Wetland delineation for Cahoon Meadow, Sequoia and Kings Canyon National Park

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Introduction

This document provides an assessment and delineation of the wetlands at Cahoon Meadow in Sequoia National Park and is part of a broader study and Environment Assessment (EA) of the potential restoration alternatives for a large erosion gully that has formed in the meadow. National Parks are not only required to minimize the destruction, loss, or degradation of wetlands but to enhance their natural and beneficial values, wherever practicable. A preliminary step in achieving these goals is an accurate description and delineation of wetland resources on Park lands. In addition to complying with internal policy regarding wetland protection, Parks must satisfy the requirements of the federal Clean Water Act. The US Army Corps of Engineers (USACOE) enforces the regulations of section 404 of this Act through a permit process. Other requirements of the Act are enforced at the State level.

The wetlands of Cahoon Meadow were delineated in accordance with the three-parameter method (hydrology, vegetation, soils) as described in the 1987 USACOE Wetlands Delineation Manual, the 2010 Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys, and Coast Region (Version 2.0), and the 2012 Final Map and

Drawing Standards for the South Pacific Division Regulatory Program. The USACOE wetland protocol calls for classifying unvegetated areas of open water as "waters of the U.S." (WoUS). However, the NPS classifies these open water areas as wetlands, using the U.S. Fish and Wildlife Service's (USFWS) Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979). The Cowardin wetland classification includes ecosystems that meet the USACOE wetland standards while also classifying shallow-inundated environments that support aquatic life (e.g., unvegetated shallow streams) as wetlands, whereas the USACOE considers these features separately, as WoUS.

Site description and access

Cahoon Meadow is a 25.118 acre fen and wet meadow wetland complex with patches of dry meadow and upland. The meadow ranges from 7260 to 7420 feet in elevation and is located 2.8 miles west of Hockett Meadow in the John Krebs Wilderness of Sequoia National Park. A large erosion gully formed within the sloping meadow (see cover photo), causing impacts to the local and downstream wetland and riparian ecosystems. As part of an effort to understand the origins, impacts, and restoration potential of erosion gullies in wetlands, Sequoia and Kings Canyon National Parks (hereafter SEKI), received funding from the Sierra Nevada Conservancy to investigate Cahoon Meadow.

Cahoon Meadow was privately held until 1980, but access to the parcel required crossing public land, so the Park issued permits for transporting cattle to Cahoon Meadow. The earliest Park records indicate that in 1918, 250 head of cattle were allowed access to the area. By 1935 the permitted number of cattle was 70, and this level of grazing seems to have been maintained until the Park purchased the property in 1980, at which time no further grazing was allowed. An old cabin at the edge of Cahoon Meadow reportedly contained signatures dating back to 1886, including what was thought to be the name of a Spanish officer (McKee Jr. 2013). This circumstantial evidence suggests that Cahoon meadow experienced grazing as early as the 1880s, possibly by sheep or horses associated with Spanish or Basque settlement.

To reach the site, drive from the town of Three Rivers, CA on California State Route 198 (called Sierra Dr. in Three Rivers) east for 3.8 miles (as measured from the town center at the intersection with N Fork Dr.). Turn right onto Mineral King Road, and drive 23.4 miles, past Silver City, to the Mineral King Ranger Station, Cold Springs Campground and trailhead. From the trailhead hike along a trail 9.5 miles south and west to Hockett Meadow Ranger Station, then 2.0 miles west to the junction of the Cahoon Rock and Evelyn Lake trails. Follow the trail west to Cahoon Rock for 1.2 miles. From Cahoon Rock down to Cahoon Meadow there is no maintained trail. The best route descends west down a steep slope from about 150-200 yards south of Cahoon Rock. Hike west and a little north down this slope and drainage for about 1.7 miles to Cahoon Meadow (Figure 1).

Methods

Cahoon Meadow was visited in June 2014 to survey the topography in and around the erosion gully, to describe the plants, soils, and hydrology of the area, to delineate the wetlands of the meadow, and to summarize the ecosystem functions and values that these wetlands provide to visitors and to the broader natural ecosystem. Potential wetland zones were delineated in the field based on homogenous plant communities, geomorphic landform, soil properties, and hydrology. The wetland study plots and topography were surveyed accurately using a total station and GPS. Back at the office, aerial imagery was used in GIS to delineate the wetland boundary where no field survey was made and where the transition to upland is obvious. The imagery used to delineate the wetlands, and displayed in the figures, was taken by the USDA National Agriculture Imagery Program (NAIP) on August 15th, 2014 at 1m resolution. Two previous independent efforts had also produced meadow/wetland boundaries for Cahoon from aerial imagery. These data were acquired for comparison purpose from 1) Sequoia and Kings Canyon National Park, which produced a map of all the meadows within its purview, and 2) the US Fish and Wildlife Service National Wetlands Inventory (NWI), which creates maps of the wetlands of the entire country.

Twenty-five augured soil holes and 7 cutbank investigations (collectively referred to as plots hereafter) were positioned throughout Cahoon Meadow to capture representative samples of the range of variability in hydrology, soils, and vegetation. Plots were located upstream of the headcut in intact wetland, at the headcut, downstream of the headcut in dewatered meadow, and in sides lobes of wetlands contiguous with the main meadow.

Each of the 25 augured holes in the meadow was left open long enough to allow the water table to come to equilibrium, after which the depth to water was recorded. Soil color, texture, composition, and depth were noted for each layer encountered while digging the holes. Seven study plots were added at cutbanks because the entire stratigraphy was accessible without the need for further ground disturbance (Figure 2). The water level at cutbank plots was evident as saturated weeping soil faces, or water cascading from the meadow surface. At the 25 augur holes vegetation was measured in 10-foot-radius homogenous-community circular plots centered on each augur hole. At cutbanks vegetation was measured in homogenous plots at the meadow surface above the exposed cutbank. Hydrologic, vegetation, and soils data from the 32 plots were used in conjunction with the total station and GPS field mapping to delineate the jurisdictional wetlands at Cahoon Meadow.

Within the 10-foot radius vegetation plot all plants were identified to species and their areal cover determined by ocular estimation by the same experienced observer. The wetland prevalence index was calculated for each plot by multiplying each species' wetland indicator status (1 for obligate, 2 for facultative wetland, 3 for facultative, 4 for facultative upland, and 5 for upland) by its areal cover, summing these products, and then dividing by the total plot vegetation cover to derive a prevalence index of wetland plants within the plot. Prevalence indices less than or equal to 3 indicate an abundance of hydrophytic vegetation, while those greater than 3 do not. In addition to having a prevalence index of 3 or greater, plots must have at least 5% total areal plant cover to qualify as having wetland vegetation present.

Most plants were identifiable in the field, but some specimens were collected, labeled, pressed, dried and taken back to the lab for identification. Several flora were used to identify plant species, but all naming conforms to the 2012 Jepson Manual: Higher Plants of California (Baldwin et al. 2012). Wetland indicator status for each species in California (Western

Mountains, Valleys, and Coast Region) was obtained from the USACOE Western Mountains, Valleys, and Coast 2014 Regional Wetland Plant List. The five categories for indicator status are obligate wetland (OBL), facultative wetland (FACW), facultative (FAC), facultative upland (FACU) or upland (UPL). Two species of moss were identified at two plots, however, non-vascular plants are generally not included in the USACOE plant list, so these had no wetland indicator status. Therefore, these two species were excluded from all calculations.

Soils were investigated at fresh vertical faces cut in a hand-dug soil pit or cutbanks. Soil texture, color, organic matter content, and redox features (color and prevalence) were described in the field. All observations were made on moist soils: dry soils were wetted and saturated soils were allowed to drain. A Munsell soil chart and grain size card were used as references for color and texture. The hydrologic parameters of depth to saturated soil and depth to water table were measured in the soil pit. No external soils data were available: soils maps are not yet finished for Sequoia-Kings Canyon National Park (Biggam, personal communication), and the NRCS database reports no data available.

Open-water areas at Cahoon Meadow consisted of the uppermost reach of Cahoon Creek flowing in the bottom of the erosion gully, three small tributary channels to this stream draining from the upper wetland over the headcut, and one disconnected channel on the forest-meadow edge of the upper wetland. All of these open-water areas were contiguous with, and functionally linked to vegetated wetlands. The center lines of the flow paths were surveyed as linear features and are displayed as blue lines on the maps. The associated active channel up to the Ordinary High Water Mark (OHWM) was determined to be the inset floodplain of the channel in the erosion gully, and the banks of the narrow tributary channels, which were simply rectangular channels within level meadow topography. The features associated with the OHWM (extent of floodplain and top of bank) were surveyed and the area below these levels are designated as potential WoUS for the purposes of USACOE permitting. Under the Cowardin wetland classification system these shallow-inundated streams are described as Upper Perennial Unconsolidated Sand/Organic Bottom (R3UB2/4) channels, and are considered wetlands in their own right by the National Park Service.

