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Natural Resource Stewardship and Science

# Florissant Fossil Beds National Monument Wetland Ecological Integrity

## *2009–2019 Synthesis Report*

Natural Resource Report NPS/ROMN/NRR—2023/2577

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Florissant Fossil Beds N.M. staff measuring groundwater depths at a long-term wetland monitoring site, 2011.

(NPS/BILLY SCHWEIGER)

# Florissant Fossil Beds National Monument Wetland Ecological Integrity

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E. William Schweiger, Joanna Lemly, Dana Witwicki, Kirk Sherrill, Ruth Whittington, Lewis Messner, Erin Cubley, Katharine Haynes

National Park Service
Rocky Mountain Inventory & Monitoring Network
1201 Oakridge Dr, Suite 200
Fort Collins, CO 80525

Editor:

Sonya Daw
National Park Service
Inventory and Monitoring Program
Ashland, OR 97520

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# Executive Summary

Wetlands at Florissant Fossil Beds National Monument (FLFO) are important because they are biodiversity hotspots and support iconic wildlife. They also provide valuable "ecosystem services" such as attenuating floods, storing water, recharging aquifers, stabilizing and sequestering sediment, storing carbon, enhancing water quality, and cycling nutrients. Wetlands also provide important aesthetic values and are highly valued by visitors. Florissant Fossil Beds NM also preserves some of the most cherished and important paleontological resources known in North America. The existing landscape, including its wetlands, helps tell the story behind the fossils the park protects. Preserving the ecological function of the landscape that holds these paleontological treasures is thus central to the park's mission.

This report summarizes 11 years (2009–2019) of wetland monitoring in three sentinel wetland complexes in FLFO. Monitoring included annual samples of 10 wet meadow and fen wetland sites in these complexes. We partition the data into a baseline period encompassing the first three years of our work for which we estimate conditions using a variety of indicators, or vital signs. We then estimate trend across the whole period of record. Results are compared to assessment points that allow us to interpret results in a management relevant context.

The following sections of the Executive Summary offer a synopsis of the most important methods and results. This is followed by high level "summary condition" statements that graphically highlight key results and provide a synthetic visual interpretation of status and trend of the park's wetlands. More detailed summary condition statements are included at the beginning of each section of the results.

## Methods

Our methods are documented in the peer-reviewed and published *Rocky Mountain Network Wetland Ecological Integrity Monitoring Protocol* (Schweiger, Gage, Driver et al. 2015; Schweiger, Gage, Haynes et al. 2015). They are largely derived from well-established and existing protocols developed by Rocky Mountain Inventory and Monitoring Network (hereafter, network) partners, including the U.S. Environmental Protection Agency, Colorado Natural Heritage Program, Montana Natural Heritage Program, and the U.S. Geological Survey. A standardized monitoring protocol facilitates comparison of the park's wetlands over time and to other wetlands in the ecoregions.

Sentinel wetland complexes are in important parts of the park: one is near the Hornbek historic site and Grape Creek close to the northern edge of the park; the Red Barn complex is also adjacent to Grape Creek but more centrally located in the park; and the Barksdale complex is again along Grape Creek but near the eastern side of the park. We collect data on vascular plant species composition, woody species stand structure and damage and mortality of woody stems (if present), soil chemistry, *in situ* groundwater chemistry, and we measure depth to water at shallow groundwater wells in each complex. (We measure depth to water by hand at all sites in later summer and with year-round loggers at one site in each complex.) Finally, we document human disturbance in and around each wetland complex.

A key step in analyzing and reporting wetland ecological integrity (WEI) data is interpreting the meaning behind a given result or set of results. In broad stroke, we interpret comparisons to reference values determined from assessment points in a collaborative way with park staff and management in the context of ecological theory, NPS Inventory and Monitoring (I&M) Division guidance, NPS resource management policies, and park management objectives. We use various terms to label levels of disturbance and ecological condition, including reference, intermediate, and non-reference. For non-biological measures such as groundwater levels, we use minor, moderate, or major levels of disturbance. A vital sign or indicator in a reference or minor disturbance state is within a range of values considered functional, intact, or loosely speaking, “good” condition. A non-reference or major disturbance status is degraded, dysfunctional or in a “bad” condition.

## Results and discussion

### *Climate and water balance*

Climate influences where wetlands occur as well as their area, biological diversity, and ecological functioning. Historical climate data show that total summer precipitation has not changed over the last seven decades in the park but mean summer temperatures increased at a rate of 0.3 °F per decade from 1950 to 2021. Climate projections indicate that summer temperatures will continue to get warmer, and that precipitation will be more variable in the future, which will undoubtably influence the hydrology of wetlands in the park.

Water balance helps us understand how temperature and precipitation interact with important features of the landscape like soils, aspect, and slope to influence water availability in FLFO wetlands. In this report, we focused on key water balance indicators that are important to wetlands, such as climate water deficit, runoff, and drainage, and used these where appropriate to improve our trend models. Climatic water deficit is a measure of unmet water demand that roughly translates to drought stress that plants experience.

Models of water balance in FLFO show high climatic water deficit during periods of drought in 2009–2013 and 2017–2019, suggesting higher drought stress to wetland plants during these times. Annual runoff decreased during these same periods because there is little excess water to generate runoff in drought years. Given overwhelming evidence in the literature, the condition of climate and water balance in FLFO wetlands warrants significant concern and will likely continue to deteriorate. Projections show a rapidly increasing climatic water deficit at FLFO, more than doubling by 2100. Runoff decreases over this period are also expected given more drought-like conditions. There will likely be less snow, earlier peak flows in streams and groundwater, warmer temperatures, and more intense storms. These projections suggest that climate change will likely reduce the number and extent of wetlands in the park and cause declines in the condition of associated flora and fauna and critical ecological functions, such as carbon and water storage.

### *Disturbance*

Human use can cause disturbance to wetlands across multiple scales and has well documented relationships with wetland condition. Wetlands at FLFO were impacted by over a century of cattle ranching and other human uses that increased soil erosion, altered hydrology, and made the area more susceptible to invasion by exotic plant species. This history of land use still impacts ecological

conditions in the park. We evaluated disturbance at FLFO wetlands using two indices that each focus on a different scale of disturbance.

The Landscape Disturbance Index (LDI) combines several types of GIS data to estimate disturbance at a landscape scale. It can be used to compare our monitoring sites to other wetlands across the park or the state. Within the park, LDI showed low levels of disturbance in the valley bottoms, where wetland sentinel sites are located, with moderate levels immediately adjacent to roads and trails. The main factor likely driving these disturbance levels was residential development in areas surrounding this relatively small park unit. LDI at our FLFO sentinel sites was low to moderate compared to other wetlands across the state that ranged from urban to pristine wilderness.

The Human Disturbance Index (HDI) focuses on smaller scale disturbances, such as trails or ditches, at each monitoring site that the crew can detect during sampling events. HDI scores at most sentinel sites were within an intermediate disturbance class and showed an overall decrease from 2009 to 2019. Of note, HDI values were reduced in the Hornbeck complex after 2012 when a deeply incised channel was filled in and restored and groundwater levels rose in the wetland. However, the cause of this is difficult to pinpoint, since the timing of the recovery also aligned with the end of a drought.

Both indicators generally showed an intermediate level of disturbance in and around our sentinel sites. The similarities in results between the LDI and HDI suggest that these estimates of disturbance are appropriate and reliable indicators, supporting their use in analyses of FLFO wetland hydrology and vegetation.

#### *Hydrology*

Groundwater is one of the most important drivers of wetland condition and a large part of what defines a wetland. The roots of wetland plants depend on access to groundwater, and seasonal and annual patterns of groundwater levels in wetlands are related to climate in the watershed. Understanding hydrology is critical to understanding influences (and interactions) of other drivers and stressors on wetlands. We evaluated two indicators of groundwater hydrology at FLFO sentinel wetlands: 1) discrete depth to water (DTW) sampled at all 10 wetland sites in late summer, and 2) continuous DTW evaluated throughout the growing season at one site in each of the three wetland complexes. Discrete DTW is useful for understanding condition and changes across all of the sites that we sample, while continuous DTW allows us to understand important seasonal patterns and connections to climate drivers.

Median groundwater level in sentinel fens was higher than in wet meadows, which is a large part of what defines these two different wetland types. Discrete groundwater levels across all sites did not have a significant trend, but measurements were often below (or drier than) their assessment points, especially during periods of drought, which led to an overall rating of caution for this indicator. Across all sites and indicators, we generally saw lower groundwater levels in response to the drought conditions in 2010–2013 and in 2017–2018. However, groundwater at site 708 in the Hornbek complex responded differently, potentially benefiting from a restoration project that filled incised channels in late summer 2012. Like other sites, groundwater levels rose at site 708 in 2014 at the end of the drought. Yet groundwater did not decrease strongly in 2017–2018 during a second drought,

like it did at other sites. Although we cannot fully tease out how much climate and the restoration project each contributed to this, we suggest that the Hornbek restoration may have enhanced resilience of the site to drought. Because of this result, the condition of continuous DTW at the restored Hornbek site was good and improving, while the other two sites were in intermediate condition and stable. Relationships between DTW and disturbance indices, especially the hydrologic alteration component of the HDI that specifically scores how human use has impacted hydrology, indicate that where or when there are more human changes to hydrology, groundwater is deeper below the surface and more difficult for plants' roots to access.

### *Vegetation*

Wetlands are biodiversity hotspots, rich in native plant species and important resources for wildlife. The condition of wetlands can be better understood by looking at the kinds of plants they support—a method called bioassessment. We evaluated four vegetation metrics using a bioassessment approach: nativity, wetland affinity, conservatism, and overall ecological condition.

The amount of native species cover is an important indicator because nonnative species can be invasive and have undesirable effects on ecosystem function. Levels of native species in our wetland sites were generally high. However, a few sites had nearly 50% total cover of invasive taxa in some years. We assessed baseline native cover of wetland sentinel sites compared to undisturbed reference condition wetlands from across the ecoregion. Fen sites were in a reference condition, whereas wet meadow sites were in intermediate condition, due to higher cover of nonnative plants and lower cover of native plants at some of these drier sites. Natives were more abundant at sites with lower human disturbance and responded positively to wetter conditions—both of which are expected and show the strong response of wetland condition to human disturbance. There was no statistical trend in relative cover of native species or any of the other vegetation indicators that we evaluated.

Hydrophytic plants are those that persist in or have an affinity for wetlands. Hydrologically stable, reference condition wetlands generally have more hydrophytic species. Fen sites, with their generally higher groundwater levels, had higher median relative cover of hydrophytic species than wet meadows. Like native cover, hydrophytic plant species cover varied by site. When compared to undisturbed sites in the ecoregion, cover of hydrophytic species at FLFO fen and wet meadow sites was in a reference condition. Overall, there was no statistical trend in relative cover of hydrophytic species, although there is a suggestion of a reduction across time and some non-linear patterns. Wetland affinity increased after the 2012 restoration at Hornbek site 708, and the increase in hydrophytes at this site appears to have persisted through 2019, suggesting that the restoration of higher groundwater levels had a lasting impact, or at least that the site became more resilient to drought. We also saw a general pattern for wetland obligate cover to be higher at sites with lower human disturbance and wetter conditions.

Conservatism, as estimated by the Floristic Quality Index (FQI), describes a species' fidelity to a specific habitat or range of environmental conditions absent human disturbance. More conservative species are not able to quickly adapt to habitat degradation and are often the first to disappear from habitats heavily impacted by human activities. Fen sites had higher median FQI than wet meadows, due to their more stable groundwater levels, and were in reference condition. Wet meadows, which

are more susceptible to natural disturbances like fluctuations in groundwater levels, had FQI scores in intermediate condition. Unexpectedly, FQI increased with disturbance at some FLFO sentinel sites, perhaps because more weedy species increased species richness and elevated FQI. However, as expected, FQI also increased at other sites with increasing groundwater level, supporting the park's maintenance of wetland hydrology.

For an overall condition index of wetlands in the park, we used the Vegetation Index of Biotic Integrity (VIBI) developed for Colorado wetlands by the Colorado Natural Heritage Program (CNHP). The VIBI combines nine individual metrics into a synthetic overall condition index (much like the Dow Jones Industrial Average index is used to understand the performance of the stock market). Compared to assessment point values from CNHP's work in Colorado mountain wetlands, we found that FLFO fens were in intermediate condition, while wet meadows were in reference condition. However, these assessment points may compare FLFO wetland sites to a disturbance gradient more pristine in nature and thus may place FLFO in lower condition classes than a more localized set of assessment points would. There was no statistically significant trend in VIBI, although there is a suggestion of a reduction across time—or a decrease in condition. However, some non-linear patterns in VIBI may also reflect improvements from the Hornbek restoration. Changes in VIBI are less persistent than some other indicators and are more strongly confounded by wetter conditions following restoration. The VIBI was negatively related with derived measures of disturbance, especially those at larger scales. Overall, the VIBI may provide a useful synthetic perspective on the park's wetland condition, but additional work is needed to better understand the tool.

### Management applications

A fundamental goal of network long-term inventory and monitoring is to provide park managers with data and information useful for protecting and managing park resources. Our monitoring of wetland ecological integrity can help in several general ways. First, our findings provide baselines for understanding the current status and future changes/trends in wetlands in FLFO. Second, our data can be used to quantify the importance of various "stressors" and "drivers" of wetland health (e.g., visitor impacts, groundwater hydrology, etc.), thereby directing limited resources to the most important stressors and drivers. Lastly, protected landscapes such as FLFO do not insulate wetlands from the direct and indirect impacts of a changing climate regime. Management and interpretive strategies should include how changing climate might shift ecological conditions in the park, and this long-term monitoring helps predict what these changes might be. Our results offer several examples of this, including the likely increased importance of runoff or drainage in maintaining future groundwater as climate shifts. Management should be sure to design restoration strategies with climate change in mind, selecting species that are more likely to adapt to future changes than others. This may also be an important, if subtle, point for the park's interpretive staff and their interaction with the public regarding climate change.

### Future wetland monitoring

This effort has been, and will continue to be, a cooperative undertaking between network staff and our partners—most importantly, park management and staff. We believe our results, representing the

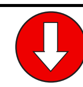
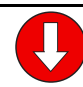
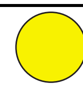
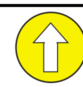
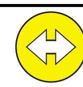
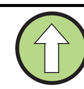
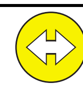
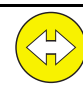
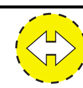
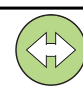
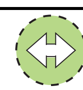
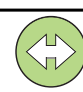
work of dedicated scientists and resource managers over several years, address our objectives, are valid, representative, and in many cases, actionable. However, our data are still relatively "short," and we are still only at the beginning—it will take many more years to have sufficient data to fully understand long-term trends. As we accrue data, we will continue to improve our understanding of the mechanisms and drivers behind wetland responses in the park.

