Floodplains Reimagined – Technical Report

Decision Support Tool for Locating Fish Food Production Activities on Rice Fields in the Sacramento Valley

Submitted by:
Ducks Unlimited, Inc. – Western Regional Office
3074 Gold Canal Drive
Rancho Cordova, CA 95670

Introduction

The floodplains of the Sacramento River Valley support the highest density of wintering waterfowl in the world, are home to an internationally recognized rice industry, provide critical rearing habitat and food supplies for endangered and threatened anadromous fish species, and serve to protect the Valley's cities and towns from catastrophic flooding. In the past these floodplain functions have been treated by agricultural producers, flood control agencies, and natural resource managers as independent of one another, or even in conflict. However, it is becoming apparent that the diverse objectives for valley floodplains can often be integrated to support multiple uses. For example, a healthy rice industry is critical to maintaining waterfowl and other waterbird populations in the Sacramento Valley, while flood control features like the Yolo Bypass can provide off-channel rearing habitat for juvenile salmon and other fish species. More recently scientists are examining the possibility of increasing juvenile fish food supplies by growing these foods (invertebrates/phytoplankton) in winter-flooded rice fields and releasing water from these fields into rivers that support threatened and endangered fish species.

Ideally future actions on floodplains will contribute to improving multiple floodplain functions. For example, conservation projects and policies can contribute to the success of the rice industry, promote healthy fish and waterfowl populations and reduce the probability of downstream flooding. Doing so requires a clear understanding of the objectives and concerns of stakeholders including rice farmers, fish and wildlife agencies, NGO's, and flood control agencies, as well as the information needed to identify and implement projects that meet stakeholder objectives, minimize their concerns, and maximize cost efficiency. Spatially-enabled Decision Support Tools (DSTs) developed with Geographic Information Systems (GIS) are often used to integrate multiple objectives, including where these objectives are associated with very different stakeholders. Stakeholders are typically asked to describe the decisions they are tasked with making and the information they need to make those decisions (e.g., agencies that have anadromous fish responsibilities may be tasked with identifying where on the floodplain to increase food production or to restore off-channel rearing habitat for juvenile salmon). A DST can be used to identify where on the floodplain multiple stakeholder objectives can be addressed in a cost-efficient and cooperative way.

Ducks Unlimited developed a DST for the Sacramento Valley to aid in locating rice fields and rating their suitability for fish food production programs. Importantly, this DST could be used by the Central Valley Joint Venture and the newly formed Central Valley Salmon Habitat Partnership to identify opportunities to cooperate on floodplain restoration projects that simultaneously meet the needs of fish, waterfowl and other species.

Methods

Development of the DST involved three primary tasks:

1. **Outreach to stakeholders and data gathering**. Conduct interviews with stakeholders (salmon biologists, rice farmers, waterfowl and shorebird biologists, and water district managers to identify concerns and/or compatibilities between stakeholders' interests. Identify and gather existing spatial datasets that will provide information required to develop the DST.

    Deliverables:

    - Outreach list and documentation of stakeholder comments
    - Database of GIS layers available for the DST.

2. **DST Development and Programming.** Develop priorities for the input data layers and design and program the GIS-based DST.

   Deliverables:

   - Completed Decision Support Tool
   - Database of GIS layers output from an example model run.

3. **Documentation and Reporting.** Produce documentation of the analysis and modeling methods used by the DST.

   Deliverables:

   - Technical memorandum documenting the analysis methods and products (included below)
   - Final Report (this document) and delivery of datasets (shared with KSN/CBEC through a OneDrive cloud folder)
   - One presentation to the Floodplains Reimagined Steering Committee.

Project Documentation

Project area

The project area for this DST is shown in Figure 1 and includes the rice producing areas in the Sacramento and Feather River watersheds. Note that this project area is larger than the Floodplains Reimagined (FR) project area, but existing primary input layers for the DST were already developed for this larger footprint and required no additional cost to manage. Additionally, long-term planning for various salmonid species in California will benefit from the information for this larger area. Outreach to stakeholders (water district managers) was limited to districts in the FR project area since funding for this project was provided through FR budgets.

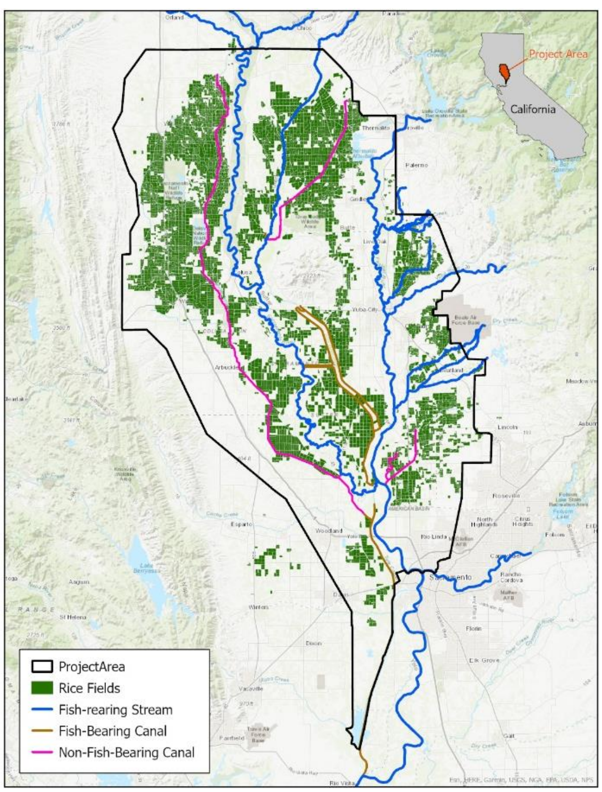


Figure 1. DST project area.

Data gathering and data development

FlowWest Rice Field Infrastructure Datasets

The primary base layer for the DST was acquired from the FlowWest riceflows4fishfood database (https://flowwest.github.io/riceflows4ff/index.html). The database consists of shapefiles of rice field geometries and the locations of outflows from arterial canals into salmonid rearing streams for the Sacramento Valley. These shapefiles can be linked to relational data tables (.csv files) containing information on the distance between each rice field and the nearest outflow point (return). Ducks Unlimited imported these layers into ArcGIS Pro software and "joined" the tabular .csv data into the rice field geometry layer's attribute table.