Wetland function and value were assessed based on the authors' extensive scientific and professional experience studying and restoring function and value in wetlands within Sequoia-Kings National Park, throughout the Sierra Nevada, and in mountain ranges around the world. Because detailed quantitative studies of the function and value of each wetland are well beyond the scope of this delineation, a qualitative assessment of the potential hydrologic, biotic, cultural, and scientific functions and values was made. Examples of functions and values that were assessed include: 1) how do hydrologic processes within the wetlands recharge local groundwater, alter surface water flow to attenuate flood peaks and dry-downs, filter sediment, and transform nutrients and how might these functions affect surrounding ecosystems and downstream water quality and quantity? 2) To what degree do flora and fauna rely on these wetlands for significant habitat? 3) How important are these wetlands to current visitor use and enjoyment of the Park, or do they have any historical importance? 4) Do these wetlands provide a current or future benefit to scientific investigations?

Results and discussion

Topographic survey

A team of two surveyors used a total station to gather accurate ground surface position and elevation data at Cahoon Meadow. The goal of the land survey was to map the extent and geometry of the erosion gully to determine the volume of sediment eroded from the meadow. In addition, vegetation, soils, and hydrologic data collection points were surveyed so that all data are spatially related. A total of 380 points were surveyed over an area 1300 feet long, up to 275 feet in width, and covering 6.75 acres. In addition, a polygon of the main gully edge, line features of smaller gullies, and data collection points that could not be obtained with the total station were collected with a Trimble Juno GPS unit.

Analysis of the survey data indicates that the gully, at its deepest point, is incised 17 feet below the original meadow surface. Gully width varies considerably, but averages about 50 feet, with a maximum width of 90 feet. The gully is 1150 feet long and 1.35 acres in extent. The most deeply and widely eroded portion of the gully is the upstream and southernmost ~570 feet of gully, terminating on its upstream end in three separate and nearly vertical headcuts, each 7-8 feet high. The uppermost gully headcut is located approximately 20 feet north of study plot 10 (see Figure 3). In total, the gully has eroded 14,950 cubic yards of sediment from the meadow and sent it downstream. The slope of the meadow surface along the surveyed reach averages 5.7%, with the steepest section just upstream of the headcut at 9.3%, getting steadily flatter downstream.

A fen and wet meadow wetland complex extends for about 820 feet upstream from the gully headcut. The contributing watershed area above the headcut is approximately 520 acres (0.815 mi^2), with the intact upstream wetland covering 14.921 acres (Figure 4 and Table 2). Downstream of the headcut the meadow drains into the gully and the water table is more than a meter below the surface. Dry, bare peat is exposed in large areas of the meadow adjacent to the gully. The total area of meadow that is dewatered and no longer a wetland is 5.018 acres, of which 0.942 acres are occupied by the sloping banks of the erosion gully. A small intact wetland 0.771 acres in size abuts the eastern edge of the dewatered wetland, 650 feet downstream of the gully headcut, and a larger 3.572 acre wetland meets Cahoon at the very bottom of the surveyed reach where the erosion gully transitions to a natural, forested stream channel. An additional 160 acres (0.250 mi^2) of contributing watershed drain into the downstream end of the gully below the headcut, for a total watershed area of 680 acres (1.065 mi^2). Figure 4 shows the investigated area, delineated wetlands, and an aerial view of the meadow. Figure 5 and Figure 6 show closer views of the north and south halves (respectively) of study area. The delineated wetland and upland areas of the meadow are summarized in Table 2.

The 15+ foot high cut banks created by the gully display the meadow stratigraphy down to bedrock in several locations. At seven cutbank exposures and 25 augured holes in the meadow, each soil layer encountered was described for color, texture, and composition. Typical exposures at cutbanks had 1-2 feet of desiccated peat at the surface, underlain by alternating layers, 0.3-2 feet thick, of coarse sand and peat. Figure 2 shows a cut bank exposure displaying the layers of peat, darker and more prominent, between loose sand layers. A 6-foot-tall person is visible on the right, for scale. These layered sediments indicate that Cahoon Meadow was formed over thousands of years in relatively stable, saturated wetland conditions (peat layers accumulate very slowly, but decompose more rapidly when drained). Periodic large sedimentation events, as evidenced by the coarse sand layers, occasionally buried the meadow, but the wetland plants and hydrology reformed peat layers on top of these disturbance deposits. Several sand layers contained pieces of charcoal, suggesting that some sedimentation events may have followed forest fires.

Hydrology

The depth to water, organic soil depth, and vegetation of the 32 investigated plots (25 auger holes and 7 cut bank exposures) are summarized in Table 1. The low winter precipitation and early spring melt of 2013-2014 meant that the conditions on site in mid-June were equivalent to peak or late-peak growing season: most plants were flowering and/or producing fruits, and water tables and soil moisture were past peak and starting to approach late-summer lows. Therefore, the water table and saturation measurements made on 24-25 June 2014 are below peak, and plants were about 12 weeks into the growing season.

Because the meadow was visited more than a month past snowmelt peak flow, in a precipitation-free period, a water table within 12 inches of the surface (USACOE hydrology indicator A2) indicated that wetland hydrology had been present for at least the first month of the growing season. The depth to water table at each plot is listed in Table 1, and if that value was 12 inches or less, wetland hydrology was present. In addition, at five other plots (7, 8, 9, 27, and 28) where the water table was deeper than 12 inches, other primary wetland hydrology indicators were observed: saturated soil within the top 12 inches (indicator A3), and/or oxidized rhizospheres along living roots within the upper 12 inches of soil (indicator C3). Each one of these hydrologic indicators – water table, saturation, or oxidized rhizospheres – within 12 inches of the ground surface is sufficient primary evidence of wetland hydrology. Wetland hydrology was present in 13 of the 32 sampled plots, and was always accompanied by wetland soils and wetland vegetation. These 13 plots were classified as wetlands, and their representative wetland areas are delineated with green outlines in Figures 3-8.

Soil

The soil at Cahoon Meadow is composed of two distinct types of layers that are interbedded, generally in 1-2 foot intervals. Across much of the meadow, including most of the saturated upstream wetland above the erosion gully, the surface layer of soil is peat. Underlying the approximately 1-foot thick peat layer is a 1-2 foot thick sandy gravel layer. The alternation of peat and sand/gravel layers continues 8-10 feet down, as far as the strata are exposed on the sides of the erosion gully (see Figure 2). The sand/gravel layers are generally poorly sorted homogenous units that we interpret as rapidly laid-down storm or snow melt high-flow deposits. The peat layers clearly reflect long periods of perennial groundwater saturation and accumulation of wetland plant organic matter. The substrates at Cahoon Meadow plots were classified as wetland soils if at least 16 of the upper 32 inches of soil was peat, following the USACOE definition for histisols (hydric soil indicator A1).

In addition to the 13 delineated wetland plots, the soil met the requirements for wetland conditions at another 9 locations, but the hydrology (in all 9 cases) and vegetation (in 7 cases) did not, and so were classified as uplands. The two plots with both wetland soils and wetland vegetation, but not wetland hydrology were plots 10 and 11. The meadow area that these plots represent is shown in orange outline on Figure 7. The remaining seven plots with only wetland soils (no wetland vegetation or hydrology) are plots 13, 14, 15, 16, 17, 23, and 25. The wetland-soil-only area represented by these seven plots is shown on Figure 7 by the dark brown outline. The remaining meadow area, where neither wetland soils, nor vegetation, nor hydrology exist, is shown in tan outline.

Vegetation

A total of 35 plant species (Table 1) were identified within the 13 wetland and 19 upland plots. The plant with the highest total cover across all wetland plots was *Carex utriculata.* In the 11 wetland plots (of 13 total) where it was present it was always the species with the highest cover. In the two wetland plots at which *C. utriculata* was absent (8 and 12), *Glyceria elata* (FACW) was the dominant plant. The species with the second-highest total cover in the wetland plots was *Bistorta bistortoides* (FACW), present in 10 of the 13 plots, followed by *Glyceria elata* (FACW, 4 of 13), *Oxypolis occidentalis* (OBL, 6 of 13), and *Carex simulata* (OBL, 3 of 13).

Plots 1 through 9 are all located in the wetland zone above the headcuts of the large erosion gully (see Figure 10). This wetland zone is 14.921 acres in size and is kept saturated by diffuse groundwater discharge. No perennial surface water flows into this wetland, but three distinct flow paths drain the northern edge of the wetland into the large erosion gully channel, which flows year-round. Plot 12 is a riparian wetland (WoUS by USACOE standards) associated with a channelized flow path that spills water over a headcut into the erosion gully. Plots 27 and 28 are located in a wetland fed by groundwater discharge separate from the source of water for the large southern wetland above the headcut (plots 1-9). Similarly, plot 32 represents a distinct groundwater discharge wetland that adjoins the erosion gully riparian wetland (WoUS) downstream from the east side in relation to the large wetland above the gully headcut.

