



Wet Meadow and Fen Mapping of Yosemite National Park

A photo interpretation mapping project of wetland resources

Natural Resource Report NPS/SIEN/NRR—2020/2145



ON THE COVER

Photo and aerial National Agriculture Imagery Program imagery (2012) of Grace Meadows, Yosemite National Park
NPS / Vegetation Branch, Resource Management & Science, Yosemite National Park

Wet Meadow and Fen Mapping of Yosemite National Park

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Abstract

Wetlands are some of the most diverse and ecologically important ecosystems on earth, yet they are also some of the most threatened. In the Sierra Nevada, meadows (both wet and dry) are estimated to occupy roughly 2% of the land area and 40–60% of these systems are in a degraded condition due to historic or current land use. Wet meadows and fens are a subset of wetlands that are largely groundwater dependent and are characterized by high water tables, organic soils, and herbaceous plant communities. The Yosemite Wetland Mapping Project was an effort conducted by the National Park Service Inventory & Monitoring Program, Sierra Nevada Network (SIEN) to identify and map all fens and wet meadows ≥ 0.5 ha within Yosemite National Park (YOSE). The aim of this mapping project was to create a feature class that shows all wet meadows and fens greater than 0.5 ha within Yosemite National Park, and classifies them as wet meadow, fen-meadow complex, and fen. This work complemented a previous effort to characterize similar habitat using the same procedures in Sequoia and Kings Canyon National Parks.

Wetland mapping was conducted by two technicians based on aerial imagery photo interpretation during the winter of 2014. Multiple years of true color and color infrared National Agriculture Imagery Program imagery were used to map and classify target wetlands based on color signature, texture, vegetation density, slope, and expert knowledge of park wetlands. Other key data that were used to inform mapping decisions included meadow field survey data, the YOSE vegetation map, wetland mapping data from the SIEN Wetland Ecological Integrity pilot study, and the National Wetlands Inventory data. All mapping was done using Environmental Systems Research Institute ArcGIS 10.1 software with versioning that allowed the two technicians to work simultaneously on the same feature class.

A total of 1,605 wetland polygons and 557 points of peat-accumulating areas were created. Seventeen polygons represent fens, 297 represent fen-meadow complexes, and the remaining 1,291 represent wet meadows within YOSE. The total area of wet meadows, fen-meadow complexes, and fens mapped was 4,307 ha, which is 1.4% of the total acreage of the park. Overall classification accuracy was estimated to be 63% (90% CI = 56–70%) based on field assessments of 139 polygons that included both target wetlands mapped by this project, as well as areas that were mapped as seasonal or perennial wetlands on the YOSE vegetation map, but were deemed to not meet the definition of a target wetland for this project. When only target vs. non-target status was considered, mapping accuracy improved to 84%, indicating that most of the mapping errors occurred when trying to distinguish among target wetland types (fen, wet meadow, or fen-meadow complex). When these error rates are taken into account, the estimated area of fen and wet meadow habitat in YOSE is 3,730 ha (1.2% of the total area of the park). The products from this project will allow managers to better understand the distribution and current status of fens and wet meadows within YOSE. This information is already being used to aid several NPS planning and monitoring efforts including the SIEN Wetland Ecological Monitoring Protocol.

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List of Acronyms

AA: Accuracy Assessment
AIS: Aerial Information Systems
BRD: Biological Resources Division, U.S. Geological Survey
CI: Confidence Interval
CIR: Color Infrared
CNPS: California Native Plant Society
DEM: Digital Elevation Model
ESRI: Environmental Systems Research Institute
GIS: Geographic Information System
GPS: Global Positioning System
MMU: Minimum Mapping Unit
NAIP: National Agriculture Imagery Program
NC: Natural Color
NPS: National Park Service
NVCS: National Vegetation Classification System
NWI: National Wetlands Inventory
QA/QC: Quality Assurance/Quality Control
SDE: Spatial Database Engine
SEKI: Sequoia and Kings Canyon National Parks
SIEN: Sierra Nevada Network (Inventory & Monitoring Program)
SOP: Standard Operating Procedure
SQL: Structured Query Language
USDA: U.S. Department of Agriculture
USGS: U.S. Geological Survey
WEI: Wetlands Ecological Integrity (monitoring project)
YWMP: Yosemite Wetland Mapping Project
YOSE: Yosemite National Park

Introduction

Wet meadows and fens (peat accumulating wetlands) play an important role in a variety of ecological functions including ground and surface water dynamics, carbon and nutrient cycling, and wildlife habitat. They also serve as hotspots of biodiversity and are some of the most productive ecosystems on earth. However, these systems are subject to a host of stressors including climate change and historic and current human use. Fens and wet meadows are of particular interest within the Sierra Nevada due to current and historic land use impacts, as well as the important ecological and hydrological functions they provide. This project leveraged existing inventories (vegetation, wetlands, soils) to map and characterize wet meadows and fens in Yosemite National Park (YOSE).

Wet Meadows

Wet meadows are characterized by seasonally saturated soils, but lack the perennial high water tables and peat soils of fens or the large seasonal and inter-annual water table fluctuations characteristic of marshes. However, wet meadows have significantly more organic matter in their soils compared to surrounding forests or dry meadows. Therefore, while wet meadows are often described as “meadows”, they are also considered wetlands, while drier meadows are not. NatureServe places most Sierra Nevada wet meadows into the Temperate Pacific Subalpine-Montane Wet Meadow ecological system type (NatureServe 2008). Wet meadow vegetation may be composed of a diverse range of species including obligate and facultative wetland species that grow in hydric or saturated soils (Lichvar et al. 2012).

Wet meadows frequently occur in stream valleys as part of larger wetland complexes, but unlike riparian ecosystems they are not characterized by high-velocity surface flows or sediment deposition from fluvial processes. High water tables early in the summer are maintained in part by snowmelt, though water tables may drop well below the soil surface in July and August. Wet meadows can also be distinguished from dry meadows where the water table is often deeper than 2 m for much of the growing season, resulting in a different assemblage of plant species.

Fens

A fen is a wetland whose primary water source is either groundwater or surface water run-off in which the production of organic matter is greater than the rate of decomposition due to anoxic conditions maintained by consistently high water tables; this allows for the development of organic soils (peat) (Wolf and Cooper 2015). In fens, peat accumulation is accompanied by a water table that typically remains within 20–40 cm of the soil surface throughout the growing season and is dominated by obligate wetland vascular plants and mosses (Sikes et al. 2013). Wetland soils with an accumulation of 40 cm peat in the top 80 cm of the soil profile are classified as histosols in the U.S. (Soil Survey Staff 1999). However, mountain wetlands in the Sierra Nevada and Rocky Mountains that contain as little as 20 cm of organic matter within the top 40 cm of the soil profile still display many of the ecological properties of fens including similar biota and hydrology (Driver 2010, Weixelman et al. 2011). Therefore, wetlands with at least 20 cm of peat within the top 40 cm in soil profiles (and met floristic and hydrologic definitions) were defined as fens in this project.

Fens have been found in three geomorphic settings in the southern Sierra Nevada: mound, slope discharge, and basin fens (Weixelman et al. 2011). Mound fens are created by strong upwellings of groundwater discharge, leading to mounded peat accumulation. Slope discharge fens are also created by springs and commonly occur on topographic breaks in a slope or at the toe of a slope. Basin fens occur along the margins of lakes or depressions and may develop floating mats of vegetation extending into the open water. Basin fens are more common in closed lake systems.

Fens are of interest because they support a characteristic flora including some rare species (Sikes et al. 2013). Furthermore, fens are an atmospheric carbon sink that develop over hundreds or thousands of years (Bartolome et al. 1990, Weixelman and Cooper 2009). In addition, fens regenerate very slowly due to low rates of peat accumulation (Amon et al. 2002, Weixelman and Cooper 2009) and may be particularly sensitive to environmental change (Sikes et al. 2013).

Management History of Meadows in Yosemite National Park

YOSE encompasses a total of 299,182 hectares (747,956 acres), of which 3% are characterized as meadows (Keeler-Wolf et al. 2012). These areas have a long history of management and use and have been prioritized for conservation in the park's Merced and Tuolumne Wild and Scenic River Management Plans (NPS 2014a, 2014b). Wetlands were and remain important resources for Native Americans. There is no evidence of significant changes to wetland vegetation due to human activity prior to European colonization in North America, however, anthropogenic burning may have played a role in reducing conifer encroachment and supporting meadow persistence in some areas. Many high elevation meadows were heavily grazed for much of the second half of the 19th century by sheep and cattle across the southern Sierra Nevada (Ratliff 1985) to the point where substantial changes to meadow vegetation are thought to have occurred (Dull 1999). Meadows today remain a prime destination for park visitors and are a source of forage for pack-stock (Kuhn et al. 2018).

Over the past decade, significant progress has been made in the mapping and assessment of Sierra Nevada wetlands (see the Sierra Nevada Meadows Data Clearinghouse: (<https://meadows.ucdavis.edu/>), but these efforts have occurred largely outside of YOSE (Sikes et al. 2013, Wolf and Cooper 2015). The lack of a comprehensive and systematic assessment of wetlands within YOSE limits inferences that can be made about wet meadows and fens within the park. Here we outline the second of two completed remote sensing projects conducted by the Sierra Nevada Network Inventory & Monitoring Program (SIEN) to detect and classify fens and wet meadows in Sierra Nevada parks; the first was in Sequoia and Kings Canyon National Parks (SEKI) (Pyrooz et al. 2015), and the second, in YOSE. The methods and resulting spatial database of the mapping effort in YOSE can help inform management decisions regarding these important ecosystems, and were used in the development of the wetland ecological integrity monitoring protocol in SIEN (Gage et al. 2018). In this report we provide information on the decision rules used to map and classify individual target wetlands and background information on the various existing datasets used to inform these decisions. We also document how the data and products have been archived and how they may be accessed. Finally, we present the summary results from the mapping project and discuss the accuracy assessment methodology used to validate the mapping and classification results.

Methods

The Yosemite Wetland Mapping Project (YWMP) established a procedure to map wet meadows and fens found within YOSE based on the same set of criteria originally developed as part of the SEKI Wet Meadow and Fen Mapping Project (Pyrooz et al. 2015). A description of each target wetland type with examples is provided in Appendix 1. The YWMP relied on a variety of technical materials and existing datasets, and defined a set of mapping criteria and decision rules in order to meet project goals. The primary approach used to produce the YWMP map was photo interpretation of aerial imagery. Aerial photography has been used to map wetlands for several decades (National Research Council 1995). Mapping wetlands using aerial photography is useful for detecting wetland boundaries, as the technician is able to view the wetland within the surrounding terrain. It is also possible to assess boundaries for areas that are difficult or impossible to access in the field. Still, there are limitations to this methodology; certain vegetation types can be difficult to differentiate remotely when vegetation, soils, or hydrology are not distinct or exhibit seasonal or temporal variability. Ancillary data and prior mapping efforts are important aids that served to help technicians make critical distinctions when classifying potential wet meadows and fens for the purpose of this project. The YWMP was conducted from Dec. 2013 to Feb. 2014 by two technicians. One technician had been a part of the SEKI Wetland Mapping Project and the other was familiar with YOSE meadows based on several seasons of meadow monitoring fieldwork as part of the Yosemite Resources Management & Science staff.

Integrating Existing Spatial Data

The YWMP relied heavily on several existing data sets to inform the mapping process, and they are described below.

Yosemite Vegetation Map

The first large (>150,000 acres) national park to have its vegetation mapped, YOSE was chosen as a pilot project for the USGS-NPS Vegetation Mapping Program (Keeler-Wolf et al. 2012). Aerial Information Systems, Inc. (AIS) performed the vegetation photointerpretation and automation between 2000 and 2002 under a subcontract through Environmental Systems Research Institute (ESRI), based on aerial photos taken in 1997. Accuracy assessment data were collected in 2002 and 2003, and the final map was completed in 2006 (Keeler-Wolf et al. 2012). The YOSE vegetation map characterized all vegetation in the park and included a significant area within a defined perimeter outside of the park boundary for a total mapped area of nearly 1.4 million acres.

The YOSE vegetation map used a 0.5 ha minimum mapping unit (MMU) standard (though a finer scale was sometimes used for wetland meadows or other areas of special concern). Because vegetation types can occur at finer scales, aggregation of vegetation types sometimes occurred (Keeler-Wolf et al. 2012), though wetland and upland types were generally not combined.

The YWMP technicians filtered units from the YOSE vegetation map so that only certain mapping units were visible. The units used to inform the YWMP included:

0981 – Permanently Flooded, Emergent, or Floating Vegetation
 3022 – Sierra Lodgepole/Bog Blueberry Forest Mapping Unit
 6110 – Sierra Willow/Swamp Onion Seasonally Flooded Shrubland Alliance
 6500 – Willow spp./Meadow Shrubland
 8000 – Intermittently to Seasonally Flooded/Saturated Herbaceous
 9000 – Seasonally – Permanently Flooded Herbaceous

These units helped technicians to key in to previously mapped meadows and areas that may contain wetland vegetation. Polygons that accurately delineated wet meadow, fen-meadow complex, and fen vegetation were copied and pasted directly into the new map. As in the SEKI vegetation map, many areas classified in the 8000 and 9000 meadow layers were found to not fit within the parameters of wet meadow, fen-meadow complex, or fen as defined by this study (Table 1). This was mostly the case in higher elevation subalpine and alpine systems where vegetation was sparse, or appeared to lack sufficient buildup of organic soils based on the available aerial imagery.

Table 1. Description of wetland type classification definitions and color signatures.

Wetland type	Decision-rule	Signature characteristics
Wet Meadow	a wetland that does not include any peat accumulation or may contain up to a 25 m x 25 m area of peat accumulation	Color infrared reflectance yields bright orange to red signatures. The texture is always smooth but may be a bit coarser with presence of larger forbs such as <i>Veratrum californicum</i> , or interspersed <i>Salix spp.</i>
Fen-Meadow Complex	a wetland that includes at least a 25 m x 25 m area of peat-accumulating soil and at least a 25 m x 25 m area that is not peat accumulating	A bright red meadow signature interspersed with the darker presence of standing water in color infrared imagery is used in mapping this category. Areas of meadow containing fen are either a darker maroon color in the color infrared or lighter, indicating a mound or buildup often with <i>Sphagnum</i> cover. Texture is smooth and often blotchy or mottled, indicating a change in the amount of standing water present.
Fen	a wetland that contains less than a 25 m x 25 m of non-peat-accumulating soil	Bright or dark red signature in color infrared imagery, a much stronger redness than a wet meadow, but with more color consistency than in a fen-meadow complex. brightness affected by presence of water. Texture is smooth, and blotchy or mottled.

Wetland Ecological Integrity Pilot Study

The Wetland Ecological Integrity Pilot Study used photointerpretation to identify wet meadows and fens in selected watersheds (CalWater 1999) in Yosemite and Sequoia and Kings Canyon National Parks (Jones 2011). The study identified a subset of 210 target wetland polygons in YOSE, using a minimum mapping unit of 0.5 ha, and classified them as fen, wet meadow, or fen-meadow complex based on their color signature, context within the landscape, and local knowledge. These sites were visited to verify their assigned classification based on vegetation, soils, and hydrologic characteristics. Delineations from this study were directly transferred into the YWMP. Field-tested

sites were used to train technicians to recognize the visual signature characteristics of fens and wet meadows in YOSE.