Finally, recent work suggests that the impact from climate change on biological condition may be offset if other stressors on a system are reduced. In a sense, this is like paying the climatic debt with accrued environmental credit. Parks like Florissant are well positioned to do this—the park already has a rich bank account full of environmental credit, given its protected context. These results offer a path forward for park resource management to further improve that environmental credit while they also work to maintain the park for future visitors.

### Summary condition

Summary condition statements are presented throughout this report as syntheses of our most important results. A summary condition statement includes supporting narrative and a symbol designed to convey with a glance the condition and trend in an indicator and our confidence in the assessment. We present high-level, visual only summary condition results for the core indicators monitored at FLFO from 2009 to 2019 in the following summary condition table (Table ES1). More detailed summary condition statements with explanatory text begin each chapter in the main body of the report. The Rocky Mountain Network's approach to the summary condition statements presented in each chapter of this report includes a fair degree of detail in the text. This allows a resource management audience to focus only on these sections of the report to glean both the most important results and some key context and description. That said, summary condition statements are simplifications of the details within the full results of this report, and they should be used with caution. For example, where there are divergent patterns in indicators within a group or across sites, the main narrative of the report and its figures should be reviewed.

**Table ES1.** Summary condition table for status and trend of select vital signs in Florissant Fossil Beds National Monument sentinel wetland sites, Colorado, 2009 to 2019. Hyperlinks connect to more detailed summary condition statements in the body of this report, which themselves synthesize the full analytical results. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/ moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

| Vital sign | Indicator | Status, trend, and confidence |
|---|---|---|
| Climate | Temperature and precipitation |  |
| Climate | Water balance (deficit, runoff) |  |
| Disturbance* | Landscape Disturbance Index (LDI) |  |
| Disturbance* | Human Disturbance Index (HDI) |  |
| Groundwater hydrology | Discrete hand measured groundwater depths |  |
| Groundwater hydrology | Hornbek continuous growing season groundwater depths |  |
| Groundwater hydrology | Red Barn continuous growing season groundwater depths |  |
| Groundwater hydrology | Barksdale continuous growing season groundwater depths |  |
| Nativity (wetland condition) | Relative cover native species |  |
| Affinity (wetland condition) | Relative cover hydrophytic species |  |
| Conservatism (wetland condition) | Floristic Quality Index |  |
| Bioassessment (wetland condition) | Vegetation Index of Biotic Integrity |  |

*Disturbance is not a formal "vital sign" for the Rocky Mountain Network, but an important indicator of wetland condition; disturbance is tracked in most of the network's monitoring protocols.

## Acknowledgments

This report was prepared by staff from the Rocky Mountain Inventory and Monitoring Network and Colorado Natural Heritage Program.

We would like to especially thank Rick Wilson and Penny Wagner, and all Florissant Fossil Beds National Monument staff for being accommodating and supportive with logistics, housing, and use of office resources and with adapting network wetland (and all) monitoring to the management needs for the park. We would like to thank everyone who assisted with, or facilitated, field work on park wetlands monitoring. We benefited from similar efforts and freely shared advice of other NPS monitoring networks, especially the Sierra Nevada Network and Northeast Temperate Network.

Finally, we thank Sonia Bingham from the National Park Service and Jeremy Sueltenfuss from Colorado State University for their detailed peer reviews that greatly improved this report. We also gratefully acknowledge guidance and input from Dr. David Cooper, Senior Research Scientist, Colorado State University for his many years of research and applied ecology on Rocky Mountain wetlands, including in Florissant Fossil Beds National Monument.

## List of Abbreviations

CDF: Cumulative Distribution Function

CNHP: Colorado Natural Heritage Program

DTW: Depth to water

EPA: Environmental Protection Agency

FLFO: Florissant Fossil Beds National Monument

HDI: Human Disturbance Index

I&M: National Parks Service Inventory and Monitoring Program

LDI: Landscape Disturbance Index

NPS: National Park Service

NRCS: Natural Resource Conservation Service

NWI: National Wetland Inventory

SEI: NPS Rocky Mountain Network stream ecological integrity monitoring program

WEI: NPS Rocky Mountain Network wetland ecological integrity monitoring program

# 1 Introduction

## 1.1 The National Park Service Inventory and Monitoring Program

The purpose of the National Park Service (NPS) Inventory and Monitoring (I&M) Program (Fancy et al. 2009) is to develop and provide scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems (i.e., ecological integrity). As part of the NPS's effort to improve park management through greater reliance on scientific knowledge, a primary role of the I&M Program is to collect, analyze, and synthesize data for specific natural resource vital signs.

The Rocky Mountain Inventory and Monitoring Network and its partner parks and scientific collaborators identified 12 high-priority vital signs for focused, long-term monitoring. These vital signs include wet and dry deposition; weather and climate; water chemistry; surface water dynamics; freshwater communities; invasive/exotic aquatic biota; groundwater dynamics; wetland communities; invasive/exotic plants; vegetation composition, structure, and soils; focal species (beaver, elk, grizzly bear, and Great Sand Dunes National Park and Preserve endemic insects); and landscape dynamics (Britten et al. 2007).

Wetland ecological integrity (WEI) monitoring (hereafter wetland monitoring or similar) in Florissant Fossil Beds National Monument (FLFO, or the park) addresses three of the network's 12 high priority vital signs: wetland communities, groundwater dynamics, and invasive/exotic plants. Two other high priority vital signs are indirectly linked with the WEI protocol: landscape dynamics, and weather and climate.

The WEI protocol (Schweiger, Gage, Driver et al. 2015) provides the rationale for the WEI design and field elements, summaries of analytical methods, an overview of data management, and an administrative plan for long-term implementation. The WEI protocol also includes a series of standard operating procedures (SOPs; Schweiger, Gage, Haynes et al. 2015) that provide detailed instructions for executing field, data management, analytical, and administrative components of the protocol.

## 1.2 Purpose of report

This report presents summaries and interpretation of status and trend WEI monitoring conducted from 2009 to 2019 in FLFO. We include data collected from 10 individual sites in three high profile FLFO wetland complexes. The results focus on disturbance within and surrounding the wetlands and the relationships among disturbance, groundwater hydrology, groundwater chemistry, soil, and vegetation. To facilitate the interpretation of condition, this report utilizes a bioassessment approach (i.e., Barbour et al. 1999) to estimate the ecological integrity (Karr 1993) of wetlands relative to undisturbed or reference conditions (Stoddard et al. 2006). The intent of this assessment of wetland condition at FLFO is to help park managers and other stakeholders better understand and effectively manage important wetland resources in the park.

## 1.3 Florissant Fossil Beds National Monument

Florissant Fossil Beds National Monument is 35 miles west of Colorado Springs, Colorado, in the Front Range of the Southern Rocky Mountains at ~2,600 m (8,530 ft) in elevation (Figure 1).

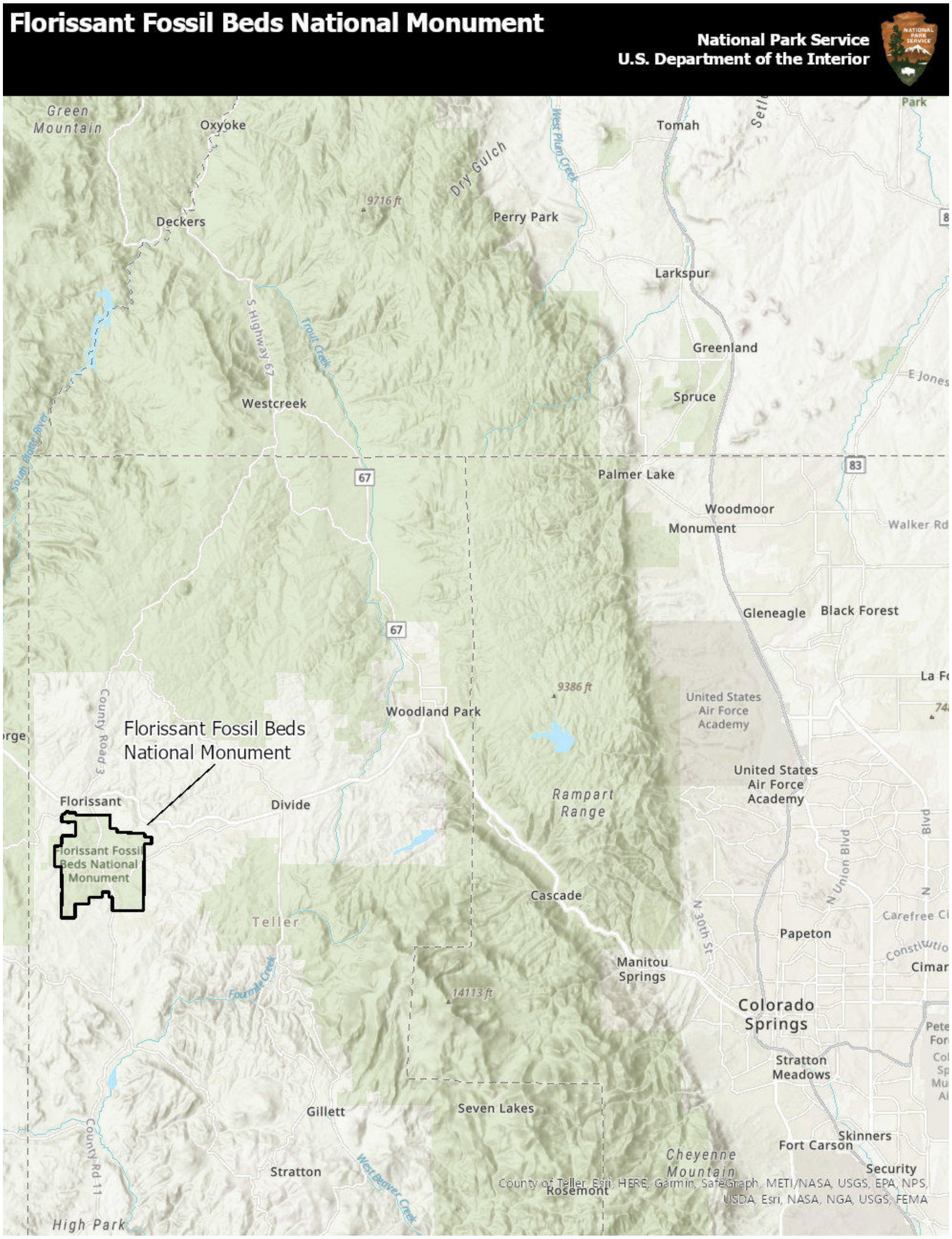



**Figure 1.** Florissant Fossil Beds National Monument and surrounding vicinity. The park is located within Colorado's Front Range, west of Colorado Springs, Colorado.

The climate is continental with a warm growing season from May to October and harsh, cold winters. Precipitation averages 370 mm (15 inches) and afternoon summer convective storms are common from mid-July to September—these late summer monsoons can be very important. The park covers 2,428 ha (6,000 ac or 9.4 $mi^2$) of tree covered hills and ridges surrounding low grassy meadows and wetlands in the montane ecological zone. Dominant tree species are ponderosa pine (*Pinus ponderosa)*, Douglas fir (*Pseudotsuga menziesii*), aspen (*Populus tremuloides*), and blue spruce (*Picea pungens*). Common grasses include Parry's oatgrass (*Danthonia parryi*), mountain muhly (*Muhlenbergia montana*), and Arizona fescue (*Festuca arizonica*).

Established as a national monument in 1969, FLFO contains paleontological, geological, and educational resources of international significance. Due to the concentration of fossils preserved in shale layers of the Florissant Formation, the park is considered one of the premier fossil resource areas of the world. The area is particularly known for its diverse, detailed, and abundant fossils of insects and vegetation, including petrified redwood stumps dating back millions of years (Figure 2). The park is also known for its cultural history dating to the homestead era of the late 1800s. The Hornbek Homestead at the northern end of FLFO (Figure 3) was home to Adeline Hornbek, the first female to file a homestead claim in the state of Colorado; Hornbek rose to prominence as a successful cattle rancher in the region (McChristal 1994; NPS 2022).

**Figure 2.** Petrified redwood tree stump in Florissant Fossil Beds National Monument. (NPS)

**Figure 3.** Hornbek Homestead at Florissant Fossil Beds National Monument, Colorado, showing the meadow character of the landscape. (© JEREMY SUELTENFUSS, CSU)

### 1.4 Wetlands of Florissant Fossil Beds National Monument

Prior to homesteading in the 1870s, the landscape that is now FLFO supported natural wet meadows, fens, and riparian wetlands at points of groundwater discharge or where surface water concentrated. The park is located high in the Grape Creek drainage, a small tributary to Twin Creek that drains to the South Platte River. In this landscape position, saturated groundwater-fed wetlands and headwater streams can be relatively common. There are two types of wetlands in FLFO, fens and wet meadows, as classified by the Rocky Mountain Network using a Rocky Mountain wetland classification system (Cooper 1998; Gage and Cooper 2013). This classification builds upon other systems but is specialized for wetlands in network parks. Our approach emphasizes both hydrology and soils. It uses intuitive names that are specific to the landscapes in and around network parks. See Appendix 1 for more details on FLFO wetlands.

#### *1.4.1 Wetland disturbance*

The wetlands of FLFO have been impacted by over a century of post-settlement land use. Originally homesteaded in the 1870s, the land encompassing FLFO was a cattle ranch until the park's formation. The central valley of FLFO contains groundwater-fed wet meadows and fens that discharge into small headwater streams. In the 1940s and 1950s, ranchers built a series of small dams and reservoirs along these streams to store seasonal stream flows for livestock watering and to irrigate hay crops. Over time, the impoundments significantly altered stream flow. In the late 20th

century, the streams avulsed around the dams, causing dramatic incision (more than 2 m in many areas) that drained the surrounding meadows (Figure 4). Heavy grazing during this time likely exacerbated the drying of meadows and fens, as cattle trampling can form pathways for drainage (Jones 2000; Cooper et al. 2005).

**Figure 4.** Deeply incised channel on Hornbek Ranch, 2011, in Florissant Fossil Beds National Monument, Colorado. (NPS/ BILLY SCHWEIGER).

As the wet meadows dried, they became more susceptible to invading exotic plant species. Today, invasive plants are pervasive and persistent throughout most FLFO wetlands. Intensive exotic species management is required each year to limit the spread of these species. Along with the hydrologic alteration from the original homestead, roads and structures continue to divert and impound water around some wetlands, continuing their vulnerability to exotic plant invasion. Although current visitor use is unlikely to have a strong effect on the wetlands, global anthropogenic impacts, such as nitrogen deposition and climate change, have influenced and will continue to influence wetland character and extent. The fens and wet meadows of FLFO are affected by all these issues, but topographic position, hydrologic regime, water inputs, and proximity to disturbance determine the degree of impact.