In addition to the 13 wetland plots, wetland vegetation was present at 3 other plots. Two of those plots (10 and 11) contained wetland soils (but no wetland hydrology), and one plot (31) had neither wetland soils nor hydrology. Two of the upland plots with wetland vegetation (10 and 11) had significant facultative wetland (FACW) or obligate wetland (OBL) plant cover dominated by *Glyceria elata* and *Scirpus microcarpus*, respectively. The other upland plot with wetland vegetation (31) contained no obligate wetland plants but was dominated by *Deschampsia caespitosa* (FACW) and *Poa pratensis* (FAC).

Significant areas of upland meadow (see Figure 7) had wetland vegetation and/or soil, indicating that the soil formed, and plants established, during wetland conditions in the past. The different zones of upland, and the degree to which they lack complete wetland indicators, may reflect the history of dewatering of the site. The upland meadow areas furthest downstream retain no wetland indicators (Figure 11), the next upstream zone contains only wetland soil, while the area just between the headcut and upstream wetland still has both wetland soil and vegetation, but lacks wetland hydrology. We interpret this spatial pattern as reflecting the advance of the headcut upstream through time, with the furthest downstream sections having been dewatered first and therefore showing the greatest degradation and loss of wetland indicators.

Two plant species of conservation concern for the Park are known to occur in Cahoon Meadow: *Drosera rotundifolia* (round leaf sundew) and *Claytonia palustris* (marsh claytonia). Round leaf sundew is a wetland obligate carnivorous plant widely distributed throughout the northern latitudes. However, the Cahoon Meadow population is the southernmost of only nine locations within SEKI, and lies within 50 miles of the southern limit of the species range in the western US. Only a few other Sierra Nevada occurrences are known further south of Cahoon, in the Sequoia National Forest. Marsh claytonia is a facultative wetland perennial herb on the California Native Plant Society watch list, rank 4.3 (uncommon in CA, not very endangered). There are 8 known occurrences within SEKI, including Cahoon Meadow.

<u>External studies</u>

We compared the data collected during this project to previous mapping and wetland characterization efforts at Cahoon Meadow. Three separate sources of data were found: 1) vegetation, soils, and hydrology data from the National Park Service Inventory and Monitoring (I&M) Program; 2) the wet meadows and fens mapping layer from the Sequoia and Kings Canyon meadow monitoring program; and 3) the US Fish and Wildlife Service's National Wetlands Inventory (NWI) map.

The I&M program conducted a study at Cahoon Meadow in July of 2009 (Jones 2011) at two study plots, shown in Figure 8. The 2 dominant plants at plot 1 were *Carex scopulorum* (OBL), and *Oxypolis occidentalis* (OBL). There was water at the surface, and >16 inches of peat in the top 32 inches of soil at plot 1. Plot 2 was dominated by *Veratrum californicum* (FAC), *Senecio triangularis* (FACW), *Carex scopulorum* (OBL), and *Bryum psuedotriquetrum* (NI). The soil was saturated in the top 12 inches (indicator A3), and the soil exhibited a depleted matrix (indicator F3) with a gleyed, low chroma color. Both of these plots contain wetland vegetation, soils, and hydrology, and their location within the delineated wetland boundary, far from the plots of this study, indicate that our understanding of the site and mapping of wetland boundaries are accurate.

When comparing our wetland boundaries, derived from a combination of intensive on-the-ground sampling and photo interpretation, to those drawn solely from aerial photography, significant differences are apparent. Both the Park's wet meadow layer and the NWI wetland map incorrectly classified large areas downstream (north) of the gully headcut as wetland or wet meadow (Figure 8). However, both external mapping efforts did a good job of including almost all of the wetland area delineated by us, including both smaller wetland arms to the north and east of the main wetland, within their boundaries.

Broader context

The wetlands delineated in this report are all part of the headwaters of the East Fork of the Kaweah River in Sequoia National Park. The outflow from Cahoon Meadow supplies Cahoon Creek, whose uppermost extent is the erosion gully headwall and small tributary channels within the meadow. No perennial surface flow enters Cahoon Meadow; its wetland hydrology is dependent on diffuse groundwater discharge. Cahoon Creek joins with the unnamed outflow stream from Evelyn Lake 0.8 miles downstream from Cahoon Meadow, and then is subsumed by the larger Horse Creek 2.3 miles downstream of the meadow. Horse Creek flows into the East Fork of the Kaweah, which joins the Kaweah River near the National Park Entrance, upstream of the town of Three Rivers, CA. The Kaweah River flows into Lake Kaweah (a reservoir) as it leaves the Sierra Nevada and enters the Central Valley. What remains of the natural flowing channel below the dam then enters the endorheic basin surrounding historic Tulare Lake. However, today most of the discharge from the Kaweah River is impounded or diverted for irrigation of agricultural lands in the Tulare basin and the San Joaquin Valley. During periods of flooding some portion of the Kaweah River flow may breach the endorheic Tulare basin and flow north into the San Joaquin River basin, eventually reaching San Francisco Bay and the Pacific Ocean via the Sacramento – San Joaquin River Delta. Because of this naturally complex, and now highly altered flow regime, it is difficult to determine whether the surface flow headwaters of the Marble Fork of the Kaweah River are connected to navigable rivers and the ocean, and therefore considered Waters of the U.S. However, the water of the Kaweah River is heavily exploited for irrigation that supports significant interstate commerce in the form of agricultural products, and this qualifies it as Waters of the U.S.. By extension, all headwaters of the Kaweah River are therefore Waters of the U.S., including all wetlands delineated in this report.

National Park Service regulations prohibit any direct business use (and thus Interstate Commercial use) of Park lands, “except in accordance with the provisions of a permit, contract, or other written agreement with the United States, except as such may be specifically authorized under special regulations applicable to a park area” (Code of Federal Regulations, Title 36, Chapter 1, Part 5, Subsection 5.3). At the time of this delineation the only apparent possible uses of the sites are for recreation and aesthetic enjoyment. All visitors, including foreign or interstate recreational travelers, are allowed to hike, swim, fish (with a California state license), and otherwise enjoy the surface flow, wetlands, and uplands in Sequoia National Park. Common business uses (potentially Interstate Commerce) of these sites within Sequoia National Park, for which a permit is required, include commercial photography and professional guide services.

Although very few visitors go to Cahoon Meadow, continuation or expansion of the effects of the large erosion gully will have far reaching impacts. The dewatering and erosion degrade downstream water quality and base flow, negatively impact vegetation and wildlife, and destroy historic and prehistoric landscapes, with their stored carbon and sedimentary records from eons past. The relative scarcity of these fen wetlands, and their unique physical and biologic characteristics make them critical landscapes for science and conservation, and keystone ecosystems for the surrounding uplands and downstream aquatic environments.

Meadows like Cahoon cover less than 3% of the Sierra Nevada land area (Fryjoff-Hung and Viers 2012) but are disproportionately important for bird (Van Riper and Van Wagtendonk 2006), insect (Simonson et al. 2001, Hatfield and LeBuhn 2007), amphibian (Morton and Pereyra 2010, Liang and Stohlgren 2011), mammal (Grenfell and Brody 1986) and plant biodiversity and habitat (Jones 2011). In addition to their biotic and ecological significance, mountain meadows can store and transform carbon and nitrogen (Norton et al. 2011), attenuate flood peaks and retain shallow groundwater and soil water (Hammersmark et al. 2008).

Specifically, Hammersmark and others used computer models of a meadow in gullied and restored (gully filled) states to demonstrate the hydrologic benefit of restoration. They showed that the restoration stored 20% more groundwater during peak spring discharge and retained 60 times more water than the gullied meadow during late summer baseflow. Total seasonal runoff from the gullied meadow was greater, but the restoration shifted the timing of the center-of-mass of flow later in the season by 16 days. This longer retention time of water in the restored condition provides soil moisture for meadow plants to grow throughout the season.

Norton and others found that degraded Sierra Nevada meadows lost nearly half of their soil organic carbon and total nitrogen due to drying of wetland soils. Nitrogen loss due to wetland soil drying proceeds as reduced forms of nitrogen (ammonium and nitrite) are oxidized to nitrate, a highly water soluble and poorly soil-retained form of nitrogen. Nitrate leaching can have significant impacts to downstream water quality, causing algal blooms, oxygen depletion, and cascading impacts to higher organisms such as invertebrates and fish. Restoration of natural fen hydrology and vegetation results in a reversal from rapid carbon loss to long term carbon storage (Chimner and Cooper 2003).