SEKI Wetland Mapping Project

YOSE photo-interpretation technicians relied on the completed SEKI map of wet meadows and fens for training purposes during the first two weeks of the project. Because the accuracy assessment for SEKI had been completed during the 2013 field season, technicians were able to compare features mapped by SEKI technicians with field assessments. Although the parks differ in that SEKI generally has steeper topography and receives less precipitation than YOSE, the two parks have enough ecological similarities that examples drawn from SEKI to illustrate the detection of fens and wet meadows were generally transferable to YOSE wetlands.

Mapping Protocols and Criteria

A set of decision rules was originally established for the development of the SEKI Wetland Mapping Project (Pyrooz et al. 2015) in order to ensure consistency and accuracy between technicians. These criteria were adapted to the YWMP (Appendix 2). Using the Yosemite vegetation map and the National Wetland Inventory (NWI; U.S. Fish and Wildlife Service 2012) layers as a guide, technicians searched for the visual signature indicating the presence of target wetland (wet meadow or fen) vegetation. They would then decide whether or not to map the target wetland feature based on whether the following established criteria were met:

- a minimum area of 0.5 ha
- a minimum average width of 15 m
- less than 33% cover of non-meadow vegetation (trees/shrubs/rocks)
- indication of consistent hydrological source/persistent greenness

Classification of fen, fen-meadow complex, and wet meadow types were based on the decision-rules and visual signature characteristics described in Table 1. An example of a wetland visual signature using color infrared imagery is provided in Figure 1.

Image signature of wet meadow and fen vegetation. In general, color infrared reflectance of wet meadows and fens has a strong, bright red visual signature, sometimes interspersed with pink to orange to maroon, depending on the presence of water. All wet meadows and fens have a mostly smooth texture, although some areas can be coarser if larger forbs or shrubs (i.e. *Salix* spp.) are present.

Dry meadows, especially in alpine and sub-alpine areas, have a lighter, pinker signature. They may be more interspersed with rock. Upland vegetation was typically less bright and less dense than wetland vegetation, although in some montane portions of the parks the signatures appear similar. Technicians considered hydrological, topographical, and landscape context to infer whether the water table remained high throughout the growing season. *Salix* spp. and other shrubs, as well as upland vegetation, may also display a strong red signature, but have a rougher texture than that of meadows. See Appendix 1 for more details.

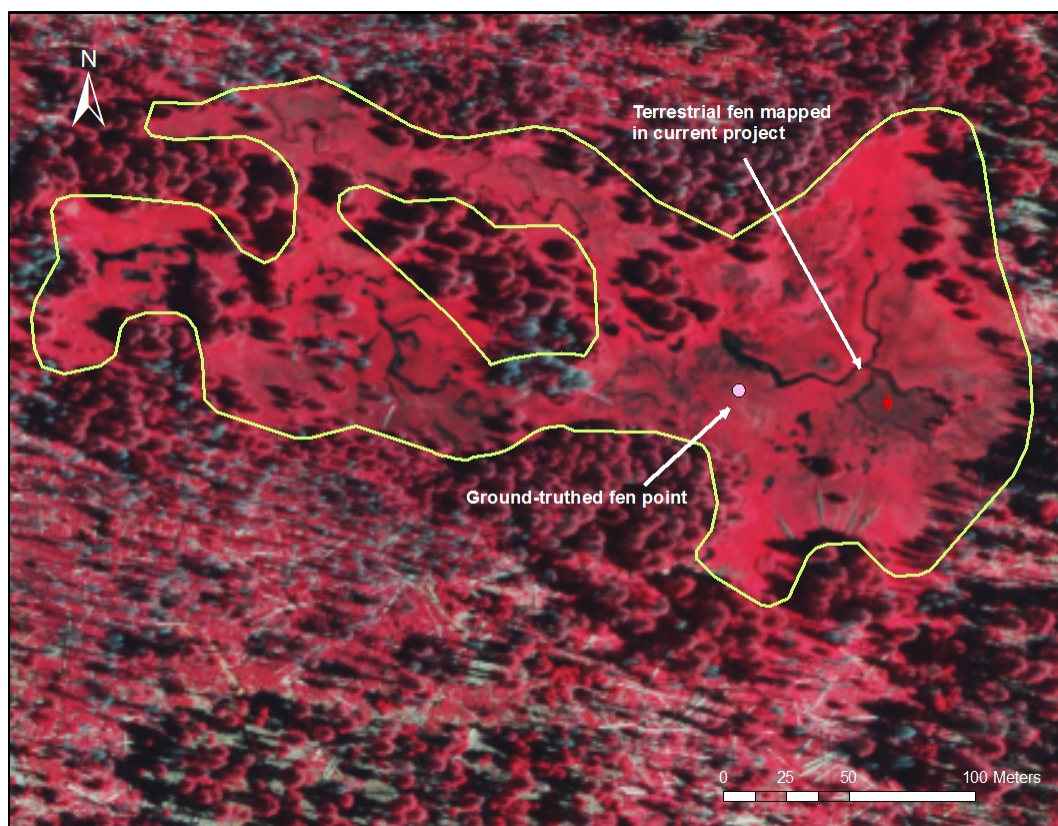


Figure 1. Use of infrared color signature to inform wetland classification based on aerial imagery. The center of the fen is indicated by the red diamond and the pink circle indicates a separate location within the wetland that was confirmed to be fen in the field. The yellow line outlines the polygon perimeter.

Emergent Vegetation

One of the main differences observed in wetland signature during the wetland mapping process for YOSE and SEKI was the greater number of permanently flooded locations in YOSE. These permanently flooded locations harbor uncommon emergent plant species and floating mats of peat accumulating areas seldomly associated with meadows in SEKI. While not necessarily difficult to detect once technicians developed a good idea of the visual signature presented by these habitats, it did precipitate a few important questions. These questions are as follows: 1) At what point do conditions become too wet to be considered a wet meadow or fen and result in a seasonal pond or marsh? and 2) How are areas without meadow vegetation that have peat accumulation in aquatic settings (i.e. floating peat bodies) classified and mapped? To address these questions, a set of criteria was developed to exclude marshes and ponds with emergent vegetation cover. If the area in question appeared to be flooded in each year of imagery available, thus giving the impression that it rarely dried out, then it was considered a water body and excluded. Questionable areas were included but noted within the comment field as possibly being too wet for sampling. Areas assumed to be peat accumulating, but without meadow vegetation (i.e. permanently inundated areas, floating peat bodies), were recorded with a peat point and flagged with a comment indicating no association with a mapped meadow. Although a few areas with these conditions are scattered throughout the park, the majority are centered to the north and west of Hetch-Hetchy reservoir along south-facing slopes.

These areas were generally associated with small- to medium-sized lakes partially to entirely covered by emergent vegetation and floating peat mats. Google Earth Imagery helped technicians to recognize the difference in visual signature as the presence of water beneath vegetation in these areas.

Because the YWMP is focused on wet meadows and fens, it was decided that despite the presence of peat accumulation, these areas in question were not within the target population of the YWMP. Hence, when presence of floating peat mats were likely or known to be present, only peat points were recorded and flagged with a comment for these areas.

Photo Interpretation Mapping Procedures

Project Materials

An integral component of a remote sensing project is the type and quality of accessible imagery and spatial data, which is then complemented by software that enables a smooth workflow. Below is a list of the types of accessible imagery and spatial data we used. Project materials used by the YWMP and their strengths and weaknesses are discussed in Table 2.

Table 2. Advantages and disadvantages of the various imagery used (NAIP – Natural Agriculture Imagine Program, ESRI, Google Earth). NC is natural color, CIR is color infrared.

Image Type	Advantages	Disadvantages
2005 NAIP NC	Good color saturation.	Poor resolution made it difficult to distinguish details, and delineate between shrubs and herbaceous vegetation.
2005 NAIP CIR	Additional infrared images when 2010 & 2012 CIR is unusable. Allows for comparison over years of varying wetness.	Infrared is pale, poorest quality of infrared imagery.
2009 NAIP NC	Supplemental imagery when other years are cloud-obscured, shadow-cast, etc.	Very low resolution makes distinguishing between shrub and herbaceous meadow vegetation difficult. Map is not contiguous; the file is divided into the four counties comprising Yosemite. Very high snow-cover in montane areas.
2010 NAIP NC	Good resolution. Generally brighter image leads to greater visibility of topographical relief and meadow contrast in wooded areas.	Lower color saturation and pale vegetation is disadvantageous when trying to distinguish between vegetation and granite in montane areas. Snow covered in montane areas.
2010 NAIP CIR	Good resolution. Generally brighter image leads to greater visibility of topographical relief and meadow contrast in wooded areas.	Lower color saturation leads to reduced contrast of wetness compared to 2012.
2012 NAIP NC	Good resolution and ability to discern shrubs from herbaceous vegetation. Vegetation in montane areas is more apparent as it contrasts with granite.	Generally darker imagery, meadows in wooded areas at lower elevations can be less apparent. More prone to shadow cover by trees and mountains.

Table 2 (continued). Advantages and disadvantages of the various imagery used (NAIP – Natural Agriculture Imagine Program, ESRI, Google Earth). NC is natural color, CIR is color infrared.

Image Type	Advantages	Disadvantages
2012 NAIP CIR	High contrast leads to wetness being generally darker and easier to distinguish.	Generally darker imagery, meadows in wooded areas at lower elevations can be less apparent. More prone to shadow cover by trees and mountains.
Google Earth	Three dimensional viewing more accurately portrays topography and slope. Interactive rotational camera angles and ability to zoom to ground-level heighten confidence in vegetation communities, wetland classifications and aquatic vs terrestrial delineations. Continually updated imagery means this is the most recent imagery accessible.	Continually updated imagery doesn't allow for viewing a collection of multiple years, or knowledge of when the image was captured. No CIR available. Occasional problems with internet connectivity.
ESRI Basemap	Very detailed imagery at high resolution (0.3m) allows for detection of finer details in the landscape and distinguishing between shrub and herbaceous vegetation communities. Beneficial in differentiating between emergent vs terrestrial vegetation and aquatic- vs terrestrial-based fens.	Larger file size leads to considerable time spent loading imagery. Under snow in many areas.

Project Work Flow

YOSE was broken down into work units by CalWater subwatersheds (CalWater 1999). Technicians worked from north to south, one watershed at a time to manually digitize features, prior to ArcMap entry.

Two technicians worked systematically within separate Calwater subwatersheds to perform an exhaustive search for target wetland vegetation, where the following was done:

- Evaluated existing vegetation polygons (8000, 9000, 6500, 6100, and 3022 units) for inclusion based on: color signature, MMU size, herbaceous and woody vegetation density, width, and slope (Table 1)
- Copied and pasted polygons from the YOSE vegetation map which met these mapping criteria
- Merged adjacent polygons which met mapping criteria to create a single polygon
- Reshaped polygons to exclude areas not meeting mapping criteria, or to include areas that did not meet mapping criteria and were previously excluded
- Created new polygons in areas where previously mapped polygons would require significant alteration to meet mapping criteria
- Examined each polygon for potential fens, and indicated known or potential fens by creating point features in the FenPeat_pt feature class

- Attributed each polygon with: wetland type, peat percentage, comments, confidence rating, mapping source, polygon author, and date (see descriptions of each field in Data Documentation and Deliverables section below)
- Searched and evaluated NAIP imagery, focusing on NWI wetland polygons, for additional wet meadows and fens meeting mapping criteria; created new polygons and entered attributes when found.

Software: ESRI ArcGIS 10.1 with versioning

The NPS standard software for working with spatial data is ESRI ArcGIS. The versioned environment available in version 10.1 allowed the team of technicians to work on the same feature class concurrently (Figure 2). This allowed for each change made to the feature class to be reviewed by the project leaders, and reduced the amount of conflicts and errors in the versions prior to posting the data in the parks' spatial data warehouse. A detailed workflow for working in a Spatial Database Engine (SDE) environment was developed by SEKI Staff for use by this project.

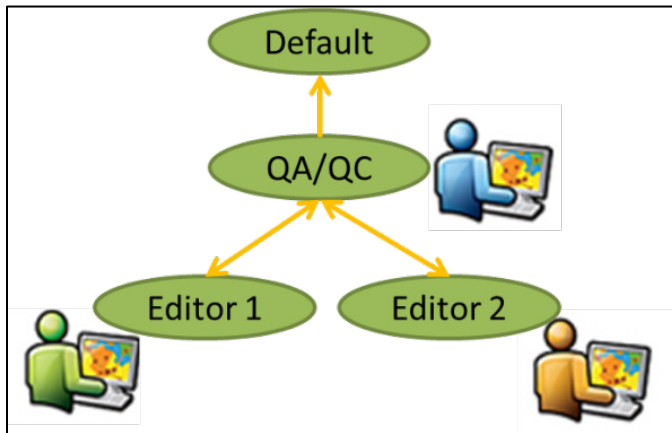


Figure 2. ESRI ArcGIS 10.1 with versioning allows multiple editors to concurrently edit a feature and merge these versions into a QA/QC version before being added to the official feature class and therefore reduced errors.

Quality Control Procedures

Upon completing the map of target wet meadow, fen-meadow, and fen locations and extents, technicians conducted a quality control review. They revisited each watershed, reviewed all polygons and attributes, and scanned watersheds for potential meadows and fens that had been overlooked in the mapping process. Technicians worked independently through the watersheds but consulted with one another on any questionable or marginal situations. Changes (aside from minimally altering line features) were recorded in a spreadsheet. The ArcMap intersect tool was used to check for duplicate polygons, and a final check of topology was completed for the master geodatabase.

Technicians worked together closely at the beginning of the project to establish consistency in their interpretations and mapping techniques. However, differences in technicians' mapping decisions may remain a potential source of error. To account for this, at the conclusion of the mapping and QC processes, technicians chose eight watersheds representing distinct areas of the park to re-map. Each

technician worked on two randomly chosen watersheds they had mapped themselves, and two that the other technician had mapped to assess omission, inclusion, and classification error rates.

Data Documentation and Deliverables

Wet Meadow and Fen Feature Dataset

The aim of this mapping project was to create a feature class that shows all wet meadows and fens greater than 0.5 ha within Yosemite National Park, and classifies them as wet meadow, fen-meadow complex, and fen. The two resulting feature classes are:

- A polygon feature class, *SEKIgis.DBO.YOSE_WetMeadowFen_py*, with boundaries of all wet meadows, fen-meadow complexes, and fens mapped based on their photo interpretation signature and with inferences from ancillary data.
- A point feature class, *SEKIgis.DBO.YOSE_FenPeat_pt*, with points that indicate locations of known or presumed peat accumulating areas in the park.