While the pressure of cattle grazing was removed from the park decades ago, erosion and gullying during the late 1990s and early 2000s occurred at a rate that concerned FLFO's managers, with likely impacts on wetlands and other systems across the park. Incision and erosion were particularly acute in the area surrounding the historic Hornbek Homestead (hereafter "Hornbek"), which is an important visitor use and demonstration area. Erosion and damage to the wetlands affects both the integrity of the ecosystems and also the visitor experience. The degraded meadows do not reflect natural conditions during the homestead era, which the public expects to see. Concern over the meadows prompted NPS to partner with researchers at Colorado State University to undertake a restoration of the meadows around the Hornbek Homestead.

#### *1.4.2 Wetland extent*

The extent of wetlands in FLFO can be estimated from two existing data products, National Wetland Inventory (NWI) mapping and the NPS vegetation map for FLFO (Story et al. 2004). NWI mapping for FLFO (Table 1; Figure 5) was updated based on 2011 aerial imagery by the Colorado Natural Heritage Program (CNHP; Lemly et al. 2016) and is now more accurate than older NWI estimates presented in the WEI protocol (Schweiger, Gage, Driver et al. 2015). The NWI area is still only approximate, however, because mapping was not verified on the ground. The NWI data are also not classified to the exact wetland types used in network monitoring or to the vegetation community, but limited to dominant plant lifeform (physiognomy) and likely water regime, following the Cowardin et al. (1979) system. The FLFO vegetation map data (Table 2, Figure 6) are older than the NWI, but were based on field data collection and are classified to park-specific vegetation (including wetland) communities.

**Table 1.** Florissant Fossil Beds National Monument (FLFO) wetland extent calculated from 2011 National Wetland Inventory (NWI) data. Polygons were hand digitized using 1-m digital color infrared imagery and attributed with the NWI Cowardin classification.

| Wetland type (Generalized NWI Class) | Count | Mean patch size (ha) | Total area (ha) | % FLFO wetland area | % FLFO land area |
|---|---|---|---|---|---|
| Palustrine Aquatic Bed (PAB) | 2 | 0.2 | 0.4 | 0.4% | <0.1% |
| Palustrine Emergent (PEM) | 59 | 1.2 | 72.5 | 70.1% | 3.0% |
| Palustrine Scrub Shrub (PSS) | 17 | 0.3 | 5.2 | 5.0% | 0.2% |
| Palustrine Unconsolidated Bottom (PUB) | 5 | 0.1 | 0.6 | 0.5% | <0.1% |
| Palustrine Unconsolidated Shore (PUS) | 3 | <0.1 | 0.1 | 0.1% | <0.1% |
| **Total Palustrine** | **N/A** | **N/A** | **78.8** | **76.2%** | **3.2%** |
| Riverine Streambed (R4SB) or Unconsolidated Bottom (R3UB) | 42 | 0.6 | 24.7 | 23.8% | 1.0% |
| **Total NWI** | **N/A** | **N/A** | **103.5** | **100.0%** | **4.3%** |

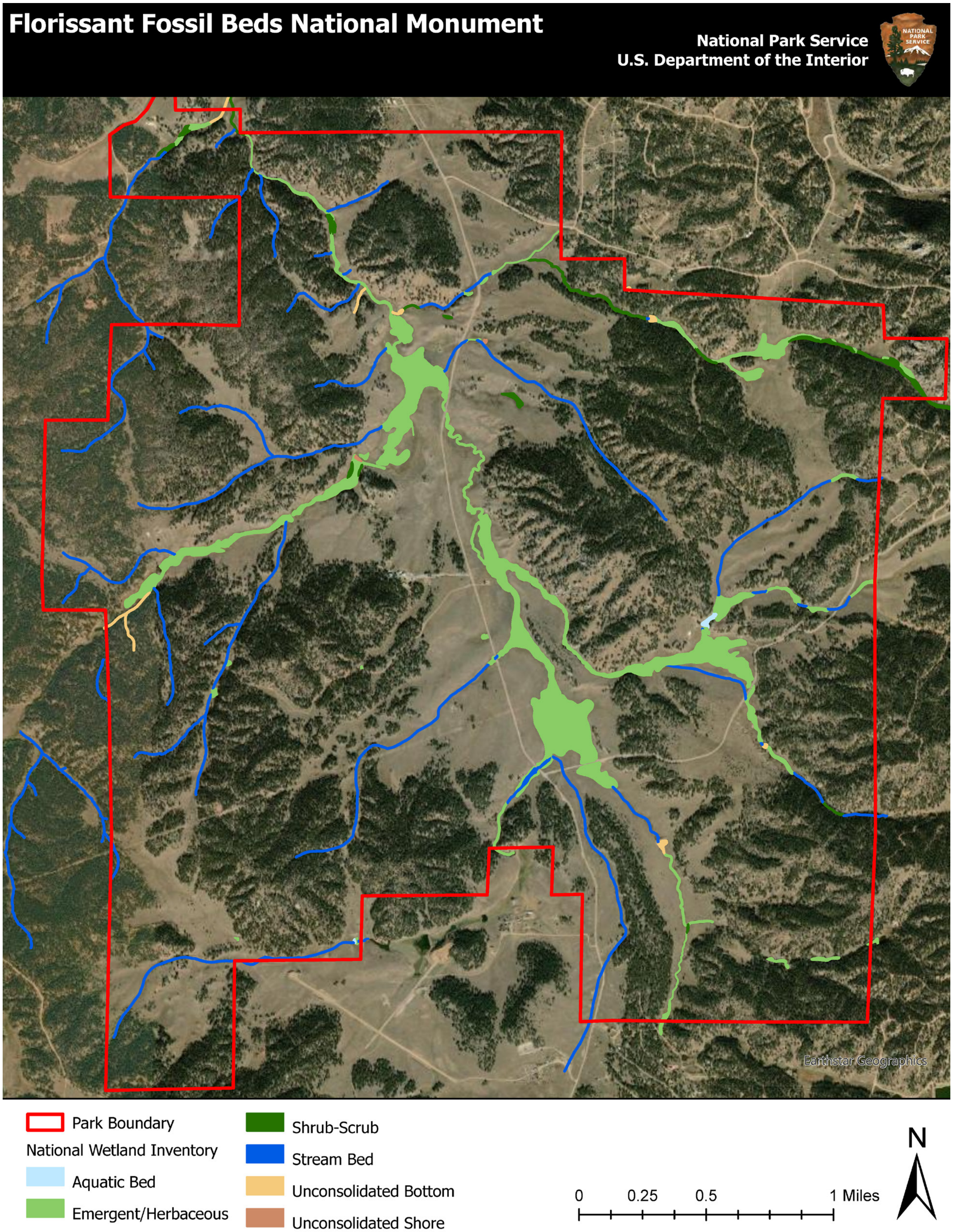



**Figure 5.** National Wetland Inventory mapping in Florissant Fossil Beds National Monument updated based on 2011 aerial imagery by the Colorado Natural Heritage Program.

**Table 2.** Florissant Fossil Beds National Monument (FLFO) wetland extent calculated from 1996 vegetation map data. Polygons were hand digitized using 1:15k imagery and attributed with park-specific map unit names.

| **Wetland type (Vegetation map mapunit)** | **Count** | **Mean patch size (ha)** | **Total area (ha)** | **% FLFO wetland area** | **% FLFO land area** |
|---|---|---|---|---|---|
| Aquatic Sedge-Beaked Sedge-Baltic Rush Herbaceous Vegetation | 44 | 2.1 | 90.8 | 92.0% | 3.7% |
| Mountain Willow Shrubland | 16 | 0.5 | 7.4 | 7.5% | 0.3% |
| Sandbar Willow Temporarily Flooded Shrubland | 2 | 0.2 | 0.4 | 0.4% | <0.1% |
| Shortfruit Willow Shrubland | 1 | 0.1 | 0.1 | 0.1% | <0.1% |
| **Total vegetation map** | **N/A** | **N/A** | **98.7** | **100.0%** | **4.1%** |

Both data sources estimate approximately 100 ha of wetland or streams within FLFO, concentrated in the central valley along the drainage network of Grape Creek and its tributaries. These 100 ha represent just over 4% of the FLFO land area. However, the NWI data include the streambeds (Riverine polygons) as well as wetlands (Palustrine polygons). Total Palustrine wetland area within the NWI mapping is only 78.8 ha compared to 98.7 ha within the park's vegetation map. This may indicate drying between 1996 and 2011 or it may be due to differences in mapping methods (or both). Both datasets show a predominance of herbaceous wetlands, classified as Palustrine Emergent in the NWI data and Aquatic (Water) Sedge-Beaked Sedge-Baltic (Mountain) Rush Herbaceous Vegetation in the vegetation map. Willow-dominated shrub wetlands occupy far less area in FLFO. Importantly, the three systems we apply to wetland classification in FLFO likely overlap and have unknown errors of ommission and commission. Where or when needed we can likely crosswalk among them based on floristic data at our sites.

Wetland area is of interest to the network because more wetland area is generally considered more desirable than less wetland area. Currently, it is difficult to say how wetland area at FLFO has changed in the recent past, but wetland area across the state and region has dramatically declined, and this is likely the case for FLFO as well. As data products are updated over time, we will carefully track how wetland extent changes in the park.

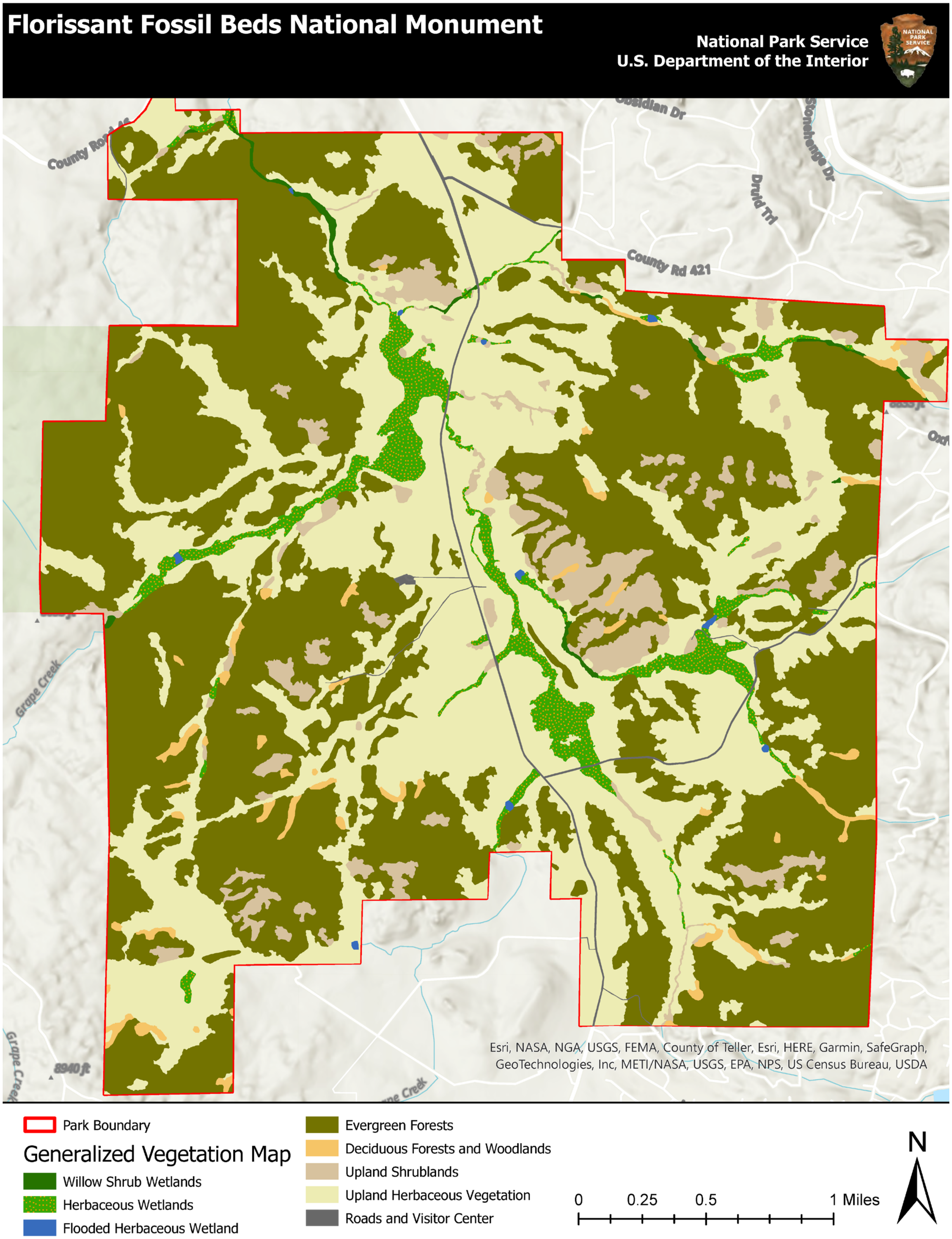



**Figure 6.** Generalized vegetation map of Florissant Fossil Beds National Monument based on 1996 conditions (Story et al. 2004).

## 1.5 Rationale and justification for wetland monitoring

There were several reasons for conducting long-term wetland monitoring in FLFO. Though wetlands comprise only a small portion of western landscapes, they are widely recognized for their importance supporting biodiversity and ecosystem functions (Naiman et al. 1993; Cooper and Sanderson 1997; Stohlgren et al. 1997; Mitsch and Gosselink 2007). In Colorado, wetlands occupy less than 2% of the landscape but contain more than 14% of the state's native plant species (Cooper 1990). Wetlands also perform valuable ecosystem services such as water purification, nutrient cycling, groundwater recharge, regulation of global levels of greenhouse gases, and are vital to many species of wildlife (Zedler and Kercher 2005). However, wetlands are among the most significantly altered ecosystems in North America due to current and historical anthropogenic impacts, including land development and hydrologic modification, as well as indirect effects like atmospheric deposition, exotic species invasion, and climate change (Patten 1998; Bedford and Godwin 2003; Zedler and Kercher 2005).

### *1.5.1 Wetlands as biodiversity hotspots*

Impacts to biodiversity and wetland functioning occur even in protected landscapes (Schweiger et al. 2016). A high amount of FLFO's floristic diversity is in the park's wetlands, yet these wetlands have a long history of human impacts from ranching and suburban land uses. This is both innately important and suggests wetlands are likely useful as indicators of FLFO's ecological integrity. Wetlands in the central valley of FLFO also provide important aesthetic values and are highly valued for visitor experiences.

A checklist of vascular plants of FLFO was created by Edwards and Weber in 1990, following eight years of surveying (Edwards and Weber 1990). The list was updated in 2002 by CNHP (Spackman Panjabi and Anderson 2002). The original species list was very inclusive and documented over 430 taxa in the park. Network monitoring in wetlands from 2009 to 2019 has documented 151 species of vascular plants in our sentinel sites. An additional 30 unique records of genera level taxa have also been recorded from these sites. Fourteen nonvascular taxa have also been identified to species, but this is likely an undercount because we only collected and identified mosses in the first two years of our work, given cost constraints. Even though we do not have a parkwide representative sample of the park's wetland flora, our species list represents 35% of the park's total known floristic diversity and wetlands only account for around 4% of the park's total area.

