U.S. Fish & Wildlife Service

Water Resource Inventory and Assessment

Ellicott Slough National Wildlife Refuge

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The mission of the National Wildlife Refuge System is to administer a national network of lands and waters for the conservation, management, and, where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans.

Front cover photograph of Calabasas Pond; back cover photograph of California red-legged frog at Prospect Pond
USFWS

Water Resource Inventory and Assessment

Ellicott Slough National Wildlife Refuge

California

Prepared by

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Abbreviations

°F	degrees Fahrenheit
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
AB	Assembly Bill
AET	actual evapotranspiration
BCC_CSM	Beijing Climate Center China Meteorological Administration Model
BCCR_BCM2	Bergen Climate Model Version 2
BCM	Basin Characterization Model
BMP	basin management plan
CADWR	California Department of Water Resources
CAP	contaminant assessment process
CASGEM	California Statewide Groundwater Elevation Monitoring
CCC	criterion continuous concentration
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CEDEN	California Environmental Data Exchange Network
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
CL-	Climate
cm	centimeter
CRLF	California red-legged frog
CSIRO	Commonwealth Scientific and Industrial Research Organization
CTS	California tiger salamander
CVP	Central Valley Project
CWD	climatic water deficit
DEM	digital elevation model
DPR	Department of Pesticide Regulation
E. coli	Escherichia coli
ECDMS	Environmental Contaminants Data Management System
ENSO	El Niño–Southern Oscillation
Eto	reference evapotranspiration
eWRIMS	Electronic Water Rights Information Management System
GAMA	Groundwater Ambient Monitoring and Assessment Program
GCM	General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GHCN	Global Historical Climatology Network

GIS	Geographic Information System
GW-	Groundwater
HAB-	Habitat
HEC-HMS	U.S. Army Corps of Engineers Hydrologic Engineering Center Hydrologic Modeling System
HS Pump	Harkins Slough Flood Control Pump
HSBV	Harkins Slough at Buena Vista Road
HUC-8	Hydrologic Unit Code 8
I&M	Inventory and Monitoring
IOC	issue of concern
IRWMP	Integrated Regional Water Management Planning
MIROC Medres	Model for Interdisciplinary Research on Climate
MPN	most probable number
NHD	National Hydrography Dataset
NWI	National Wetlands Inventory
NWIS	National Water Information System
PCM	Parallel Climate Model General Circulation Model
PCS	Permit Compliance System
PDO	Pacific Decadal Oscillation
PDSI	Palmer Drought Severity Index
PET	potential evapotranspiration
PNA	Pacific North American pattern
PRG	Preliminary Remediation Goals
PRISM	Parameter-Elevation Regressions on Independent Slopes Model
PVGB	Pajaro Valley Groundwater Basin
PVIGSM	Pajaro Valley Integrated Ground and Surface Water Model
PVWMA	Pajaro Valley Water Management Agency
RCP	Representative Concentration Pathways
RCRAInfo	Resource Conservation and Recovery Act Information
Rec-	Recommendation
Refuge System	National Wildlife Refuge System
Region 8	Pacific Southwest Region
RHI	region of hydrologic influence
SB	Senate Bill
SCCIRWMD	Santa Cruz County Integrated Regional Water Management District
SCLTS	Santa Cruz long-toed salamander
Service	U.S. Fish and Wildlife Service
SOI	Southern Oscillation Index
SSURGO	Soil Survey Geographic Database
SW-	Surface Water
SWP	State Water Project
SWRCB	California State Water Resources Control Board
TDS	total dissolved solids
TMDL	total maximum daily load

TRI	Toxic Release Inventory
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
USHCN	United States Historic Climatology Network
WDL	Water Data Library
WE-	Water Entitlements
WQ-	Water Quality
WRB	Water Resources Branch
WRIA	water resource inventory and assessment
WRMN	Water Resources Monitoring Network

Executive Summary

This water resource inventory and assessment summary report for Ellicott Slough National Wildlife Refuge describes current hydrologic information; identifies water resource needs and issues of concern; and makes recommendations for research, coordination, and monitoring to improve refuge management and decisionmaking. Characterization of refuge water resources included the following major subject areas:

- water entitlements and policy
- climate
- surface water
- groundwater
- water-related habitats
- water management and infrastructure
- soils
- water quality

Located in the Pajaro Valley of Santa Cruz County, the refuge is south of the city of Santa Cruz and northwest of the city of Watsonville. Encompassing 315.55 acres and a 289-acre managed inholding, the refuge includes the Ellicott Unit, Calabasas Unit, Harkins Slough Unit, and the Buena Vista Property (the aforementioned managed inholding; figure 1 and appendix A, figure A1).

The primary purpose of ephemeral refuge ponds within the Calabasas Unit, Ellicott Unit, and Buena Vista Property is to provide breeding and recruitment habitat for the endangered Santa Cruz long-toed salamander (*Ambystoma macrodactylum croceum*), California tiger salamander (*Ambystoma californiense*), and California red-legged frog (*Rana draytonii*). These refuge breeding ponds are located mostly in headwater basins that have relatively natural drainage patterns (unaffected by dams, diversions, or water regulation); water eventually drains to sloughs or to the Pacific Ocean. Water management of breeding ponds includes periodic maintenance of pond water levels (occurring at Calabasas Pond in the Calabasas Unit and Prospect Pond in the Ellicott Unit) and periodic supplementation with pumped groundwater (occurring at Ellicott and Prospect Ponds in the Ellicott Unit) to support and promote amphibian recruitment.

The Harkins Slough Unit, Calabasas Unit, and the eastern portion of the Buena Vista Property within the Pajaro River Watershed are within the larger Watsonville Slough system. This system flows southwest and then south before confluence with the Pajaro River, Monterey Bay, and Pacific Ocean. The region surrounding Watsonville Slough used to contain a much more extensive wetland and estuarine complex, but it has since been modified to meet the needs of adjacent agricultural and urban land uses. There is currently no active water management of Harkins Slough by refuge operations.

Highlighted Water Resources Issues of Concern

Water Entitlements and Policy

- The water right at Calabasas Pond in the Calabasas Unit has a purpose of use (recreation) that does not match its current use (fish and wildlife enhancement), and actual water use is not being measured at the current time. Furthermore, it is uncertain whether water use for managed breeding ponds should be reported to the State of California because the capacity and use of water in these ponds are not known. These issues could put the refuge at a disadvantage if there are water rights disputes or audits in the future.
- Ellicott Slough National Wildlife Refuge is located in the Pajaro Valley Groundwater Basin, which is designated as a high priority basin in overdraft; this means that groundwater regulations may be enforced for the basin in the future to comply with California

groundwater legislation. Groundwater use inspections, monitoring and reporting, curtailment, and fees may be imposed on the refuge in the future to ensure compliance.

Climate

- Climate change models showed that increases in mean temperatures (0.3–6.3 degrees Fahrenheit) and potential evapotranspiration (0–8.2 percent) result in an increase in climatic water deficit (water demand required to meet existing habitat needs) by 144.1–477.1 acre-feet per year by 2100. This issue would probably be of the greatest concern for the Ellicott Unit, Buena Vista Property, and Calabasas Unit, which all require specific water supplies to maintain breeding ponds. Groundwater use may be required to offset these water losses. However, the impacts of these changes are unknown because refuge water quantity requirements have not been determined.
- Sea level rise as a result of climate change has the potential to increase the frequency and magnitude of seawater intrusion into the Watsonville Slough system, including Harkins Slough (which is currently a freshwater slough). The impacts of seawater intrusion and salinity increases on refuge biological objectives are not known at this time.
- Mean water levels in Harkins Slough might change between -0.7 and +3.0 feet (by 2050 and 2100, respectively) as a result of sea level rise and other water management events. The impacts of these changes on refuge biological objectives are not known at this time.

Surface Water

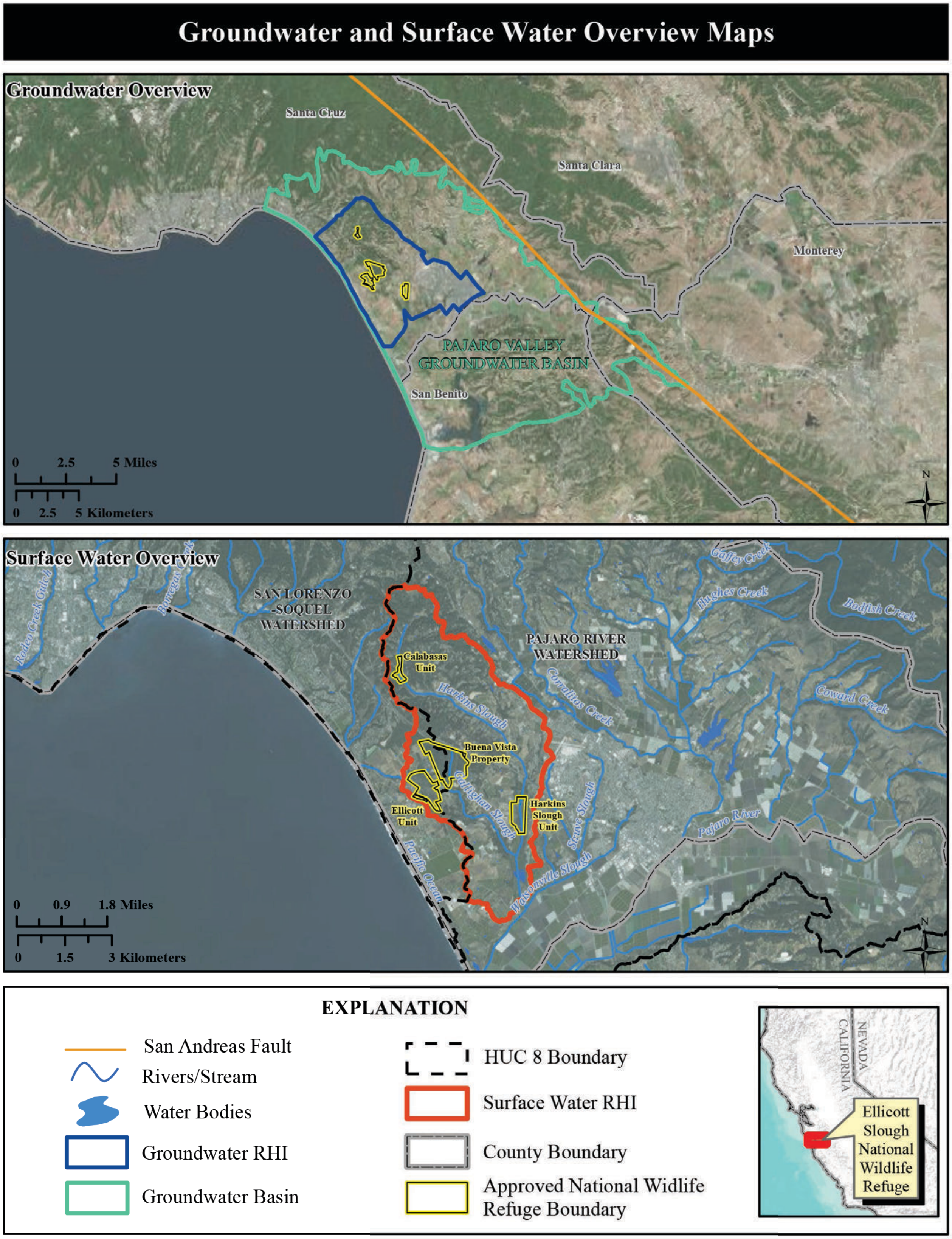
- Managed properly, intermittent storm events could help easily fill Calabasas Pond and other ponds, although too much water could damage infrastructure and temporarily damage habitats.

Groundwater

- Because groundwater pumping is in excess of recharge, water levels in the Pajaro Valley Groundwater Basin have been generally decreasing, and drought conditions have greatly affected groundwater levels in the aquifer of the region. However, the impacts of these conditions on water availability to Ellicott Slough National Wildlife Refuge are currently unknown because historical water level data in refuge wells were not available.

Water-Related Habitats and Water Management

- Development has substantially reduced and fragmented habitat for federally listed amphibians, preventing species movement between upland areas and breeding ponds. Creating new ponds could reduce fragmentation and improve opportunities for recruitment. Ideally, sites for these ponds would have poor drainage and adequate natural runoff. Initial investigation for this report indicated that no areas within fee and title lands are optimally suitable for pond development, but some moderately suitable areas could be investigated further.
- Climate and runoff variability results in variable water levels in breeding ponds. This variability can affect successful recruitment of Santa Cruz long-toed salamander and California tiger salamander. Recruitment of Santa Cruz long-toed salamander at Ellicott Pond was observed to fail in years when precipitation was less than 20 inches from October to July. Specific water level response to changing climate conditions could not be quantified because water level data were not available for analysis.
- Elevated water levels and stagnant open water conditions in Harkins Slough—especially during winter months—likely result from Watsonville Slough inflow. The exact cause for sudden inundation in Harkins Slough is not known; it may be caused by changing flow dynamics in the Watsonville Slough system due to subsidence from shallow groundwater withdrawal and peat mining or due to sedimentation and vegetation overgrowth in the Watsonville and Harkins Sloughs.



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10; Map Production Date: March 3, 2014; Source Data: Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, May 2014; Streams, Water Bodies and HUC 12 boundaries from U.S. Geological Survey National Hydrography Dataset Plus v2.10, 2012; County lines from U.S. Geological Survey, accessed 2013; Bulletin 118 boundaries from California Department of Water Resources 2010 ; Imagery from ESRI basemap package, 2014; Region of Hydrologic Influence boundaries delineated from 10-meter digital elevation model through StreamStats Web Application USGS, 2014

Figure 1. Major groundwater and surface water basin boundaries, and other geographic features, near Ellicott Slough National Wildlife Refuge.

Water Quality

- Eutrophic conditions—including elevated concentrations of chlorophyll-a and low concentrations of dissolved oxygen—persist in Harkins Slough because of extensive agricultural land use in the surrounding watershed, seasonal open water marshes, and stagnant water circulation. Pumping Harkins Slough water downstream from the refuge may enhance circulation and delay the onset of eutrophic conditions, although more data are needed to quantify this relation.
- There is potential for Harkins Slough to be periodically impacted by seawater intrusion into the Watsonville Slough system (especially in winter months). Incursion of seawater into Harkins Slough could lead to formation of a persistent seawater lens underlying a freshwater zone. The impact of salinity increases on refuge biological objectives is not known at this time.
- Elevated concentrations of metals such as lead, aluminum, and iron in surface water at Harkins Slough pose an ecological risk to aquatic organisms. Furthermore, concentrations of metals such as barium, chromium, lead, and selenium were detected above site screening levels in shallow groundwater at the Harkins Slough Unit. Concentrations of these constituents vary with time and different hydrologic conditions. The impact of elevated concentrations of these constituents on refuge biological objectives is not known at this time. Sources of nutrients to delivered water are likely from agricultural runoff upgradient from the Goose Lake Canal, of which nitrogen may be the controlling factor (limited nutrient) in algae growth.
- Harkins Slough is currently listed as a 303(d) water for *Escherichia coli* (E. coli) and fecal coliform, with an U.S. Environmental Protection Agency total maximum daily load approval date of 2007. Concentrations of these bacteria adversely affect water contact recreation, although currently there are no types of water recreation permitted within the refuge. The impact of these concentrations on other biological resources at the refuge is not known at this time.
- Excessive pumping and drought conditions in the Pajaro Valley Groundwater Basin will increase the risk of seawater intrusion into the freshwater aquifer in the future, which could negatively impact water quality of breeding ponds that rely on groundwater sources. To mitigate, refuge staff may have to treat groundwater or find another water source, and such sources are limited.
- Total dissolved solids and nitrates are contaminant threats to groundwater in the Pajaro Valley Groundwater Basin that are influenced by deep percolation of applied irrigation water, non-point source runoff, and leaking septic systems. These concentrations may pose a risk to survival of salamanders, although more information is needed to determine whether concentrations found in the refuge are threats to Santa Cruz long-toed salamander, California tiger salamander, and California red-legged frog.

Highest Priority Recommendations

- Due to the potential for a substantial number of water quality issues and changes in the hydrologic regime at Harkins Slough, it is important to establish clear biological objectives for Harkins Slough and associate those objectives with management targets for optimal water quality and water level conditions in the unit. Establishing objectives is critical for determining whether potential water quality issues and changes in the hydrologic regime pose a threat to achieving refuge biological objectives and whether mitigation should occur.
- Dependent upon biological objectives and associated water quality targets for Harkins Slough, the U.S. Fish and Wildlife Service should implement a seasonal or continuous surface water quality monitoring program. This program should include seasonal or continuous measurement of physical parameters, chlorophyll-a, nutrients, and water levels as well as seasonal or biannual sampling of metals including aluminum, iron,

and lead. This information can be used to better understand the relationships among eutrophication, rainfall, runoff, and Harkins Slough pump operation and to monitor whether concentrations of constituents of concern threaten aquatic health.

- Dependent upon biological objectives and associated water level targets for Harkins Slough, the U.S. Fish and Wildlife Service should install a staff gage in the Harkins Slough Unit or coordinate with Pajaro Valley Water Management Agency to obtain current water level records at the Harkins Slough to monitor changes in hydrologic conditions that affect water quality conditions.
- The U.S. Fish and Wildlife Service should record water levels in breeding ponds (Ellicott Pond, Prospect Pond, Buena Vista Pond, and Calabasas Pond) with dates and times, especially at times of recruitment surveys, and store these data in a digital database to facilitate data analysis and transfer. This information can be used to determine water level response as a result of runoff and water management and to associate water level conditions to breeding success of amphibians.
- Where feasible, the U.S. Fish and Wildlife Service should determine a water budget for refuge ponds (how much water is needed to fill refuge ponds to adequate water levels) to help determine water requirements for refuge management, determine if water rights adequately cover refuge water use, plan for potential groundwater use monitoring requirements, and quantify the relation of water availability to climate conditions and impacts on breeding success of amphibians. The following techniques should be developed: estimate the current storage capacity (bathymetry) of breeding ponds and tie capacity to water level measurements to measure pond water storage at given intervals, measure groundwater use required to fill ponds to adequate water levels, and periodically measure how much water is leaving refuge ponds through water control structure weirs.

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Chapter 1—Introduction

This water resource inventory and assessment (WRIA) summary report for Ellicott Slough National Wildlife Refuge (Ellicott Slough Refuge or refuge) describes current hydrologic information, provides an assessment of water resource needs and issues of concern (IOCs), and makes recommendations regarding refuge water resources.

This WRIA is intended to be a reference for ongoing water resource management and strategy development. The report focuses on current hydrologic conditions at Ellicott Slough Refuge, and it was developed with cooperation and assistance from the refuge's project leader and staff. This report summarizes selected hydrologic data from U.S. Fish and Wildlife Service (Service) databases and records and publicly available hydrologic information from local, state, and federal agencies, universities, and other sources, that are relevant to understanding of refuge water resources.

The long-term goal of the National Wildlife Refuge System (Refuge System) WRIA effort is to provide up-to-date, accurate data on Refuge System water quantity and quality in order to acquire, manage, and protect adequate supplies of clean and fresh water. An accurate water resource inventory is essential for prioritizing issues and tasks and taking prescriptive actions that are consistent with the established purposes of each refuge. Reconnaissance-level water resource assessments are used to identify and evaluate water rights, water quantity (if data are available), known water quality issues, water management, threats to water supplies, and other water resource issues for each field station. This information provides critical information to refuge managers, wildlife biologists, field staff, regional office personnel, and U.S. Department of the Interior managers that can be used to achieve effective wildlife habitat management and conservation. Hydrologic and water resource information compiled during the WRIA process aids the development of other key documents for each refuge including comprehensive conservation plans, the contaminant assessment process (CAP), and water-related research projects by Service staff, universities, and other agencies.

WRIAs are recognized as an important part of the National Wildlife Refuge System Inventory and Monitoring (I&M) initiative and are outlined in the I&M 7-year plan (U.S. Fish and Wildlife Service 2013). The Pacific Southwest Region (Region 8) I&M Initiative developed this WRIA report.

The hydrologic information collected during this WRIA project will be used for other ongoing planning and assessment projects for Ellicott Slough Refuge. Goals, objectives, and strategies for the refuge were determined through a 15-year comprehensive conservation plan completed in 2010 (U.S. Fish and Wildlife Service 2010a). Water quality and pollutant source information was compiled in the Ellicott Slough Refuge CAP in 2012 (Aceituno 2010).

Chapter 2—Description of Refuge

2.1 Refuge Overview

Establishment of the Ellicott Slough Refuge was authorized under the Endangered Species Act of 1973 (16 United States Code [U.S.C.] 1531 et seq.) and the Emergency Wetlands Resources Act of 1986. Currently, the Ellicott Slough Refuge includes the Ellicott Unit, Calabasas Unit, and Harkins Slough Unit, which together total 315.55 acres. The Buena Vista Property, a managed inholding, is 289 acres (U.S. Fish and Wildlife Service 2010a:7).

The Ellicott Unit (168.35 acres) was added to the refuge through a series of transfers starting in 1973. A parcel on the land within the unit was found to contain one of the only two known active breeding ponds for the Santa Cruz long-toed salamander (*Ambystoma macrodactylum croceum*; SCLTS). In 1973, the California Department of Fish and Game (now California Department of Fish and Wildlife [CDFW]) acquired the property and some adjacent upland property, designating a 30-acre acquisition as a State Ecological Reserve to protect the aquatic and terrestrial lifecycle needs of SCLTS. These 30 acres were later included as part of the Ellicott Unit and managed by the Service under a memorandum of understanding with CDFW. Within the Ellicott Unit, the Service owns 133.24 acres in fee and title and manages the remaining acres under easement or agreement (U.S. Fish and Wildlife Service 2010a:4).

The 32-acre Calabasas Unit was added to the refuge in 1999. After SCLTS and California red-legged frog (*Rana draytonii*; CRLF) were found on the property, it was transferred by the Trust for Public Land to the Wildlife Conservation Board who then transferred it to the Service for maintenance of coastal shrub and pond habitat (U.S. Fish and Wildlife Service 2010a:7).

The 116-acre Harkins Slough Unit was added to the refuge in 2005. Starting in the 1950s, the Harkins Slough Unit was agricultural property. In 1994, the unit was inundated during a flood event and never drained. It was reclaimed by the Farm Service Agency, who then transferred the property to the Service because of its value as a freshwater wetland habitat for migratory birds (U.S. Fish and Wildlife Service 2010a:7).

The 289-acre Buena Vista Property was added to the refuge as a managed property in 2004. The Trust for Public Land, with support from agencies, acquired this property to protect an ephemeral pond that was found to be breeding habitat for SCLTS and California tiger salamander (*Ambystoma californiense*; CTS). This property was later transferred to CDFW. At the time of this report, the Service was working cooperatively with CDFW to develop a formal agreement to cooperatively manage the property (U.S. Fish and Wildlife Service 2010a:7).

Currently, the primary conservation priority for the Ellicott Slough Refuge is recovering and conserving SCLTS and other sensitive amphibians. The refuge also provides breeding habitat for CTS and CRLF, both of which are federally listed species. Critical habitat for CRLF can be found on the Ellicott and Harkins Slough Units and the Buena Vista Property. CTS is federally listed as threatened in central California; however, designated critical habitat does not include Santa Cruz County (U.S. Fish and Wildlife Service 2010a:8).

The primary purpose of the refuge ponds within the Calabasas Unit, Ellicott Unit, and Buena Vista Property is to provide breeding and recruitment habitat for the endangered SCLTS, CTS, and CRLF. Water management and infrastructure, including water control structures on some units and groundwater wells to extract supplementary water, are used to help control water levels to promote recruitment. Further details can be found in section 4.5, "Water-Related Habitats, Water Management, and Infrastructure."

Threatened and endangered plants are also found at the Ellicott Slough Refuge, although consideration of hydrologic impacts on these species was beyond the scope of this report. The refuge supports the federally listed as endangered robust spineflower (*Corizanthe robusta robusta*), for which the Buena Vista Property contains critical habitat. The Harkins Slough Unit is critical habitat for the federally listed Santa Cruz tarplant (*Holocarpha macradenia*), although it is not known whether this species is present at the refuge (U.S. Fish and Wildlife Service 2010a:8).

The refuge's longer-term habitat management goals and objectives for the period 2010–2025 are currently driven by its comprehensive conservation plan (U.S. Fish and Wildlife Service 2010a). General goals, objectives, and strategies of the plan most directly related to water resources and water-related habitat management include the following:

- Restore, protect, and enhance special status amphibian populations in Santa Cruz County (Goal 1) by meeting the following objectives:
  - Develop and implement management actions for ephemeral breeding ponds (Ellicott Pond, Calabasas Pond, and Buena Vista Pond) and over-summering habitat to support amphibian recruitment (Objective 1.2). Strategies include the following: develop a water management plan to ensure that existing ponds remain functional breeding sites (Strategy 1.2.1), conduct hydrological and soil surveys for existing ponds to inform management actions, assess the feasibility of constructing new breeding pond sites, and identify new lands for acquisition (Strategies 1.2.3 and 1.2.4).
  - Conduct a habitat management study to examine the feasibility of restoring the Harkins Slough Unit to provide additional native amphibian habitat (Objective 1.3). This study would include a hydrological assessment of Harkins Slough (Strategy 1.3.1).
  - Within 5 years of plan approval, develop a map to identify suitable amphibian habitat and buffers for protection in perpetuity through fee acquisition and easements (Objective 1.5). Specific strategies involving water resources analysis were not listed in the plan but could include identification of areas with suitable soils and water flow for efficient pond development.
- Identify, assess, and adapt to current and future climate change impacts on refuge sources (Goal 6) by meeting the following objectives:
  - Conduct an analysis of climate-related scenarios through modeling and assess potential impacts on refuge resources (Objective 6.1). Strategies include the following: conduct flood-risk and climate-risk analysis of lands on and adjacent to the refuge (Strategy 6.1.1); conduct climate change modeling to predict habitat changes for refuge habitat types (Strategies 6.1.2 and 6.1.3); promote research that evaluates climate change–related effects on endangered species populations and ephemeral pond hydrology, including analyzing changes in rainfall patterns and temperature (Strategy 6.1.5); identify locations for pond creation and acquisition (existing ponds or future pond sites) to offset climate change impacts (Strategy 6.1.6); and assess seawater intrusion for Harkins Slough as a result of sea level rise (Strategy 6.1.9).

2.2 Topography, Landforms, and Vegetation

Ellicott Slough Refuge is located in the Pajaro Valley in Santa Cruz County, south of the city of Santa Cruz and northwest of the city of Watsonville (approximately 0.7–2.2 miles from the Monterey Bay shore; figure 1). The refuge is located in the Monterey Bay Plains and Terraces Level IV Ecoregion (Griffith et al. 2008; appendix A, figure A2). The refuge is located within the Central California Ecoregion (figure A3), which consists of mountains, hills, valleys, and plains in the southern Coast Ranges of California (U.S. Fish and Wildlife Service 2010a). The refuge falls within the Coast Ranges Geomorphic Province (Belitz et al. 2003; figure A4). The Coast Ranges contain valleys and mountain ranges that trend northwest from 2,000 to 6,000 feet above sea level. The San Andreas Fault is almost parallel to the valley and ranges, with the Pacific Ocean to the west (figure 1). The Coast Ranges are further split into the Northern Coast Ranges and Southern Coast Ranges by the San Francisco Bay, with the refuge located in the northwestern portion of the Southern Coast Ranges.

The entire refuge drainage basin covers two major drainage basins. Calabasas Unit, Harkins Slough Unit, the eastern portion of the Buena Vista Property, and a small southwestern portion of the Ellicott Unit are within the Pajaro River Watershed Hydrologic Unit Code 8 (HUC-8) drainage basin. The remaining areas are within the San Lorenzo–Soquel Watershed HUC-8 drainage basin.

Harkins Slough Unit, Calabasas Unit, and the eastern portion of the Buena Vista Property within the Pajaro River Watershed are within the larger Watsonville Slough system (figure 1). The Watsonville Slough system includes Watsonville Slough, Harkins Slough, Gallighan Slough, West Struve Slough, Struve Slough, and Hanson Slough. Harkins Slough Unit, and the upstream Calabasas Unit, are within the Harkins Slough system. The Buena Vista Property drains to the Gallighan Slough system. Gallighan Slough converges with Harkins Slough and then Watsonville Slough. This system flows southwest and then south before confluence with the Pajaro River, which drains to the Monterey Bay and Pacific Ocean. The region surrounding Watsonville Slough used to contain a much more extensive wetland and estuarine complex, but it has since been modified to meet the needs of adjacent agricultural and urban land use (U.S. Fish and Wildlife Service 2010a).

The topography of the refuge ranges from flat to hilly, with elevations varying among the four units. Elevations in the four units, in feet above mean sea level, range as follows: 181–291 feet in the Calabasas Unit, 115–305 feet in the Ellicott Unit, 5–121 feet in the Harkins Slough Unit; and 179–486 feet in the Buena Vista Property.[1]

The majority of refuge lands reside in the northwestern portion of the Pajaro River Watershed, which is in an area of complex and active geology (active faults). The Pajaro River Watershed is divided by the San Andreas Fault. Human-made structures like levees and channels cannot be considered permanent in the Pajaro River Watershed due to ongoing geologic deformation. The elevation of streambeds and stream gradients change by several feet per century as a result of geologic activity such as fault creep and the 1906 San Francisco Earthquake. The Pajaro River's course continues to be modified due to active transform faulting (side-to-side movement) (Bodensteiner et al. 2003).

2.3 Geology and Hydrogeology

This section describes the geological and hydrogeological setting of an area near the Ellicott Slough Refuge. More information about groundwater availability (conditions and levels) can be found in section 4.4, "Groundwater."

The refuge is located in the northwestern coastal portion of the Pajaro Valley Groundwater Basin (PVGB), which covers about 120 square miles in southern Santa Cruz County and northern Monterey County. The northern boundary of the PVGB is the surface expression of the contact between the Pajaro Valley Quaternary alluvium and the marine sedimentary deposits of the Pliocene Purisima formation. The southern boundary of the PVGB is geographically defined by the drainage divide between Elkhorn and Mojo Sloughs (figure 2). The groundwater subbasins to the south of the PVGB are the lower Salinas River Valley and the Salinas Valley at Langley (California Department of Water Resources 2006). The western border of the PVGB is Monterey Bay. The eastern border is a well-defined hydrogeologic boundary created by the impermeable rocks east of the San Andreas Fault, which act as a barrier to groundwater flow into or out of the PVGB (Carollo Engineers 2013).

The basement rock formation in the PVGB is Cretaceous and granitic with poorly

[1] Elevation values derived from a 10-meter digital elevation model (DEM).

permeable and consolidated rocks at depths of 2,000–4,000 feet. The basement rock is overlain by westward dipping layers of a late Tertiary and Quaternary age (Muir 1972). The unconsolidated Mio-Pliocene Purisma formation (referred to as the Purisma formation) begins at depths ranging from near land surface along the northern and eastern boundaries of PVGB to as deep as 900 feet near the mouth of the Pajaro River. The bottom of the Purisma formation can be found at depths from about 1,000 feet near Watsonville to 3,500 feet in the Corralitos area (Muir 1972). The Purisma formation consists of layered silt and sandy silt deposits.

The Aromas Sands formation (referred to as Aromas Sands) unconformably[2] overlays the Purisma formation, and outcrops are found throughout the central and northern portions of the PVGB as well as offshore on the continental shelf (Hanson 2003). The Aromas Sands ranges in thickness from 500–1,000 feet and consists of well-sorted sands from younger eolian deposits and older fluvial deposits (Carollo Engineers 2013). The Aromas Sands consists of interbeds of clay and poorly sorted gravel. Unconsolidated Pleistocene terrace deposits and Holocene alluvium and dune deposits are present in much of the valley above the Aromas Sands. These deposits can be found with depths of 245 feet (Muir 1972). The alluvium underlies the alluvial plain and extends into adjoining stream canyons. This alluvium consists of unconsolidated gravel, sand, and silt, with silty clay and clay lenses. The dune deposits are fine- to medium-grained quartz sands, while the terrace deposits are composed of moderately to poorly sorted silt, sand, silty clay, and gravel (Muir 1972).

The surficial geology near the refuge varies depending on the unit (figure 3). The northernmost unit, Calabasas Unit, comprises undifferentiated alluvial deposits from the Holocene age and fluvial lithofacies from the Pleistocene age. The Buena Vista Property mainly comprises Aromas Sands from the Pleistocene age with a small amount of Coastal terrace deposits and fluvial lithofacies. The Ellicott Unit contains eolian facies, Coastal terrace, Aromas Sands, and eolian deposits of Manresa Beach. The Harkins Slough Unit has Basin Deposits (Holocene) and Pleistocene fluvial lithofacies (Brabb et al. 1997).

The PVGB is composed of several hydrogeologic units of varying complexity, but they are connected geologically and function as a single groundwater basin. The groundwater flow system (or aquifer) can be divided into major geologic units because there is no formal designation for the aquifers in the PVGB. The developed portion of the PVGB consists generally of three aquifer units separated vertically by two confining layers of less permeable, finer grained material (Johnson et al. 1988). These units include the Purisima formation, the Aromas Sands (upper and lower), and alluvium (older and younger). The Purisma formation (1,000–2,000 feet below ground surface) is moderately permeable but lies at significant depths beneath the much of the PVGB. This formation is exposed to the surface near the foothills. This aquifer is more heavily developed in the regions north of the PVGB. The Aromas Sands formation is the main production portion of the aquifer because it is a permeable unit and yields moderate quantities of water. The alluvium is permeable and yields moderate quantities of water but is relatively shallow, which may increase the susceptibility to contamination (Carollo Engineers 2013).

The lower aquifer is found in the older fluvial portions of the Aromas Sands at depths ranging between 300 and 600 feet below sea level. Water elevations are closer to the surface at locations both farther to the east in the valley and nearer to the coast. The lower confining region, between the lower and middle aquifer, is made up of numerous interbedded clay and silty clay beds in the fluvial portion of the Aromas Sand (Johnson et al. 1988).

The middle aquifer is located about 100–200 feet below sea level. This portion of the aquifer is the most intensely developed. This aquifer is made up of basal gravel beds in the alluvium and terrace deposits that reside in the lower eolian and upper fluvial portions of the Aromas Sand (Johnson et al. 1988). The confining layer that separates the middle and upper aquifer is not continuous and comprises extensive clay beds. The upper alluvial aquifer closest to land surface is confined and up to 50 feet thick, consisting of

[2] Unconformably means that the contact between rock strata shows a marked discontinuity in the geological record and typically does not have the same direction of stratification.

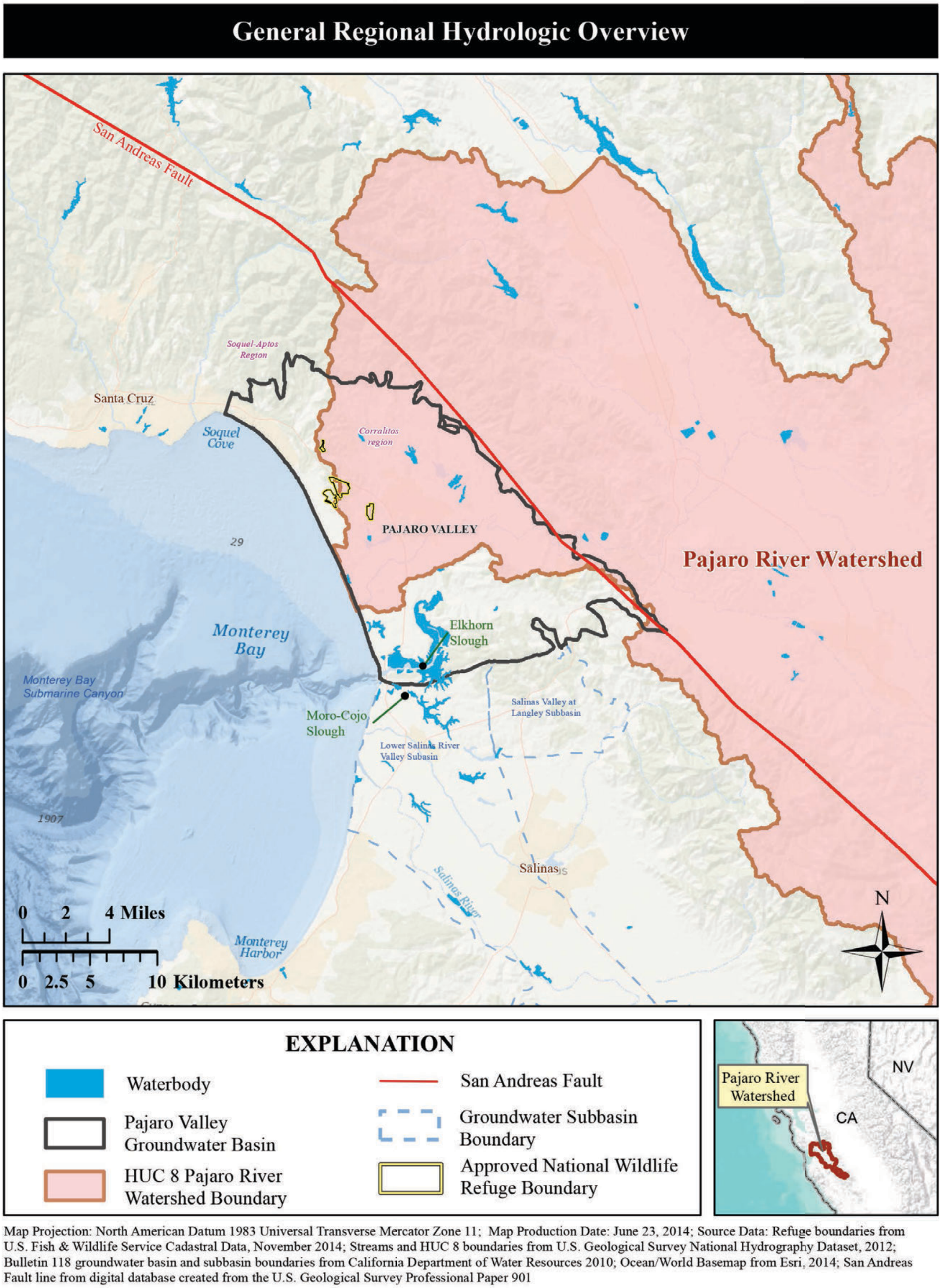
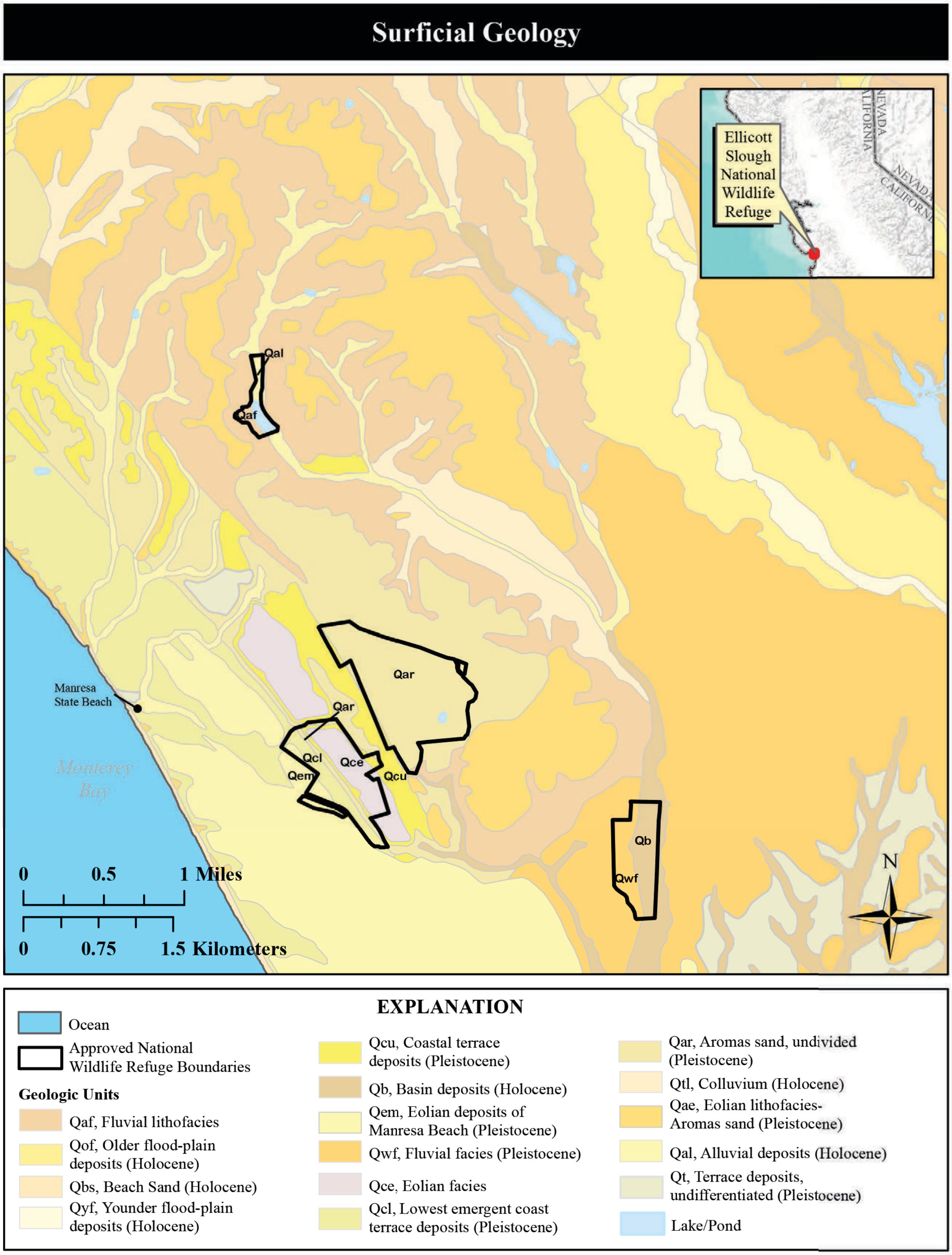


Figure 2. General regional hydrologic overview map.



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10; Map Production Date: November 09, 2012, Edited September 24, 2014; Source Data: Geology from U.S. Geological Survey Geologic Map of Santa Cruz County, California, 1997; Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, November 2012; Water bodies from NHDPlus U.S. Geological Survey and U.S. Environmental Protection Agency,2012

Figure 3. Surficial geology for Ellicott Slough National Wildlife Refuge.

discontinuous water-bearing zones found in the upper portion of the Aromas Sand, terrace deposits, and cross bedded gravels and sands (Johnson et al. 1988).

The upper Purisma formation, which underlies the lower aquifer, has not been developed in the vicinity of the refuge because this formation is at depths of 1,000–2,000 feet below sea level in this region. The sequence of rock formations are westward dipping; therefore, this formation comes closer to the surface toward the northwest region of the PVGB and is more readily available as a groundwater source in that region. For this reason, the Purisma is the principal water source for the Soquel-Aptos region north of the PVGB (figure 1) and north-central Santa Cruz areas (Johnson et al. 1988). The Aromas Sands outcrops are found in the north and central part of the PVGB, offshore on the continental shelf, and in the Monterey submarine canyon (Johnson et al. 1988).

Vertical and lateral movement of water is limited by clay layers that are interspersed in the aquifers. Sediments of layered marine and terrestrial coarse-grained deposits of Quaternary and Tertiary age make up the alluvial aquifers. These aquifers are separated by extensive fine-grained deposits that potentially restrict vertical movement of groundwater and seawater intrusion in the coastal subareas. Seawater intrusion and groundwater pumping occur in the coarse-grained deposits, which are extensive (Hanson 2003). The middle aquifer of the PVGB is where most of the confining clay layers are thickest. Here, these clay layers trend almost parallel to the Pajaro River (Carollo Engineers 2013). Inland towards Watsonville the aquitards thin and are discontinuous in the foothill region (Hanson 2003).

2.4 Hydroclimatic Setting

Ellicott Slough Refuge is located approximately 1.5 miles off the central coast of California in the northeastern portion of Monterey Bay. Meteorological conditions in this region are predominantly determined by the north Pacific high pressure system. The refuge is located on the eastern edge of this system (Ruffner 1985). Large-scale subsidence (areas where large masses of cooler, drier air descend from higher to lower elevations, causing an increase in barometric pressure), which occurs over the subtropical regions, is the major cause of the north Pacific high pressure system (Nuss 2014).

In May–October, storms generally progress in a northerly direction to Monterey Bay because the north Pacific high pressure center moves north from subtropical regions with a mean wind direction that is northeast or northwest. As a result, there is little to no rainfall in the summer (Ruffner 1985). In the winter (November–April) this pressure system moves southward, and the wind direction changes to a more westerly direction (Nuss 2014). This allows storm centers to move into California. The majority of rain falls during the winter season due to the increasing presence of mid-latitude storms.

The passing of weather systems migrating across the area can result in substantial changes to general weather patterns. For example, as a result of topographic variations in the region, rainfall varies greatly from approximately 59 inches in the Santa Lucia or Santa Cruz Mountains to approximately 19–20 inches in Monterey (Nuss 2014). Ellicott Slough Refuge receives an average of 20–30 inches per year, which is substantially lower than the Santa Cruz Mountains, which lie to the north and receive over 45 inches per year (figure 4).

During most of the dry season, the region surrounding the refuge typically has persistent clouds and cooler temperatures. The combination of cool ocean surface temperatures and subsidence produces a well-defined atmospheric mixed layer near the ocean surface. As a result, clouds, fog, and temperatures that are distinctive of the ocean surface are found within this atmospheric mixed layer (Nuss 2014).