The feature class includes 1,463 wetland polygons over 0.5 ha area, and 557 peat points (Figure 3). An additional 142 polygons under 0.5 ha in size were directly copied from the 1997 vegetation map, bringing the total number of mapped wetlands to 1605 (Table 3). Seventeen wetland features were classified as fens, 297 were classified as fen-meadow complexes, and 1,291 were classified as wet meadows. Most of the 557 peat points occurred within the fen-meadow complexes, as only 17 of the wetland features were determined to be purely fen habitat. Of the 314 fen and fen-meadow complexes, 74 of them (24%) are estimated to be peat accumulating in at least 50% of their area. The total area of wet meadows, fen-meadow complexes, and fens mapped is 4,307 ha (10,643 acres), comprising 1.4% of the total acreage of the park. The average polygon size is 2.68 ha, and the largest meadow mapped was Tuolumne Meadows, at 135.4 ha. Wet meadows and fens were occasionally included with other types of vegetation alliances in the YOSE vegetation map, as was the case in the SEKI vegetation map (Pyrooz et al. 2015). The Sierra Lodgepole/Bog Blueberry Forest and Sierra Willow/Swamp Onion Seasonally Flooded Shrubland appeared to often include wet meadow vegetation. However, there was generally substantial agreement among the YWMP polygons and areas mapped as 8000 – Intermittently to Seasonally Flooded/Saturate Herbaceous or 9000 – Perennially Flooded Herbaceous alliances in the YOSE vegetation map.

Table 3. Summary of number of polygons, total meadow area, and average feature size of YWMP polygons in YOSE.

Measure	Fen	Fen-Meadow Complex	Wet Meadow	Total
Number of polygons	17	297	1291	1605
Cumulative Area (hectares)	12.3	1267.3	3027.6	4307.2
Mean Area (hectares)	0.72	4.27	2.35	2.68

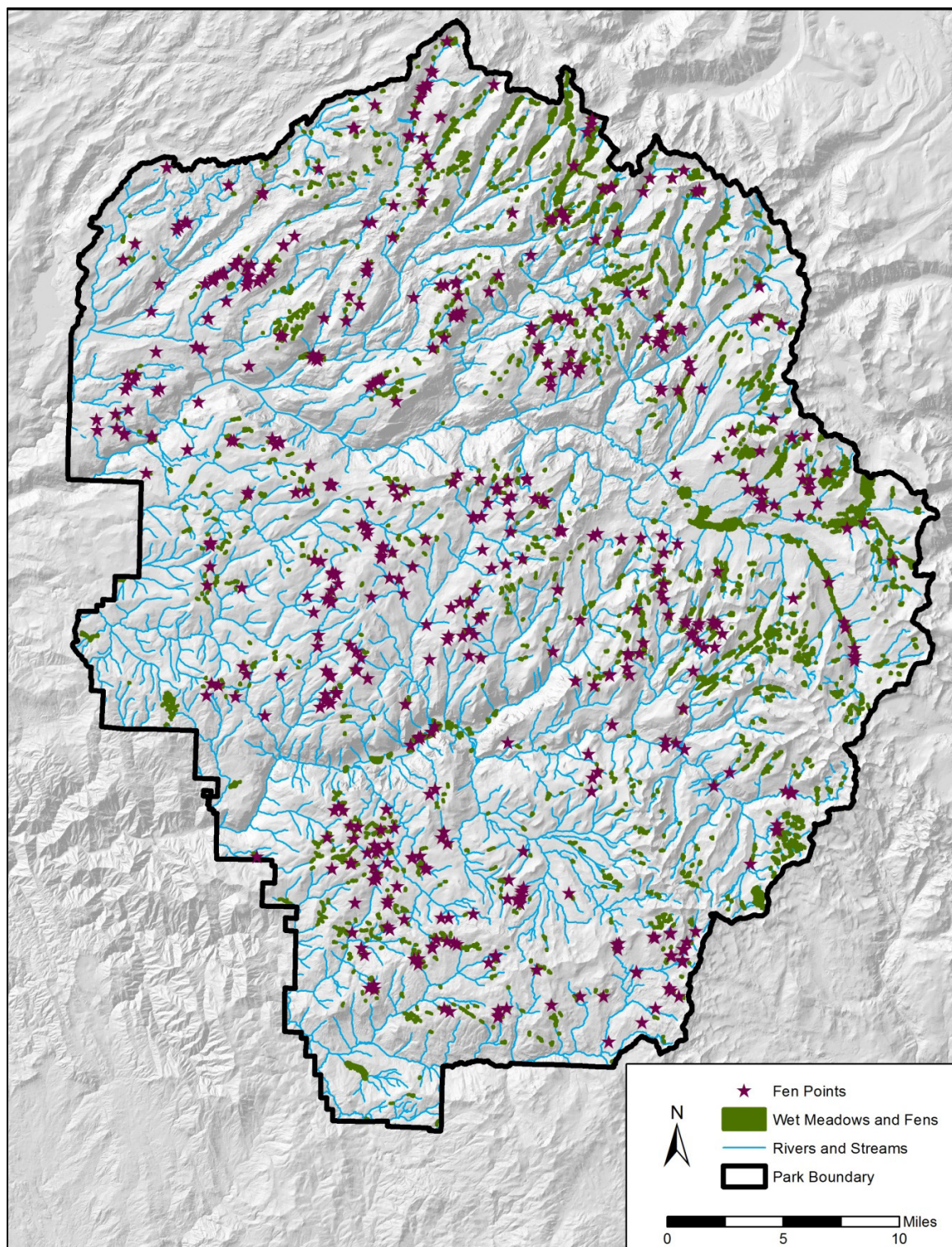


Figure 3. Overview map of locations of wet meadows, fens, and peat points in Yosemite National Park. A total of 1,605 areas were mapped as fen or wet meadow, as well as 557 distinct peat points (often, but not exclusively within mapped target wetland polygons).

Each polygon in WetMeadowsFens_py is attributed with the following attributes:

- *Wetland Type*: Wet meadow, Fen-Meadow Complex, or Fen
- *Peat Percentage*: Estimate of the percentage of the area of the polygon that is peat accumulating
- *Comments*: Any clarifications; i.e., if a considerable amount of woody vegetation is present, the comment field provides an estimate of percent cover; if it is thought a fen may be present but the technician was not confident enough to place a point, a comment was made; if a peat point is placed but the technician was uncertain, this is mentioned here.
- *Confidence Rating*: Indication of how confident the technician was in making the decision to map and attribute the polygon. Values are integers from 1–5, where 1 indicates up to 20% confident, 2 is 20–40% confident, 3 is 40–60% confident, 4 is 60–80% confident, and 5 is 80–100% confident. For the finished product, technicians took extra care to review all polygons attributed with a confidence level of 3 or less in an attempt to increase their confidence, and the majority of features have a 4 or 5.
- *Mapping Source*: Indicates primary imagery relied upon to define the wetland boundary
- *Polygon Author*: Initials of technician
- *Date*: When the polygon was created

The feature dataset is posted to IRMA as: YOSE_Wetlands_20170711.gdb, and metadata for the YWMP feature class are provided in Appendix 3.

Accuracy Assessment

An accuracy assessment estimates the extent and types of discrepancies between field observations and mapping classifications. Two types of accuracy assessment methods were used: an estimate of intra- and inter-technician variability, and a validation of the map classification accuracy based on field site visits.

Observer Variability

Technician variability was estimated by repeated mapping of selected watersheds. To assess the variability between technicians and within individuals, technicians completed a re-mapping of eight selected watersheds in YOSE. Watersheds were subjectively chosen to span alpine, subalpine, and montane vegetation zones. Each technician re-mapped two watersheds they had done themselves and two that were mapped by the other technician. In addition to wetland type, the total area mapped by wetland type within a watershed, as well as the average polygon size were compared.

Observer Variability Results

Within the eight selected watersheds, 160 wetland polygons were mapped in the original mapping effort and 179 were mapped during the QC process (Tables 4a and 4b). The second mapping occurred immediately following the completion of all of the sub-watersheds in YOSE. Therefore, the time between mapping events ranged from a few days to several weeks, depending on the selected sub-watershed. Wetlands were assigned to the same wetland type >80% of the time (Table 5). In general, map agreement was stronger in watersheds that were re-mapped by the same technician (93% agreement) compared to watersheds that were re-mapped by the alternate technician (74% agreement). There was >80% agreement in the total area mapped as each wetland type and the average size of the polygons, both within and between technicians (Table 5).

Table 4a. Summary of initial mapping (1st) and remapping (2nd) for the number of wet meadows (WM), fen-wet meadow complexes (F-WM), fens (F), total number of features, and total target wetland area in the four watersheds used to assess agreement *within* technicians. NP: Natalie Pyrooz, AD: Adam Dickenson.

Watersheds	WM		F-WM		F		Total features		Total area (ha)	
	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd
Middle Piute Creek (NP)	16	15	0	0	0	0	16	15	32.7	33.1
Upper Frog Creek (NP)	19	21	1	0	1	0	21	21	38.1	35.0
Tiltill Creek (AD)	6	7	1	0	0	0	7	7	51.7	48.7
Hutching Creek (AD)	15	20	2	2	0	0	17	22	37.3	49.9
Total	56	63	4	2	1	0	61	65	159.8	166.7

Table 4b. Summary of initial mapping (1st) and remapping (2nd) for the number of wet meadows (WM), fen-wet meadow complexes (F-WM), fens (F), total number of features, and total target wetland area in the four watersheds used to assess agreement *between* technicians (b). NP: Natalie Pyrooz, AD: Adam Dickenson.

Watersheds	WM		F-WM		F		Total features		Total area (ha)	
Between Technician	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd
Lukens Lake (AD, NP)	16	30	14	11	1	0	31	41	50.4	57.8
Kuna Creek (AD, NP)	24	30	0	0	0	0	24	30	54.2	71.1
Smedberg Lake (NP, AD)	14	9	3	1	0	0	17	10	37.3	45.7
Grant Creek (NP, AD)	17	27	8	4	2	2	27	33	43.9	50.3
Total	71	96	25	16	3	2	99	114	185.8	224.9

Table 5. Summary of percent agreement encountered between mapping technicians (repeating work done by the other technician) and by the same person over time (repeating previous work). “Features” indicates percent agreement for the number of wetlands mapped in each watershed. “Total Area” indicates percent agreement for the total area mapped in each watershed, and “Avg. Area” indicates the percent agreement for the average wetland feature size mapped in each watershed.

Re-mapping by:	Features	Total Area	Avg. Area
Original technician	93%	90%	94%
Alternate technician	74%	83%	81%
Overall agreement	83%	86%	87%

Field Accuracy Assessment of the YWMP

The field-based accuracy assessment for the YWMP was conducted from 2015 to 2017. The accuracy assessment provides a quantitative assessment of what types of classification errors were most common during mapping and their potential causes. The design and methods employed for the accuracy assessment draw heavily on recommendations from the NPS Vegetation Inventory Thematic Accuracy Assessment Procedures Report (Lea and Curtis 2010).

Sampling Design

Field crews were assigned a sample of wetland features to visit in order to verify the location, extent, and classification assigned to them during the photointerpretation component of the project. Target meadows are those wetlands that were included in the YWMP feature class and include all wetlands that met the definitions for wet meadow, fen-meadow complex, or fen. To evaluate the possibility that features were excluded from the YWMP that should have been included, polygon features from the YOSE vegetation map that were classified as 8000 (Intermittently to Seasonally Flooded Meadow Unit) and 9000 (Semi-Permanently to Permanently Flooded Meadow Unit) that were not included in the YWMP polygon layer were used as “non-target” features to evaluate type 2 error rate (i.e., rejecting a vegetation polygon that did meet the definition of a target wetland). Also targeted in the accuracy assessment were sites selected as part of the WEI long-term monitoring project. The

field crews were provided with the location and boundaries of the features to be assessed, but not the wetland type they had been assigned during the mapping process.

Site Selection Criteria

Sample Size. The goal for sample sizes for each map class was 30 individual observations following NPS accuracy assessment procedures (Lea and Curtis 2010). This standard has been used by NPS Vegetation Inventory projects for map classes that occupy greater than 50 ha of total area as it provides a balance between precision and cost.

Spatial Criteria. The minimum mapping unit for accuracy assessment polygons was 0.5 ha, and 15 meters wide, to align with the spatial criteria used in photointerpretation. A random subsample of sites was selected from the 1605 mapped polygons. The crew then sampled sites within subwatersheds with existing sampling and monitoring obligations of the SIEN WEI Monitoring crew. Although randomly selected sites within the park were not evenly distributed spatially, meadows and fen-meadow complexes from each of the montane, subalpine, and alpine zones were represented (Figure 4).

Aggregation of Fen and Fen-Meadow Complex Classes. Out of 1,605 mapped polygon features, only 17 were mapped as fen. Because these 17 sites were scattered across the park, it was not feasible to obtain the recommended sample size of five features (Lea and Curtis 2010) with the available resources. Therefore, we did not conduct an accuracy assessment and are unable to describe the accuracy of that class on its own. The fen class was combined with the fen-meadow complex class for the purpose of the accuracy assessment. Field technicians could, however, classify a polygon as fen if it fit the criteria instead of a fen-meadow complex.

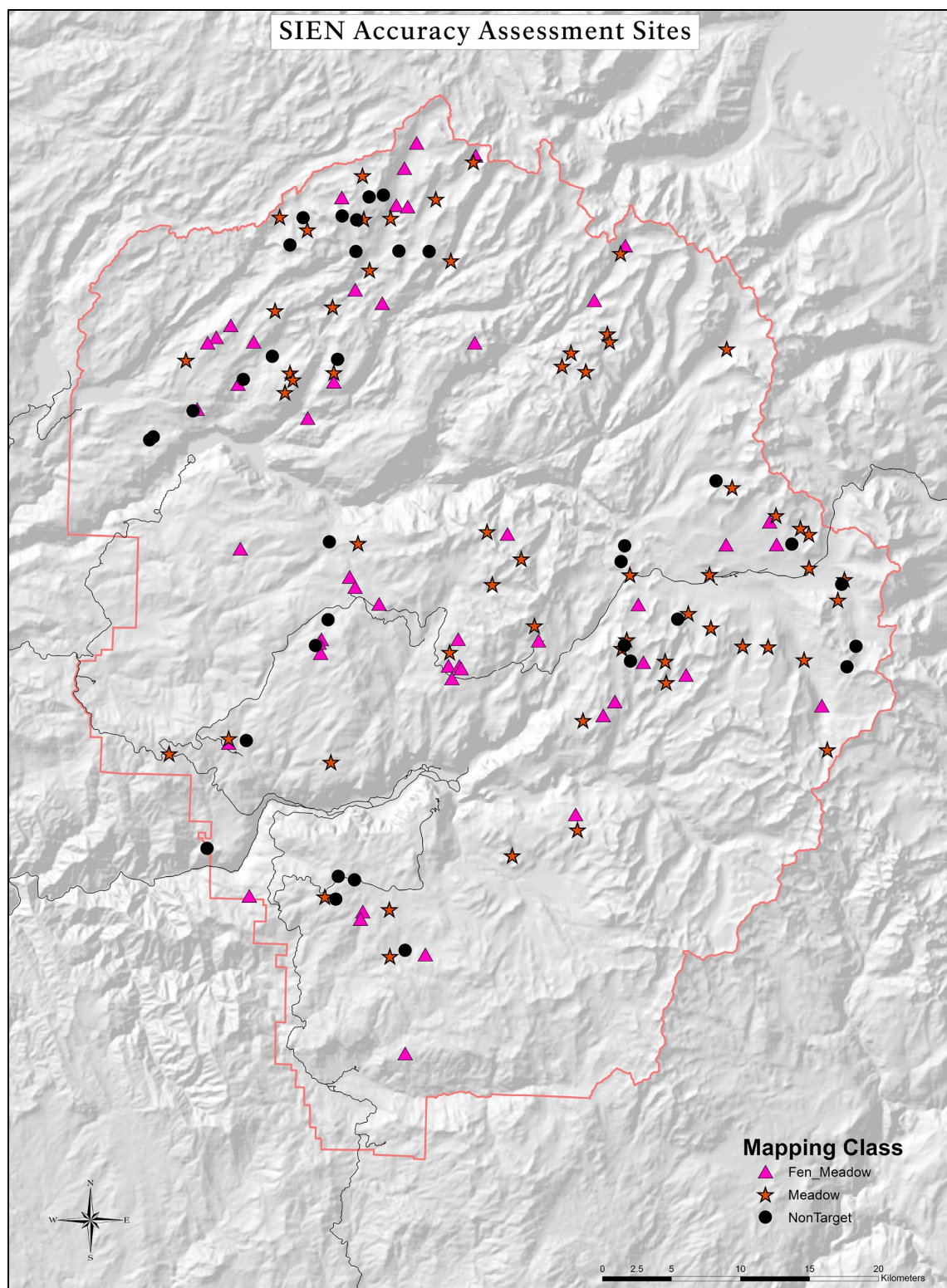


Figure 4. Locations of sites visited and surveyed as a part of the accuracy assessment component of the Yosemite wetland mapping project. Symbols and colors indicate the field classification of each site.

