Swainson's Hawk and Other Raptor Foraging Use of Solar Array Fields within an Agricultural Landscape in Sacramento County

October 2013

Prepared for:

RECURRENT ENERGY

Prepared by:

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Introduction

Recurrent Energy constructed four photovoltaic solar energy projects in south Sacramento County in 2012. All occur within an agricultural landscape used by foraging raptors, including the state-listed Swainson's hawk (*Buteo swainsoni*). Because of its dependence on agricultural foraging habitats in the Central Valley, loss of suitable agricultural lands to urban development may be considered a significant environmental impact on the Swainson's hawk pursuant to the California Environmental Quality Act (CEQA) (CDFG 1994). Loss of suitable agricultural land is typically mitigated through a compensatory process of acquisition, management, and preservation of replacement agricultural lands. To streamline its process for determining mitigation for losses of Swainson's hawk habitat, Sacramento County enacted a local ordinance that provides a mitigation option for habitat compensation using replacement ratios derived using a parcel size formula (Sacramento County 2006). However, during the environmental review process with the County, Recurrent Energy questioned whether the installation of a solar array would preclude Swainson's hawk foraging and therefore be considered a significant loss of foraging habitat similar to other types of development projects.

Swainson's hawks are highly active aerial hunters. Typical foraging behavior is a relatively low (less than 100 meters) circling flight above suitable foraging habitat. They avoid fields with tall or dense vegetation because this condition reduces visibility and access to prey (Bechard 1982, Estep 2009). However, some crops such as vineyards may provide some open accessible foraging space within the field (i.e, between the vineyard rows). The extent to which Swainson's hawks and other raptors would attempt to capture prey between rows of tall vegetation such as vineyards is uncertain, but is generally considered negligible, and thus vineyards and other similar cover types are considered unsuitable foraging habitat (CDFG 1994). Swolgaard et al. (2007) found some use of vineyards by foraging Swainson's hawks, but not to the extent of other crops and land cover types in the surrounding landscape. Still, the Swolgaard et al. (2007) study revealed that Swainson's hawks are not entirely averse to hunting in these conditions.

A typical solar array, however, has a greater separation between rows than do most vineyards. Recurrent also prepared a management plan for each of their solar projects that included establishing and maintaining a grass substrate that would promote sustainable rodent populations that are the primary source of prey for Swainson's hawks and other raptors. The solar trackers also provide perching opportunities for those species that typically hunt from perches, such as red-tailed hawk (*Buteo jamaicensis*) and American kestrel (*Falco sparverius*). A report prepared for Recurrent Energy and presented to the County and the California Department of Fish and Wildlife (CDFW) (Estep 2011a) concluded that because at least 60 percent of the area within the solar arrays would remain potentially available for foraging and that entire area (including beneath the solar panels) would provide habitat for small rodent populations, Swainson's hawks and other raptors may continue to use solar array fields for foraging and that mitigation that addresses habitat compensation for solar projects could be scaled based on the extent of use. The report recommended conducting an observational study to evaluate

foraging use of solar fields, which could be used to determine mitigation options for future solar projects.

While the County and the CDFW determined that there was insufficient evidence that indicated solar fields would continue to provide value to foraging Swainson's hawks, both indicated that with additional evidence through the recommended observational studies, they were open to further discussions regarding the affect of solar fields within an agricultural landscape.

Once the projects were constructed and operating, and once grasses were firmly established on the sites, Recurrent Energy undertook a one-year research project to examine the extent of use of the solar projects by Swainson's hawks and other raptors. This report summarizes the results of that research project.

Location

Due to their proximity to each other, three of the four solar projects (RE Bruceville LLC, RE Kammerer LLC, and RE McKenzie LLC, were used in this study. The study area is located at and in the vicinity of these three project sites in South Sacramento County. All are south of the City of Sacramento and east of Interstate 5 (Figure 1). The Kammerer and Bruceville project sites are immediately south of the City of Elk Grove between Interstate 5 and State Route 99. The McKenzie project site is just north of the City of Galt and just east of State Route 99 (Figure 1).

Description of the Solar Projects

The three solar projects, ranging in size from 105 acres to approximately 200 acres, consist of an array of photovoltaic solar panels installed in east-west-facing rows. The panels are connected uniformly in rows along a solar tracker frame that maintains conformity and allows the panels to pivot along a single axis as they track the sun. The trackers are set into the ground using 4-inch galvanized steel poles set in 1-foot concrete pads spaced approximately 10 feet apart along the row. The 8-foot-long solar panels are installed onto the frame with a 2-foot minimum clearance from the ground to panel edge at a 45 degree angle, the maximum tilt angle. The total height of the structure reaches a maximum of approximately 10 feet at full 45 degree tilt. Panel rows are spaced 20 feet apart from pole to pole. With 8-foot-long panels, this leaves 12 feet of open space between each row at horizontal, and slightly larger open space as the trackers angle. The collection systems are underground with the exception of grid tie inverters, which are spaced uniformly throughout each project site. Power is delivered to an onsite solar substation. Each project also includes internal gravel access roads and an 8-foot-high chain link security fence around the perimeter.

A management plan prepared for each site includes the establishment of grasses throughout the project sites, including beneath and between the trackers and solar panels.