The Palmer Drought Severity Index (PDSI) responds to long-term weather conditions and provides a coarse-level indication of regional meteorological wet or dry periods (National Center for Atmospheric Research 2013). The index incorporates antecedent precipitation, moisture supply, and moisture demand that may reflect the climate of previous years (Dai et al. 2004). Within the Central Coast Drainage Climate Division, recent (1981–2013) dry periods generally include 1981, 1984–1992, 1994, 1997, 1999, 2001–2002, 2004, 2007–2009, and 2012–2013. Recent wet periods generally include 1982–1983, 1995, 1996, 1998, 2000, 2003, 2005, 2006, 2010, and 2011. Of these, 1990, 2007, 2008, and 2013 were extremely dry, and 1982–1983, 1995, 1998, and 2005 were extremely wet (figure 5). The wettest year on record from 1895 to 2013 was 1983.

2.5 Land Use and Land Cover

Land uses and land cover for the region surrounding Ellicott Slough Refuge were determined for the drainage areas for units of the refuge (Calabasas, Ellicott, and Harkins Slough Units and the Buena Vista Property). Methods describing data sources for land cover and vegetation are described in section 3.1, "Geographic Information System Data and Maps," and methods describing how basins were delineated can be found in section 3.3 under the subheading "Analysis Methods for Water-Related Habitats, Water Management, and Infrastructure."

Land cover in the drainage basins for the Calabasas Unit is predominantly mixed forest (53.1 percent), developed open space[3] (19.7 percent), and evergreen forest (17.5 percent). Herbaceous cover, shrub/scrub, emergent herbaceous wetland, and low intensity developed land account for less than 10 percent of the total land cover (figure 6).

Land cover in the drainage basins that contribute water to the Harkins Slough Unit and Calabasas Unit is mainly mixed forest (26.8 percent), developed open space (24.6 percent), herbaceous cover (17.9 percent), evergreen forest (11.2 percent), and shrub/scrub (7.8 percent). Low intensity developed land, medium intensity developed land, high intensity developed land, cultivated cropland, deciduous forest, emergent herbaceous wetlands, hay/pastureland, and woody wetlands compose less than 10% of the total area (figure 6). All types of developed area within the Harkins Slough Basin are concentrated in the riparian area of Harkins Slough.

Land cover in the drainage basins for the Buena Vista and Ellicott Units is predominantly shrub/scrub (25.5 percent), mixed forest (23.4 percent), and developed open space (20.1 percent). Low intensity developed land, evergreen forest, herbaceous cover, cultivated cropland, medium intensity developed land, and wood wetlands comprise about 30 percent of the total area (figure 6).

Total acreage of land in farms in Santa Cruz County has increased 20 percent from 1997 to 2012 but decreased 20 percent in Monterey County (table 1). Acres of irrigated land in Santa Cruz County and Monterey County increased 24.0 percent and 0.5 percent, respectively (U.S. Department of Agriculture 2014a).

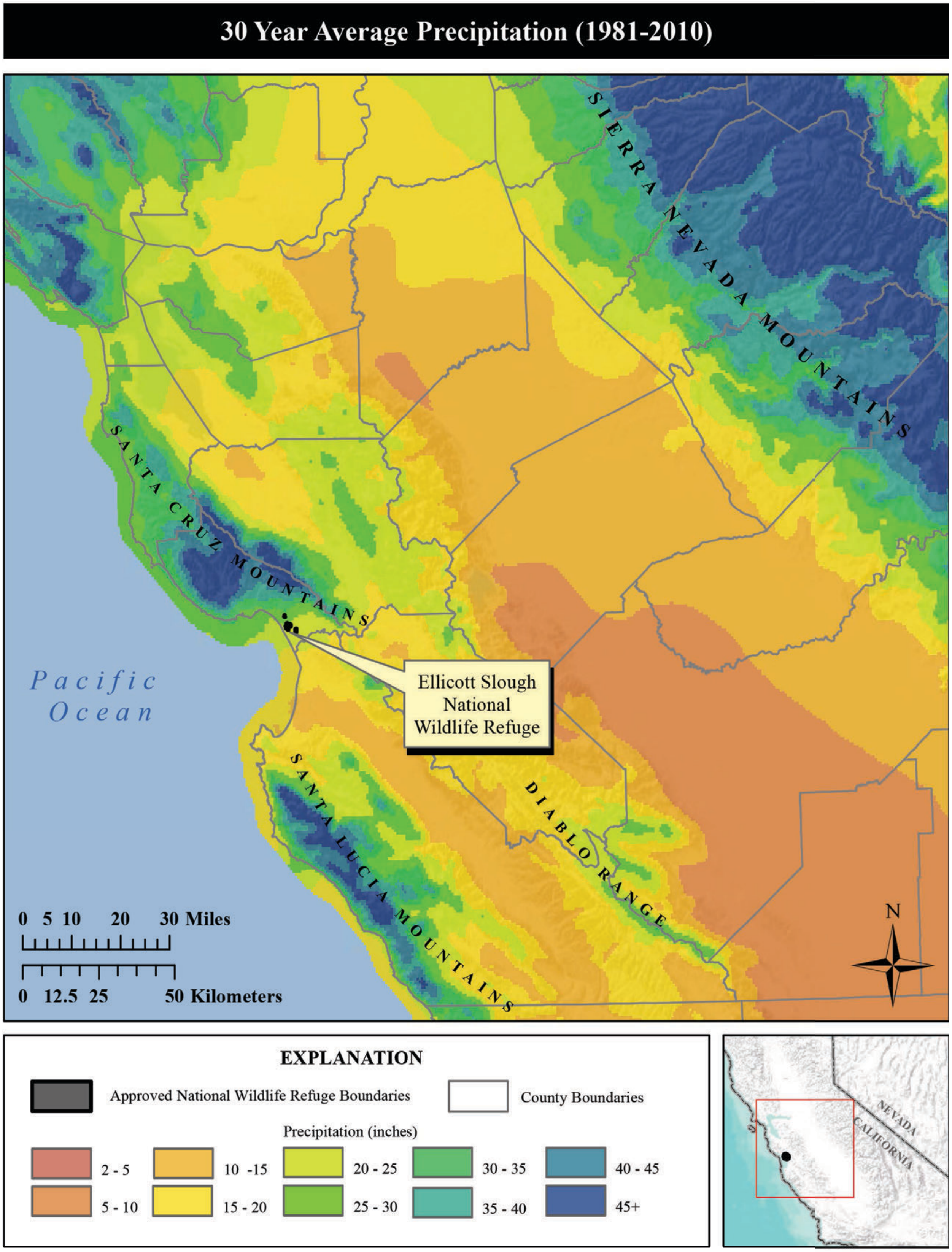
The Calabasas Unit is covered by northern coastal scrub throughout the unit, riparian woodland in the north, and coastal grasslands throughout the unit. A lesser amount of San Andreas coastal live oak woodland was surveyed in the southwest. An ephemeral pond, Calabasas Pond, was surveyed in the southeastern portion of the unit (appendix A, figure A5).

The Ellicott Unit is composed predominantly of San Andreas coastal live oak woodland, coastal grassland, riparian woodland, and northern coastal scrub, with closed-cone coniferous forest mostly in the eastern and southeastern region (appendix A, figure A5). Smaller land coverage of eucalyptus stands, native and nonnative herbs, and an ephemeral pond are also present.

The Buena Vista Property is covered predominantly by San Andreas coastal live oak woodland (approximately 63 percent), and the rest of the property is covered by acacia stands, coastal grasslands, northern coastal scrub, eucalyptus stands, San Andreas maritime chaparral, closed-cone coniferous forest, and a small area with ephemeral pond (appendix A, figure A5).

Approximately 50 percent of the Harkins Slough Unit is covered by water, which constitutes the majority of the eastern portion of the unit. The remaining area is covered by coastal grasslands throughout the western region, northern coastal scrub in the northwest, San

[3] Developed open space is defined as "areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes" (Multi-Resolution Land Characteristics Consortium 2011).



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10; Map Production Date: December 19, 2012, Edited September 24, 2014; Source Data: Precipitation Grid from PRISM Climate Group;Terrain from ESRI Online Map Services; Refuge and county boundaries from U.S. Fish & Wildlife Service Cadastral Data, November 2014;

Figure 4. Mean annual precipitation in a region surrounding Ellicott Slough National Wildlife Refuge, 1981–2010.

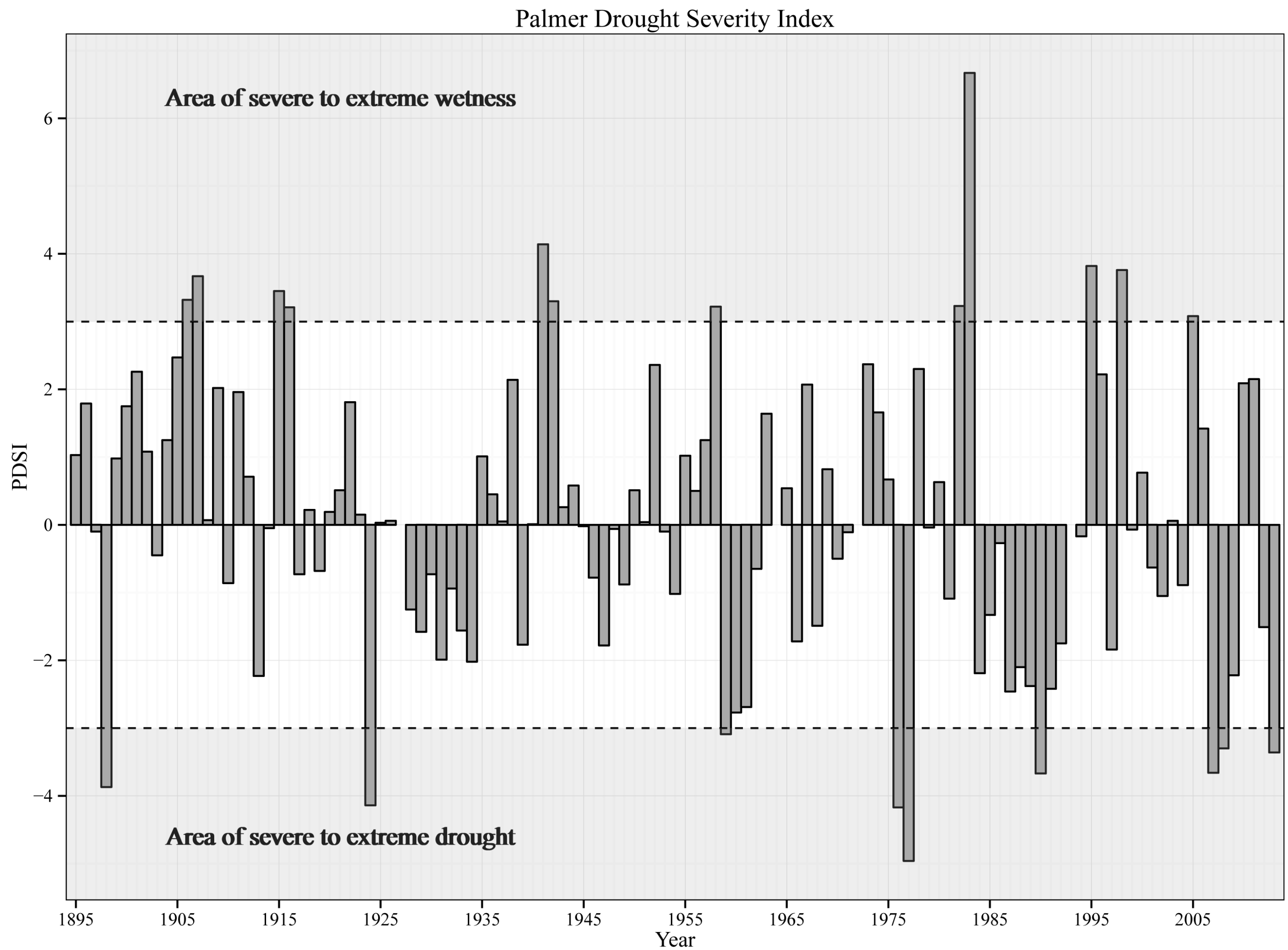
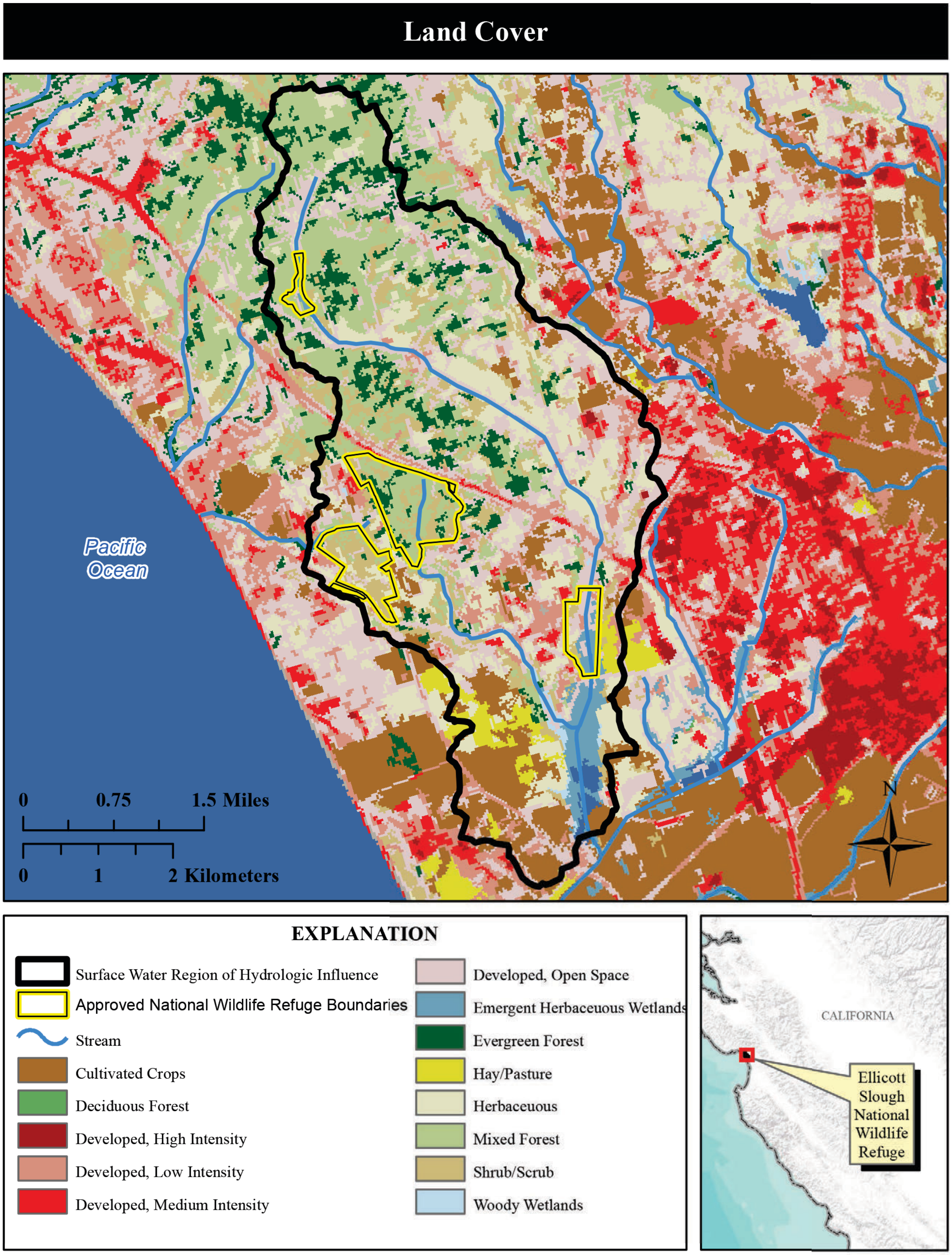


Figure 5. Palmer Drought Severity Index for the Central Coast Drainage Climate Division, 1895–2013.



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10; Map Production Date: November 13, 2012; Source Data: Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, November 2012; U.S. Geological Survey (USGS) National Land Cover Dataset, 2009; Region of Hydrologic Influence boundaries delineated from 10-meter digital elevation model through StreamStats Web Application USGS, 2014

Figure 6. Land cover in reference to drainage basin boundaries on and near Ellicott Slough National Wildlife Refuge.

Andreas coastal live oak woodland sporadically covering the western half, riparian woodland mainly to the north with some southwestern coverage, native and nonnative herbs bordering the water on the west and covering portions of the northwest, and freshwater marsh also bordering the northern water-covered region (appendix A, figure A5).

Table 1. Estimates of agricultural land and irrigated farmland in Santa Cruz and Monterey Counties from 1997 to 2012.

Census type	*Year*	*Santa Cruz County*	*Monterey County*
Land in farms (acres)	2012	99,983	1,268,144
	2007	47,489	1,327,972
	2002	67,166	1,260,613
	1997	80,343	1,531,933
Irrigated land (acres)	2012	28,897	263,835
	2007	19,641	232,969
	2002	23,677	253,205
	1997	21,991	262,399

Chapter 3—Methods

The WRIA for Ellicott Slough Refuge was conducted by gathering information on water resources for the refuge:

- studies and reports on relevant water resources investigations and research publicly available on the internet or available in hard copy in refuge files
- publicly available surface water, water quality, and groundwater data from local, state, and national agencies that are accessible in digital format through internet servers
- interviews with refuge staff and field visits to verify locations of infrastructure

A summary of the main methods used to inventory and assess water data is provided in this chapter. Selected methods are provided in sections of this report where interpreted information is provided.

3.1 Geographic Information System Data and Maps

Geographic Information System (GIS) datasets and maps were generated in ArcGIS version 10.1 software (Environmental Systems Research Institute 2010). Flow path and direction, ditches and streams, and infrastructure were identified and interpreted using aerial imagery such as the U.S. Department of Agriculture (USDA) National Agriculture Imagery Program (1-meter resolution, 2009, U.S. Department of Agriculture 2014b) and refuge field visits. This information was used to supplement hydrologic information in maps and datasets in this report if this information provided additional detail or improvement to nationally available sources such as the National Hydrography Dataset (NHD; U.S. Geological Survey 2014) and National Wetlands Inventory (NWI; U.S. Fish and Wildlife Service 2014a). GIS imagery and datasets available at Ellicott Slough Refuge scale were also used if available (and are described in later sections of this report).

Soils analysis was performed using the Soil Survey Geographic database (SSURGO; Natural Resources Conservation Service 2014). Geospatial soil survey information was downloaded and clipped to the refuge boundary, and soil characteristics and properties important to water management and soil morphology were inventoried by map unit (including soil unit name, drainage class, parent bedrock and development landform, saline conditions, depth to water table and layers restricting water movement, water storage capacity, and slope of formation).

Soil drainage classes identified in SSURGO refer to the frequency and duration of wet periods under conditions similar to those in which the soils developed. Alteration of the water regime by refuge management practices does not affect the natural drainage class unless the soil morphology has been changed. Natural soil drainage class is a function of water table, soil wetness, landscape position, and soil morphology. Soil characteristics such as redoximorphic features (soil mottling, caused by oxidation and reduction of minerals, such as iron or manganese, caused by saturated conditions within the soil) indicate the depth and duration of seasonal saturation under undisturbed conditions. Drainage class was defined or estimated as part of soil surveys and applied to soil map units of soil groups and complexes. Poorly drained soils support capacity to hold water longer than excessively drained areas, which have a higher tendency to recharge to groundwater more quickly after inundation (Natural Resources Conservation Service 2014).

Regional and landscape-level land cover was used to analyze land cover characteristics of refuge drainage areas. The U.S. Geological Survey (USGS) National Land Cover Database was used for the year 2006 (Multi-Resolution Land Characteristics Consortium 2011). General patterns and the percentage of each land cover classification with the study area were assessed.

Vegetation and local land cover data were previously mapped for Ellicott Slough Refuge in 2010 in preparation for its comprehensive conservation plan (U.S. Fish and Wildlife Service 2010b) and were used to describe water-dependent habitats within the refuge. The vegetation and land cover dataset was generated through interpretation of high resolution (1-meter spatial resolution) aerial photography from the National Agriculture Imagery Program acquired in summer 2009. Field sampling was conducted in March 2010 to inform the interpretation process, but no formal classification accuracy assessment was conducted (U.S. Fish and Wildlife Service 2010a).

3.2 Selection of Hydrologic Data

Identification of Spatial Boundary Conditions to Inventory Hydroclimate and Hydrologic Monitoring Data

All climate, surface water, and groundwater monitoring stations (water quantity and quality) that provided data for this report were selected by defining a region of hydrologic influence (RHI) for Ellicott Slough Refuge. Regions within the RHI are referred to in the remainder of this section as the climate RHI, surface water RHI, and groundwater RHI. Smaller areas were also generated for refuge unit–specific analysis where identified.

The climate RHI was estimated by reviewing regional annual temperatures and precipitation, climatic patterns, the topography of the region, and the information presented in section 2.4, "Hydroclimatic Setting." The northwestern border extends toward the city of Santa Cruz to account for dominant wind patterns and the presence of the Santa Cruz Mountains that channel winds off the ocean and south towards the refuge. The eastern boundary encompasses an area with a similar topography to the refuge. The remainder of the area south towards Salinas was eliminated because the average precipitation there was substantially different from the area near the refuge including Watsonville.

The surface water RHI was created by using the USGS StreamStats Application (U.S. Geological Survey 2014a) to delineate a drainage basin area that contained all four refuge units. The delineation point for Harkins Slough Unit was first placed at the lowest elevation where water exits the refuge boundary, but it was then revised to just below the Harkins Slough–Gallighan Slough confluence. This change accounted for some of the downstream area of Harkins Slough after water exits the refuge as well all areas within and upstream of the refuge. The delineation points for the Buena Vista Property, Ellicott Unit, and the Calabasas Unit were placed at the lowest elevation where water leaves the managed refuge boundary (to account for all water within and upstream of the refuge). Calabasas Unit is upstream of the Harkins Slough Unit and along Larkin Valley Creek, which drains to Harkins Slough. Therefore, the drainage basin delineated for the Calabasas Unit is completely within the Harkins Slough drainage basin. The resultant drainage basin for the Buena Vista Property is also encompassed by the delineation of the Harkins Slough–Gallighan Slough confluence. After downloading the drainage basin delineations from StreamStats, the edges were smoothed to more accurately reflect topographically correct drainage basin boundaries.

Because of the complexity of the Harkins Slough and the larger encompassing Watsonville Slough system, the surface water RHI for the refuge does not include all of the area that may influence water within the refuge boundary. Harkins Slough is influenced by inflow from Watsonville Slough to the east at certain times of year (see section 4.3, "Surface Water"). Additional areas that included nearby reaches of Watsonville Slough (within 1 mile of the Harkins Slough–Watsonville Slough confluence) were included when selecting relevant water monitoring stations. However, this area was not included in the final polygon for the surface water RHI in order to remain focused on areas with the largest influence on the Harkins Slough Unit while keeping major drainage areas intact. Inclusion of the entire Watsonville Slough would have substantially increased the area for which hydrologic monitoring stations would need to be inventoried, most of which were assumed to be of less influence to Harkins Slough than areas within the Harkins Slough drainage basin.

The groundwater RHI was delineated using a georeferenced map (Hanson 2003:figure 1c) in ArcGIS 10.1. This map displays groundwater subbasins within the Pajaro Valley groundwater region. The groundwater subbasins that encompass the refuge are the San Andreas, Harkins Slough, and Watsonville areas.

Inventory of Hydroclimate and Hydrologic Monitoring Data

All climate, surface water, and groundwater monitoring stations (water quantity and quality) that provided data for this report were selected within the respective RHI boundaries described above, with some exceptions (as described in later sections). Monitoring station locations and data were referenced and obtained using only publicly available internet sources (appendix B, tables B1–B3) and refuge archival records. If fully processed and readily available in digital format at the time of this report, data from selected monitoring stations were used to characterize recent hydrologic conditions and to assess trends. If monitoring station information for the same station was provided on more than one database or server, then a decision was made: if a server provided more easily accessible location information or hydrologic data, or included a longer period of record for that station, then that server was selected. Not all data from stations inventoried as shown in tables B1–B3 were used in this report because some stations' periods of record were too short to identify trends or to describe hydrologic variability (as described in later sections). However, omitted stations were listed for potential use in other assessments.

Climate monitoring stations were inventoried to determine which stations provided data that represented climate conditions at the refuge or in the RHI. Sources of climate station information included the California Irrigation Management Information System (CIMIS; California Department of Water Resources 2014a), Integrated Pest Management Program California Weather Database (University of California–Davis 2014), U.S. Historical Climatology Network (USHCN, Easterling et al. 2009), California Data Exchange Center (CDEC; California Department of Water Resources 2014b), the Global Historical Climatology Network (GHCN, National Oceanic and Atmospheric Administration 2014a), and MesoWest Climate Data Portal (University of Utah 2015). Sixteen climate stations within the climate RHI were located (figure 7; appendix B, table B1); these were found through CIMIS, MesoWest Climate Data Portal, CDEC, IPM, and GHCN (table B1).

Surface water quantity monitoring stations (including streamflow and water level monitoring stations; figure 8) were selected if they were within the surface water RHI (figure 1) or were within 1 mile upstream of the Harkins Slough–Watsonville Slough confluence. This additional area was selected because flow from Watsonville Slough can enter Harkins Slough during certain times of year (see section 4.3, "Surface Water"). Sources of surface water quantity stations that were inventoried included the National Water Information System (NWIS), the Service's Region 1/8 Water Resources Branch (WRB) Water Resources Monitoring Network (WRMN; data are housed in the WISKI system and are accessed by contacting the WRB office in Portland, Oregon), CDEC, and refuge reports and digital files or data if location information was readily available. A network of surface water stations is monitored by the Pajaro Valley Water Management Agency (PVWMA) and included four existing stations within the surface water RHI and extended area (Balance Hydrologics 2014:26); however, digital hydrologic data were not readily accessible to the public, and therefore these stations were not included in the final inventory. Four water level stations were inventoried in the surface water RHI (figure 8; appendix B, table B2). These stations were staff gages used by refuge staff to monitor water levels in management ponds (see section 4.5, "Water-Related Habitats, Water Management, and Infrastructure"). However, no water level information was available from refuge archival records at this time.

Groundwater level water monitoring wells (figure 8) were selected if they were within the groundwater RHI (figure 1) and had digitally available water level data within the past 10 years. Sources of groundwater level wells that were inventoried included NWIS, Water Data Library (WDL; California Department of Water

Resources 2014c), the Service's Region 1/8 WRB WRMN, California Statewide Groundwater Elevation Monitoring System (CASGEM; California Department of Water Resources 2014d), and refuge reports and digital files or data if location information was readily available. Twenty-seven groundwater level stations were inventoried in the groundwater RHI; all stations inventoried were found in CASGEM (figure 8; appendix B, table B2).

Water quality monitoring stations within the surface water and groundwater RHIs were inventoried to assess what types of water quality data are being collected in waters that influence refuge water resources and streamflow. Surface water quality and groundwater quality monitoring stations were selected using the same spatial criteria used for surface water quantity and groundwater level monitoring stations, respectively, as described above. Water quality stations were selected only if they had digitally available water quality data collected within the past 10 years. Selected data from these monitoring stations were analyzed to determine if aquatic life criteria thresholds from the U.S. Environmental Protection Agency (USEPA) were equaled or exceeded (see discussion on water quality data assessment below) to fill information gaps where literature searches did not provide relevant summaries of the water quality data. Sources of selected groundwater quality station information included WDL, NWIS, the California Environmental Data Exchange Network (CEDEN; California Environmental Data Exchange Network 2014), California GeoTracker Groundwater Ambient Monitoring and Assessment Program[4] (GAMA; California State Water Resources Control Board 2014a), the Service's Environmental Contaminants Data Management System (ECDMS; U.S. Fish and Wildlife Service 2014b), and historical Service reports if location information and water quality results were readily available (accessed by contacting Service personnel in Arlington, Virginia). Eight water quality stations were located using these criteria (figure 8; appendix B, table B3).

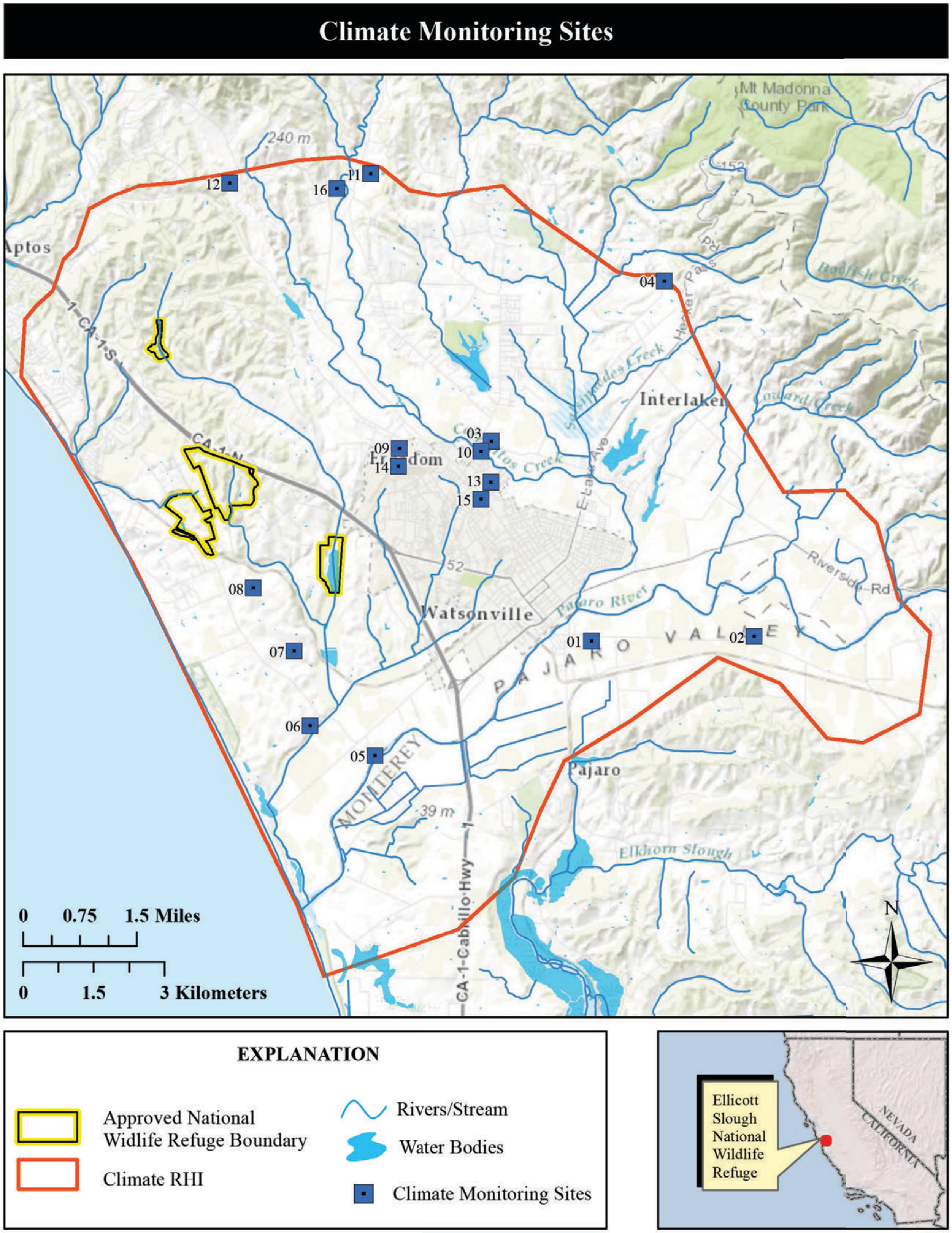
Some water quality monitoring data are collected in association with surface water and groundwater contaminant sites depending on the regulatory requirements for permitted discharges or wastewater cleanup. Water quality data collected at contaminant source locations were not inventoried as water quality monitoring stations in this report because data were difficult to obtain, and results from this sampling were assumed to be mostly applicable to localized cleanup activities. However, potential contaminants from these sources are discussed in the report (see section 4.7, "Water Quality").

Modeled Hydroclimate and Hydrologic Data

Additional geospatial models were used to supplement information from stations or to account for variation in parameters over space. The two main geospatial models used to supplement monitoring station information in assessing water resources for Ellicott Slough Refuge were the Parameter-elevation Regressions on Independent Slopes Model (PRISM; PRISM Climate Group 2014) and Basin Characterization Model (BCM; Flint and Flint 2012).

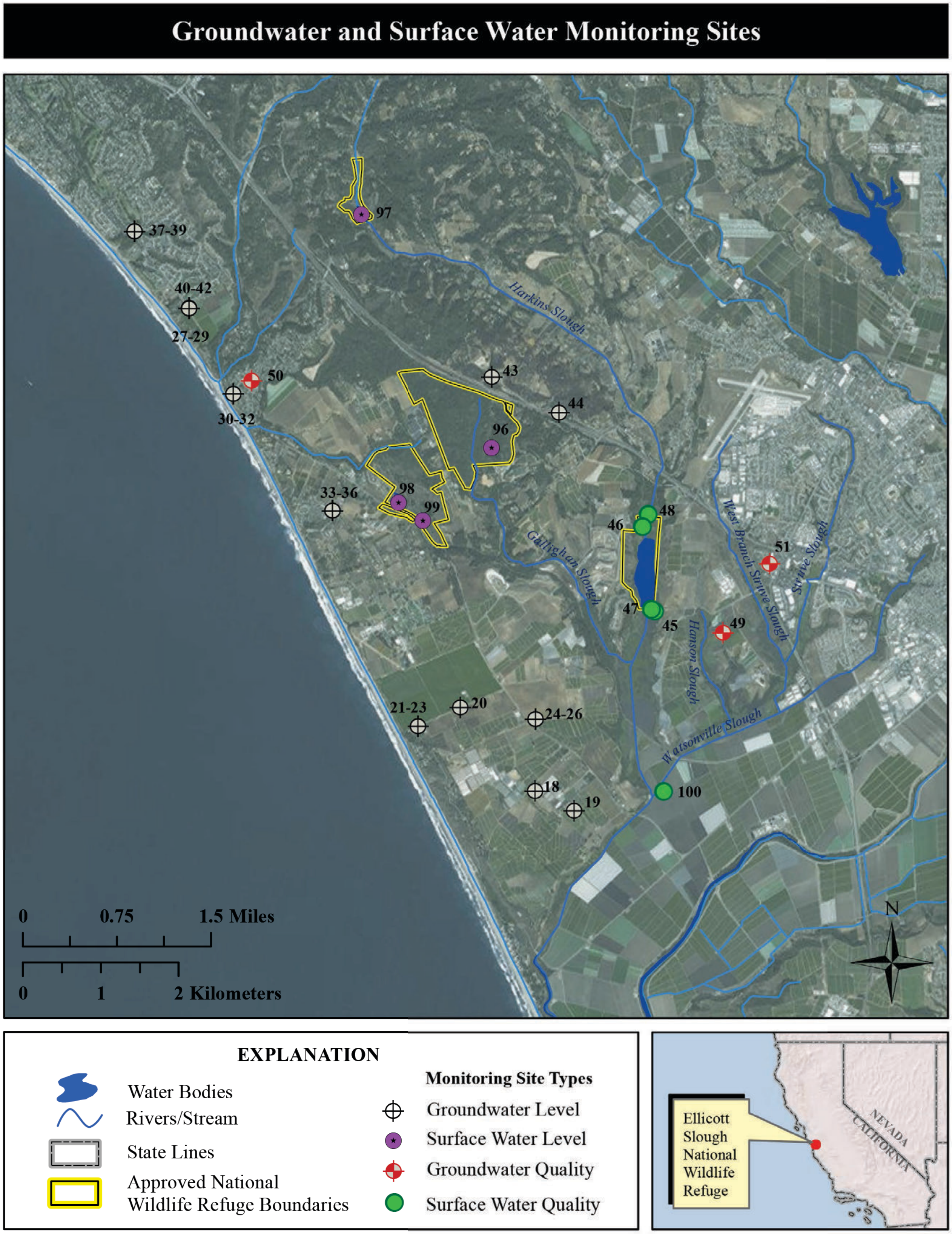
The PRISM model was used to map 30-year mean precipitation for the region surrounding the refuge and was used to characterize recent conditions in selected subbasins within the surface water RHI to compare with habitat conditions in managed ponds (see section 4.5, "Water-Related Habitats, Water Management, and Infrastructure"). PRISM is an analytical model that uses climate monitoring data, a digital elevation model (DEM; topography and orographic features), and atmospheric characteristics to generate estimates of monthly and annual precipitation and temperature (PRISM Climate Group 2014). For comparison with habitat conditions in managed ponds at the refuge, PRISM raster layers were clipped to selected subbasins within the surface water RHI, and monthly PRISM rasters were compiled for the period 1998–2013 using a script developed for

[4] Stations were only selected in GAMA if they fell under the following monitoring networks: GAMA-SWRCB domestic, GAMA-LLNL (Lawrence Livermore National Laboratory), Department of Pesticide Regulation (DPR), and the California Department of Water Resources (CADWR).



Map Projection: North American Datum 1983 California Teale Albers; Map Production Date: February 27, 2014; Source Data: World topo map from ESRI Online base map Services 2014; Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, November 2014; Streams and water bodies from U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Survey (USGS), National Hydrography Dataset (NHD) Plus Version 2.1, 2012

Figure 7. Climate stations located near Ellicott Slough National Wildlife Refuge.



Map Projection: North American Datum 1983 California Teale Albers; Map Production Date: February 27, 2014; Source Data: National Imagery Program (NAIP) 2014 from ESRI Online Map Services; Refuge and State boundaries from U.S. Fish & Wildlife Service Cadastral Data, May 2014; Streams and water bodies from U.S.

Figure 8. Monitoring stations for groundwater level and quality and surface water quality and quantity on and near Ellicott Slough National Wildlife Refuge.

the R statistical program (The R Project for Statistical Computing 2014).

BCM was used to project effects of climate change on temperature, precipitation, climatic water deficit (CWD), and groundwater recharge. BCM is driven by high resolution (270-meter) temperature and precipitation data downscaled from PRISM that is used to characterize water budget at the land surface. Calculation of variables associated with water budget incorporates static inputs (elevation, bedrock properties, soil properties), and downscaled or modeled time variable inputs (precipitation/snow, temperature, derivatives from solar radiation) to produce water budget outputs (CWD,[5] runoff, recharge) for current conditions and forecasted for a range of climate change scenarios (Flint and Flint 2007). As part of CWD, potential evapotranspiration (PET)[6] is the total amount of water that can evaporate/transpire given temperature, solar radiation, and other variables. Actual evapotranspiration (AET), which is used to calculate CWD, is controlled by soil characteristics (porosity, field capacity, wilting point, and infiltration to bedrock) (Flint and Flint 2007).

3.3 Analysis of Hydrologic Data

Analysis Methods for Water Entitlements and Policy

Ellicott Slough Refuge currently only has one water right for the Calabasas Unit (WestWater Research LLC 2014). However, water right diversions within the surface water RHI were also identified to show sources of diversion near the refuge. Water right point of diversion information was inventoried from the Electronic Water Rights Information Management System (eWRIMS; California State Water Resources Control Board 2014b).

Groundwater legislation requires that California Bulletin 118 Groundwater Basins[7] (California Department of Water Resources 2003) that are designated as medium- or high-priority by CASGEM[8] to have groundwater sustainability plans by 2020 or 2022 depending on the state of overdraft. These plans will be administered by a local groundwater sustainability agency or by the California State Water Resources Control Board (SWRCB) if necessary (appendix D). Groundwater legislation requires that local agencies or SWRCB regulate the use of groundwater to achieve sustainability as outlined in these plans. This may require inspections, reporting of water use, or enactment of fees, which can have an

[5] CWD is the difference between PET and AET and represents the amount of additional water that would have evaporated or transpired had it been present in the soils (Flint and Flint 2007). Negative values indicate water storage.

[6] Reference evapotranspiration (ETo), measured at CIMIS stations, more closely resembles PET than AET because it is measured primarily from climate factors (solar radiation, humidity, vapor pressure, air temperature, and wind speed), but unlike AET, it does not take into account the ability of underlying soils to store or transmit water to recharge or the atmosphere. Differences in modeled PET and ETo likely occur because a reference crop is not defined in PET and because weather data measured at a station in which ETo is estimated are typically collected from a well-defined reference environment (well-irrigated and well-maintained grass area). ETo can be measured accurately only at the climate station; accordingly, PET is used to estimate PET over large areas. For this reason, PET is more useful than ETo for comparing water demand between areas.

[7] Bulletin 118 Groundwater Basins are those basins identified in the CADWR Bulletin 118 Report, which was released to the public in 2003 and has been updated since. Online technical descriptions and GIS-compatible maps of 515 groundwater basins and subbasins were part of the effort to publish the bulletin.

[8] Criteria used to determine groundwater basin priority include the overlying population, projected growth of the overlying population, public supply wells, total wells, overlying irrigated acreage, reliance on groundwater as the primary source of water, relative impacts on groundwater, and other information determined by CADWR (California Department of Water Resources 2014d).

impact on refuge groundwater use. Actions taken to successfully improve groundwater sustainability will benefit refuges that use groundwater because these actions should ensure that adequate groundwater resources will be available for use in the future.

To determine whether refuges may be affected by groundwater management and regulation in the future, Bulletin 118 Groundwater Basins were intersected with refuge boundaries using ArcGIS (California Department of Water Resources 2014e). The priority of that basin, as determined by CASGEM, was referenced.

Although the appropriation of water rights in the first few decades following California's statehood generally involved individuals and private companies, many surface water rights are currently held by local public agencies including special districts and municipalities. Legally, some of these agencies actually hold long-term "contract entitlements" rather than "rights" to surface water; in these cases, local parties have contracts with federal or state agencies that run large projects and hold the associated water rights (Hanak and Stryjewski 2012).

To better understand the water supply decisions that may affect highly developed or water-limited areas such as those surrounding Ellicott Slough Refuge, it is important to identify water management districts and agencies (private, federal, and state), water planning regions, and conservation areas of interest to water supply partners that intersect refuge boundaries or the RHI. Review of selected planning documents associated with these areas was used to identify and summarize spatially concurrent water supply information (including identification of threats and opportunities if available) of relevance to refuge water resources.

Ellicott Slough Refuge and the surface water and groundwater RHIs were intersected with the boundaries of California water districts (including Central Valley Project [CVP],[9] State Water Project [SWP],[10] and private water districts[11]) and California Integrated Regional Water Management Planning (IRWMP) regions. CVP, SWP, and private water districts were delineated by the U.S. Bureau of Reclamation Mid-Pacific Service Center in coordination with the California Department of Water Resources (CADWR; U.S. Bureau of Reclamation 2011). Other district boundaries and planning regions relevant to the refuge may exist; however, inventorying all of these was beyond the scope of this report, and therefore this summary was limited to the boundaries described above.

The California IRWMP process,[12] administered jointly by CADWR and SWRCB, is a collaborative effort to manage all aspects of water resources in a region as well as cross jurisdictional, drainage basin, and political boundaries. Boundaries for planning areas were originally self-determined by interested districts with common water resources issues and needs but were ultimately modified and accepted through a regional acceptance process administered and reviewed by CADWR (California Department of Water Resources 2014f).

Analysis Methods for Climate

Characterization of Recent Conditions

To evaluate existing climate characteristics relevant to Ellicott Slough Refuge, climate station information and PRISM data were summarized to estimate precipitation,

[9] Districts with CVP contracts are areas where federal CVP contracts provide water to the district in California. More information about the CVP can be found at http://www.usbr.gov/mp/cvp.

[10] SWP district boundaries are areas where state contracts provide water to the district in California. More information on the SWP can be found at http://www.water.ca.gov/swp.

[11] Private water district boundaries are areas where private contracts provide water to the district in California.

[12] Regulations and authorities regarding California IRWMP were established by State Proposition 84 of 2006, which authorizes grant funding for a wide variety of water resources projects; this authorization resulted in a modification of the California Water Code Section 10541(f), effective March 2009, to provide guidance on the definition and objectives of IWRMP regions.

temperatures, and evapotranspiration conditions that affect the refuge. In general, climate data were used to assess the following near the refuge:

- range of observed daily and monthly temperatures
- range of observed monthly and annual precipitation
- comparison of both temperature and precipitation near the refuge and in the surface water RHI
- range of daily and annual reference evapotranspiration (ETo) near the refuge

Two climate stations were selected for analysis of recent conditions. The Watsonville Waterworks station (station 16, figure 7; GCHN station 49473) was selected for analysis of temperature and precipitation conditions near the refuge. This station was optimal for estimating climate conditions at the refuge because the period of record was 1908–present. The Green Valley station (also known as Freedom station 3, figure 7; CIMIS station 111) was selected to evaluate ETo. This station was optimal for estimating ETo near the refuge because it was the closest station to the refuge (2.1 miles) with the longest and most consistent period of record (1992–present) of those CIMIS stations inventoried.

To plan for effective water resource management, an understanding of the expected interannual variability of climate, or climate predictability, is required. Climate change may pose further uncertainty regarding this variability; however, a baseline understanding of the current variability in climate conditions that affect the refuge can help evaluate future impacts associated with the magnitude, frequency, and duration of climate conditions.

An understanding of global climate factors and large-scale circulation patterns that influence the variability of temperature and precipitation at a scale relevant to refuge water resources is useful for understanding climate predictability. Numerous studies have examined the use of teleconnection indices that indicate the effect of these large-scale circulation patterns on local climate (temperature and precipitation).