For millennia, mountain meadows throughout the Sierra Nevada have accumulated mineral sediment and organic carbon (Wood 1975) from which prehistoric climate and vegetation have been reconstructed (Anderson and Smith 1994). Contained within this preserved record of accumulated carbon and sediment is evidence of the relatively stable meadow hydrologic and biogeomorphic processes over the past several thousand years (Benedict 1982, Ratliff 1985): frequent and/or large soil disturbance events would have destroyed the integrity of this layered history. In addition, the relative stability of wetland conditions, as evidenced by the 10,000 year accumulation of wetland soil, indicates that these ecosystems are naturally resistant to the broad fluctuations in climate that have occurred since the end of the last ice-age. This suggests that Sierra wetlands such as Cahoon Meadow, with their ecological processes intact, should remain functional through projected anthropogenic changes in climate. However, in a degraded state with lowered water tables and exposed eroding sediment, impacted wetlands will suffer greater degradation under the projected increases in temperature (and therefore plant water demand) and increased rain intensity and the attendant greater erosive force of runoff events.

As part of this wetland delineation and the broader assessment of the impacts and restoration potential of Cahoon Meadow, preliminary carbon flux data were collected at a subset of the sample sites. Carbon flux readings were taken in full sun between 10am and 2pm on 25 June 2014. Measurements of plant photosynthetic uptake of CO_2 from the atmosphere, and ecosystem respiration (plant metabolism and microbial soil decomposition) of CO_2 back to the air were made using a 1-foot diameter plastic chamber connected to an infrared gas analyzer (IRGA). These readings were scaled to a daily time span, and the net ecosystem exchange was calculated as a simple sum of daily photosynthesis (by convention, a negative value) and daily respiration. The intact wetland above the erosion gully (where no wetland indicators are missing) was photosynthesizing at about the same rate as it was respiring, resulting in a near-zero net CO2 flux (Figure 9). Upland meadow zones missing wetland hydrology, or missing both hydrology and vegetation, experienced a net loss (positive values, indicating net respiration to the atmosphere) of about 4 g of CO_2-carbon per square meter per day. Upland zones that had no wetland indicators (missing wetland hydrology, vegetation, and soils) had no photosynthesis (no plants) and only a small amount of respiration, resulting in a small net loss of CO_2. The low net loss at the site missing all three wetland indicators is likely due to two main factors: 1) the soil at the site doesn’t contain enough organic thickness to qualify as a wetland soil, probably due to extensive decomposition and/or erosion, so there’s less carbon left for microbes to respire and 2) the soil here was extremely dry, which inhibits soil microbial respiration. There were no live plants in the extremely dry conditions at this last site. The net loss of carbon from the two upland zones with partial wetland indicators is due mostly to dramatically lower photosynthesis than the intact wetland zone.

Figures and tables

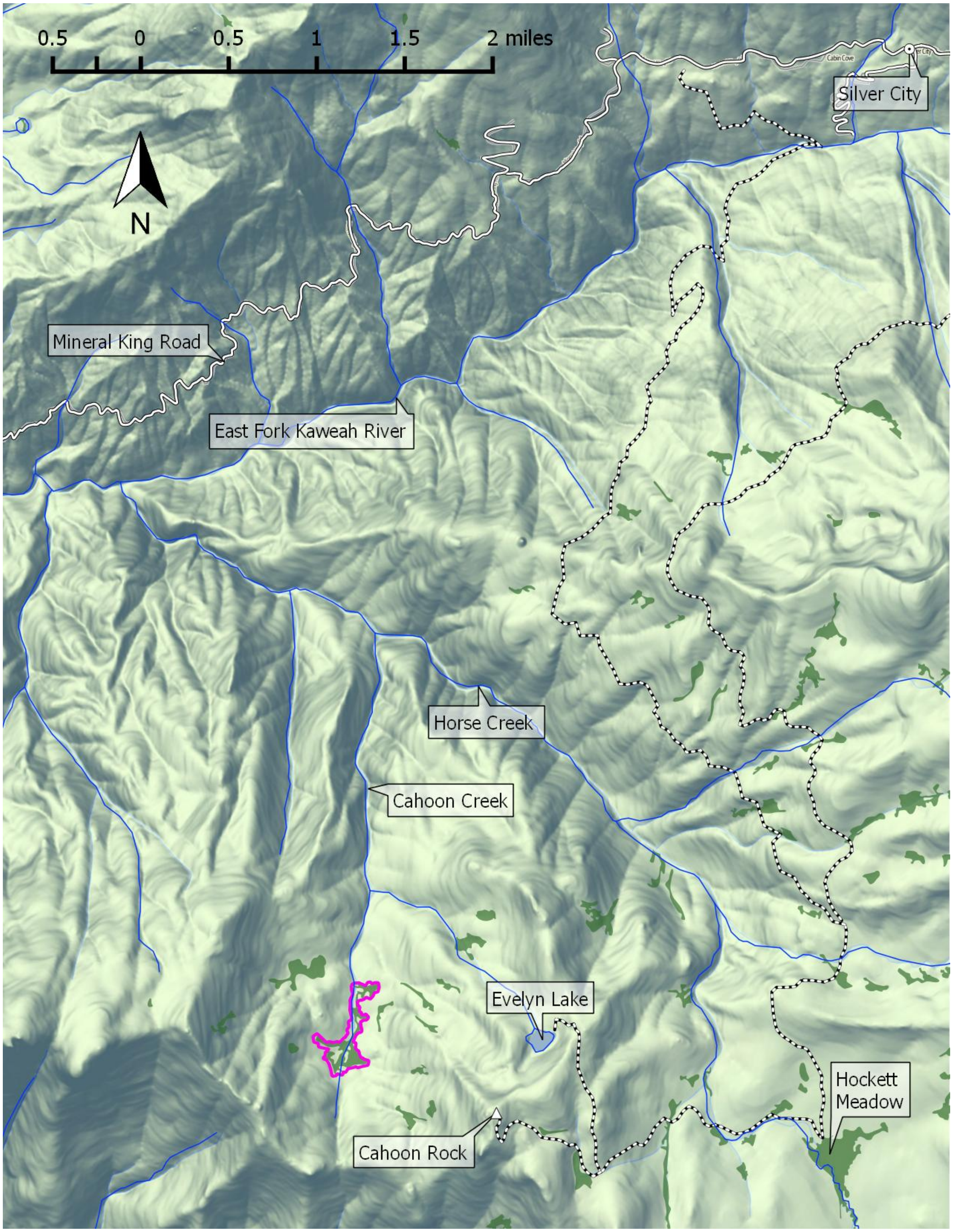

Figure 1. Shaded relief topographic map showing the study area at Cahoon Meadow (pink border), wet meadows in the region as mapped by the Park (dark green), hiking trails used to access the Cahoon area (black-white dashed lines), and labelled built and natural features.

Figure 2. Vertical gully headcut exposure showing alternating 1-2 foot thick layers of dark peat (at surface) and lighter coarse sand. Note 6-foot tall second author in upper right for scale, slumped soil and vegetation on right, wetland vegetation growing on the meadow surface, and water drops free-falling from the saturated surface at lower left.