Ducks Unlimited made a few minor corrections to the FlowWest data layers prior to utilizing the layers in the DST. First, after interviews with some of the water district operations managers two errors were identified in the outflow locations associated with some fields. Two new returns were identified along the Sutter Bypass' east borrow ditch. Flows from Sutter Extension Water District return to the Bypass at a DWR pumping station near Obanion Road and flows from rice fields in the Montna Farms area return to the bypass at a return near Sawtelle Avenue. These two returns were added to the shapefiles and distances between the appropriate rice fields and their returns were recalculated and updated in the rice field shapefile attribute table. Additionally, the Richvale Irrigation District's operations manager identified a block of rice fields that, with the proper drainage ditch and water control structure management, can be redirected to return directly into Butte Creek rather than into the Cherokee Canal (which has a greater return distance to Butte Creek). The return distances for these fields were also recalculated and updated in the database.

The second change to the database is associated with the canal types in the database. The FlowWest data identified outflow points as flowing either directly into a fish-rearing stream or indirectly into secondary canals that then flow to fish-rearing streams. The distance calculations for fields flowing to indirect return locations were a combination of the distance from the rice field to the indirect return plus the additional canal distance from that indirect return location to a fish-rearing stream. However, some of the canals that these indirect returns flow into are actually juvenile-fish-bearing canals (e.g. – the Sutter Bypass and Yolo Bypass canals). Ducks Unlimited identified these returns and re-labeled the database with three possible return types: 1. Direct returns to fish-rearing streams, 2. Indirect returns to fish-bearing canals, and 3. Indirect returns to non-fish-bearing canals. From interviews with salmon biologists, it is unclear if food added to these fish-bearing canals is potentially beneficial, detrimental, or insignificant to juvenile salmon survival, but the ability to run the model while accounting for these differences could be valuable. The distances of rice fields to either a fish-rearing stream or a fish-bearing canal was calculated for each rice field and added to the shapefile as an additional attribute field. Either attribute (1. Distance to fish-rearing stream, or 2. Distance to a fish-rearing stream OR fish-bearing canal) can be utilized by the DST. The difference between these two distance calculations can be seen in Figure 2.

Water District Boundaries

Surface water delivery to rice fields is managed by water districts throughout the Sacramento Valley and the ability to deliver this water varies by water district based on the district's location, water source, and water rights. A shapefile of water district boundaries was downloaded from the California State Geoportal (https://gis.data.ca.gov/) and clipped to the project area.

Traditional Winter-flooding Patterns in Sacramento Valley Rice Fields

Winter-flooding of rice fields is a traditional practice used for post-harvest decomposition of rice straw. This practice is also significantly important to maintaining wintering waterfowl populations in California's Central Valley. It is estimated that 74% of food energy resources for wintering waterfowl in the Sacramento Valley are provided by rice "waste-grain" remaining in the fields post-harvest. Winter-flooding of these fields at appropriate depths provides access to this food resource. Additionally, rice