For example, the El Niño–Southern Oscillation (ENSO) phenomenon[13] as indicated by the Southern Oscillation Index[14] (SOI), is related to precipitation, snow accumulation, and streamflow in western North America (Cayan et al. 1998; Francis et al. 1998). During El Niño, the southwest tends to be wet and the northwest tends to be dry (negative SOI)—and conversely so for La Niña (positive SOI) (Dettinger et al. 1998). Redmond and Koch (1991) showed that October–March precipitation was most strongly correlated with SOI averaged over the July–November period.

Another teleconnection index commonly analyzed is the Pacific Decadal Oscillation (PDO),[15] which is related to precipitation and temperature. Gershunov and Barnett (1998) demonstrated that when PDO and ENSO are in phase (El Niño—warm PDO; La Niña—cold PDO), the ENSO climate signals described above are stronger and more stable with regard to winter precipitation in the western United States, whereas out-of-phase relations between PDO and ENSO have a weaker climate signal.

Precipitation and temperature data from the Watsonville Waterworks climate station were compared with SOI and PDO to determine if these teleconnections were strongly linked to temperature and precipitation affecting the refuge and whether these teleconnections can be used to predict climate characteristics at and near the refuge.

[13] El Niño is an oscillation of the ocean temperatures in the equatorial Pacific that has implications for global weather. El Niño is characterized by unusually warm ocean temperatures, whereas La Niña is characterized by unusually cool temperatures in the equatorial Pacific (National Oceanic and Atmospheric Administration 2014b).

[14] The SOI is an index that combines the Southern Oscillation (differences in ocean temperatures in the equatorial Pacific) and is computed as monthly mean sea level pressure anomalies at Tahiti and Darwin (National Oceanic and Atmospheric Administration 2014c).

[15] The PDO is a pattern of Pacific climate variability that shifts phases on an inter-decadal scale (20–30 years) and is detected as warm or cool surface waters in the Pacific Ocean north of 20 degrees latitude (National Oceanic and Atmospheric Administration 2014d).

A Kruskal–Wallis test[16] was used to compare the distribution of cool-season precipitation (October–March, as percent above mean) and temperature (average annual in degrees Fahrenheit [°F]) to the distribution of SOI (July–November) and PDO (October–March). SOI was divided into phases of El Niño years (SOI of less than or equal to -0.5), neutral years (SOI between -0.5 and 0.5), and La Niña years (SOI greater than or equal to 0.5). PDO was divided into phases of warm years (PDO greater than 0.5), neutral years (PDO between 0.5 and -0.5), and cool years (PDO less than -0.5). Temperature and precipitation values for each year were assigned the teleconnection categories listed above based on the corresponding year. The Kruskal–Wallis test was run to compare more than one distribution in multi-distribution groups to determine which distributions were different. Results of the Kruskal–Wallis test are presented as a table in this report. A boxplot was developed to show differences in the distributions of temperature and precipitation between teleconnection groups.

Estimation of Trends in Response to Climate Change and Anthropogenic Stressors

To evaluate existing trends between precipitation and temperature resulting from climate change, time-series trends in precipitation and temperature were evaluated for the PRISM dataset because long-term information (1910–present) were available. Time-series were generated from monthly precipitation (total inches) and monthly temperature (maximum, minimum, and range of difference between maximum and minimum) for the following aggregated time-periods: seasonal (four seasons), cool-season (October–March), and annual. In addition, time-series were generated for precipitation and temperature (range of difference between maximum and minimum only) for 12 separate months.

The Kendall's tau statistical time-series trend test was run to test whether all time-series trends were statistically significant at a p-value of 0.05 (Sen 1968; Dietz 1989; Kendall and Gibbons 1990) and compute the Sen slope.[17]

Because the Kendall's tau statistical test is used to estimate the presence of a monotonic trend (singular direction with time), smaller scale shifts (shifts in climate within the period of record tested) in climate may result in signal noise that precludes accurate detection of trends over a long period of time (Helsel and Hirsch 2002:323–334). To determine which parameters had the most persistent trends (trends that remained significant and in the same direction for variable time periods over the period of record), the following time-periods were tested: 1910–2012, 1925–2012, 1950–2012, and 1983–2012 (last 30 years).

To evaluate existing precipitation and temperature trends as a result of climate change, time-series trends in annual and seasonal precipitation and temperature were evaluated for the Watsonville Waterworks climate station because long-term information (at least 1908–present) was available.

Climate change projections for temperature, precipitation, PET, CWD, and recharge within the refuge boundaries were modeled by comparing four climate change scenarios overlayed with BCM model inputs and outputs by comparing mean conditions for 1971–2010, 2010–2039 (near future), and 2070–2099 (distant future). Climate change scenarios were modeled in BCM using six different General Circulation Models (GCMs): Geophysical Fluid Dynamics Laboratory (GFDL) model, Model for Interdisciplinary Research on Climate (MIROC Medres), Beijing Climate Center China Meteorological Administration Model (BCC_CSM), Bergen Climate Model Version 2 (BCCR_BCM2), Parallel Climate Model General

[16] The Kruskal–Wallis test was used to compare multiple datasets simultaneously to determine if the locations of distributions among all groups were statistically different at a p-value of 0.05.

[17] Kendall's tau test is a non-parametric statistical test that can be used to indicate the likelihood of upward or downward trends in data with time. Tau coefficients range from -1.0 to 1.0; a tau of -1.0 indicates that every datum decreased with time, and a tau of 1.0 indicates that every datum increased with time. A trend slope is a measure of trend magnitude that was computed using the Sen slope estimator. The Sen slope is estimated by computing the median of all slopes between each possible data pair in the time-series (Sen 1968).

Circulation Model (PCM), and the Commonwealth Scientific and Industrial Research Organization (CSIRO). All models were run using medium to high carbon dioxide emissions or medium to high increase in carbon dioxide concentrations; all models were run using the A2 emissions scenario,[18] with the exception of BCC_CSM which was run under the similar RCP6.0[19] carbon concentration scenario (Flint and Flint 2012).

Climate change will result in global sea level rise that could ultimately affect flow dynamics in coastal estuaries, sloughs, and drainage basins. A literature review of known impacts of sea level rise in the Monterey Bay region was performed to evaluate climate change as a potential threat or change to refuge water quantity and quality. Of particular note, a modeling study of the Watsonville Slough system (Balance Hydrologics 2014) examined the impact of sea level rise in 2050 and 2100 on water levels in Harkins Slough and other sub-watersheds using a HEC-RAS hydrodynamic model.[20]

Analysis Methods for Surface Water

The four units of Ellicott Slough Refuge are affected heavily by surface water. Natural runoff is used to supply water to managed ponds and Harkins Slough. Complex flow dynamics in the Watsonville Slough affect water supply to Harkins Slough (U.S. Fish and Wildlife Service 2010a).

Characterization of Recent Conditions

No long-term gaging records were available to evaluate trends or characteristics of surface water supply to refuge units, but supplementary sources were used to characterize surface water supply at the refuge. A literature review was performed for previous modeling projects used to determine drainage basin size and flow characteristics for each managed pond or water body in the refuge (Ellicott Pond, Prospect Pond, Buena Vista Pond, Calabasas Pond, and Harkins Slough).

Where this information was lacking, the USGS StreamStats web application (U.S. Geological Survey 2014a) was used to generate estimates of drainage areas and flood-flow characteristics. StreamStats uses a regional regression to estimate flood-flow characteristics based on drainage basin size, altitude, and mean annual precipitation (Gotvald et al. 2012). StreamStats allows for delineation using a 10-meter DEM and flow path information obtained from manual editing and processing of the NHD dataset of major stream sources (Ries et al. 2008).

Drainage patterns were analyzed throughout the surface water RHI to better understand water sources and directions of flow on and near the refuge. A flow accumulation grid was obtained from NHD Plus (Horizon Systems Corporation 2014) and was used to generate estimates of generalized flow directions. The flow accumulation grid was generated from a 10-meter DEM. Flow arrows were added to areas receiving flow from a minimum upstream drainage basin area of 0.0002 square mile.

A comprehensive set of hydrologic and hydraulic models was developed for the Watsonville Slough system (which includes Harkins Slough) by Balance Hydrologics for the Santa Cruz County Resource Conservation District (Balance Hydrologics 2014). This analysis included a 1-year period of enhanced surface water monitoring through flow and water elevation gages and water quality sampling stations. The analysis was used to gain a better understanding of the intra-annual and interannual

[18] Several families of emission scenarios are discussed in the International Panel on Climate Change's fourth assessment report. Scenario A2 is the carbon emissions in a differentiated world and is characterized by self-reliance in terms of resources and less emphasis on economic, social, and cultural interactions between global regions. Economic growth is uneven, and the income gap between now industrialized and developing parts of the world does not narrow (Solomon et al. 2007).

[19] Representative Concentration Pathways (RCP) are four greenhouse gas concentration trajectories adopted by the International Panel on Climate Change for its fifth assessment report (Richard et al. 2008). Each trajectory represents a possible range of radiative forcing values in the year 2100 relative to pre-industrial values.

[20] HEC-RAS is River Analysis System developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (for more information, see http://www.hec.usace.army.mil/software/hec-ras).

flow and water level characteristics of the Watsonville Slough system and to help simulate various scenarios such as sea level rise, changes in water export, and changes in maintenance of channels and infrastructure (Balance Hydrologics 2014). A HEC-HMS hydrologic model was developed for the Watsonville Slough and used to compute the initial water balance for Harkins Slough based on rainfall, irrigation losses, groundwater percolation, evapotranspiration, and pumped export of water. Major highlights of that study as they relate to understanding the dynamics of Harkins Slough were summarized.

Estimation of Trends in Response to Climate Change and Anthropogenic Stressors

No data were available to evaluate the response of surface water to climate change on and near Ellicott Slough Refuge. However, results from a hydrologic assessment by Balance Hydrologics (2014) were summarized; the report summarized flow records and modeled changes in flow to investigate impacts of water infrastructure changes and maintenance and sea level rise on flow dynamics of Harkins Slough and the larger Watsonville Slough.

Analysis Methods for Groundwater

Ellicott Slough Refuge relies on pumped groundwater for maintenance of managed ponds in the Ellicott Unit (Ellicott Pond and Prospect Pond). Wells are also located in the Harkins Slough Unit but are not currently used (WestWater Research 2014).

Characterization of Recent Conditions

Groundwater in and near the groundwater RHI was analyzed in various reports. Information about flow direction, recharge, yield, and other current groundwater conditions were summarized for the groundwater RHI. A groundwater level map was developed for the PVWMA groundwater basin management plan (Carollo Engineers 2013). This map was used to describe average water level conditions and groundwater flow direction.

Estimation of Trends in Response to Climate Change and Anthropogenic Stressors

The period of record for available groundwater levels in the groundwater RHI is not long enough (less than 30 years) to analyze long-term trends in response to climate change or anthropogenic stressors. However, Carollo Engineers (2013) investigated trends in groundwater levels in response to groundwater extraction and seawater intrusion. See section 4.4, “Groundwater.”

Analysis Methods for Water-Related Habitats, Water Management, and Infrastructure

A summary of the presence of water-related habitats in each refuge unit was made using vegetation data from the Service (see section 3.1, “Geographic Information System Data and Maps”) and NWI. The percentage of the unit that includes water-related habitats was stated.

Current water management information was obtained from interviews with refuge staff and mapping of infrastructure within refuge units. Additional details about infrastructure were summarized from existing plans for pond construction for Ellicott Pond and Prospect Pond in the Ellicott Unit and Buena Vista Pond in the Buena Vista Property.

Water management needs and an optimal hydroperiod for management of selected priority species of concern, including threatened and endangered amphibians (SCLTS, CTS, and CRLF; WestWater Research 2014), were determined from available literature.

The relation between amphibian recruitment and seasonal precipitation was assessed to determine if water availability in ponds affected recruitment success. Climate conditions were used because water level information for managed ponds was not available at the time of this report. Annual recruitment surveys were available over the period 1992–2013 with qualitative information concerning whether ponds were dry by the end of the summer or were supplemented with groundwater (D. Kodama, refuge manager, U.S. Fish and Wildlife Service; digital communication; May 2014). Recruitment data were available for Ellicott Pond for 1992–2013, Buena Vista Pond for 2009–2013; and Calabasas Pond for 2006–2013. Recruitment data were available for SCLTS and CTS for all ponds except Calabasas in which recruitment data were only available for SCLTS. Total precipitation over the period October–July was used to correlate to recruitment success. Precipitation was averaged from monthly PRISM grids over the water supply basins for the Buena Vista Property, Ellicott Unit, and Calabasas Unit. The delineation points for these three units were placed at the lowest elevation where water leaves the managed refuge boundary (to account for all water within and upstream of the unit). Delineations of water supply subbasins were made using USGS StreamStats.

The modeling study by Balance Hydrologics (2014) was used to summarize water level conditions for Harkins Slough. Balance Hydrologics (2014) used the HEC-RAS model to estimate water level characteristics in Harkins Slough (mean and annual range of water elevation) and to simulate the impact on water levels under various scenarios such as sea level rise, changes in water export, and changes in maintenance of channels and infrastructure (Balance Hydrologics 2014).

Analysis Methods for Water Quality

Assessment of Recent Conditions

Refuge water quality was assessed by summarizing water quality reports for areas in and near the refuge, assessing the latest 303(d) and 305(b) status for surface water supplies within the surface water RHI, identifying potential contaminant sources on and near the refuge, and comparing selected water quality data with established USEPA aquatic life criteria. Information about the Clean Water Act and the definition of 303(d) and 305(b) status for applicable waters can be found in appendix D. Previous water quality reports analyzed included a CAP report summary for the refuge (Aceituno 2010). In addition, published reports and studies relating to relevant water quality information were identified and summarized in this report. Previous water quality studies were referenced only if published reports could be located.

Both 303(d) (listed) and 305(b) (assessed) waterbodies were identified for stream segments within the surface water RHI. The 2008–2010 Integrated Report web map application was used to identify impaired reaches under the 303(d) guidelines. Results from the 2008–2010 Integrated Report were available through SWRCB as GIS data files and through an interactive map (California State Water Resources Control Board 2014c). The GIS data files and interactive map were used to locate listed reaches on and near the refuge, and information about the status and schedule for total maximum daily load (TMDL) development was shown for any 303(d) reaches. The 305(b) reaches were used to determine which reaches have data available and to identify potential data gaps for water quality information relevant to the refuge.

Potential contaminant sources that could affect refuge groundwater and surface water were identified using the USEPA Envirofacts Database (U.S. Environmental Protection Agency 2014a) and California GeoTracker (California State Water Resources Control Board 2014a). Contaminant sources contained in these databases were used to inventory sites assumed to have the most direct impact on groundwater and surface water quality near the refuge. Queried USEPA data systems are listed below (sites may be listed in more than one of these data systems):

- Permit Compliance System (PCS), which lists sites with National Pollutant Discharge Elimination System discharge permits
- Resource Conservation and Recovery Act Information (RCRAInfo), which lists hazardous waste storage/disposal sites (including active and conditionally exempt small quantity generators and transporter sites)
- Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), which lists superfund sites
- Toxic Release Inventory (TRI), which lists sites that release various toxic chemicals in the environment

PCS sites were inventoried if they were upstream of refuge resources; these sites were inventoried using the same criteria used for selecting surface water monitoring stations. RCRAInfo, CERCLIS, and TRI sites were inventoried using the same criteria used for selecting groundwater monitoring stations. Sites listed in RCRAInfo, CERCLIS, and TRI were assumed to have a more direct effect on groundwater because contamination at these sites is typically confined to areas of land not directly connected to streams or other surface waterbodies. PCS sites were assumed to have a more direct effect on surface water because permitted discharges are connected to surface waterbodies.

California GeoTracker data were used to inventory the following sites:

- GeoTracker cleanup sites, including land disposal, leaking underground storage tanks, SWRCB cleanup program sites, and military cleanup program sites
- Permitted underground storage tanks

All California GeoTracker contaminant sources were assumed to be localized and disconnected from surface water drainage systems; therefore, an assumption was made that these sources posed more of a threat to groundwater than to surface water. However, it is possible for contaminants to be transported off-property during storm events and contribute to surface water drainage systems, especially if the contaminant source is not properly contained or protected by erosion-control infrastructure.

Readily available water quality data for stations on and near the refuge were compared to USEPA aquatic life criteria (freshwater criteria continuous concentrations, or CCCs[21]) to determine if thresholds had been exceeded. Constituents from these sites were compared to established CCCs only if the required part of water (dissolved or total[22]) matched the designated threshold of the CCC. In addition, the CCC thresholds for several constituents such as lead, cadmium, zinc, and nickel are related to hardness; accordingly, these constituents were only compared to CCCs if hardness data were available.

Estimation of Trends in Response to Anthropogenic Stressors

The period of record for water quality data is less than 10 years. This period is not long enough to analyze long-term trends in response to anthropogenic stressors.

3.4 Development, Scoping, and Ranking of Recommendations

Inventory and assessment of refuge water entitlements and policy, climate, surface water, groundwater, soils, habitats, water management, and water quality were used to determine 20 potential IOCs for the refuge that were relevant to existing refuge management objectives. These specific objectives were intended to help better understand or mitigate water-related threats.

Based on these IOCs, 15 recommendations for monitoring activities or management actions were developed; these are identified throughout this report and are summarized in "Chapter 5—Summary of Issues of Concern and Recommendations." Recommendations are tied back to relevant IOCs.

Scoping Recommendation Costs, Timeframes, and Participants

The time and costs required to implement recommendations were estimated for each recommendation. Costs do not necessarily reflect new costs to the refuge budget but do

[21] The CCC is an estimate of the highest concentration of a material in surface water to which an aquatic community can be indefinitely exposed without an unacceptable effect resulting (U.S. Environmental Protection Agency 2014b).

[22] Dissolved samples are those that have been filtered for particulates and are dependent upon the filter size used. Total samples are whole samples that are not filtered. Concentrations of total samples are often greater than concentrations of dissolved samples because some constituents, such as nitrogen and phosphorus, bind to particulates that might be filtered out of dissolved samples. Aquatic life criteria are often used for dissolved samples because it is assumed that dissolved constituents are more readily available for biological uptake.

include both equipment and salary time regardless of whether these costs are already paid for by another project or program. For recommendations to implement long-term baseline monitoring, the number of years was capped at 3, which was assumed to be the minimum number of years needed to derive beneficial information to address the associated IOC. Estimates of time and costs apply only to the actions involved in the recommendation itself and do not reflect the cost and time required for any associated prerequisites. Estimated costs are subject to error, and those costs would be borne by the agency or group that conducts the recommended action; estimated costs do not necessarily reflect costs to the refuge budget.

Potential participants in each recommended action were identified based on their capabilities to perform work related to the recommended action. However, actual participants are subject to change dependent on staff capacity or agency objectives.

Ranking Recommendations

The 15 recommendations were ranked based on their ability to address the 20 IOCs, their ability to meet 10 water-related objectives to better understand or mitigate water-related threats, and their feasibility in terms of time and cost. In total, 6 of the 10 objectives used for evaluation were specifically identified by refuge staff during several needs assessments conducted by the Service Region 8 I&M Initiative (Richmond et al. 2012; WestWater Research 2014). One of the 10 objectives (locating suitable ponds) was identified from the comprehensive conservation plan and discussions with refuge staff in October 2014.

- **Ensure an optimal hydroperiod for habitat management:** Help Ellicott Slough Refuge staff better understand and plan for the hydroperiod of salamander breeding ponds (retention and draining of water at appropriate times of year) to ensure that water management activities support breeding and recruitment success.
- **Help create connectivity between upland and wetland habitats to improve recruitment success:** Identify locations where new breeding ponds could feasibly be developed based on water supply access and drainage characteristics.
- **Protect groundwater supply:** Help Ellicott Slough Refuge staff better understand factors that control groundwater availability in the aquifer and impacts from groundwater extraction in the region.
- **Determine best use for existing infrastructure:** Help Ellicott Slough Refuge staff determine the best uses of existing water infrastructure on the Harkins Slough Unit.
- **Understand water uses in surrounding region:** Help Ellicott Slough Refuge staff better understand water uses and water rights in the drainage basins surrounding the refuge.
- **Assess impact of contaminant sources:** Help Ellicott Slough Refuge assess impacts from agricultural runoff (sedimentation, herbicides, pesticides, and fertilizers) on Harkins Slough. Determine impact of degraded water quality from water sources to all refuge units (including groundwater and storm runoff).
- **Improve water rights reporting:** Ensure that water use reporting for water rights is being filed accurately, consistently, and correctly.

The remaining three objectives—one of which was based on a goal—were identified in the "I&M Annual Work Plan for Fiscal Year 2013" (U.S. Fish and Wildlife Service 2013):

- **Provide water rights information to improve decisionmaking** (Objective 2.6[23]).
- **Improve access to hydrologic data to improve decisionmaking** (based on Goal 1[24]).

[23] Objective 2.6 includes developing a plan to improve access to water rights information for refuges in the Pacific Southwest Region to help those refuges meet legal requirements (U.S. Fish and Wildlife Service 2013:6).

[24] Goal 1 involves accessing information so that refuges and their partners have easy access to priority refuge natural resource data to support effective analysis and decisions, meet legal requirements, protect the Refuge System's investment in data collection, and provide continuity when staff changes (U.S. Fish and Wildlife Service 2013:5).

- **Understand impacts of climate change:** Assess the exposure and vulnerability of national wildlife refuges to climate change (Objective 2.8[25]).

Recommendations were listed in ranked order, with priority placed on the top five recommendations and associated prerequisites. Additional information about the scoring criteria and process can be found in appendix C.

[25] Objective 2.8 includes plans to analyze the effects of climate change on water resources (water supply and evapotranspiration demands) for selected refuges and to begin evaluating the feasibility of applying this analysis to additional refuges (U.S. Fish and Wildlife Service 2013:7).

Chapter 4—Inventory and Discussion of Refuge Water Resources

4.1 Water Entitlements and Policy

Refuge Water Rights

The Service is owner and claimant to one licensed appropriative water right, Application Number 18687, which is associated with the Calabasas Unit. This right has a priority date of May 1, 1959, and was initially established under private ownership. The right has an official purpose for stockwatering and recreational use, which was the beneficial use employed by the previous owner and claimants of the water right. The maximum diversion rate is 48 acre-feet per year to be collected for storage, and the period of collection is October 1 to May 1. The license permits the licensee to keep the reservoirs full by replacing water beneficially used, or lost through evaporation and seepage, and to refill the reservoir if emptied for necessary maintenance or repair (California State Water Resources Control Board 1967).

The point of diversion is at the southern end of the Calabasas Unit, and diverted water is currently being stored in a pond for salamander breeding; this use does not match the official purpose of use for the right. Refuge staff have expressed concern regarding whether storing water in the pond for salamander breeding constitutes the beneficial use of stockwatering and, if not, whether the purpose of use should be changed. **The Service should determine whether changing the purpose of use to match the actual beneficial use is the best course of action and, if so, the Service should start the process to change the purpose of use to "fish and wildlife protection and enhancement."**

Refuge staff believe the water allocated could have been the amount needed to fill a former reservoir on the property (D. Kodama, refuge manager, U.S. Fish and Wildlife Service; oral communication; January 2014). Historically, refuge staff have reported the maximum amount to prevent the loss of the right to non-use. Staff have reported water storage as the estimated average depth of the pond when the pond is deepest (4 feet) multiplied by the acreage of the pond.[26] However, at the time of this report, no reports could be found on the eWRIMS system. **The Service should ensure that water use reports are being properly submitted to the SWRCB under the water right.**

Other smaller ponds on other units are currently being managed by refuge staff for salamander breeding: Ellicott Pond, Prospect Pond, and Buena Vista Pond. The State of California requires uses of small domestic impoundments to be registered; uses include incidental stock watering and irrigation use, small irrigation use, and livestock pond use. Of uses listed by SWRCB, livestock pond use most closely matches the current use of these ponds; this use is defined as a water impoundment structure constructed for livestock watering use

[26] The acreage of the pond was estimated from aerial imagery to be 2.6 acres, but this size does not necessarily reflect the acreage of maximum pond extent or the acreage that the refuge has used to report water use to SWRCB. Because records could not be located, the acreage used in this computation was not available at the time of this report.

not to exceed direct diversion of 4,500 gallons per day, or diversion to storage of 10 acre-feet per year, and this use allows for incidental aesthetic, recreational, or fish and wildlife purposes (California State Water Resources Control Board 2014e). At this time it is unknown whether refuge ponds exceed these size or diversion quantities.

To accurately estimate water use for reporting to SWRCB and to determine whether water rights are sufficient to cover existing refuge water uses, the Service should conduct a bathymetric survey and develop a water monitoring program at all ponds to determine water storage and use. Service staff can measure water use by measuring outflow from Calabasas Unit (see section 4.5, "Water-Related Habitats, Water Management, and Infrastructure") and by measuring water levels in the pond. The weir stick method can be used to estimate flow from Calabasas Unit as the outflow (see section 4.5). **Development of bathymetry for the pond in the Calabasas Unit would allow for estimation of water storage in the pond at different water level elevations.** Further investigation is needed to ensure that this is the most efficient method for water rights reporting.

A water rights map was not developed for this report because place of use information was not available in a digital format at the time of the report. However, water rights maps are useful for managing water rights, including understanding legal diversions and applications of water. **The Service should delineate legal POU data to develop a water rights map for Ellicott Slough Refuge.**

Other Water Rights

Four other appropriative water rights were found to be active within the surface water RHI at the time of this report, for a total maximum diversion of 2,034.9 acre-feet per year (figure 9; appendix B, table B4).

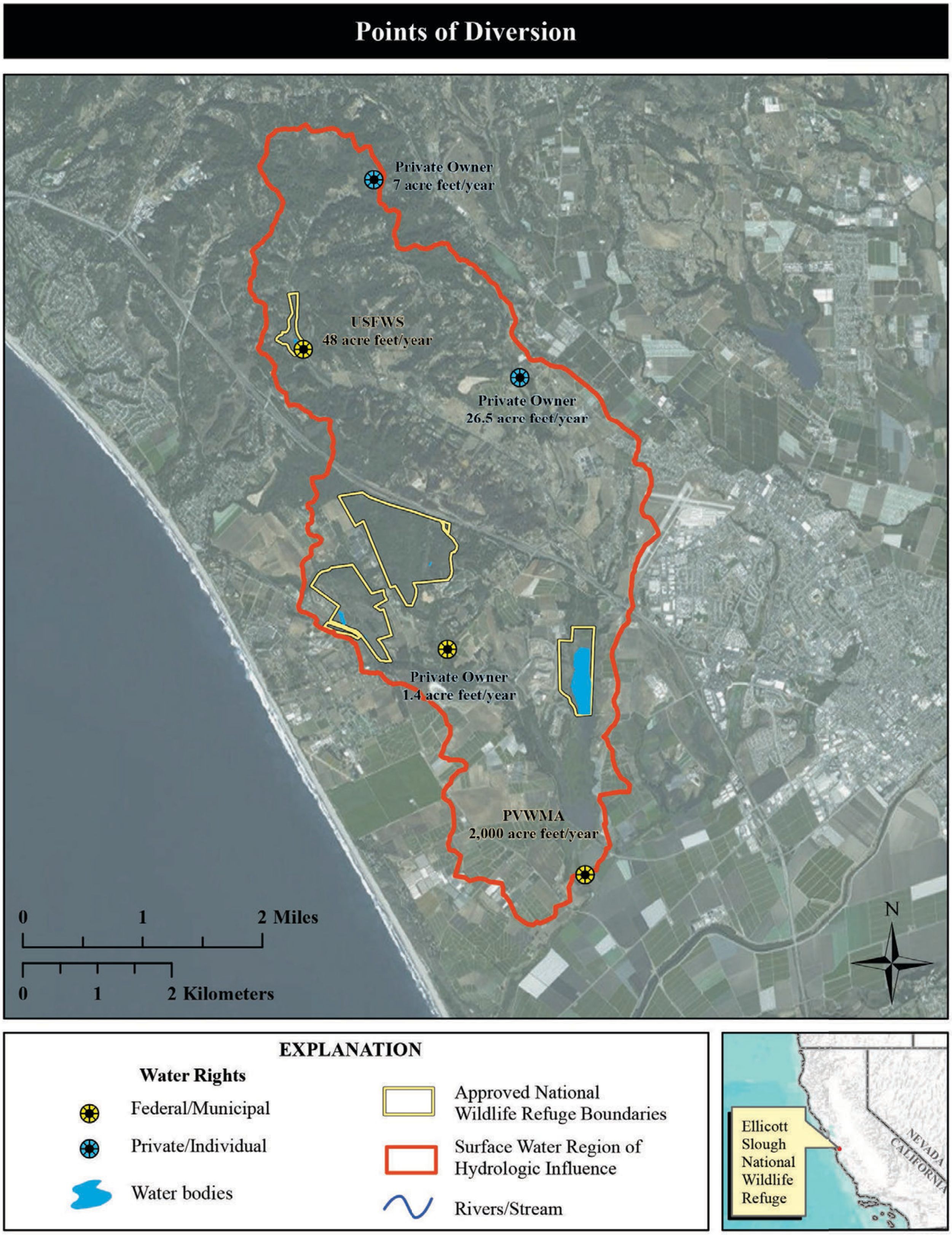
Two rights were located upstream of refuge units. The smallest upstream water right of 7 acre-feet per year is a privately owned right located upstream from the Calabasas Unit (figure 9) for an unnamed tributary to Harkins Slough. The priority date for this right is June 22, 1959, and the official purposes are for stockwatering, domestic use, fire protection, and irrigation. Another right for Harkins Slough is for diversion of 26.5 acre-feet per year. The priority date for this right is August 19, 1957, and the purposes are irrigation, stockwatering, and recreational use. The water right is most likely downstream of Calabasas Unit and upstream of the Harkins Slough Unit. The mapped point of diversion is about 1.5 southeast of the Calabasas Unit but is not on any mapped body of water (figure 9), which may be the result of an error in the documented location of the right.

Two additional rights were found within the Harkins and Gallighan Sloughs but are downstream from refuge water sources. A right for 2,000 acre-feet per year on Harkins Slough is owned by PVWMA and is used for industrial, irrigation, recreation, fish and wildlife enhancement, stockwatering, fish culture, and municipal use. This water right is used to supply water for a groundwater recharge project, although the estimated yield of that project is 1,100 acre-feet per year (Carollo Engineers 2013). Water diverted through this project may impact water levels and water quality in Harkins Slough (see section 4.3, "Surface Water," and section 4.7, "Water Quality"). A small right for 1.4 acre-feet per year is privately owned on Gallighan Slough and is used for industrial use, stockwatering, and fire protection. This small right is not estimated to have any impact on refuge water resources.

At this time none of the rivers associated with or near the refuge units (Harkins Slough, Gallighan Slough, or the Pajaro River) are fully appropriated streams according to CADWR. This indicates that water rights claims may be filed in the future to extract water from these rivers.

Groundwater Regulation

Ellicott Slough Refuge is part of the PVGB, which is designated by CASGEM as a high priority basin. CASGEM ranked this basin with a priority of 24.75 (statewide, the highest priority basin is ranked 27). According to CASGEM, the PVWMA has indicated that the PVGB is significantly in overdraft due to



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10; Map Production Date: March 7, 2014; Source Data: Imagery from U.S. Department of Agriculture National Agriculture Imagery Program (NAIP) 2012 ESRI Online Map Services; Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, May 2014; Streams from U.S. Environmental Protection Agency (EPA) and the U.S. Geological Survey (USGS) National Hydrography Dataset (NHD) Plus Version 2.1, 2012; Points of Diversion from California Waterboards Online GIS Service, 2013; Region of Hydrologic Influence boundaries delineated from 10-meter digital elevation model USGS, 2014

Figure 9. Locations of water rights in the region of hydrologic influence for Ellicott Slough National Wildlife Refuge.

continued seawater intrusion and groundwater storage depletion.

Designation of the PVGB as a high priority basin in overdraft means that a groundwater sustainability plan must be developed for this basin by 2020. Additionally, a local groundwater management authority—to be determined under state groundwater policies—may have the authority to enforce groundwater use measures to achieve sustainability under this plan. This could include groundwater use inspections, monitoring and reporting, curtailment, and fees. **The Service should continue to follow developments with groundwater sustainability planning in the PVGB to better help Ellicott Slough Refuge prepare for monitoring and reporting of groundwater use per future requirements.**

Other Water Supply Agreements and Planning Efforts

Pajaro Valley Water Management Agency

Ellicott Slough Refuge is completely within the PVWMA (figure 10). PVWMA was founded in 1984 and is a state-chartered water management district with the authority to manage existing and supplemental water supplies to prevent overdraft and to provide sufficient water supplies to users within the district. Groundwater overdraft and seawater intrusion are substantial issues within the region, which is dependent on groundwater for irrigation (see section 4.4, "Groundwater," and section 4.7, "Water Quality"). PVWMA has the authority to manage groundwater resources in the basin, although priority agency activities are typically focused on halting seawater intrusion by balancing overdraft conditions in the basins and on projects to supply non-potable irrigation water (Pajaro Valley Water Management Agency 2014). The priority of PVWMA activities is agricultural use. However, the refuge utilizes groundwater for maintenance of some ponds in the Ellicott Unit (see section 4.4, "Groundwater," and section 4.5, "Water-Related Habitats, Water Management, and Infrastructure"); therefore, projects and actions implemented by PVWMA for groundwater management may have an impact on refuge water resources. PVWMA currently has contracts to import water under the CVP administered by the U.S. Bureau of Reclamation. PVWMA has an existing contract for 6,260 acre-feet per year from CVP to be acquired from Mercy Springs Water District as well as a pending contract for an additional 19,900 acre-feet per year. PVWMA also has the ability to enter into groundwater banking agreements and purchase water from other contractors (Carollo Engineers 2013).

A basin management plan (BMP) guides and prioritizes all of the major projects and programs pursued by PVWMA. The current version of the BMP was adopted in 2002 and includes five major programs and projects: a recycled water program, water conservation program, a coastal distribution system and pipeline, the Harkins Slough Recharge Project, and an imported water pipeline to convey CVP water with local aquifer storage and recovery (Carollo Engineers 2013). Of these, the Harkins Slough Recharge Project is most directly relevant to the Ellicott Slough Refuge. Completed in 2011, this project diverts water from Harkins Slough to a groundwater recharge basin downstream from the refuge. From this basin, it is pumped and distributed to users throughout the basin through a coastal distribution system. The coastal distribution system does not cover refuge lands (Carollo Engineers 2013; see section 4.3, "Surface Water").

Integrated Regional Water Management Plans

Ellicott Slough Refuge is within the Santa Cruz County Integrated Regional Water Management District (SCCIRWMD; figure 11). This district is a multi-stakeholder and multi-agency planning effort. The initial integrated regional water management plan was funded in 2005 through the Proposition 50 Bond Measure. The plan allows the SCCIRWMD to identify updated priorities and strategies that address water resource challenges facing the region. Additional funding was awarded by the SWRCB in 2007 and by CADWR in 2011 to support plan updates and technical studies (Santa Cruz Integrated Regional Water Management 2014).

Several projects completed or planned under this management plan may be beneficial to refuge management and water resources. These include the Watsonville Sloughs Integrated Watershed Restoration Program, the Stormwater Pollution Prevention Program, a series of groundwater recharge projects, and the Watsonville Sloughs Hydrology Study.

The Watsonville Sloughs Integrated Watershed Restoration Program restored 11.5 acres of habitat and resulted in reduced sediment load delivery potential. Phases 1 and 2 of the program implemented 40 habitat and/or water quality restoration projects (Santa Cruz Integrated Regional Water Management 2014).

The Stormwater Pollution Prevention Program may improve water quality throughout the county and at the refuge, which receives some water from upland runoff. Projects under this program include public outreach, green business certification, pilot projects to reduce herbicide application for treatment of invasive species, and installation of water clarifiers at county facilities (Santa Cruz Integrated Regional Water Management 2014).

SCCIRWMD's series of projects to enhance groundwater recharge include determining suitable locations for recharge, developing stormwater recharge designs to capture runoff, and completing a pilot facility for the stormwater recharge capture (Santa Cruz Integrated Regional Water Management 2014).

The Watsonville Sloughs Hydrology Study was a combined modeling and hydrologic monitoring project with the goal of producing data and modeling tools to better understand the hydrology and hydraulics of Watsonville Slough. The study can be used to support the development of resource management strategies to enhance water supply, flood management, ecosystem restoration, water quality, and recreational opportunities. The hydraulic and hydrologic models of the entire slough system that were developed will provide a means to better understand the overall function of the sloughs (Balance Hydrologics 2014).

4.2 Climate

Recent Conditions

The mean monthly temperature near Ellicott Slough Refuge was 46.6 °F and ranged from 28.9 to 56.7 °F.[27] Generally, maximum temperatures were observed in June and July and minimum temperatures were observed in December and January (figure 12). The month and year with the greatest mean monthly temperature near the refuge was July 1992 (56.7 °F).

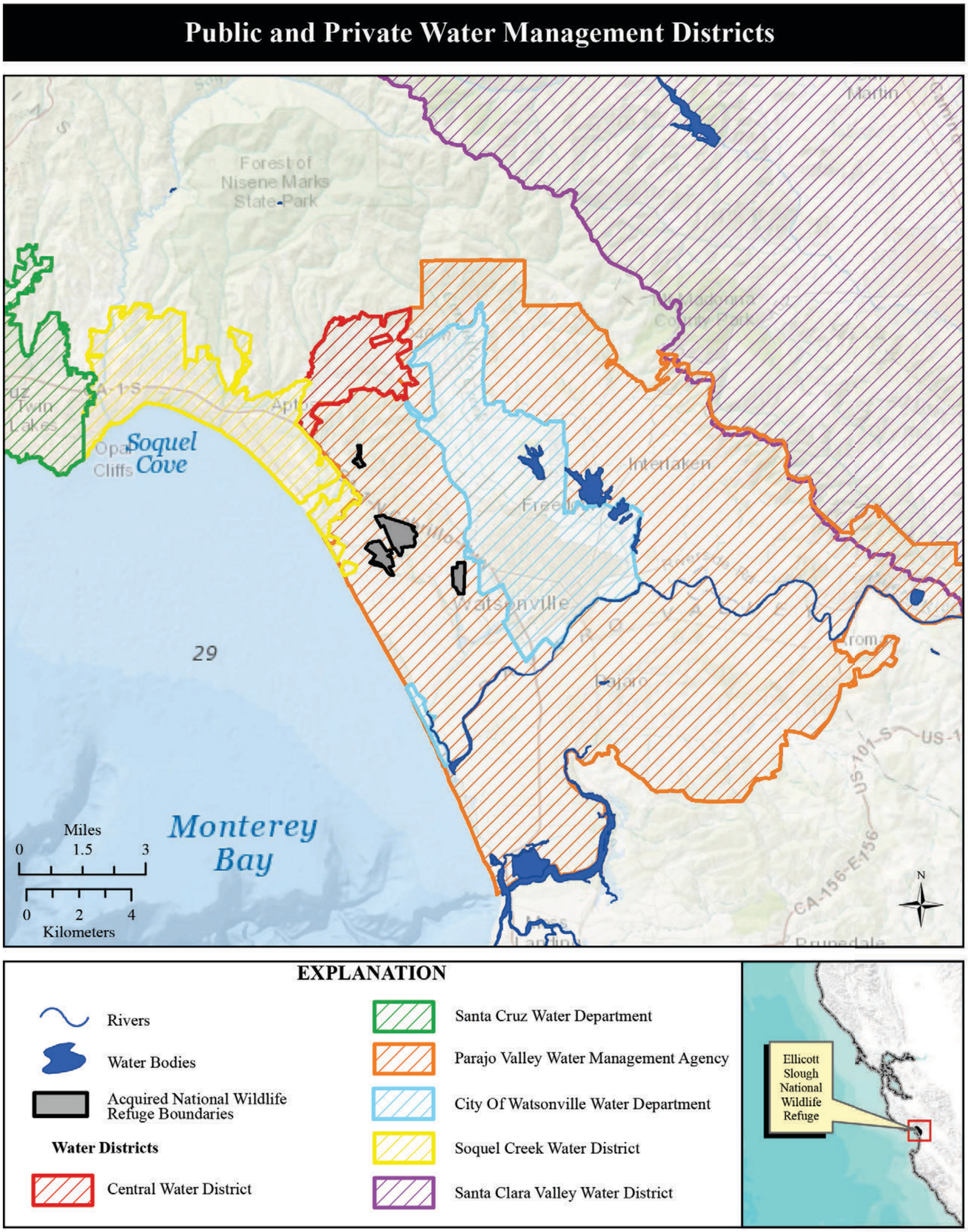
The mean total water year precipitation near Ellicott Slough Refuge was 21.7 inches per year.[27] Annual precipitation ranged from 8.9 inches in 2002 to 46.3 inches in 1998. Mean monthly precipitation near the refuge was 1.8 inches. The month and year with the greatest precipitation near the refuge was February 1998 (16 inches).

ETo near Ellicott Slough Refuge is variable throughout the year based on data from CIMIS station 111 (1992–2013; figure 13). Average daily ETo over the period of record is 0.12 inch and has ranged from 0 (many dates in December through January) to 0.34 inch (May 2, 2001) over the period of record. Monthly ETo ranged from 0.03 to 0.25 inch (June and January, respectively).

Historical Climate Trends

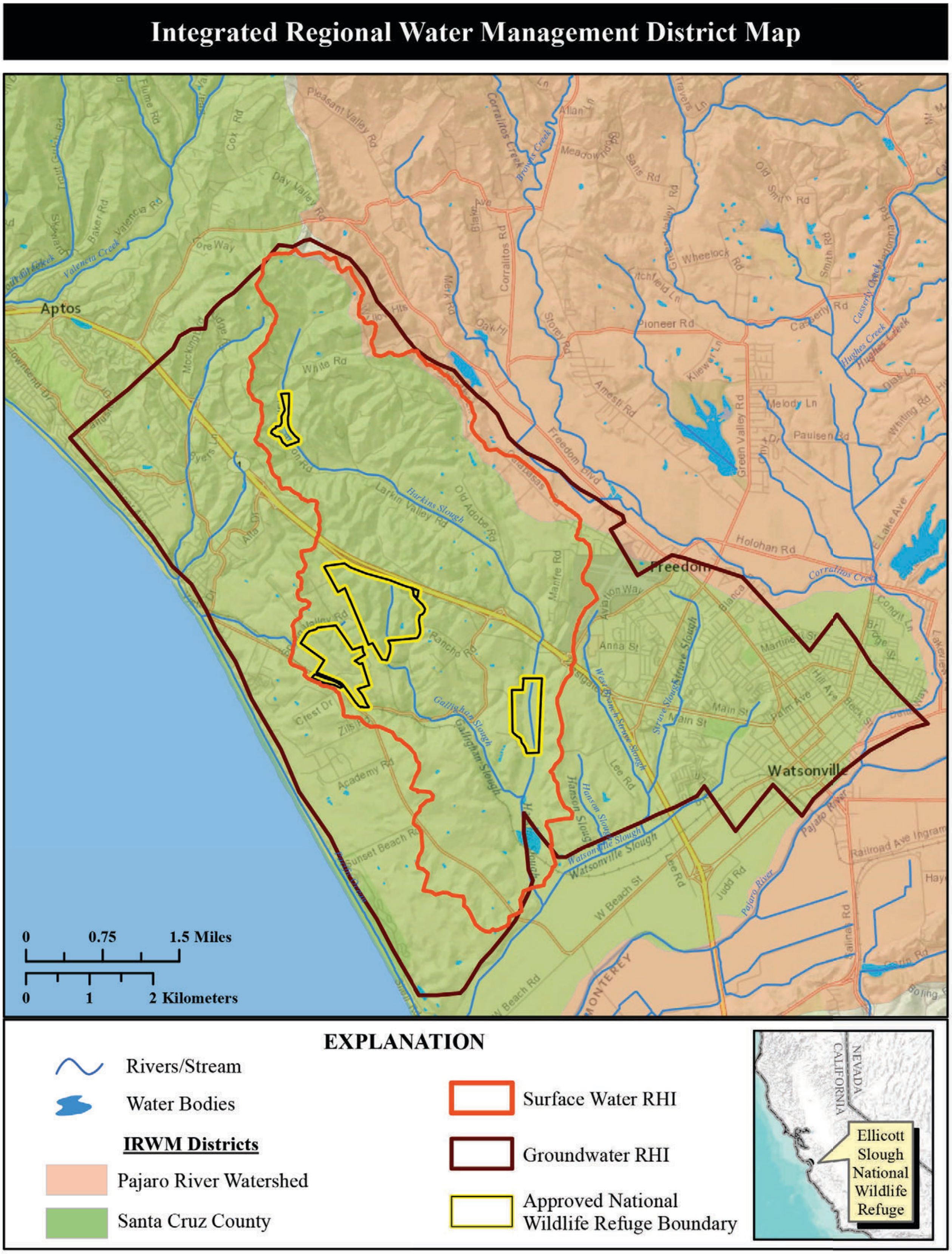
One might expect a slightly greater likelihood of warmer conditions near Ellicott Slough Refuge during La Niña (positive phase of the SOI), warm phase of PDO and positive phase Pacific North American pattern (PNA) (appendix A, figure A6; appendix B, table B5). Statistically significant differences in both maximum and minimum temperatures were observed for the phases of PDO and PNA, whereas a statistically significant difference for the phases of SOI was only observed for maximum temperature (figure A6). No statistically significant differences were observed between any teleconnection and precipitation.

[27] These figures are based on 1984–2013 data from the Watsonville Waterworks station (GHCN station 49473).