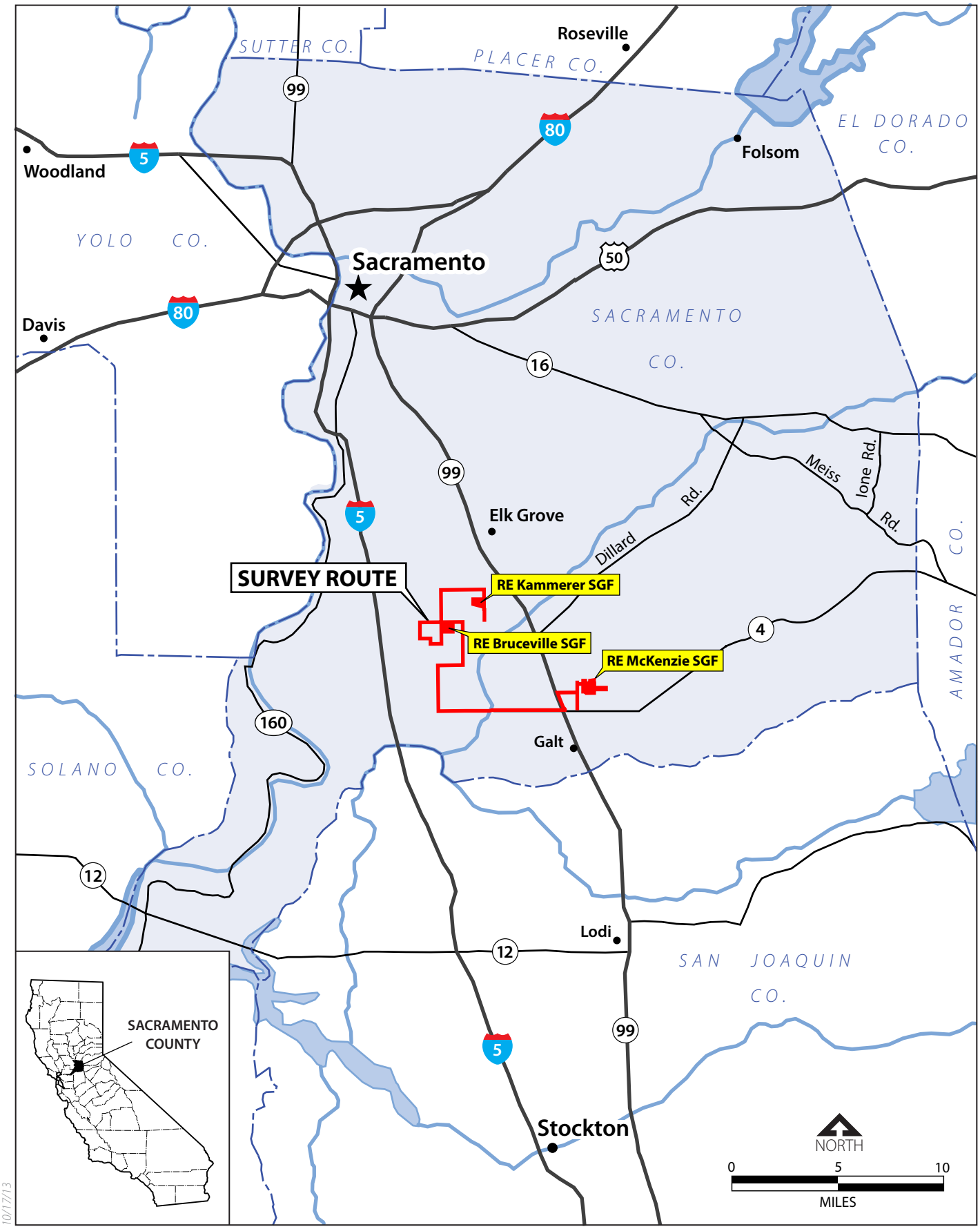


Figure 1
Regional Location

The grasses are maintained at a low (4 to 12 inches) height through a sheep grazing program that periodically rotates between the sites as needed. The grass ground cover is designed to encourage the establishment of rodent populations to promote raptor use of the site as well as to provide for rodent refugia to aid in the reestablishment of rodent prey populations on adjacent farmlands following cultivation.

Physiography and Land use

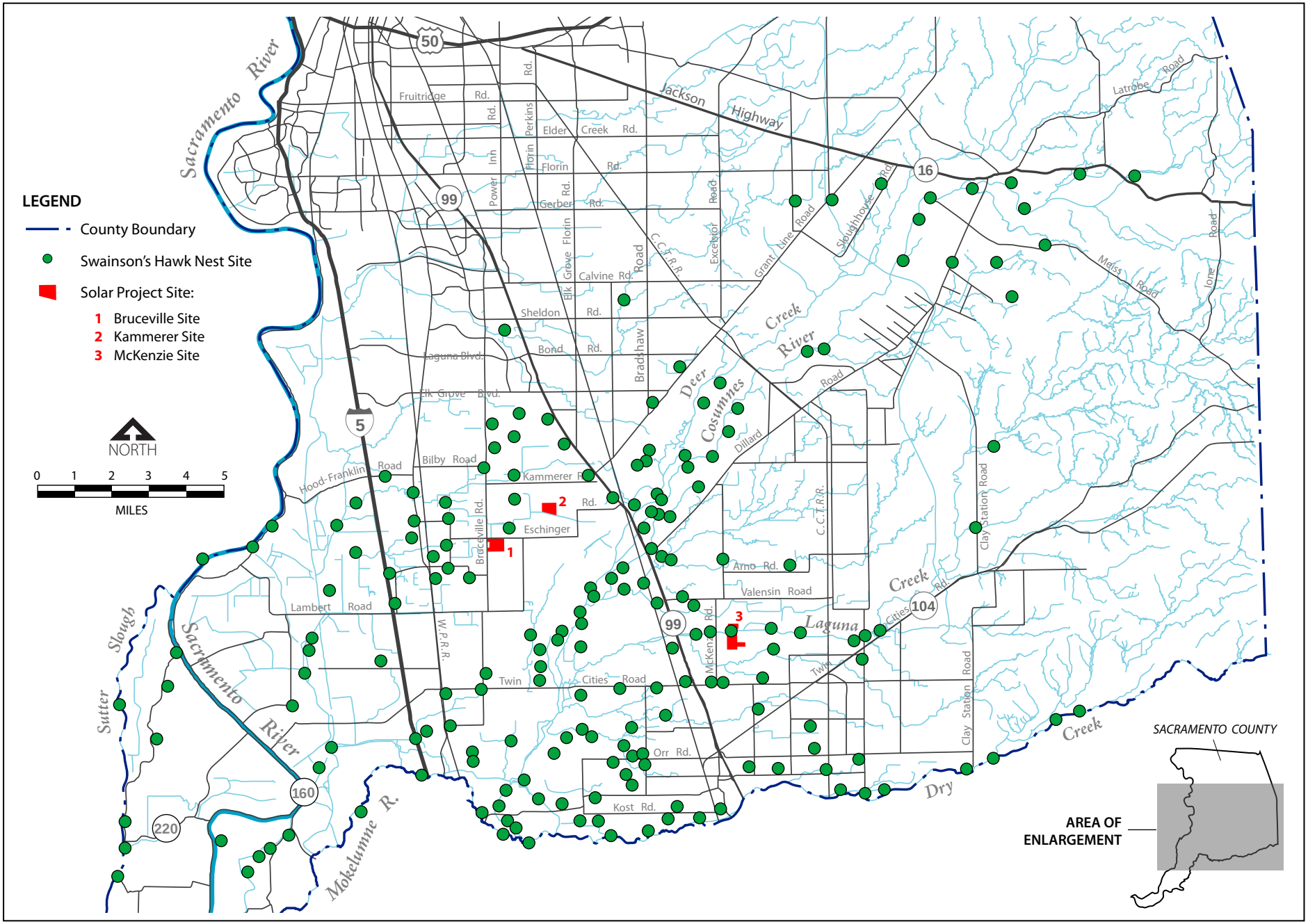
The surrounding land use is entirely agricultural, consisting of a combination of irrigated pasture, dry pasture, and irrigated cropland. Dominant crop types in the area include oat hay, alfalfa, corn, wheat, and vineyards. Rural urban areas also occur throughout the area including farm and ranch residences and related facilities and dairies. The landscape is flat with virtually no topographic relief other than seasonal and perennial drainages. Trees occur along riparian corridors, roadsides, and field borders, and around farm and ranch residences. These trees provide nesting habitat for several of the raptor species in the study area including Swainson's hawk, red-tailed hawk, red-shouldered hawk (*Buteo lineatus*), white-tailed kite (*Elanus leucurus*), and American kestrel.

Distribution of Nesting Swainson's Hawks in South Sacramento County

The Swainson's hawk occurs throughout the undeveloped portions of Sacramento County. Surveys have been conducted throughout Sacramento County for several decades resulting in a substantial number of breeding records (California Natural Diversity Data Base 2013, Estep 2007, 2009a, 2012). Surveys conducted in 2006 reported a total of 188 active breeding sites in Sacramento County south of Jackson Highway (State Route 16) (Estep 2007). More recent surveys (Estep 2009a, 2012) reported additional active breeding sites within and south of the City of Elk Grove. Figure 2 illustrates the locations of reported Swainson's hawk nests in South Sacramento County in the vicinity of the project sites. The highest nesting density was found in the interior of the county where the land use is predominantly irrigated cropland and irrigated pastureland.