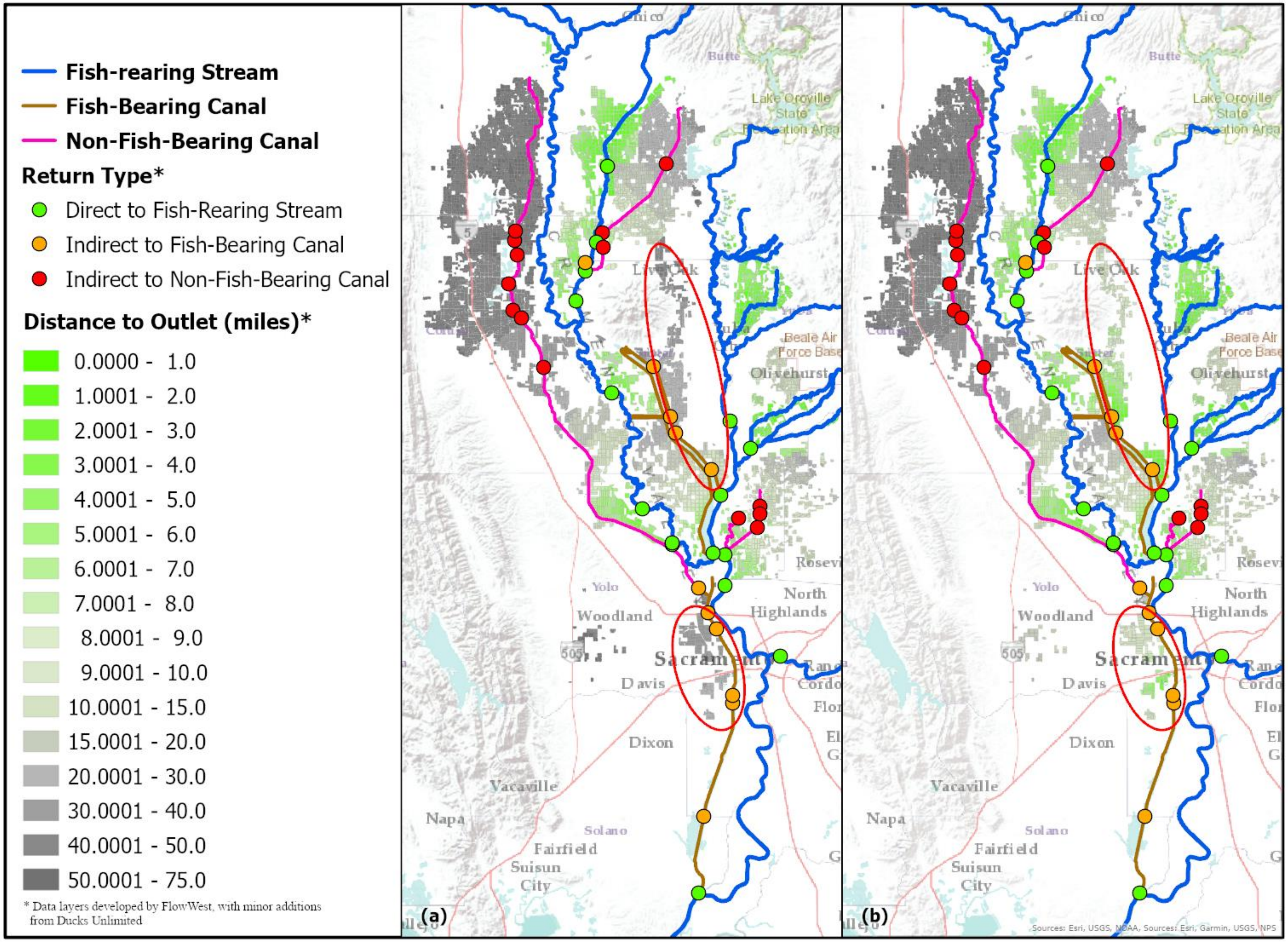


Figure 2, (a) (b). Distance between rice fields and nearest outlet to (a) Fish-Rearing Streams only, or (b) a Fish-Rearing Stream or Fish-Bearing Canal. Red ovals highlight areas with significant differences if food delivered to juvenile-fish-bearing canals is considered beneficial.

farmers can benefit from additional income by leasing these flooded fields to waterfowl hunters during the waterfowl hunting season (roughly mid-October to January 31). Understanding which fields are traditionally flooded in winter months will help to identify where potential conflicts or benefits may result from fish food production activities in these areas.

To address this, an analysis of Landsat and Sentinel satellite imagery from 2016 – 2023 was made using Google Earth Engine to map the frequency of winter flooding on a monthly basis for rice fields in the Sacramento Valley (https://4932539.users.earthengine.app/view/wetfrequencycv). GEE mapping was provided by Patrick Donnelly (Intermountain West JV / Univ. of Montana). Frequency maps are estimated for each month as a count of years flooded during the 8-year period.

Shorebird Priority Areas

Data layers representing monthly habitat suitability for four shorebird species (Dunlin, Dowitchers, Black-necked Stilt and American Avocet) were provided by Point Blue Conservation Science. Values in these data layers ranged from 0 to 1, with values above 0.4 (Dunlin and Am. Avocet) or 0.5 (Dowitcher and Black-necked Stilt) considered suitable habitat (Conlisk, et al., 2022). Values above this threshold were exported to create suitable habitat for each species in each month. An "all-speceis" suitability map was created for each month (November to April) by stacking the four individual species layers and choosing the highest value from those four layers.

Water District Maintenance Schedules

Through interviews with water district operations managers, information was obtained defining when water delivery to all or portions of water districts are shut down for various times throughout the winter months. A polygon layer containing these locations and times was created. This layer is incomplete at this time. There are 79 water districts within the project area and all could not be contacted in the time-frame of this project. To prioritize which districts would be contacted first, the water districts shapefile was intersected with the rice field distance layer and acreage-by-distance summaries were created (Appendix A, Table 1). Interviews were prioritized with water districts having at least 10,000 acres of rice fields within 20 miles of a return (Salmon biologists have observed food resources being transported up to 20 miles downstream from drained rice fields – pers. comm. J. Montgomery). Six water districts account for 60% of rice fields falling in this range, and five of those six water districts were interviewed for this project.

Stakeholder Outreach

Table 1. Outreach List.

Organization	Name/Role	Stakeholder Group
CalTrout	Jacob Montgomery - ecologist	Salmon/Fish
CDFW	Bjarni Serap - Biologist	Salmon/Fish
UC Davis	Carson Jeffries	Salmon/Fish
Richvale I.D.	Sean Early – General Manager	Water Districts
R.D. 108	Jordan Navarrot – Superintendent	Water Districts
Sutter Extension W.D.	Operations Manager	Water Districts
Sutter Mutual W.C.	Operations Manager	Water Districts
Western Canal District	Ted Trimble – General Manager	Water Districts
Carter Farms	Ben Carter - Farmer	Rice
Point Blue Conservation Science	Matt Reiter – Ecologist	Shorebirds
Ducks Unlimited	Virginia Getz - Biologist	Waterfowl
Ducks Unlimited	Mark Petrie - Biologist	Waterfowl
Ducks Unlimited	Dan Smith – Research Scientist	Waterfowl

Outreach was conducted with water district operations managers, salmon biologists, rice farmers, shorebird biologists and waterfowl biologists to gather information and opinions on ranking the suitability of rice fields for a fish-food production program. These phone interviews were used to review the accuracy of GIS data layers, obtain new data layers, and gather information on concerns and/or compatibility of a fish-food production program in relation to these stakeholders' interests. Table 1 lists the stakeholders contacted.

Input from Salmon biologists

Input from salmon biologists centered around two primary issues, 1. The need to accurately map and understand rice field locations and infrastructure characteristics required to transport food from the fields to the returns to fish-bearing waters, and 2) the need for better information regarding the benefits of a rice field food production program to salmonids.

Comments and input from the interviews are summarized below.

- The existing FlowWest data layer for rice field distances to returns will be highly valuable in identifying fields that are locationally suitable for a fish food program. More quality control may be required in some areas though to improve on the accuracy of the dataset.
- The distance of the rice field from the return is not the only factor affecting the ability to transport food resources. For example, the size and flow rates of the canals can have a significant impact also. Exporting food-laden water into a very large, relatively slow-moving or stagnant canal may only result in dilution of the food resources and lower transport distances. Exporting into smaller canals that lead to a return may provide for a greater 'head' of food-laden water within the canal and result in the ability to transport that water greater distances. "**The most effective next steps would be further work to verify the accuracy of the distance layer and to understand the physical characteristics of canal systems leading to the returns**". This further investigation is not required throughout the valley and for all returns. Using acre summaries to identify returns that are connected to fields within 20 miles of the returns will help prioritize where this additional work would be most effective.
- The ability to coordinate draw-down of multiple fields in unison improves the ability to effectively transport foods. Working with water districts having sufficient water rights to flood and drain large acreages simultaneously will increase effectiveness.
- Understanding the availability of existing food resources throughout the fish-rearing streams could provide a way to prioritize where a rice field fish food program could most benefit juvenile salmon. Future studies are warranted to gather this information along the length of the river system and at different times throughout the year.
- The idea of prioritizing food delivery to specific return locations at certain times of year to target the benefits toward individual salmon runs (e.g. – winter-run vs. spring run, etc) as part of the DST is not possible to accomplish at this time. First, the specific locations of juvenile salmon within sections of the rivers at various times of the year is not fully understood yet, and more importantly the timing of movements by juvenile salmon down the river is highly dependent on water flow levels and will vary from year to year based on weather, temperature and precipitation patterns. The ability to predict the timing of these movements and map them in detail can't be done currently.
- The in-progress layer identifying when various water districts shut down their supply canals for maintenance may help in prioritizing field enrollment. Areas without surface water delivery are limited to groundwater as a source for flooding fields. Groundwater typically lacks the biological material and particulate matter transported in surface water so typically requires a longer period of flooding to produce equivalent concentrations of fish foods.