### *1.5.2 Protecting and understanding ecological integrity*

Wetland ecological integrity monitoring focuses on the estimation and the interpretation of the ecological integrity of wetlands in the park (Schweiger, Gage, Driver et al. 2015). Ecological integrity is the capacity to support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region (Karr 1991). It is a complex, multidimensional concept and usually a single indicator is insufficient to characterize it. Therefore, we use an integrated set of response measures, including hydrology, soils, and disturbance. These are important aspects of wetlands, and they also help us to better apply bioassessment via community-level floristic composition and vegetation structure to FLFO's wetlands.

### *1.5.3 Regulatory needs*

Regulatory considerations under the NPS Organic Act, the Clean Water Act, and other laws, regulations and policies relative to network wetland monitoring are summarized in the network WEI protocol (Schweiger, Gage, Driver et al. 2015). While regulatory considerations provide an important context for network WEI monitoring, our emphasis on long-term ecological integrity monitoring is a key distinction from wetland monitoring conducted by other federal agencies like the EPA and states.

### *1.5.4 Restoration support*

Restoration activities can reestablish the ecological integrity of impaired wetlands, although these efforts on National Park Service lands may be expensive. However, recent collaborations between the National Park Service, the Army Corps of Engineers, and various private organizations highlight the potential to achieve wetland restoration goals through regulatory wetland mitigation. Wetland mitigation is required when organizations need to offset impacts to other wetlands. The difficulty of this process on public lands includes identifying impaired wetlands, but also identifying reference wetlands and establishing thresholds to evaluate restoration success. By partnering with the National Park Service, impacts to nonpark wetlands can be mitigated by paying for restoration on public (i.e., NPS) lands, thereby significantly lowering the investment required by the NPS.

During the summer of 2012, researchers studied the topography, vegetation, and groundwater of meadows surrounding the Hornbek Homestead. These data were used to develop cross sections to characterize incised channel widths and depths, calculate volumes of available fill from historical dams on site and volumes needed to fill reaches of the incised channel. These data were used to develop topographic maps of disturbed meadows and undisturbed reference meadows. Vegetation plots were analyzed to relate hydrologic conditions to vegetation composition. Using these data, a pilot restoration project was designed and implemented in the fall of 2012. The pilot project moved approximately 400 $m^3$ of fill from three small relict earthen dams to form plugs in the existing incised channels to measure the water table response to the project (Figure 7). Although 2012 was an exceedingly dry year, the water table increased, indicating that completely filling the channels and recreating the sheet flow hydrologic system was possible and vital to the restoration of the Hornbek complex. Techniques used in the successful pilot project will be applied throughout FLFO in the future.

**Figure 7.** Before, during, and after filling views (top to bottom) of one of five soil plugs placed in an eroded gully during the pilot restoration project near the Hornbek Homestead in Florissant Fossil Beds National Monument, fall 2012. (© JEREMY SUELTENFUSS, CSU)

### 1.6 Monitoring objectives

The general goals for long-term ecological monitoring of FLFO wetlands focus on documenting the status and trend in condition, understanding the causes of changes, especially where change is relatable to human disturbance, and assisting in the application of WEI results to park management. We summarize our objectives here; see Schweiger, Gage, Driver et al. (2015) for more detail.

The objectives of wetlands monitoring at FLFO are:

1) Determine the status and trend at sentinel sites for the following wetland responses:
   a) Anthropogenic disturbance
   b) Groundwater hydrology
   c) Vegetation
2) Evaluate and interpret status and trend in select responses based on assessment points.

# 2 Methods

## 2.1 Sample design and sample size

The relatively small size of FLFO and the limited number of wetlands within the park facilitated a targeted sentinel site-based approach to site selection. Sentinel monitoring locations ("sites") were selected with no randomization; rather, location was based on a series of largely subjective factors. Most importantly, they were located based on an expectation that the sampled wetland was important and useful for understanding site specific patterns in wetland condition over time in FLFO. Sentinel sites were in places where the expert opinion of Rocky Mountain Network scientists and our partners (especially FLFO) felt that long-term changes in key drivers like hydrology would be meaningfully characterized by our monitoring and/or where issues, such as high levels of anthropogenic disturbance, were known or suspected to occur. Finally, we attempted to locate sentinel sites in places that were more accessible given the frequency at which data are collected.

Following these guidelines, the network, our collaborators and the park selected three FLFO sentinel site wetland complexes: the first is adjacent to the historic Hornbek Homestead (hereafter referred to as "Hornbek"); the second is near the Maytag or Red Barn (hereafter "Red Barn"); and the third is easily accessed from the Barksdale picnic area (hereafter "Barksdale"; Figure 8). All three are located within the headwaters of the Grape Creek drainage, which generally flows north through the park. Though located near the channel of Grape Creek, hydrologic inputs to all three sentinel complexes are likely a mix of overbank flooding, groundwater discharge, and overland flow. Further details on each complex and sites selected within each are provided in Appendix 1.

Sample size within a sentinel site complex and the frequency of sampling across time were evaluated over the baseline years of the protocol's implementation based on the variability in vegetation type and likely hydrologic regimes within each. Three sentinel sites each were installed at Hornbek and Barksdale and four sites were installed at Red Barn (Figure 8). Full sampling events (including vegetation and all other methods) at all sites were conducted in 2010, 2011, 2012, and 2015. In all other years, sampling rotated through the sentinel sites within each complex (with some exceptions due to logistical constraints). Full samples were conducted at the peak of the growing season. Additional "partial" sample events were conducted as needed for groundwater depths. See Appendix 2 for more details on sample effort.

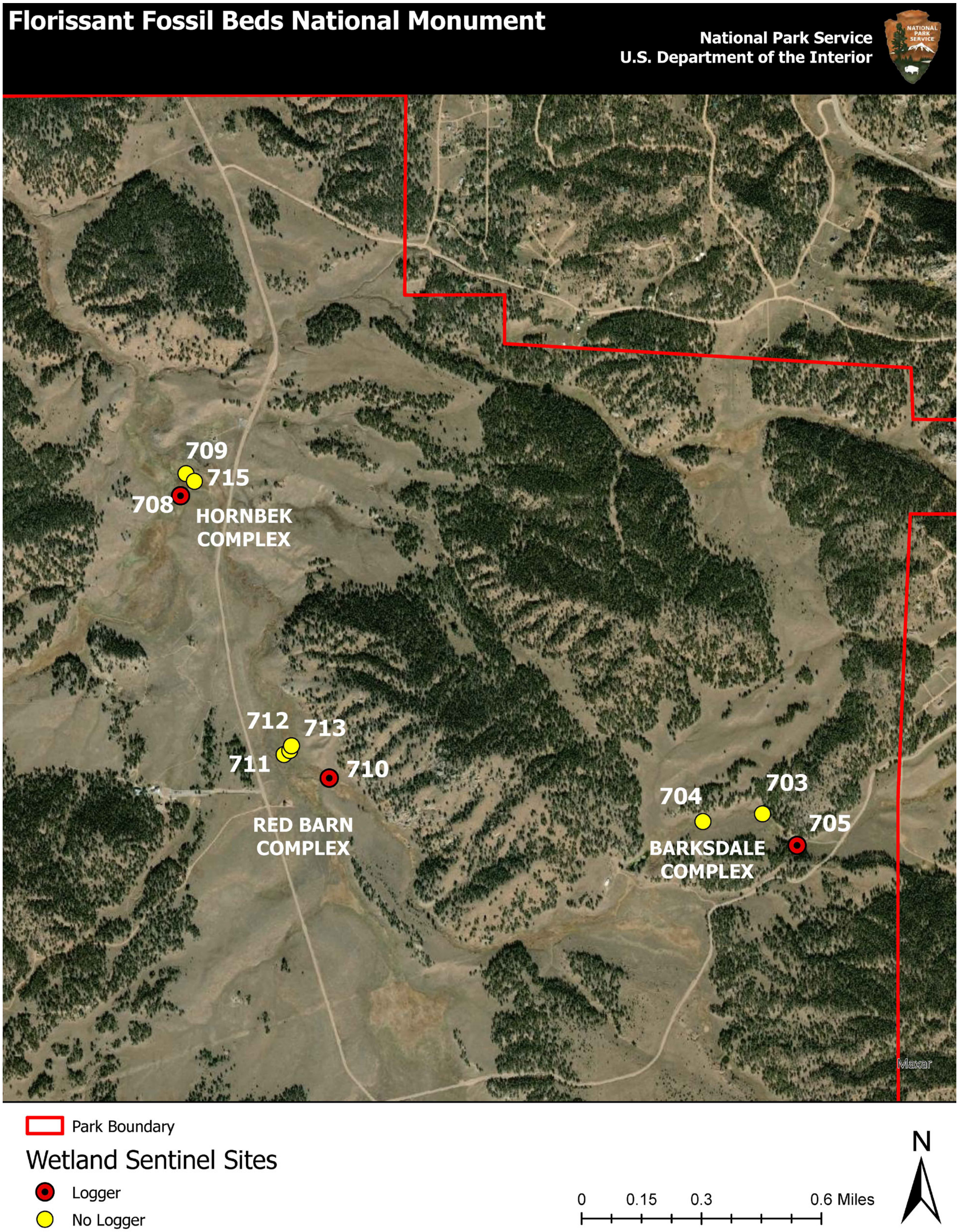



**Figure 8.** Map of wetland sentinel sites in Florissant Fossil Beds National Monument, Colorado.

## 2.2 Field methods

All field methods are described in Schweiger, Gage, Haynes et al. (2015) and only briefly summarized below. The wetland ecological integrity (WEI) protocol includes a broad spectrum of indicators to help evaluate the ecological integrity of wetlands in FLFO.

### *2.2.1 Indicator summary*

We collect vascular plant species composition and document damage and mortality of woody stems. We also collect field and laboratory soil chemistry samples, document *in situ* groundwater conductivity and pH, and measure depth to water at a shallow groundwater well in the center of the site. Finally, we document human disturbance in and around each site and in the wetland complex.

### *2.2.2 Site layout*

A WEI site consists of a 10 × 10 m plot with two scales of nested subplots (Figure 9). The largest, outer plot or "macroplot" contains one "subplot" (16 $m^2$) with four 1 $m^2$ "microplots" nested within the subplot. At most sites, a groundwater monitoring well is in the center of the nested plots. Each cardinal direction corner of the subplot is monumented with an approximately 8 in. long piece of ½ in. diameter rebar, capped with an aluminum survey marker stamped with site information. When possible, markers were pounded flush with the ground surface.

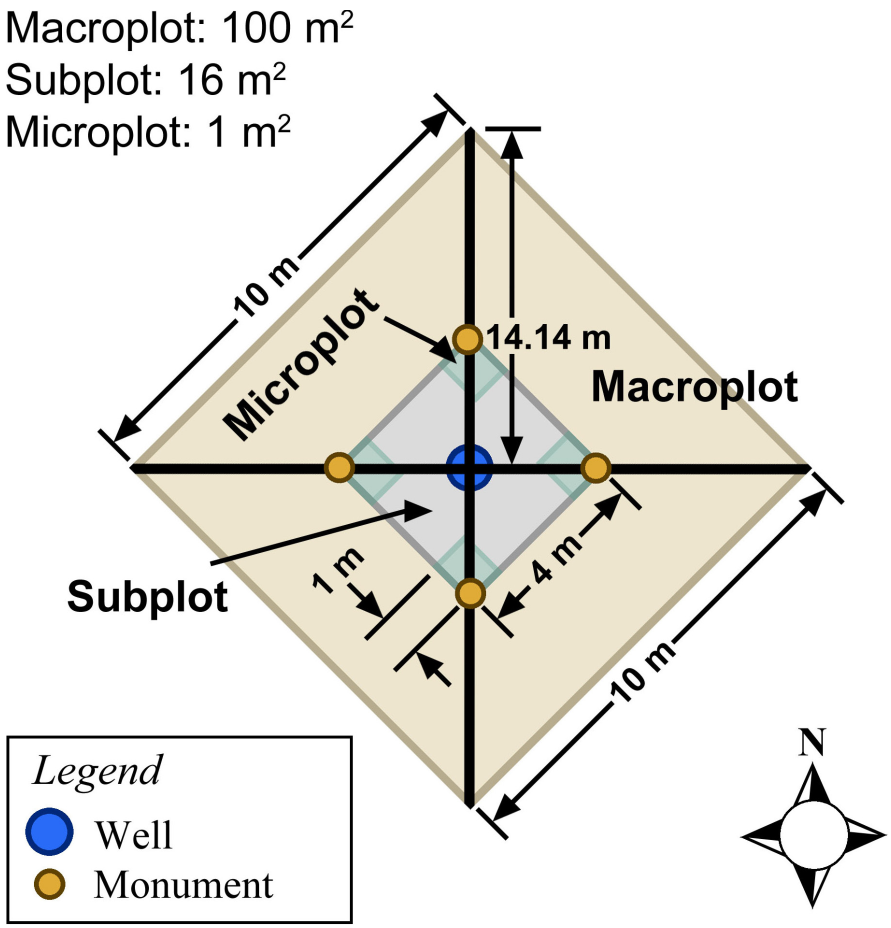



**Figure 9.** Wetland ecological integrity sample plot used by the Rocky Mountain Inventory and Monitoring Network for sampling vegetation, hydrology, soils, and disturbance. Plots are always oriented with North at the top of the plot. Rebar is capped with a standard Rocky Mountain Network monument cap. The center of the plot is a groundwater well at most sites. Pins are placed temporarily to aid in plot layout and then removed following sampling.

#### *2.2.3 Human disturbance*

An important part of the WEI protocol is to characterize human disturbance in and around each wetland site and complex (Table 3). The field methods include rapidly employed categorical metrics related to human land use and disturbance modified from Faber-Langendoen et al. (2006), Rocchio (2007a, b), and Mack (2007). Importantly, crews do not make judgment calls on the level or effect of a disturbance on wetland condition in the field, focusing instead on its occurrence and spatial proximity to a site. Several of the metrics are also evaluated in the office using a GIS (in some cases GIS data are more precise and accurate). As summarized below, these data are synthesized into a semi-quantitative Human Disturbance Index (HDI) that is used in all network parks.