Purpose

This study was designed to meet the following objectives (1) examine how and the extent to which Swainson's hawks and other raptors forage on or otherwise use the solar facilities; and (2) evaluate the use of solar facilities and other available land uses/cover types relative to their availability on the landscape.



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SOURCE: Estep 2007.

Figure 2
Swainson's Hawk Distribution in the Vicinity of the Solar Project Sites

Methods

Strip Transect Road Surveys

The strip transect road survey method (Fuller and Mosher 1987) was used to evaluate relative foraging use of different land cover types, including the solar arrays. A 26-mile survey route was selected based on the following factors:

- Incorporating the three solar facilities into the design
- Road/vehicle accessibility
- Visibility
- Road safety
- Diversity of land cover types

The survey area extended 600 feet from each side of the road for a total width of 1,200 feet. Initially, all land cover types were mapped and classified along the survey route. To conduct the survey, the surveyor slowly drove at a consistent pace between 10 and 15 mph, stopping as needed to identify and record raptors and raptor behavior within the survey area. Recorded behaviors included the following:

- Circling below 100 meters
- Soaring below 200 meters
- Flying through the survey area below 200 meters
- Kiting/Hovering
- Perching (adjacent poles/trees/fences)
- Standing on ground
- Prey capture attempt
- Prey capture successful
- Prey capture unsuccessful
- Aerial foraging

The surveyor recorded data as raptors were observed within the 1,200-foot-wide transect survey area. Land cover type and status, including vegetation height, and farming activity were recorded for each occurrence. Start times were variable in order to account for differences in foraging use patterns. Using this method, a reliable statistical analysis can be performed that measures habitat use as a proportion of availability. In other words, it determines whether a habitat type is used more or less than expected relative to its availability. In this way we can evaluate the relative use of all cover types in the survey area, including the solar array fields.

A survey form along with an accompanying data code sheet and field maps with the route and land cover types illustrated were used to record observational and related data while in the field. Surveys were conducted during daylight hours and were not conducted during severe weather events such as heavy rainfall, winds greater than 20 mph or foggy

conditions. Surveys were conducted twice weekly by the same surveyor between March 28 and August 29, 2013 for a total of 42 surveys.

Habitat Mapping. Land cover types were mapped and characterized in the field along the survey route on 7.5 minute USGS quadrangle maps. Current 2013 land use was documented in the field according to the land cover type categories listed below.

- Oats
- Irrigated pasture
- Dry pasture
- Solar field
- Alfalfa
- Tilled
- Wheat
- Vineyard
- Corn
- Grass
- Miscellaneous row/truck crop
- Wetland/riparian
- Ruderal/Urban

Field boundaries were recorded, confirmed, or adjusted as needed on USGS base maps. Tilled was included separately because some fields were tilled and unplanted for approximately one-half of the survey period before being planted. Rural residences and their surrounding footprint (e.g., barns, out buildings, yards, and equipment storage areas), adjacent ruderal areas, and other agricultural facilities, mainly dairies, were combined into a single category – Ruderal/ Urban. Following the initial field mapping of habitat/land use categories, the data were then re-mapped using aerial photos to confirm field boundaries.

These maps were then converted to graphic maps using Adobe Illustrator. Habitat/land use cover type acreages were calculated from the graphic maps using a plug-in filter from Telegraphics Inc. While this process provided a reasonably accurate representation of land cover types along the survey route, it did not exclude interior farm roads and other edge features. As a result, the acreage totals may exceed the actual acreage for some types. However, this was considered to have a negligible effect on the total calculations or the relative abundance of the various types.

Several crop type rotations occurred during the survey including wheat, oats, and tilled fields rotating to corn, and some tilled fields planted to vineyards. These rotations or conversions occurred at approximately the mid-point of the survey. To account for these changes and to satisfy the assumption that habitat availability is constant throughout the study (Manly et al. 2002), we used the same approach as Swolgaard et al. (2008) by tallying the areas of all fields that changed crops midseason, dividing the values in half, and assigning those values to each habitat.

Analysis. Documented raptor occurrences and acreages of land cover types were compiled and proportions of land cover types and occurrences within each land cover type calculated. Of the six species documented during the survey, only Swainson's hawk, red-tailed hawk, and American kestrel had sufficient occurrences to be included in the statistical analysis. The null hypothesis stated that Swainson's hawks and other raptor species used each habitat for foraging in proportion to its availability in the survey area. Therefore, only behaviors that represented foraging were included in the analysis. For Swainson's hawk, only circling below 100 meters, the typical foraging behavior of Swainson's hawks, kiting/hovering, and prey capture attempts were included as foraging behaviors. Perching behavior was excluded because the species does not typically hunt from a perch. Perching was included as a foraging behavior for red-tailed hawk and American kestrel, species that often hunt from perches. Hypothesis testing for selection of foraging habitat consisted of a chi- square test for goodness of fit, followed by chi-square testing of individual types to determine if use was disproportionate to availability and whether it was positively or negatively correlated. While this approach may be regarded as very conservative compared with other more robust statistical tests used in habitat use/availability studies, it was considered appropriate to address the rather narrow objectives (use of solar array fields) of this one-year study.

Stationary Observation Points

In addition to the road transect surveys, surveys were also conducted from stationary observation points around the perimeter of the three solar arrays. The purpose of these surveys was to document additional use of the solar fields by all raptor species and to increase the opportunity to record prey captures or prey capture attempts, which are generally less frequently observed during road transect surveys. Stationary observation point surveys were conducted at all three solar projects once per week in a rotational sequence between May 7 and August 28 for a total of 17 separate four-hour observation periods.

Results and Discussion

Habitats and Land Cover Types within the Survey Area

Table 1 presents the types and corresponding acreages of land cover/habitat types within the survey area. Figures 3a,b, and c illustrate the distribution of these types along the survey route. The land use along the approximately 26-mile route and throughout much of the south Sacramento County area consists of a mixture of grazing lands in the form of both irrigated and non-irrigated pasturelands and cultivated lands. Of the 3,794 acres within the survey area, 80 percent are active agricultural types including irrigated and non-irrigated pasturelands (31 percent), seasonally or annually cultivated crops (32 percent), semi-perennial hays (10.6 percent), and perennial crops (6.5 percent). The remaining 20 percent of the land uses consist of urban/ruderal (10.8 percent),

LEGEND

- Survey Route
- Survey Area (1,200' total width)
- Solar Facility — 199 Ac.

KEY TO VEGETATION TYPES

- Irrigated Pasture — 381 Ac.
- Oats — 430 Ac.
- Dry Pasture — 48 Ac.
- Alfalfa — 153 Ac.
- Ruderal/Urban — 180 Ac.
- Wheat — 49 Ac.
- Tilled — 32 Ac.
- Vineyard — 161 Ac.
- Grass — 17 Ac.
- Other Row/Grain Crop — 6 Ac.

CONVERTED LAND USE

- Wheat to Corn — 38 Ac.
- Oats to Corn — 17 Ac.
- Tilled to Corn
- Tilled to Vineyard — 36 Ac.