- More work could be done to quantify the effective distance of transporting food resources. Existing research documents measurable increases in food availability up to six miles downstream from a rice field project and anecdotal evidence of benefits up to twenty miles downstream, but better understanding and documentation of benefits at larger distances would help in targeting an effective rice-field program.
- There is some debate about the benefits of a rice field fish food production program for salmon recovery efforts. A biologist expressed concerns that juvenile survival is still most affected by flow rates and river temperatures. In high flow water years, river waters might not be food-limited for juvenile salmon so the relative benefit of additional food from rice fields is unknown. In low flow water years, food resources might be limiting but water may be more effectively used to maintain river flows rather than diverted into fields for food production. In those dry years, water supplies for food production programs should come from other watersheds or from groundwater, but there are potentially negative environmental issues associated with those options. More work needs to be done to understand existing food resources in various stretches of the river within individual years and in years of varying water availability and flow.

Input from Water Districts

Input from water district managers was overwhelmingly positive when discussing a rice field fish food production program, but nearly all water districts that were interviewed conveyed information about their standard operations that might limit their ability to supply water at various times throughout the year. A shapefile was created to identify these limitations when they were spatially explicit and predictable on an annual schedule. Interviews were conducted with water districts that supply 60% of rice fields within 20 miles of a return to fish-bearing waters, but further work needs to be done to gather information from all major water districts in the study area before this data layer will be fully usable for the DST.

- For nearly all water districts interviewed, early water-year water deliveries (November and early-December) can regularly be affected by Term 91 curtailments.
- Much of the Richvale I.D. and portions of Western Canal District are not as affected by curtailments and may have better water availability in November and December
- Many water districts, including Richvale I.D., Western Canal, and Sutter Extension shut down their supply canals in mid- to late-January and will not supply water again until the beginning of the planting season, typically late March or early April.
- Some water districts may be limited on the number of acres they can provide water to each day. For example, R.D. 108 has a maximum rate of 240 cfs for their winter diversions. This results in an ability to flood only about 300-500 acres/day. This may affect their ability to drain/fill large acreages of rice fields in unison. Further interviews with the remaining water districts should inquire about any similar restrictions that may impact those water districts.

Input from Shorebird Interests

Point Blue Conservation Science staff was interviewed to obtain their understanding of how a rice field fish food program might interact with shorebird interests. In theory the addition of water to the landscape should benefit shorebirds, but fields enrolled in a fish food program are flooded too deeply for shorebirds to effectively forage, except in “flashy” two-to-three-day intervals as the fields are drawn down and reflooded. A fish food field must be drained as quickly as possible to export that food the greatest distance possible, but shorebirds benefit when a field is drawn down slowly. It is unclear whether shorebirds will be able to locate and utilize a "flashy" field for foraging before it is reflooded at a depth that is too deep to forage.

- Under current practices, some farmers will install boards in their fields to opportunistically capture and hold rainwater to aid in decomposition. These shallowly flooded fields provide ideal shorebird habitat. If these fields were enrolled in a fish food program and flooded more deeply, shorebird habitat would potentially be lost.
- After February 1st when the majority of farmers drain their fields to dry them out in preparation for planting, any fields enrolled in a fish-food program would likely offer some additional shorebird foraging habitat.

Input from Waterfowl Interests

Flooding rice fields in winter benefits growers by reducing organic matter, primarily rice straw, which must be removed before the next crop can be planted (Bird et al. 2000). Waterfowl, particularly dabbling ducks, are attracted to these flooded fields which have favorable water depths and contain waste grain and invertebrates that waterfowl forage on (Elphick and Oring 1998; Petrie et al. 2016; Matthews et al. 2022). Dry rice fields are beneficial to geese and provide an estimated 95 percent of food resources available to wintering geese in the Central Valley (CVJV 2020). Benefits flow both ways, as waterfowl foraging activities in flooded fields increase the breakdown of rice straw (Bird et al. 2000). Rice growers also receive financial compensation from hunters by providing hunting access to these flooded rice fields during the waterfowl hunting season. Many hunters and rice growers have formed long-term relationships through these agreements, resulting in a tradition of waterfowl hunting in rice fields in the Sacramento Valley.

The importance of rice to waterfowl populations in the Sacramento Valley cannot be understated. Winter flooded rice provides 74% of the total food energy for wintering waterfowl in the Sacramento Valley, and the Sacramento Valley supports up to 3.4 million wintering waterfowl (Table 2).

Table 2. Average waterfowl population counts in the Sacramento Valley.

Date	Goose Total	Duck Total	Waterfowl Total
23-Aug	0	177,142	177,142
7-Sep	0	249,837	249,837
22-Sep	62,744	308,212	370,957
7-Oct	197,080	532,952	730,032
22-Oct	350,579	859,962	1,210,541
6-Nov	514,616	1,236,864	1,751,481
21-Nov	659,537	1,703,667	2,363,204
6-Dec	690,973	2,356,833	3,047,806
21-Dec	703,252	2,736,657	3,439,910
5-Jan	683,878	2,674,046	3,357,924
20-Jan	617,208	2,371,094	2,988,302
4-Feb	567,750	2,049,705	2,617,455
18-Feb	496,769	1,728,158	2,224,927

6-Mar	237,324	973,321	1,210,646
21-Mar	42,399	530,283	572,682

Ducks Unlimited sees both potential benefits and conflicts between waterfowl interests and a rice field fish food production program. Supporting salmon recovery will only increase the recognized value of the rice industry as a wildlife friendly agricultural practice, which will be a long-term benefit to waterfowl by increasing the stability of the rice industry. Additionally, the multiple benefits of water availability for rice straw decomposition, salmon, shorebird, and waterfowl habitat may help to maintain water supply reliability for these beneficial uses in the future. However, there are some concerns about the timing and extent of fields enrolled in a fish food program that should not be ignored.