**Table 3.** Human Disturbance Index component metrics used within the wetland ecological integrity protocol at Florissant Fossil Beds National Monument. "GIS" indicates that the measure includes data from both field and GIS based data sources.

| **Type of metric** | **Component** |
|---|---|
| Alterations within buffers and landscape context (weight = 0.33) | Average buffer width (gis) |
| | Land use in 100 m buffer |
| | Percentage of unfragmented landscape within 1 km (GIS) |
| | Riparian corridor continuity |
| | Onsite land use |
| Hydrologic alterations (weight = 0.34) | Hydrologic alterations |
| | Upstream surface water retention (GIS) |
| | Upstream/ onsite water diversions/ additions (GIS) |
| | Floodplain interaction |
| Physical/Chemical disturbances (weight = 0.33) | Bank stability |
| | Substrate/ soil disturbance |
| | Algal Blooms |
| | Sediment/turbidity |
| | Toxics/heavy metals |

### *2.2.4 Groundwater hydrology*

Groundwater monitoring wells at each site were hand-augured and cased with slotted PVC pipe to a depth adequate for measuring depth to a shallow water table (usually 1 to 2 meters). Manual readings of depth to groundwater (DTW) were conducted with every visit to a site. In the early years of sampling, wells were read multiple times per year, but the frequency was reduced later in the project to once per year at peak growing season when water stress on vegetation was likely highest. Given the shallow nature of most FLFO wetland water tables, simple hand tapes or voltmeters were used for manual readings. Seven replicate blind readings were taken by different crew members.

Continuous DTW was recorded in one well per sentinel complex ever hour year-round with submersed pressure transducers. These loggers require correction for atmospheric pressure, and we maintained a barometric pressure logger at FLFO headquarters. Logging was ideally conducted over an entire water year with an hourly frequency. Raw data were corrected for pressure offsets and ambient atmospheric values and for well casing or logger "stick up" above the ground.

By convention we use negative values for a DTW below ground. A DTW equal to zero is at ground level and positive values are a DTW above ground (or standing water above the soil surface). A site that becomes wetter over time or is wetter than another wetland equates to DTW values becoming less negative—thus, technically, "greater," as they approach zero (i.e., a site with DTW = −10 cm is wetter than a site with DTW = −30 cm).

### *2.2.5 Soil and groundwater chemistry*

*Note that we elected to move chemistry results to an appendix for this report. Soil is sampled infrequently over time given its likely slow rate of change. In contrast,* in situ *water chemistry may vary more rapidly than our protocol can capture. More work is needed on these datasets to fully integrate them into future reporting efforts.*

Composite soil samples were taken from the well bore or a soil pit at 0 to 20 cm and analyzed in a lab for 23 parameters, including pH, conductance, cation exchange capacity, nutrient concentrations, percent organic matter, and several ions or salts (e.g., P, Mg, Mn, Al, Ca). A second sample was taken at around 40 cm and analyzed for percent organic matter. Soil samples were taken with the initial site installation in 2009 and again in 2015 in the same locations. In addition to soil samples, soil profiles were described with the initial installation of each site. Soil profile methods were generalized from the Natural Resources Conservation Service Web Soil Survey (Soil Survey Staff, NRCS 2022) and Schoeneberger et al. (2002). Soil color texture, structure, and consistency were used to distinguish and identify soil layers (or approximate soil horizons and depths). Organic matter in peat was characterized using the Von Post system (Von Post 1924).

With each full sample event we measured three *in situ* water chemistry parameters relevant in wetlands: temperature, specific conductance (SC), and pH (Forman and Alexander 1998; Kim et al. 2001; Chipps et al. 2006; NPS 2002). Water samples were taken (in order of preference) from bailed wells, directly from groundwater (in saturated sites) using a pore sipper, from other groundwater sources (i.e., springs), from non-flowing surface water, or from flowing surface water. We used various water chemistry multiparameter probes over the years (e.g., In-Situ Inc. AT400) calibrated and error checked following NPS (2002).

### *2.2.6 Vegetation*

Plant species composition was quantified at full sample events within six nested subplots in each site. All vascular taxa in each subplot were identified to species as possible with their canopy cover visually estimated (Mueller-Dombois and Ellenberg 1974). Areal cover was averaged across all subplots before inclusion in analysis. Plant nomenclature followed (Weber and Wittmann 2001) in the field through 2016, and then switched to Ackerfield (2015), with all nomenclature crosswalked for analysis. Difficult specimens that could not be confidently identified in the field were collected and submitted to herbaria for subsequent identification. In 2010 we included species level identification of nonvascular taxa. Following Belland and Vitt (1995). Small samples of all mosses were collected from plots to be sent for outside identification by experts. Nonvascular taxa were dropped after 2010 given costs associated with their specialized identification.

## 2.3 Ancillary data

To help understand patterns and factors driving changes in wetlands, many analyses use predictors or covariates beyond the data collected within the protocol itself as ways to help understand patterns and lend insight into the factors controlling or impacting wetland condition.

### *2.3.1 Landscape composition and disturbance*

Landscape and disturbance data were summarized at each site or from across a site's catchment (Figure 10). Measures include four metrics of anthropogenic land use, three metrics of hydrologic alteration, and the Landscape Disturbance Index (LDI) model developed by the Colorado Natural Heritage Program (CNHP 2021; Table 4). The LDI is a unitless index that ranges from 0 to >2000 (but note that the distribution is very long tailed, with most values less than 600). The LDI is estimated in a GIS from multiple data layers with dates ranging from circa 2010 to 2020. It uses a distance decay function to approximate the overlapping and spatially variable impact of anthropogenic land uses, including agriculture, urban development, roads and trails, oil and gas development, surface mining, wind turbines, and solar installations on any specific location across Colorado.

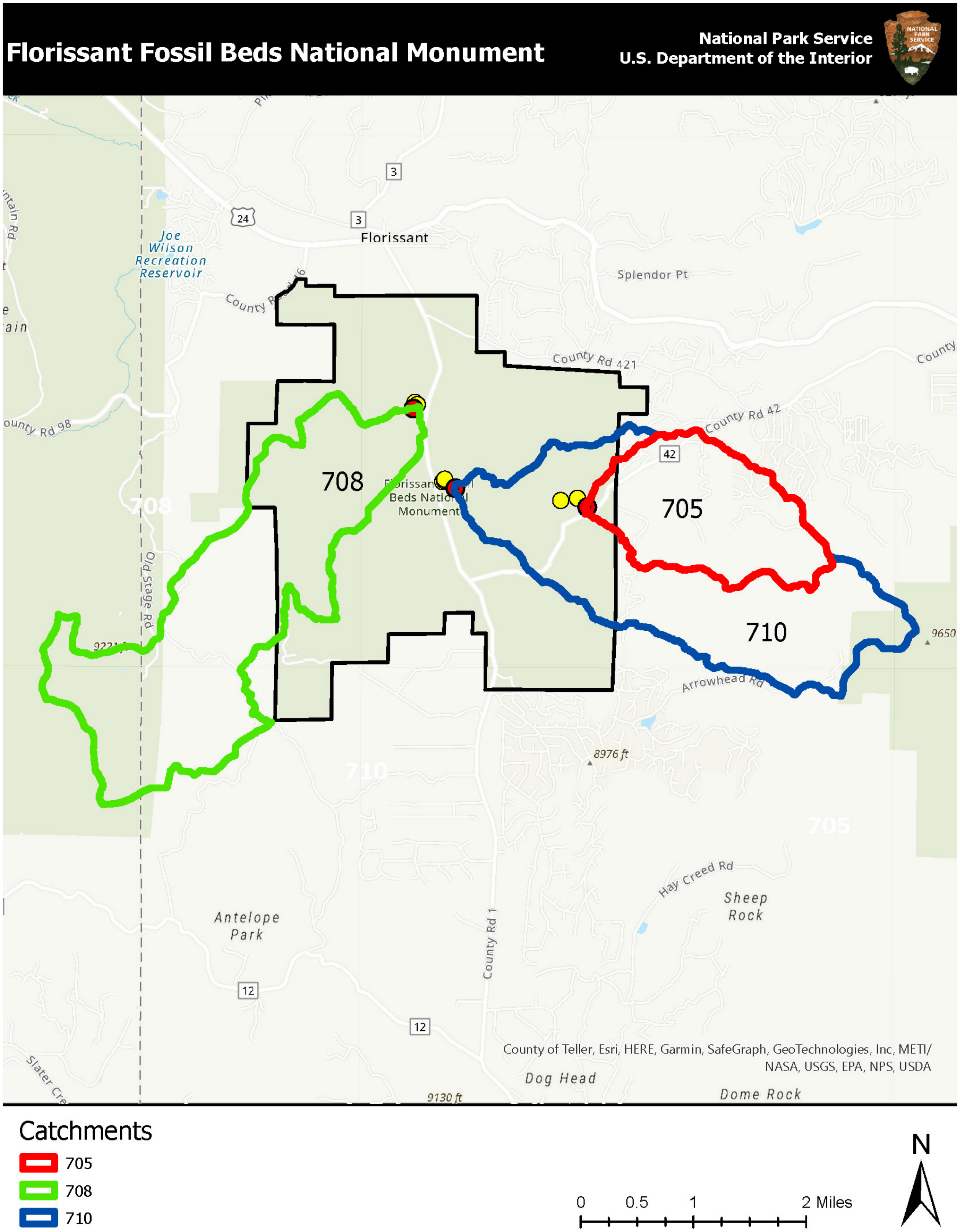



**Figure 10.** Example catchments for wetland sites, Florissant Fossil Beds National Monument, Colorado.

**Table 4.** Summary of ancillary data used within the wetland ecological integrity protocol at Florissant Fossil Beds National Monument (FLFO), Colorado.

| Metric | Scale, units | Data sources |
|---|---|---|
| **Percent anthropogenic land cover in a 1 km buffer of the site** | 1 km buffer, % | Vegetation map (Story et al. 2004); National Land Cover Database (Fry et al. 2001); Analytical Tools Interface for Landscape Assessments (Riitters et al. 2000) |
| **Percent anthropogenic land cover in a 100 m buffer of the site** | 100 m buffer, % | Vegetation map (Story et al. 2004); National Land Cover Database (Fry et al. 2001); Analytical Tools Interface for Landscape Assessments (Riitters et al. 2000) |
| **Distance to closest anthropogenic feature** | Meters | FLFO GIS data |
| **Road–stream crossing** | Number per unit area in catchment | FLFO GIS data; Attila (Riitters et al. 2000) |
| **Number of diversions in the upstream catchment** | Catchment, count | FLFO GIS data |
| **Percent catchment with upstream diversion** | Catchment, % | FLFO GIS data |
| **Landscape Disturbance Index (LDI)** | Score at site | Colorado Natural Heritage Program (CNHP 2021) |

### *2.3.2 Climate and water balance*

Although temperature and precipitation are often used to characterize the climatic context of a study area, variables within the water cycle in a watershed (also known as water balance) are often stronger indicators of ecological processes than temperature and precipitation alone. Water balance variables (Table 5) reflect or incorporate the interaction of temperature and precipitation with topographic and edaphic (i.e., soil-related) properties that control temporal water availability in wetlands (Dobrowski 2011; Munson et al. 2015; Thoma et al. 2020). For example, stream flow in much of the western North America is controlled by the abundance and timing of snow melt that occurs months after winter precipitation (Hostetler and Alder 2016); vegetation growth is closely linked to soil moisture and water deficit (Daubenmire 1968; Littell et al. 2008; Stephenson 1998), and fire is more closely related to aridity than precipitation (Littell et al. 2016; Williams et al. 2015), although wetting events diminish fire potential (Holden et al. 2018). Additional background on water balance is provided in Appendix 3.

**Table 5.** Summary of water balance variables used within the wetland ecological integrity protocol at Florissant Fossil Beds National Monument, Colorado.

| Water balance variable (units) | Description |
|---|---|
| Evapotranspiration (actual (AET) and potential (PET)) (mm) | ET is the movement (loss) of water from both plant transpiration and soil evapotranspiration.<br>PET is the "conceptual maximum" water loss from a large homogeneous vegetation-covered area that never lacks water and represents the climatic demand for water relative to the available energy.<br>AET is the realized loss of water from soil via evaporation and transpiration. |
| Runoff (mm) | The amount of water that leaves a system exceeding water use by plants and storage in soils. It is estimated as the daily change in soil water minus AET plus direct runoff (i.e., from impervious surfaces). |
| Drainage (mm) | Runoff accumulated across days via base ("slow") and event based ("fast") runoff. |
| Climatic water deficit (mm) | Unmet evaporative demand for water; what vegetation would use but does not have; estimated as PET−AET. |
| Soil moisture (mm) | Water stored in soil (mm) given idealized loss from soil via PET. |
| Growing degree days (degree C) | Amount of energy available in a day for plant growth; estimates the accumulation of heat units required for plant growth and development or temperature above a base temperature threshold that is necessary for plant growth. |

## 2.4 Analyses

Publications by Schweiger, Gage, Driver et al. (2015) and Schweiger et al. (2016, 2017) provide a summary of the general WEI analytical approach, and Appendix 4 provides specific details for analyses presented in this report.

### *2.4.1 Reporting units*

Results are presented at two scales: wetland type (fen or wet meadow) and sentinel complex (Hornbek, Barksdale, and Red Barn). Two exceptions to the scale at which data are presented include continuously logged groundwater heights (DTW), where results are given for specific sites with a logger, and remotely sensed disturbance indices (i.e., LDI) that include a whole-park report scale. We do interpret select patterns at the site scale within wetland type or sentinel complex where this improves application to wetland management, but for simplicity, we focus mostly on wetland type or sentinel complex.

### *2.4.2 Metrics and indices*

We address several WEI objectives in FLFO via derived metrics or indices of human disturbance and vegetation community structure. These are summarized in the following sections.

#### 2.4.2.1 Human disturbance

We estimate general human disturbance at each FLFO WEI site using a Human Disturbance Index (HDI) modified from Faber-Langendoen et al. (2006), Rocchio (2007a, b), and Mack (2007). HDI

ranges from 0 to 100 with higher scores indicating higher levels of human disturbance. The HDI provides an independent measure of wetland condition against which vegetation attributes and other WEI results are assessed to determine relationships with changes in disturbance regimes across the park and over time. We also use the Landscape Disturbance Index (LDI) built and maintained by the Colorado Natural Heritage Program (CNHP 2021). It estimates disturbance using a variety of data (i.e., human land use, urban devolvement, roads, trails, oil, and gas features) that are combined and weighted based on their type and proximity to natural areas (Figure 11). Most source data date from around 2014 to 2021. The LDI is a unitless index that ranges from 0 to >2000 (but note that the distribution is very long tailed, with most values less than 600).


**Figure 11.** Foot trail (indicated by arrow) immediately adjacent to site 703 in the Barksdale complex, Florissant Fossil Beds National Monument, Colorado, 2021. This is an example of a feature included in the Human Disturbance Index. The trail likely influences the hydrology of the site and may allow more access to the wetland with the potential for direct impacts. (NPS/ BILLY SCHWEIGER)

<u>2.4.2.2 Vegetation</u>

The WEI protocol generates over 300 individual vegetation metrics within nine groups: conservatism (floristic quality), duration (i.e., annual, perennial), ground cover, life form composition (i.e., woody, graminoids), nativity (including rarity, invasiveness, and noxious weed status), taxonomic diversity,

taxonomic composition, salt tolerance, wetland status or affinity, woody stem density, and woody stem condition. Summaries of metric calculation are in Schweiger, Gage, Driver et al. (2015) and in R code available on request to the Rocky Mountain Network.