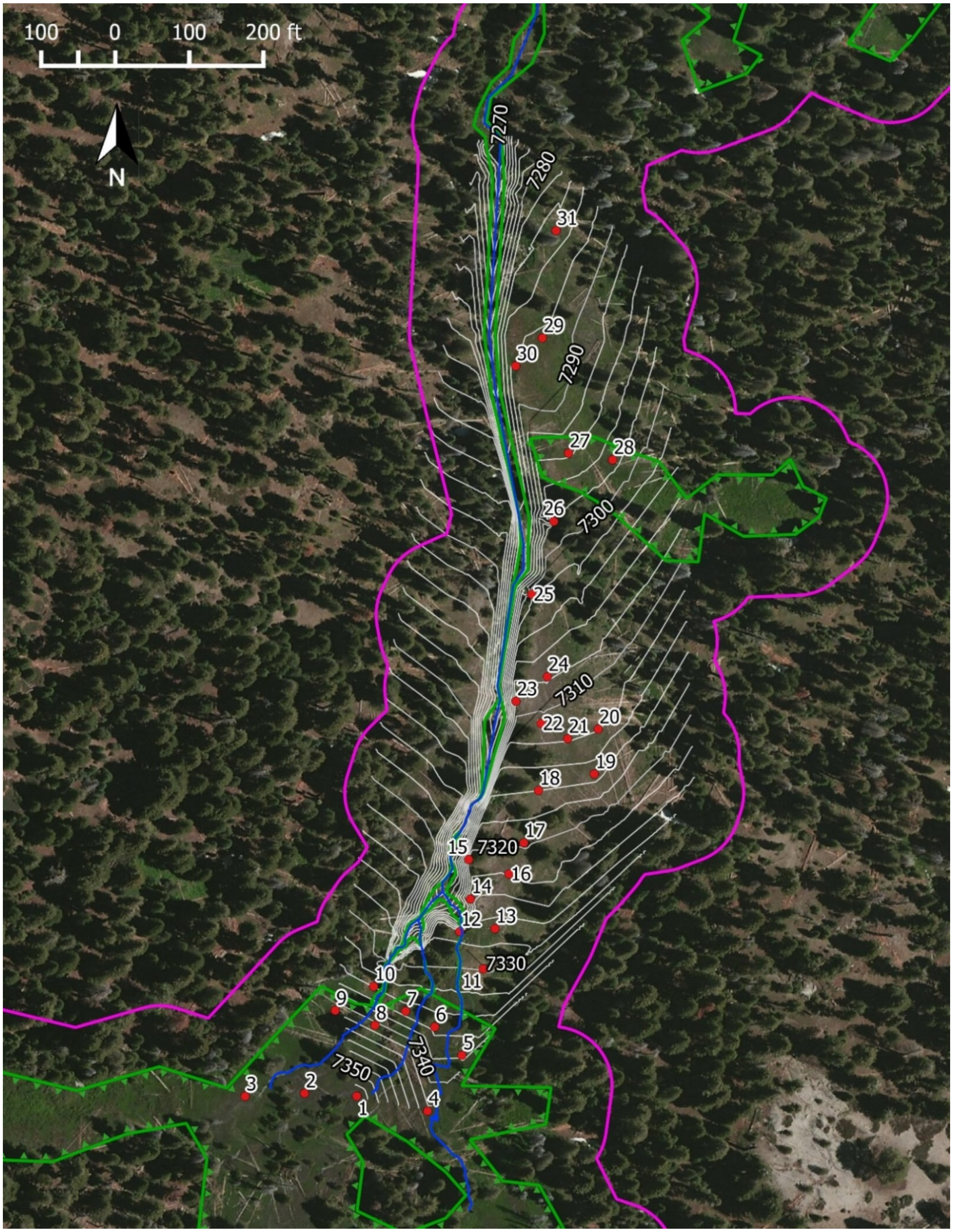

Figure 3. Surveyed topography (white lines, 2-foot contour interval, labelled every 10 feet) in and adjacent to the large erosion gully in Cahoon Meadow. Delineated wetlands (green toothed outlines), data plot locations (numbered red dots), and channelized perennial flow paths (blue lines) are shown. Note the narrow wetland zone delineated along main channel and tributaries. The uppermost gully headcut is located ~20 feet north of plot 10.

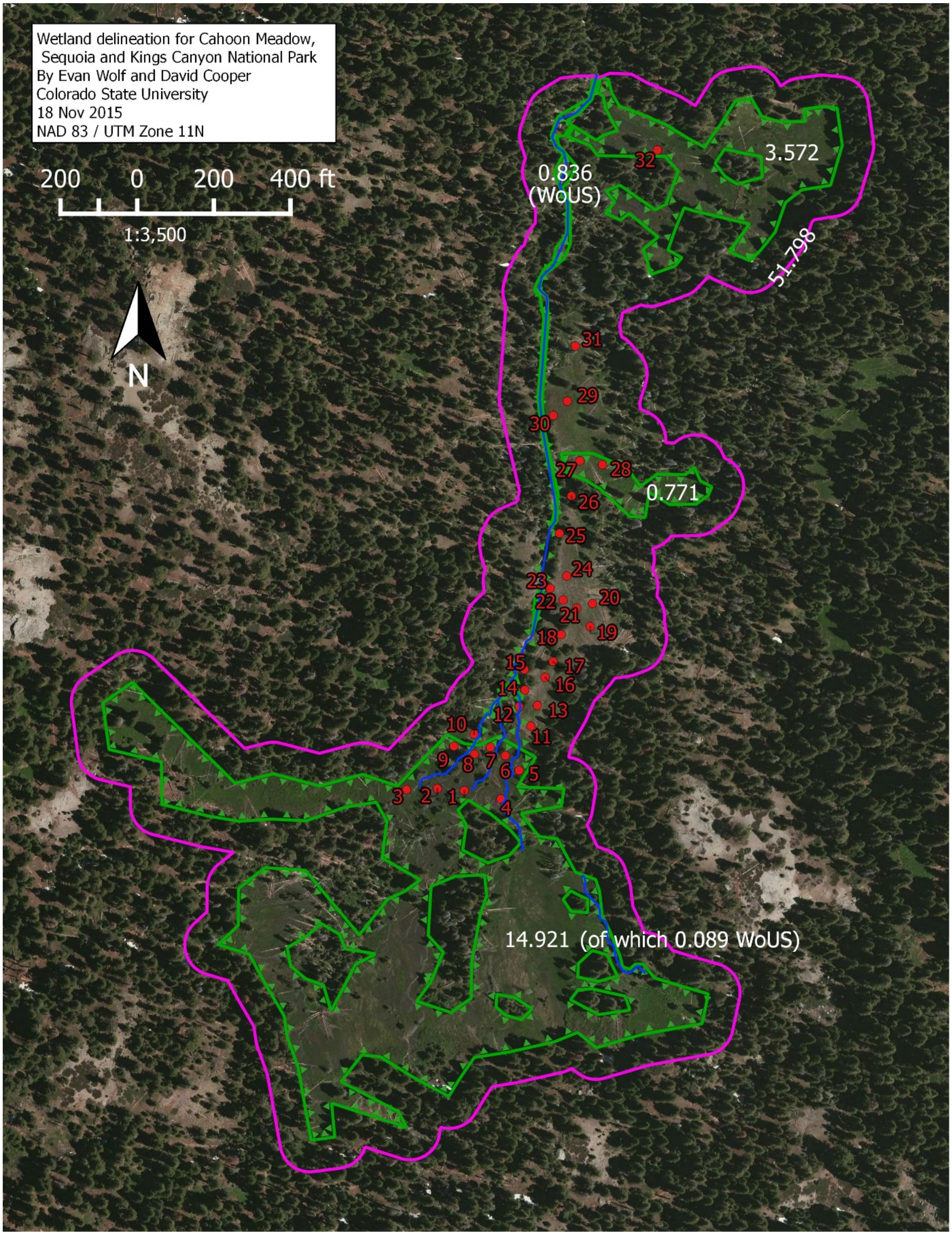

Figure 4. Aerial image overlaid with the investigated area (purple outline), delineated wetlands (green toothed outlines, labelled with area in acres), data plot locations (numbered red dots), and channelized perennial flow paths (blue lines). Note the narrow wetland zone (0.836 ac + 0.089 ac within upper wetland) delineated along main channel and tributaries, classified as USACOE Waters of the US (WoUS). Meadow slope and water flow is generally from south to north.