RE KAMMERER SGF

RE BRUCEVILLE SGF

MATCH LINE (see Map 2b)

KAMMERER RD

ESCHINGER RD

ROAD

PACIFIC BLVD

Landing Strip

Pleasant BM 16

Bruceville

R5E R6E

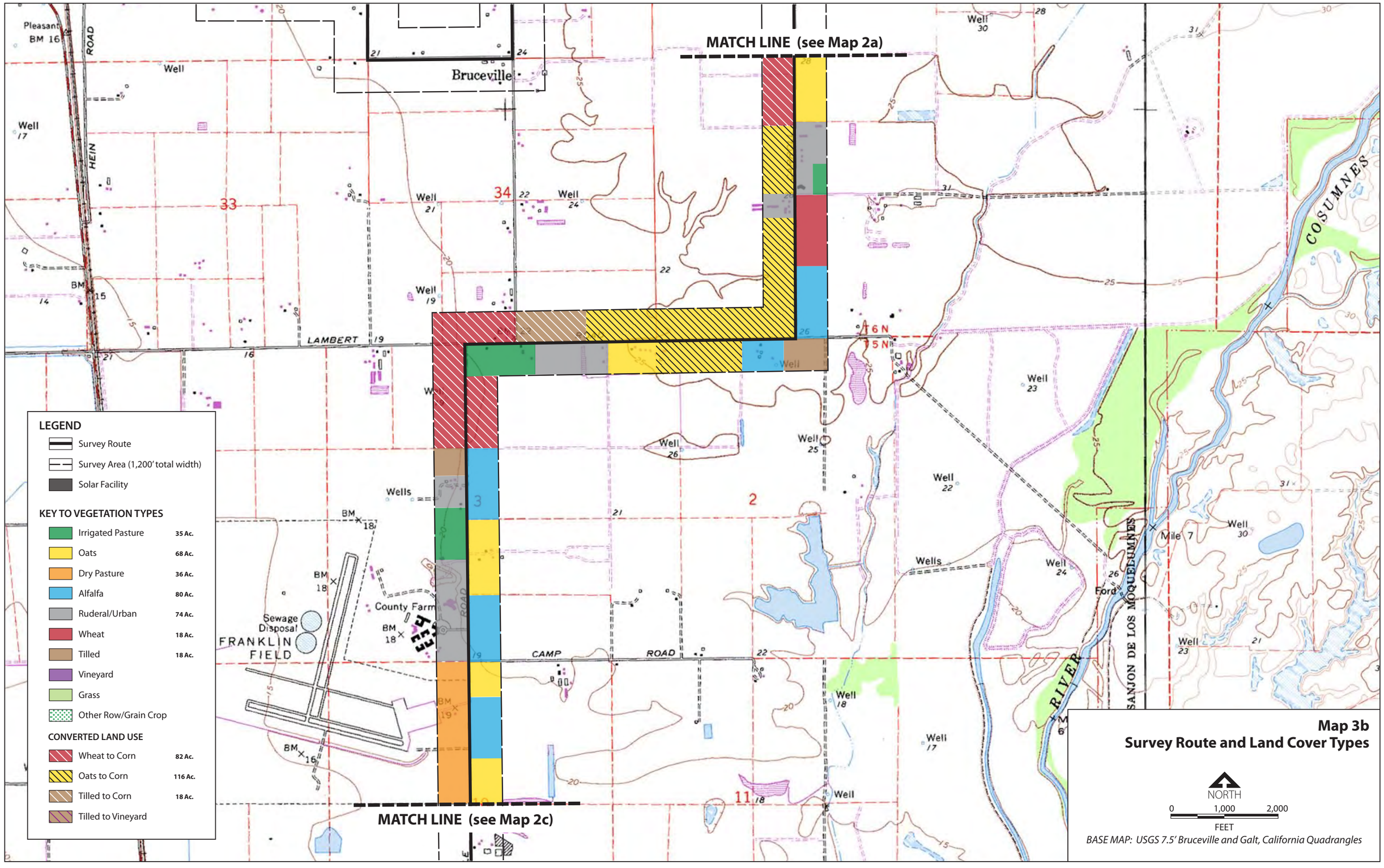
Map 3a
Survey Route and Land Cover Types

NORTH

0 1,000 2,000

FEET

BASE MAP: USGS 7.5' Bruceville and Galt, California Quadrangles



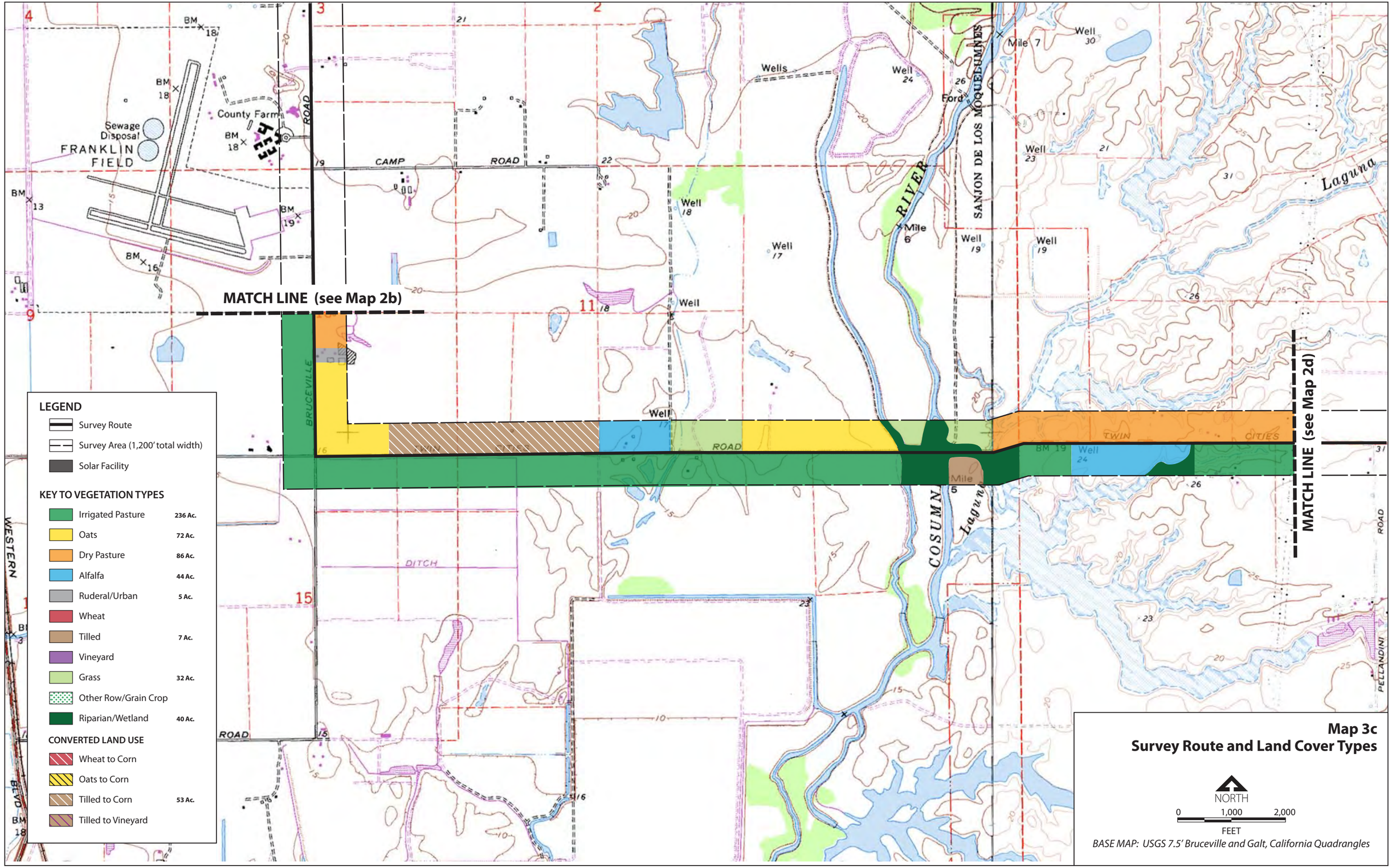
Map 3b
Survey Route and Land Cover Types