- Fish food fields are flooded at a depth) greater than optimum foraging depth for dabbling ducks (12"), so fish food fields will effectively lower or eliminate food availability to foraging waterfowl. Flooding of fields for fish food production in November will have minor impacts on waterfowl foraging availability, but as peak waterfowl numbers enter the valley in late December through January the loss of foraging opportunity becomes increasingly impactful.
- It is unknown what happens to waste grain when a fish food field is rapidly drained to transport fish foods, but it is assumed that some percentage of that food resource will be transported out of the field and lost to waterfowl utilization.
- Waterfowl hunting leases on rice fields can provide significant financial benefits to rice-growers. Enrolling traditionally leased fields in a fish food program could jeopardize these long-term relationships and have significant impacts on the waterfowl hunting community. Loss of hunting opportunities due to short-term draining of a field might have low impacts in early November, but as peak waterfowl numbers enter the valley in late December through January the loss of hunting opportunities becomes highly impactful.
- The ability to re-flood a field (ideally to a depth for waterfowl foraging) after a fish food field has been drained is the primary concern for waterfowl management. If water supplies are shut off in a water district and a field cannot be reflooded, the waterfowl habitat value is completely lost. Refilling a field and maintaining it in that condition while peak waterfowl numbers are in the valley is key to maintain the multi-species benefits of rice fields.
- After the end of the waterfowl hunting season (effectively January 31st) most farmers will immediately begin pulling their boards to dry their fields in preparation for spring planting and little water remains on the landscape. From February 1st forward, any field enrolled in a fish food program will provide at least some increase in habitat availability. While rice grain may be mostly foraged out from fields at this point, the reflooding of a field and growth of invertebrates in the fish food fields will provide a marginal increase in available habitat at that time of year.

Input from Rice Farmers

Provided that enrollment in a fish food production program is entirely voluntary on a landowners part (which it is), farmers voiced few or no concerns about these programs. Their primary concerns are that they can drain their fields early enough to prepare for and initiate spring planting, and that they are financially compensated for the costs and effort required to manage the water on their fields.

Model Development and Programming

The DST was developed in ESRI's ArcGIS Pro software. It consists of a series of steps that initially rates rice fields on their suitability for salmon food production and transport and then factors in additional layers representing shorebird and waterfowl interests (Figure 3). These two additional layers were the only layers identified by stakeholders initially. As more stakeholders view the model and its outputs, we hope to receive suggestions for additional layers to be developed and included into the model. As written, the model can easily add in new layers as they are developed in the future.

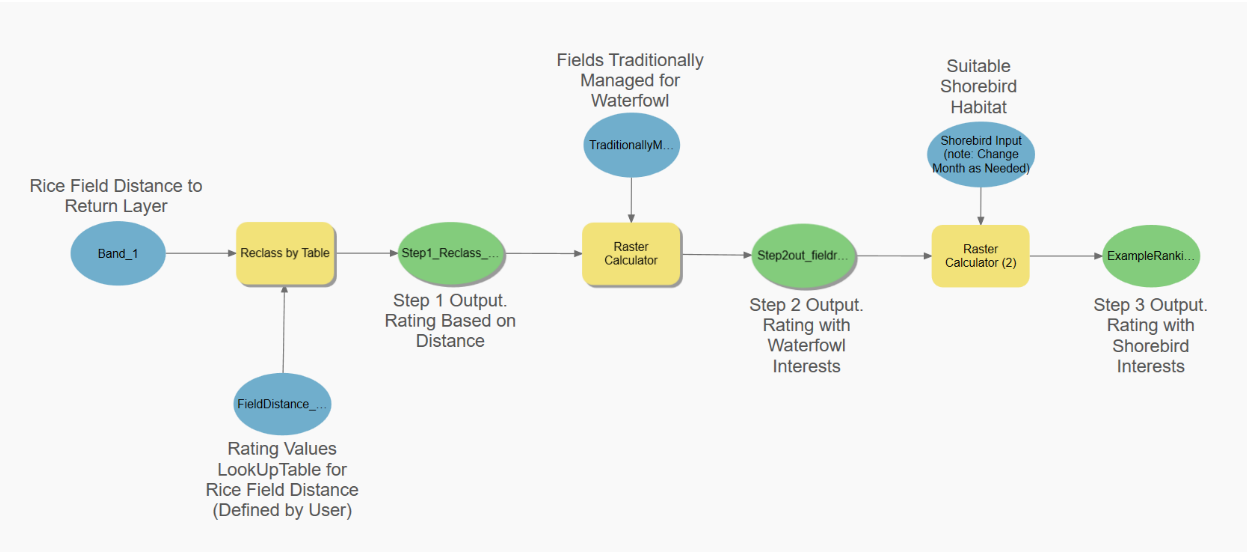


Figure 2. Model layout.

Outputs from example model runs are shown below. The assumptions used in the model runs are unique by month based on variations in waterfowl and shorebird assumptions.

Step 1:
Recode rating values for rice field distance to return

From Distance	To Distance	Output Rating
0.0	3	10
3.1	6	8
6.1	10	6
10.1	15	4
15.1	20	2
20.1	75	0