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10; Map Production Date: February 26, 2014; Source Data: Water Districts from U.S. Bureau of Reclamation Private Water District Boundary Dataset, 2003; Rivers from U.S. Geological Survey National Hydrography Dataset Plus Version 2.1, 2012; Watermaster Boundary digitized from California Department of Water Resources Northern District Watermaster Service Areas Map, accessed March 2012 (date of map development unknown); Hillshade derived from U.S. Geological Survey Digital Elevation Model, 10-meter, 2012; Imagery from ESRI Basemaps, NAIP 2012.

Figure 10. Proximity of Ellicott Slough National Wildlife Refuge to water districts.



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 11; Map Production Date: March 3, 2014; Source Data: Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, May 2014; Streams and Waterbody data from U.S. Geological Survey National Hydrography Dataset, 2010; IRWMP Districts boundary from California Department of Water Resources 2014; Region of Hydrologic Influence boundaries delineated from 10-meter digital elevation model through StreamStats Web Application USGS, 2014; Bulletin 118 groundwater basin boundaries from California Department of Water Resources, 2010, NatGeo World Map from ESRI online services

Figure 11. Proximity of Ellicott Slough National Wildlife Refuge to Integrated Regional Water Management Planning boundaries.

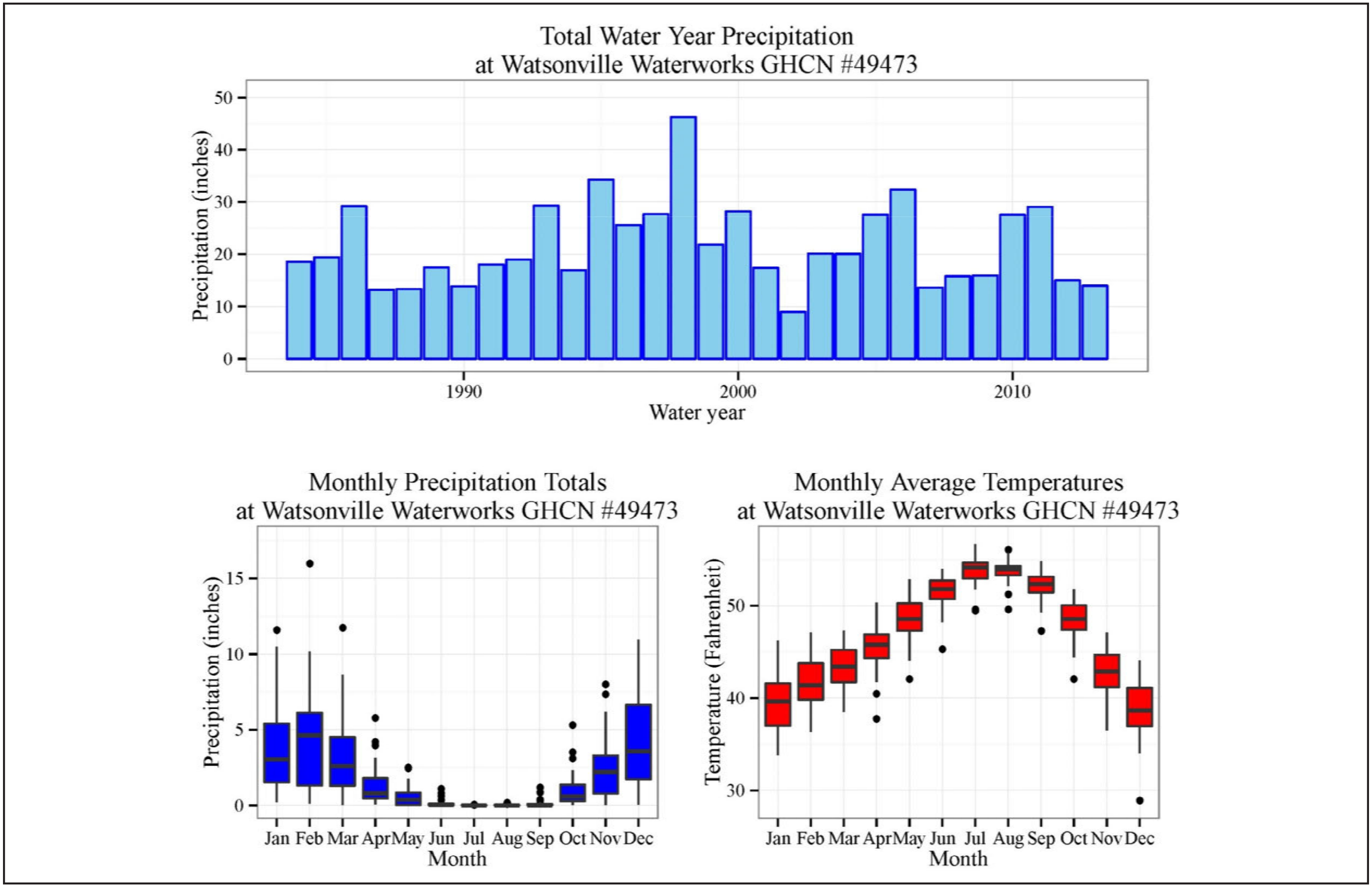


Figure 12. Monthly and annual precipitation and temperature at the Watsonville Waterworks climate station (Global Historical Climatology Network station 49473), 1984–2013.

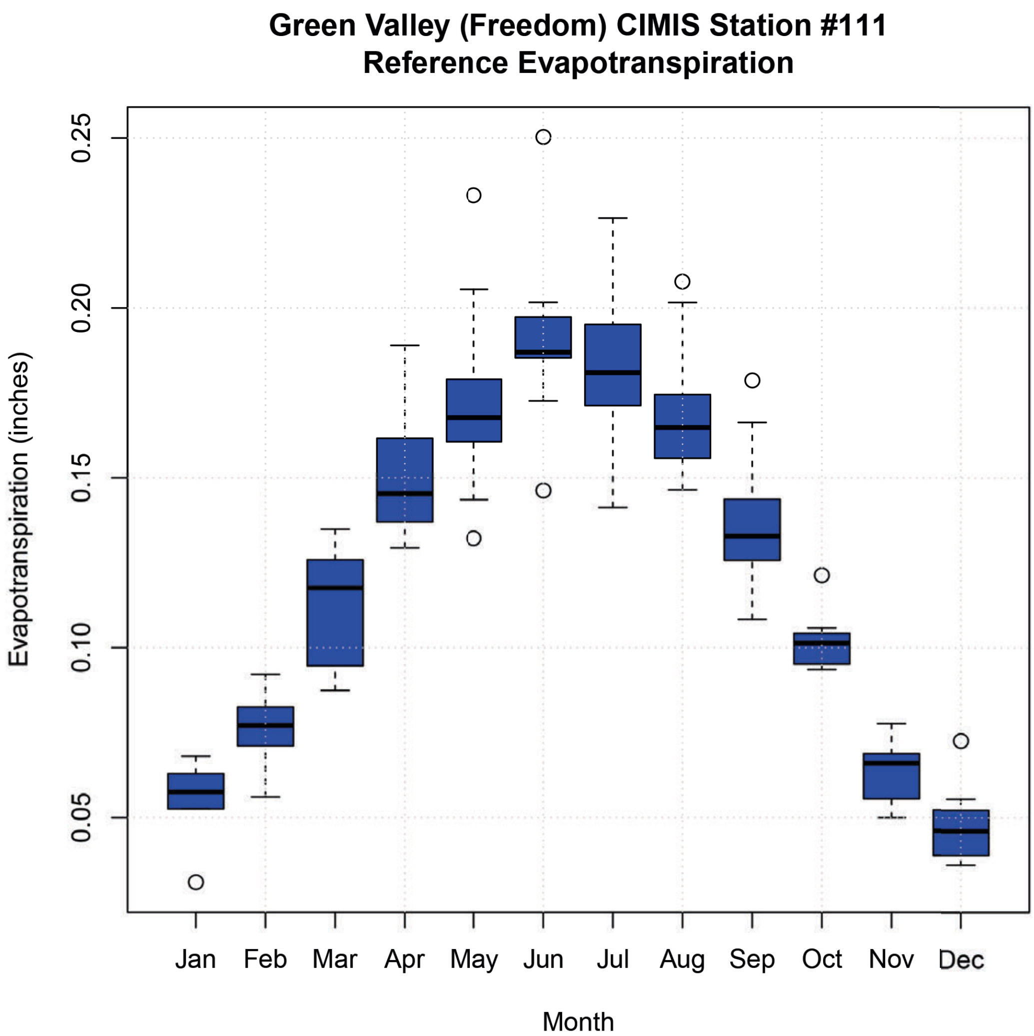


Figure 13. Reference evapotranspiration at Green Valley climate station (California Irrigation Management Information System station 111), 1992–2013.

Trends in temperature were highly variable near Ellicott Slough Refuge but showed the most persistent increases (changes in every time period tested) in fall minimum temperatures (appendix B, table B6). Increases in fall temperatures ranged from 0.03 to 0.06 °F per year (ranging from 1.9 to 6.2 °F over the time periods tested). Many other seasons and months showed increases in maximum or minimum temperature near the refuge over the entire period of record (1910–2013) or from 1950 to 2013 (figure 14), but only fall season minimum temperatures continued to show trends since 1984. Temperatures during all other months and seasons have stabilized.

Very few trends in precipitation were observed, and no trends were observed since 1950 (figure 14). Only annual increases in precipitation were observed from 1910 to 2013 and again from 1925 to 2013, ranging from 0.05 to 0.06 inch per year (ranging from 5.2 to 5.3 inches over the time periods tested), respectively.

Climate Change

Climate change could shift the hydroclimate of the western United States. The warming of 0.6–1.1 °F observed during the last half century over the western United States affected the relationship between climate and hydrologic response (Smith et al. 2000; Barnett et al. 2008).

Regional models predict mean annual temperatures will increase 2.9–3.4 °F by 2070 for the Central Western California Ecoregion, while other studies that focused on the Central Coast hydrologic region (within the Central Western California Ecoregion) indicate a temperature increase of 4.1 °F will occur with a doubling of atmospheric carbon dioxide (Point Blue Conservation Science 2011:35). In addition, according to regional climate models, extreme temperature events are expected to increase in the central coast, with mean maximum and minimum temperatures projected to increase by 3.6 and 3.5 °F, respectively. The number of days exceeding 89.9 °F is projected to increase 12 days per year along with a 15-day per year increase in the frequency of extremely hot days (Point Blue Conservation Science 2011). On average, the frost-free growing season is projected to start 34 days sooner and last approximately 47 days longer. The models show the number of extreme cold days decreasing by 57 days along with 8 fewer days below 32 °F.

Predictions in change of precipitation vary greatly among different models. Some predictions show a decrease in mean annual precipitation of 2.4–7.4 inches by 2070. However, other models show that even with a doubling of carbon dioxide, there will be no significant change in precipitation patterns on the central coast (Point Blue Conservation Science 2011).

Changes in 30-year forecasts for precipitation and recharge values were uncertain among models, showing either decreases or increases by 2100. Changes in mean 30-year precipitation at Ellicott Slough Refuge ranged from -26.96 to 11.62 percent of historical values (1981–2010), with the Panel Climate Model showing the greatest increase and MIROC Medres showing the greatest decrease (figure 15; table B7). Changes in recharge had the greatest range in percent change from historical values, ranging from -65.19 to 38.30 percent.

Changes in 30-year forecasts for mean, maximum, and minimum temperature showed an increase under all model and emission scenarios through 2100 (figure 15). By 2100, increases in maximum temperature ranged from 0.7 to 8.2 °F, while increases in the mean minimum temperature ranged from 0.3 to 6.3 °F. PET, which is directly related to temperature, also showed an increase ranging from 0 to 8.2 percent compared with historical values.

CWD showed an overall slight increase with most models, with GFDL and MIROC Medres showing the greatest increases by 2100 (20.9 and 23.3 percent, respectively). By 2010–2039, CWD increases ranged from 0.4 to 2.4 inches per year, representing a 1.2 to 8 percent increase, or an additional 19.9 to 129.3 acre-feet per year of water input required over the refuge to maintain current or future habitats. By 2070–2100, CWD increases ranged from 2.9 to 9.6 inches per year, representing a 4.4 to 23.3 percent increase in the water demand for refuge lands, or an additional 144.1 to 477.1 acre-feet per year of water input required. This indicates that refuge staff may have to increase groundwater pumping to supplement additional water demand, find alternative ways to supply water, or further increase water use efficiency.

Increases in water demand would probably be of the greatest concern for units in which water levels of breeding ponds are being maintained, including the Ellicott, Buena Vista, and Calabasas Units (see section 4.5, "Water-Related Habitats, Water Management, and Infrastructure"). Currently, the water quantity needed to support breeding ponds is not known; therefore, the impacts of increases in water demand on the refuge are not known. **Determining a water budget for refuge ponds would be helpful for determining whether predicted increases in CWD pose a problem for breeding pond management.**

Estimates of global sea level rise for California suggest a possible sea level rise of 14.2 inches by 2050 and a high estimate of 55.1 inches by 2100 (Ramstorf 2007; Cayan et al. 2008). Sea levels were estimated to have already risen 7.1 inches from 1900 to 2005 (Center for Ocean Solutions 2014). Sea level rise is not uniform across California, as is evidenced in the central California coast and other areas along the west coast, which hasn't shown a significant increase in sea level over the past several decades (California Energy Commission 2006, Largier et al. 2010).

Sea level rise in the central California coast and other areas may have been suppressed because of recent patterns in large scale climate regimes, but it could change with climate variability and climate change. A combination of variables drives local variations in sea level including local wind and current patterns, salinity, changes in ocean temperatures, and large scale climate regimes such as the ENSO and PDO. ENSO and PDO both affect the weather, storms, and ocean temperature along the coast of California (Wingfield and Storlazzi 2007). ENSO events (shifting of the ENSO phase from La Niña to El Niño) are characterized by elevated water levels along with increased precipitation and waves caused by a southerly shift in the jet stream (Storlazzi and Wingfield 2005). Studies by Bromirski et al. (2011) have indicated that the PDO could be driving climate changes that affect variability of sea levels. The PDO has caused large-scale shifts in the temperature pattern of the ocean. Cooler phases of PDO are associated with decreases in sea level rise, whereas warmer phases are associated with increases. The resultant variability of sea level along the California coast may exceed global average sea level at times (Bromirski et al. 2011).

The effect of climate change and sea level rise on coastal wetlands will likely increase coastal erosion. The southern coast of Monterey Bay is eroding more rapidly than other coastal areas in the state. Erosion rates between 1 and 6 feet per year have been measured at the coastal dunes between the mouth of the Salinas River and Monterey Harbor (Center for Ocean Solutions 2014). Sea cliffs in northern Monterey Bay have an average retreat rate of 0.17–2.1 feet per year, with 4.4 square miles of coastline found to be susceptible to erosion due to sea level rise. Cliffs and coastal dunes are predicted to retreat up to 720 feet and 1,300 feet, respectively. By 2100, a total of 1.8 miles of shoreline in Santa Cruz County could be lost (Heberger et al. 2009).

Climate change and sea level rise will also likely increase the inundation of low-lying habitats and estuaries along coastal floodplains. These areas will be exposed to a greater risk of major flooding events, storm surges, high tides, and wave action (Heberger et al. 2009). Elevated sea levels combined with increases in winter storm intensity and increases in wave heights will increase the risk of coastal inundation (Storlazzi and Wingfield 2005) and possible inundation of upstream slough systems with seawater (Balance Hydrologics 2014). As storm waters recede, coastal water quality will likely decline as a result of mobilization of debris, fertilizers, and other contaminants (Largier et al. 2010). This may result in an impact on low-lying wetlands in the coastal floodplain or floodplain of Pajaro River, such as Watsonville Slough and the Harkins Slough subbasin.

Water levels in Harkins Slough might change by a range of -0.7 to +3.0 feet (by 2050 and 2100, respectively) as a result of sea level rise and other water management events (Balance Hydrologics 2014). Sea level rise scenarios included increases by 14–55 inches (2050–2100 estimates, respectively). These scenarios also included improved channel maintenance and an increase in pumping of water for export.[28] With only 14 inches of sea

[28] The PVWMA actively can pump up to 2,000 acre-feet per year out of Harkins Slough to a neighboring basin for purposes of groundwater recharge, but the agency actually pumps water on a variable basis

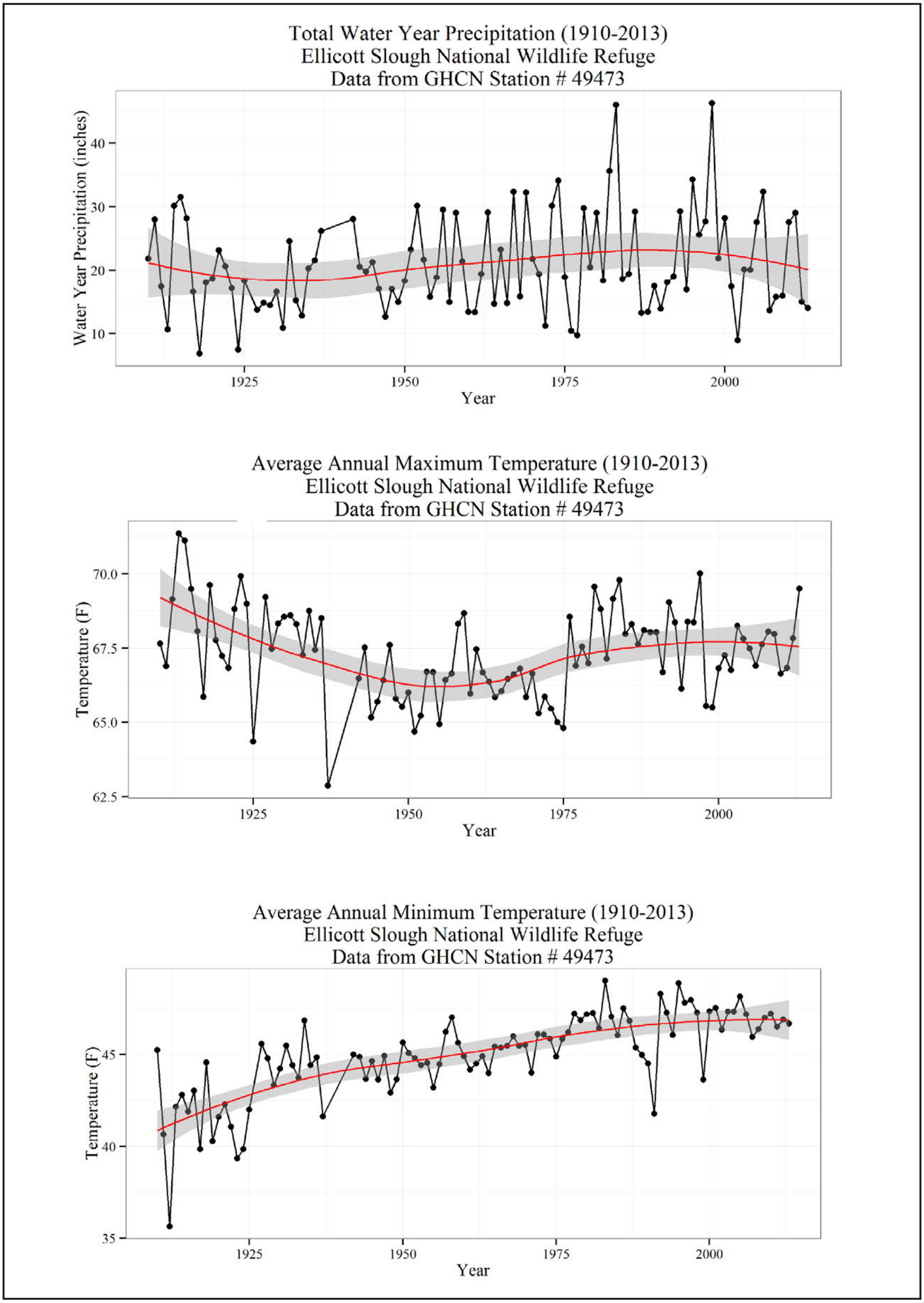


Figure 14. Trends in annual minimum temperature at the Watsonville Waterworks climate station (Global Historical Climatology Network station 49473), 1910–2013.

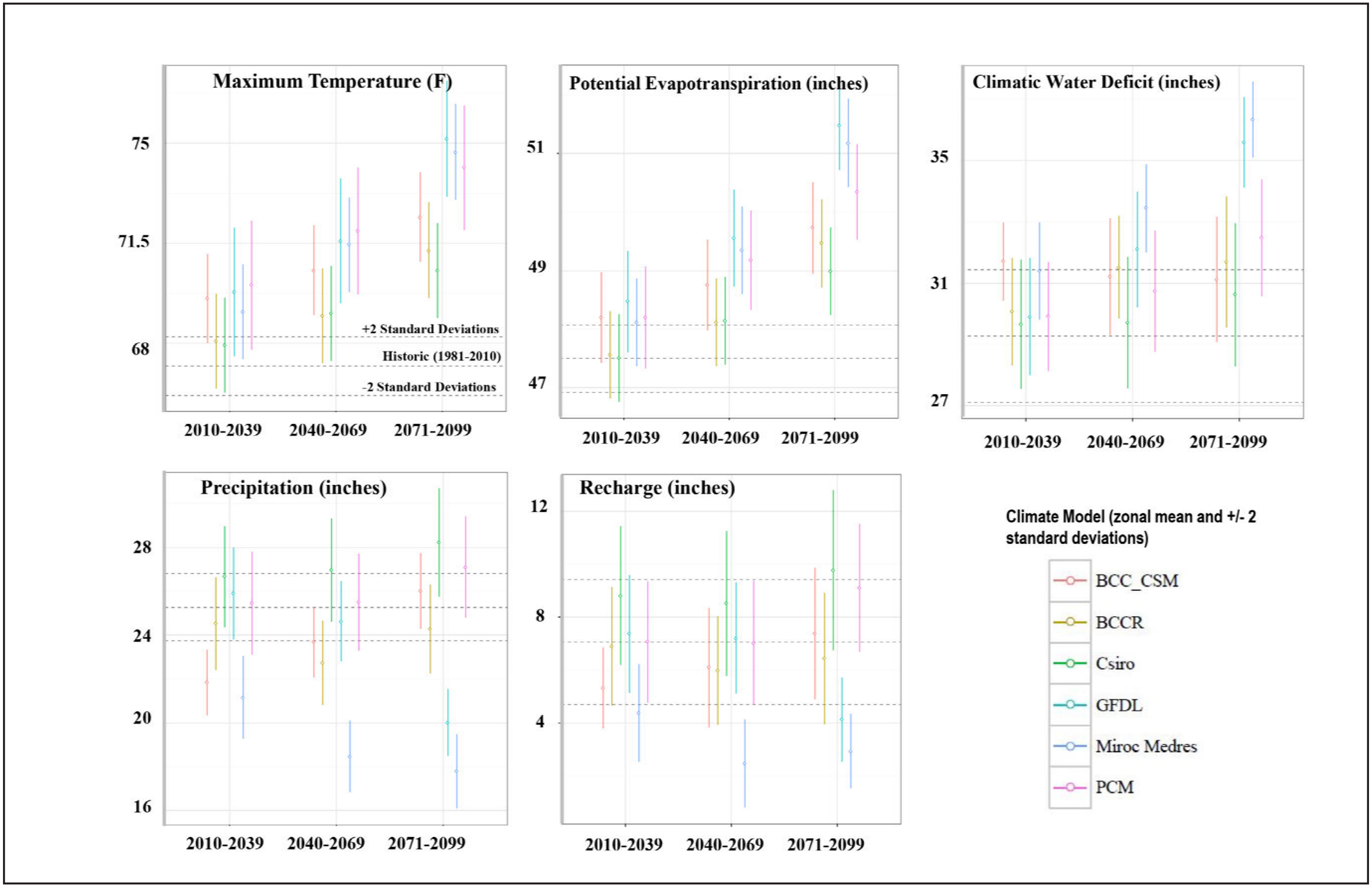


Figure 15. Historical and projected 30-year mean and spatial variability of potential evapotranspiration, maximum air temperature, climatic water deficit, and precipitation within the Ellicott Slough National Wildlife Refuge boundary, 1981–2100.

level rise, mean water levels decrease because channel maintenance (removal of vegetation in slough channels) and an increase in pumping result in decreases in water levels in Harkins Slough. Therefore, 14 inches of sea level rise is not enough to result in sustained inundation of seawater into the Watsonville Slough system and Harkins Slough. Balance Hydrologics (2014) states that any water level changes under the 14-inch sea level rise scenario would be largely confined to winter months. However, 55 inches is enough to cause substantial increases in seawater incursions to the slough system and throughout the year, potentially causing the southern end of Harkins Slough to convert completely to a salt marsh system. A lack of channel maintenance, and decreases in pumping because of a lack of freshwater conditions, might further increase water levels. However, these scenarios are presented as worst-case conditions without infrastructure improvements or increases in freshwater runoff (Balance Hydrologics 2014). See section 4.3, "Surface Water," for more information about the dynamics of Harkins Slough within the Watsonville Slough system and the impacts of coastal inundation.

4.3 Surface Water

As noted in section 2.2, "Topography, Landforms, and Vegetation," the entire Ellicott Slough Refuge drainage basin covers two major drainage basins. Calabasas Unit, Harkins Slough Unit, the eastern portion of the Buena Vista Property, and a small southwestern portion of the Ellicott Unit are within the Pajaro River Watershed HUC-8 drainage basin. The remaining areas are within the San Lorenzo–Soquel Watershed HUC-8 drainage basin (figure 1).

The Buena Vista Property, Ellicott Unit, and Calabasas Unit are on primarily headwater drainage basins and have relatively small drainage basins (table 2), whereas Harkins Slough is farther downstream in the Watsonville Slough system. Calabasas Unit, which is located in the upstream portion of the Larkin Valley drainage area,[29] drains to the Harkins Slough system and reaches the Harkins Slough Unit approximately 4 miles downstream. Harkins Slough Unit, Calabasas Unit, and the eastern portion of the Buena Vista Property within the Pajaro River Watershed are within the larger Watsonville Slough system, which eventually drains to the Pajaro River and Pacific Ocean (figures 1 and 16; see section 2.2, "Topography, Landforms, and Vegetation").

Ellicott Unit and the western portion of the Buena Vista Property do not have a definitive drainage to any major body of water. These headwater areas drain westward to small tributaries that drain to the Monterey Bay and Pacific Ocean (figure 16).

Ellicott Pond, Prospect Pond, Buena Vista Pond, and Calabasas Pond are the focus of most water management activities and are managed for salamander breeding (see section 4.5, "Water-Related Habitats, Water Management, and Infrastructure"). Ellicott Pond and Prospect Pond are located in the Ellicott Unit. Buena Vista Pond is located in the eastern portion of the Buena Vista Property and is within the Pajaro River Watershed. Calabasas Pond is within the Calabasas Unit and drains to Larkin Valley Creek, which becomes Harkins Slough after it crosses under Highway 1 (figure 16).

The catchments around the managed ponds are very small, and drainages are typically ephemeral. This means that these drainages are likely usually dry unless there is runoff from a precipitation event (referred to as "storm flow"). Estimated local drainage patterns near Ellicott Pond and Prospect Pond within the Ellicott Unit using a 10-meter DEM show that water most likely drains northwesterly toward the outlet of the Ellicott Unit Drainage Area. Local drainage patterns in the Buena Vista Property drainage

based on pump capacity and water quality limitations. Model forecasts were made under a scenario where PVWMA can pump an increased amount up to its capacity. See section 4.3, "Surface Water," for more information.

[29] According to NHD, Harkins Slough is the name of the entire water body through this drainage area. For purposes of this report, the Larkin Valley drainage area is considered that area of Harkins Slough upstream from Highway 1. This name is used to correspond to local references found in literature, and in communication with refuge staff.

basin show that water flows south toward Gallighan Slough. Local drainage patterns for Calabasas are more clearly defined by greater local topography; ephemeral flow paths drain toward the center of the valley upgradient from the pond (figure 16).

The drainage area for Prospect Pond is a smaller fraction of the larger drainage that contains both Prospect and Ellicott Ponds and has relatively low storm flows. The individual drainage area and stormflow for Prospect Pond (not mapped) was estimated at 0.012 square mile (Ruttenberg 2012). Ruttenberg (2012) provided analyses of estimated storm flow rates at Prospect Pond to assist with redesign of the pond (see section 4.5, "Water-Related Habitats, Water Management, and Infrastructure"). This estimate was made using a flow routing model (EFH2).[30] The estimates for the 2-year to 100-year storm flow were 0.1 to 2.7 cubic feet per second (cfs), respectively (table 2).

The drainage area for Ellicott Pond is a small fraction of the larger drainage area, but storm flows are higher than for Prospect Pond. The individual drainage area and stormflow for Ellicott Pond (not mapped) was estimated at 0.065 square mile (Moehling 2014). Moehling (2014) also provided analyses of estimated storm flow rates for Ellicott Pond to assist with redesign of the pond (see section 4.5, "Water-Related Habitats, Water Management, and Infrastructure") and was developed using EFH2. Moehling (2014) only reported estimates for the 100-year 24-hour storm flow, and this value—19 cfs—was used to redesign the pond infrastructure.

The Buena Vista Pond captures water within a small depression, which was too small to be delineated using a 10-meter DEM (not mapped); therefore, estimates of storm flow frequency could not be made using regression. The drainage area for the pond is estimated to be less than 0.05 square mile.[31]

The drainage area for Calabasas Pond is the largest of the ponds and has the greatest estimated natural storm flow. Delineation with a 10-meter DEM resulted in a drainage area of 1.47 square miles. The outlet to this pond is at the southern terminus of the Calabasas Unit and flows south toward Harkins Slough. Estimates of natural peak storm flow at the outlet from regional regression for 2- to 100-year storm flow was 62 to 412 cfs, respectively (table 2); actual storm flow may be lower if water is being actively stored in the Calabasas Pond. Flow through the Larkin Valley drainage area is very "flashy" (rapid rise and fall of stream flows), indicating that daily average flows are likely far less than instantaneous storm flow estimates (Cbec 2013).

Managed properly, intermittent storm events could quickly fill Calabasas Pond and other ponds, although too much water could damage infrastructure and habitats. For example, a 2-year event could fill Calabasas Pond from empty to the maximum capacity of storage specified in the water right—48 acre-feet—in about 9 hours, not accounting for infiltration, recharge, or evapotranspiration. With these same assumptions, a 100-year event could fill Calabasas Pond from empty to the maximum capacity in about 2 hours. However, 48 acre-feet is likely more storage capacity than is needed for current management. Therefore, the times presented above are overestimates, and the pond will likely fill to current target capacity more quickly. **The Service should estimate the current storage capacity (bathymetry) and total water needs of each pond, as currently managed, to help better plan for operational management during storm events.**

Harkins Slough has a drainage area of 11.5 square miles and constitutes about 59 percent of the total drainage area of Watsonville Slough and 55 percent of the total ponded area of Watsonville Slough (Balance Hydrologics 2014). The upstream runoff area from the Harkins Slough Unit is 0.2 square mile (table 2) and is 1.1 percent of the total drainage area of the Watsonville Slough system.

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[30] Moehling (2014) considers EFH2 more reliable than regional regression because it is a discrete model that is representative of local soils, precipitation, slope, and land cover.

[31] Based on visual estimate from a larger drainage basin capturing ephemeral drainages from Buena Vista Pond and other areas to the east.

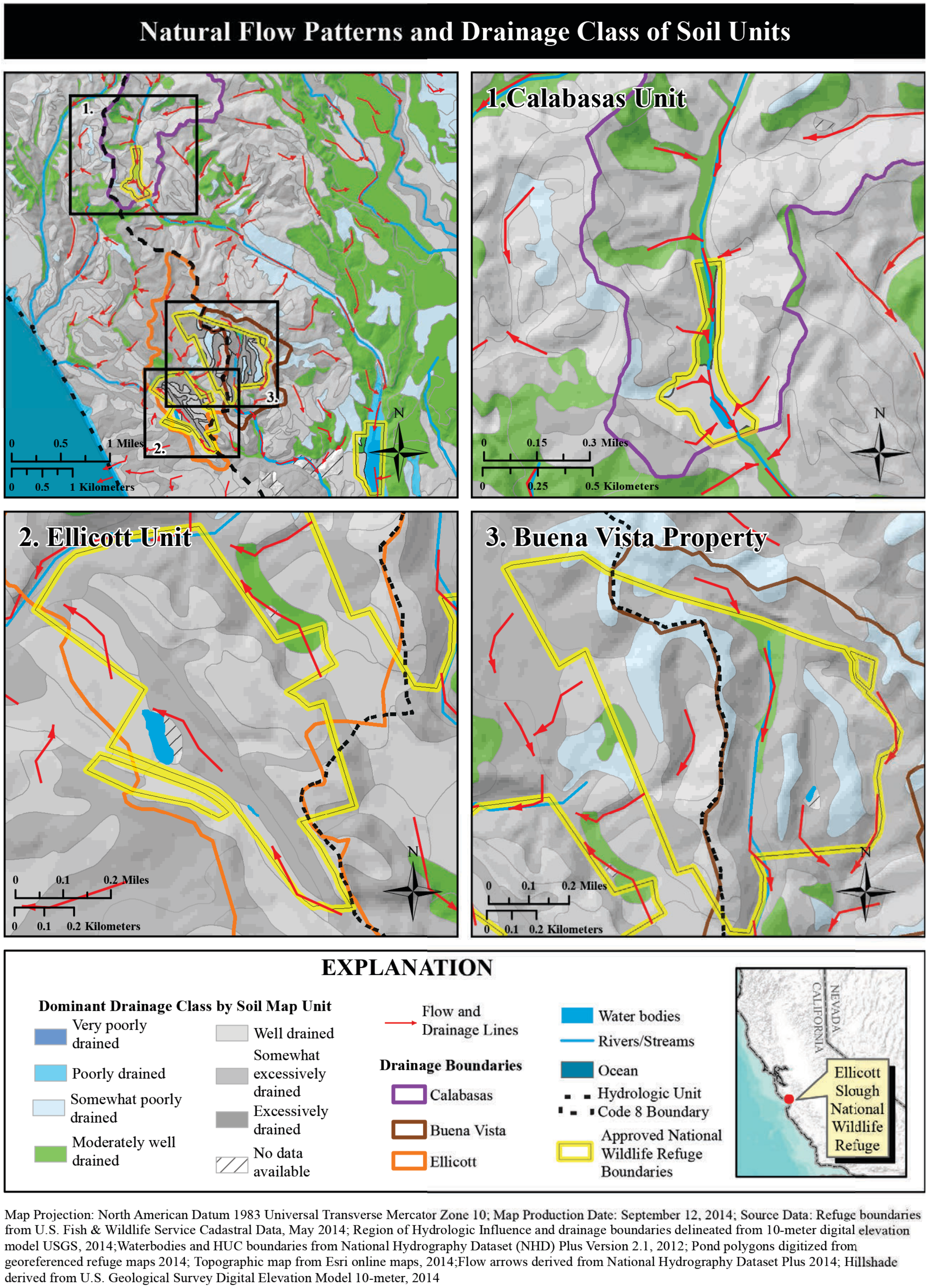

Figure 16. Natural flow and drainage paths on and near Ellicott Slough National Wildlife Refuge in comparison with drainage classification of soils for 1) Calabasas Unit, 2) Ellicott Unit, and 3) Buena Vista Property.

Table 2. Basin characteristics and streamflow estimates for drainages on and near units of Ellicott Slough National Wildlife Refuge.

Unit name	*Description of delineation point*	*Drainage area (square miles)*	*Flood frequency statistics (return period and probability of occurrence)—2-year (50%)*	*Flood frequency statistics (return period and probability of occurrence)—5-year (50%)*	*Flood frequency statistics (return period and probability of occurrence)—10-year (50%)*	*Flood frequency statistics (return period and probability of occurrence)—25-year (50%)*	*Flood frequency statistics (return period and probability of occurrence)—50-year (50%)*	*Flood frequency statistics (return period and probability of occurrence)—100-year (50%)*	*Drainage area and flood frequency source*
Calabasas Unit	At water control structure at pond outlet	1.47	62	139	198	279	343	412	Regional regression (Gotvold et al. 2012)
Harkins Slough Unit	At culvert at Highway 1	6.2	219	482	681	952	1165	1391	Regional regression (Gotvold et al. 2012)
	At southern end of Harkins Slough Unit (Harkins Slough Road)	7.1	245	540	763	1067	1305	1557	Regional regression (Gotvold et al. 2012)
	At confluence of Harkins Slough and Watsonville Slough	11.5	Not determined	Not determined	Not determined	Not determined	Not determined	Not determined	Drainage area from Balance Hydrologics (2014)
Ellicott Unit	At outlet of Ellicott Pond	0.065	Not determined	Not determined	Not determined	Not determined	Not determined	19	Flow-routing model (Moehling 2014)
	At outlet of Prospect Pond	0.012	0.1	0.3	1.2	1	1.3	2.7	Flow-routing model (Rutherberg 2013)

Note: If estimated by regional regression, drainage area was determined from USGS StreamStats web application using the specified delineation point.

Since 2001, Harkins Slough has been perpetually inundated with water and has since left approximately 150 feet of Harkins Slough Road covered with up to 2.5 feet of water (Swanson Hydrology and Geomorphology et al. 2003).[32] Those working in and around the sloughs have also witnessed significant changes in water level dynamics over the last several decades. Examples include a markedly higher surface elevation with overall seasonally higher water levels, inundation of extensive areas in the slough bottomlands, and perceived increases in erosion rates as evidenced by sediment accumulations in and near slough channels (Balance Hydrologics 2014).

The exact cause for sudden inundation in Harkins Slough is not known but possibly was caused by changes in flow dynamics in the Watsonville Slough system. Possible causes include land subsidence due to shallow groundwater withdrawal and mining and decomposition of organic peat and soils (Gordon 1996), and the Harkins Slough Road acting as a control structure and constricting flow out of the unit (Swanson Hydrology and Geomorphology et al. 2003). Other possible causes are sedimentation and vegetation overgrowth in the Watsonville Slough and Harkin Slough channels, resulting in ponded or constricted water and therefore a change in relative water levels between areas of the slough system (Balance Hydrologics 2014:3). Any of these factors could result in a change in flow dynamics of the slough system, which could have resulted in ponding of water into Harkins Slough.

Harkins Slough has very low runoff volume and peak flow rates. Based on records at a gaging station,[33] only 4 percent of the rainfall was converted into net runoff (Balance Hydrologics 2014:48).[34] Sources of loss include groundwater recharge, irrigation use, and other water uses which remained unaccounted. Estimates of natural peak storm flow (peak storm flow under natural conditions) at the outlet of the Harkins Slough Unit from regional regression for 2- to 100-year storm flow was 245 to 1,557 cfs, respectively (table 2). However, this amount is likely an overestimate of the actual peak flow based on the findings from Balance Hydrologics (2014) because the regression only takes into account drainage area and precipitation; drainage basin specific water losses are not accounted for with the regression method. Furthermore, more than 20 flood control structures were found to be present in the area upstream from the Harkins Slough Unit (Cbec 2013). These flood control structures can attenuate runoff by retaining storm water and reduce the magnitude of flood flows downstream.

Currently, water inflow from Watsonville Slough is a major source of water for Harkins Slough. Based on a 2012 hydrologic data collection and interpretive analysis, water levels in Watsonville Slough at the confluence with Harkins Slough were consistently higher than water levels in Harkins Slough, leading to persistent flow of water from Watsonville Slough into Harkins Slough over and through existing weirs and culverts (Balance Hydrologics 2014:3). The confluence of Harkins Slough and Watsonville Slough is located approximately 1.35 miles downstream from the southern border of the Harkins Slough Unit, in an area that is currently planned for a wetland restoration. The wetland restoration may affect the dynamics of flow between Watsonville and Harkins Slough (Balance Hydrologics 2014:18).

Some water is removed from Harkins Slough by pumping. PVWMA operates the Harkins Slough flood control pump (HS pump)[35] that is used to transport water west of the Watsonville Slough to a groundwater recharge area. PVWMA has the right to move up to 2,000 acre-feet per year under its appropriative water permit (see section 4.1, "Water Entitlements

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[32] Harkins Slough Road is located at the southern border of the Harkins Slough Unit.

[33] The Harkins Slough at Buena Vista Road (HSBV) gaging station, which was added by Balance Hydrologics (2014) as part of the monitoring and modeling project, was not included in the surface water station inventory because data were not readily available to the public at the time of this report. The station is located at latitude 36.9379 and longitude -121.808 and is 1.2 miles upstream from the northern border of the Harkins Slough Unit.

[34] Because the runoff rate was substantially small compared to rainfall, regression models were not used to estimate peak flow runoff rates in this drainage basin because they will likely overestimate storm flow.

[35] The HS pump is located 1.5 miles downstream of the southern border of the Harkins Slough Unit.

and Policy"),[36] but on average, it only pumps 630 acre-feet per year[37] (Balance Hydrologics 2014:18). PVWMA typically pumps between January and May (figure 17).

There is a potential for Harkins Slough to be impacted by seawater intrusion into the Watsonville Slough system and indirectly impacted by flow and water levels at the mouth of the Pajaro River. The portion of Watsonville Slough downstream from the confluence with Harkins is a dynamic, tidally-influenced system that is seasonally affected by seawater, inflow from the Pajaro River, and water levels in the mouth of the Pajaro River. A non-functional weir located where Watsonville Slough crosses Shell Road[38] (2 miles downstream of the confluence of Harkins Slough and Watsonville Slough) is the main interface between freshwater upstream and brackish or saline water downstream. Downstream of this location, the tidal channel[39] flows south to a lagoon formed by a bar-built estuary at the mouth of the Pajaro River. Waves and other coastal storm events occasionally result in water overtopping or breaching the bar, or the bar is purposely breached to avoid local flooding along the mouth of the Pajaro River. Bar breach results in introduction of seawater into the lagoon and tidal channel, which is more likely to occur during winter months. Salinity measurements after a major over-topping event on January 6, 2012, indicated that seawater moved up-channel in the sloughs above a railroad crossing in Harkins Slough (1.2 miles downstream from the southern border of the Harkins Slough Unit) (Balance Hydrologics 2014:41).

Not including inflow from Watsonville Slough or other sources, Harkins Slough generally experiences a net loss of water from April through September (figure 17). Inflow from Watsonville Slough and from seawater intrusion was not included in the water balance computation; therefore, it is possible for the monthly net input of water to increase during winter months when these events are more likely to occur. However, these water balance parameters indicate that Harkins Slough is a net sink for water over the course of an average water year, based on the contributing drainage basin alone.

4.4 Groundwater

This section provides a summary of characteristics of groundwater within and near the Ellicott Slough Refuge groundwater RHI, which is limited to the PVGB. The geologic framework and composition of the PVGB and associated aquifers was described in section 2.3, "Geology and Hydrogeology." This section discusses the quantity and movement of groundwater within the aquifer.

Ellicott Slough Refuge has wells capable of pumping groundwater at the Ellicott Unit (for breeding ponds at the Ellicott Pond and Ponds) and Harkins Slough. At the time of this report, the only well that refuge staff plans on actively pumping groundwater from is for Prospect Pond in the Ellicott Unit (see section 4.5, "Water-Related Habitats, Water Management, and Infrastructure," for more information about water use activities). Currently, refuge staff are not monitoring the quantity of water that is pumped, and so the amount of groundwater used by the refuge is unknown at this time. **The Service should monitor the quantity of groundwater that is used for refuge purposes to better understand the quantity required for habitat management and to ensure that there is adequate pumping capacity for refuge needs.**

Ellicott Slough Refuge is likely utilizing groundwater from the Lower Aromas Sand. A report by Johnson et al. (1988) shows a transect running along the Monterey Bay coast that corresponds with a stratigraphic cross-section showing the different geologic layers along that transect. Based on observations from this

[36] Water permit under application number A030522 specifies that this water is only to be diverted from November 1 to May 31, not to exceed the rate of 30 cfs. PVWMA has estimated the yield of its pump to be 1,100 acre-feet per year (Carollo Engineers 2013).
[37] Based on pump records for the period 2002–2012 (Balance Hydrologics 2014:88).
[38] Watsonville Slough crosses Shell Road approximately 1.7 miles downstream of the confluence of Harkins Slough and Watsonville Slough.
[39] The downstream area from where Watsonville Slough crosses Shell Road to the Pajaro River is referred to as the tidal channel.

transect, it appears the Prospect well located in the Ellicott Unit was drilled down to the Lower Aromas Sand. Refuge staff believe the pond in the Buena Vista unit is affected by a perched aquifer under the pond (D. Kodama, refuge manager, U.S. Fish and Wildlife Service; oral communication). However, boring logs for the construction of refuge groundwater wells were unavailable at the time of this report. Without boring logs to indicate where the well is screened, the portion of the aquifer from which the Ellicott Slough Refuge is withdrawing is unknown. **The Service should locate boring logs for all previously constructed wells to further understand the groundwater source for the refuge units.** Such logs can be accessed from the drilling company or consulting firm that performed or oversaw the well installation.

Groundwater accounts for 90 percent of the water used in the Pajaro Valley (Carollo Engineers 2013), of which 84 percent is used for agriculture and 16 percent is used for municipal and industrial (Hanson 2003). The quantities used by agriculture have increased over the past 40 years. The annual consumptive was estimated at 50,000 acre-feet per year between 1964 and 1987 and 56,000 acre-feet per year between 1987 and 1997. Municipal water use increased from 9,000 acre-feet per year between 1964 and 1987 to 10,000 acre-feet per year between 1987 and 1997 (Hanson 2003).