NORTH

0 1,000 2,000

FEET

BASE MAP: USGS 7.5' Bruceville and Galt, California Quadrangles



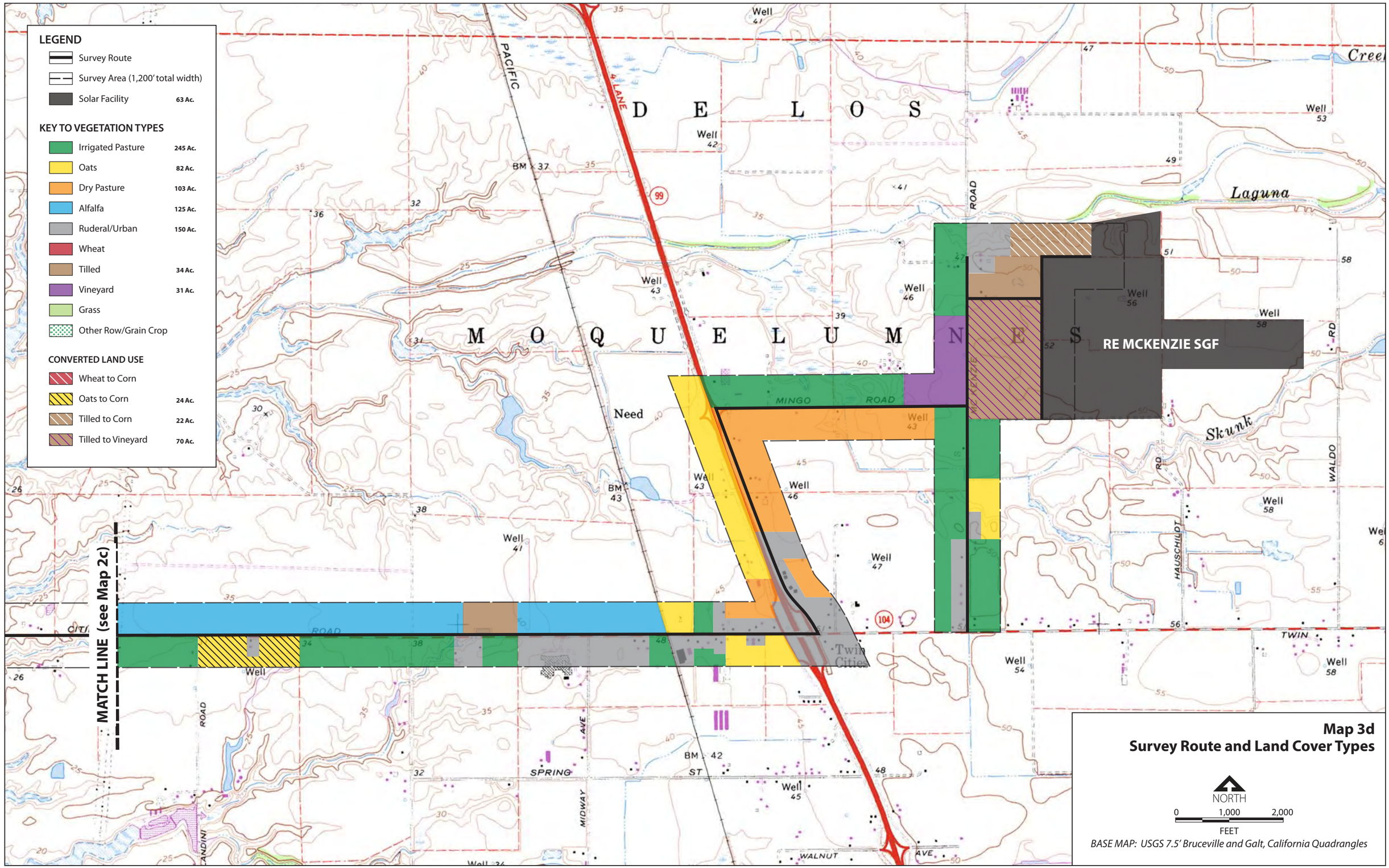
Map 3c
Survey Route and Land Cover Types

NORTH

0 1,000 2,000

FEET

BASE MAP: USGS 7.5' Bruceville and Galt, California Quadrangles


LEGEND
Survey Route
Survey Area (1,200' total width)
Solar Facility 63 Ac.
KEY TO VEGETATION TYPES
Irrigated Pasture 245 Ac.
Oats 82 Ac.
Dry Pasture 103 Ac.
Alfalfa 125 Ac.
Ruderal/Urban 150 Ac.
Wheat
Tilled 34 Ac.
Vineyard 31 Ac.
Grass
Other Row/Grain Crop
CONVERTED LAND USE
Wheat to Corn
Oats to Corn 24 Ac.
Tilled to Corn 22 Ac.
Tilled to Vineyard 70 Ac.
MATCH LINE (see Map 2c)
RE MCKENZIE SGF
D E L O S
M O Q U E L U M N E S
PACIFIC
4 LANE
99
104
MINGO ROAD
ROAD
SPRING ST
AVE
MIDWAY
WALNUT AVE
HAUSCHILDT RD
WALDO RD
Laguna
Skunk
TWIN
Twin Cities
Need
BM 43
BM 42
Well
Map 3d
Survey Route and Land Cover Types
NORTH
0 1,000 2,000
FEET
BASE MAP: USGS 7.5' Bruceville and Galt, California Quadrangles

uncultivated grassland (1.3 percent), riparian (1.1 percent), and solar array fields (6.9 percent).

Table 1. Land cover/habitat types and corresponding acreages within the survey area.

Land Use Type	Acres	Percent of Total
Irrigated Pasture	897	23.6
Oats	730	19.2
Ruderal/Urban	409	10.8
Alfalfa	402	10.6
Dry Pasture	273	7.2
Solar Array Field	262	6.9
Vineyard	245	6.5
Tilled	180	4.7
Corn	174	4.6
Wheat	127	3.3
Grass	49	1.3
Riparian	40	1.1
Other Row/Grain Crop	6	0.2
Total	3,794	100

Irrigated and Non-irrigated Pasturelands. Irrigated pasture is the most common land use type in the survey area comprising nearly one-quarter of the survey area. These pastures are planted with grasses (e.g., bromes, ryegrass), irrigated, and grazed by livestock. They may be periodically cultivated and replanted. Non-irrigated, or dry pastures are uncultivated natural grasslands that are grazed by livestock. Both types are used by Swainson's hawks and other foraging raptors but are considered to have only moderate value due to low rodent prey populations compared to some cultivated lands (Estep 1989, 2009).