We focus on four vegetation metrics or indices in this report selected by best professional judgment to represent important ecological characteristics of FLFO wetlands and because they are useful for park resources managers. We include one metric each to estimate nativity, wetland affinity, and conservatism, and one more synthetic bioassessment index that estimates overall ecological integrity.

For nativity, we selected relative percent cover of native species, excluding nonnative species. This metric describes the portion of the biomass within a site occupied by known native species. For wetland affinity we selected relative percent cover of obligate and facultative wetland species. This metric reflects the predominant soil moisture condition that influences species composition. It allows us to examine patterns in soil moisture between sites and over time as restoration efforts attempt to raise the water table in areas that were damaged by former ditching and draining. For conservatism, we selected the Floristic Quality Index (FQI), which is calculated as the average conservatism value of the species observed within a sampling event multiplied by the square root of species richness. Finally, we present the Vegetation Indices of Biotic Integrity (VIBI) bioassessment index developed by the Colorado Natural Heritage Program (Lemly and Rocchio 2009; Rocchio 2007a). The VIBI combines between four and nine individual vegetation metrics depending on wetland type. These metrics represent different characteristics of the vegetation community composition and structure that respond in predictable ways to human disturbance by changing in interpretable ways with increasing disturbance.

#### *2.4.3 Status*

We define status as a "snap shot" evaluation of a WEI response over a well-defined and relatively concise range in time (Olsen et al. 1999), such as a baseline or initial period of monitoring. In FLFO, we define as a baseline period for status estimates the first three years of sampling (2009–2011). We assume these years are a well bounded or distinct period of wetland response. *However, because we do not have a representative survey of wetlands in FLFO, we may only infer status (and trend) results to sampled sites.*

We present a variety of statistics relevant for status estimates for this baseline but focus on medians, given better performance on data with complex distributions or that are strongly influenced by outliers. This is especially relevant when data are summarized by a complex that combines wetland types. Where there is meaningful variability across the baseline years, we include additional interpretation of measures of variance. We visualize baseline status estimates with box plots that show medians, and interquartile range and outliers (defined as 1.5 times the interquartile range).

##### 2.4.3.1 Summary of patterns among indicators

For each class of result type (i.e., disturbance, hydrology, vegetation) we present a series of bivariate correlations as a matrix of scatter plots between two variables plus their correlation. We use a nonparametric Pearson rank correlation coefficient to accommodate non-normal data. Bivariate correlations do not account for non-linear relationships or any confounded interactive effects among

estimates of disturbance, but they provide a useful perspective for possible management relevant patterns amongst WEI variables.

### *2.4.4 Trend*

We define trend as a non-cyclic, directional change in a response measure across time that can be with or without pattern (Urquhart et al. 1998). It is estimated using a variety of statistical tools summarized below. Model and data processing R code is available from the Rocky Mountain Network via the Integrated Resources Management Applications (IRMA) portal and/or via github. Additional details (and there are many) for both of the following methods are in Appendix 3. We estimate trends for all variables with repeat samples presented in this report. Details of these models depend on the structure of a given variable as follows.

#### 2.4.4.1 One to several discrete measurements a year: disturbance, vegetation metrics, discrete groundwater

We first visually examine general patterns across time in smoothed loess fits to HDI, DTW, relative percent cover of native species, relative percent cover of obligate and facultative wetland species, the Floristic Quality Index, and the Vegetation Indices of Biotic Integrity. These models have no correction for statistical structure in the data; however, they qualitatively help show how a response changes, including any suggestions of non-linearity. These do not represent a proper statistical test of trend but given the complexity in some of the data, and hence model, they are nevertheless very useful.

We next estimate linear mixed-effects models using restricted maximum likelihood (REML; VanLeeuwen et al. 1996; Heard et al. 2012) that specifically addresses trend estimation for correlated data (i.e., the correlations across time that naturally occur in repeated measures ecological data). Mixed model analysis provides a general, flexible approach in these situations because it allows a wide variety of correlation patterns (or variance/covariance structures) to be explicitly modeled. Mixed model results are presented in a familiar ANOVA format with coefficients, standard errors, and the significance of the term (p value).

#### 2.4.4.2 Continuously measured depth to water

We analyze continuous (hourly but summarized to a daily time step) groundwater data using generalized additive models (GAM; Wood 2011) for continuous DTW data. GAM models can include non-linear or "smooth" functions for all or a subset of the predictor(s) or independent variables evaluated in a model as patterns in data indicate. Smooths are regularized nonparametric functions that can fit simple to very complex non-linear relationships. GAM models may also include predictors with a linear relationship with the response and/or with an *a priori* non-linear relationship such as a log. The approach also allows a robust evaluation of autocorrelation in DTW data, and we include adjustments for this as needed. As with mixed models we use a model selection approach to create a final model. However, continuous DTW data allow several additional potential predictors also measured on daily time steps such as climate and water balance and we evaluate and include these terms as they improve model fit and add to the interpretative capacity of a model. GAM results are presented in a familiar ANOVA format with parametric term coefficients, standard errors, the

significance of the term (p value) and relative importance (grouped for factor predictors like season). Trend and visuals of GAM also use partial residuals as the main visual.

#### *2.4.5 Significance*

For all models we treat statistical significance or ("p values") as a somewhat fluid concept (*sensu* Wellek 2017). Statistical significance is assigned at a p value of $\leq$0.10. We feel a higher threshold is appropriate for highly variable ecological data. Marginal significance is in the p value range of 0.10 to ~0.20. However, we will interpret patterns at higher p value levels if there are ecological reasons to do so.

### 2.5 Assessment

#### *2.5.1 Overview*

Assessment is the process by which the condition of an ecological resource, such as a single wetland or a population of wetlands in a park, is placed into classes that describe or interpret this condition. In the most colloquial sense, these condition classes or these interpretations might be labeled "good" or "bad." In broad stroke, we compare our monitoring results to reference values determined from "assessment points" (AP). We interpret these comparisons in a collaborative way with park staff and management in the context of ecological theory, NPS Inventory and Monitoring Division guidance, NPS resource management policies, and park management objectives. We use various terms to label levels of disturbance for ecological condition, including reference, intermediate, and non-reference. For non-biological measures we use minor, moderate, or major to describe levels of disturbance. A vital sign or indicator in a reference or minor disturbance state is within a range of values considered functional, intact, or loosely speaking, "good" condition. A non-reference or major disturbance status is degraded, dysfunctional or in a "bad" condition.

#### *2.5.2 Assessment points*

We assess the condition of FLFO wetland types and complexes by comparing monitoring data to "assessment points." Assessment points (Bennetts et al. 2007) are numeric values of an indicator used as benchmarks to evaluate the status or trend in condition of a vital sign. Assessment points can be defined or set by scientists and park managers using several methods, including (in general order of preference): 1) direct definition by park management, 2) adoption from regulatory criteria, or 3) via application of ecological theory (which can overlap with the first two methods). However, none of these forms of AP were readily available for FLFO wetland data. Therefore, we use two additional methods: 4) development of AP from distributions of indicator data at wetland sites within FLFO's ecoregion(s) that are known or expected to be undisturbed by human activities (these are known as "ecoregional assessment points"), and 5) AP defined by other authors using a variety of methods.

Ecoregional reference sites used for assessing FLFO wetland vegetation were drawn from a Colorado Natural Heritage Program (CNHP) database of over 3,000 wetlands and riparian sample events (CNHP 2022). We extracted 374 wet meadows and 174 fen sample events from the CNHP database spanning 2008 to 2018 and subset this to sites rated as excellent or good in terms of their disturbance using CNHP wetland methods (Appendix 5; Lemly et al. 2013). For groundwater depths, sites from the CNHP database and a Rocky Mountain Network WEI database were used. Fewer CNHP sites had groundwater data and only 120 wet meadow or fen CNHP events were available at sites rated

excellent/good that were sampled between 2008 and 2018. We also used network data from 300 events sampled between 2007 and 2019 at undisturbed sites as defined by the network in Schweiger et al. (2016, 2017; Rocky Mountain Network unpublished data). Undisturbed event groundwater data were further restricted to the late summer months of July–September when water tables are likely most limiting for vegetation production and to sites between 2000 and 3000 m in elevation.

We interpret comparisons between an indicator and its AP in a collaborative way with park staff and management in the context of park management objectives, NPS resource management policies, and general ecological theory. We do not perform statistical tests of status or trend estimates relative to an assessment point. Comparisons are instead whether a response or some proportion of responses over time is above or below an assessment point, with no estimate of the statistical probability of this occurrence.

These assessment methods have been in use in one form or another for decades but were most explicitly defined in Stoddard et al. (2006). They are in use by the US Environmental Protection Agency (US EPA 2016), and several states, including Colorado (CDPHE 2012) and Montana (Suplee et al. 2005). We add terminology that aligns with earlier work by the NPS Natural Resource Condition Assessment program. The network uses a common assessment methodology across all our protocols in all six of our parks We develop and present assessment point methodology for wetlands in Schweiger et al. (2017). FLFO has accepted our approach as a general and flexible framework for interpreting WEI data in the park. We provide additional details and update our approach for application to FLFO WEI in Appendix 5.

#### *2.5.3 Summary condition*

Select results are summarized in "summary condition" statements within tables that include a brief description of an indicator (variable) or a class of indicators, summaries of the status and trend in the condition of these indicators, and our confidence in the result. Summary condition statements are important for rapid integration into park resource management and interpretation. However, they are a simplification of details presented in our full results and discussion sections and should be used with caution. They are most reliable when we have assessment points for a given measure or metric, especially when these have either a direct connection to ecological processes, management, or relevancy from other research.

### 2.6 Data availability

Data presented in this report and additional figures, tables, and model output are available from the Rocky Mountain Network. Quality checked data packages are on the Integrated Resources Management Applications (IRMA) portal within the NPS DataStore.

Data products have been bundled into a wetlands ecological integrity status and trend project for the park, available at: https://irma.nps.gov/DataStore/Reference/Profile/2278524

Individual data package components are listed below:

- Site Event Metadata: https://irma.nps.gov/DataStore/Reference/Profile/2278733
- Herbaceous Vegetation: https://irma.nps.gov/DataStore/Reference/Profile/2284008

- Woody Vegetation: https://irma.nps.gov/DataStore/Reference/Profile/2279557
- Depth to Water Hand: https://irma.nps.gov/DataStore/Reference/Profile/2279555
- Depth To Water Time Series data: https://irma.nps.gov/DataStore/Reference/Profile/2278541
- Soil Chemistry: https://irma.nps.gov/DataStore/Reference/Profile/2284748
- Discrete Water Quality Logger: https://irma.nps.gov/DataStore/Reference/Profile/2279116
- Human and Natural Disturbance Index: https://irma.nps.gov/DataStore/Reference/Profile/2284806

# 3 Results and Discussion

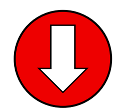
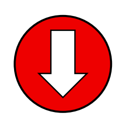
The following sections present results and interpretation for data collected at Florissant Fossil Beds National Monument (FLFO) sentinel wetlands from 2009 to 2019. We begin each major section with a set of summary condition statements as syntheses of the most important results for specific climate, disturbance, hydrology, and vegetation indicators. These summary condition statements include supporting narrative and a symbol designed to convey with a glance the condition and trend in an indicator and our confidence in the assessment. We include results and interpretation for all wetland indicators except groundwater and soil chemistry in the main narrative of this report. We elected to move chemistry results to an appendix given the need for a better examination of the time frames and methods needed to understand the role of soil and water chemistry in the condition of the park's wetlands. The Rocky Mountain Network approach to summary condition includes a fair degree of detail in the text. This allows a resource management audience to focus only on these sections of the report to glean both the most important results and some key context and description.

## 3.1 Climate

### *3.1.1 Summary condition*

We begin by summarizing indicators of climate conditions in the park (Table 6) and follow with details for each indicator. We end with a discussion of modeled future climate change and the resulting implications for park wetland resources.

**Table 6.** Summary condition table for climate and water balance at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, in 2009–2019. These condition statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not of an indicator's value. Summary condition statements are a considerable simplification of the details behind each indicator—they should be used with caution. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Temperature and precipitation | Long-term climate conditions influence where wetlands occur as well as their area, biological diversity, and ecological functioning. Climate change is and will likely become even more of an important driver of wetland condition in FLFO in the future. Summers at FLFO have been getting warmer, with projections suggesting even warmer summers with more variable precipitation in the future. These changes will impact the hydrology and condition of wetlands in the park. They will likely reduce the number and extent of wetlands and cause declines in the condition of associated flora and fauna and critical ecological functions, such as carbon and water storage.<br>We currently lack numeric assessment points for climate, but given overwhelming evidence in the literature, the condition of climate warrants significant concern as it continues to deteriorate.<br>Given the complexity of the models and data behind the impacts of climate change, and of real site-specific variability in climate driven processes in the park's wetlands, we give our assessment medium confidence. |  |
| Water balance | Water balance helps us understand how temperature and precipitation interact with features of the landscape like vegetation, soil, and aspect. Generally speaking, water balance is how climate (temperature and precipitation) matters in an ecological system.<br>At FLFO, climatic water deficit increased and runoff decreased during two droughts (2009–2013 and 2017–2019) that occurred during our monitoring period. These both have drying impacts on wetlands. They can also interact with more localized resource management actions undertaken by the park, such as the restoration in the Hornbek wetland complex, complicating the interpretation of the effects of this restoration work. Patterns like this are expected to continue and increase in magnitude in future projections.<br>We currently lack numeric assessment points for water balance variables, but given overwhelming evidence in the literature, the condition of water balance warrants significant concern and continues to deteriorate.<br>Water balance models and how changes caused by climate interact with wetlands are complex, and we give our assessment medium confidence. Additional research on water balance effects at FLFO is needed. |  |

### *3.1.2 Temperature and precipitation*

Gonzalez (2014) and NOAA (2022) summarize historical climate data for FLFO and the surrounding county. From 1950 to 2021 summer precipitation was relatively unchanging (Figure 12) but mean summer temperatures increased at a rate of 0.3 °F per decade (Figure 13). Climate plays an important role in wetland formation and persistence through surface and groundwater hydrology. This in turn has direct and indirect effects on the condition of wetland vegetation.