Groundwater is recharged primarily from three sources in the PVGB:

- precipitation in the valley that reaches groundwater by infiltration or seepage from streams
- seepage from the Pajaro River as it crosses the valley carrying runoff that comes from upstream from the valley
- precipitation over the Soquel-Aptos watershed[40] that infiltrates and moves southeast into the PVGB (Muir 1972)

However, geochemical data from Hanson (2003) indicate that there was very little vertical flow through the layered aquifer systems. Data from Hanson (2003) show that water from the lower Aromas Sand in the coastal region was recharged thousands of years ago, which would mean that the water source is nonrenewable (Hanson 2003).

The overall general flow of groundwater through the alluvial aquifers has been from the mountains to the coast, excluding cones of depression in areas along the mouth of the Pajaro River and in the city of Watsonville. In the northern region of the aquifer, groundwater moves south and southwest, away from the San Andreas Fault. In the southern region of the aquifer, the groundwater movement has historically moved west. However, heavy groundwater pumping has altered groundwater flow in that region (Hanson 2003).

Groundwater flow in the PVGB moves from both the recharge areas east of Watsonville and north of Monterey County toward large troughs in the center of the valley. These troughs are caused by excessive groundwater pumping (Carollo Engineers 2013). Waters from the coastal areas also appear to flow toward the same pumping trough (figure 18). Groundwater flow in the southern region of the basin appears to flow from northern Monterey County to the northeast towards Pajaro Valley and then westward toward the coast (Carollo Engineers 2013).

Annual variations in groundwater levels are caused by weather conditions, groundwater pumping, recharge, and other factors. Because groundwater pumping is in excess of recharge, water levels in the PVGB generally have been decreasing (RMC 2002). Prior to 1900, artesian conditions[41] were originally present in wells along the Monterey Bay coast. However, by the early 1900s, artesian well heads started to decrease due to groundwater overdraft. By the 1940s, some artesian flow was still observed but only in the winter months. By 1970, water levels in wells west of Watsonville were found to be consistently below sea level from May to December (California Department of Water Resources 2006). Currently, there are no coastal wells under artesian conditions. The loss of artesian well conditions, the presence of water levels dropping below sea level, and the groundwater trough in the center of the PVGB have resulted in seawater intrusion (RMC 2002).

[40] This watershed boundary was not mapped for this report. However, the boundary of these watersheds is located near the Soquel-Aptos region, north and east of PVGB (figure 2).

[41] Artesian conditions occur when water flows out of a well as a result of pressure differences rather than pumping.

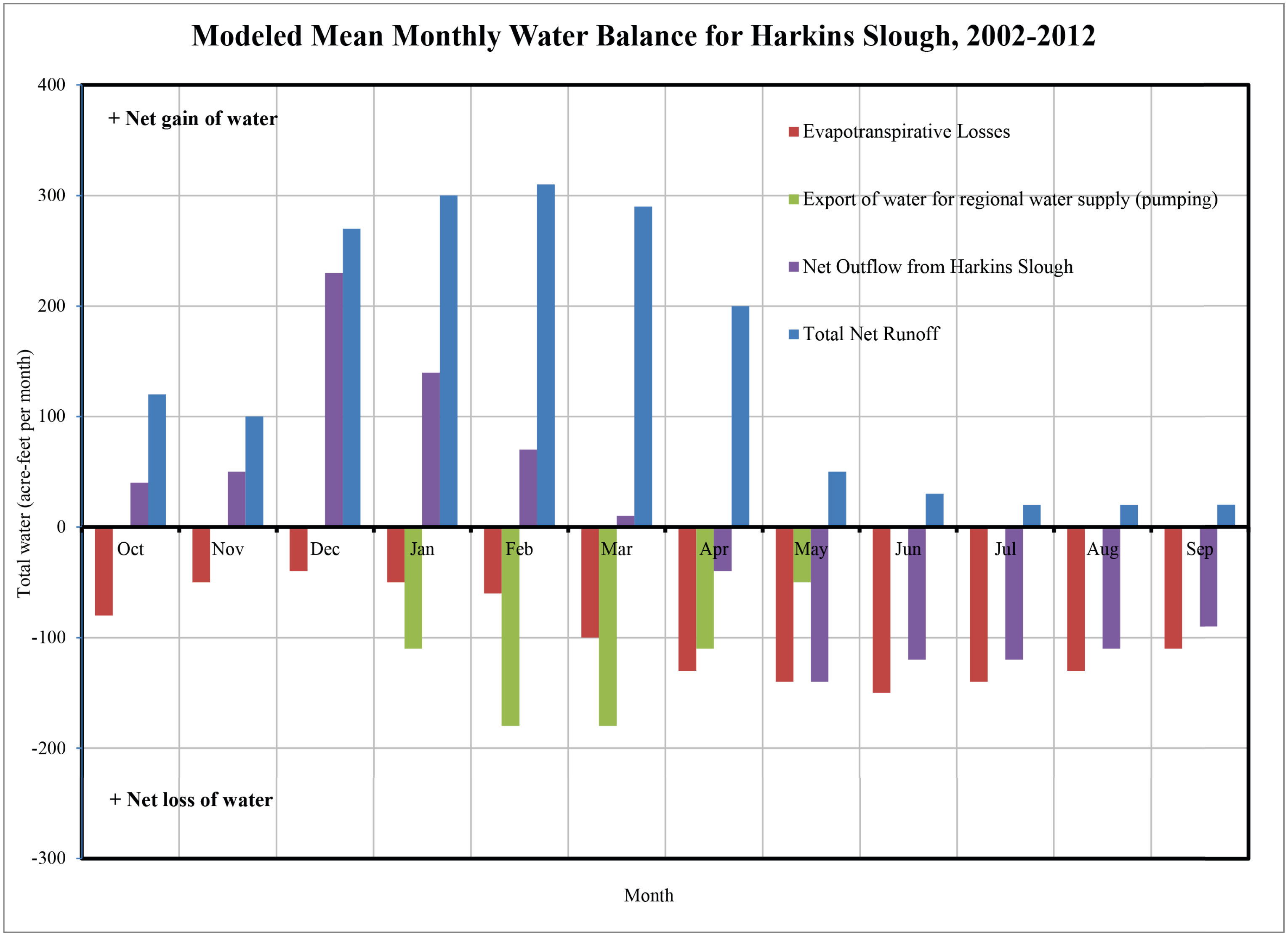
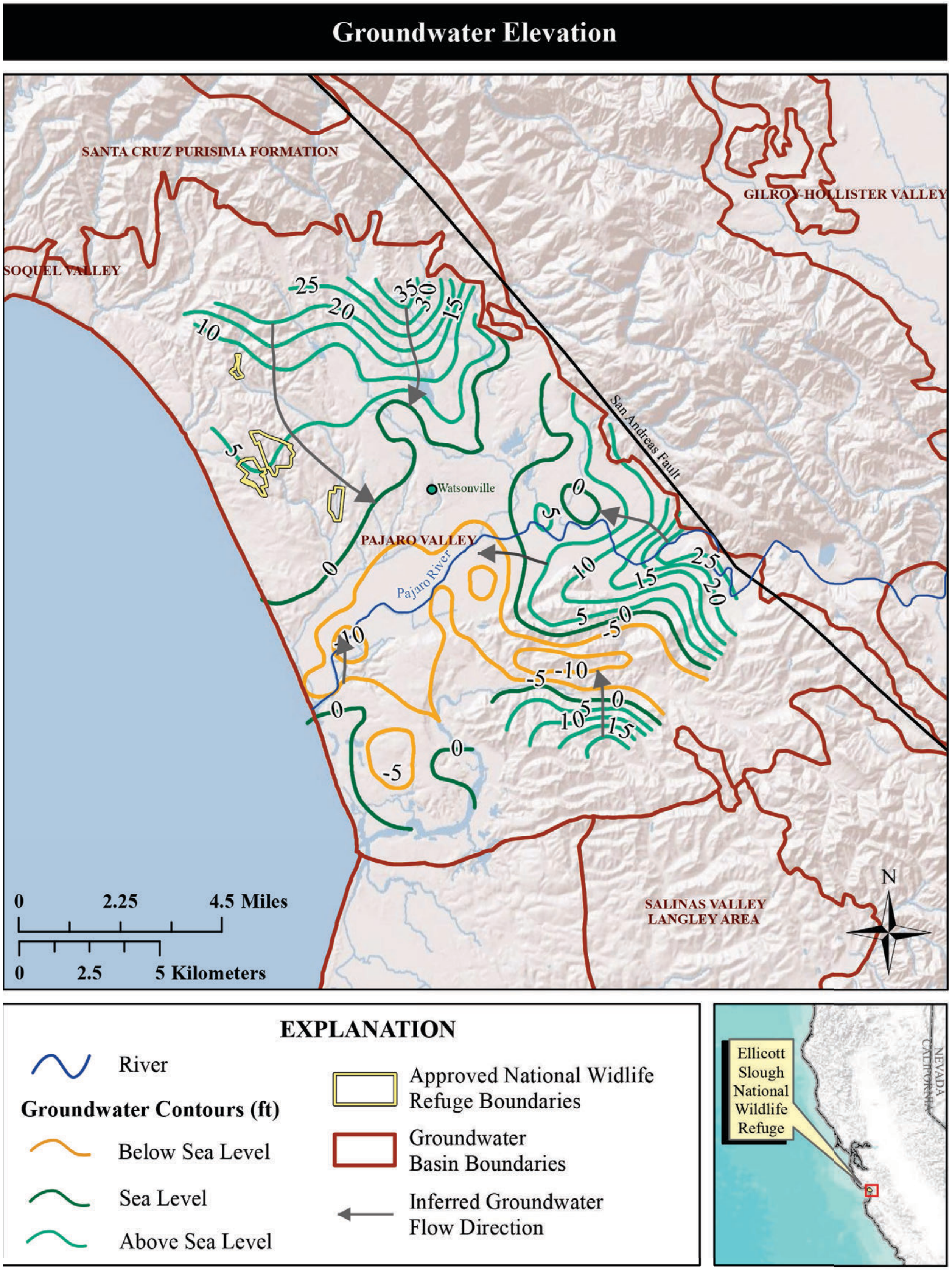


Figure 17. Mean monthly water balance for Harkins Slough, as determined by a HEC-RAS model developed for the Watsonville Slough system (2002–2012) (adapted from Balance Hydrologics 2014).



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 11; Map Production Date: April 21, 2014; Source Data: Bulletin 118 boundaries from California Department of Water Resources 2010; Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, May 2012; Groundwater Contour lines from Carollo Engineers 2013; World Shaded Relief from ESRI basemaps, 2014; Rivers from U.S. Geological Survey National Hydrography Dataset, 2010

Figure 18. Groundwater levels and flow direction of the Pajaro Valley Groundwater Basin near Ellicott Slough National Wildlife Refuge.

In the past, drought conditions have greatly affected groundwater levels in the PVGB. After 6 years of drought in 1992, water levels were below sea level in over 63 percent of the PVGB (Carollo Engineers 2013). In the fall of 1998—after 4 years of wet winters—water levels were below sea level in over 48 percent of the basin, which indicated that while some areas recovered during this wet period, much of the region did not recover as a result of continued overdraft (pumping in excess of recharge) (RMC 2002).

Excessive pumping and drought conditions increase the risk of seawater intrusion into the freshwater aquifer. In 2011, the groundwater levels from the PVWMA network of monitoring wells showed a trough below sea level throughout the valley floor that still exists at the time of this report. This trough is centered on the Pajaro River (Carollo Engineers 2013). Seawater intrusion in Pajaro Valley is a result of the water-level declines from sustained pumpage (Hanson 2003). From maps published by PVWMA, it appears that seawater intrusion is not currently affecting the groundwater levels near Ellicott Slough Refuge. However, if overdraft continues, this could be an issue of concern. Increased chloride levels would likely negatively impact groundwater used for breeding ponds that support threatened and endangered species. To mitigate, Ellicott Slough Refuge staff may have to treat groundwater or find another water source, yet new water sources are extremely limited in this region. **The Service should measure groundwater levels on a quarterly basis to determine changes in response to seasonal variations and drought. The Service should sample groundwater for chloride on an annual basis to determine if seawater intrusion has become an issue.**

The total water storage capacity for the PVGB is estimated to be 2,000,000 acre-feet above the Purisma formation. Between 1964 and 1997, an estimated 300,000 acre-feet of fresh water storage was lost from the basin. This loss includes 200,000 acre-feet as a result of seawater intrusion and 100,000 acre-feet as a result of overdraft and declining groundwater levels (California Department of Water Resources 2006).

A finite differencing model that simulates groundwater conditions—the Pajaro Valley Integrated Ground and Surface Water Model (PVIGSM)—was used to estimate the sustainable yield of the PVGB. A sustainable yield of 24,000 acre-feet per year was estimated for the groundwater basin under current pumping conditions. The results from the model indicate that sustainable yield could be increased by up to 100 percent in the basin if coastal pumping ceased and the groundwater supply was replaced by water from another source. The results from the model simulations also indicate that a reduction in pumping and increase in water from another source would result in a hydrostatic barrier that would prevent seawater intrusion (California Department of Water Resources 2006). If further seawater intrusion can be prevented, then it is likely that saline water would not make its way into the groundwater that services the refuge units.

4.5 Water-Related Habitats, Water Management, and Infrastructure

Refuge Breeding Ponds

The primary purpose of the refuge ponds within the Ellicott Unit, the Buena Vista Property, and Calabasas Unit is to provide breeding and recruitment habitat for the endangered SCLTS and threatened CTS and CRLF. Although Ellicott Slough Refuge is also within a recovery unit for CRLF, the current status and size of the population at the refuge is unknown. Small numbers of larvae were detected consistently between 2000 and 2006 as well as in 2011 and 2012 on the Calabasas Unit (U.S. Fish and Wildlife Service 2010a).

SCLTS moves from upland habitat to ponds to breed between mid-November and March, with most individuals arriving January–February (U.S. Fish and Wildlife Service 2004). It is during this time that the need for adequate water in the ponds is greatest. Eggs are laid individually on submerged stalks of spikerush or similar aquatic vegetation about 2–3 centimeters (cm) apart (U.S. Fish and Wildlife Service 2004). SCLTS prefers shallow water for breeding (1–2 feet of water) in the pond where vegetation is present (C. Caris, wildlife biologist, U.S. Fish and Wildlife Service; oral communication;

August 2014). The amount of water needed by SCLTS in each pond is not known at this time.

For SCLTS, breeding ponds should be inundated during the late winter and should dry out in the middle of summer. Ideally, breeding ponds should:

- fill in most years and remain inundated from January through June;
- maintain these depths through the breeding season;
- dry out by August during most years, or on a consistent basis prior to the onset of fall rains, in order to prevent colonization of nonnative species such as bull frogs;
- include drawdowns over a several week period (Cbec 2013).

Water levels can also be managed to reduce pond volume and subsequently raise water temperature to incite transformation of larvae into adults (Cbec 2013).

The CTS life history is very similar to SCLTS, and this species generally requires shallow ephemeral ponds with vegetation for breeding during winter months (U.S. Fish and Wildlife Service 2010a). Among salamanders, CTS requires a relatively short period to complete development of aquatic larvae and may breed successfully in ponds that are inundated for at least 3–4 months (Shaffer and Trenham 2005). In cooler weather, the development period may be prolonged, with inundated periods in excess of 4 months (U.S. Fish and Wildlife Service 2009). In nearby Monterey County, documented breeding habitat of CTS was found in ponds 1–7 feet deep and inundated 10 weeks to 1 year (Trenham 2001). The amount of water needed by CTS in each pond is not known at this time. Information about the ideal timing for pond inundation in the area around the refuge could not be found at the time of this report.

CRLF water requirements are different from CTS and SCTLS because this species generally requires more water and longer inundation periods. Ideally, breeding ponds should:

- be perennial, provided that there are no invasive aquatic species such as various fish species, American bullfrogs, and burrowing crayfish;
- be filled with the onset of winter rains and dry out just prior to the following rainy season (Cbec 2013:11).

Ponds that dry in September or October can still be productive, but they should not dry earlier than this time. Ponds that dry out by August are not likely to be productive (Cbec 2013:11). The greatest potential for ideal CRLF breeding habitat is generally located farther downstream in the Larkin Valley (Cbec 2013:14).

Water management and infrastructure are used to help control water levels to promote recruitment. According to refuge staff, too much interannual fluctuation of pond levels may increase the risk that emergent vegetation will dry or be inundated; emergent vegetation is required for successful recruitment (C. Caris, wildlife biologist, U.S. Fish and Wildlife Service; oral communication; August 2014).

At the time of this report, all of the ponds were equipped with staff gages that measure to 0.01 foot so that refuge personnel can estimate the depth of water in the ponds to ensure that adequate water levels are maintained; however, data from these staff gages were not available for analysis. **Water levels should be recorded with dates and times, especially at times of recruitment surveys, to help determine optimal pond water levels for successful breeding and recruitment of SCLTS and CTS, and to better correlate this data with other hydrologic and climatic conditions.** Biweekly to monthly readings of water levels would facilitate a better understanding of the timing of pond inundation and drainage to determine if pond water levels are suitable to serve the life history needs of SCLTS, CLTS, and (to a lesser extent) CRLF.

Because of intense groundwater development in the Pajaro Valley groundwater basin, the quantity of high quality groundwater for use in augmenting water levels in ponds may be limited in the future. In addition, climate change will likely increase the water demand for maintaining water levels at current rates. Although use of groundwater is relatively infrequent,[42]

[42] Groundwater has only been used to augment water at Ellicott Pond twice (1992 and 2004), and Prospect Pond in 2014. The refuge staff have noted successful recruitment those years (D. Kodama, refuge manager, U.S. Fish and Wildlife Service; written communication; November 2014).

quantifying the amount of groundwater needed for successful recruitment during drought years would help refuge staff determine future pumping requirements if and when supplies become more limited. This information may also be required in the future for groundwater use reporting (see section 4.1, "Water Entitlements and Policy").

Habitat for federally listed amphibians has been substantially reduced and fragmented by development, resulting in restricted movement between upland areas and breeding ponds (U.S. Fish and Wildlife Service 2010a:34). An objective listed in the comprehensive conservation plan is to identify suitable habitat and buffers for protection through fee acquisition and easements (U.S. Fish and Wildlife Service 2010a:52). **Identification of suitable sites for new breeding ponds within and near fee and title acquisitions would help to reduce fragmentation of amphibian habitat and improve opportunities for successful recruitment.** Ideally, breeding ponds should be located in areas that accumulate substantial runoff (are located away from watershed ridges or drainage divides) and are located over soils with moderate to poor drainage to improve retention (see section 4.6, "Soils"). This would avoid the necessity to pump groundwater to augment water levels in ponds or for costly soil amendments to improve water retention.

Buena Vista Property

Over 99.8 percent of this unit does not have water-related vegetation. This unit contains one approximately 0.35-acre pond for breeding and recruitment of SCLTS. Buena Vista Pond was classified in NWI as palustrine unconsolidated shore (figure 19), with a water regime of temporarily flooded and diked and impounded (modifiers not mapped in figure 19). However, this pond was not diked and impounded at the time of classification. **Therefore, the water regime for Buena Vista Pond should be corrected in NWI to improve the local accuracy of NWI.**

No active water management occurs in the Buena Vista Property. At the time of this report, surface runoff is the only way this pond fills during the rainy season. There is a staff gage in place within the pond for noting water levels when precipitation is sufficient to fill the pond.

Some refuge ponds have been modified to increase efficiency of water storage to better maintain pond water levels. Redesign work commenced on Buena Vista Pond on October 10, 2014, following completion of the Ellicott Pond redesign (C. Caris, wildlife biologist, U.S. Fish and Wildlife Service; digital communication; December 2014). Work plans included excavating approximately 650 cubic yards of soil from an 85-foot by 85-foot section at the southern end of the pond. After approximately 12 inches of top soil was removed, a layer of bentonite was spread at a density of approximately 5 pounds per square foot. The top soil was then replaced on top of the bentonite layer, level with the original grade. As with Ellicott Pond (see below), the redesign was intended to make a smaller portion of the original pond better able the hold water throughout the amphibian breeding and larval metamorphosis during average rainfall years (Moehling 2014).

No patterns were observed between precipitation totals and recruitment success at Buena Vista Pond, although only 5 years of data were available and trends cannot be identified with this period of record. From 2009 to 2013, recruitment of SCLTS at Buena Vista Pond was successful only 2 of 5 years, and CTS was successful 1 of 5 years.

Ellicott Unit

Most of the Ellicott Unit does not have water-related habitat. On average approximately 15 percent of this unit is riparian woodland; 2 percent of the unit is without ephemeral ponds, and another 1 percent has ephemeral ponds with emergent vegetation.[43] These ponds were classified as palustrine unconsolidated shore using the same classification scheme as NWI (figure 19); however, Ellicott Pond and Prospect Pond were not delineated in NWI. **Including**

[43] Values calculated with ArcGIS using vegetation data from U.S. Fish and Wildlife Service (2010b).

these ponds in the NWI dataset would improve the local accuracy of NWI.

The Ellicott Unit has two wells that provide water to help ensure the population recruitment of the endangered SCLTS and the threatened CTS and CRLF (U.S. Fish and Wildlife Service 2010a). These wells are used to supplement pond water levels when runoff is not available.

One well with a pump is located approximately 370 feet north of Ellicott Pond; specific well depth, pump capacity, and water level data were unobtainable at the time of this report. This well can be used to augment water levels when needed (figure 20). Groundwater is pumped from the well and then run through an underground pipe that flows into the northern edge of the pond.

A second pump and well in the Ellicott Unit is used to augment Prospect Pond (U.S. Fish and Wildlife Service 2010a). This second well is located approximately 775 feet uphill to the east/northeast of Prospect Pond. A 5,000-gallon storage tank is adjacent to the well. This tank is dark in color so that water temperature can be increased before the water is piped underground to the pond (C. Caris, wildlife biologist, U.S. Fish and Wildlife Service; oral communication; August 2014). A pipe and outflow structure is located west of the pond and is operated to facilitate drainage. There are three piezometers located in the vicinity of Prospect Pond that are used for monitoring the water pressure of groundwater. At the time of this report, no data on piezometer readings were available.

Prior to this report, a plan was developed to redesign Ellicott Pond to increase its storage, thereby improving its ability to hold water throughout the amphibian breeding and larval metamorphosis during average rainfall years. This redesign included excavating a lower-elevation area within the pond near the drainage system. On September 5, 2014, excavation at Ellicott Pond began, and approximately 950 cubic yards was removed from a 100-foot by 60-foot area. This excavation was intended to increase pond depth to approximately 4 feet with a 5:1 slope. Following excavation, the area was reseeded with native vegetation.

Prospect Pond was redesigned in 2012, which included placement of a bentonite liner to help with water retention (Ruttenberg 2012). The pond and its outflow infrastructure were designed for the 10-year storm flow (1.2 cfs). An auxiliary overflow was designed to handle a minimum of the 100-year stormflow (2.7 cfs) (Ruttenberg 2012; see section 4.3, "Surface Water").

Since Prospect Pond was enhanced in 2012, larval SCLTS and several sub-adult CTS individuals were observed in the pond in 2013.

With regard to recruitment for SCLTS, Ellicott Pond was observed to fail in years when precipitation was less than 20 inches from October to July and no groundwater was used to augment water levels, with the exception of 2003 (figure 21). No patterns were observed between precipitation, groundwater augmentation, and the recruitment of CTS. From 1992 to 2013, Ellicott Pond had an estimated 15 years of successful recruitment for SCLTS, whereas recruitment for CTS was only successful for 11 years. Recruitment of both species was observed for 8 of those years. At this time there are no clear patterns with respect to groundwater augmentation and recruitment of CTS. Recruitment of SCLTS was successful in the 2 years in which groundwater was applied (1992 and 2004), although groundwater was not applied in the years with precipitation less than 20 inches.

Calabasas Unit

About a quarter of the entire unit contains water-related habitat. Nearly 22 percent of this unit is covered in riparian woodland, and 6 percent is ephemeral pond land.

The lower portion of Calabasas Pond was classified as Palustrine unconsolidated bottom (figure 19) but with a water regime that is semi-permanently flooded and diked and impounded (modifiers not shown in figure 19). The upper portion of Calabasas Pond was classified as freshwater emergent wetland (figure 19), but with a water regime that is seasonally flooded and diked and impounded. Calabasas Pond was changed from a recreational pond to a breeding pond after pond acquisition in 1999. After the time of wetland classification, stored water has likely been reduced and the water regime is more seasonal. Therefore, this water body would be more appropriately classified with a modifier of seasonally flooded. Because depth information and aquatic vegetation within the pond was unavailable at the time of this report, it is

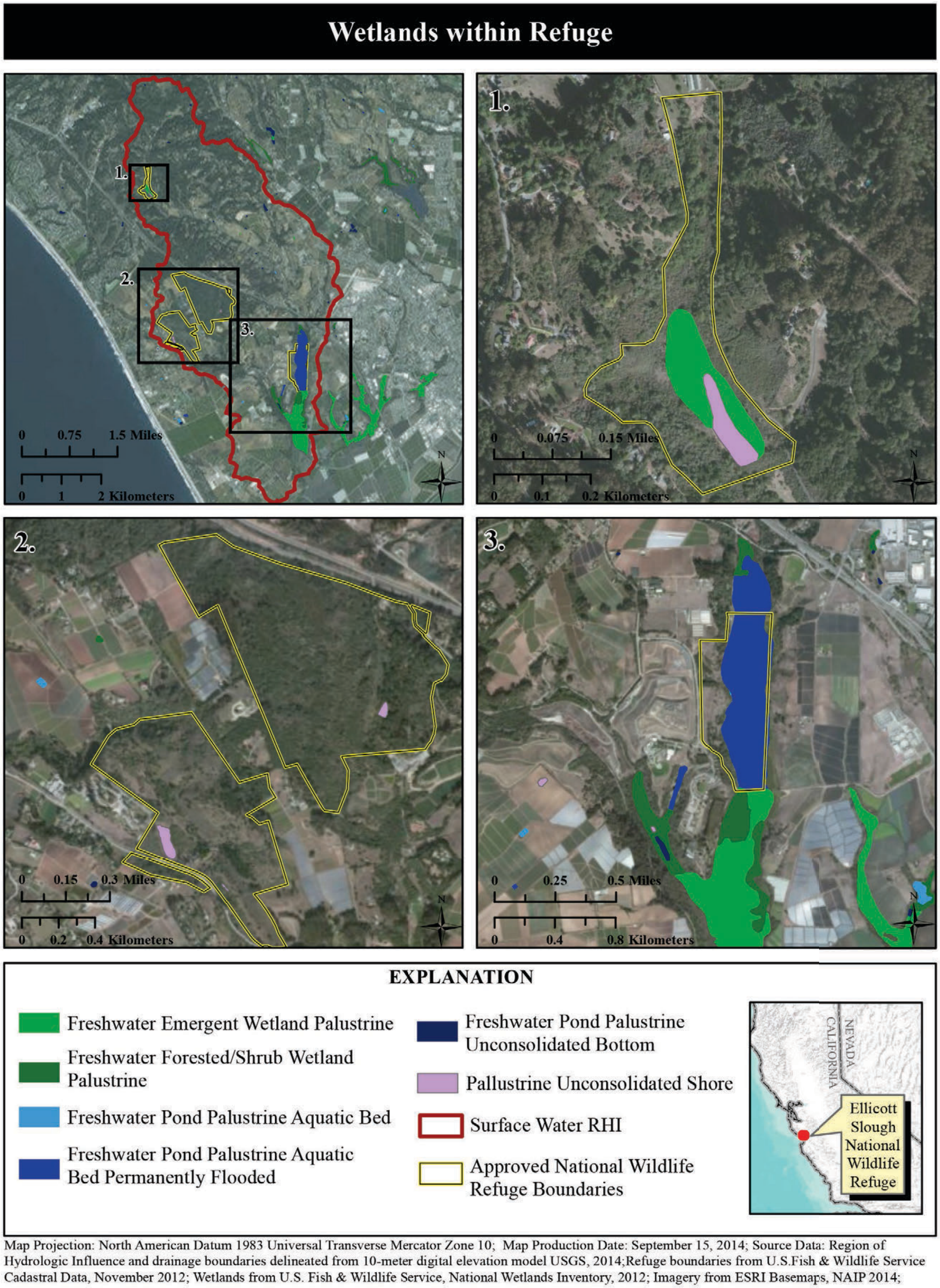


Figure 19. Wetlands on and near Ellicott Slough National Wildlife Refuge.

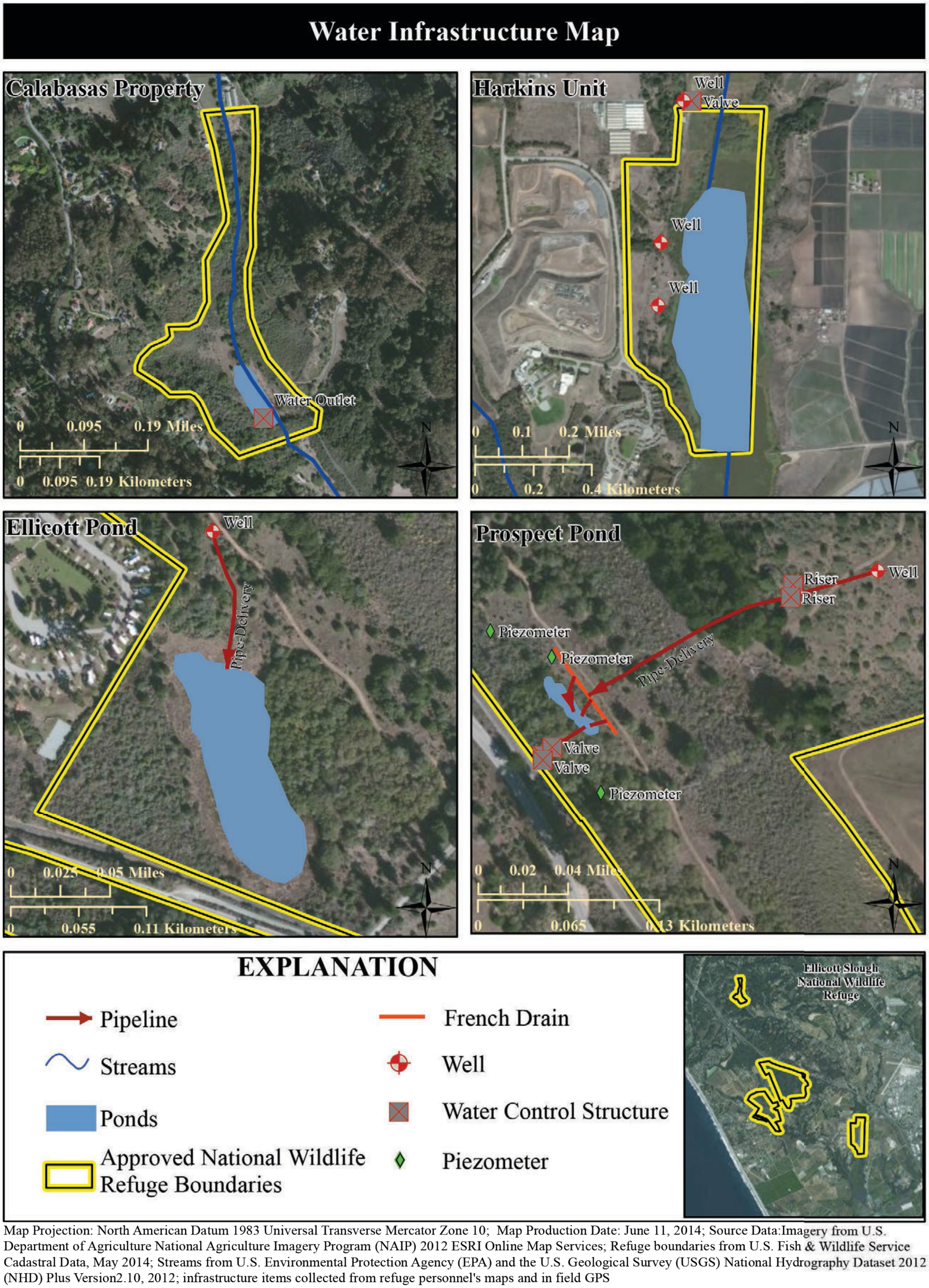


Figure 20. Water management conceptual map and locations of water infrastructure for Ellicott Slough National Wildlife Refuge.

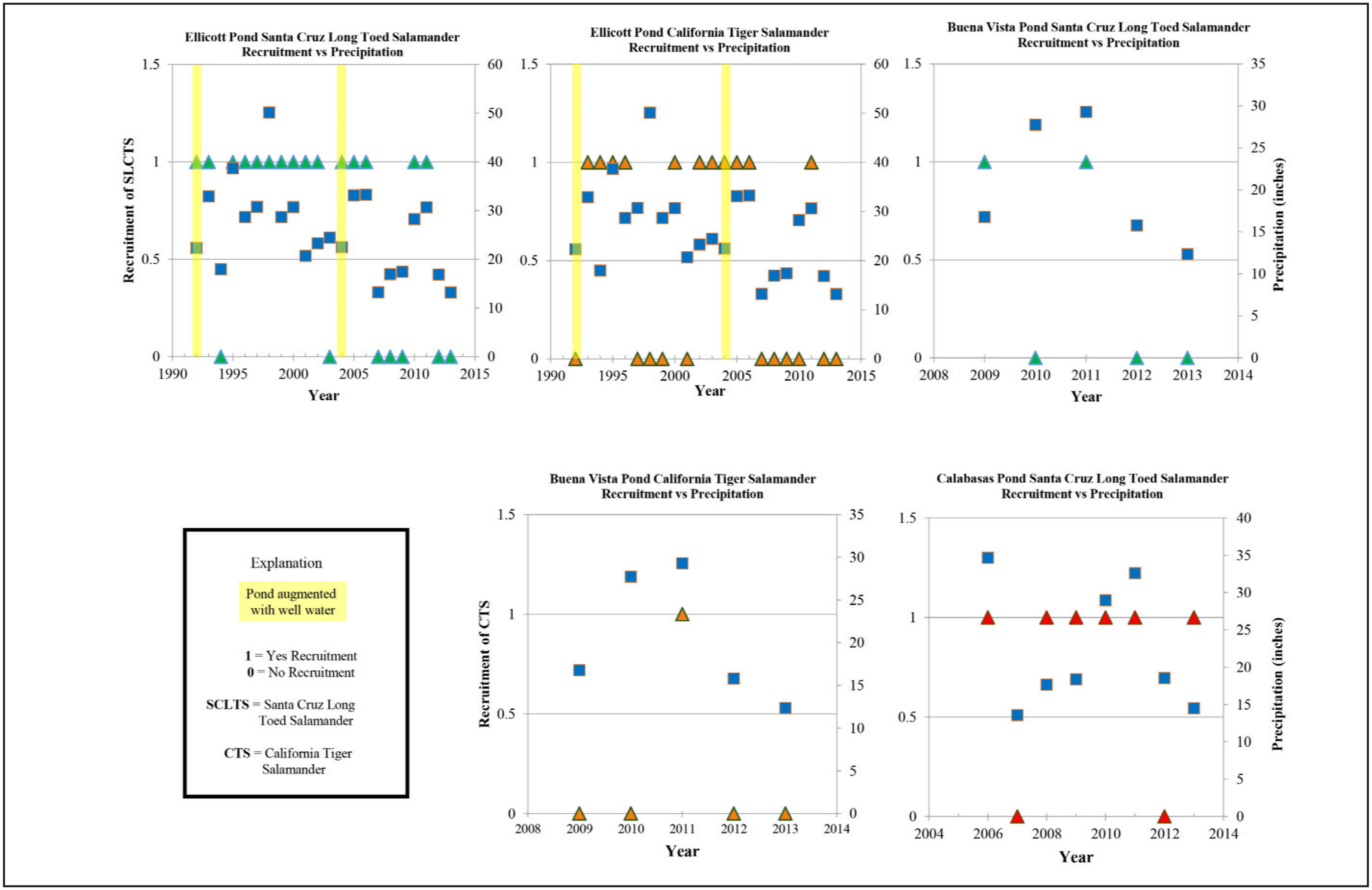


Figure 21. Comparison of recruitment success and precipitation from October to July at Ellicott Pond, Buena Vista Pond, and Calabasas Pond in the Ellicott Slough National Wildlife Refuge, 1992–2013.

uncertain whether unconsolidated bottom is the most accurate classification of this pond. **Investigating and updating the classification of Calabasas Pond in the NWI dataset would improve the local accuracy of NWI.**

Calabasas Pond within the Calabasas Unit is a shallow pond in the upper portion of the Larkin Valley Creek within Harkins Slough. This pond was historically a permanent reservoir with an earthen dam. Santa Cruz County of Public Works intentionally breached a portion of the dam around 1980 after it was determined to be structurally unsound; this breach resulted in a shallower ephemeral pond in the footprint of the old reservoir. During a substantially wet year (1998–1999), the earthen dam was breached again and the pond drained more quickly than expected. Refuge staff subsequently used sand bags to fill in the breach and retain enough water in the pond for SLCTS. A permanent repair to the breach was completed in 2006 (D. Kodama, refuge manager, U.S. Fish and Wildlife Service; written communication; November 2014). Breeding and recruitment of SCLTS occurs regularly at this pond site when water levels are sufficient (C. Caris; wildlife biologist, U.S. Fish and Wildlife Service; oral communication; August 2014). From 2006 to 2013, the 2 years with failed recruitment were also years in which precipitation from October through July was less than 15 inches. However, only 8 years of data were available for analysis—a period of record likely not long enough to identify trends.

Harkins Slough Unit

There is currently no water management occurring within the Harkins Slough Unit, which is continually inundated with stagnant water (see section 4.3, “Surface Water”). Approximately 46 percent of the Harkins Slough Unit is composed of open water, 15 percent is freshwater marsh (roughly 3.5 percent of which has emergent vegetation or aquatic vegetation), and 5 percent is riparian woodland.

A majority of the Watsonville Slough was originally classified as palustrine emergent freshwater wetland in NWI (figure 19), likely before the pond was permanently inundated in 2001. However, because Harkins Slough is now a permanently inundated open water body, this water body is more appropriately classified as palustrine freshwater pond with an aquatic bed that is permanently flooded. The classification was updated in figure 19 to reflect this estimate. **Investigating and updating the classification of Harkins Slough in the NWI dataset would improve the local accuracy of NWI.**

Three wells have been inventoried on this unit, none of which were in use at the time of this report[44] (figure 20). The well depth of the northernmost well is approximately 134.8 feet below ground surface with a depth to water of 9.55 feet, and the southernmost well was 27 feet deep and was dry. The remaining well was not accessible at the time of this report; accordingly, water level and hole depth information is currently unavailable. A set of pipes and valves was located approximately 90 feet east of the northern well. The purpose of these pipes and valves was unknown at the time of this report; however, this infrastructure could possibly be associated with another well. **Completion of mapping of all pipe systems and determination of all well characteristics would assist with better understanding of the functionality of refuge infrastructure.** This information can be used to determine if infrastructure should be permanently abandoned or if there is a potential use for infrastructure for habitat management.

Mean water elevation of Harkins Slough ranged from 3.0 to 8.5 feet, with a mean of 5.6 feet (North American Vertical Datum of 1988, or NAVD).[45] In most years, the model indicated that Harkins Slough generally settled into a winter base elevation of 6.5 feet. Increases in water surface elevation are fairly small in magnitude (on the order of 1 foot or less), and recovery to this base level generally occurred within about a week (Balance Hydrologics 2014:116–117).

Water levels in Harkins Slough have the potential to be substantially lowered under various water management scenarios modeled in HEC-RAS, but will likely increase under

[44] This statement is based on an inventory of infrastructure that occurred in March 2013.

[45] These figures are based on hydraulic modeling with HEC-RAS over the period 2002–2012 (Balance Hydrologics 2014).

climate change (Balance Hydrologics 2014). Water levels were lowered under the following modeling scenarios: 1) sediment and vegetation removal from channels in downstream portions of Watsonville Slough, 2) wetland restoration at the confluence of Harkins and Watsonville Sloughs, and 3) pump capacity increased from a mean of 630 to 1,100 acre-feet per year. Mean modeled water levels showed that water levels were lowered by 1.7 feet in this scenario where all three conditions were present. To a lesser extent, water levels would also be lowered without sediment and vegetation removal (a mean of 0.7 feet). Modeled sea level rise scenarios for 14 inches by 2050 and 55 inches by 2100 indicate that in spite of restoration and facility improvements, water levels would likely increase unless action is taken to improve water management infrastructure in the Watsonville Slough (see section 4.2, "Climate").

Understanding the implications of flow dynamics and water level changes on refuge objectives for Harkins Slough Unit is limited. Currently, there are few plans to maintain or manage water levels in Harkins Slough because biological objectives have not been established. **Establishing clear biological objectives for the Harkins Slough Unit would help the Service to understand impacts of factors that affect water levels and to identify actions for supporting best management practices in the slough system.**

Due to the complex dynamics of water flow in Harkins Slough and throughout the Watsonville Slough Unit, measuring of water levels in Harkins Slough is important to monitor monthly and seasonal fluctuations. **The Service should install a staff gage in the Harkins Slough Unit or coordinate with PVWMA to obtain current water level records at the Harkins Slough at Railroad station used in the monitoring and modeling study (Balance Hydrologics 2014:26).**[46] These data will be more useful if the Service can establish water level objectives or water quality objectives (which are related in part to water levels; see section 4.7, "Water Quality") to protect priority biological resources.

4.6 Soils

There are 14 different soil classifications on the refuge. Of the 8 unique soil types, 5 are the same general type (same name) but with different slopes (table 3).

The drainage classification was compared with flow accumulation to determine potentially suitable areas for future pond development, and potentially suitable areas were described for each unit. Ideally, breeding ponds should be located in areas that accumulate substantial runoff (that is, located away from watershed ridges or drainage divides) to improve access to runoff and should be located over soils with moderate to poor drainage to improve retention. **Refuge staff should strongly consider these areas for future breeding pond locations and prioritize these areas for further investigation.** Unfortunately, no areas with substantial flow accumulation were located in areas with poorly drained or somewhat poorly drained soils (see details below). **Refuge staff could still investigate these areas after rain events to determine if ponding has occurred and monitor water levels after inundation to determine if the area may be suitable for water retention.**

[46] This station was not included in the surface water station inventory because data were not readily available to the public at the time of this report. However, data may be obtainable by contacting PVWMA, which currently maintains this station as part of a monitoring network. The station is located at latitude 36.8978 and longitude -121.805.

Table 3. Characteristics of soil map units occurring on and near Ellicott Slough National Wildlife Refuge.

Soil map unit		*Map units (fig. 22)*	*Slope (percent)*	*Percent of soil map unit found within refuge*	*Area in acres*	*Landform*	*Parent bedrock*	*Depth to water table (inches)*	*Inches depth to restrictive layer (material)*	*Drainage*	*Water storage capacity (rating)*
Clear Lake clay, moderately wet		119	0 to 2	12.0	75.3	Basin floors	Sedimentary rock alluvium	36–72	>80	Poorly drained	15.8 (very high)
Elkhorn-Pfeiffer complex	Elkhorn (composes 45 percent of unit)	136	30 to 50	10.1	60.5	Terraces	Marine deposits	>80	>80	Well drained	15.8 (very high)
	Pfeiffer (composes 25 percent of unit)					Hills	Marine deposits and/or residuum weathered from sandstone	>80	40–66 (paralithic bedrock)	Well drained	10.0 (high)
Baywood loamy sand		105	2 to 15	6.7	40.1	Dunes	Eolian deposits	>80	>80	Somewhat excessively drained	8.4 (moderate)
		106	15 to 30	27.2	162.3	Dunes	Eolian deposits	>80	>80	Somewhat excessively drained	8.4 (moderate)
		107	30 to 50	6.2	37.2	Dunes	Eolian deposits	>80	>80	Somewhat excessively drained	8.4 (moderate)
Elder sandy loam		129	0 to 2	1.8	10.5	Fans, plains	Alluvium	>80	>80	Well drained	15.3 (very high)
		130	2 to 9	6.2	36.8						

Soil map unit		*Map units (fig. 22)*	*Slope (percent)*	*Percent of soil map unit found within refuge*	*Area in acres*	*Landform*	*Parent bedrock*	*Depth to water table (inches)*	*Inches depth to restrictive layer (material)*	*Drainage*	*Water storage capacity (rating)*
Elkhorn sandy loam		133	2 to 9	2.6	15.4	Alluvial fans, terraces	Marine deposits	>80	>80	Well drained	15.8 (very high)
		134	9 to 15	1.4	8.3						
		135	15 to 30	7.8	46.4						
Watsonville loam		177	2 to 15	4.0	23.9	Marine terraces	Alluvium	>80	>80	Somewhat poorly drained	6.2 (moderate)
	Watsonville loam: thick surface	179	2 to 15	5.4	32.1						
Tierra-Watsonville complex	Tierra (composes 55 percent of unit)	174	15 to 30	2.8	16.4	Marine terraces, fan terraces	Sedimentary rock alluvium	>80	>80	Moderately well drained	5.7 (low)
	Watsonville (composes 30 percent of unit)					Marine terraces, fan terraces	Sedimentary rock alluvium	>80	>80	Somewhat poorly drained	6.2 (moderate)
Fluvaquentic Haploxerolls-Aquic Xerofluvents complex		139	0 to 15	2.9	17.2	Flood-plains	Alluvium	30–59	>80	Moderately well drained	7.2 (moderate)

Buena Vista Property

Seven different soil classifications are found in the Buena Vista Property, consisting of five separate soil types (figure 22): Baywood Loamy Sand, Elkhorn Sandy Loam, Elkhorn-Pfeiffer complex, Watsonville Loam, Tierra-Wastonville complex, and Fluvaquentic Haploxerolls-Aquic Xerofluvents complex. The Baywood loamy sand, Fluvaquentic Haploxerolls-Aquic Xerofluvents, and the Watsonville Loam are considered to have moderate available water storage capacity, while Elkhorn sandy loam is considered to have very high available water storage capacity.