Seasonally or Annually Cultivated Crops. Within the survey area, these include oat hay, corn, and wheat crops, much of which is grown as silage to support local dairy operations. Tilled lands are cultivated lands that are between plantings and were included as a separate type because most of these areas were in a tilled condition for approximately one-half of the survey period before being planted to corn, which is often planted later in the season. These crops have variable suitability as foraging habitat depending on vegetation height and density, which influences prey accessibility (Bechard 1982, Estep 2009). Of the types found in the survey area, oat hay likely provides the highest value due to large rodent prey populations and relatively early harvest, which increases prey accessibility. After cutting, oat fields may continue to provide foraging value if the field is not disked and prepared for the following planting.

Semi-Perennial Hays. These are alfalfa hay fields that remain uncultivated for at least 3 consecutive years. During the spring and summer months, alfalfa fields are mowed approximately once per month and may be irrigated as frequently as once per week. This

is considered a high value foraging crop type for Swainson's hawk and other raptors because of the lack of seasonal or annual cultivation and because the regular mowing and irrigation operations increase prey accessibility (Estep 2009).

Perennial Crops. The only perennial crop type in the survey area is vineyards. While some use by Swainson's hawks has been documented (Swolgaard et al 2008), vineyards are generally considered to have very low foraging value because as they mature, the vegetation becomes tall and dense and largely precludes foraging access (Estep 1989).

Urban/Ruderal. Rural farm and ranch residences and associated out-buildings, dairy facilities, and other farming and ranching facilities occur along the survey route. Ruderal weedy or grassy patches also occur within or adjacent to some of the developed areas. While these areas provide relatively little foraging value, they may receive raptor activity in the form of perching, and where suitable trees or utility poles occur around their perimeter.

Uncultivated Grassland and Riparian. The survey route crosses the flood plain of the Cosumnes River where a small amount of riparian and associated uncultivated grassland were documented. The riparian forest in this area supports high value nesting habitat but would not typically be used for foraging by raptor species documented during the survey with the exception of the red-shouldered hawk. The small patches of grasslands may be used by foraging raptors, but usually do not support the prey abundance and accessibility compared with open, cultivated lands.

Solar Array Fields. A description of the three Recurrent solar fields is provided in the Introduction section. In addition to the Bruceville, Kammerer, and McKenzie solar projects, two other solar energy projects occur along the survey route and were incorporated into the survey area (Figure 3)

Strip Transect Road Surveys

A total of 975 raptor occurrences were documented within the survey area. Three of the seven documented species, Swainson's hawk, red-tailed hawk, and American kestrel comprised 91 percent of the total occurrences. Swainson's hawk comprised nearly 40 percent of the total occurrences (Table 2).

Table 3 indicates the number of occurrences by species within each habitat or land cover type. Five of the 14 habitat/land cover types, oats, alfalfa, solar field, tilled, and irrigated pasture, comprised 73.2 percent of all occurrences. Over 14 percent of all documented occurrences and 13 percent of all Swainson's hawk occurrences were in solar fields. Thirty percent of all American kestrel occurrences were in solar fields.

Table 2. Species occurrences documented within the survey area.

Species	Number of Occurrences	Percent of Total
Swainson's hawk	375	38.5
Red-tailed hawk	304	31.2
American kestrel	207	21.2
Northern harrier	38	3.9
White-tailed kite	30	3.1
Red-shouldered hawk	17	1.7
Osprey	4	0.4
Total	975	100

Table 3. Species occurrences documented within each habitat/land cover type.

	SWHA	RTHA	AMKE	NOHA	WTKI	RSHA	OSPR	Total	% of Total
Oats	86	40	21	6	11	1	0	165	16.9
Alfalfa	73	40	33	9	1	0	0	156	16.0
Solar field	49	17	61	12	0	0	1	140	14.4
Tilled	48	53	37	0	0	2	1	130	13.3
Irr. pasture	50	57	8	1	1	5	1	123	12.6
Dry pasture	6	40	3	0	4	2	1	56	5.7
Rural/Urban	17	13	16	4	8	2	0	56	5.7
Field edge*	11	6	9	0	3	4	0	33	3.4
Vineyard	12	14	10	5	0	0	0	41	3.2
Corn	7	21	7	1	1	0	0	37	3.8
Wheat	5	2	2	0	0	1	0	10	1.0
Grass	6	1	0	0	1	0	0	8	0.8
Riparian	5	0	0	0	0	0	0	5	0.5
Misc. row crop	0	0	0	0	0	0	0	0	0
Total	375	304	207	38	30	17	4	975	100

SWHA = Swainson's hawk; RTHA = red-tailed hawk; AMKE = American kestrel; NOHA = northern harrier; WTKE = white-tailed kite; RSHA = red-shouldered hawk; OSPR = osprey.
*Field or road edge was not a mapped habitat type, so these data are not included in the statistical analysis.

Tables 4, 5, and 6 show the behaviors associated with each occurrence in each habitat/land cover type for the Swainson's hawk, red-tailed hawk, and American kestrel, respectively. Swainson's hawks (Table 4) generally spend less time perching, particularly while foraging, than do red-tailed hawks and American kestrels, species that often hunt from perches. Typical hunting behavior of Swainson's hawk is a circling flight at an altitude less than 100 meters. The largest proportion of Swainson's hawk occurrences (48 percent) were of circling flights below 100 meters. In contrast, the largest proportion of Red-tailed hawk and American kestrel occurrences (75 percent and 64 percent, respectively) were of perching individuals (Tables 5 and 6).

Table 4. Swainson's hawk behaviors – all occurrences

	Behaviors									
	P	**S**	**C**	**F**	**CA**	**CS**	**CU**	**G**	**K**	total
Oats	13	11	43	2	1	1	2	10	3	86
Irrigated pasture	10	9	26	2				1	1	49
Solar field	8	9	29	2					1	49
Alfalfa	17	8	27		1	3	3	14		73
Tilled	10	1	21	1		4	1	9	1	48
Wheat	1	1	2	0				1		5
Vineyard	1		10	1						12
Corn	3		4							7
Field edge	7	1	4							12
Grass	3		2					1		6
Ruderal/Urban	6		8	1	1				1	17
Dry pasture	2		3	1						6
Riparian	3		2							5
Misc. row crops										0
Total	84	40	181	10	3	8	6	36	7	375

P = perching; S = soaring below 200 m; C = circling below 100 meters; F = Flying below 200 meters; CA = prey capture attempt; CS = prey capture successful; CU = prey capture unsuccessful; G = standing on the ground; K = kiting/hovering.

Table 5. Red-tailed hawk behaviors – all occurrences

	Behaviors									
	P	**S**	**C**	**F**	**CA**	**CS**	**CU**	**G**	**K**	total
Oats	31		6					3		40
Irrigated pasture	51		5							56
Solar field	3	3	10		1					17
Alfalfa	25	1	7	4	1			3		41
Tilled	40		9	1	1			2		53
Wheat	1		1							2
Vineyard	9	1	4							14
Corn	16		4				1			21
Field edge	4			1				1		6
Grass	1									1
Ruderal/Urban	11		2							13
Dry pasture	36		3				1			40
Riparian										0
Misc. row crops										0
Total	228	5	51	6	3		2	9		304

P = perching; S = soaring below 200 m; C = circling below 100 meters; F = Flying below 200 meters; CA = prey capture attempt; CS = prey capture successful; CU = prey capture unsuccessful; G = standing on the ground; K = kiting/hovering.