Field Methodology

A detailed description of the methods used by the field crews to assess the accuracy of the meadow classification is provided in Pyrooz et al. (2015). The field assessment methods are adapted from Method 3 of the NPS thematic accuracy assessment procedures (Lea and Curtis 2010). This methodology uses qualified and trained, but non-expert, technicians as field observers, who also collect supplemental data to support the map class assignment they choose. Field observers were proficient in identifying the plant species that characterize montane, subalpine, and alpine wet meadows and fens of the Sierra Nevada. When unable to make a confident identification, they collected vouchers of unknown dominant species. They were trained in estimating distance and area in the field to assess whether wetland boundaries met the established spatial criteria. They calibrated herbaceous cover estimates and trained in the use of a soil probe to conduct peat detection at the beginning of the field season. For safety purposes technicians usually worked in teams of two or three, but occasionally worked alone. A few sites that were hazardous to access were not sampled. Observers navigated to sites using topographic maps and Garmin Global Positioning System (GPS) units. Technicians were also equipped with maps that included aerial imagery and polygon boundaries to help them determine site boundaries using their surroundings.

Determination of Mapping Classification in the Field

Upon reaching a selected site, observers surveyed the entirety of the site, paying close attention to hydrological influences, dominant plant species, and potential peat-accumulating areas. The presence or absence of peat soils was assessed using a soil probe, which indicated likelihood of peat when it could be inserted smoothly, often in a wet area. The presence of sand, gravel, or larger rocks in the soil creates a gritty sound or prevents the soil probe from penetrating deep into the earth.

If peat was present and appeared to meet the minimum conditions to be considered a fen (at least 20 cm of organic soil in the top 40 cm), observers collected a point location or created a polygon if peat extent was $>25 \text{ m}^2$. Additional information that was collected included hydrological indicators (i.e. soil moisture, presence/absence of groundwater features, streams, and pools), estimated percent cover of hydrogeomorphic types (Weixelman et al. 2011), herbaceous canopy cover, soil indicators (presence/absence and extent of peat accumulation, and/or fine-textured organic soils), and dominant plant species. After collecting these data, observers would make a determination as to whether the polygon should be classified as a fen, wet meadow, fen-meadow complex, or non-target feature.

Field Accuracy Assessment Results

Data were collected for 139 accuracy assessment sites and included geospatial references, wetland type, as well as supplemental information and photographs for each location (Table 6). The sample contingency table (Table 7) is a summary of the data, which compares the classification of sampled polygons during the mapping process with their classification based on field observations. The rows represent the sample data (Map Classes) and the row total is the number of accuracy assessment observations for that class. The columns represent the reference data, or observed classifications recorded in the field. The values in the shaded diagonal cells indicate the number of occurrences when field and mapping classifications agree.

Table 6. Distribution of accuracy assessment sites per wetland mapping class.

Mapped wetland class	Total observations
Wet meadow	57
Fen or Fen- meadow complex	48
Non-target	34
Totals	139

Table 7. Sample contingency tables comparing mapped and observed wetland type classifications from the 139 random accuracy assessment sites. Shaded cells, also marked with an asterisk, indicate the number of polygons where the field classification matched the initial assigned mapping class. Rows indicate wetland classes there were mapped and columns indicate field classification.

Sample Data (Map Classes)	Fen-Meadow	Meadow	Non-Target	Total	User's Accuracy
Fen-Meadow or Fen	24*	24	0	49	50.0%
Meadow	6	35*	16	57	61.4%
Nontarget	0	7	27*	34	79.4%
Column Total	30	66	43	139	–
Producer's Accuracy	80.0%	53.0%	62.8%	–	Overall Accuracy: 61.9%

Two types of accuracy were calculated: user's and producer's accuracy. User's accuracy determines the percentage of correct predictions based on the map; for example, if a wet meadow is selected by looking at the map, this is the likelihood that when one arrives at that site it is indeed a wet meadow. Producer's accuracy is the calculated number of correct predictions based on references; for example, if an area is known to be a wet meadow, this is the probability that it has been classified and mapped correctly. Overall accuracy, in contrast, is calculated as percentage of polygons where the field classification matched the initial assigned mapping class.

The population contingency table calculates accuracy using values that are the proportion of the target area, rather than a raw count (Table 8). It includes an estimate of the true area for each map class, as well as overall accuracy. Overall accuracy is the proportion of the total area that is correctly mapped. In any test of this nature there may be agreement between sample and reference data due only to chance. The calculation of the Kappa statistic accounts for this. A Kappa statistic of one occurs when there is perfect agreement, and a Kappa of zero is when the results are the same as if it were left to chance.

Table 8. Population contingency table. Observation values indicate the proportion of the total target area assigned to each map class. Estimated True Area is the estimated total area of each map class after accounting for the probability that it was mapped correctly. Producer's and Overall Accuracy are point estimates of class accuracy. Shaded cells, also marked with an asterisk, indicate the proportion of area where the field classification matched the initial assigned mapping class.

Sample Data (Observations Selected within Map Class)	Fen- Meadow	Meadow	Non- Target	Row Total	Map Class Area (ha)	User's Accuracy with 90% Confidence Interval
Fen-Meadow or Fen	0.1138*	0.1138	0.0000	0.2277	1279.7	50.0% (37.1%–62.9%)
Meadow	0.0568	0.3312*	0.1514	0.5394	3031.9	61.4% (49.9%–72.9%)
Non-Target	0.0000	0.0480	0.1850*	0.2329	1309.3	79.4% (66.5%–92.3%)
Column Total	0.1729	0.4907	0.3364	1.000	5620.9	Overall Accuracy (with 90% Confidence Interval): 63.0% (56.1%–69.9%) Point Estimate, Overall Accuracy: Kappa Statistic (with 90% Confidence Interval): 41.8% (31.1%–52.5%)
Estimated True Area (ha)	959.0	2771.1	1890.8	–	–	Overall Accuracy (with 90% Confidence Interval): 63.0% (56.1%–69.9%) Point Estimate, Overall Accuracy: Kappa Statistic (with 90% Confidence Interval): 41.8% (31.1%–52.5%)
Producer's Accuracy with 90% Confidence Interval	66.7% (63.2%– 70.2%)	67.2% (62.0%– 72.3%)	55.0% (50.4%– 59.5%)	–	–	Overall Accuracy (with 90% Confidence Interval): 63.0% (56.1%–69.9%) Point Estimate, Overall Accuracy: Kappa Statistic (with 90% Confidence Interval): 41.8% (31.1%–52.5%)

Overall Accuracy. Overall accuracy was estimated at 63.0% (90% CI = 56.1–69.9%). This is below the minimum mapping standard of 80% accuracy (AIS 2007). However, when the data are simplified to only target vs. non-target classes, overall accuracy increases to 83.5% (90% CI = 78.4–88.7%). The largest source of classification error was from difficulty in accurately distinguishing wet meadows from fen-meadows. Interestingly, fen-meadows were rarely mis-mapped as wet meadows, indicating the greater variation in wet meadow visual signature compared to areas with fens.

Estimated Acreages. The mapped area of fen-meadow complex (including fen), meadow, and non-target polygons was 1,280 ha, 3,032 ha, and 1,309 ha, respectively. When adjusted based upon the proportion of correctly mapped areas, it is estimated that there are 959 ha of fen-meadow complex and fen and 2,771 ha of wet meadow in YOSE. This represents roughly 1.2% of the park's total area. There are an estimated additional 1,891 ha of wetlands mapped as 8000 – Intermittently to

Seasonally Flooded Meadow Unit or 9000 – Semi-Permanently to Permanently Flooded Meadow Unit that would not meet the definition of a target wetland for this project.

The results of the accuracy assessment indicate that wet meadow and fen vegetation can be accurately (>80%) distinguished from other vegetation types in YOSE and that these vegetation types do not align perfectly with the 8000 – Intermittently to Seasonally Flooded Meadow Unit or 9000 – Semi-Permanently to Permanently Flooded Meadow Unit vegetation classes in the YOSE vegetation map. These features are also relatively rare in the park, accounting for <2% of the landscape; they are widely distributed, but tend to be more concentrated in the higher elevation eastern half of the park.

Comparison to YOSE Vegetation Map Meadow Classes (8000 & 9000 map units)

There was substantial agreement among the area mapped as target wetland by the YWMP and the Intermittently to Seasonally Flooded Meadow Unit (8000) and Semi-Permanently to Permanently Flooded Meadow Unit (9000) from the YOSE vegetation map (Table 9). Overall, 81% of the area mapped as target vegetation in the YWMP was contained in either the 8000 or 9000 map units in the YOSE vegetation map. The remainder occurred within other mapping classes. This percentage was even higher for fen and fen-meadow complex map classes, as 86% of these wetland types occurred within the 8000 and 9000 map units. A majority (69%) of area mapped as 8000 or 9000 in the YOSE vegetation map were not considered target vegetation by the YWMP. Some of the main reasons for this were polygon size not meeting the MMU of ≥ 0.5 ha, occurring on steep slopes that were unlikely to have well developed soils, and the exclusion of narrow (<15 m wide) polygons from the YWMP map units. Based on the accuracy assessment results, most of the 8000 and 9000 map unit area not mapped as target wetlands by the YWMP would not meet the definition of a target wetland used in this report.

Table 9. Area (ha) of overlap among the YOSE YWMP mapping classes and YOSE meadow vegetation map classes – Intermittently to Seasonally Flooded Meadow Unit (8000) and Semi-Permanently to Permanently Flooded Meadow Unit (9000).

YWMP Map Class	YOSE Vegetation Map Class		
	8000	9000	Other
Wet meadow	2,148 (71%)	252 (8%)	632 (21%)
Fen-Meadow Complex	921 (73%)	163 (13%)	183 (14%)
Fen	9.1 (74%)	1.9 (16%)	1.2 (10%)
Non-Target	6,915 (69%)	700 (63%)	NA

Comparison to SEKI Accuracy Assessment

The classification accuracy of the YWMP was lower than for the map created for SEKI (Pyrooz et al. 2015). In SEKI, overall map accuracy was estimated to be 83% compared to only 63% for YOSE. The main source of error in YOSE was the difficulty in distinguishing between wet meadows and fen-meadow complexes (user's accuracy of 51% vs. 69% for YOSE and SEKI, respectively). The accuracy of distinguishing between wet meadows and non-target habitat was also lower in YOSE

(79%) compared to SEKI (92%), though these errors were less common than classification errors among target wetland types.

Possible causes of these classification errors include different mapping technicians for the two projects having different levels of familiarity with the wetlands that they were mapping. We tried to partially account for this by having one technician work on both projects alongside a technician with field experience in each park. Additionally, there is a longer history of meadow monitoring, assessment of grazing impacts, and wetland surveys in SEKI (Hopkinson et al. 2013) compared to YOSE. Therefore, the baseline understanding of where these systems occur on the landscape has received more evaluation and verification over the years at SEKI compared to YOSE.

Summary

The main goal of the YWMP was to identify and map all fens and wet meadows ≥ 0.5 ha in size within YOSE. Multiple years of aerial imagery were used to map and classify target wetlands based on color signature, texture, vegetation density, slope, and expert knowledge of park wetlands. In YOSE, a total of 1,605 wetland polygons and 557 peat points were created. These data provide a detailed spatially explicit representation of important wetland habitat throughout YOSE that was unknown prior to this project. Based on these results, approximately 22% of the mapped wet meadows and fens ≥ 0.5 ha in size in YOSE are thought to be peat accumulating. The total estimated area of mapped wet meadows, fen-meadow complexes, and fens within the park is 3,644 ha (1.2% of the total acreage of YOSE). Overall classification accuracy was estimated to be 63%, though when only the distinction between target and non-target vegetation was considered the accuracy rate increased to 84%. The most common error in the map was misclassification of wet meadow as fen-meadow. Non-target habitat was rarely miss-classified as a target wetland type. It will be up to the individual user of this product to determine if this level of accuracy meets their needs.

Informed management of meadows requires an understanding of where they occur, their current condition, and key drivers of past and future ecosystem change. The products from the YWMP allow managers to better understand the distribution and current status of fens and wet meadows within YOSE. These products can be used by multiple user groups including researchers, resource managers, and the public to address multiple goals including investigating questions related to resource stewardship and restoration, long-term planning and management, research related to wet meadow and fen condition, distribution, and function.

A secondary goal of this report was to thoroughly document the procedures and decision criteria used to generate the wetland polygon and peat point feature classes so that the methods would be repeatable. Repeated mapping has been a widely used approach to evaluate change in wetland extent and condition over the landscape (Miller and Rogan 2007, Dahl 2011). While this map represents a snapshot in time of the current spatial extent of wet meadows and fens in YOSE, the mapping process could be repeated in the future to evaluate changes in wetland extent and classification.