The Baywood Loamy Sand has slopes that range from 15 to 50 percent. These soils are dispersed throughout the Buena Vista Property and cover the largest area. This soil is somewhat excessively drained (figure 22) and derived from eolian deposits that are located on dune landforms. The Baywood Loamy Sand is the soil type found under the Buena Vista Pond, which may explain why poor water retention has been reported in the past (D. Kodama, refuge manager, U.S. Fish and Wildlife Service; oral communication; May 2014). At the time of this report, there was a planned pond restoration project that includes adding a clay liner to improve water retention (D. Kodoma, refuge manager, U.S. Fish and Wildlife Service; oral communication; May 2014).

The Elkhorn Sandy Loam is mainly located towards the western border of the Buena Vista Property. This soil is well drained, found on alluvial fans and terraces, and derived from marine deposits.

The Elkhorn-Pfeiffer complex is generally a gravelly sandy loam. This soil complex is found along the eastern border of the Buena Vista Property, located on terraces and hills, and derived marine deposits and weathered sandstone. This soil is considered well drained.

The Wastonville Loam soils are classified at a slope ranging from 2 to 15 percent. These soils are somewhat poorly drained, found on marine terraces, and derived from alluvium.

The Fluvaquentic Haploxerolls-Aquic Xerofluvents complex contains a variety of sandy to clay layers throughout the units that are well stratified. This complex is considered moderately well drained, is found on floodplains, and is derived from alluvium.

Soils with poor to somewhat poor drainage are generally located near basin ridges and not located in areas with substantial flow accumulation (greater than a 0.0002-square-mile drainage area; figure 16). These areas may be suitable pond areas because of enhanced retention but may need alternative water sources such as groundwater or diversions to help fill ponds. However, an area just west of Buena Vista Pond has moderately well drained soils and substantial flow accumulation. This area would be more likely to receive runoff during rain events, although it might be somewhat difficult to retain water once inundated.

Ellicott Unit

The Ellicott Unit contains six different soil classifications, consisting of four soil types with varying percent slopes: Baywood Loamy Sand, Elder Sandy Loam, Elkhorn Sandy Loam, and Elkhorn-Pfeiffer complex (figure 22). Baywood Loamy Sand, Elkhorn Sandy Loam, and Elkhorn-Pfeiffer Complex are explained above.

The Elder Sandy Loam accounts for two classifications in this unit with different slopes ranging from 0 to 9 percent. Derived from alluvial plains and fans, this soil type is known to be well drained with very high available water storage capacity.

Both the Elkhorn Sandy Loam and Baywood Loamy Sand soils are found under the areas where ponds are managed. These soil types have been described as well drained to somewhat excessively drained. According to refuge personnel, recent boring logs taken during pond rehabilitation planning indicate that clay soil is located under the Ellicott Pond in some areas. It is possible for Elkhorn Sandy Loam to contain clay loams, although the SSURGO classification indicates that these anomalies are usually found at depths between 20 and 60 inches. However, heterogeneities in the soil profile may account for the unexpected clay soil type found in this part of the unit. This type of soil is more optimal for water retention.

Because most of the soils in the Ellicott Unit are well to somewhat excessively drained, it is unlikely that other areas would be suitable for future pond development without soil amendments or sourcing of water supply from groundwater. An area in the northwest corner of the unit does have the potential to accumulate runoff, and it could be investigated after rain events to determine if ponding occurs (figure 16).

Calabasas Unit

The Calabasas Unit is predominately covered by Elkhorn-Pfeiffer complex, especially in the southern half and the eastern edge of the northern area of the unit (figure 22). This soil type is well drained with a high to very high available water capacity, located on terraces or hills, and derived from marine deposits or weathered sandstone.

Because this soil type is well drained (figure 22) and has a high capacity to transmit water, efficiency of water retention in the breeding pond may be reduced. This is especially a problem during drought years where runoff contributions are lower.

No areas with substantial flow accumulation were located in areas with poorly drained or somewhat poorly drained soils (figure 16). However, a small area of somewhat poorly drained soil is located on the western edge of the Calabasas Unit, just west of the existing Calabasas Pond. Flow accumulation is likely minimal at this location, but this area could be investigated further after rain events to determine if ponding has occurred. The drainage valley upstream from the existing Calabasas Pond may also be a potentially suitable location for future pond development because it is moderately well drained but is along a defined flow path for runoff to accumulate.

Harkins Slough Unit

The Harkins Slough Unit has five soil classifications that are made up of four different soil types. Soil types include Clear Lake Clay, Tierra-Watsonville complex, Watsonville Loam, and Elkhorn Sandy Loam complex (figure 22). Elkhorn Sandy Loam complex is described above.

The majority of the unit contains Clear Lake Clay, which is poorly drained. This soil type is found in the same general area as Holocene Era basin deposits (figure 3) and located under the freshwater wetland.

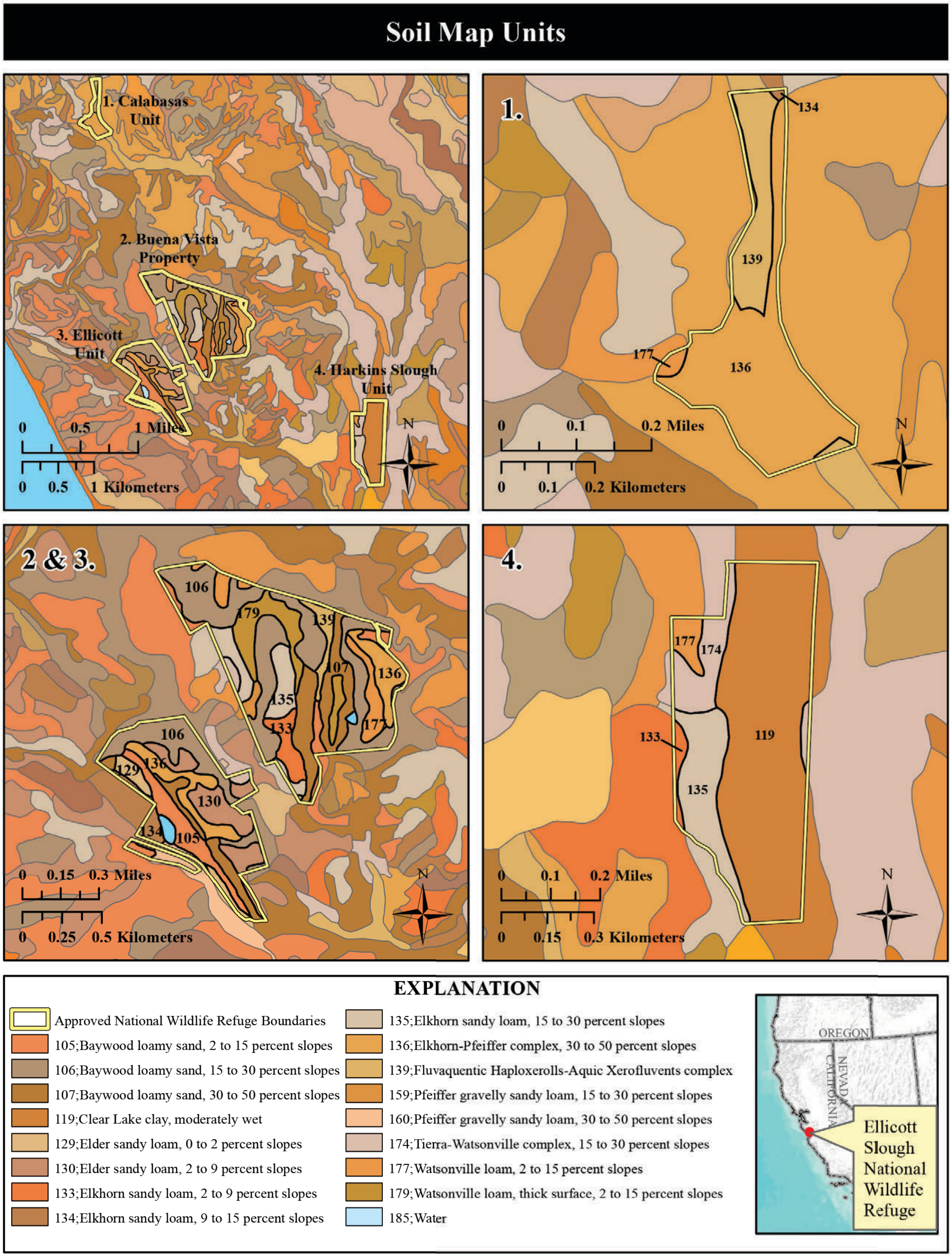
The northeastern portion of this unit contains the Tierra-Watsonville complex and Watsonville Loam, which range from moderately well drained to somewhat poorly drained (figure 16). These soils are found on marine and fan terrace landforms derived from alluvium from sedimentary rock. These soils are generally layered with sandy clay loam overlain by clay-to-clay loam and topped with loam-to-sandy loam.

4.7 Water Quality

Surface Water Quality

The hydrologic and water quality conditions in Harkins Slough and the larger Watsonville Slough system have been significantly impacted by human activities. Extensive agricultural land use in the surrounding drainage basin (since 1931) has contributed to non-point source pollution. In addition, seasonal open water marshes and stagnant water circulation have developed through the slough system, as a result of recent increases in winter flooding. These factors have contributed to eutrophic conditions throughout the Watsonville Slough system (Swanson Hydrology and Geomorphology 2002).

Swanson Hydrology and Geomorphology (2002) was consulted by the PVWMA to study the hydraulic and water quality impacts of the HS Pump, which may improve water quality in Harkins and Watsonville Slough through circulation. From June 2001 to August 2002, they monitored or analyzed depth and water quality data (total dissolved solids [TDS], dissolved oxygen, salinity, pH, nutrients, BOD, boron, coliform, and oil and grease) in both Harkins and Watsonville Sloughs to investigate the impact on these parameters from pumping. The HS Pump, located at the confluence of the Harkins and Watsonville Sloughs, withdrew water to facilitate groundwater recharge and supplement agricultural irrigation water supply in the Watsonville Slough watershed. Swanson Hydrology and Geomorphology (2002) found that there was less impact on water levels when the initial water volume in Harkins Slough was elevated (as indicated by a depth of 3–4 feet in



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10; Map Production Date: November 13, 2012; Source Data: Soils from U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Geographic Database (SSURGO), 2012; Source Data: Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, November 2014

Figure 22. Soil map units found on and near Ellicott Slough National Wildlife Refuge.

Upper Harkins Slough), which can be observed during wet periods or storm events. In these conditions, it is assumed that pumping increased the circulation and flow of water in the lower reaches of Watsonville Slough without lowering water levels (Swanson Hydrology and Geomorphology 2002).

Operation of the pump during spring months might also delay the start of eutrophic conditions in Watsonville Slough. However, Swanson Hydrology and Geomorphology (2002) did not have enough data to identify a quantitative relationship among water quality, pumping, and seasonal rainfall. Swanson Hydrology and Geomorphology (2002) also states that despite improvement in local water quality as a result of pump operation, pumping has little ecological value without further restoration. High nutrient enrichment and lack of bank vegetation continue to degrade water quality within the slough in spite of pump operation.

Results of the Level II pre-acquisition survey study at Harkins Slough (U.S. Fish and Wildlife Service 2005) showed elevated concentrations of lead in surface water that pose an ecological risk for long-term exposure of aquatic organisms. According to this study, this value is also above the residential and industrial screening levels. Elevated concentrations of lead were found in a surface water sample taken in July 2004. However, follow-up sampling in December 2004 at the same sampling locations did not document lead concentrations above laboratory quantitation levels; this was likely because high, early season rainfall diluted the surface water and lead concentrations fell below detectable levels (U.S. Fish and Wildlife Service 2005). However, Service personnel resampled surface water at three locations around Harkins Slough in July 2006 and found no detectable lead (U.S. Fish and Wildlife Service 2014b; sites 46–48, figure 8; sites 46–48, appendix B, table B3). This finding indicates that lead is either no longer an issue or that elevated lead concentrations were caused by a temporary contamination event.

A comparison of surface water samples at Harkins Slough to the CCC also showed that aluminum and iron concentrations have exceeded aquatic life criteria. Surface water sampled on the north and south ends of the Harkins Slough Unit (HS-SW-01B, HS-SW-02B, and HS-SW-03B) by the Service in 2006 indicated total recoverable metal detections of aluminum and iron concentrations higher than the CCC (88 micrograms per liter [µg/L] and 1,000 µg/L, respectively). Aluminum was detected in all three sample locations at concentrations ranging from 1,200 to 2,470 µg/L. Iron was detected at all three sites at levels ranging from 2,600 to 3,500 µg/L.

However, caution should be taken when comparing the results of these samples with the CCC. All CCC criteria are for dissolved concentrations. The samples were not filtered and therefore did not represent dissolved metals; rather, they represented total recoverable metal (B. Montgomery, analytical chemist, U.S. Fish and Wildlife Service; written communication; July 2014). **Future sampling conducted by the Service should include dissolved concentrations in order to more accurately compare samples with the CCC.**

The survival of the spotted salamander (*Ambystoma maculatum*) embryo was negatively correlated with the concentration of aluminum in temporary ponds (Canadian Council of Ministers of the Environment 2003). It is not known if the same aluminum concentrations would have the same effect on CTS or SCLTS. At this time there are no plans to facilitate recruitment of either salamander species in the Harkins Slough Unit. **Should recruitment be facilitated in the future, surface water quality testing would be beneficial for checking metal concentrations to ensure embryonic survival should the above study results correlate to CTS and SCLTS.**

Harkins Slough has been identified as impaired under Section 303(d) of the Federal Clean Water Act for selected constituents (figure 23; appendix B, table B8). Harkins Slough, which travels through both the Calabasas Unit and the Harkins Slough Unit, is currently listed for chlorophyll-a and low dissolved oxygen with an estimated TMDL completion date of 2021. Exceedances in chlorophyll-a and low dissolved oxygen could adversely affect warm freshwater habitat.

If the Service is interested in restoring Harkins Slough, implementing a seasonal or continuous water quality monitoring program—including monitoring physical parameters and chlorophyll-a, nutrients, and

water levels—would be useful to better understand the relationship among seasonal rainfall, pump operation, and other factors. Because aluminum, iron, and lead are of historical concern in Harkins Slough, the water quality monitoring program should also include seasonal or biannual sampling of metals to better associate these parameters with variable hydrologic conditions.

Harkins Slough is also currently listed for *Escherichia coli* (E. coli) and fecal coliform, with a USEPA TMDL approval date of 2007. E. coli and fecal coliform exceedances adversely affect water contact recreation, although currently there are no types of water recreation allowed in the Harkins Slough Unit. Other studies support the finding that Harkins Slough is contaminated by bacteria (fecal coliform and E. coli), which, again, are mostly an issue for recreational uses of the slough. Hager et al. (2004) conducted a monitoring study to investigate bacteria contamination of the Watsonville Slough system to determine exceedance of water quality standards identified in the Central Coast Region Basin Plan. Samples were collected from 15 sites along 5 waterways in the system during the summer and winter of 2003. Except for the most downstream site in the Pajaro estuary, all other sites exceeded water contact recreation objectives in either the summer or winter. No single geographic area or land use could be isolated as the source.

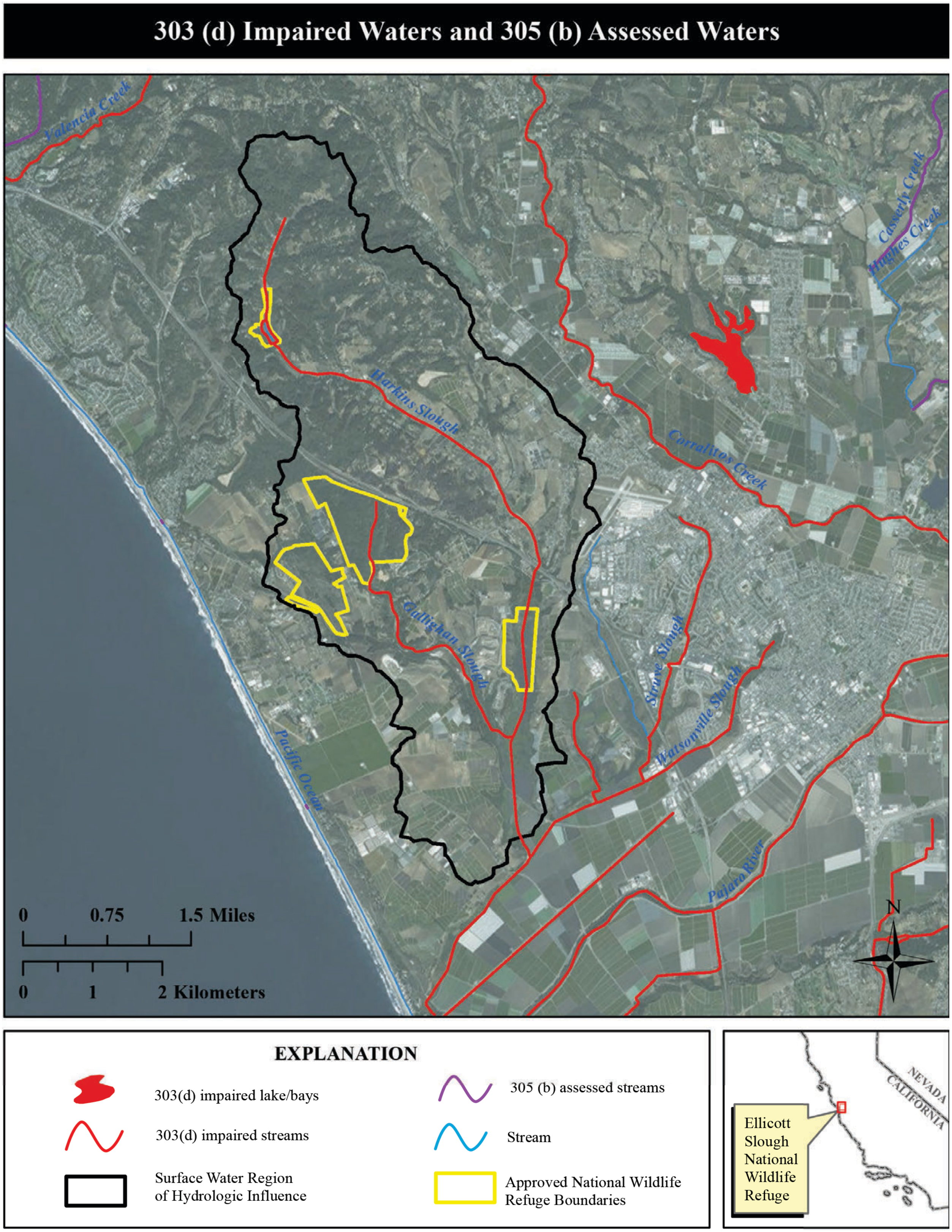
The largest areas of fecal coliform contamination were near the confluence of Harkins Slough and Watsonville Slough and the heavily urbanized areas of upper Struve Slough (figure 1; Hager et al. 2004). However, two sampling locations on Harkins Slough at Harkins Road (at the southern border of the Harkins Slough Unit) and upstream of Harkins Slough at Ranport Road (approximately 0.3 mile upstream from the Harkins Slough Unit boundary) showed bacteria concentrations that greatly exceeded objectives for water contact recreation (10 percent of samples exceeded 400 most probable number (MPN)/100 mL) for both fecal coliform (80–100 percent of samples in winter and 20–80 percent in summer) and E. coli (60–100 percent in winter and 20–80 percent in summer) (Hager et al. 2004).

Gallighan Slough has also been identified as impaired under Section 303(d) with a USEPA TMDL approval date of 2007, although no impacts on warm freshwater habitat were listed. Gallighan Slough is listed for E. coli and fecal coliform, which adversely affect water contact recreation. The source of these pollutants is unknown. The headwaters for Gallighan Slough are approximately 0.14 mile to the west of Buena Vista Pond and 0.45 mile from Prospect Pond in the Ellicott Unit. Gallighan Slough may also receive surface runoff from both the Ellicott Unit and Buena Vista Property (figure 1).

Sea level rise—especially under a scenario with an increase of 55 inches by 2100—has the potential to increase the salinity in Harkins Slough as a result of seawater intrusion into the Watsonville Slough system (see section 4.2, “Climate” and section 4.3, “Surface Water”). Coastal storm events and wave over-topping at the mouth of the Pajaro River could result in salt seawater entering the slough system, resulting in flooding of the area downstream of Harkins Slough and an encroachment of salt water into Harkins Slough where it meets Watsonville Slough. Incursion of seawater into Harkins Slough could lead to prolonged density stratification of Harkins Slough because of mixing with freshwater runoff from the upstream drainage basin and inflows from Watsonville Slough. Because salt water is denser than freshwater, this mixing could result in a persistent seawater lens underlying a freshwater zone. Currently, Harkins Slough is a freshwater system, with specific conductance ranging from 393 to 648 microsiemens per centimeter (µS/cm).[47]

Understanding the implications of degraded water quality for refuge objectives for Harkins Slough Unit is limited. Currently, there are few plans to maintain or manage water in Harkins Slough because specific biological objectives have not been established (D. Kodama, refuge manager, U.S. Fish and Wildlife Service; oral communication; May 2014). **Establishing clear biological objectives for the Harkins Slough Unit would help the Service to understand**

[47] Specific conductance in freshwater ranges from 0 to 1,300 µS/cm, specific conductance in brackish water ranges from 1,301 to 28,800 µS/cm, and specific conductance in salty water is greater than 28,800 µS/cm (Hem 1985).



Map Projection: North American Datum 1983 California Teale Albers; Map Production Date: February 26, 2014; Source Data: Refuge boundaries from U.S. Fish & Wildl Service Cadastral Data, May 2012; Imagery from National Agriculture Imagery Program (NAIP) ESRI Online Map Services, 2012; 303(d) and 303(b) data from Californi State Water Resources Control Board, 2012; Unassessed streams from U.S. Geological Survey, National Hydrography Dataset, 2009; Canals from U.S. Bureau of Reclamation, 2007; Region of Hydrologic Influence boundaries delineated from 10-meter digital elevation model through StreamStats Web Application (USGS, 2014)

Figure 23. 303(d) listed impaired waterbodies and 305(b) assessed waterbodies on and near Ellicott Slough National Wildlife Refuge.

impacts of factors that affect water levels and to identify actions for supporting best management practices in the slough system to improve water quality.

Groundwater Quality

Contaminant threats to groundwater in the PVGB include high chloride levels from seawater intrusion, TDS, and nitrates (Carollo Engineers 2013). Hanson (2003) also reported high chloride, sulfate, and nitrate concentrations in groundwater southeast of Watsonville and in an area northwest of the Pajaro River that has high specific conductance and boron. Constituents of concern in irrigation water in the Pajaro Valley, which is derived primarily from groundwater, include nitrates, salinity, sodium, toxicity from chloride and sodium, and crop pathogens, specifically phytophthora (Carollo Engineers 2013).

According to Hanson (2003), long-term changes resulting from groundwater development and water level changes have an influence on water quality, including salinity and nitrate contamination. Coastal groundwater wells investigated in this study were found to be saline. However, other changes in groundwater quality chemistry might indicate additional seawater intrusion, changes in surface water inflows, and infiltration of irrigation return flows and runoff (Hanson 2003). The wells sampled in Hanson (2003) were 1–5 miles south or southeast of the refuge; no samples directly represent refuge water quality. However, seawater intrusion continues to be a major source of possible contamination for all wells in the Pajaro Valley if the progression is not stopped.

Regions of high salinity in groundwater have been expanding (see section 4.4, "Groundwater"). Aquifers along the coast have elevated chloride concentrations from seawater intrusion (Hanson 2003), which at this time does not appear to affect refuge wells either because the aquifers are shallow or not far enough inland. The middle and lower portions of the Aromas Sands appear to have the most substantial increases in chloride concentrations (RMC 2002). Because the chloride levels are higher in the deeper confined aquifer layers (200–8,500 mg/L) compared to shallow aquifers (50–500 mg/L), this implies that seawater is intruding along the coast in the middle to lower portions of the Aromas Sands. This might indicate that drilling deeper for better water may not be a viable option in the future as intrusion moves inland and more wells are lost to seawater impacts (RMC 2002). As of 2010, PVWMA is identifying best management practices to help alleviate seawater intrusion and groundwater overdraft and developing a salt and nutrient management plan (Carollo Engineers 2013).

Nitrate and TDS concentrations might also be elevated in groundwater throughout the Pajaro Valley. Nitrate concentrations in shallow groundwater might be caused by deep percolation of applied irrigation water (Hanson 2003). TDS concentrations in some groundwater quality samples from a sampling network in the Pajaro Valley indicated exceedance of water quality objectives for irrigation uses (Carollo Engineers 2013). Nitrate contamination is a problem in groundwater recharged by irrigation drainage, recharged by the Pajaro River (which is subject to non-point source runoff), and near areas with densely sited septic tanks. Marco et al. (1999) showed a strong sensitivity of the survival of the northwestern salamander (*Ambystoma gracile*) to relatively low levels of both nitrate (45 mg/L) and nitrite (5 mg/L). It is unclear whether the salamander species of concern at Ellicott Slough Refuge (CTS and SCLTS) would experience the same effects at the same nitrate and nitrite levels as the amphibians in this study. **However, given nitrate and nitrite issues present in groundwater throughout the Pajaro Valley, nitrate and nitrite concentrations in groundwater used for pond maintenance should be periodically tested to ensure that levels are safe for exposure to these and other species.**

The Service investigated water quality concerns at Harkins Slough in a Level II pre-acquisition survey contaminant assessment. Sampling took place in July 2004 and consisted of samples of surface and subsurface soil, surface water and sediment, groundwater (both from drilled soil boring and from onsite wells), and construction materials from buildings on the property. Analyses looked for the following: pesticides, herbicides, volatile organic compounds, metals, nitrate, polychlorinated biphenyls, asbestos, lead, coliform bacteria, TDS, and suspended solids (U.S. Fish and Wildlife Service 2005). Where elevated metals concentrations were detected, further sampling of groundwater and soils was conducted in December 2004.

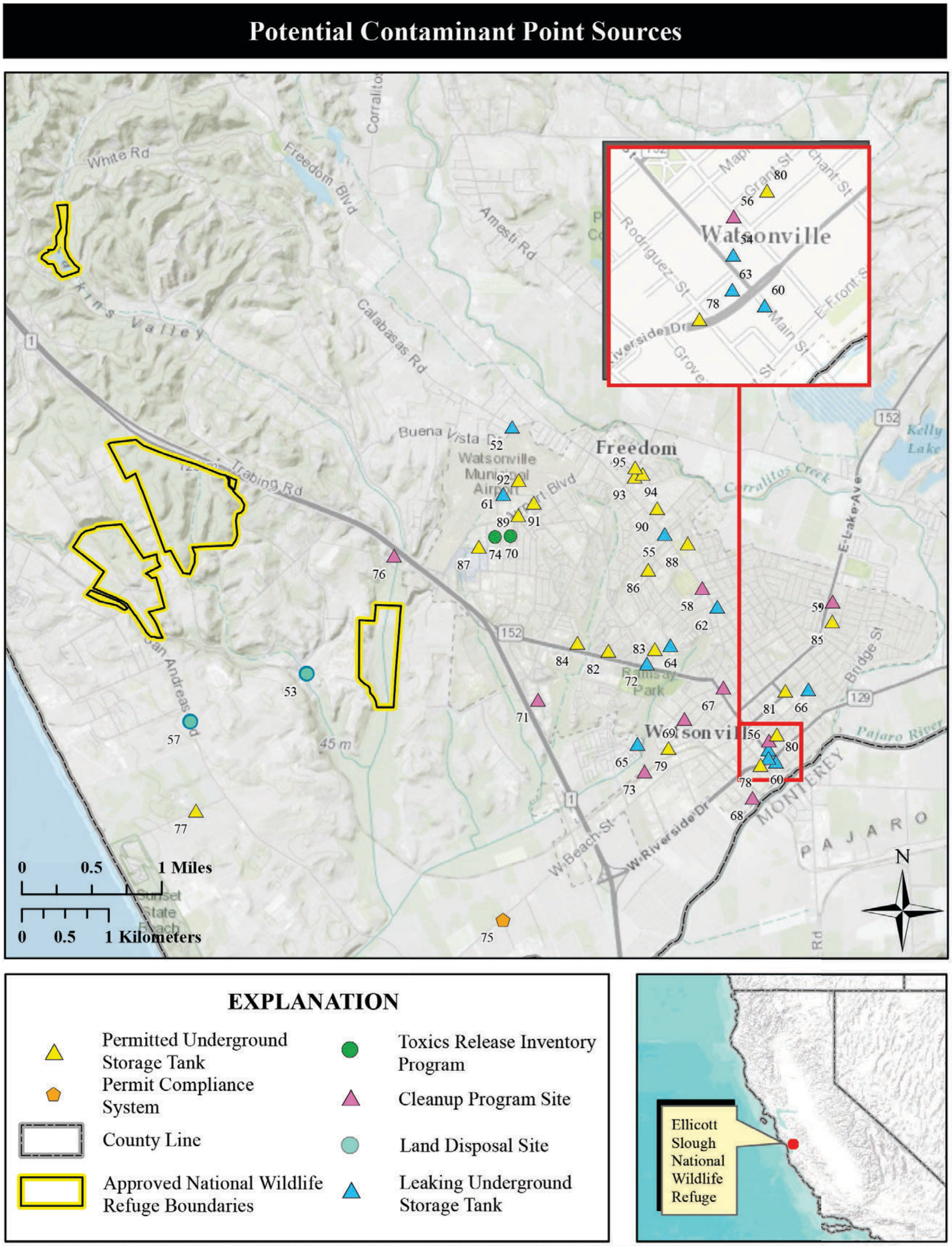
Results of the pre-acquisition survey showed localized soil contamination near an old building on the property and elevated levels of arsenic in soil. One of twelve soil samples from above the concrete slab of a building on the property had detections of analytes above project screening levels for site remediation activities (USEPA Region IX Preliminary Remediation Goals [PRG]). These included methlyene, chlordane, chromium, lead, DDE, DDD, and DDT. A subsequent soil sample taken downgradient of a concrete slab of the building and 1 foot beneath the soil did not show any of the analytes to be above screening levels; however, arsenic was detected slightly above site screening levels (2.1 milligrams per kilogram). This indicated that the contamination of most of the analytes had not extended past the slab of the building and may have been attributed to leaking storage containers found there (U.S. Fish and Wildlife Service 2005).

Results of the pre-acquisition survey also showed concentrations of metals above the site screening levels, elevated nitrate, and bacteria in groundwater. Elevated concentrations of metals were detected in one shallow groundwater sample (6 feet below ground surface). Subsequent groundwater sampling of 13 additional locations revealed all concentrations at or below site screening criteria for barium and chromium, while lead and selenium were not detected in any of the samples (U.S. Fish and Wildlife Service 2005). An agricultural well on the property, taken from deep groundwater (160 feet below ground surface), showed elevated nitrate concentrations and bacteria. Nitrate contamination is a regional issue in the Pajaro Valley. Fecal coliform was detected in a drinking water sample from an onsite residence well in both July and December 2014 (U.S. Fish and Wildlife Service 2005). Another Service investigation in 2004 also found fecal coliform contamination in one drinking water well, but the source of the contamination was not determined at that time (Aceituno 2010). Depending on their location and depth, unused groundwater wells can be a conduit for transporting contaminants between aquifers (California Department of Water Resources 1991). **For this reason it is recommended that any onsite unused wells be properly abandoned, destroyed, and sealed** according to the specifications of Environmental Health Services of Santa Cruz County (County of Santa Cruz 2014).

Of the three groundwater samples taken within the Ellicott Slough Refuge groundwater RHI, one well (MSMB-09, site number 51, figure 8) indicated an exceedance of the CCC for dissolved oxygen and a potential exceedance of chromium. The CCC minimum is 4.0 mg/L for dissolved oxygen; MSMB-09 measured 2.9 mg/L on August 15, 2005. Since the water sample is from groundwater, the dissolved oxygen level would likely increase once exposed to ambient conditions for a sufficient amount of time. Chromium concentrations also exceeded the CCC in this well. However, the CCC was for the hexavalent speciation, but the species of chromium in the sample (hexavalent or trivalent) was not specified. The sample results from August 15, 2005, were 14.2 µg/L, which is above the CCC for hexavalent chromium (11 µg/L) but below the CCC for trivalent chromium (74 µg/L). This well is located approximately 2.5 miles southeast of the ponds in Ellicott Slough Unit and the Buena Vista Property that are used as recruitment areas for threatened and endangered species.

Forty-four potential contaminant point sources were identified near Ellicott Slough Refuge, most of which are near the city of Watsonville and near Harkins Slough and all of which were assumed to contribute to contamination of groundwater. Of these sources, 3 are south and 41 are west and southwest of the refuge boundaries (figure 24). Most contaminant point sources (40) are in or near the city of Watsonville. No contaminant point sources are near the Calabasas Unit. Five point sources are within 1 mile of the Harkins Slough Unit. Four sources are within 1.5 miles of the Ellicott Unit and Buena Vista Property. Of these sources, two are landfill/disposal sites (site numbers 53 and 57, figure 24), one is a permitted underground storage tank (site number 77, figure 24), and one is an agricultural chemical company (site number 76, figure 24).

There are 19 permitted underground storage tank sites included in the inventory described above (appendix B, table B9). These



Map Projection: North American Datum 1983 California Teale Albers; Map Production Date: February, 2014; Source Data: Topographic map and imagery ESRI basemaps; Contaminant points from California State Water Resources Control Board, 2011, U.S. Environmental Protection Agency, 2014, and California Energy Commission, 2014; Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, May 2014;

Figure 24. Contaminant point sources near Ellicott Slough National Wildlife Refuge.

sites are not known to be leaking any contaminants at this time. However, if leaks were to occur in the future, the groundwater near the sites would be vulnerable to contamination.

Ten of the contaminant sites indicated soil and groundwater contamination from gasoline or fuel additive products from leaky underground storage tanks. Remediation is ongoing at five of these sites, and remediation has been completed at the other five sites (California State Water Resources Control Board 2014d).

Several landfills are located near refuge units. The Buena Vista Disposal Site is located less than a half mile west of the Harkins Slough Unit border and a little over a mile southeast of the Buena Vista Property southern border (site 53, figure 24). The City of Watsonville Landfill is located approximately 0.6 mile south of the Ellicott Unit (site 57, figure 24). No contaminants are known at this time to come from either of these sites (California State Water Resources Control Board 2014d). Both sites are currently being monitored for potential contamination.

The Western Farm Services Green Gro Facility is located upstream from the Harkins Slough Unit, and this location is a potential source of nitrate and 1,2-dichloropropane (1,2-D) in groundwater downgradient from the site. This site is a former agricultural chemical company that operated its facility at this location (site 76, figure 24) from the 1960s to 1996. The facility was used for distribution and storage of pesticides, fertilizers, and soil fumigants for agricultural use. Soil and groundwater were affected by nitrate and 1,2-dichloropropane (1,2-D). Contaminated soils in these areas were removed in 2000, and an injection/extraction system operated from 1998 to 2003 for denitrification of the aquifer (URS 2008). Sampling as of 2008 indicated that none of the wells nearest to the Harkins Slough Unit showed any detections of 1,2-D or nitrate in either the upper or lower aquifers. However, the groundwater gradients in both the upper and the lower aquifers flow to the south and southeast generally toward the Harkins Slough Unit, indicating that these sources could potentially affect the quality of extracted groundwater (URS 2008).

Two Pacific Gas and Electric Company former manufactured gas plants (sites 69 and 69, figure 24) and two dry cleaner sites (sites 58 and 59, figure 24) are potential contaminant sources in the Watsonville area, but not necessarily for the refuge. GeoTracker reports indicate that groundwater flow is to the southwest and southeast, which would mean that any potential groundwater contamination would flow away from the refuge boundaries. All four locations have had some remediation take place, and sites 59 and 69 were undergoing active remediation projects at the time of this report (California State Water Resources Control Board 2014d).

While groundwater contamination is a concern for Harkins Slough Unit, this issue is not of immediate concern because groundwater is not currently used for refuge management. **However, if refuge staff decide to use groundwater for management in the future, water quality sampling should be repeated to determine if concentrations are safe for exposure to aquatic organisms.** This sampling should include a repeat of metal sampling (including barium, hexavalent chromium sampling, selenium, and lead), bacteria, and nutrients. Groundwater should also be sampled for TDS and pesticides.

Chapter 5—Summary of Issues of Concern and Recommendations

This chapter summarizes general IOCs for water entitlements and policy, climate, surface water, groundwater, water-related habitats, and water quality. (No IOCs were specifically identified for soils, the other subject area covered by this WRIA.) Recommendations were summarized from bolded recommendations in the previous chapters. Listed below each recommendation are the IOC(s) addressed, prerequisite recommendations (other actions required before the recommendation can be carried out), estimated resources required (time and cost), and potential partners to assist with implementing the recommendation. Using the process described in section 3.4, "Development, Scoping, and Ranking of Recommendations," and detailed in appendix C, recommendations were scored and prioritized to arrive at the top five recommendations and associated prerequisites. Tables C1 and C2 in appendix C show scoring and ranking results.

5.1 Issues of Concern

Water Entitlements and Policy

Water Entitlements (WE-) 1: The water right at Calabasas Pond has a purpose of use (recreation) that does not match its current use (fish and wildlife enhancement). This issue could put the refuge at a disadvantage if there is a water rights dispute or audit in the future.

WE-2: The refuge is not accurately estimating actual water use and storage; water use reports (estimates only) have been submitted to the SWRCB but could not be located at the time of this report. These issues could put the refuge at a disadvantage if there is a water rights dispute or audit in the future.

WE-3: Ellicott Slough Refuge is located in the PVGB, which is designated as a high priority basin in overdraft; this means that in the future, groundwater regulations may be enforced for the PVGB to comply with California groundwater legislation. Groundwater use inspections, monitoring and reporting, curtailment, and fees may be imposed on the refuge to ensure compliance.

Climate

Climate (CL-) 1: Climate change models showed that mean temperatures increased from 0.3 to 6.3 °F and PET increased from 0 to 8.2 percent. These factors resulted in an increase of CWD (water demand required to meet existing habitat needs) by 144.1 to 477.1 acre-feet per year by 2100. This issue would probably be of the greatest concern for the Buena Vista Property and Ellicott and Calabasas Units, which require specific water supplies to maintain breeding ponds, although the impacts of these changes are unknown because refuge water quantity requirements have not been determined.

CL-2: Sea level rise as a result of climate change has the potential to increase the frequency and magnitude of seawater intrusion into the Watsonville Slough system, including Harkins Slough. Currently, Harkins Slough is a freshwater system, with specific conductance ranging from 393 to 648 µS/cm. The impact of intrusion of seawater and increases in salinity on refuge management is not known at this time because specific biological objectives for the unit have not been identified.

CL-3: Mean water levels in Harkins Slough might change by a range of -0.7 to +3.0 feet (by 2050 and 2100, respectively) as a result of sea level rise and other water management events. The impact of these changes on refuge management is not known at this time because specific biological objectives for the unit have not been identified.

Surface Water

Surface Water (SW-) 1: Managed properly, intermittent storm events could help easily fill Calabasas Pond and other ponds, although too much water can damage infrastructure and habitats.

Groundwater

Groundwater (GW-) 1: Because groundwater pumping is in excess of recharge, water levels in the PVGB have generally been decreasing, and drought conditions have greatly affected groundwater levels in the aquifer. However, the impact of these conditions on water availability to Ellicott Slough Refuge is currently unknown because historical water level data in refuge wells were not available.

Water-Related Habitats, Water Management, and Infrastructure

Habitat (HAB-) 1: Development has substantially reduced and fragmented habitat for federally listed amphibians, preventing species movement between upland areas and breeding ponds. Creating new ponds could reduce fragmentation and improve opportunities for recruitment. Ideally, sites for these ponds would have poor drainage and adequate natural runoff. Initial investigation in this report indicated that no areas within fee and title lands are optimally suitable for pond development, but some moderately suitable areas could be investigated further.

HAB-2: Climate and runoff variability results in variable water levels in breeding ponds. This variability can affect successful recruitment of SCLTS and CTS. Recruitment of SCLTS at Ellicott Pond was observed to fail in years when precipitation was less than 20 inches from October to July. No clear pattern in climate and recruitment failure could be observed for CTS and SCLTS at other ponds (Calabasas, Prospect, and Buena Vista). Specific water level response to changing climate conditions could not be quantified because water level data were not available for analysis, which hinders effective planning of water level management in response to variable climate conditions.

HAB-3: There are unused wells and other infrastructure associated with wells on refuge property. Unused wells can be a conduit for transporting groundwater contaminants between aquifers.

HAB-4: Elevated water levels and stagnant open water conditions in Harkins Slough, especially during winter months, is likely a result of inflow from Watsonville Slough. The exact cause for sudden inundation in Harkins Slough is not known; it may be caused by changing flow dynamics in the Watsonville Slough system due to subsidence from shallow groundwater withdrawal and peat mining or due to sedimentation and vegetation overgrowth in the Watsonville and Harkins Sloughs.

Water Quality

Water Quality (WQ-) 1: There is a potential for Harkins Slough to be periodically impacted by seawater intrusion into the Watsonville Slough system and indirectly impacted by flow and water levels at the mouth of the Pajaro River. This is especially a concern in winter months. Incursion of seawater into Harkins Slough could lead to prolonged density stratification of Harkins Slough because of mixing with freshwater runoff from the upstream drainage basin and inflows from Watsonville Slough. Because salt water is denser than freshwater, this mixing could result in a persistent seawater lens underlying a freshwater zone. The impact of increases in salinity on refuge management is not known at this time because specific biological objectives for the unit have not been identified.

WQ-2: Excessive pumping and drought conditions in the PVGB increase the risk of seawater intrusion into the freshwater aquifer. Although seawater is not yet known to have intruded into the area where groundwater is accessed by Ellicott Slough Refuge, if intrusion continues, this could potentially have a negative impact on the water quality of breeding ponds that are periodically supplied with groundwater sources. To mitigate, refuge staff may have to treat groundwater or attempt to find another water source, and such sources are limited in this region.

WQ-3: Eutrophic conditions—including elevated concentrations of chlorophyll-a and low concentrations of dissolved oxygen—persist in Harkins Slough because of extensive agricultural land use in the surrounding watershed, seasonal open water marshes, and stagnant water circulation. Pumping of Harkins Slough water downstream from the refuge may enhance circulation and delay the onset of eutrophic conditions, although more data are needed to quantify this relation.

WQ-4: Elevated concentrations of metals such as lead, aluminum, and iron in surface water at Harkins Slough pose an ecological risk for long-term exposure of aquatic organisms. However, concentrations of these constituents vary with time and different hydrologic conditions. Aluminum and iron samples were not filtered; consequently, an accurate comparison with aquatic life criteria could not be made.

WQ-5: Harkins Slough is currently listed for E. coli and fecal coliform, with an USEPA TMDL approval date of 2007. Concentrations of these bacteria adversely affect water contact recreation, although currently there are no types of water recreation permitted within the refuge. The impact of these concentrations other biological resources at the refuge is not known at this time.

WQ-6: TDS and nitrates are contaminant threats to groundwater in the PVGB that are influenced by long-term increases in groundwater development. Elevated concentrations in shallow groundwater may be caused by deep percolation of applied irrigation water, non-point source runoff, and leaking septic systems. These concentrations might pose a risk to survival of salamanders, although more information is needed to determine whether concentrations found in Ellicott Slough Refuge are a threat to SCLTS, CTS, and CRLF. The impact of elevated concentrations of these constituents on refuge management at the Harkins Slough Unit is not known at this time because specific biological objectives for the unit have not been identified.

WQ-7: Concentrations of metals, such as barium, chromium, lead, and selenium were detected above site screening levels in shallow groundwater at the Harkins Slough Unit. However, subsequent sampling of groundwater showed that these constituents were below site screening levels. The impact of elevated concentrations of these constituents on refuge management is not known at this time because specific biological objectives for the unit have not been identified.

WQ-8: Forty-four potential contaminant point sources were identified near Ellicott Slough Refuge, most of which are near the city of Watsonville and Harkins Slough Unit and all of which were assumed to contribute to groundwater contamination. These include 19 permitted underground storage tank sites. Several landfills are located very close to refuge units. All contaminant point sources identified are potential sources of chlorinated and petroleum hydrocarbons, organochlorine compounds, pesticides, fertilizers, PCE, TCE, metals, arsenic, freon, nutrients, inorganics, diesel fuel, and polynuclear aromatic hydrocarbons.

5.2 Summary of Recommendations

Top Priority Recommendations

Recommendation (Rec-) 1 (Management Planning): Establish clear biological objectives for Harkins Slough and associate those objectives with management targets for optimal water quality and water level conditions in the unit.