Table 6. American kestrel behaviors – all occurrences

	Behaviors									
	P	**S**	**C**	**F**	**CA**	**CS**	**CU**	**G**	**K**	total
Oats	11		2	1	1	2	1		2	20
Irrigated pasture	6						2			8
Solar field	36	1	13	6	3		1		2	62
Alfalfa	19		2	2	2	3	1	1	3	33
Tilled	26		1	2	1		1		5	36
Wheat	2									2
Vineyard	10									10
Corn	7			1						8
Field edge	5		3	1						9
Grass										0
Ruderal/Urban	9		2	2			1		2	16
Dry pasture	2			1						3
Riparian										0
Misc. row crops										0
Total	133	1	23	16	7	5	7	1	14	207

P = perching; S = soaring below 200 m; C = circling below 100 meters; F = Flying below 200 meters; CA = prey capture attempt; CS = prey capture successful; CU = prey capture unsuccessful; G = standing on the ground; K = kiting/hovering.

To examine the extent of foraging within solar fields and to evaluate the foraging use of solar fields and other habitats/land use types relative to their availability within the survey area, those behaviors that were considered foraging behaviors were isolated from the total occurrences and used in the statistical analysis. For the Swainson's hawk this included the following behaviors:

- Circling below 100 meters
- Kiting/Hovering
- Standing on ground
- Prey capture (attempt, successful, unsuccessful)

For the red-tailed hawk and American kestrel, perching was also included as a foraging behavior. Note that with the exception of prey capture types and kiting/hoving, the remaining behaviors could be attributed to activities other than foraging. However, these are the primary foraging techniques of these species, and including them provides a reasonable estimation of foraging use for purposes of a comparative analysis.

Swainson's Hawk

Table 7 shows the relationship between foraging occurrences and habitat/land use type acreages for Swainson's hawk. Seventy-four percent of the foraging occurrences were in oat, alfalfa, tilled, and solar fields. A total of 12.8 percent of the foraging occurrences were in solar fields, which included only seven percent of the available habitat within the survey area.

Table 7. Swainson's hawk foraging occurrences within each habitat/land use type.

Land Use Type	Acres	Percent of Total	SWHA Foraging Observations	Percent of Total
Solar Array Field	262	7.0	30	12.8
Irrigated Pasture	897	23.9	28	11.9
Oats	730	19.5	60	25.5
Dry Pasture	273	7.3	3	1.3
Alfalfa	402	10.7	48	20.4
Ruderal/Urban	409	10.9	10	4.3
Corn	174	4.6	4	1.7
Wheat	127	3.4	3	1.3
Tilled	180	4.8	36	15.3
Vineyard	245	6.5	10	4.3
Grass	49	1.3	3	1.3
Other Crops	6	0.2	0	0
	3,754	100	235	100

The first chi-square test determines whether or not foraging use was in proportion to the availability of the habitats/land cover types in the survey area. As expected, the pattern of use indicated a high degree of habitat selectively and thus the null hypothesis was rejected ($\chi^2_{11.d.f.= 24.72}$ $P<0.01$) (Table 8). In other words, Swainson's hawks are selecting or avoiding specific crop or land cover types for foraging. Next, the contribution of the individual types are evaluated with regard to their significant contribution (positive or negative) to the chi-square determination (yellow highlighting). Those with an observed use that exceeds the expected use, have a significant positive contribution (orange highlighting) and those with an expected use that exceeds the observed use have a significant negative contribution (blue highlighting) ($\chi^2_{1.d.f.= 3.84}$ $P<0.05$). In other words, Table 8 indicates that Swainson's hawks appear to be using solar array fields, oats, alfalfa, and tilled fields at a significantly greater frequency than would be expected relative to their availability in the survey area.

Some caution is needed when interpreting these results. While the results indicate that habitat/land cover types overall are not used in proportion to their availability and that certain types have a significant contribution to this result, it does not necessarily indicate that those that do not have a significant contribution or that have a significant negative association have less overall value. For example, irrigated pasture accounted for the fifth highest number of Swainson's hawk foraging occurrences, but because irrigated pasture was particularly common within the survey area, the expected use exceeded the observed use. So while it does not appear to have been selected over other land cover types or used in proportion to its availability, 12 percent of all documented Swainson's hawk foraging occurred in irrigated pastures, and therefore this type, regardless of its availability or use, clearly has foraging value to this species.

Table 8. Chi-square values for Swainson's hawk.

Land Use Type	Available Habitat (%)	Observed Use of Habitat (Frequency)	Expected Use of Habitat (Frequency)	Chi-square Contribution
Solar Array Field	7.0	30	16.45	11.16
Irrigated Pasture	23.9	28	56.17	14.13
Oats	19.5	60	45.83	4.38
Dry Pasture	7.3	3	17.12	11.65
Alfalfa	10.7	48	25.15	20.76
Ruderal/Urban	10.9	10	25.62	9.52
Corn	4.6	4	10.81	4.29
Wheat	3.4	3	7.99	3.12
Tilled	4.8	36	11.28	54.17
Vineyard	6.5	10	15.28	1.82
Grass	1.3	3	3.06	0.001
Other Crops	0.2	0	0.47	0.47
	100	235	235	135.47*

*135.47 represents the sample statistic in the chi-square analysis. To be considered significant, this value must exceed the Critical Value (24.72, P<0.01).

Red-tailed Hawk

Table 9 shows the relationship between foraging occurrences and habitat/land use type acreages for red-tailed hawk. Five types made up 77.2 percent of the foraging occurrences, irrigated pasture, tilled fields, dry pasture, alfalfa, and oats. Only 14 (5 percent) of red-tailed hawk occurrences were in solar fields.

Table 9. Red-tailed hawk foraging occurrences within each habitat/land use type.

Land Use Type	Acres	Percent of Total	RTHA Foraging Observations	Percent of Total
Solar Array Field	262	7.0	14	5.0
Irrigated Pasture	897	23.9	56	20.0
Oats	731	19.5	37	13.2
Dry Pasture	273	7.3	40	14.3
Alfalfa	402	10.7	36	12.9
Ruderal/Urban	409	10.9	13	4.6
Corn	174	4.6	21	7.5
Wheat	127	3.4	2	0.7
Tilled	180	4.8	47	16.8
Vineyard	245	6.5	13	4.6
Grass	49	1.3	1	0.4
Other Crops	6	0.2	0	0
	3,755	100	280	100

As expected, the pattern of use for red-tailed hawk also indicated a high degree of habitat selectively and thus the null hypothesis was rejected ($\chi^2_{11.d.f.= 24.72}$ $P<0.01$) (Table 10). The contribution of the individual types indicated that dry pasture, corn fields, and tilled fields were used significantly more than their relative availability and oats, ruderal/urban, and wheat were used significantly less than their relative availability ($\chi^2_{1.d.f.= 3.84}$ $P<0.05$).

As noted above, lack of a significant contribution or a significant negative contribution does not necessarily indicate lack of value. For example, over 13 percent of red-tailed hawk foraging occurrences were in oat fields, but because oat fields were particularly common within the survey area, the expected use exceeded the observed use. But despite the significant negative contribution to the sample statistic (Table 10) oat fields clearly have foraging value to this species. Similarly for alfalfa, while the extent of foraging occurrences did not significantly contribute to rejecting the null hypothesis, 13 percent of the foraging occurrences were in alfalfa, suggesting that regardless of its use relative to its availability, alfalfa fields also have foraging value to this species.