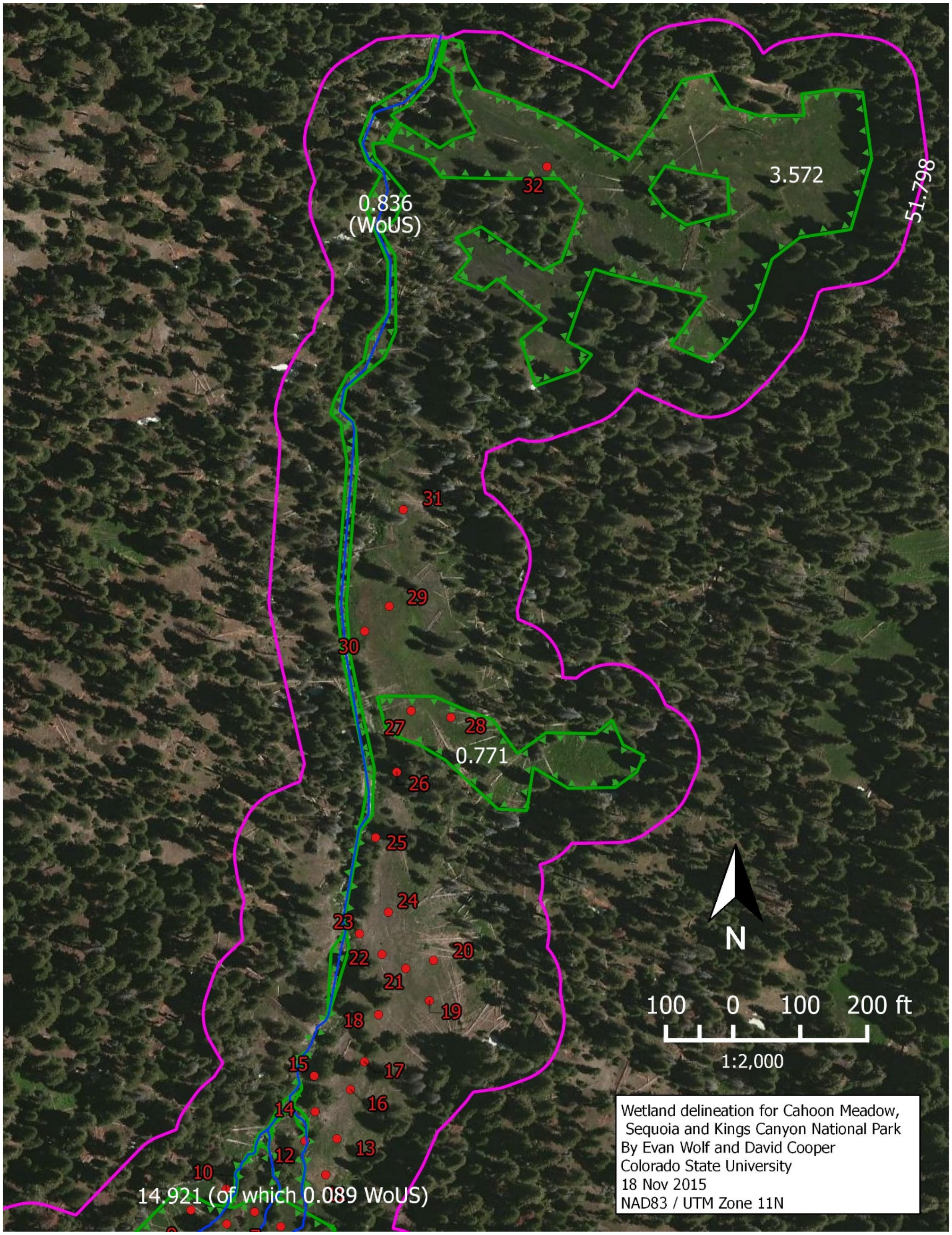

Figure 5. Zoom in on north section of Figure 3, with the investigated area (purple outline), delineated wetlands (green toothed outlines, labelled with area in acres), data plot locations (numbered red dots), and channelized perennial flow paths (blue lines). Scale is 1:2,000

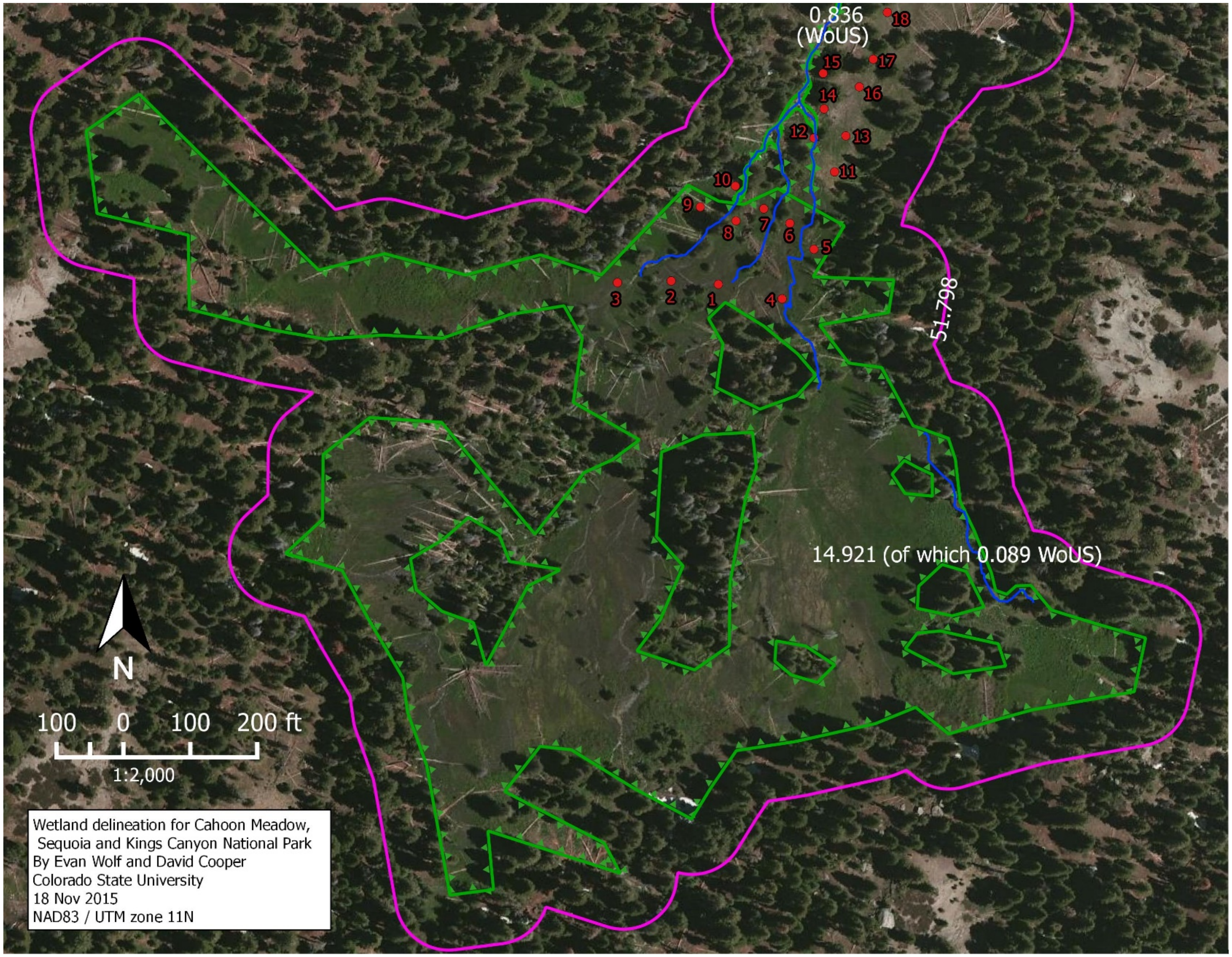

Figure 6. Zoom in on south section of Figure 3, with the investigated area (purple outline), delineated wetlands (green toothed outlines, labelled with area in acres), data plot locations (numbered red dots), and channelized perennial flow paths (blue lines). Scale is 1:2,000.

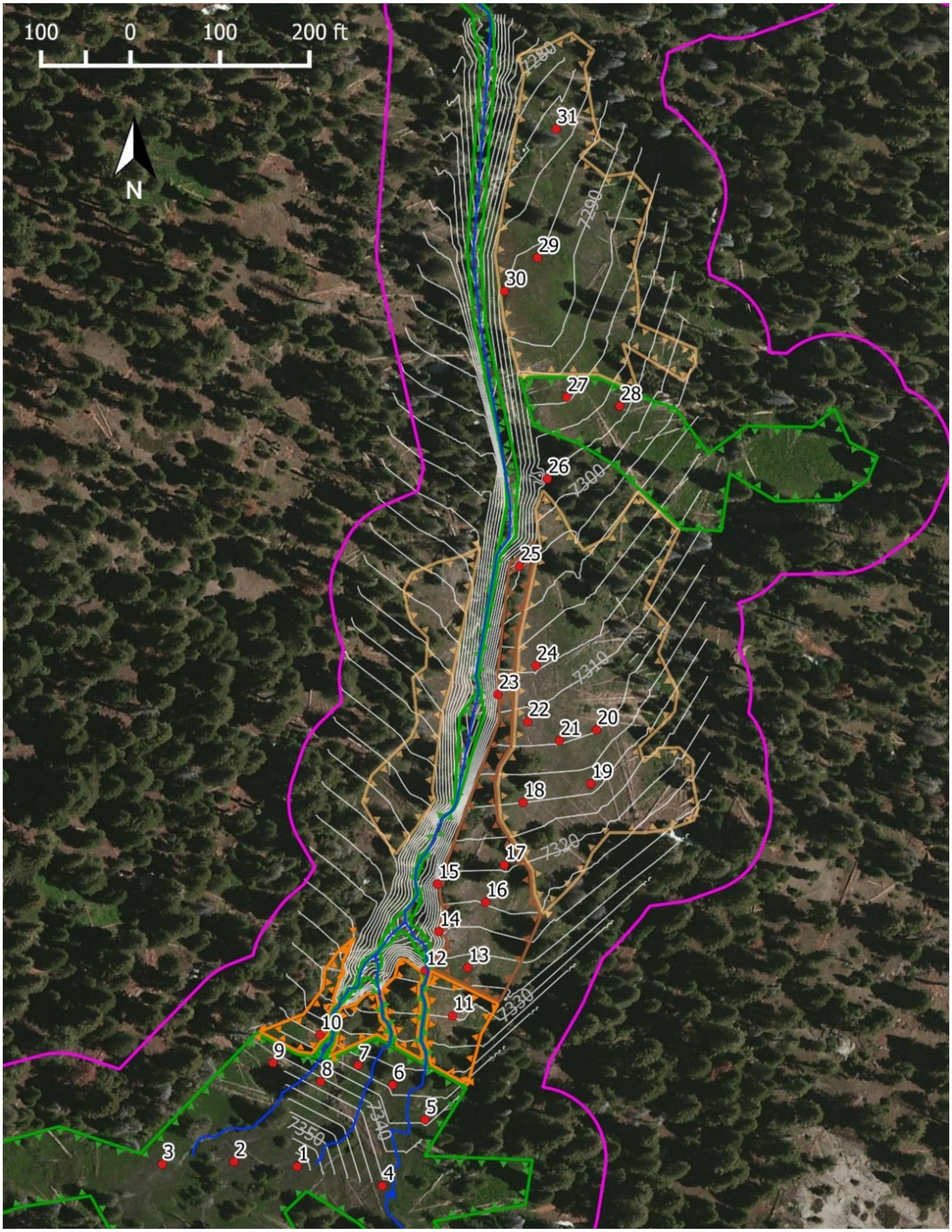

Figure 7. Upland zones within the meadow (unforested or patchy small trees on flat ground) show where wetland vegetation and soils exist without wetland hydrology (orange polygons), where only wetland soils are present (dark brown polygon), and where flat meadow shows no wetland indicators (light tan). Note the narrow wetland zone delineated along the main channel and tributaries. The steep erosion gully edges are also classified as upland, and are interpreted as former meadow.