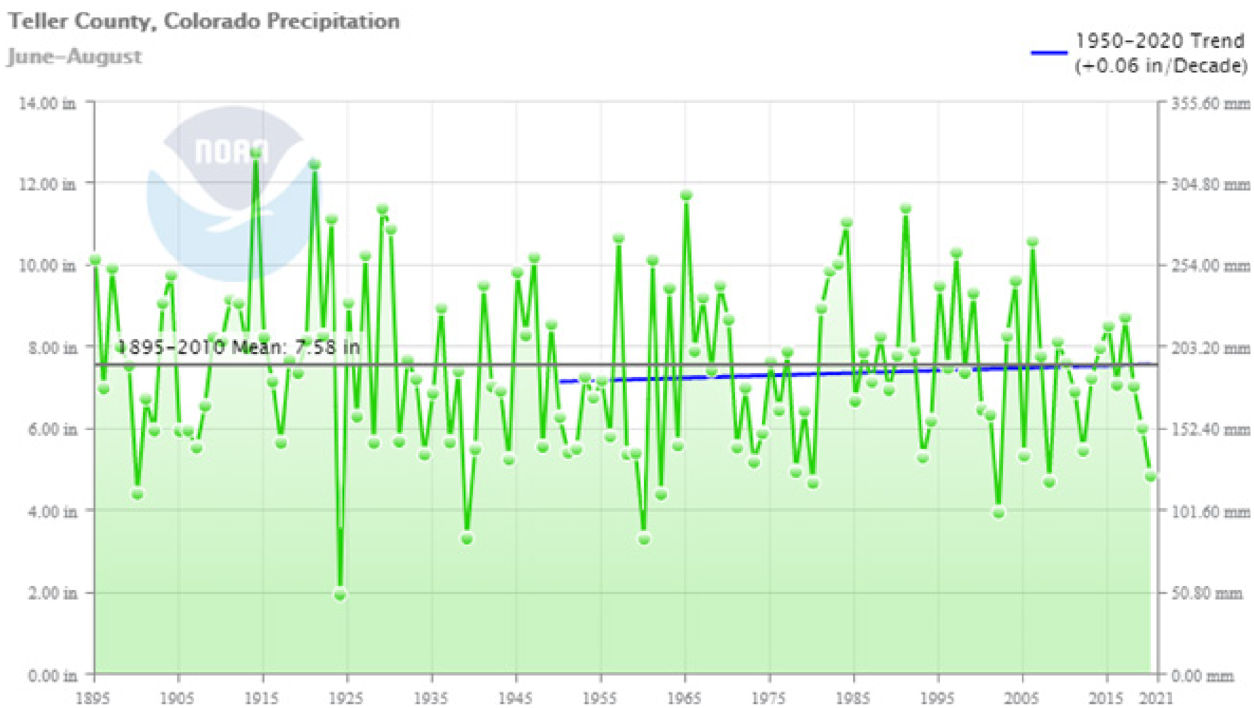



**Figure 12.** Mean June–August precipitation from 1895 to 2021, Teller County, Colorado. Data from 1950 to 2021 show a very small increasing trend of 0.06 in/decade. Data and figure are from NOAA (2022).

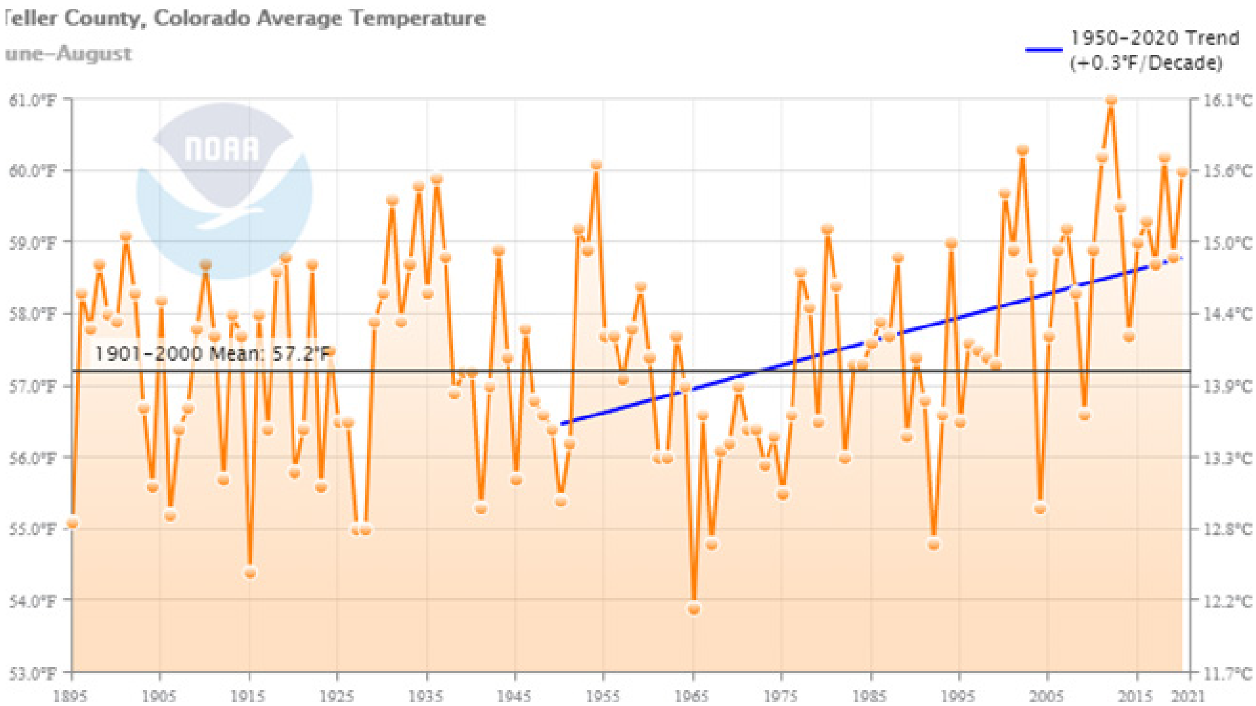



**Figure 13.** Mean June–August temperature from 1895 to 2021, Teller County, Colorado. Data from 1950 to 2021 show an increasing trend of 0.3 °F/decade. Data and figure are from NOAA (2022).

#### *3.1.3 Water balance*

Although temperature and precipitation are often used to characterize the climatic context of a park, elements of water balance can have a stronger relationship with ecological processes. Water balance variables incorporate the interaction of temperature and precipitation with topographic (elevation, slope, and aspect) and edaphic (i.e., soil-related) properties that control temporal water availability in many streams and wetlands (Dobrowski 2011; Munson et al. 2015; Thoma et al. 2020). For example, the "dry" experienced by wetland plants on south facing slopes with a high evaporative demand is not really comparable to the "dry" experienced by plants on soils with low water-holding capacities such as sand that have a low water availability, and these differences are reflected in vegetation patterns across sites. Thoma et al. (2016, 2020) show that water balance parameters can predict the influence of climate on vegetation at a fine temporal scale, which presents an opportunity to forecast vegetation response with short lead times. Water balance plays an important role in our models of continuous groundwater depths, as detailed below.

Figure 14 provides examples of two water balance variables, climatic deficit, and runoff, summarized as annual growing season means at FLFO wetland sites where we had groundwater loggers. Deficit (also called climatic or evaporative deficit) is the unmet evaporative demand from vegetation for water. Loosely speaking it is how vegetation experiences drought (i.e., higher deficit equates to more intense drought impacts on vegetation). Deficit peaked between 2010–2012 and again in 2018 with lower values in 2009 and 2014–2017. Patterns were similar across sites although deficit was lower at the wet meadow site 710 in the Red Barn complex with a hydrologic regime driven by both surface and groundwater sources. Runoff follows an essentially inverse pattern. In drought years there is

little excess water to generate runoff while in wet years there is sufficient water (i.e., greater than both the storage capacity of soil and water lost from evapotranspiration) to result in runoff from a site. Site 708 had lower runoff in nearly every year but was more like the other two sites in drought periods. We present detailed models of patterns between water balance and groundwater hydrology from 2009 to 2019 in the hydrology section below.

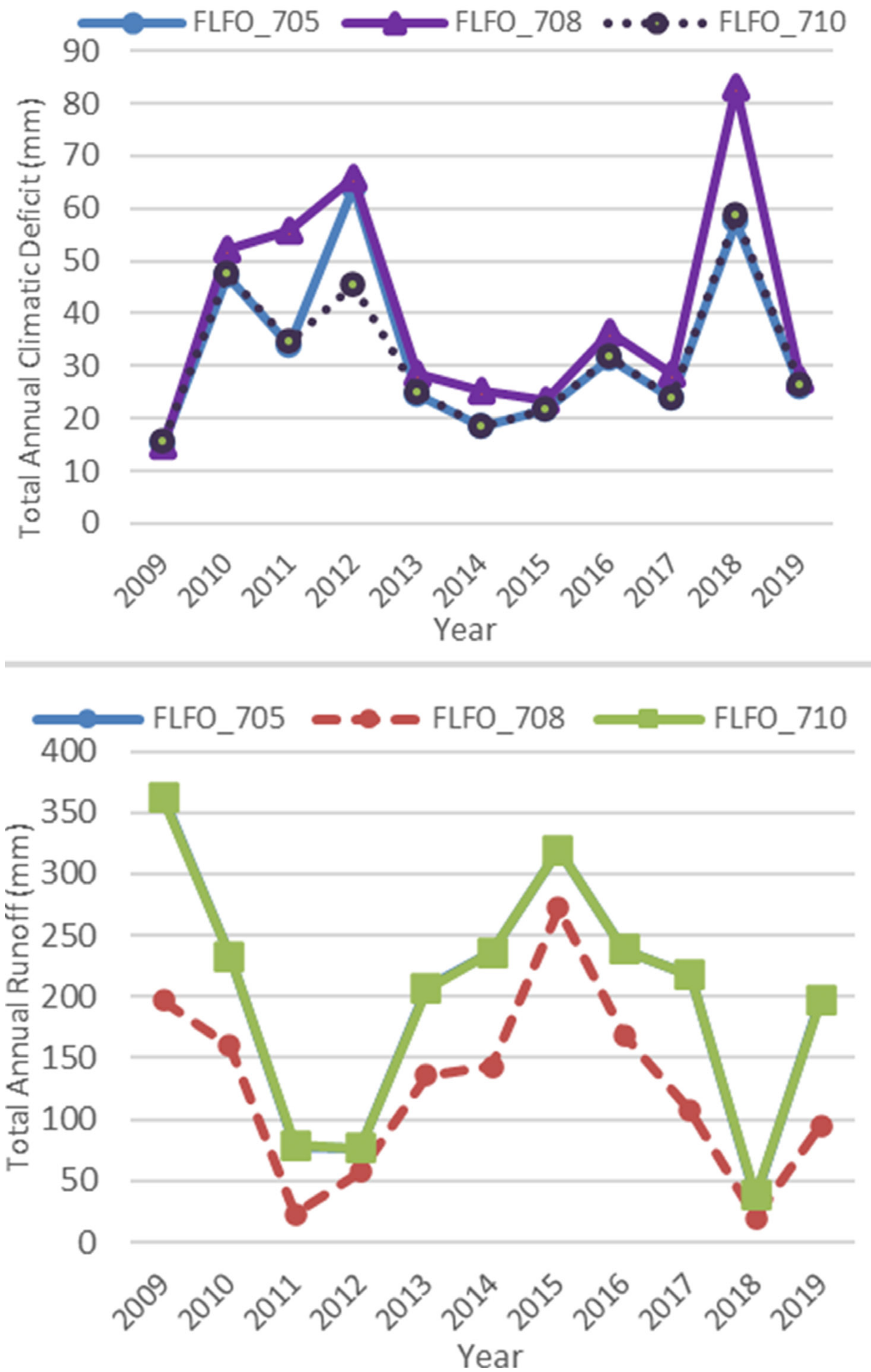



**Figure 14.** Total annual climatic deficit and runoff from 2009 to 2019 at wetland sites with groundwater depth loggers in Florissant Fossil Beds National Monument. Deficit (top) and runoff (bottom) are estimated from site scale water balance models as detailed in text. Runoff at sites 705 and 710 is nearly identical and thus these lines overlap in the bottom panel and are not visible as separate curves.

### *3.1.4 Climate change*

On average, climate change models predict slightly higher precipitation in FLFO in 2100 compared to 2000, but individual models vary widely (Figure 15). There is more certainty that variation in precipitation will increase across the region, meaning alternating periods of drought and more intense flooding (Schlesinger and Mitchell 1987; Mitchell et al. 1990; Alder and Hostetler 2013). This increase in precipitation is largely predicted to be increases in rain, not snow. FLFO is projected to be hotter under nearly all possible climate change scenarios (Figure 15; Seager et al. 2007; Garfin et al. 2014; Ault et al. 2014; Alder and Hostetler 2013). Many patterns in temperature already regularly exceed their historical range of variability (Monahan and Fisichelli 2014). Climate change models use a well-developed but complex process that first predicts historical patterns to formulate the model then applies scenarios across a range of possible human greenhouse gas emissions ("Representative Concentration Pathways"; RCP) to predict future conditions. Individual climate change models vary in detail, and so, often, they are averaged (producing a predicted median and a range for a given RCP, as shown in Figure 15).

These changes in temperature and precipitation have many implications for the water cycle in the park. Predictions from Alder and Hostetler (2013) using a similar water balance model as ours but built from climate change model predicted temperature and precipitation, show a rapidly increasing climatic deficit, more than doubling by 2100 in the high emissions scenario (Figure 15). Runoff decreases over this period, as would be expected given more drought-like conditions. These projections suggest that climate change will likely reduce the number and extent of wetlands and cause declines in the condition of associated flora and fauna and critical ecological functions, such as carbon and water storage (OTA 1993; Field et al. 2007). Protected landscapes such as FLFO do not insulate wetlands from the direct and indirect impacts of a changing climate regime. Other expected shifts in climate that will impact the hydrologic regimes supporting FLFO wetlands include less snow, earlier peak flows, overall reduced stream flow, warmer temperatures, and more intense storms (Barnett et al. 2008).

