shorter time period of ponded water and fewer days of saturated percolation.

Water application is dependent on existing infrastructure. High flow capacity with the ideal, consistent flow may not be possible at some sites. But participating growers should maximize the net applied water (inflow minus outflow) as much as practically possible while still meeting other requirements.

5.2.5 Monitoring

Participating growers were instructed how to record flow data and maintain irrigation logs, which were customized to each unique field set-up and included recording any parameters required to calculate water deliveries. Flow data was recorded incorrectly in some instances. Consulting engineers were able to interpret and correct the data after consulting with the participants. But it is essential that participants know how to correctly read and record data for the selected flow measurement method such as recording the totalizer on a flow meter (Figure 16) or measuring flow rate with a weir stick (see Section 3.4.1.3 for other flow measurement methods). We also encountered issues with delivery of water to non-Program fields. Participants should avoid using water delivery infrastructure to deliver water to other fields, or plan for the occurrence so accounting does not include water applied on other fields.

It is also recommended to limit surface outflows as much as possible during flooding and completely shut all inlets and outlets throughout flooding period to allow as much of the remaining water to percolate as possible. Rain data and field outflow data should continue to be collected after the flooding period has ended until water has fully infiltrated into the ground.

Figure 16. Flow meter installed in an in-flow pipe.

Avian field technicians recorded water depths and conducted systematic surveys on each participating field to monitor bird presence using a bid survey protocol developed by the Migratory Bird Conservation Partnership.

5.3 2019-2020 Program Results

5.3.1 Quantifying groundwater recharge

The four sites enrolled in the Program between 2019 and 2020 were flooded at depths no higher than 4 inches for 30 consecutive days in September-October, both years. A field-scale water budget approach (see Section 3.4.1) was used to analyze results. In total, for both the 2019 and 2020 programs, participating growers generated an estimated 766 acre-feet (approximately 1.9 acre-feet per acre) of deep percolation to support groundwater recharge on 403 acres of temporary shorebird habitat (Table 5-2).

5.3.2. Quantifying environmental benefits

Analysis of 98 bird surveys from the 2019 Program showed that the multi-benefit recharge fields (totaling 143 acres) supported high densities of shorebirds throughout and beyond the 30-day flooding period. Field technicians counted 3,000 waterbirds, with an average density of 4.7 shorebirds per acre. This is comparable to what was observed in rice fields that were enrolled in TNC's BirdReturns fall program during the severe drought of 2014-2015. We did not observe any instances where water was too deep, and shorebirds were not using the habitat, which is the most frequent compliance issue in the BirdReturns program.

Table 5-2. Estimated average recharge volume and temporary wetland habitat formation for the Colusa multi-benefit groundwater recharge project 2019-2020.

Description	**Acres Enrolled in Program**	**Recharge, AF/year (Calculated or Estimated)**
One (1) site in Colusa County flooded for 30 consecutive days in Sept-Oct 2019.	143	366 (calculated)
Three (3) sites in Colusa County flooded for 30 consecutive days in Sept-Oct 2020.	261	400 (calculated)

5.4 Conditions and constraints on operation

The primary constraints for this Program are (1) the availability of sufficient surface water supply, and (2) the participation of growers with fields conducive to groundwater recharge.

Surface water supply conditions needed for this project include:

- availability of surface water supplies that are sufficient to flood participating fields according to the specified flooding depth and duration;
- appropriate timing of surface water supply availability during the project (July 15-Oct. 1 and/or March 15-April 30) when wetland habitat for waterbirds migrating along the Pacific Flyway is most critically needed; and
- reliability of surface water supplies, based on historical reliability and expected future reliability.

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