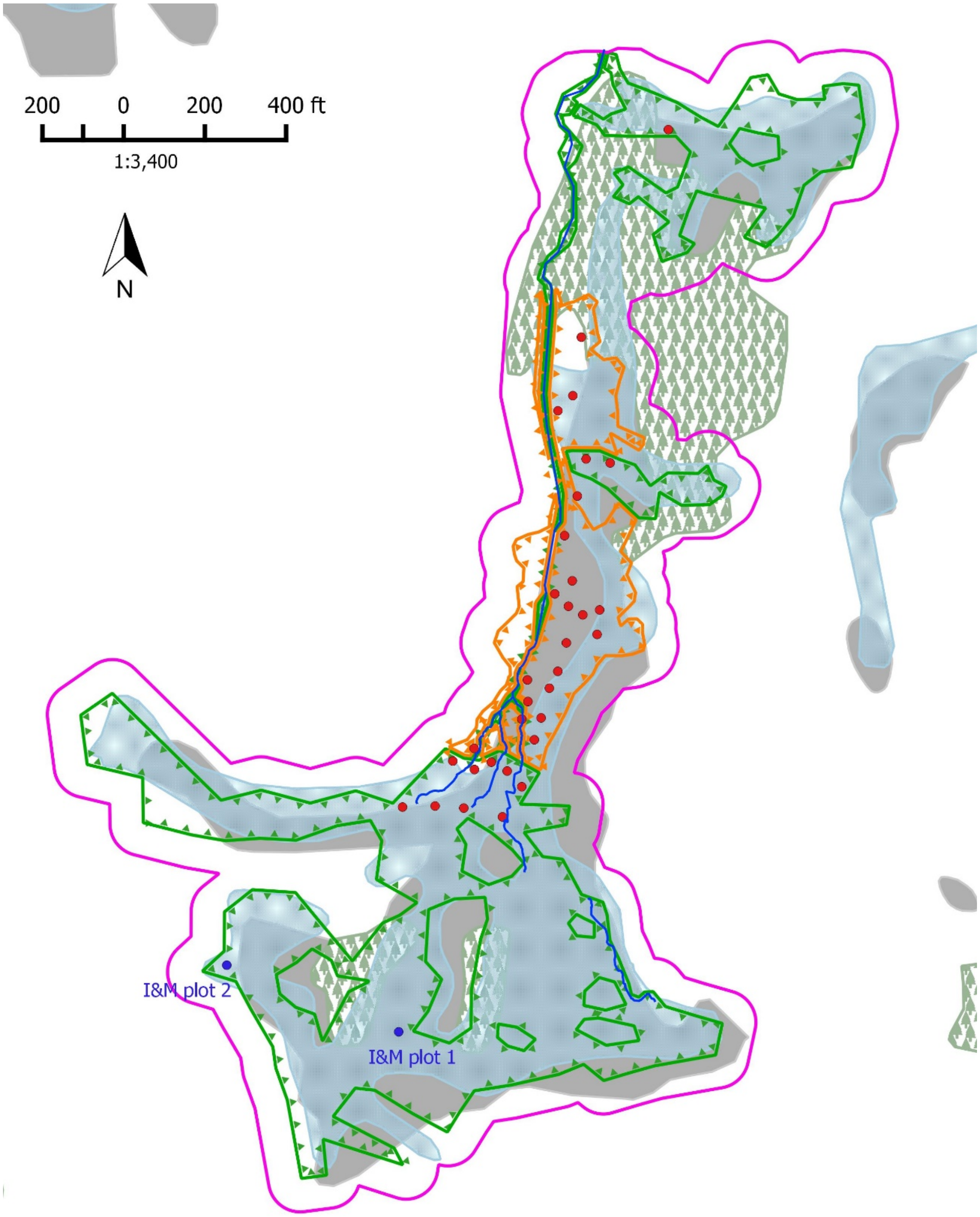

Figure 8. Overlay of the data collected directly by this project (red dots = data points, green-toothed line = wetland boundary, orange-tooth line = upland meadow or former meadow, purple line = study extent) with data from other efforts. Blue dots are field study plots from the Inventory and Monitoring Network meadows project. The blue-shaded polygons are wet meadows drawn by air-photo interpretation as part of SEKI's meadow monitoring program. The blue polygon at Cahoon meadow was classified as a fen/wet meadow complex with 10% of its area having peat at the surface. The grey-shaded and tree-symbol polygons are the National Wetlands Inventory air-photo-interpreted wetland extents. The grey areas were designated as palustrine emergent vegetation in saturated conditions (Cowardin code PEMB), and the tree-symbol areas were classified as palustrine forested vegetation in saturated conditions (PFOB).

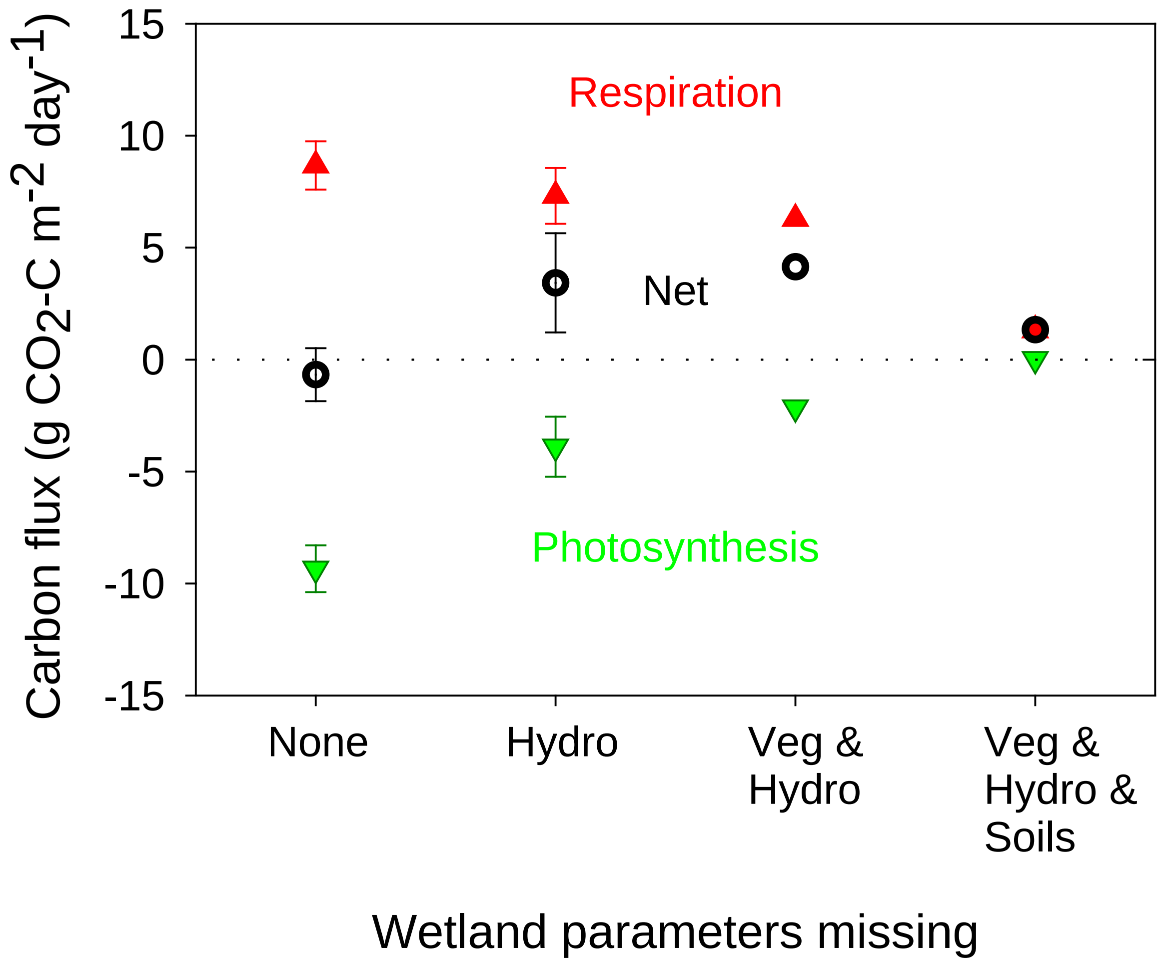

Figure 9. Single-day peak-growing season carbon flux measurements for wetland and non-wetland zones. Net carbon flux is the sum of photosynthesis (defined as a negative value) and respiration, with a positive value indicating net loss of CO_2 from the ecosystem to the atmosphere. The categories of missing wetland parameters correspond to the upland meadow zones delineated in Figure 7.