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Appendix I: Descriptions and Examples of Wetland Types

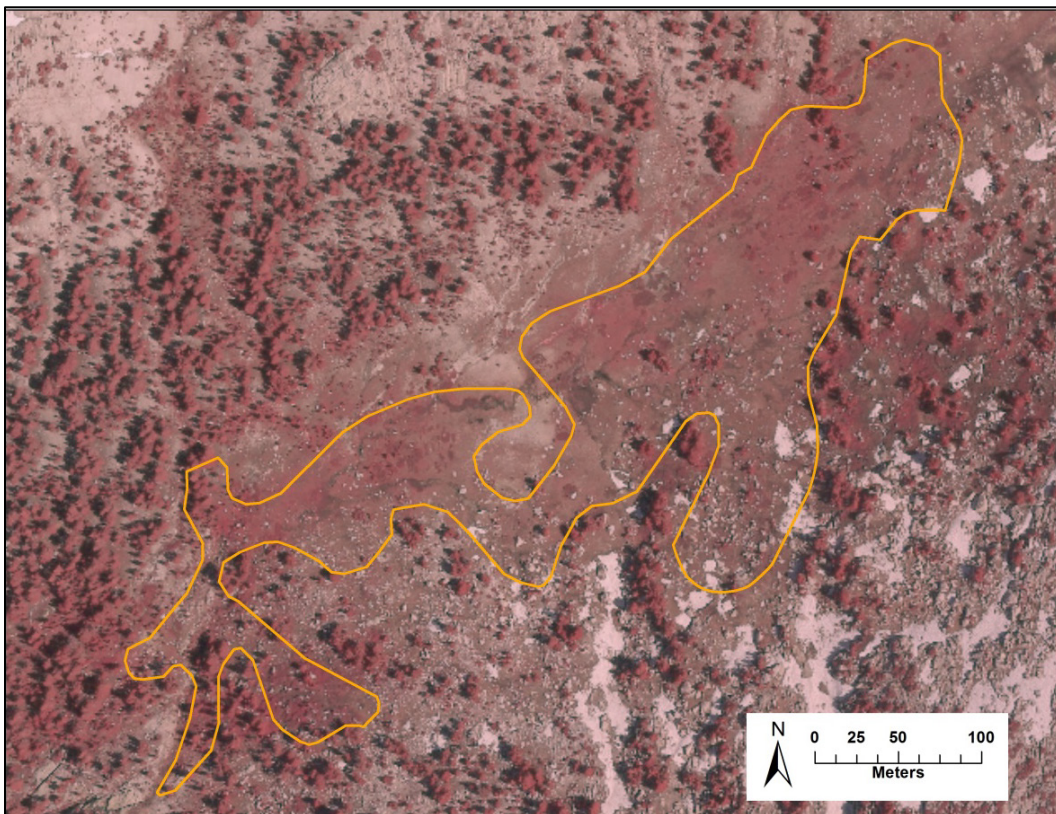
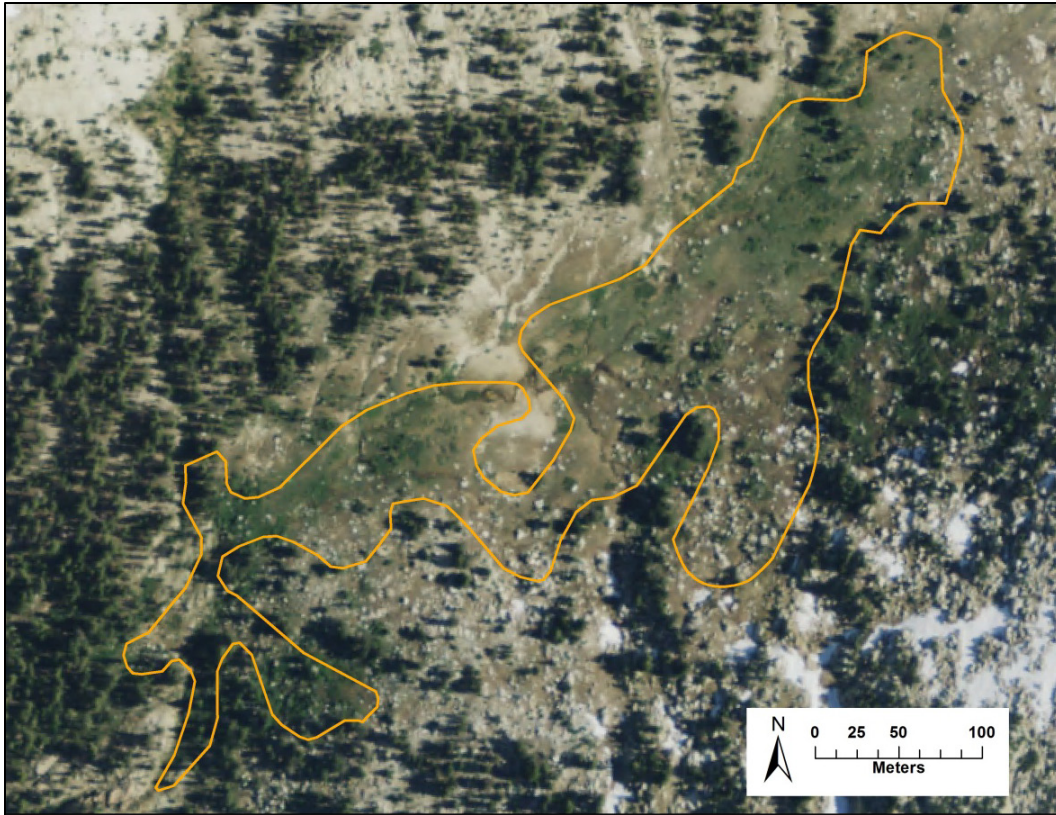
This appendix supplements the Wet Meadow and Fen Mapping of Yosemite National Park report by providing descriptions of each of the wetland types (wet meadow, fen-meadow complex, fen) and their photo interpretation signatures. Examples of each type are shown in natural color and color infrared NAIP imagery.

Wet meadow

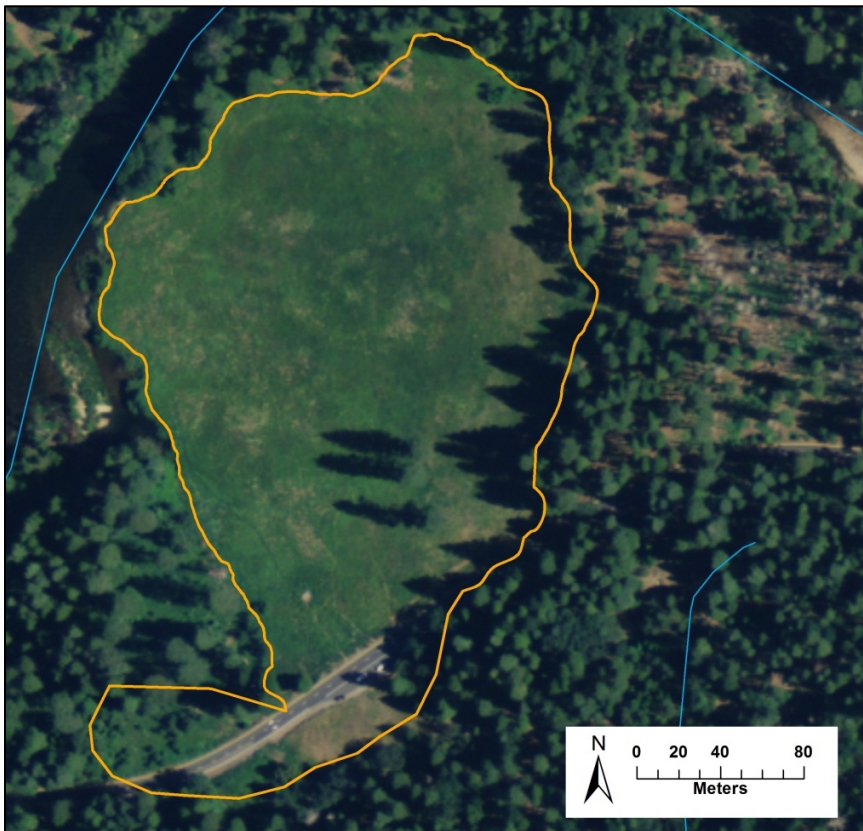
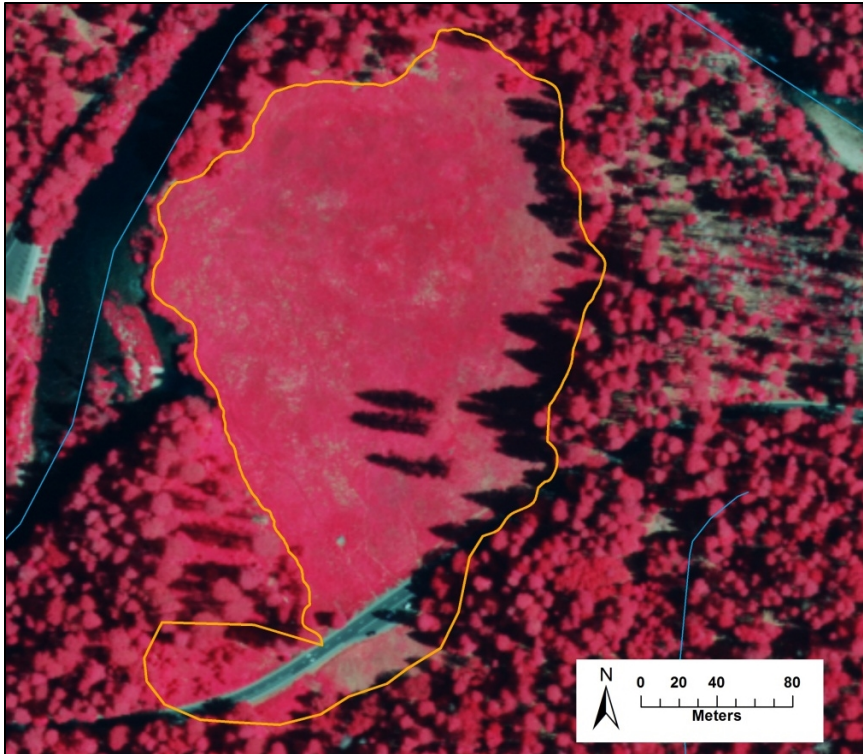
Wet meadows typically occur on small to moderate slopes and landscape concavities of varying aspect at montane, sub-alpine, and alpine elevations. Vegetation is a dense herbaceous composition of graminoids and forb species, although a sparse shrub or tree layer may be present. Hydrology is palustrine, riverine, or lacustrine. Wet meadows frequently have standing water present at the early part of the growing season which may or may not persist through the end of the growing season. Unlike fens, wet meadows lack perennially high water tables, which may drop to a meter or more below the soil surface in July and August.

PHOTO INTERPRETATION SIGNATURE:

Wet meadows display a photo signature that varies depending on wetness, species composition, and elevation. Color infrared reflectance is high and yields bright orange to red signatures. Higher elevation (alpine and subalpine) wet meadows can tend towards a pinkish hue in drier or shallower soils. The texture is always smooth but may be a bit coarser with presence of scattered shrubs (i.e. *Salix*) or larger forbs such as *Veratrum californicum*.



Wet Meadow, Sub-Alpine.



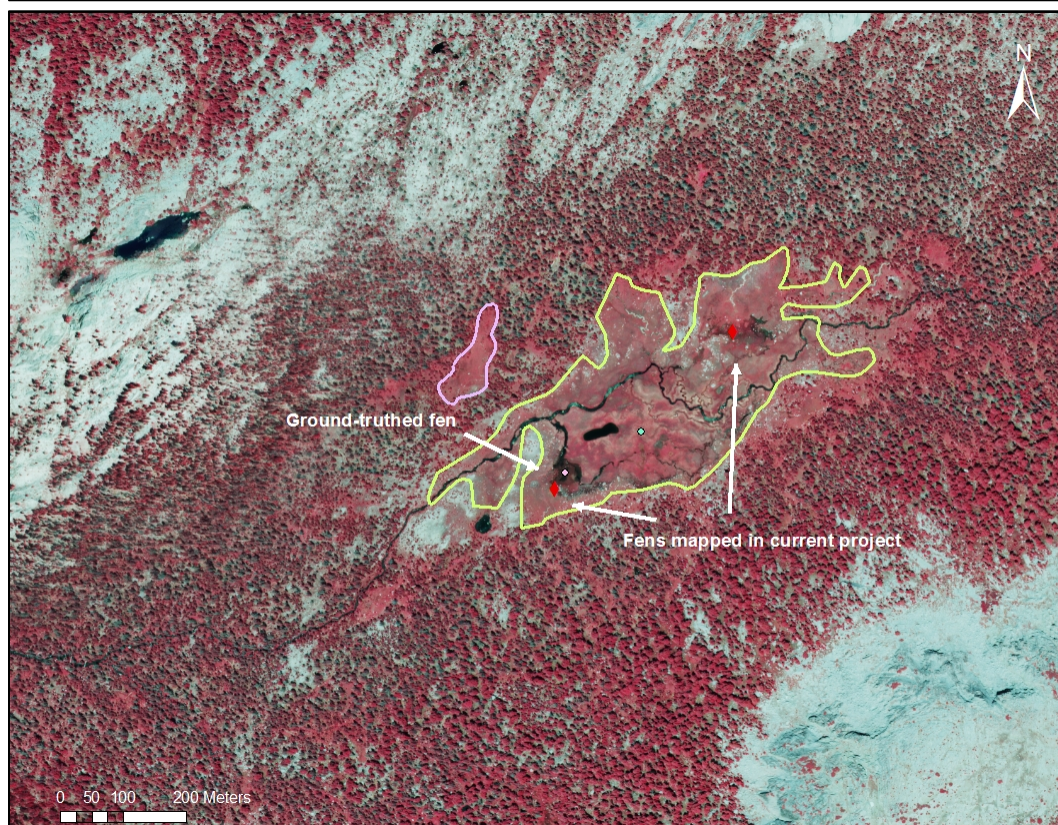
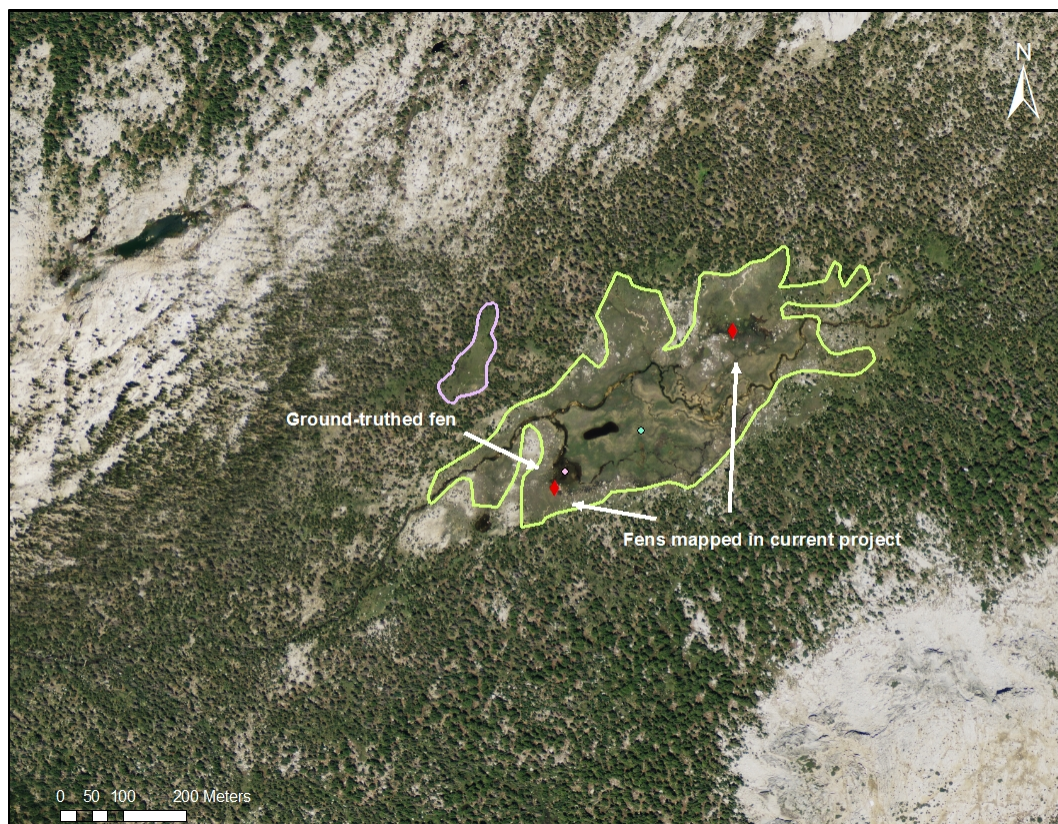
Wet Meadow, Montane.