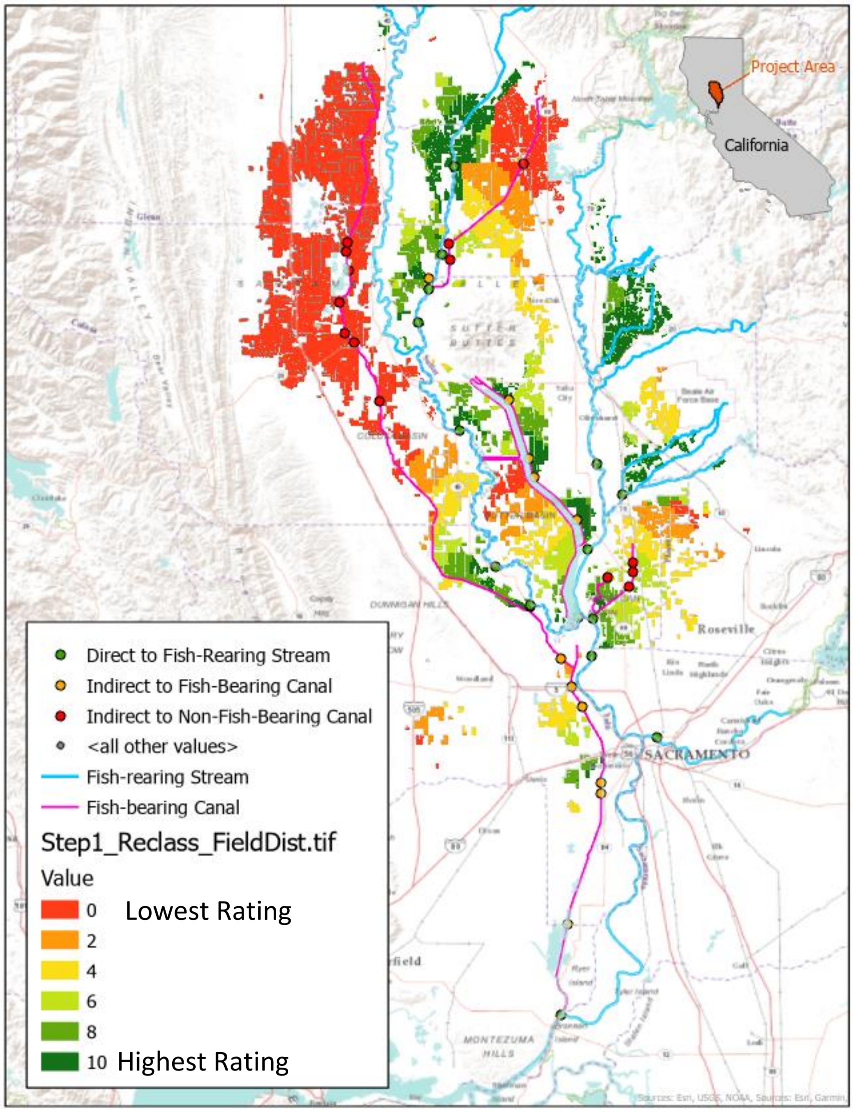


Figure 3. Output map - Rice field ratings based on distance to return.

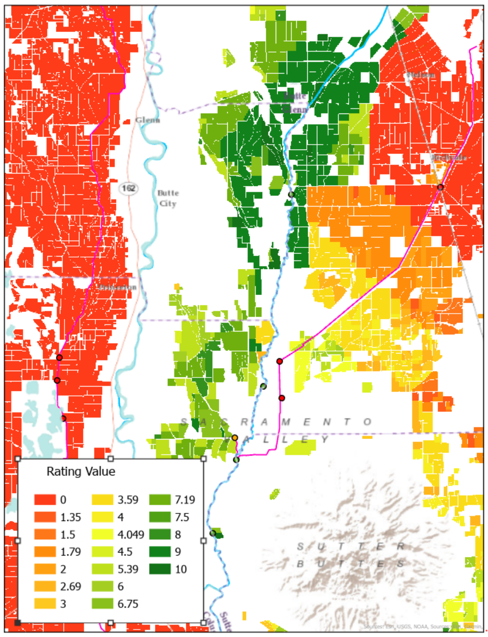
Step 2.
Adjust values based on waterfowl interests

Waterfowl concerns vary by month for waterfowl. Output from step 1 is reduced by a multiplier for fields traditionally managed for waterfowl. Each month is run separately and receives its own output.

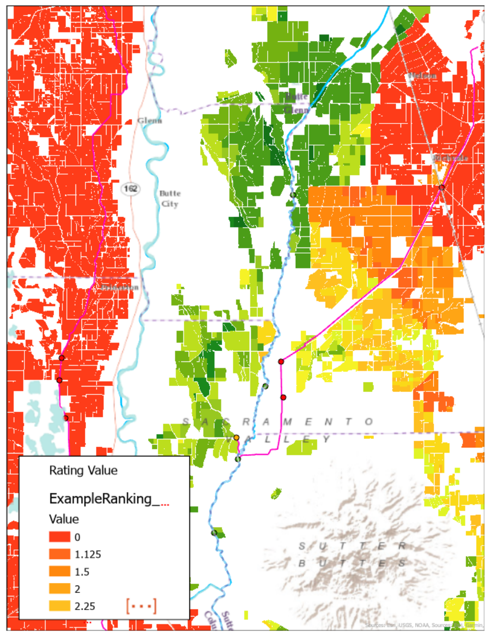
Month	Multiplier	Comment
Nov	.9	Waterfowl numbers increasing, Hunting impacts low, Reflooding potential high
Dec	.75	Near peak waterfowl, Hunting impacts moderate to high, Reflooding potential high
Jan	.5	Waterfowl at peak numbers, Hunting impacts high, Potential for reflooding lower
Feb	1	No waterfowl concerns in February

Step 3.
Adjust values based on shorebird suitability

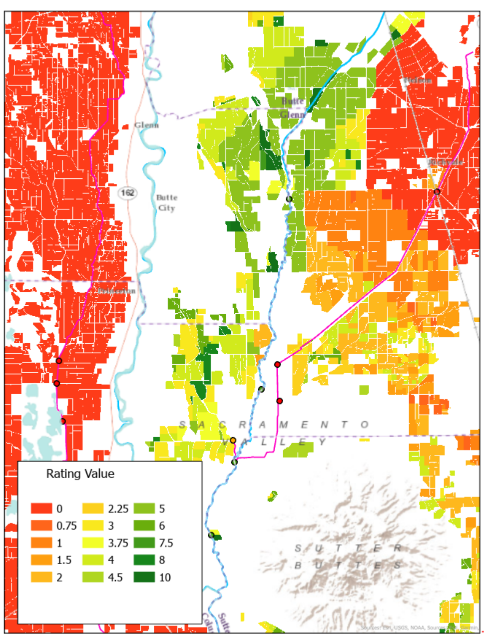
Outputs from step2 are reduced by a multiplier for fields with suitable shorebird habitat. Shorebird suitability varies by month. The multiplier for shorebird habitat (used .75 in this example) stays the same in each month, but the spatial distribution of shorebird habitat changes monthly so each month is run separately with the appropriate shorebird layer. Example output maps for example model runs for November through February are shown in Figures 4 – 7 for an area along Butte Creek.