- IOCs addressed: CL-2, CL-3, WQ-1, WQ-3, WQ-4, WQ-5, and WQ-7
- Estimated time and resources required: 1–2 years and moderately expensive
- Prerequisite recommendations: None
- Potential lead participants: Refuge staff, Service I&M Initiative, and consultants

Rec-2 (Water Quality Monitoring): Dependent upon biological objectives and associated water quality targets for Harkins Slough, implement a seasonal or continuous surface water quality monitoring program, which includes the following recommended analyses:

- Seasonal or continuous measurement of physical parameters, chlorophyll-a, nutrients, and water levels to better understand the relationship among eutrophication, rainfall and runoff, and Harkins Slough pump operation
- Seasonal or biannual sampling of metals (including aluminum, iron, and lead) to monitor whether concentrations threaten aquatic health and to better associate these parameters with variable hydrologic conditions
- Sample for dissolved constituents to ensure that concentrations can be adequately compared to aquatic life criteria
- IOCs addressed: CL-2, WQ-1, WQ-3, WQ-4, and WQ-7
- Estimated time and resources required: 3 or more years and moderately expensive
- Prerequisite recommendations: Rec-1
- Potential lead participants: Refuge staff (oversee contracts with cooperative agencies or consultants), cooperative agencies (with funding support from Region 8 I&M and oversight from refuge staff), and consultants (with funding support from Service I&M Initiative and oversight from refuge staff)

Rec-3 (Water Level Monitoring): Install a staff gage in the Harkins Slough Unit or coordinate with PVWMA to obtain current water level records at Harkins Slough in order to monitor changes in hydrologic conditions that can impact water quality. If installing a staff gage, record water level information in a digital database to facilitate data use and transfer. This information is more useful if biological water level and water quality targets can be established.

- IOCs addressed: HAB-4 and WQ-3
- Estimated time and resources required: 1–2 years and inexpensive
- Prerequisite recommendations: Rec-1
- Potential lead participants: Refuge staff or Region 1/8 WRB (for installation of a staff gage or coordination with PVWMA), Region 8 I&M (for coordination with PVWMA)

Rec-4 (Water Level Monitoring): Breeding pond water levels should be recorded with dates and times, especially at times of recruitment surveys, and be stored in a digital database to facilitate data analysis and transfer. This information can be used to determine water level response as a result of runoff and water management and associate water level conditions to breeding success of amphibians.

- IOCs addressed: WE-2 and HAB-2
- Estimated time and resources required: 1–2 years and inexpensive
- Prerequisite recommendations: None
- Potential lead participants: Refuge staff, with support from Region 1/8 WRB and Region 8 I&M to help with designing monitoring and data storage protocols
- Note: tied in priority with Rec-5

Rec-5 (Bathymetry and Water Quantity Monitoring): Where possible, determine a water budget for refuge ponds (that is, how much water is needed to fill refuge ponds to adequate water levels) to help determine water requirements for refuge management; determine if water rights adequately cover refuge water use; plan for potential groundwater use monitoring requirements; and determine relationship of water availability to climate conditions and impacts on breeding success of amphibians. The following techniques should be developed:

- Estimate the current storage capacity (bathymetry) of breeding ponds and tie capacity to water level measurements to measure pond water storage at given intervals
- Measure groundwater use required to fill ponds to adequate water levels by reading and recording pump rates when pumps are in use
- Measure on a periodic basis (once per week as water is flowing) the quantity of water leaving refuge ponds through water control structure weirs
- IOCs addressed: WE-2, WE-3, CL-1, SW-1, and HAB-1
- Estimated time and resources required: more than 3 years and moderately expensive
- Prerequisite recommendations: None

- Potential lead participants:
  - For bathymetry: contractor and Region 1/8 WRB (to help design contracts for bathymetry or conduct surveys)
  - For groundwater use and outflow measurement: refuge staff and Region 1/8 WRB or Region 8 I&M (to help design monitoring and data storage protocols)
  - For water budget computation: Region 1/8 WRB, Region 8 I&M, and refuge staff
- Note: tied in priority with Rec-4

Other Recommendations

Rec-6 (Water Quality Monitoring): Periodically perform water quality sampling of groundwater used to manage breeding ponds at Ellicott Unit. Sampling should occur at least once every 1–3 years, or prior to first annual use, and screen for the following constituents:

- Nitrate and nitrite concentrations to ensure that levels are safe for exposure to SLCTS, CTS, and other species
- Chloride and other major ions (including sodium, potassium, and sulfate) to determine if seawater intrusion is affecting groundwater quality
- IOCs addressed: WQ-2 and WQ-6
- Estimated time and resources required: 3 or more years and moderately expensive
- Prerequisite recommendations: None
- Potential lead participants: Refuge staff (oversee contracts with cooperative agencies or consultants), cooperative agencies (with funding support from Region 8 I&M and oversight from refuge staff), consultants (with funding support from USFWS I&M Initiative and oversight from refuge staff)

Rec-7 (Water Management and Infrastructure): Investigate new areas for suitable breeding habitat within and near fee and title acquisitions. To avoid costly soil amendments or reliance on alternative water sources such as pumped groundwater, consider areas that have poorly drained to somewhat poorly drained soils or areas that receive substantial runoff. Investigate areas identified in this report after rain events to determine if ponding has occurred, and monitor water levels after inundation to determine if the areas are suitable for water retention.

- IOCs addressed: HAB-1
- Estimated time and resources required: 1–2 years and inexpensive
- Prerequisite recommendations: None
- Potential lead participants: Region 1/8 WRB and refuge staff
- Note: tied in priority with Rec-8, Rec-9, Rec-10, Rec-11, Rec-12, and Rec-13

Rec-8 (Water Entitlements and Policy): To protect the refuge in future water rights disputes or audits, ensure that water use reports are being properly submitted to the SWRCB under the water right.

- IOCs addressed: WE-2
- Estimated time and resources required: 1–2 years and inexpensive
- Prerequisite recommendations: None
- Potential lead participants: Region 1/8 WRB and refuge staff
- Note: tied in priority with Rec-7, Rec-9, Rec-10, Rec-11, Rec-12, and Rec-13

Rec-9 (Water Entitlements and Policy): Follow developments with groundwater sustainability planning in the PVGB to better help Ellicott Slough Refuge prepare for future requirement monitoring and reporting of groundwater use.

- IOCs addressed: WE-3
- Estimated time and resources required: 1–2 years and inexpensive
- Prerequisite recommendations: None
- Potential lead participants: Region 1/8 WRB, regional refuge management, and refuge staff
- Note: tied in priority with Rec-7, Rec-8, Rec-10, Rec-11, Rec-12, and Rec-13

Rec-10 (Water Entitlements and Policy): Determine whether changing the purpose of use to match actual beneficial use of water on the refuge is the best course of action, and if so, start the process of changing the purpose of use to "fish and wildlife enhancement" to protect the refuge in future water rights disputes or audits.

- IOCs addressed: WE-1

- Estimated time and resources required: 1–2 years and inexpensive
- Prerequisite recommendations: None
- Potential lead participants: Region 1/8 WRB
- Note: tied in priority with Rec-7, Rec-8, Rec-9, Rec-11, Rec-12, and Rec-13

Rec-11 (Water Quantity Monitoring): If groundwater is to be used for water level management in Harkins Slough, periodically sample groundwater quality to determine if concentrations of metals (including barium, hexavalent chromium, lead, and selenium) and nitrates are safe for exposure to aquatic organisms. Sample for dissolved constituents to ensure that concentrations can be adequately compared to aquatic life criteria.

- IOCs addressed: WQ-6 and WQ-7
- Estimated time and resources required: 3 or more years and moderately expensive
- Prerequisite recommendations: Rec-1
- Potential lead participants: Refuge staff (oversee contracts with cooperative agencies or consultants), cooperative agencies (with funding support from Region 8 I&M and oversight from refuge staff), and consultants (with funding support from Service I&M Initiative and oversight from refuge staff)
- Note: tied in priority with Rec-7, Rec-8, Rec-9, Rec-10, Rec-12, and Rec-13

Rec-12 (Water Management and Infrastructure): Locate boring logs for all previously constructed wells to further understand the groundwater source for the refuge units. Consult with a hydrologist for use of boring log data.

- IOCs addressed: HAB-3
- Estimated time and resources required: 1–2 years and inexpensive
- Prerequisite recommendations: None
- Potential lead participants: Refuge staff (obtain boring logs) and Region 1/8 WRB or Region 8 I&M (review boring logs)
- Note: tied in priority with Rec-7, Rec-8, Rec-9, Rec-10, Rec-11, and Rec-13

Rec-13 (Water Level Monitoring): Measure water levels in actively used refuge wells on a monthly basis to better understand changes in water levels in response to seasonal and long-term pumping of the PVGB.

- IOCs addressed: GW-1
- Estimated time and resources required: 3 or more years and moderately inexpensive
- Prerequisite recommendations: None
- Potential lead participants: Refuge staff (obtain water level measurements) and Region 1/8 WRB or Region 8 I&M (review and interpret data)
- Note: tied in priority with Rec-7, Rec-8, Rec-9, Rec-10, Rec-11, and Rec-12

Rec-14 (Water Entitlements and Policy): Delineate legal place of use data to complete the water rights map for Ellicott Slough Refuge to ensure that refuge water use is compliant with established water rights.

- IOCs addressed: WE-1
- Estimated time and resources required: 1–2 years and inexpensive
- Prerequisite recommendations: None
- Potential lead participants: Region 1/8 WRB and Region I&M
- Note: tied in priority with Rec-15, Rec-16, and Rec-17

Rec-15 (Water Management and Infrastructure): Properly abandon wells and other infrastructure that is not in use.

- IOCs addressed: HAB-3
- Estimated time and resources required: 1–2 years and moderately inexpensive
- Prerequisite recommendations: None
- Potential lead participants: Refuge staff (oversee contract) and contractor
- Note: tied in priority with Rec-14, Rec-16, and Rec-17

Rec-16 (Water Management and Infrastructure): Complete the mapping of all pipe systems and identify well characteristics in Harkins Slough to determine best use of infrastructure for refuge water management.

- IOCs addressed: HAB-3
- Estimated time and resources required: 1–2 years and moderately inexpensive.
- Prerequisite recommendations: None
- Potential lead participants: Refuge staff (oversee contract) and contractor

- Note: tied in priority with Rec-14, Rec-15, and Rec-17

Rec-17 (Habitat Information Improvement): Update and improve the NWI dataset to improve accuracy of NWI at local levels.

- IOCs addressed: Does not directly address an IOC
- Estimated time and resources required: 1–3 years and inexpensive
- Potential lead participants: Service National Wetlands Inventory Program, cooperative agencies, universities, and consultants
- Note: tied in priority with Rec-14, Rec-15, and Rec-16

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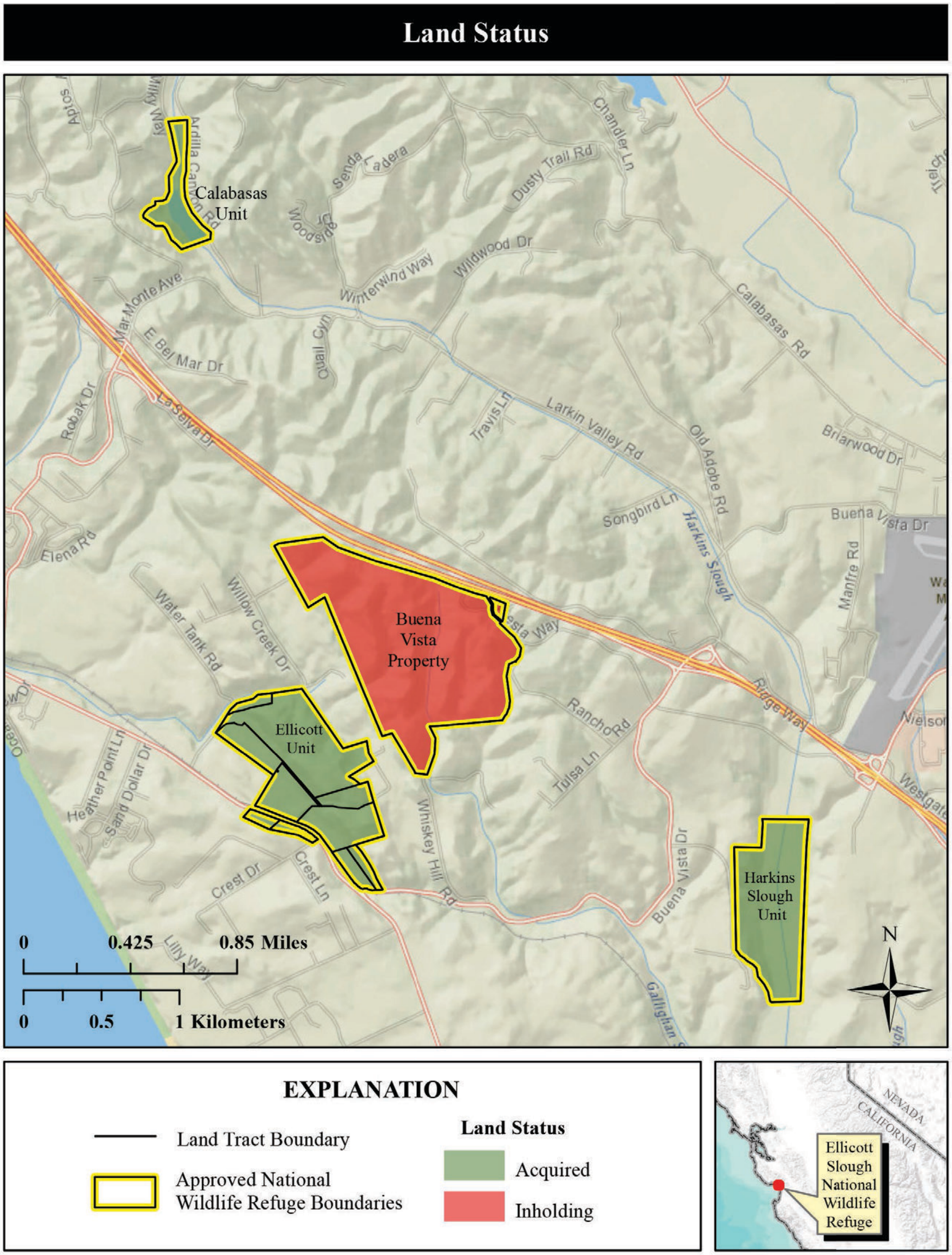
Appendix A

Reference Figures



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10; Map Production Date: November 07, 2012; Source Data: Refuge land status and refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, May 2012; imagery and terrain from ESRI Basemaps

Figure A1. Approved land acquisition boundaries; properties currently acquired by U.S. Fish and Wildlife Service in fee and title for Ellicott Slough National Wildlife Refuge.

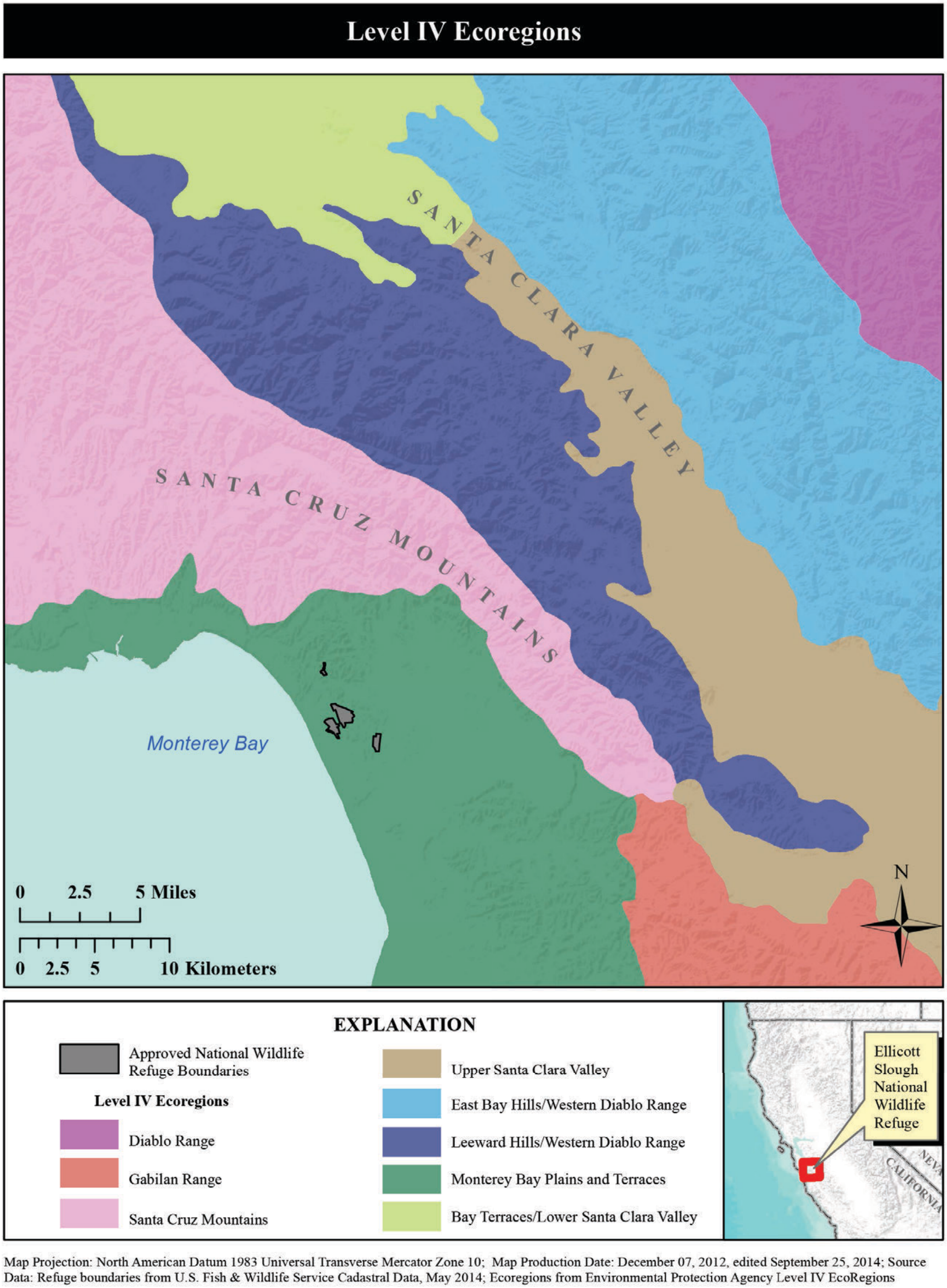
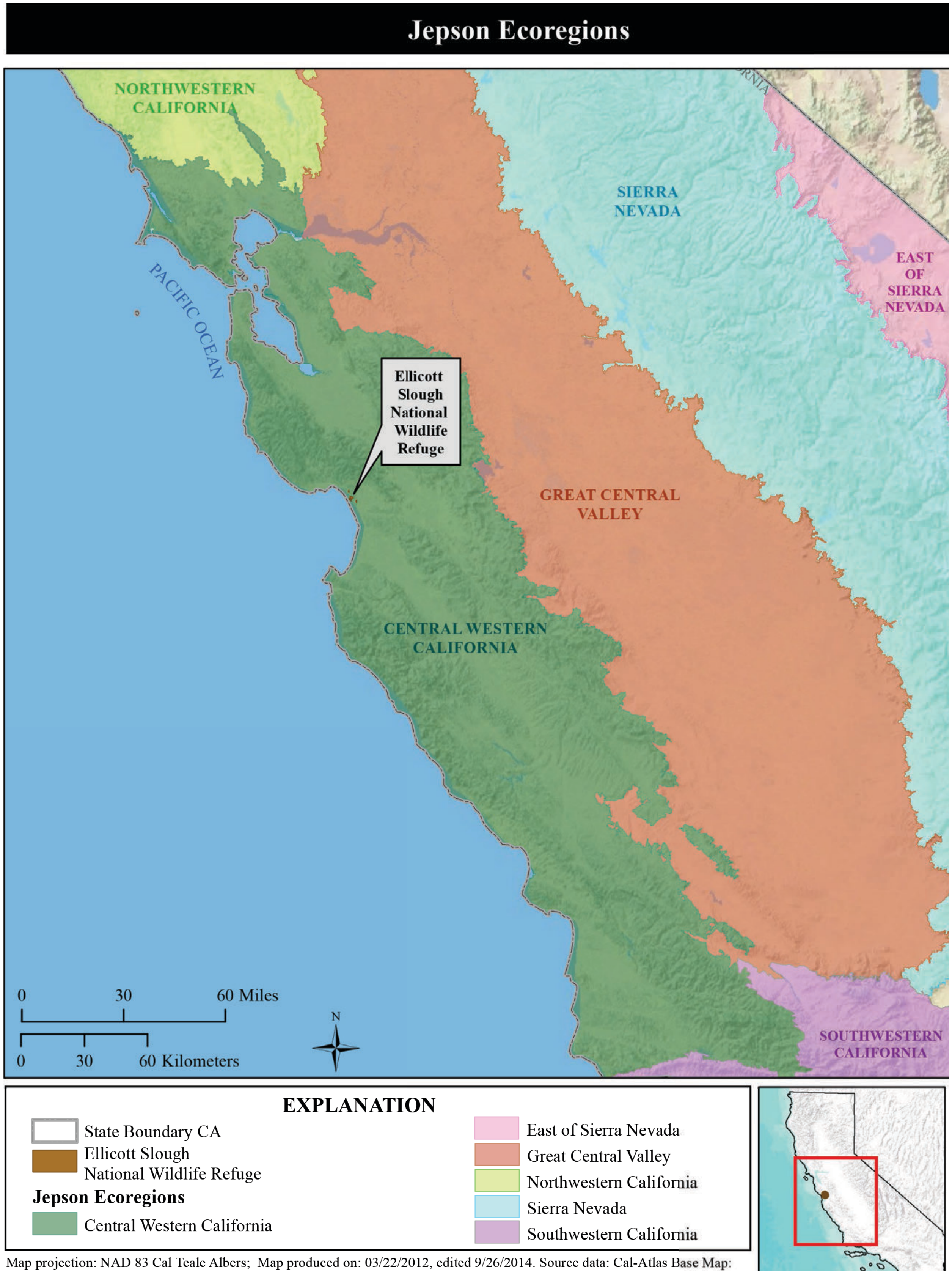
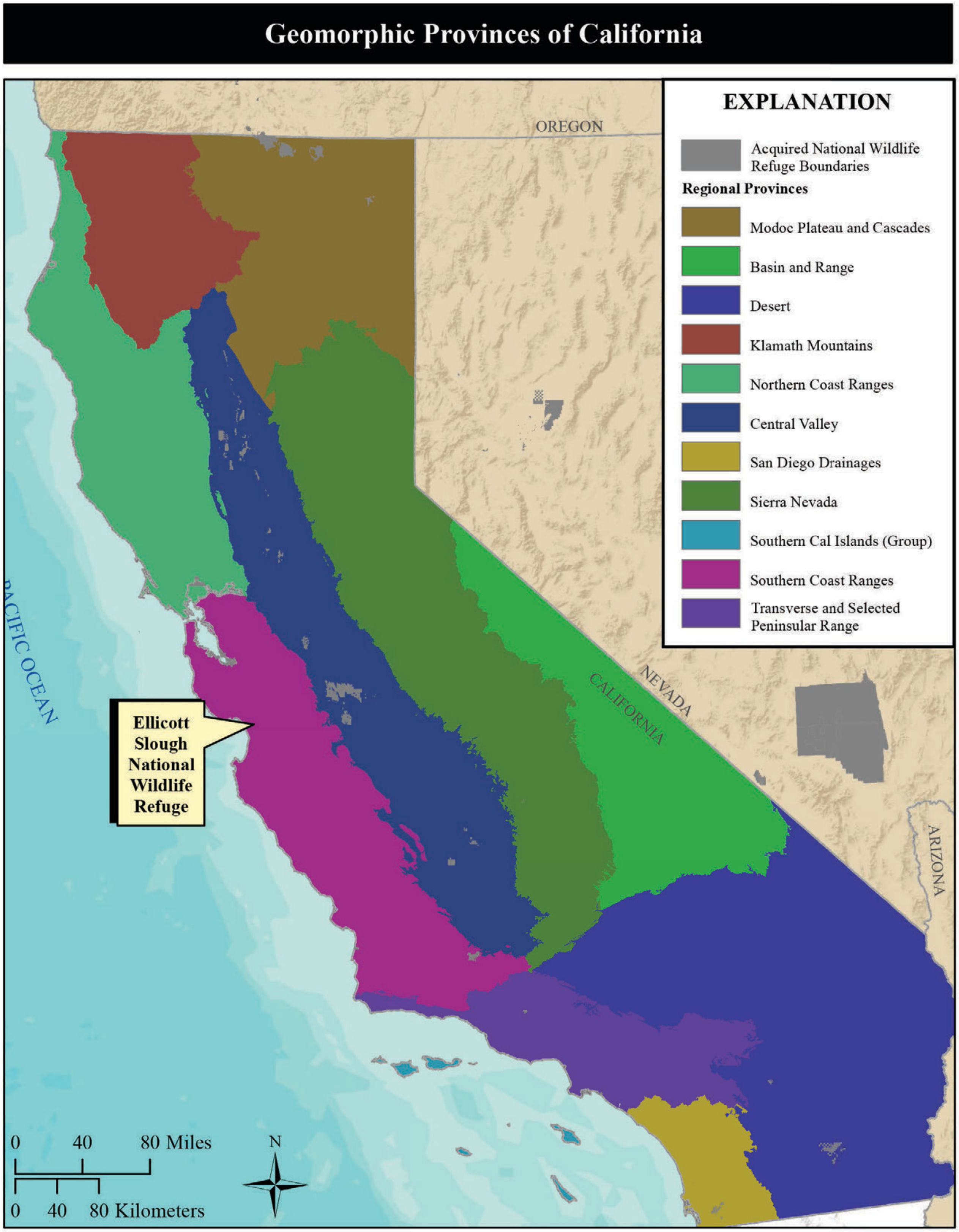


Figure A2. Environmental Protection Agency Level IV Ecoregion boundaries in the vicinity of Ellicott Slough National Wildlife Refuge.



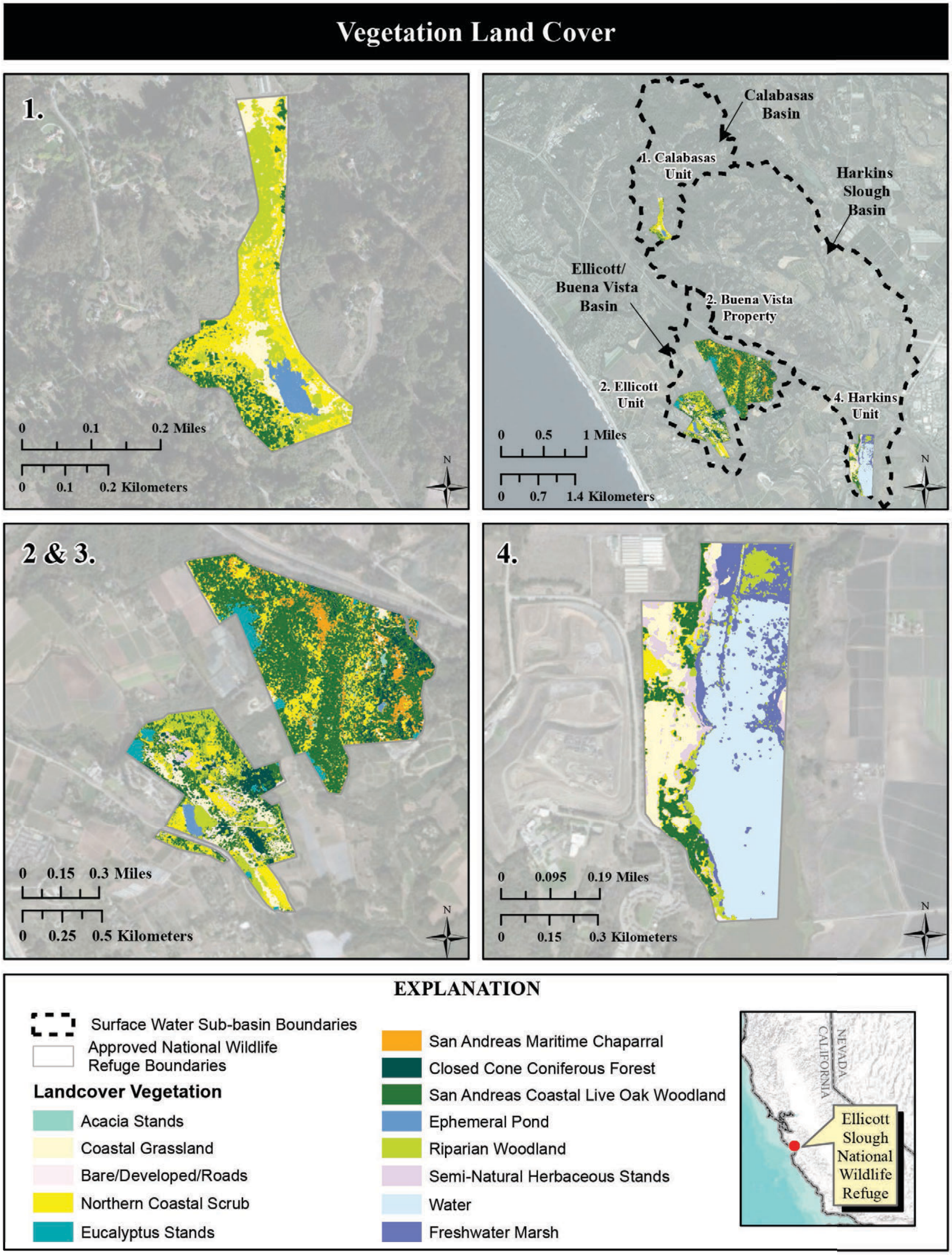
Map projection: NAD 83 Cal Teale Albers; Map produced on: 03/22/2012, edited 9/26/2014. Source data: Cal-Atlas Base Map: US National Parks Service Physical and Ocean; Jepson Ecoregions, State boundaries and Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, November 2014

Figure A3. Jepson Ecoregion boundaries in the vicinity of Ellicott Slough National Wildlife Refuge.



Map Projection: North American Datum 1983 California Teale Albers; Map Production Date: December 06, 2012, edited September 24, 2014; Source Data: Geomorphic provinces from US Geological Survey Water Resource Investigation Report 03-4166 (Belitz and others, 2003); Refuge boundaries from U.S. Fish & Wildlife Service Cadastral Data, May 2014; Hillshade derived from 30 Meter Digital Elevation Model.

Figure A4. Geomorphic Province boundaries in the vicinity of Ellicott Slough National Wildlife Refuge.



Map Projection: North American Datum 1983 Universal Transverse Mercator Zone 10; Map Production Date: April 15, 2014; Source Data: Vegetation data from U.S.Fish & Wildlife Service Division of Refuge Planning Sacramento CA, 2010; Source Data: Refuge boundaries from U.S.Fish & Wildlife Service Cadastral Data, November 2014; Basin boundaries delineated from 10-meter digital elevation model through StreamStats Web Application USGS, 2014.

Figure A5. Local vegetation cover map.

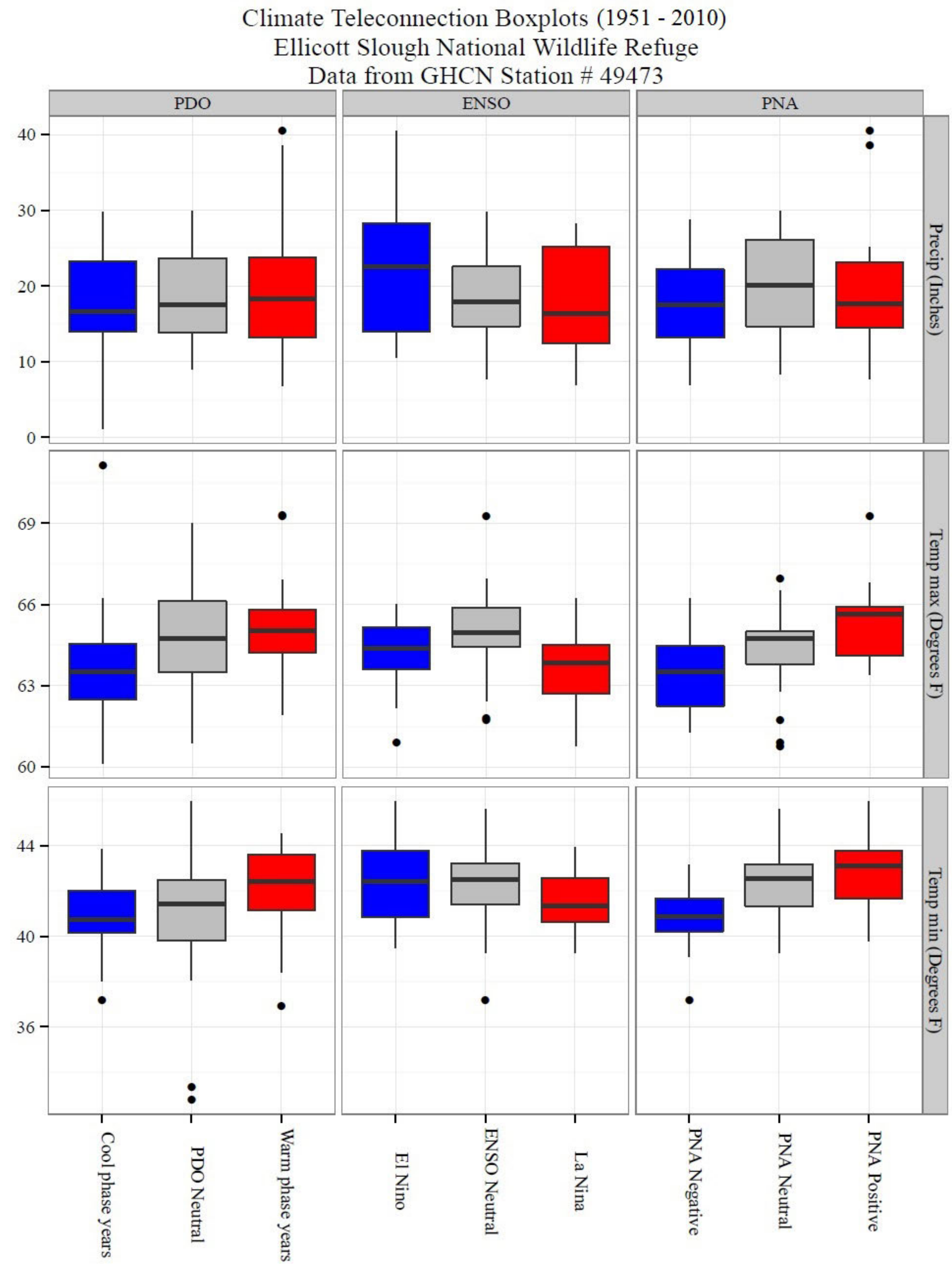


Figure A6. Comparison of mean October–March precipitation and July–November El Niño Southern Oscillation (SOI) for the previous year, near Ellicott Slough National Wildlife Refuge Drainage Basin for the period 1951–2010 (PDO, Pacific Decadal Oscillation; ENSO, El Niño Southern Oscillation; precipitation is in inches; temperature is in degrees Fahrenheit).

Appendix B

Reference Tables

Table B1. Climate stations on and near Ellicott Slough National Wildlife Refuge.

Map number (figure 7)	*Station name*	*Station operator*	*Agency/network hosting data server*	*Station identification*	*Period of record*	*Temporal resolution—Temp*	*Temporal resolution—Evap*	*Temporal resolution—Precip*	*Temporal resolution—Humidity*	*Temporal resolution—Sol. Rad.*	*Temporal resolution—Wind Speed*	*Elevation (feet)*
1	Pajaro	CADWR	CIMIS	129	1995–present	H	H	H	H	H	H	65
2	San Juan (East Wastonville)	CADWR	CIMIS	16	1982–1995	H	H	H	H	H	H	44
3	Green Valley (Freedom)	CADWR	CIMIS	111	1992–present	H	H	H	H	H	H	110
4	Webb (North Watsonville)	CADWR	CIMIS	4	1982–1988	H	H	D	H	H	H	230
5	Beach (Watsonville)	CADWR	CIMIS	3	1982–1986	H	H	D	H	H	H	10
6	West Watsonville	CADWR	CIMIS	95	1989–1995	H	H	D	H	H	H	100
7	Watsonville West	Parajo Valley Water Management	CIMIS	177	2000–2006	H	H	H	H	H	H	212
8	Watsonville West 2	Parajo Valley Water Management	CIMIS	209	2007–present	H	H	H	H	H	H	240
9	Watsonville Municipal Airport	City of Watsonville	UOU	KWVI	2004–present	H	–	–	H	–	H	161
10	Corralitos Creek @ freedom	Santa Cruz Co	CDEC	CCF	2010–present	–	–	E	–	–	–	100
11	Corralitos Creek @ freedom	Cal Fire	CDEC	COR	1984–present	H	–	H	H	H	H	450
12	Pleasant Valley	Santa Cruz Co	CDEC	PLV	2010–present	–	–	E	–	–	–	360
13	City of Watsonville	Watsonville Waterworks	UCDIPM	9473	1951–2010	D	–	D	–	–	–	95
14	Watsonville Municipal Airport	NOAA	NCDC	GHCND:USW00023277	1998–present	D	–	D	D	–	D	160.105
15	Watsonville Waterworks	NOAA	NCDC	GHCND:USC00049473	1908–present	D	–	D	–	–	–	95.1444
16	Corralitos	NOAA	NCDC	GHCND:USC00042051	1948–1951	D	–	D	–	–	–	270.013

Key: CADWR = California Department of Water Resources; CIMIS = California Irrigation Management Information System; UCDIPM = University of California Davis Integrated Pest Management Database; CDEC = California Data Exchange Center; NCDC = Natural Climatic Data Center; UOU = University of Utah; Temp = temperature; Evap = reference evapotranspiration; Sol. Rad. = Solar Radiation; H = hourly continuous; D = daily continuous

Notes: Temporal resolution represents finest temporal resolution of parameter information available in digital form.

The San Juan (East Wastonville), Webb (North Watsonville), Beach (Watsonville), West Watsonville, and Watsonville West stations are inactive.

Table B2. Groundwater and surface water level measurement locations on and near Ellicott Slough.

Map number (figure 8)	*Station identification*	*Parameter*	*Alternate station name*	*Distance from refuge (miles)*	*Type of station*	*Agency/network hosting data server*	*Is data available online?*	*Available period of record*	*Active or inactive*	*Collection frequency*
18	368903N1218193W001	GWL	HSPDMW1	1.7/ 2.1	Observation	CASGEM	Yes	10/3/2011–11/5/2013	Active	B
19	368881N1218136W001	GWL	PV11	1.7/ 2.1	Observation	CASGEM	Yes	10/3/2011–11/5/2013	Active	B
20	368998N1218303W001	GWL	PV13	1.3	Observation	CASGEM	Yes	10/14/2011–10/31/2011	Active	B
21	368975N1218364W003	GWL	PV1D	1.5	Observation	CASGEM	Yes	10/14/2011–10/31/2011	Active	B
22	368975N1218364W002	GWL	PV1M	1.5	Observation	CASGEM	Yes	10/14/2011–10/31/2011	Active	B
23	368975N1218364W001	GWL	PV1S	1.5	Observation	CASGEM	Yes	10/14/2011–10/31/2011	Active	B
24	368986N1218194W003	GWL	PV8D	1.2 / 1.6	Observation	CASGEM	Yes	10/14/2011–10/31/2011	Active	B
25	368986N1218194W002	GWL	PV8M	1.2 / 1.6	Observation	CASGEM	Yes	10/14/2011–4/2/2013	Active	B
26	368986N1218194W001	GWL	PV8S	1.2 / 1.6	Observation	CASGEM	Yes	10/14/2011–10/31/2011	Active	B
27	369454N1218708W001	GWL	SC-A2A	1.4/1.7	Observation	CASGEM	Yes	10/31/2011–10/8/2012	Active	I
28	369454N1218708W002	GWL	SC-A2B	1.4/1.7	Observation	CASGEM	Yes	10/31/2011–10/8/2012	Active	I
29	369454N1218708W003	GWL	SC-A2C	1.4/1.7	Observation	CASGEM	Yes	10/31/2011–10/8/2012	Active	I
30	369356N1218642W001	GWL	SC-A3A	1.2	Observation	CASGEM	Yes	10/31/2011–9/6/2013	Active	B
31	369356N1218642W002	GWL	SC-A3B	1.2	Observation	CASGEM	Yes	10/31/2011–9/6/2013	Active	B
32	369356N1218642W003	GWL	SC-A3C	1.2	Observation	CASGEM	Yes	10/31/2011–9/6/2013	Active	B
33	369223N1218495W001	GWL	SC-A4A	0.5	Observation	CASGEM	Yes	10/31/2011–9/11/2013	Active	B
34	369223N1218495W002	GWL	SC-A4B	0.5	Observation	CASGEM	Yes	10/31/2011–9/11/2013	Active	B
35	369223N1218495W003	GWL	SC-A4C	0.5	Observation	CASGEM	Yes	10/31/2011–9/11/2013	Active	B
36	369223N1218495W004	GWL	SC-A4D	0.5	Observation	CASGEM	Yes	10/31/2011–9/11/2013	Active	B
37	369542N1218789W001	GWL	SC-A8A	1.6 / 2.3	Observation	CASGEM	Yes	10/31/2011–9/12/2013	Active	B
38	369542N1218789W002	GWL	SC-A8B	1.6 / 2.3	Observation	CASGEM	Yes	10/31/2011–9/12/2013	Active	B
39	369542N1218789W003	GWL	SC-A8C	1.6 / 2.3	Observation	CASGEM	Yes	10/31/2011–9/12/2013	Active	B
40	369454N1218708W004	GWL	SC-A2RA	1.4/1.7	Observation	CASGEM	Yes	4/11/2013–9/11/2013	Active	B
41	369454N1218708W005	GWL	SC-A2RB	1.4/1.7	Observation	CASGEM	Yes	4/11/2013–9/11/2013	Active	B
42	369454N1218708W006	GWL	SC-A2RC	1.4/1.7	Observation	CASGEM	Yes	4/11/2013–9/11/2013	Active	B
43	369381N1218267W001	GWL	SCC11S01E26AP	0.15	Residential	CASGEM	Yes	9/13/2011–10/16/2013	Active	B
44	369341N1218169W001	GWL	SCC11S01E36AP	0.15	Residential	CASGEM	Yes	9/13/2011–10/16/2013	Active	B
96	BV staff gage	SWL	SW	Onsite	BV staff gage	USFWS	No	Periodic	Active	I
97	Calabasas staff gage	SWL	SW	Onsite	Calabasas staff gage	USFWS	No	Periodic	Active	I
98	Ellicott staff gage	SWL	SW	Onsite	Ellicott staff gage	USFWS	No	Periodic	Active	I
99	Prospect staff gage	SWL	SW	Onsite	Prospect staff gage	USFWS	No	Periodic	Active	I

Key: USFWS = U.S. Fish and Wildlife Service; CASGEM = California Statewide Groundwater Elevation Monitoring; GWL = groundwater level; SWL = surface water level; B = biannually; I = instantaneous.

Notes: Collection frequency refers to a distinguishable pattern; however, some datasets may be missing some records in some years.

The period of record represents the times when digital and processed information were readily available for summary or analysis. Other groundwater level information collected at different time steps may be available for other dates.

Table B3. Water quality measurement locations on and near Ellicott Slough National Wildlife Refuge.

Map number (figure 8)	*Station name*	*Parameter*	*Agency/network hosting data server*	*Station identification*	*Period of record*	*Physical*	*Inorganics, metals*	*Inorganics, non-metal*	*Nutrients*	*Organics*	*Microbio-logical*	*Comment*
45	Harkins Slough at Harkins Slough Road	SWQ	CEDEN	305HAR	2006 & 2011	X				X		2 sampling dates in 2006 and 2011
46	HS-SW-01B	SWQ	ECDMS-USFWS	HS-SW-01B	2006	X	X	X				
47	HS-SW-02B	SWQ	ECDMS-USFWS	HS-SW-02B	2006	X	X	X				
48	HS-SW-03B	SWQ	ECDMS-USFWS	HS-SW-03B	2006	X	X	X				
49	1482670032239	GWQ	GeoTracker-GAMA	1482670032239	6/7/2010		X					1 time measurement
50	MSMB-05	GWQ	GeoTracker-GAMA	501592	8/8/2005	X	X	X				1 time measurement
51	MSMB-09	GWQ	GeoTracker-GAMA	501685	8/15/2005	X	X	X				1 time measurement
100	Watsonville Slough upstream Harkins Slough	SWQ	CEDEN	305WSA	2006 and 2011	X				X		2 sampling dates in 2006 and 2011

Key: CEDEN = California Environmental Data Exchange Center; USFWS = U.S. Fish and Wildlife Service; ECDMS = Environmental Contaminants Data Management System; GeoTracker-GAMA = GeoTracker Groundwater Ambient Monitoring and Assessment Program; GWQ, groundwater quality; SWQ, surface water quality.

Table B4. Water rights near Ellicott Slough National Wildlife Refuge filed by U.S. Fish and Wildlife and by claimants other than the U.S. Fish and Wildlife Service.

Point of diversion number (figure 9)	*Application number*	*Status*	*Water right owner*	*Issue date*	*Relation to refuge*	*Water right type*	*Source name*	*Purpose of use (legal)*	*Claimed maximum discharge (acre-feet/ year)*
1	A018687	Licensed	U.S. Fish and Wildlife Service	5/1/1959	Upstream	Appropriative	Harkins Slough	Stockwatering, recreational	48.0
2	A018816	Licensed	Private Owner	6/22/1959	Owned by U.S. Fish and Wildlife Service	Appropriative	Unnamed tributary	Stockwater, domestic, fire protection, irrigation	7.0
3	A017784	Licensed	Private Owner	8/19/1957	Upstream and downstream	Appropriative	Unnamed tributary	Stockwatering, recreational	26.5
4	A030522	Permitted	Pajaro Valley Water Management Agency	6/8/2000	Downstream	Appropriative	Harkins Slough	Industrial, irrigation, recreational, fish and wildlife enhancement, stockwatering, fish culture, municipal	2,000
5	A011887	Licensed	Private Owner	5/22/1947	Downstream	Appropriative	Gallighan Slough	Industrial, stockwatering, fire protection	1.4

Table B5. Kruskal-Wallis non-parametric test comparing differences in the distribution of temperature.