Table 10. Chi-square values for red-tailed hawk.

Land Use Type	Available Habitat (%)	Observed Use of Habitat (Frequency)	Expected Use of Habitat (Frequency)	Chi-square Contribution
Solar Array Field	7.0	14	19.6	1.6
Irrigated Pasture	23.9	56	66.9	1.9
Oats	19.5	37	54.6	5.7
Dry Pasture	7.3	40	20.4	18.8
Alfalfa	10.7	36	30.0	1.2
Ruderal/Urban	10.9	13	30.5	10.0
Corn	4.6	21	9.6	13.5
Wheat	3.4	2	9.5	5.9
Tilled	4.8	47	13.4	84.3
Vineyard	6.5	13	18.7	1.7
Grass	1.3	1	3.6	1.9
Other Crops	0.2	0	0.5	0.5
	100	280	280	147

*147 represents the sample statistic in the chi-square analysis. To be considered significant, this value must exceed the Critical Value (24.72, $P<0.01$).

American Kestrel

Table 11 shows the relationship between foraging occurrences and habitat/land use type acreages for American kestrel. Three types made up 62.2 percent of the foraging occurrences, solar array fields, alfalfa, and tilled fields. Nearly 17 percent of all foraging occurrences were in solar fields.

Table 11. American kestrel foraging occurrences within each habitat/land use type.

Land Use Type	Acres	Percent of Total	AMKE Foraging Observations	Percent of Total
Solar Array Field	262	7.0	55	30.7
Irrigated Pasture	897	23.9	8	4.5
Oats	731	19.5	19	10.6
Dry Pasture	273	7.3	2	1.1
Alfalfa	402	10.7	31	17.3
Ruderal/Urban	409	10.9	16	8.9
Corn	174	4.6	7	3.9
Wheat	127	3.4	2	1.1
Tilled	180	4.8	29	16.2
Vineyard	245	6.5	10	5.6
Grass	49	1.3	0	0
Other Crops	6	0.2	0	0
	3,755	100	179	100

The pattern of use for American kestrel also indicated a high degree of habitat selectively and thus the null hypothesis was rejected ($\chi^2_{11.d.f.= 24.72}$ $P<0.01$) (Table 12). The contribution of the individual types indicated that solar fields, alfalfa, and tilled fields were used significantly more than their relative availability, and irrigated pasture, oats, and dry pasture were used significantly less than their relative availability ($\chi^2_{1.d.f.= 3.84}$ $P<0.05$).

Foraging use of solar fields by American kestrels was particularly high due mainly to the high proportion of perching occurrences (58 percent) (Table 6). The solar panels and the perimeter fence provided excellent perching habitat for kestrels.

Table 12. Chi-square values for American kestrel.

Land Use Type	Available Habitat (%)	Observed Use of Habitat (Frequency)	Expected Use of Habitat (Frequency)	Chi-square Contribution
Solar Array Field	7.0	55	12.5	144.5
Irrigated Pasture	23.9	8	42.8	28.3
Oats	19.5	19	34.9	7.2
Dry Pasture	7.3	2	13.1	9.4
Alfalfa	10.7	31	19.2	7.3
Ruderal/Urban	10.9	16	19.5	0.6
Corn	4.6	7	8.2	0.2
Wheat	3.4	2	6.1	2.8
Tilled	4.8	29	8.6	48.4
Vineyard	6.5	10	11.6	0.2
Grass	1.3	0	2.3	2.3
Other Crops	0.2	0	0.4	0.4
	100	179	179	251.6

*251.6 represents the sample statistic in the chi-square analysis. To be considered significant, this value must exceed the Critical Value (24.72, P<0.01).

Stationary Observation Points

Using the same definition for foraging behavior as was used during the driving transect surveys, Table 13 indicates that the majority of occurrences in solar fields during the stationary observation surveys were of foraging birds (74 percent). A total of 148 foraging occurrences were documented during the 68 hours ours of observation. Sixty-nine of these (47 percent) were of Swainson's hawks, 64 percent of which were foraging observations.

Table 14 shows the different behaviors of each species within the solar fields. Nearly 10 percent of the total foraging occurrences and over 7 percent of the Swainson's hawk foraging occurrences were prey captures or prey capture attempts.

Table 13. Total number of occurrences and the proportion of foraging occurrences in solar fields for all species observed.

Species	Total occurrences	Foraging occurrences	Percent Foraging occurrences
Swainson's hawk	108	69	63.9
Red-tailed hawk	23	23	100
American kestrel	58	48	82.8
Northern harrier	10	8	80
Total	199	148	74.4

Table 14. Behaviors in solar fields (all species). Foraging behaviors are highlighted.

	Behaviors								
	P	**S**	**C**	**K**	**F**	**G**	**CA**	**CS**	**CU**
SWHA		38	62	2	1		3	1	1
RTHA	2		19		1		1		
AMKE	32		5	2	10	2	2	2	3
NOHA	2				7		1		
Total	36	38	86	4	19	2	7	3	4

P = perching; S = soaring below 200 m; C = circling below 100 meters; F = Flying below 200 meters; CA = prey capture attempt; CS = prey capture successful; CU = prey capture unsuccessful; G = standing on the ground; K = kiting/hovering. SWHA = Swainson's hawk; RTHA = red-tailed hawk; AMKE = American kestrel; NOHA = northern harrier.

Conclusions

1. Swainson's hawks use and forage within managed solar array fields. The results of the driving transect surveys and the stationary observation point surveys indicate foraging use of the solar array fields by Swainson's hawks and other raptors. While it is difficult to observe the precise locations of prey capture attempts in solar array fields due to their height, the rows of solar trackers may not preclude foraging in the open grasslands between them. However, foraging hawks may also be focused primarily on the wider spaces between the sub-areas within the projects and around the perimeter of the projects. Of key importance is the management of a grassland substrate to promote rodent populations and maintaining this substrate at a height that promotes visibility and access to prey. Unlike most crop types, this condition is available in solar fields throughout the spring and summer breeding season, and thus provides a consistent and available source of prey. Many crop types, while important in the overall agricultural matrix, may be available for a relatively short period of time during the breeding season due to the planting, growth, and harvesting regime.

2. Swainson's hawk foraging use of solar array fields exceeds what would be expected based on their availability. This suggests that not only were the solar array fields being used by foraging Swainson's hawks, but that they were being selectively used at greater frequency than some of the other habitats/land cover types in the survey area.

3. Within the diverse agricultural landscape of the study area, the presence of the managed solar array fields (i.e., managed grassland substrate) did not appear to negatively affect the Swainson's hawk and other raptors. The solar array fields were used for foraging similarly to other moderate to high value agricultural cover types and their presence did not appear to affect the overall use of the landscape by Swainson's hawks or other raptors. As one element of an otherwise diverse agricultural matrix, the solar array fields provided a consistent and an apparently reasonably accessible source of prey, particularly for Swainson's hawks and American kestrels. However, this outcome should be viewed with some caution in that while this study indicated a positive

relationship, only 7 percent of the survey area was solar array field. How raptors might respond if this proportion was greater is unknown. Despite the generally positive relationship found in this study, there is likely a threshold that would begin to indicate a more negative outcome as the increase of solar array fields, like that of any single land cover type, affects the diversity of the agricultural landscape.

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