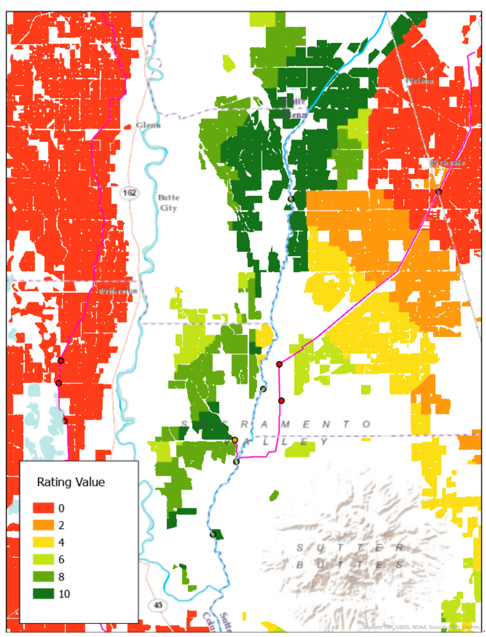
November Rankings



December Rankings



January Rankings



February Rankings

Ranking values for fields get progressively lower from November through January as waterfowl use in the valley increases and traditional waterfowl management regimes are needed. In February the need for additional habitat occurs, so ranking values for fish food feels increase dramatically. Under this scenario there would be no change in the rating maps for February, March and April so only February is displayed.

Conclusion

Next Steps

The DST and example output maps will be presented to the FR Steering Committee and/or Advisory Committee meetings to solicit comments. It is expected that this will initiate discussions on additional data layers that can be added to the DST model. Initial next steps prioritized by stakeholders are listed below.

- Continue to interview water district managers to QC the distance to return layer.
- Gather additional information on water district maintenance schedules, Term 91, and water rights to complete this layer
- Develop additional layers identified by Steering Committee and Advisory Committee comments.

References

Bird J.A., Pettygrove G.S., Eadie J.M. (2000). The impact of foraging on the decomposition of rice straw: mutual benefits for rice growers and waterfowl. Journal of Applied Ecology 37:728–741.

[CVJV] Central Valley Joint Venture. (2020). Central Valley Joint Venture 2020 implementation plan: Sacramento, California: U.S. Fish and Wildlife Service.

Conlisk, Erin E., Gregory H. Golet, Mark D. Reynolds, Blake A. Barbaree, Kristin A. Sesser, Kristin B. Byrd, Sam Veloz, and Matthew E. Reiter. 2022. "Both Real-Time and Long-Term Environmental Data Perform Well in Predicting Shorebird Distributions in Managed Habitat." Ecological Applications e2510. https://doi.org/10.1002/eap.2510

Elphick, C. S., & Oring, L. W. (1998). Winter management of Californian rice fields for waterbirds. Journal of Applied Ecology, 35, 95–108.

Matthews, L.J., Petrie, M., & Eadie, J.M. (2022). Impacts of Changing Postharvest Agricultural Practices on Abundance of Waste Grain in California's Central Valley. Journal of Fish and Wildlife Management, 13(2), 32–333. https://doi.org/10.3996/JFWM-21-061

Petrie, M. J., Fleskes, J.P., Wolder, M.A., Isola, C.R., Yarris, G.S., & Skalos, D.A. (2016). Potential effects of drought on carrying capacity for wintering waterfowl in the central valley of California. Journal of Fish and Wildlife Management, 7(2), 408–422. https://doi.org/10.3996/082015-JFWM-082

Appendix A. Table 1. Summary of rice field acreages by water district and distance to return.

Note: Grey highlighted cells are water districts connecting to the Floodplains Reimagined project area and having >10,000 acres of rice fields within 20 miles of an output to juvenile-fish-bearing waters. Green highlights indicate that interviews were conducted with operations managers from these districts.

	Distance to Fish-Rearing Stream or Fish-Bearing Canal									
Water District	le 5 mi	5-10 mi	10-15 mi	15-20 mi	20-30 mi	30-40 mi	40-50 mi	50-75 mi	Total Acres	Sum less than 20mi
RECLAMATION DISTRICT NO. 108	5,900	6,199	9,339	7,630	1,019	-	-	-	30,087	29,068
WESTERN CANAL DISTRICT	23,869	2,841	-	0	15,841	114	-	-	42,666	26,710
SUTTER M.W.C.	954	8,334	8,704	6,828	4,611	-	-	-	29,431	24,820
SOUTH SUTTER W.D.	672	6,901	9,716	7,452	1,778	-	-	-	26,519	24,741
BIGGS-WEST GRIDLEY W.D.	-	2,013	9,711	7,364	400	-	-	-	19,488	19,088
RICHVALE I.D.	2,983	315	4,287	9,909	8,585	-	-	-	26,080	17,495
SUTTER EXTENSION W.D.	4,237	6,197	1,282	-	-	-	-	-	11,716	11,716
SUTTER BUTTE M.W.C.	6,208	2,942	348	-	-	-	-	-	9,499	9,499
RECLAMATION DISTRICT NO. 1004	5,740	3,281	-	-	-	-	-	-	9,020	9,020
BROPHY WATER DISTRICT	-	1,613	6,434	357	-	-	-	-	8,404	8,404
CONAWAY PRESERVATION GROUP, LLC	-	2,351	5,671	-	-	-	-	-	8,022	8,022
NATOMAS CENTRAL M.W.C.	2,074	5,651	149	-	-	-	-	-	7,874	7,874
CORDUA IRRIGATION DISTRICT	7,095	-	-	-	-	-	-	-	7,095	7,095
HALLWOOD IRRIGATION COMPANY	5,136	-	-	-	-	-	-	-	5,136	5,136
SOUTH YUBA WATER DISTRICT	3,716	824	-	-	-	-	-	-	4,540	4,540
RAMIREZ WATER DISTRICT	4,398	-	-	-	-	-	-	-	4,398	4,398
MERIDIAN FARMS WATER COMPANY	3,367	715	-	-	-	-	-	-	4,082	4,082
PLEASANT GROVE-VERONA M.W.C.	2,798	928	-	-	-	-	-	-	3,726	3,726
BUTTE WATER DISTRICT	-	-	2,773	947	1,046	-	-	-	4,767	3,721
COLUSA DRAIN M.W.C.	639	132	1,155	1,494	3,057	4,968	7,458	2,546	21,449	3,421