Station or area	*Climate variable*	*June–September SOI Phase (El Niño/Neutral/La Niña)—Chi-square*	*June–September SOI Phase (El Niño/Neutral/La Niña)—p-value*	*October through March PDO Index Phase (Warm Phase/Neutral/Cool Phase)—Chi-square*	*October–March PDO Index Phase (Warm Phase/Neutral/Cool Phase)—p-value*	*October–March PNA Index Phase (Negative Phase/Neutral/Positive Phase)—Chi-square*	*October–March PNA Index Phase (Negative Phase/Neutral/Positive Phase)—p-value*
Precipitation (annual percent above mean for 1951–2010)	Watsonville Waterworks climate station 49473	2.20	0.33	0.25	0.88	0.78	0.68
Maximum temperature (mean annual in degrees Fahrenheit)	Watsonville Waterworks climate station 49473	7.57	0.02	11.95	0.00	12.05	0.00
Minimum temperature (mean annual in degrees Fahrenheit)	Watsonville Waterworks climate station 49473	4.67	0.10	6.79	0.03	12.98	0.00

Key: SOI = Southern Oscillation Index; PDO = Pacific Decadal Oscillation; PNA = Pacific North American Pattern.

Notes: June–September SOI values were averaged for the year prior to, and October–March values were averaged for the same year as, the annual average of precipitation and temperature values.

El Niño was assumed to be an SOI of less than or equal to -0.05, neutral phase was assumed to be an SOI between -0.05 and 0.05, and La Niña phase was assumed to be an SOI of greater than or equal to 0.05.

Warm phase and cool phase were assumed to be negative and positive PDO index values, respectively.

Negative phase was assumed to be a PNA of less than or equal to -0.05, neutral phase was assumed to be a PNA between -0.05 and 0.05, and positive phase was assumed to be a PDO of greater than or equal to 0.05.

Table B6. Results of time-series trend analysis of annual and seasonal precipitation and temperature from the Watsonville Waterworks climate station (station 49473) near Ellicott Slough National Wildlife Refuge.

Time period/parameters	*1910–2013 tau*	*1910–2013 p-value*	*1910–2013 percent of median*	*1910–2013 median*	*1925–2013 tau*	*1925–2013 p-value*	*1925–2013 percent of median*	*1925–2013 median*	*1950–2013 tau*	*1950–2013 p-value*	*1950–2013 percent of median*	*1950–2013 median*	*1984–2013 tau*	*1984–2013 p-value*	*1984–2013 percent of median*	*1984–2013 median*
Annual																
Precipitation	0.13	0.05	0.05	19.72	0.15	0.04	0.06	19.76	-0.01	0.88	-0.01	20.93	0.09	0.479	0.08	20.17
Max temperature	-0.03	0.61	0.00	67.45	0.13	0.08	0.01	67.15	0.29	0.00	0.03	66.91	-0.15	0.261	-0.02	67.90
Average temperature	0.38	0.00	0.03	56.26	0.33	0.00	0.03	56.40	0.40	0.00	0.04	56.62	-0.01	0.943	0.00	57.23
Min temperature	0.55	0.00	0.05	45.37	0.46	0.00	0.04	45.64	0.41	0.00	0.04	46.09	0.02	0.901	0.00	47.05
Winter																
Precipitation	0.04	0.56	0.01	11.45	0.07	0.35	0.02	11.84	0.00	0.97	0.00	12.41	0.05	0.736	0.03	11.86
Max temperature	-0.09	0.18	-0.01	61.63	0.06	0.41	0.01	61.46	0.16	0.05	0.03	61.46	0.02	0.852	0.01	61.61
Average temperature	0.07	0.30	0.01	50.41	0.12	0.10	0.01	50.33	0.20	0.02	0.03	50.39	0.03	0.825	0.01	50.81
Min temperature	0.17	0.01	0.02	38.75	0.12	0.11	0.02	38.78	0.14	0.11	0.03	39.32	-0.05	0.721	-0.01	39.62
Spring																
Precipitation	0.10	0.13	0.01	4.00	0.06	0.44	0.01	4.12	0.03	0.71	0.01	4.22	-0.03	0.860	-0.03	4.45
Max temperature	-0.05	0.47	-0.01	66.14	0.06	0.39	0.01	66.08	0.30	0.00	0.05	65.84	-0.18	0.159	-0.07	66.95
Average temperature	0.15	0.03	0.02	55.43	0.17	0.02	0.02	55.46	0.34	0.00	0.05	55.48	-0.20	0.125	-0.06	56.42
Min temperature	0.35	0.00	0.04	44.60	0.27	0.00	0.03	44.87	0.31	0.00	0.05	45.20	-0.12	0.344	-0.03	46.28
Summer																
Precipitation	-0.04	0.58	0.00	0.12	-0.04	0.56	0.00	0.12	-0.08	0.38	0.00	0.12	0.03	0.816	0.00	0.06
Max temperature	0.00	0.98	0.00	70.94	0.12	0.11	0.01	70.82	0.28	0.00	0.04	70.61	-0.24	0.066	-0.08	71.33
Average temperature	0.38	0.00	0.03	61.28	0.36	0.00	0.03	61.34	0.43	0.00	0.05	61.58	-0.11	0.395	-0.02	62.41
Min temperature	0.62	0.00	0.06	51.38	0.55	0.00	0.05	51.68	0.53	0.00	0.06	52.52	0.25	0.054	0.04	53.33
Fall																
Precipitation	0.11	0.12	0.01	3.25	0.08	0.27	0.01	3.27	-0.06	0.47	-0.01	3.48	-0.05	0.697	-0.03	3.33
Max temperature	-0.07	0.28	-0.01	70.82	0.06	0.41	0.01	70.58	0.05	0.56	0.01	70.67	0.13	0.326	0.03	70.88
Average temperature	0.35	0.00	0.03	58.55	0.31	0.00	0.03	58.67	0.17	0.04	0.02	58.96	0.25	0.052	0.06	59.27
Min temperature	0.57	0.00	0.06	46.88	0.46	0.00	0.05	47.12	0.27	0.00	0.03	47.63	0.28	0.032	0.05	48.11
Cool Season																
Precipitation	0.01	0.83	0.00	7.05	0.09	0.25	0.02	6.94	0.02	0.79	0.01	7.46	0.01	0.972	0.00	7.87
Max temperature	-0.02	0.80	0.00	69.13	0.10	0.18	0.01	69.05	0.12	0.17	0.01	69.13	-0.05	0.695	-0.02	69.68
Average temperature	0.42	0.00	0.03	57.99	0.33	0.00	0.03	58.24	0.27	0.00	0.03	58.52	0.11	0.392	0.03	58.88
Min temperature	0.55	0.00	0.06	47.38	0.44	0.00	0.04	47.69	0.37	0.00	0.04	47.96	0.25	0.058	0.05	48.50
January																
Precipitation	-0.01	0.85	0.00	3.71	0.03	0.66	0.01	3.51	-0.13	0.14	-0.03	3.99	0.03	0.804	0.02	3.03
Max temperature	0.13	0.06	0.01	49.28	0.19	0.01	0.03	49.28	0.26	0.00	0.05	49.33	0.12	0.363	0.05	49.91
Average temperature	0.20	0.00	0.03	37.94	0.18	0.02	0.03	37.94	0.20	0.02	0.05	38.39	0.04	0.775	0.02	39.56
Min temperature	0.01	0.93	0.00	60.08	0.12	0.11	0.02	60.08	0.24	0.01	0.05	60.08	0.08	0.520	0.03	60.26

Time period/parameters	*1910–2013 tau*	*1910–2013 p-value*	*1910–2013 percent of median*	*1910–2013 median*	*1925–2013 tau*	*1925–2013 p-value*	*1925–2013 percent of median*	*1925–2013 median*	*1950–2013 tau*	*1950–2013 p-value*	*1950–2013 percent of median*	*1950–2013 median*	*1984–2013 tau*	*1984–2013 p-value*	*1984–2013 percent of median*	*1984–2013 median*
February																
Precipitation	0.05	0.51	0.00	3.07	0.02	0.75	0.00	3.07	0.09	0.31	0.01	3.07	-0.03	0.832	-0.02	4.64
Max temperature	0.06	0.40	0.01	51.71	0.10	0.20	0.02	51.71	0.12	0.15	0.02	51.71	-0.12	0.335	-0.05	51.89
Average temperature	0.16	0.02	0.02	40.28	0.14	0.06	0.02	40.28	0.15	0.08	0.03	40.46	-0.03	0.844	0.00	41.00
Min temperature	-0.10	0.17	-0.01	62.96	0.02	0.79	0.00	62.33	0.07	0.43	0.01	62.24	-0.09	0.497	-0.04	62.96
March																
Precipitation	0.08	0.27	0.01	2.41	0.06	0.45	0.00	2.44	0.03	0.76	0.00	2.58	-0.12	0.357	-0.05	2.58
Max temperature	0.07	0.31	0.01	53.11	0.11	0.15	0.02	53.06	0.28	0.00	0.05	53.06	-0.12	0.344	-0.05	54.32
Average temperature	0.22	0.00	0.04	42.44	0.21	0.01	0.03	42.44	0.29	0.00	0.06	42.44	-0.09	0.486	-0.04	43.79
Min temperature	-0.09	0.19	-0.02	63.95	0.00	0.97	0.00	63.68	0.21	0.02	0.05	63.32	-0.04	0.748	-0.03	64.31
April																
Precipitation	0.04	0.52	0.00	0.98	-0.03	0.68	0.00	1.08	-0.09	0.28	-0.01	1.02	0.09	0.498	0.01	0.81
Max temperature	0.10	0.16	0.01	55.54	0.11	0.14	0.02	55.58	0.24	0.01	0.04	55.58	-0.24	0.069	-0.09	56.48
Average temperature	0.24	0.00	0.03	44.60	0.18	0.01	0.02	44.78	0.19	0.03	0.03	44.96	-0.17	0.186	-0.05	45.77
Min temperature	-0.04	0.59	-0.01	67.10	0.04	0.59	0.01	66.74	0.23	0.01	0.05	66.65	-0.25	0.052	-0.14	67.64
May																
Precipitation	-0.06	0.44	0.00	0.29	-0.02	0.83	0.00	0.27	0.03	0.71	0.00	0.20	-0.02	0.872	0.00	0.37
Max temperature	0.18	0.01	0.02	57.65	0.20	0.01	0.03	57.65	0.34	0.00	0.05	57.74	-0.07	0.592	-0.03	58.69
Average temperature	0.35	0.00	0.05	47.30	0.28	0.00	0.04	47.48	0.33	0.00	0.05	47.84	-0.01	0.943	0.00	48.65
Min temperature	0.01	0.93	0.00	68.36	0.11	0.17	0.02	67.82	0.28	0.00	0.05	67.82	-0.09	0.497	-0.04	69.08
June																
Precipitation	-0.07	0.37	0.00	0.04	-0.04	0.57	0.00	0.04	0.00	0.97	0.00	0.03	0.04	0.785	0.00	0.02
Max temperature	0.28	0.00	0.03	60.44	0.27	0.00	0.03	60.44	0.37	0.00	0.05	60.62	0.00	0.972	0.00	61.48
Average temperature	0.48	0.00	0.05	50.54	0.43	0.00	0.05	50.72	0.44	0.00	0.06	50.72	0.17	0.198	0.05	51.80
Min temperature	-0.05	0.50	-0.01	70.88	0.02	0.81	0.00	70.70	0.17	0.05	0.04	70.70	-0.10	0.422	-0.04	71.33
July																
Precipitation	0.05	0.52	0.00	0.00	0.12	0.17	0.00	0.00	0.08	0.40	0.00	0.00	0.22	0.140	0.00	0.00
Max temperature	0.33	0.00	0.03	61.57	0.33	0.00	0.03	61.61	0.41	0.00	0.05	61.61	-0.03	0.807	-0.01	62.33
Average temperature	0.58	0.00	0.05	51.98	0.53	0.00	0.05	52.07	0.50	0.00	0.06	52.88	0.20	0.132	0.05	54.14
Min temperature	-0.01	0.93	0.00	70.52	0.05	0.51	0.01	70.52	0.19	0.03	0.04	70.34	-0.26	0.053	-0.10	70.70
August																
Precipitation	-0.03	0.75	0.00	0.00	-0.04	0.64	0.00	0.00	-0.13	0.16	0.00	0.00	0.14	0.325	0.00	0.00
Max temperature	0.38	0.00	0.04	61.79	0.36	0.00	0.04	61.97	0.34	0.00	0.05	62.33	-0.04	0.734	-0.01	62.56
Average temperature	0.52	0.00	0.05	52.70	0.47	0.00	0.05	52.70	0.41	0.00	0.06	53.42	0.21	0.107	0.05	54.05
Min temperature	0.11	0.13	0.01	71.06	0.17	0.02	0.02	71.06	0.23	0.01	0.05	71.42	-0.22	0.086	-0.10	72.05

Time period/parameters	*1910–2013 tau*	*1910–2013 p-value*	*1910–2013 percent of median*	*1910–2013 median*	*1925–2013 tau*	*1925–2013 p-value*	*1925–2013 percent of median*	*1925–2013 median*	*1950–2013 tau*	*1950–2013 p-value*	*1950–2013 percent of median*	*1950–2013 median*	*1984–2013 tau*	*1984–2013 p-value*	*1984–2013 percent of median*	*1984–2013 median*
September																
Precipitation	-0.11	0.13	0.00	0.02	-0.03	0.75	0.00	0.01	-0.16	0.09	0.00	0.01	-0.21	0.149	0.00	0.00
Max temperature	0.30	0.00	0.03	62.02	0.31	0.00	0.03	62.20	0.18	0.04	0.03	62.51	0.19	0.143	0.05	62.87
Average temperature	0.49	0.00	0.06	51.44	0.43	0.00	0.05	51.62	0.29	0.00	0.04	51.80	0.17	0.208	0.05	52.34
Min temperature	0.00	0.95	0.00	73.04	0.10	0.20	0.02	72.86	0.08	0.36	0.02	72.86	0.14	0.284	0.07	73.04
October																
Precipitation	0.01	0.84	0.00	0.63	0.07	0.37	0.00	0.61	0.07	0.42	0.00	0.58	0.02	0.901	0.00	0.56
Max temperature	0.32	0.00	0.03	59.41	0.27	0.00	0.03	59.54	0.15	0.08	0.02	59.95	0.18	0.164	0.04	59.72
Average temperature	0.44	0.00	0.06	47.12	0.35	0.00	0.05	47.66	0.24	0.01	0.04	48.11	0.17	0.185	0.07	48.38
Min temperature	-0.01	0.87	0.00	71.78	0.11	0.13	0.02	71.60	0.05	0.57	0.01	71.78	0.05	0.721	0.02	71.87
November																
Precipitation	0.08	0.24	0.01	2.01	0.03	0.67	0.00	2.23	-0.10	0.25	-0.01	2.34	-0.12	0.357	-0.04	2.14
Max temperature	0.13	0.07	0.01	54.23	0.14	0.06	0.02	54.50	0.08	0.34	0.02	54.50	0.20	0.129	0.07	54.64
Average temperature	0.37	0.00	0.06	41.90	0.28	0.00	0.05	42.44	0.12	0.16	0.02	42.80	0.20	0.133	0.07	43.25
Min temperature	-0.16	0.02	-0.03	67.19	-0.02	0.79	0.00	66.02	0.01	0.87	0.00	66.02	0.10	0.422	0.06	67.01
December																
Precipitation	-0.03	0.69	0.00	3.35	0.00	0.96	0.00	3.30	0.01	0.87	0.00	3.57	0.10	0.468	0.06	3.30
Max temperature	0.04	0.56	0.00	49.73	0.09	0.25	0.01	49.73	0.05	0.53	0.01	49.91	0.16	0.222	0.05	50.00
Average temperature	0.11	0.13	0.02	37.94	0.07	0.39	0.01	38.21	0.04	0.66	0.01	38.48	0.11	0.388	0.07	38.48
Min temperature	-0.13	0.07	-0.02	60.98	0.02	0.81	0.00	60.53	0.03	0.74	0.01	60.98	0.06	0.665	0.03	60.98

Key: p-Value = probability level; tau = Kendall's tau.

Notes: Precipitation is measured in inches; temperature is measured in degrees Fahrenheit.
Results shaded in blue are statistically significant downward trends at a p-value of 0.05; results shaded in blue are statistically significant upward trends at a p-value of 0.05.

Table B7. Historic and future estimated values for selected climate variables relevant to Ellicott Slough National Wildlife Refuge.

Climate variable (inches or degrees Fahrenheit)	*Boundary of consideration*	*1981–2010 Historic BCM*	*2010–2039 Csiro*	*2010–2039 BCCR*	*2010–2039 GFDL*	*2010–2039 Miroc Medres*	*2010–2039 BCC_ CSM*	*2010–2039 PCM*	*2040–2069 Csiro*	*2040–2069 BCCR*	*2040–2069 GFDL*	*2040–2069 Miroc Medres*	*2040–2069 BCC_ CSM*	*2040–2069 PCM*	*2070–2099 Csiro*	*2070–2099 BCCR*	*2070–2099 GFDL*	*2070–2099 Miroc Medres*	*2070–2099 BCC_ CSM*	*2070–2099 PCM*
Precipitation (inches)	Refuge boundary	24.9	26.2	24.1	25.5	20.8	21.5	25.1	26.5	22.4	24.2	18.2	23.3	25.1	27.8	23.9	19.7	17.5	25.6	26.7
Tmax (mean Fahrenheit)	Refuge boundary	67.2	67.9	68.1	69.8	69.1	69.6	70.1	69.0	69.0	71.7	71.5	70.6	72.0	70.6	71.3	75.4	74.9	72.5	74.3
Tmin (mean Fahrenheit)	Refuge boundary	46.4	46.8	46.8	47.7	47.6	47.5	46.7	48.0	47.7	49.5	49.7	48.6	48.2	49.6	50.3	52.6	52.8	50.3	50.3
Potential ET (inches)	Refuge boundary	47.7	47.7	47.8	48.7	48.3	48.4	48.4	48.4	48.3	49.8	49.6	49.0	49.4	49.2	49.7	51.6	51.4	49.9	50.5
CWD (inches)	Refuge boundary	29.8	30.2	30.6	30.4	31.9	32.2	30.4	30.2	32.0	32.6	33.9	31.7	31.2	31.1	32.2	36.0	36.7	31.6	33.0
Recharge (inches)	Refuge boundary	7.0	8.7	6.8	7.3	4.3	5.2	6.9	8.4	5.9	7.1	2.4	6.0	6.9	9.6	6.3	4.1	2.9	7.3	9.0

Key: BCM = Basin Characterization Model (Flint and Flint 2012); CWD = Climatic Water Deficit; F = degrees Fahrenheit; ET = evapotranspiration; Csiro = Commonwealth Scientific and Industrial Organization model; BCCR = Bergen Climate Model Version 2; GFDL = General Circulation Model Climate Change Model from Geophysical Fluid Dynamics Laboratory); Miroc Medres = Model for Interdisciplinary Research on Climate; BCC_CSM = Beijing Climate Center, China Meteorological Administration; PCM = General Circulation Model Climate Change Model from Parallel Climate Model.

Notes: Csiro developed by the Centre for Australian Weather and Climate Research.

BCCR developed by Bjerknes Centre for Climate Research (Norway).

Miroc Medres developed by the Center for Climate System Research, Tokyo, Japan and National Institute for Environmental Studies, Ibaraki, Japan.

All climate variables were derived from 270 grid-cell data layers as input (precipitation and temperature) and output (snowpack, actual ET, potential ET, and CWD) from the Basin Characterization Model (BCM) (Flint and Flint 2012; Flint and Flint 2007) and clipped to the boundary of consideration.

Historic snowpack was analyzed for the period 1971–2000.

Table B8. 303(d) listed impaired water bodies and 305(b) assessed water bodies on and near Ellicott Slough National Wildlife Refuge from final California 2010 Integrated Report.

Waterbody	*California Integrated Report Category*	*Constituent*		*Samples*	*Beneficial use not supported*	*Schedule*
Harkins Slough	305(b)	Ammonia (unionized)	Do not list	No exceedances of criteria		
Harkins Slough	305(b)	Chlorpyrifos	Do not list	No exceedances of criteria		
Harkins Slough	305(b)	Diazinon	Do not list	No exceedances of criteria		
Harkins Slough	305(b)	Turbidity	Do not list	25 exceedance out of 45 samples		
Harkins Slough	305(b)	Unknown toxicity	Do not list	No exceedances of criteria		
Harkins Slough	305(b)	pH	Do not list	8 exceedance out of 93 samples	–	
Harkins Slough	303(d)	Chlorophyll-a	Listed	8 exceedance out of 14 samples	Warm freshwater habitat	Estimated TMDL completion: 2021
Harkins Slough	303(d)	Low dissolved oxygen	Listed	20 exceedance out of 45 samples	Warm freshwater habitat	Estimated TMDL completion: 2021
Harkins Slough	303(d)	Escherichia coli (E. coli)	Listed	45 exceedance out of 70 samples	Water contact recreation	None given
Harkins Slough	303(d)	Fecal coliform	Listed	35 exceedance out of 55 samples	Water contact recreation	None given
Gallighan Slough	305(b)	Total coliform	Do not list	8 exceedance out of 9 samples	Beneficial use removed from list	
Gallighan Slough	305(b)	Turbidity	Do not list	9 exceedance out of 12 samples		
Gallighan Slough	305(b)	pH	Do not list	No exceedances of criteria		
Gallighan Slough	303(d)	Escherichia coli (E. coli)	Listed	4 exceedance out of 9 samples	Water contact recreation	None given
Gallighan Slough	303(d)	Fecal coliform	Listed	3 exceedance out of 9 samples	Water contact recreation	None given
Watsonville Slough	305(b)	Ammonia (unionized)	Do not list	No exceedances of criteria		
Watsonville Slough	305(b)	Chlorophyll-a	Do not list	No exceedances of criteria		
Watsonville Slough	305(b)	Chlorpyrifos	Do not list	No exceedances of criteria		
Watsonville Slough	305(b)	Diazinon	Do not list	No exceedances of criteria		

Waterbody	*California Integrated Report Category*	*Constituent*		*Samples*	*Beneficial use not supported*	*Schedule*
Watsonville Slough	305(b)	Sediment toxicity	Do not list	1 exceedance out of 2 samples		
Watsonville Slough	305(b)	Sedimentation/ siltation	Do not list	No exceedances of criteria		
Watsonville Slough	305(b)	Total coliform	Do not list	94 exceedance out of 101 samples	Beneficial use removed from list	
Watsonville Slough	305(b)	Unknown toxicity	Do not list	No exceedances of criteria		
Watsonville Slough	305(b)	pH	Do not list	82 exceedance out of 1070 samples		
Watsonville Slough	303(d)	Low dissolved oxygen	Listed	18 exceedance out of 20 samples	Warm freshwater habitat	Estimated TMDL completion: 2021
Watsonville Slough	303(d)	Turbidity	Listed	91 exceedance out of 262 samples	Warm freshwater habitat	Estimated TMDL completion: 2021
Watsonville Slough	303(d)	Escherichia coli (E. coli)	Listed	45 exceedance out of 89 samples	Non-contact recreation, water contact recreation	None given
Watsonville Slough	303(d)	Fecal coliform	Listed	30 exceedance out of 69 samples	Non-contact recreation, water contact recreation	None given
Watsonville Slough	303(d)	Pesticides	Listed	91 exceedance out of 262 samples	Warm freshwater habitat	Estimated TMDL completion: 2021

Notes: 303(d) water bodies are U.S. Environmental Protection Agency Clean Water Act waters in which technology-based regulations and other required controls are not stringent enough to meet the water quality standards set by the State of California.

Section 305(b) of the federal Clean Water Act requires that states and other entities prepare and submit a Watershed Assessment Report to the U.S. Environmental Protection Agency on every even-numbered year. The 305(b) reports and monitoring data are used to compile a list of impaired waters, commonly referred to as the 303(d) list.

Table B9. Contaminant point sources near Ellicott Slough National Wildlife Refuge.

Site map number (figure 24)	*Contaminant source name*	*Type of site*	*Potential contaminants of concern*	*Data source*	*Station identification*	*Comment*
52	Brothers Country Corner Market	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700161	
53	Buena Vista Disposal Site	Land Disposal Site	Chlorinated hydrocarbons, inorganics, wastewater effluent	GeoTracker	L10008111979	Contaminants found in 2000. Groundwater flow is south east and away from refuge
54	Chevron Station #9-0160*	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700126	Several remediation systems in combined plume
55	Chevron Station 9-7517 (Former)	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700043	Active remediation
56	City of Watsonville Parking Lot	Cleanup Program Sites	Chlorinated hydrocarbons	GeoTracker	SL0608724283	Several remediation systems in combined plume
57	City of Watsonville Landfill	Land Disposal Site	Chlorinated hydrocarbons	GeoTracker	L10006622590	Unlined closed landfill with impermeable cover
58	Don Heim & Son Dry Cleaners	Cleanup Program Sites	Tetrachloroethylene (PCE)	GeoTracker	SL0608709416	Active remediation
59	East Lake Dry Cleaners (Former)	Cleanup Program Sites	Tetrachloroethylene (PCE), Trichloroethylene (TCE)	GeoTracker	SLT3S1681329	No releases from site to-date
60	Former Arco	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700154	No releases from site to-date
61	Former Exxon 7159	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700307	Active remediation
62	J's Gas & Save	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700117	No remediation; verification and site closure pending

Site map number (figure 24)	*Contaminant source name*	*Type of site*	*Potential contaminants of concern*	*Data source*	*Station identification*	*Comment*
63	Main Street Watsonville Commingled Plume Group	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700175	
64	Marty Franich Chrysler Dodge	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700172	Active remediation
65	MF Farming Company	Leaking Underground Storage Tank Cleanup Site	Organochlorine compounds, diesel, gasoline, agricultural chemicals	GeoTracker	T10000004135	No releases from site to-date
66	Pajaro Valley Unified School District	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700237	Active remediation
67	PG&E—Former Manufactured Gas Plant #1	Cleanup Program Sites	Metals, heavy metals, petroleum (fuels, oils), polynuclear aromatic hydrocarbons	GeoTracker	SLT3S1091318	No remediation; verification and site closure pending
68	PG&E Service Station	Cleanup Program Sites	Arsenic, polynuclear aromatic hydrocarbons, diesel, gasoline, waste oil	GeoTracker	SL0608793505	Active remediation
69	PG&E—Former Manufactured Gas Plant #2	Cleanup Program Sites	Arsenic, polynuclear aromatic hydrocarbons, diesel, gasoline, waste oil	GeoTracker	SLT3S0111284	Active remediation
70	Samina	Toxic Release Inventory Program	Inorganics, metals,	Environmental Protection Agency Envirofacts	110000484501	No releases from site to-date
71	Spectra Mat	Cleanup Program Sites	Perchloroethylene	GeoTracker	SLT3S5591368	Active remediation
72	Ultramar Becon #737	Leaking Underground Storage Tank Cleanup Site	Petroleum hydrocarbon and associated compounds	GeoTracker	T0608700262	Active remediation
73	UPRR Row Adjacent to Granite Construction	Cleanup Program Sites	Arsenic, diesel, other metal, waste oil	GeoTracker	T10000002086	No releases from site to-date

Site map number (figure 24)	*Contaminant source name*	*Type of site*	*Potential contaminants of concern*	*Data source*	*Station identification*	*Comment*
74	Watsonville Hospital	Toxic Release Inventory Program	Freon	Environmental Protection Agency Envirofacts	110001149891	No releases from site to-date
75	Watsonville Waste Water Treatment Plant	Permit Compliance System—National Pollution Discharge Elimination System	Nitrogen, ammonia total [as N], polychlorinated biphenyls [PCBs]	Environmental Protection Agency Envirofacts	110013819706	
76	Western Farm Services—Green Grow Facility	Cleanup Program Sites	Fertilizers, pesticides, herbicides	GeoTracker	SL203221260	Active remediation
77	Bontadelli Brothers	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0002860	
78	Nakano Foods Inc.	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003233	
79	Granite Rock Company	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003278	
80	Frank's Chevron #9-0160	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003350	
81	S.Martinelli & Company	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003307	
82	7-Eleven Store #32323	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003602	
83	Breacon Station #5-737	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003211	
84	Crossroad Chevron	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003259	
85	East Lake Union 3741-30551	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003216	
86	Paul Trucking Company	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003300	
87	Watsonville Community Hospital	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003321	

Site map number (figure 24)	*Contaminant source name*	*Type of site*	*Potential contaminants of concern*	*Data source*	*Station identification*	*Comment*
88	One Stop Exxon #33	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0000579	
89	Pacific Bell NF690	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0001758	
90	Beacon Station #3-400	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003208	
91	7-Eleven Store #2234-20608	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0001257	
92	City of Watsonville Airport	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003239	
93	E's Ranch Milk	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0002078	
94	Freedom Shells	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0003180	
95	Freedom Fuels	Permitted Underground Storage Tank	Unknown	GeoTracker	FA0000547	

Appendix C

Prioritization of Recommendations

Recommendations were ranked based on their ability to address 20 issues of concern (IOCs), their ability to address threats associated with 10 water-related objectives or goals, and their feasibility in terms of time and cost (figure C1).

To assess how well the recommendations addressed IOCs and met the objectives and goal, the following steps were followed:

1. Each IOC was scored on whether it aligned with an objective. For example, an IOC was given a maximum possible score of 10 (aligned with all 10 water-related objectives or goals) and a minimum possible score of 0 (aligned with none of the objectives or goals).
2. Relevant IOCs were listed for each recommendation, and the IOC score from step 1 was substituted for each listed IOC. These scores were summed for each recommendation, yielding an overall score of how well the recommendation met objectives or goals.

The scores were then adjusted based on the feasibility of each recommendation:

3. Recommendations estimated to take 1–3 years to implement were assigned a score modifier of +1; recommendations that would take longer than this were given a modifier of 0.
4. Expensive recommendations (costing more than $100,000 per year) were given a score modifier of +1; moderately expensive recommendations (costing between $25,000 and $100,000 per year) were given a score modifier of +2; moderately inexpensive recommendations (costing between $5,000 and $25,000 per year) were given a score modifier of +3; and inexpensive recommendations (costing less than $5,000 per year) were given a score modifier of +4.

Recommendations were then listed in ranked order, with priority given to the top five recommendations and any associated prerequisites.

Table C1. Scoring of issues of concern based on how well each issue addresses water-related program objectives identified by Ellicott Slough National Wildlife Refuge staff and the Region 8 I&M Initiative.

IOC	*Based on refuge water-related objectives—optimal hydroperiod*	*Based on refuge water-related objectives—identify new pond locations*	*Based on refuge water-related objectives—declining groundwater*	*Based on refuge water-related objectives—optimal infrastructure use*	*Based on refuge water-related objectives—other water uses in area*	*Based on refuge water-related objectives—water quality impact to wildlife*	*Based on refuge water-related objectives—water rights reporting*	*Based on Region 8 I&M water-related objectives (FY2013)—Lack of accurate or clarified water asset or supply information for decisionmaking*	*Based on Region 8 I&M water-related objectives (FY2013)—Lack of hydrologic information for decisionmaking*	*Based on Region 8 I&M water-related objectives (FY2013)—Uncertainty in water availability and climate change impacts on water resources*	*Final IOC score*
WR-1	0	0	0	0	0	0	1	0	0	0	1
WR-2	0	0	0	0	0	0	1	0	0	0	1
WR-3	0	0	1	0	0	0	0	0	0	0	1
CL-1	1	0	0	0	0	0	0	0	1	1	3
CL-2	0	0	0	0	0	1	0	0	0	1	2
CL-3	0	0	0	0	0	0	0	0	0	1	1
SW-1	1	0	0	0	0	0	0	0	0	0	1
GW-1	0	0	1	0	0	0	0	0	1	0	2
HAB-1	0	1	0	0	0	0	0	0	0	0	1
HAB-2	1	0	0	0	0	0	0	0	1	0	2
HAB-3	0	0	0	1	0	0	0	0	0	0	1
HAB-4	0	0	0	0	1	1	0	0	0	0	2
WQ-1	0	0	0	0	0	1	0	0	0	0	1
WQ-2	0	0	1	0	1	1	0	0	0	0	3
WQ-3	0	0	0	0	0	1	0	0	1	0	2
WQ-4	0	0	0	0	0	1	0	0	0	0	1
WQ-5	0	0	0	0	0	1	0	0	0	0	1
WQ-6	0	0	1	0	0	0	0	0	1	0	2
WQ-7	0	0	0	0	0	1	0	0	1	0	2
WQ-8	0	0	0	0	0	1	0	0	0	0	1

Key: IOC = issue of concern; Region 8 I&M = Pacific Southwest Region Inventory and Monitoring Initiative; 0 = no; 1 = yes; WR = water rights; CL = climate; SW = surface water; GW = groundwater; HAB = habitat; WQ = water quality.

Note: Issues of concern are listed by code in the main body of the water resource inventory and assessment report.

Table C2. Scoring of recommendations for Ellicott Slough National Wildlife Refuge based on how well each recommendation addresses issues of concern and feasibility.

Recommendation	*Prerequisite recommendations*	*Issues of concern score*	*Modifier code for estimated cost*	*Modifier for estimated time required*	*Total score*	*Rank*
Rec-1	None	10	2	1	13	1
Rec-2	Rec-1	8	2	0	10	2
Rec-3	Rec-1	4	4	1	9	3
Rec-4	None	3	4	1	8	4
Rec-5	None	6	2	0	8	4
Rec-6	None	5	2	0	7	6
Rec-7	None	1	4	1	6	7
Rec-8	None	1	4	1	6	7
Rec-9	None	1	4	1	6	7
Rec-10	None	1	4	1	6	7
Rec-11	Rec-1	4	2	0	6	7
Rec-12	None	1	4	1	6	7
Rec-13	None	2	3	1	6	7
Rec-14	None	1	4	0	5	14
Rec-15	None	1	3	1	5	14
Rec-16	None	1	3	1	5	14
Rec-17	None	0	4	1	5	14

Key: Modifier for estimated costs: 1 = expensive; 2 = moderately expensive; 3 = moderately inexpensive; 4 = inexpensive.

Modifiers for estimated time required: 1 = 1–3 years; 0 = greater than 3 years.

Notes: Time and cost reflect resources to address the recommendation not including any prerequisite recommendations.

The prerequisite recommendations column shows other recommendations that are required before the recommendation can be completed.

Total score is the sum of Issue of Concern score (from table C1), modifier code for estimated cost, and modifier for estimated time required; rank is based on total score among recommendations and is the same for tied scores.

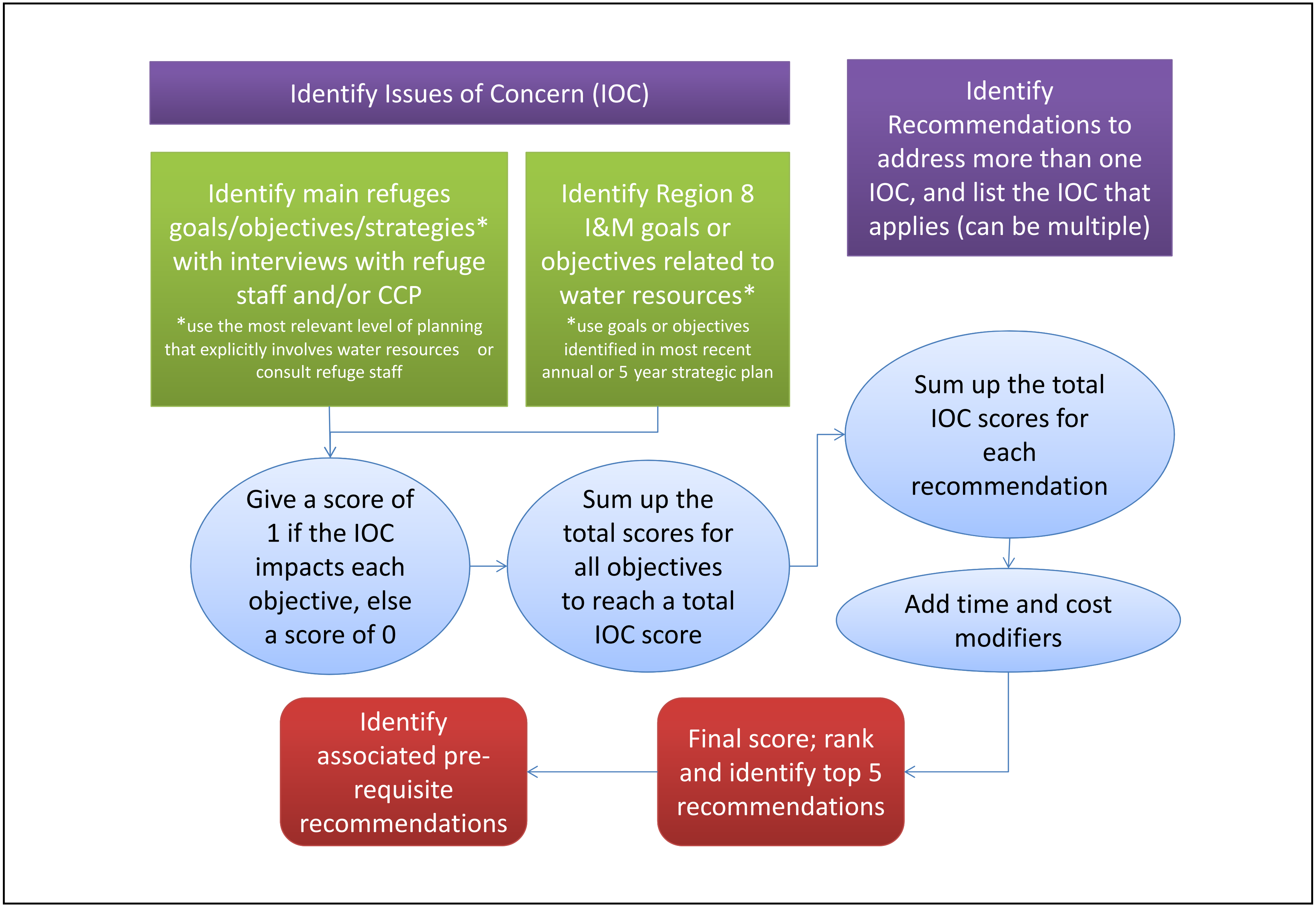


Figure C1. Process used to score and highlight top recommendations based on feasibility and alignment with program objectives.

Appendix D

Overview of California State Water Law and Policy

California water law is a mixture of prior appropriation doctrine, or "first in time—first in right," and riparian doctrine. Other types of rights exist in California, including reserved rights (water set aside by the federal government when it reserves land for the public domain), pueblo rights (a municipal right based on Spanish and Mexican law), and prescriptive rights (right acquired through adverse possession of another right-holder's water right) (California State Water Resources Control Board 2014e; California State Water Resources Control Board 2014f). Because reserved rights, pueblo rights, and prescriptive rights do not likely apply to U.S. Fish and Wildlife Service lands, those rights are not discussed here. The following paragraphs include discussions of aspects of California state water law that are relevant to National Wildlife Refuges.

The State Water Resources Control Board (SWRCB) has jurisdiction over water use permits in California and acts as arbiter of all disagreements over water rights. The California Water Code was enacted in 1914 and explicitly states that all waters of California are public property and that a water right is a usufructuary right[1] (California State Legislature 2014a).

An appropriative right is a right for removal of any water from a stream for delivery to non-adjacent parcels and requires a permit from the SWRCB. Under appropriative doctrine, water shortages are distributed to users according to the priority rule; those with the earliest priority dates have the right to use their full amount of water ahead of users with later priority dates. Priority is date of initiation—for example, the date of permit application or date that construction or diversion began if prior to Water Code in 1914. Appropriative rights may be lost by abandonment or nonuse (forfeiture). Nonuse is the failure to put the water to beneficial use for 5 years. Abandonment is intentional or voluntary nonuse (California State Legislature 2014a).

New surface water uses or changes to existing uses (transfers) must be done through a permit application process with the California State Water Resources Control Board. Appropriative rights undergo an application, permit, and licensing process. The license is the final confirmation of the water right and remains effective per the terms of the right (California State Water Resources Control Board 2014f).

Riparian rights are incorporated into the California Constitution, and riparian doctrine states that all riparian land owners (owners whose property touches the stream, river, or pond) have equal rights to use that water reasonably. The land where water is used (riparian land) must be contiguous to the stream, and riparian land must be within the drainage basin of the stream as determined by present natural topography. A riparian right holder is only authorized to use an amount of water that is both reasonable and beneficial, providing that other riparian water users are not injured. Riparian water rights cannot be lost for nonuse and cannot be transferred for use upon a nonriparian parcel of land. A parcel of land loses its riparian status forever when severed from land bordering the stream by conveyance, unless the conveyance document specifically reserves the riparian right. A riparian right does not grant the right to store the water for seasonal use (generally greater than 30 days) (California State Water Resources Control Board 2014f).

[1] Usufructuary water rights are rights to take the water from a stream into physical possession for the purpose of putting it to beneficial use.

Beneficial use is the measure and limit of appropriative water rights in California. All uses of surface water require an appropriative water right and the water must be used beneficially, unless the user has a riparian right. Riparian rights are generally senior to most appropriative rights, and riparian landowners may use natural flows directly for beneficial purposes on riparian lands without applying for a permit. The state recognizes fish and wildlife (enhancement of fish and wildlife resources) and water quality control (protection and improvement of waters) as beneficial uses (California State Legislature 2014a).

Water right permittees and licensees are required to file annual Progress Reports of Permittee and Reports of Licensee, respectively. With some exceptions, others who divert water, including diverters under claims of riparian rights and pre-1914 appropriative rights, are required to file Statements of Use and Diversion (Initial Statements and Supplemental Statements) annually (California State Water Resources Control Board 2014f).

SWRCB's duties are not limited to permits and licenses. It may be called upon to adjudicate water for entire systems or to act as an arbiter in court cases involving water rights. Statutory adjudication is a process by which the comprehensive determination of all water rights in a stream system is made. This happens if a claimant petitions the SWRCB for adjudication and SWRCB finds the action necessary in the public interest. Statutory adjudications are initialized after adoption of an Order of Determination and filing it with the appropriate Superior Court. A court hearing is used to determine merits and handle objections. The final step is a court decree (California State Water Resources Control Board 2014f).

The State established the Watermaster Program in 1924 to provide for general public welfare and safety after many injuries and some deaths resulted in disputes over adjudicated water rights. Watermaster service is administered by the California Department of Water Resources (CADWR). Watermaster service areas are created by the CADWR either at the request of water users or by order of the Superior Court. The main purpose of the Watermaster Program is to ensure water is allocated according to established water rights as determined by court adjudications or agreements by an unbiased, qualified person, thereby reducing water rights court litigation, civil lawsuits, and law enforcement workload. Watermaster services also help to prevent the waste or unreasonable use of water (California State Water Resources Control Board 2014f).

In contrast to surface water, groundwater in California is largely unregulated. With few exceptions, overlying landowners are allowed to make reasonable use of groundwater without obtaining permission or approval and can continue to extract water regardless of the condition of the aquifer (California State Water Resources Control Board 2014e).

However, over the years groundwater legislation has been enacted that details requirements for local management and regulation of groundwater. This legislation requires management and oversight by CADWR.

The Groundwater Management Act of 1992, originally established under State Assembly Bill (AB) 3030, was intended to encourage local agencies to work cooperatively to manage groundwater resources within their jurisdictions and to provide a methodology for developing a groundwater management plan. AB 3030 has been modified by State Senate Bill (SB) 1938 and AB 359, which modified the Groundwater Management Act by requiring any public agency seeking state funds administered by the CADWR for the construction of groundwater projects to prepare and implement a groundwater management plan with required components, including identification of groundwater recharge areas. This applies to management areas that overlay Bulletin 118 groundwater basins or to those agencies that have groundwater management authority outside of those basins (California Department of Water Resources 2014f).

On November 4, 2009, the State Legislature amended the Water Code with SB c7-6, which mandates a statewide groundwater elevation monitoring program to track seasonal and long-term trends in groundwater elevations in California's groundwater basins. In accordance with this amendment, CADWR developed the California Statewide Groundwater Elevation Monitoring (CASGEM) program (California Department of Water Resources 2014d).

On September 16, 2014, the governor signed a series of bills to establish a framework for statewide regulation of groundwater. These bills include SB 1168, AB 1739, and SB 1319. SB 1168 requires that all Bulletin 118 Groundwater Basins designated by CADWR (through CASGEM) as high- or medium-priority that are subject to critical conditions of overdraft be managed under a groundwater sustainability plan by the year 2020. High- or medium-priority basins that are not subject to overdraft must be managed under a groundwater sustainability plan by the year 2022 (California State Legislature 2014b).

SB 1168, in combination with AB 1739, authorizes any local agency to become a groundwater sustainability agency, which gives authorization for the agency to regulate groundwater use by law through such measures as inspections, required water use reporting, and imposition of water use fees, if necessary (California State Legislature 2014c). SB 1319 would additionally authorize SWRCB to designate certain high- and medium-priority basins as a probationary basin if, after 2025, these basins were still in a state of significant overdraft. SB 1319 authorizes the SWRCB to develop an interim plan for groundwater sustainability and regulate groundwater use if the local agency cannot effectively remediate the problem (California State Legislature 2014d).

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