Fen-Meadow Complex

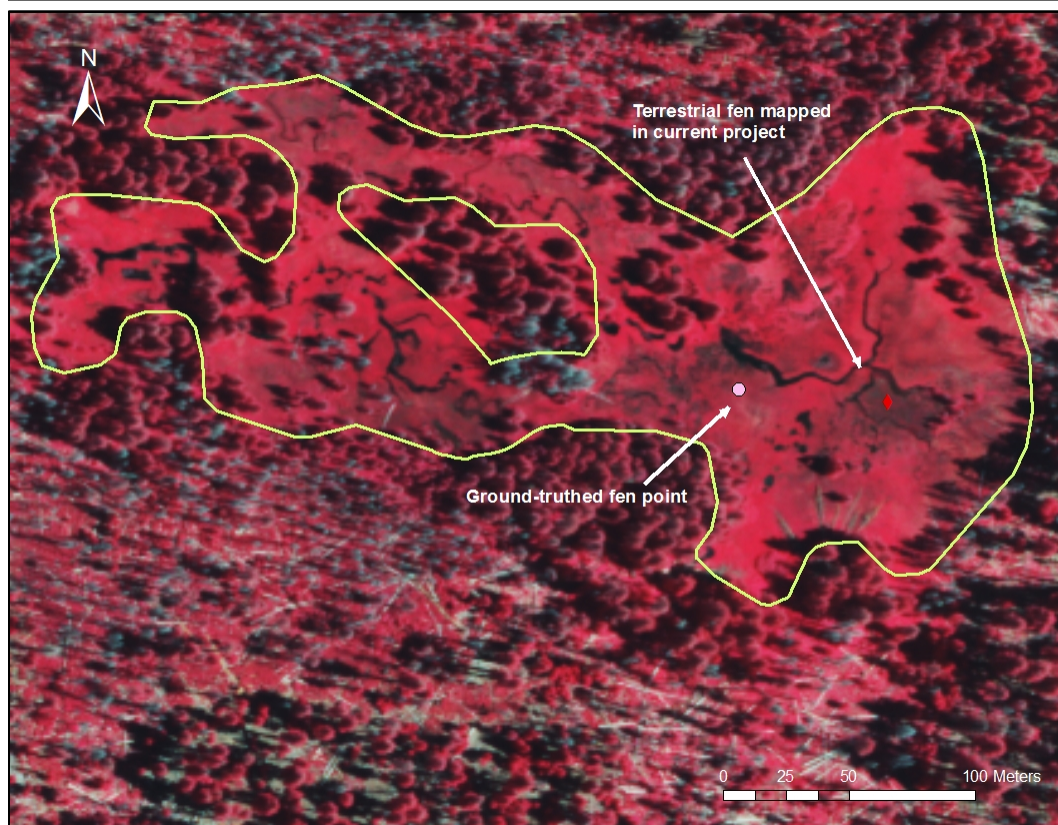
Fen-meadow complexes typically occur on small to moderate slopes and landscape concavities of varying aspect at montane and sub-alpine elevations. Vegetation is typically a dense herbaceous composition of graminoids and forb species, although a sparse shrub or tree layer may be present. Meadow hydrology is palustrine, riverine, or lacustrine. Groundwater systems are necessary to create slope or mound fens, while basin fens are dependent on lacustrine systems or seasonally to perennially flooded depressions. Fen-meadow complexes often have standing water that persists through the end of the growing season in at least parts of the complex.

PHOTO INTERPRETATION SIGNATURE:

Fen-meadow complexes display a photo signature that varies depending on fen type (slope discharge, mound, or basin), wetness, species composition, and elevation. These signatures often appear the most varied and complex. The presence of standing water, a darker red signature, intermixed with a bright red meadow signature in color infrared imagery indicates this type of wetland. Water signature may affect the brightness of the actual vegetation's reflectance. Areas of the meadow containing fen are typically a maroon color in the color infrared, and oftentimes blotchy or mottled, indicating an increase in the amount of standing water present. Stands of *Eleocharis* stand out as darker than surrounding vegetation in true-color imagery, and monocultures of *Carex utriculata* or *C. vesicaria* in depressional fens often are evident and show up as a darker depressional with water at surface level. Presence of *Sphagnum* often shows up as lighter markings in wet areas, while other mosses such as *Drepanocladus* may create darker signatures.



Fen-Meadow Complex, Sub-Alpine.



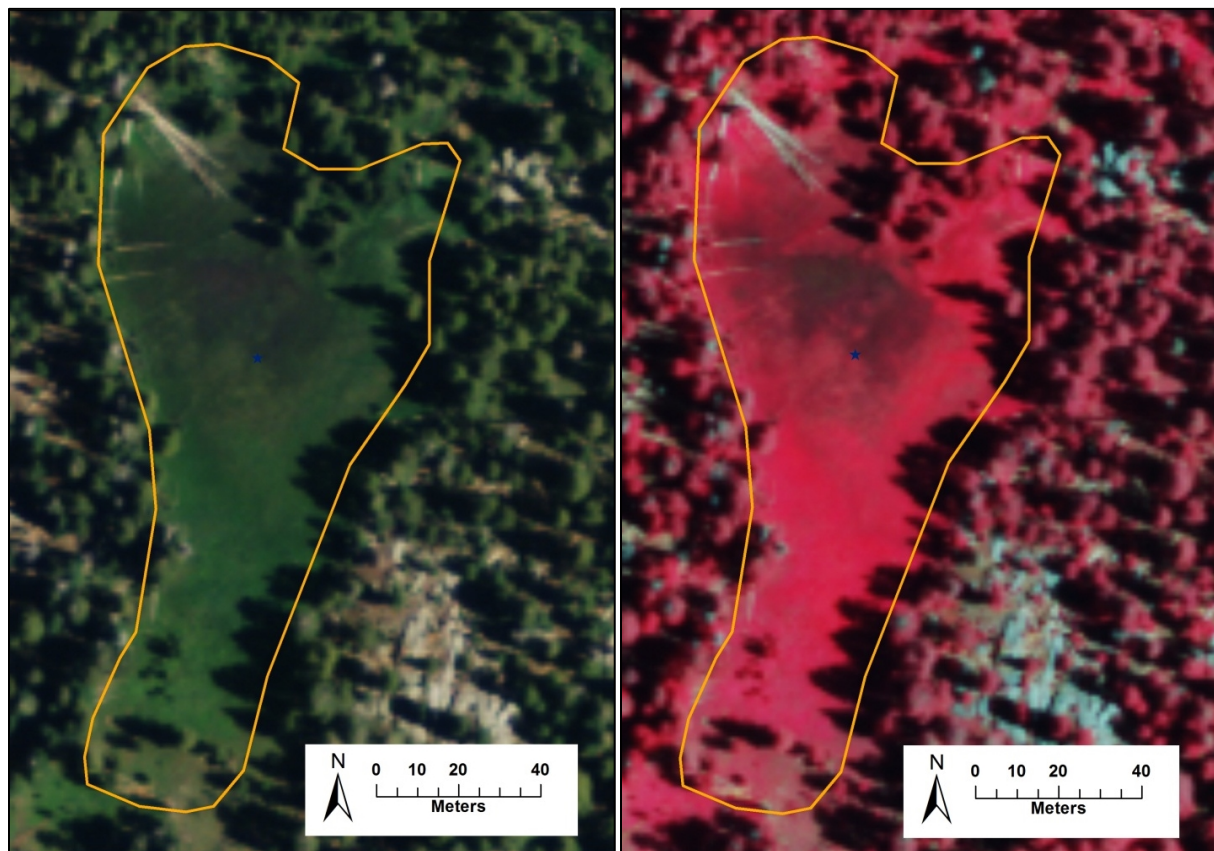
Fen-Meadow Complex, Montane.

Fen

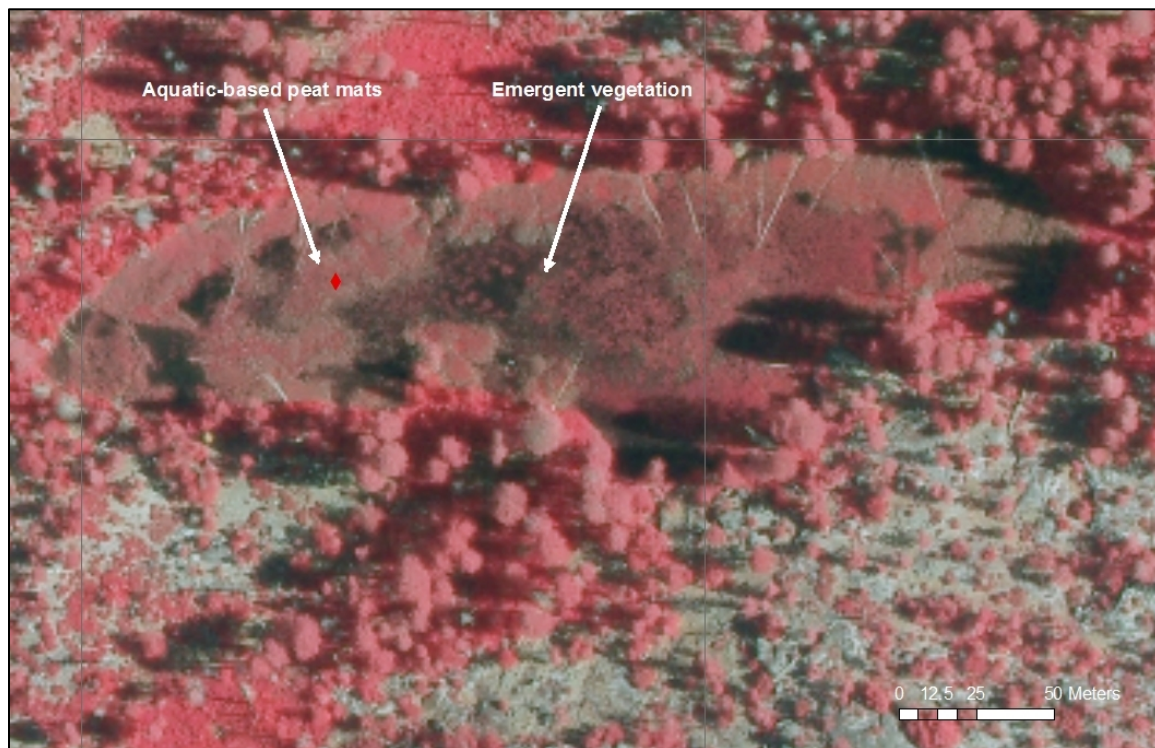
Fens typically occur on gentle slopes and landscape concavities of varying aspects at montane and sub-alpine elevations. Vegetation is typically a dense herbaceous composition of graminoids and forb species. In a few cases, trees and shrubs occur in fens. Hydrology is typically palustrine or lacustrine. Slope and mound fens are dependent on the presence of springs, while basin fens typically occur in association with lacustrine systems or seasonally to perennially flooded depressions. Fens often have standing water that persists through the end of the growing season. The water table typically remains within ~20–40 cm of the soil surface.

PHOTO INTERPRETATION SIGNATURE:

The photo signature that fens display varies depending on fen type (slope discharge, mound, or basin), wetness, species composition, and elevation. The presence of standing water creates a bright or dark red signature in color infrared imagery. Water signature may affect the brightness of the actual vegetation's reflectance. Texture of a fen is always smooth, and oftentimes blotchy or mottled. Stands of *Eleocharis* stand out as darker than surrounding vegetation in true-color imagery, and monocultures of *Carex utriculata* or *C. vesicaria* in depressional fens often are evident by showing up as a darker depressional with water at surface level. The presence of *Sphagnum* often shows up as lighter markings in evidently wet areas, while other mosses such as *Drepanocladus* may create darker signatures.



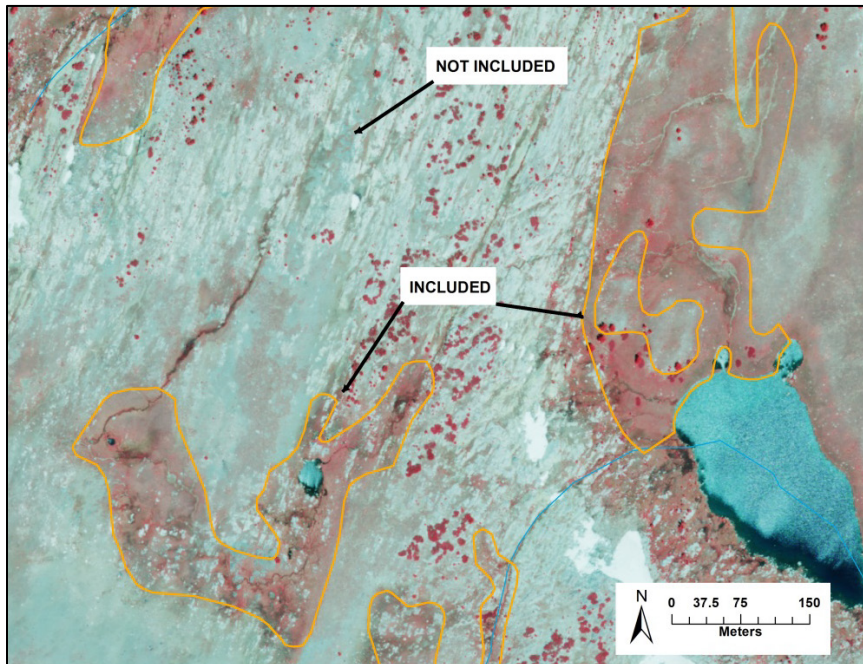
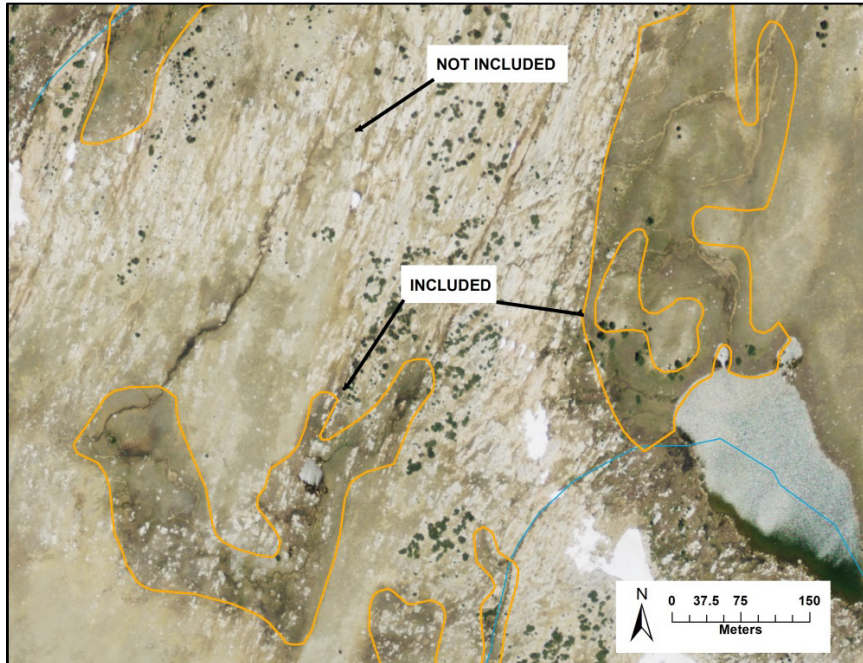
Fen, Snow Creek: Non-fen portion of wetland is smaller than 25m x 25m.