BROWNS VALLEY I.D.	2,779	-	-	-	-	-	-	-	2,779	2,779
NORTH DELTA WATER AGENCY	1,310	-	658	-	-	-	-	-	1,968	1,968
RIVER GARDEN FARMS COMPANY	1,824	104	-	-	-	-	-	-	1,928	1,928
WHEATLAND WATER DISTRICT	1,501	35	263	-	-	-	-	-	1,800	1,800
WESTERN PLACER I.D.	-	-	771	747	-	-	-	-	1,518	1,518
YOLO COUNTY F.C.W.C.D.	1,232	184	-	-	-	-	-	-	1,416	1,416
PELGER M.W.C.	-	-	-	823	411	-	-	-	1,234	823
BABER, JACK ET AL	657	-	-	-	-	-	-	-	657	657
TISDALE IRRIGATION AND DRAINAGE COMPANY	449	108	-	-	-	-	-	-	557	557
CARTER M.W.C.	-	478	-	-	-	-	-	-	478	478
LLANO SECO RANCHO	88	360	-	-	-	-	-	-	449	449
LOMO COLD STORAGE AND MICHELLI, JUSTIN	425	-	-	-	-	-	-	-	425	425
GRIFFIN, JOSEPH, AND PRATER, SHARON	249	110	-	-	-	-	-	-	358	358
CAMP FAR WEST I.D.	349	-	-	-	-	-	-	-	349	349
EASTSIDE M.W.C.	305	-	-	-	-	-	-	-	305	305
GLENN-COLUSA I.D.	230	-	-	-	-	6,459	29,334	63,105	99,129	230
OTTERSON, MIKE (WELLS, JOYCE)	-	229	-	-	-	-	-	-	229	229
NENE RANCH, LLC	-	222	-	-	-	-	-	-	222	222
DUNNIGAN W.D.	-	-	-	187	-	-	-	-	187	187
YOLO-ZAMORA W.D.	-	-	145	-	-	-	-	-	145	145
MCM PROPERTIES	-	142	-	-	-	-	-	-	142	142
FORRY, LAURIE E.	47	61	-	-	-	-	-	-	108	108
LAUPPE, BURTON AND KATHRYN (1289)	99	-	-	-	-	-	-	-	99	99

CITIZENS UTILITIES COMPANY	-	-	79	-	-	-	-	-	79	79
ANDREOTTI, BEVERLY F., ET AL	76	-	-	-	-	-	-	-	76	76
GOMES, JUDITH	70	-	-	-	-	-	-	-	70	70
LAUPPE, BURTON AND KATHRYN (1364)	63	-	-	-	-	-	-	-	63	63
LONON, MICHAEL E.	56	-	-	-	-	-	-	-	56	56
CUMMINGS, WILLIAM S.	52	-	-	-	-	-	-	-	52	52
MOREHEAD, JOSEPH A. AND BRENDA	48	-	-	-	-	-	-	-	48	48
LINDA COUNTY W.D.	-	-	41	-	-	-	-	-	41	41
FEATHER W.D.	38	-	-	-	-	-	-	-	38	38
BARDIS, CHRISTO D. ET AL (BROOMIESIDE FARMS)	-	-	-	35	211	-	-	-	246	35
RECLAMATION DISTRICT NO. 10	27	-	-	-	-	-	-	-	27	27
COLUSA DRAIN WATER USERS ASSOC	-	-	5	8	-	2	14	54	82	13
RECLAMATION DISTRICT NO. 2035	-	-	-	10	-	-	-	-	10	10
JOAN/WILMARTH S. LEWIS	4	-	-	-	-	-	-	-	4	4
ROGER C. WILBUR	0	-	-	-	-	-	-	-	0	0
COLUSA COUNTY W.D.	-	-	-	-	286	-	-	-	286	-
HOWALD FARMS, INC.	-	-	-	-	243	-	-	-	243	-
PACIFIC REALTY ASSOC (M & T CHICO RANCH)	-	-	-	-	144	-	-	-	144	-
STEIDLMAYER, ANTHONY E. ET AL	-	-	-	-	110	67	-	-	177	-
MAXWELL I.D.	-	-	-	-	-	-	4,410	118	4,528	-
ODYSSEUS FARMS	-	-	-	-	-	-	90	-	90	-
LA GRANDE W.D.	-	-	-	-	-	-	48	1,072	1,120	-
CACHIL DEHE BAND OF WINTUN INDIANS OF THE COLUSA INDIAN COMMUNITY	-	-	-	-	-	-	8	15	23	-
PROVIDENT I.D.	-	-	-	-	-	-	-	14,160	14,160	-
PRINCETON-CODORA-GLENN I.D.	-	-	-	-	-	-	-	7,712	7,712	-
PROVIDENT I.D. - WILLOW CREEK	-	-	-	-	-	-	-	2,026	2,026	-
KANAWHA W.D.	-	-	-	-	-	-	-	950	950	-

WESTSIDE W.D.	-	-	-	-	-	-	-	159	159	-
GLENN VALLEY W.D.	-	-	-	-	-	-	-	156	156	-
GREEN VALLEY CORPORATION (5211)	-	-	-	-	-	-	-	87	87	-
GLIDE W.D.	-	-	-	-	-	-	-	74	74	-
WILLOW CREEK M.W.C.	-	-	-	-	-	-	-	52	52	-
TUTTLE, CHARLES W. AND NOACK, SUE T.	-	-	-	-	-	-	-	33	33	-
CALIFORNIA WATER SERVICE CO.	-	-	-	-	-	-	-	0	0	-
ROBERTS DITCH IRRIGATION COMPANY	-	-	-	-	-	100	398	-	497	-
SYCAMORE FAMILY TRUST	-	-	-	-	-	4,605	-	-	4,605	-
Total Acres	91,765	53,271	61,532	43,793	37,742	16,314	41,760	92,318	438,494	250,360
Cumulative Total Acres	91,765	145,035	206,567	250,360	288,102	304,416	346,176	438,494		