Figure 10. Overview of southern intact wetland above the headcut, representative of the vegetation in plots 1-9 (green zone in Figure 7).

Figure 11. A dry meadow terrace with remnants of a former peat soil that is no longer thick enough to qualify as a wetland soil. This area no contains no wetland indicators and is representative of plots 18-22, 24, and 29-31 (light tan zone in Figure 7).

Plot		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Delineated wetland?		YES	YES	YES	YES	YES	YES	YES	YES	YES	-	-	WoUS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	YES	YES	-	-	-	YES
Wetland vegetation?		YES	YES	YES	YES	YES	YES	YES	YES	YES	yes	yes	YES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	YES	YES	-	-	yes	YES
Wetland hydrology?		YES	YES	YES	YES	YES	YES	YES	YES	YES	-	-	YES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	YES	YES	-	-	-	YES
Wetland soil?		YES	YES	YES	YES	YES	YES	YES	YES	YES	yes	yes	YES	yes	yes	yes	yes	yes	-	-	-	-	-	yes	-	yes	-	YES	YES	-	-	-	YES
Organic soil thickness (in)		27	26	32	32	17	26	28	26	28	22	20	20	16	24	24	18	20	4	4	8	8	8	23	12	22	15	16	24	14	15	2	24
Water table depth (in)		11	8	1	10	10	1	22	20	13	>45	72	0	65	>43	>40	>57	>99	>33	>30	>26	>26	>28	>35	>31	>35	>39	19	22	>37	>33	>30	10
Other primary hydrologic indicators								A3, C3	A3, C3	A3, C3																		C3	C3				
Total aeral veg. cover		103	89	115	105	103	112	91	108	120	97	81	54	40	10	4	50	51	25	21	36	31	23	2	16	40	40	15	79	50	35	40	100
Prevalence index		1.1	1.1	1.2	1.3	1.3	1.1	1.2	2.0	1.4	2.4	1.6	1.8	3.5	3.6	3.0	4.4	4.2	5.0	4.8	4.5	3.7	4.7	5.0	4.9	3.8	3.8	1.0	1.1	4.1	4.7	2.5	1.3
Bare ground		--	--	--	--	--	--	--	--	--	5	20	50	60	85	95	40	40	80	80	70	80	80	95	95	50	50	45	5	50	60	10	--
Litter		--	--	--	60	80	70	10	80	--	-	-	--	-	5	1	15	15	10	-	3	5	15	3	5	10	10	40	80	-	5	60	40
Species	Wetland status																																
Carex utriculata	OBL	60	40	40	75	60	90	70	--	70	-	15	--	-	-	-	-	-	-	1	1	10	-	-	-	-	-	15	70	-	-	-	70
Oxypolis occidentalis	OBL	--	7	30	--	10	1	--	10	7	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Carex simulata	OBL	30	10	10	--	--	--	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Scirpus microcarpus	OBL	--	--	--	--	--	--	--	--	--	-	40	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Eleocharis quinqueflora	OBL	--	15	10	--	--	--	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Carex jonesii	OBL	5	10	--	--	--	--	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Stachys albens	OBL	--	--	--	--	--	--	--	5	--	3	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Carex scopulorum	OBL	--	--	--	--	--	5	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Viola macloskeyi	OBL	--	--	--	--	1	--	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Glyceria elata	FACW	--	--	--	--	--	--	5	70	15	60	15	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Bistorta bistortoides	FACW	7	--	15	30	25	15	15	5	25	-	-	--	-	-	-	-	-	-	-	-	-	1	-	-	-	-	--	7	-	-	1	25
Deschampsia caespitosa	FACW	--	--	--	--	7	--	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	20	--
Stellaria longipes	FACW	--	--	--	--	--	--	--	--	--	-	-	--	10	-	-	3	5	-	-	-	-	-	-	-	-	-	--	--	5	-	-	--
Dodecatheon jeffreyi	FACW	1	3	7	--	--	--	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	1	--
Senecio triangularis	FACW	--	--	--	--	--	--	--	7	--	-	1	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Thalictrum alpinum	FACW	--	--	--	--	--	--	1	--	--	5	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Juncus saximontanus	FACW	--	1	1	--	--	--	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	5	-	-	--
Galium trifidum	FACW	--	--	1	--	--	1	--	2	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	1
Epilobium ciliatum	FACW	--	--	--	--	--	--	--	1	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	1
Pinus contorta	FAC	--	--	--	--	--	--	--	--	--	-	-	--	-	-	4	-	-	-	-	-	-	1	-	1	15	15	--	--	-	-	-	--
Ribes nevadense	FAC	--	--	--	--	--	--	--	--	--	15	-	--	-	-	-	-	-	-	-	-	-	-	-	-	10	10	--	--	-	-	-	--
Poa pratensis	FAC	--	--	--	--	--	--	--	--	--	-	-	--	10	-	-	5	3	-	-	-	-	-	-	-	-	-	--	--	5	-	10	--
Veratrum californicum	FAC	--	--	--	--	--	--	--	3	--	-	-	--	-	1	-	-	-	-	-	-	-	-	-	-	-	-	--	1	-	-	5	--
Equisetum arvense	FAC	--	--	1	--	--	--	--	--	3	1	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	3
Potentilla gracilis	FAC	--	--	--	--	--	--	--	--	--	1	-	--	-	5	-	-	1	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Perideridia parishii	FAC	--	3	--	--	--	--	--	1	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	1	-	-	-	--
Luzula comosa	FAC	--	--	--	--	--	--	--	3	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Achillea millefolium	FACU	--	--	--	--	--	--	--	--	--	10	7	--	10	2	-	10	20	-	-	15	1	1	-	-	-	-	--	--	5	10	3	--
Gayophytum diffusum	UPL	--	--	--	--	--	--	--	--	--	-	-	--	-	2	-	25	15	20	15	15	15	15	-	10	15	15	--	--	5	15	-	--
Carex multicostata	UPL	--	--	--	--	--	--	--	--	--	1	3	--	10	-	-	7	5	5	5	5	5	5	2	5	-	-	--	--	25	10	-	--
Arabidopsis thaliana	UPL	--	--	--	--	--	--	--	--	--	1	-	--	-	-	-	-	1	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Agrostis pallens	UPL	--	--	--	--	--	--	--	1	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Boechera retrofracta	UPL	--	--	--	--	--	--	--	--	--	-	-	--	-	-	-	-	1	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Bryum pseudotriquetrum	NI	--	15	15	--	--	--	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--
Philontus fontana	NI	--	10	--	--	--	--	--	--	--	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	--

Table 1. Summary of hydrology, soils, and vegetation data used to determine wetland status of the 32 sampled plots. Other primary hydrologic indicators listed for wells 7, 8, 9, 27, and 28 follow USACOE standards and are as follows: A3 – Saturation, and C3 – Oxidized rhizospheres along living roots. Values for Bare ground, Litter, and individual plant species are % areal cover. Wetland indicator status is noted after each plant species name, NI=No indicator (applies to two moss species, these were not used to calculate prevalence index or total veg. cover). See text for discussion of prevalence index. Note that Plot 12 is designated as Waters of the US (WoUS) by USACOE standards because it lies below the Ordinary High Water Mark (OHWM) of the associated perennial stream.

Zone	Acres
Wetland above erosion gully headcut (0.089 ac are WoUS)	14.921
Middle east-side wetland arm	0.771
Lower east-side wetland	3.572
Riparian channel wetland (WoUS)	0.836
WETLAND MEADOW SUBTOTAL	20.100
USACOE Waters of the US (WoUS)	0.925
USACOE wetlands (WoUS excluded)	19.175
Upland, drained meadow, with wetland soils and veg (orange zone)	0.400
Upland, drained meadow, with wetland soils (brown zone)	0.572
Upland, drained meadow (tan zone)	3.104
Upland, erosion gully banks	0.942
UPLAND MEADOW SUBTOTAL	5.018
TOTAL MEADOW AREA	25.118
UPLAND FOREST AREA	26.680
TOTAL PROJECT AREA (purple zone)	51.798

Table 2. Summary of delineated wetland and upland areas of Cahoon Meadow. Zone colors refer to Figure 7.

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