Fen: Floating peat mats, not associated with meadow.

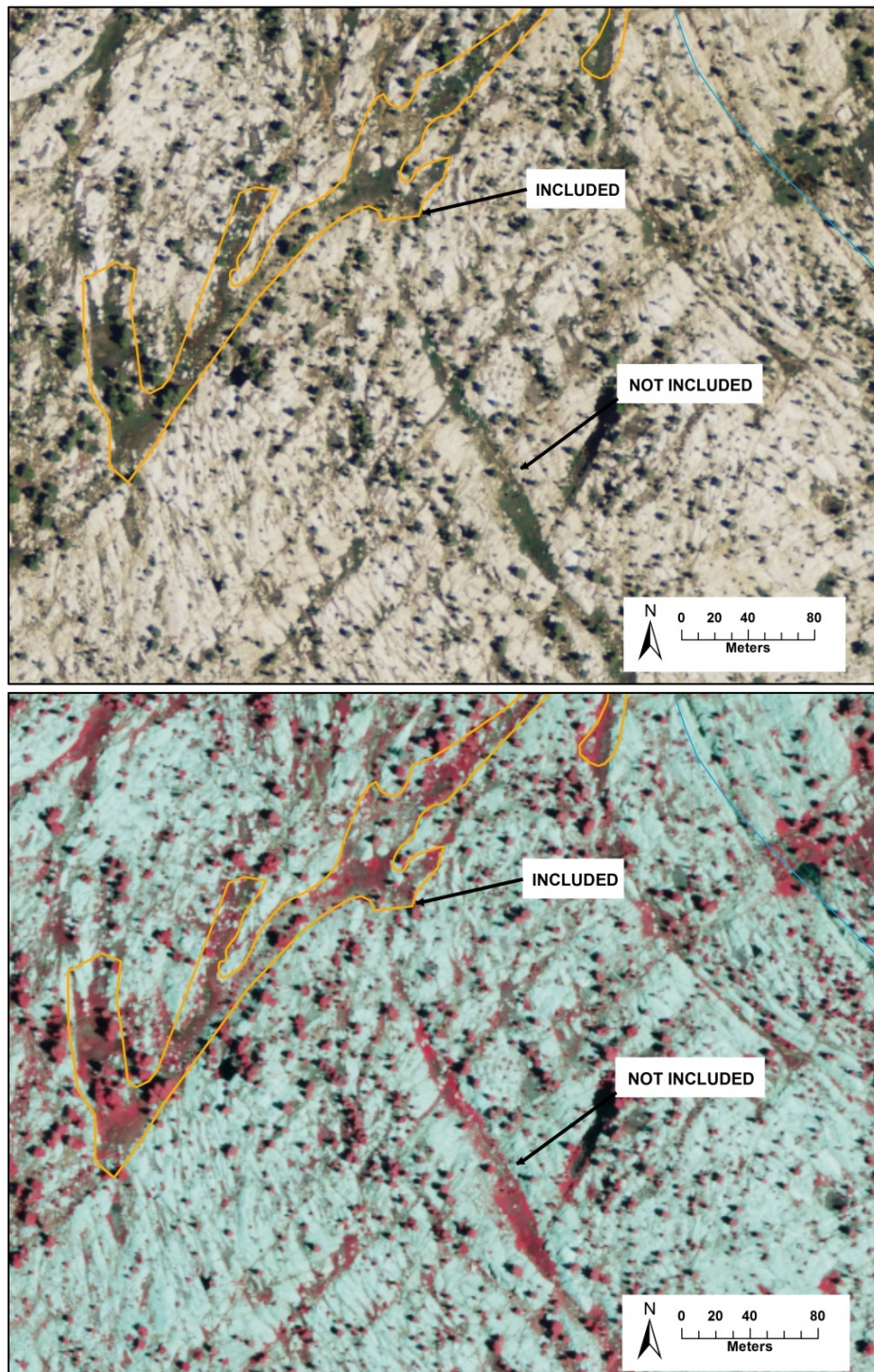
Appendix II: Examples of Mapping Criteria

Methods: Alpine – snowmelt driven vegetation



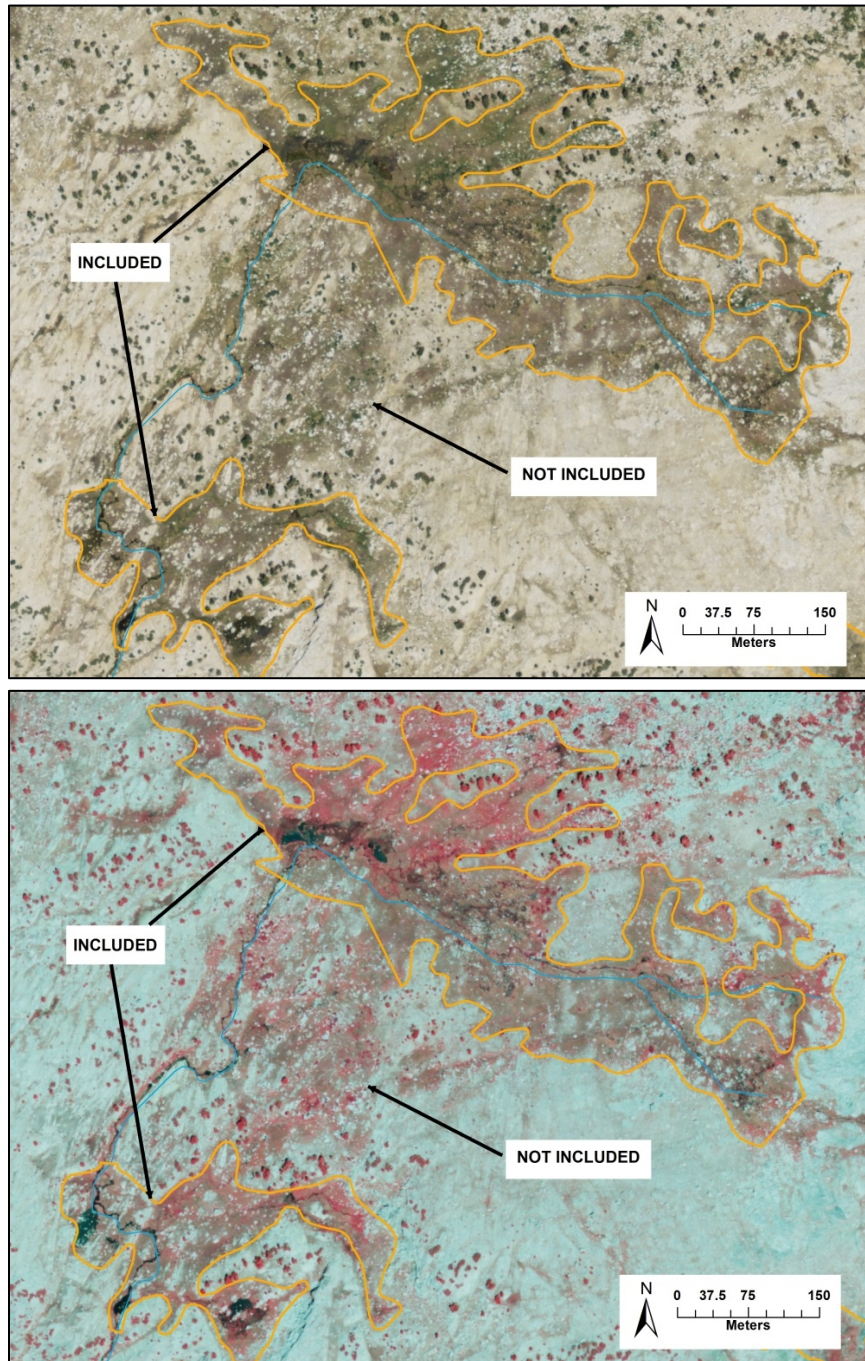
Snowmelt driven vegetation on the left is close to the target signature but lacks significant soil development to classify as wet meadow. The included area on the left meets vegetation density, wetness, and minimum size standards. (*poly # 8415*).

Methods: Alpine/Subalpine – 15-meter rule



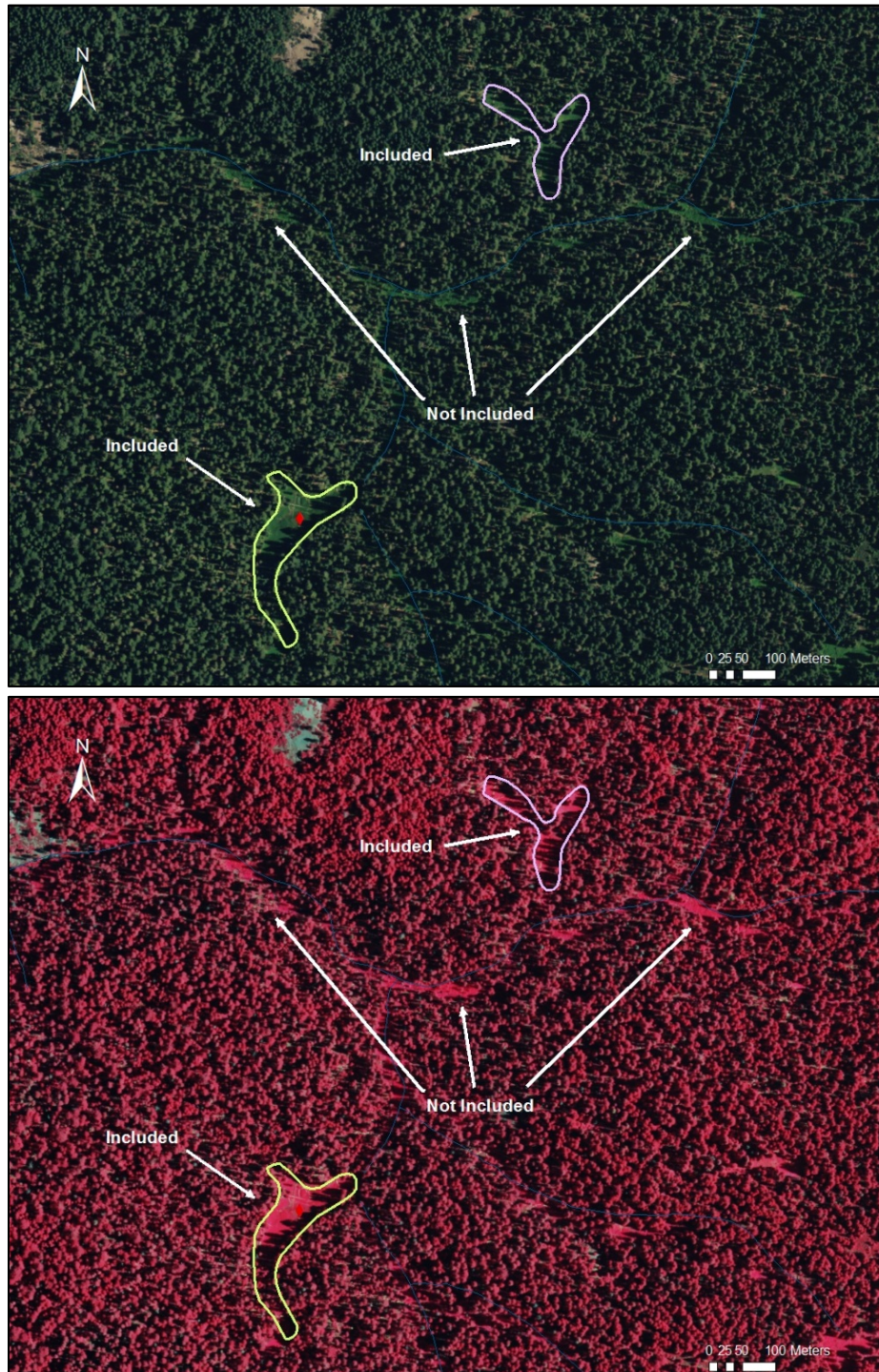
Meadow vegetation occurring in strips less than 15 meters wide was not included. The strip on the right of this image has intermittent vegetation patches and on average is less than 15 meters wide and was therefore not included. The strip in the upper left has more consistent meadow vegetation that is at least 15 meters wide, and consequently it was mapped as a meadow. (*poly* # 1261).

Methods: Alpine/Subalpine – Vegetation Density



Many areas, particularly in the alpine and subalpine, were on the cusp of inclusion or exclusion. In this image, the area within the polygons meets vegetation density requirements of appearing to have at least 2/3 cover of meadow vegetation. Excluded vegetation was found to be too rocky and sparse for purposes of this project. (*poly # 10093 & 10084*).

Methods: Montane – Stream Vegetation



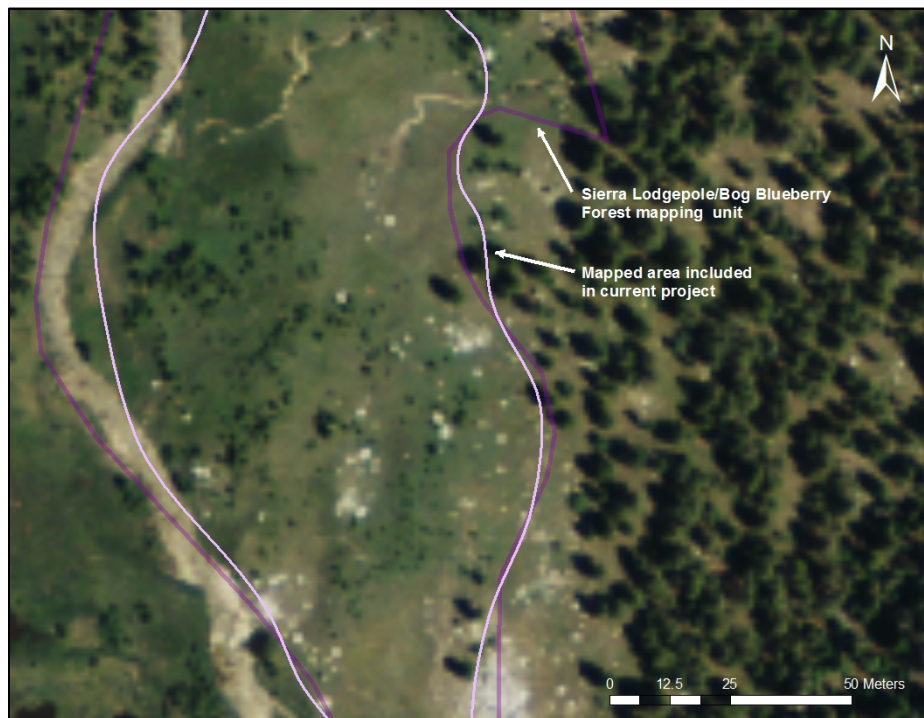
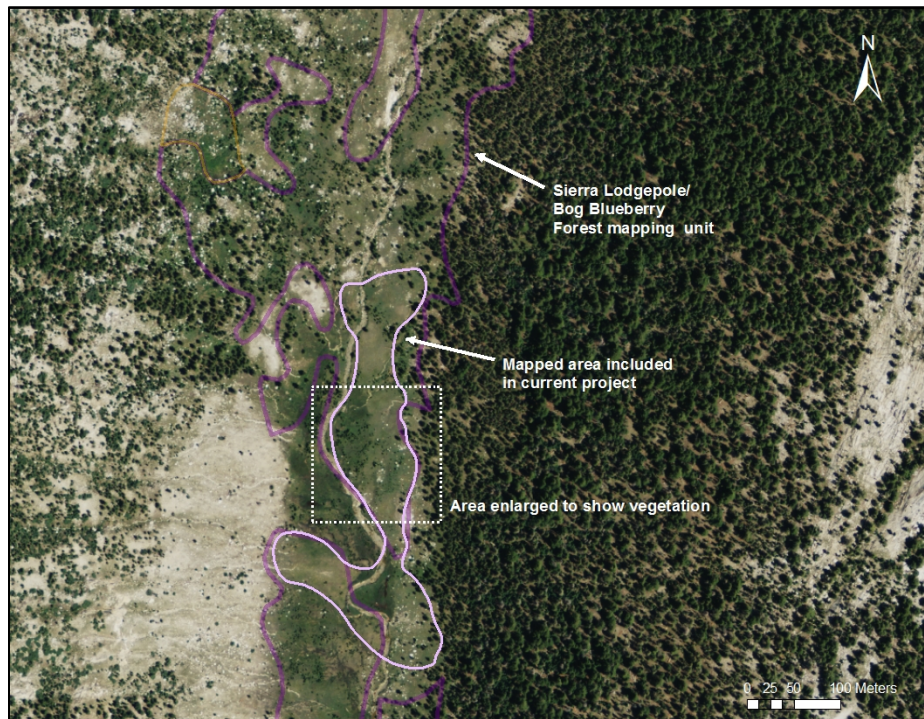
Streamside vegetation may contain meadow species, but narrow corridors of primarily riparian vegetation composition were excluded. Small pockets of meadow may form along streams, with species connectivity along stream banks, but this does not meet the definition of a meadow. The excluded areas are representative of where vegetation and hydrology are present, but they are too narrow and give way to dominant lodgepole cover. (*poly* # 9291 & 9295).

Methods: Subalpine/Montane – Tree & Shrub Cover



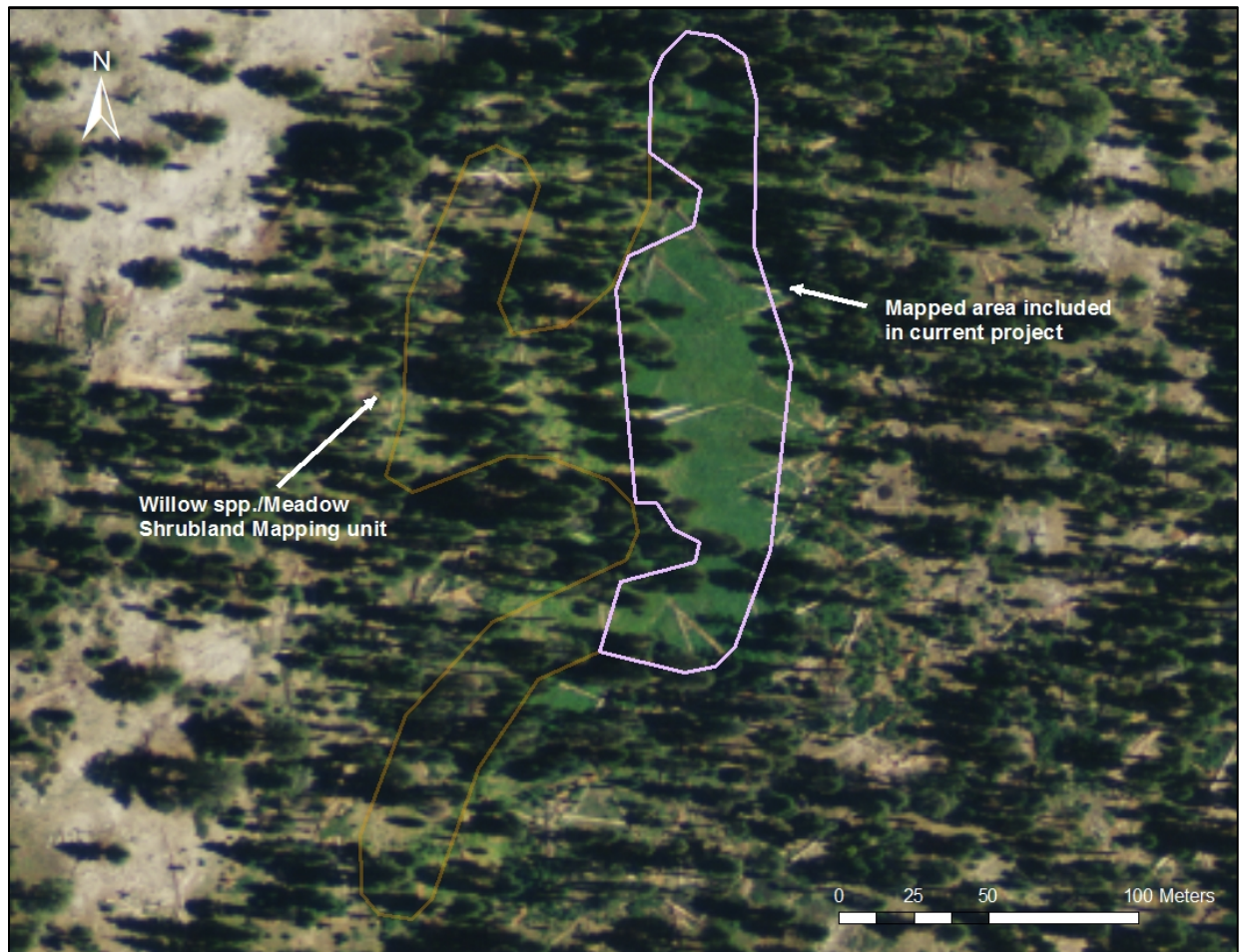
Meadow community species must meet a minimum of 2/3 cover to be defined as a meadow within the scope of this project. Areas of particularly high density of non-meadow vegetation such as shrubs, trees, rock out-croppings and ponds were excluded from meadow mapping efforts. (*poly # 4790*).

**Methods: Utilizing Polygons from other Mapping Units in the YOSE Veg Map –
3022 – Sierra Lodgepole/Bog Blueberry Forest Mapping Unit**



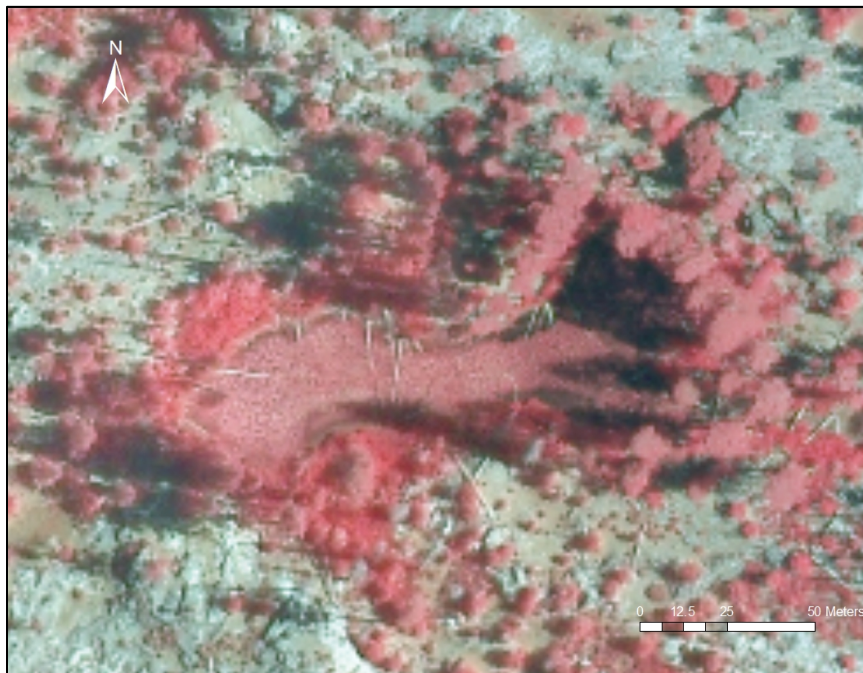
Areas originally mapped in the 3022 unit are outlined in dark purple; vegetation within the light purple polygon was included in the current project, as wet-meadow vegetation species appear to be dominant. (poly# 11787).

**Methods: Utilizing Polygons from other Mapping Units in the SEKI Veg Map –
6110 – Willow spp./Meadow Shrubland Mapping Unit**



Higher resolution imagery led technicians to reclassify the eastern part of this polygon as meadow. Originally considered a part of the 6110 Willow spp./Meadow Shrubland Mapping Unit, this area was included due to the use of better imagery.

Methods: Identifying Emergent Vegetation



Small lakes and ponds with emergent vegetation and floating peat mats are not uncommon in Yosemite National Park (as seen in these true color and color infrared NAIP images). In some cases, differentiation from terrestrial vegetation was difficult when emergent cover was thick, and the signature of water presence was similar to that which is found in fens. The clarity of Google Earth imagery helped technicians learn the emergent vegetation signature, and better discern emergent vegetation and floating peat mats from meadows. Google Earth imagery cannot be published here, but can be made available locally as a mapping tool.

Appendix III. Wet Meadow and Fen Mapping Project Feature Class Metadata

SEKIGIS.DBO.YOSE_WetMeadowFen_py
SDE Feature Class

Tags

National Park Service, Vegetation, Plants, Biota, Wetlands, Fens, Meadows, Groundwater,
Yosemite National Park, YOSE

Summary

Wetland classification, wet meadows and fens, wetland ecological integrity

Description

The Wet Meadows and Fens Feature Class of Yosemite National Parks was produced over a three month period (December 2013 through February 2014) to identify and classify all target wetlands (wet meadows and fens) >0.5 hectare in the parks. Over 1600 polygons represent wetlands in three classes: wet meadows, fen-meadow complexes, and fens. Classifications are as follows: a wet meadow is a wetland that does not include any peat accumulation or may contain up to a 25x25 square meter area of peat accumulation; a fen-meadow complex is a wetland that includes at least at 25x25 square meter area of peat-accumulating and non-peat-accumulating soil; a fen contains less than 25x25 square meter area of non-peat-accumulating soil. Overall spatial accuracy of the resulting map products is equivalent to 1:24000 National Map Accuracy Standards. Mapped polygons are based on photo interpretation of Natural Color and Color Infrared NAIP aerial photography from 2005, 2009, 2010, and 2012 as well as Google Earth and the ESRI World Imagery Basesmap. Ancillary data informing mapping decisions included: the YOSE Vegetation map, the National Wetlands Inventory Wetland Layer, the YOSE Rivers and Streams Layer, the Yosemite Contiguous Meadow Survey data, and YOSE Meadow Gridpoints. Supporting documentation for the feature class (report, accuracy assessment) are located in the SEKI network at: [S:\sien\monitoring_projects\wetlands\projects\WEI_delineation_project](#). The project was a collaboration between the YOSE Vegetation and Ecological Restoration Branch, SEKI GIS Staff, and the SIEN Inventory and Monitoring Program; photo interpretation was performed by two technicians under contract.

Credits

National Park Service – Sierra Network and Yosemite National Park

Use limitations

Any person using the information presented here should fully understand the data collection and compilation procedures, as described in these metadata and associated documentation, before beginning analysis. The burden for determining fitness for use lies entirely with the user. For purposes of publication or dissemination, citations should be given to the National Park Service. This data should not be used for navigational purposes.

Extent

West: -118.993847

East: -118.243620

North: 37.230271

South: 36.301942

SEKlgis.DBO.YOSE_WetMeadowFen_py

SDE Feature Class

Tags

National Park Service, Vegetation, Plants, Biota, Wetlands, Fens, Meadows, Groundwater,
Yosemite National Park, YOSE

Summary

Wetland classification, wet meadows and fens, wetland ecological integrity

Description

The Wet Meadows and Fens Feature Class of Yosemite National Parks was produced over a three month period (December 2013 through February 2014) to identify and classify all target wetlands (wet meadows and fens) >0.5 hectare in the parks. Over 1600 polygons represent wetlands in three classes: wet meadows, fen-meadow complexes, and fens. Classifications are as follows: a wet meadow is a wetland that does not include any peat accumulation or may contain up to a 25x25 square meter area of peat accumulation; a fen-meadow complex is a wetland that includes at least at 25x25 square meter area of peat-accumulating and non-peat-accumulating soil; a fen contains less than 25x25 square meter area of non-peat-accumulating soil. Overall spatial accuracy of the resulting map products is equivalent to 1:24000 National Map Accuracy Standards. Mapped polygons are based on photo interpretation of Natural Color and Color Infrared NAIP aerial photography from 2005, 2009, 2010, and 2012 as well as Google Earth and the ESRI World Imagery Basesmap. Ancillary data informing mapping decisions included: the YOSE Vegetation map, the National Wetlands Inventory Wetland Layer, the YOSE Rivers and Streams Layer, the Yosemite Contiguous Meadow Survey data, and YOSE Meadow Gridpoints. Supporting documentation for the feature class (report, accuracy assessment) are located in the SEKI network at: [S:\sien\monitoring_projects\wetlands\projects\WEI_delineation_project](#). The project was a collaboration between the YOSE Vegetation and Ecological Restoration Branch, SEKI GIS Staff, and the SIEN Inventory and Monitoring Program; photo interpretation was performed by two technicians under contract.

Credits

National Park Service – Sierra Network and Yosemite National Park

Use limitations

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Extent

West: -118.993847

East: -118.243620

North: 37.230271

South: 36.301942

YOSE_FenPeat_pt SDE Feature Class

Tags

National Park Service, Vegetation, Plants, Biota, Wetlands, Fens, Meadows, Groundwater,
Yosemite National Park, YOSE

Summary

Wetland classification, fens, wetland ecological integrity

Description

The Wet Meadows and Fens Feature Class of Yosemite National Park was produced over a three month period (December 2013 through February 2014) to identify locations of fens within park boundaries. More than 500 peat points identify locations where fens are known or presumed to occur. Overall spatial accuracy of the resulting map products is equivalent to 1:24000 National Map Accuracy Standards. Mapped polygons are based on photo interpretation of Natural Color and Color Infrared NAIP aerial photography from 2005, 2009, 2010, and 2012 as well as Google Earth and the ESRI World Imagery Basesmap. Ancillary data informing mapping decisions included the YOSE Vegetation map, the National Wetlands Inventory Wetland Layer, the YOSE Rivers and Streams Layer, the Yosemite Contiguous Meadow Survey data, and YOSE Meadow Gridpoints. Supporting documentation for the feature class (report, accuracy assessment) are located in the SEKI network at:

[S:\sien\monitoring_projects\wetlands\projects\WEI_delineation_project](#). The project was a collaboration between the YOSE Vegetation and Ecological Restoration Branch, SEKI GIS Staff, and the SIEN Inventory and Monitoring Program; photo interpretation was performed by two technicians under contract.

Credits

National Park Service – Sierra Network and Yosemite National Park

Use limitations

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Extent

West: -118.957839

East: -118.250777

North: 37.201896

South: 36.308257

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 104/170664, June 2020

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

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