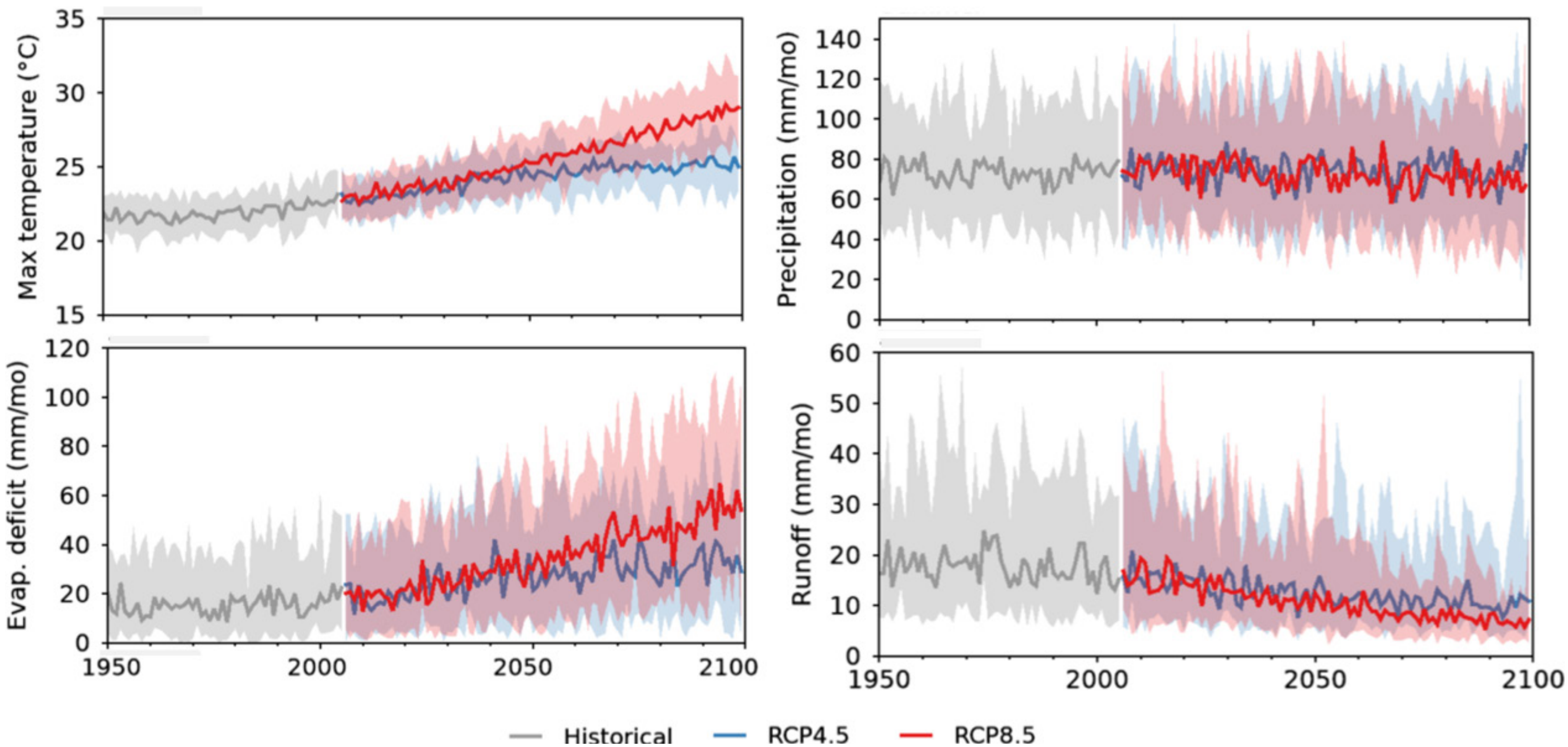



**Figure 15.** Climate and water balance for Teller County, Colorado. Historical (gray) and predicted emissions scenarios for maximum summer temperature (degree C; upper left), summer precipitation (mm/mo; upper right), climatic (or evaporative) deficit (mm/mo; lower left) and runoff (mm/mo; lower right). The median of 20 climate change models at a Representative Concentration Pathway 4.5 (in blue) and 8.5 (in red) with 10th to 90th percentile range across models is shown by the respective shaded envelopes. Data and figure are courtesy Alder and Hostetler (2013).

## 3.2 Human disturbance

### *3.2.1 Summary condition*

We begin by summarizing disturbance in park wetlands through two disturbance indexes (Table 7) and follow with details for each of the indexes. We end with a discussion of the patterns among multiple disturbance indicators for the park.

**Table 7.** Summary condition table for human disturbance at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, in 2009–2019. These condition statements summarize the status, trend, and our confidence for each indicator. The direction of arrow refers to the change in condition, not an indicator's absolute value. Summary condition statements are considerable simplifications of the details behind each indicator—they should be used with caution. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

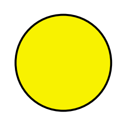
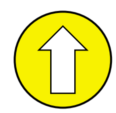
| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Landscape Disturbance Index (LDI) | FLFO is relatively small and surrounded by growing development. Park management is undoubtedly aware of how external factors can influence ecological condition inside the park. We expect that human disturbance, both inside and outside of the park, will interact with shifting climate patterns, compounding stress on wetland ecological condition.<br><br>Human use can cause disturbance to wetlands across multiple scales and has well documented relationships with wetland condition. The Landscape Disturbance Index (LDI) combines several types of GIS data, such as land use and distance to roads, to estimate an overall disturbance level at a site. Because it is based on contiguous parkwide GIS data, it is one of the few indicators in this report that we can apply to the entire park, giving it unique value. LDI values were highest in the southern end of the park where residential roads abut the park boundary. Within the park, LDI showed low levels of disturbance in the valley bottoms, where wetland sentinel sites are located, with moderate levels immediately adjacent to roads and trails.<br><br>Compared to Rocky Mountain National Park and Great Sand Dunes National Park and Preserve (other Rocky Mountain Network parks along the Rocky Mountain Front Range and central mountain corridor), FLFO had a higher mean LDI value, probably due to its small size and the surrounding residential development. LDI in FLFO was low to moderate in a statewide context, ranging from urban to pristine wilderness. These comparisons suggest caution, or an intermediate disturbance level.<br><br>LDI data were only collected once between 2010 to 2020 and so we cannot estimate trend. If the LDI is updated, we will include trend estimates.<br>Our confidence in the LDI is medium given the broader scale the index was developed for. |  |

**Table 7 (continued).** Summary condition table for human disturbance at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, in 2009–2019. These condition statements summarize the status, trend, and our confidence for each indicator. The direction of arrow refers to the change in condition, not an indicator's absolute value. Summary condition statements are considerable simplifications of the details behind each indicator—they should be used with caution. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Human Disturbance Index (HDI) | The Human Disturbance Index (HDI) is site specific, focusing on smaller scale disturbances than the LDI. It varies across time as it is measured during each sample event. However, disturbances included in the HDI are constrained by what a crew can "see."<br><br>Most baseline HDI values were in an intermediate disturbance class with small percentages in the major class and a few with minor disturbance. HDI was generally similar in fens and wet meadows. Barksdale was the least disturbed complex.<br><br>Evaluation of temporal patterns and a trend model of linear changes across time indicated a decrease in overall HDI at wetland sentinel sites from 2009 to 2019. In particular, disturbance decreased for the Hornbek complex after 2012, when a deeply incised channel within the Hornbek complex was restored and water levels rose within a portion of the wetland. (This may also have been helped by the end of a drought; see the hydrology section.) The decrease in HDI over the decade may also reflect best management practices put into place by the park.<br><br>Our confidence in HDI data itself is high. However, our assessment points could be improved by including undisturbed sites from across a broader ecoregion or other Rocky Mountain Network parks and the methods we use for other indicators. Future work should address this. Therefore, our overall confidence is medium. |  |

### *3.2.2 Background and relevancy*

Documenting and interpreting the response of wetlands to disturbance across time and space is in many ways the core purpose of wetland ecological integrity (WEI) monitoring as wetlands can be sensitive to anthropogenic and other disturbances. For example, road-zone effects have been especially well documented (Boarman and Sazaki 2006; Palomino and Carrascal 2007; Wilbert et al. 2008; Eigenbrod et al. 2009; Parris and Schneider 2008). There is also evidence of impacts from both urban and exurban development (Odell and Knight 2001; Hansen et al. 2005; McDonald et al. 2009), energy development (BLM 1999; Wilbert et al. 2008; Nasen 2009; Lovich and Ennen 2011; Naugle 2011), and agriculture (Davis et al. 1993; de Jong et al. 2008). Finally, large ungulates can also influence wetland condition (i.e., Zeigenfuss et al. 2002; Coughenour 2002), although this is more complex given the many interactions among ungulates and other species (i.e., beavers) relevant in wetland condition and the important role of the carrying capacity of a site.

Two primary measures of disturbance were collected and analyzed for FLFO wetlands. The first was derived from the Colorado Natural Heritage Program's Landscape Disturbance Index (LDI; CNHP 2021) and the second was an on-site evaluation of disturbance using the Rocky Mountain Network Human Disturbance Index (HDI). We summarize these in the following sections.

### *3.2.3 Landscape Disturbance Index*

To apply the LDI to FLFO sentinel sites, we extracted its value at the specific coordinates of each of our sites. The distance decay functions in the LDI are intended to convey the impacts of a land use at a specific distance from a focal point rather than the impact generalized across a watershed. Thus, a specific value at a monitoring site conveys more information than a watershed or complex-wide average would and better shows the gradient of disturbance between individual sites.

#### 3.2.3.1 Assessment points

The Colorado Natural Heritage Program (CNHP 2021) describes LDI scores of 0 as no impact, up to 250 as low impact, 250 to 500 as moderate impact, and above 500 as high impact. We use these breaks as assessment points and create four disturbance classes: 0 = None (or Minimal), > 0–250 = Low, >250–500 = Moderate, and >500 = High.

#### 3.2.3.2 Status

Because the LDI is available statewide we develop estimates for FLFO and other network parks and then compare these park scale values—in a sense these are additional assessment points. We then develop LDI summaries by wetland complex and type and compare values across these scales.

*Relative to other Rocky Mountain Network parks*

The LDI is a statewide model, which allows comparisons between three network parks along the Rocky Mountain Front Range and central mountain corridor: Rocky Mountain National Park (ROMO), Florissant Fossil Beds National Monument, and Great Sand Dunes National Park and Preserve (GRSA). We split GRSA into the park unit with the main dune field and a heavily historically disturbed area to the west of the dune field and the mountain preserve area with far less human use (Schweiger et al. 2017). Each park is unique in its specific geography and landscape position, but the results reveal important similarities and differences. All three parks are much less disturbed than the developed and heavily agricultural areas outside of parks and at lower elevations (Figure 16), but each park still contains areas of high disturbance.

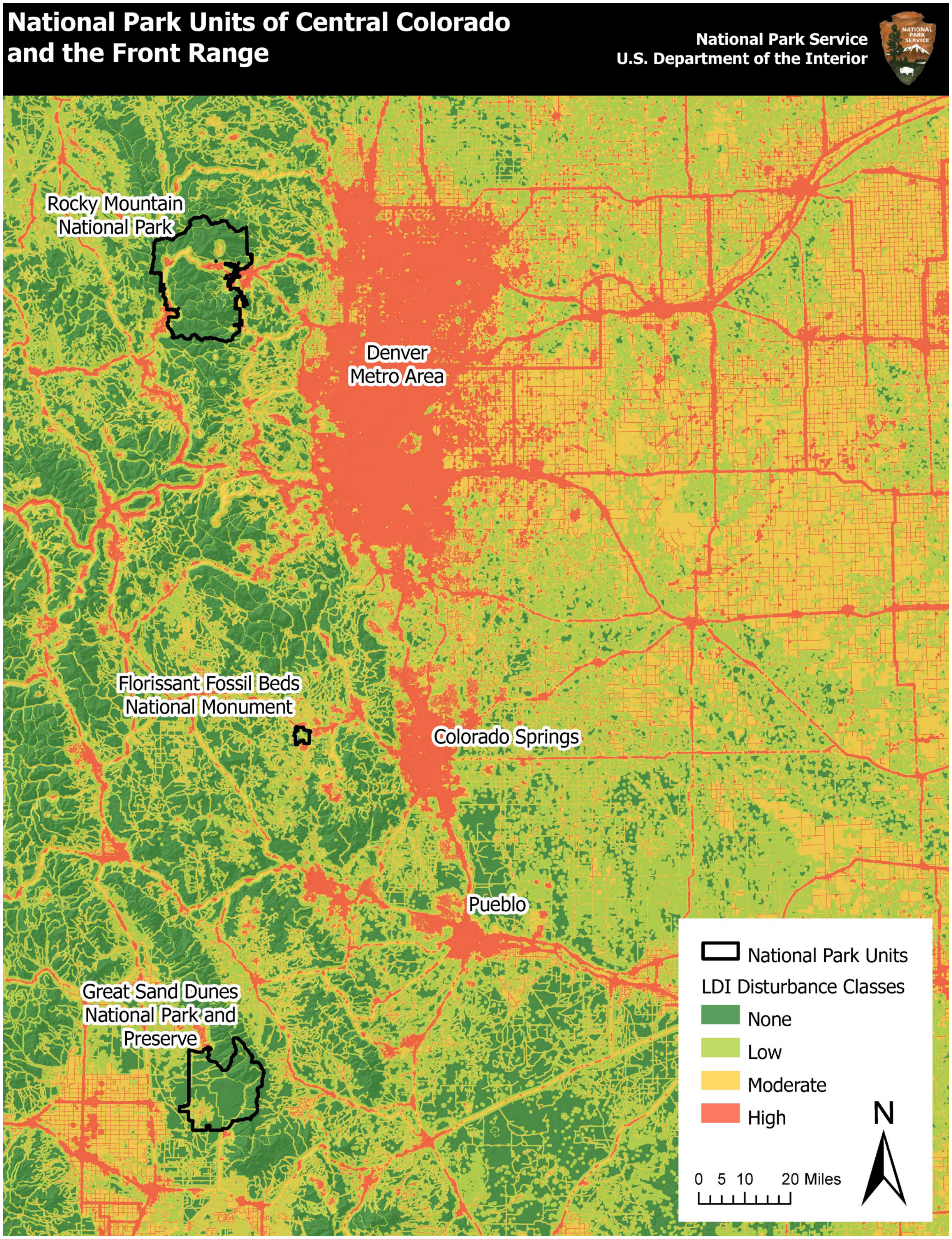



**Figure 16.** Landscape Disturbance Index (LDI) model across the Colorado Front Range, including Rocky Mountain National Park, Florissant Fossil Beds National Monument, and Great Sand Dunes National Park and Preserve. Higher disturbance values are shown in orange and red colors.

The minimum score for all three parks was 0, indicating negligible disturbance as estimated with the model's component layers (Table 8). All mean and median values were in a minor disturbance class although each park had maxima that were in a major disturbance range. The highest maximum value across all three parks was along the heavily used front country roads of ROMO, near Estes Park. ROMO receives more than four million visitors annually and most enter the park through the Estes Park corridor. The second highest maximum value was near the entrance of GRSA, in an area with a long history of ranching and grazing (Schweiger et al. 2017). Despite having the marginally lowest maximum LDI value, FLFO had the highest mean and median LDI values, indicating that low and moderately disturbed lands represent a larger share of the park's total area and its immediate surroundings. This makes sense due to the park's much smaller size and location within a residential and agricultural landscape. There is also no wilderness component to FLFO, unlike ROMO and GRSA. All parks had high CV values suggesting that even in FLFO select areas (generally the interior of the parks) had low LDI far from physical human disturbances such as roads, development, utility lines, or energy development.

**Table 8.** Landscape Disturbance Index (LDI) scores for three National Park Service units along the Front Range of Colorado, including Rocky Mountain National Park, Florissant Fossil Beds National Monument, and Great Sand Dunes National Park and Preserve. Values include coefficient of variation (CV), standard deviation (SD), minimum (min.) and maximum (max.) scores for each park. Major and Minor disturbance assessment point columns give assessment points with the greater than (“>”) or less than (“<”) signs indicating where, relative to the assessment point, a disturbance level falls.

| National Park Service unit | LDI median | LDI mean | LDI CV | LDI SD | LDI min. | LDI max. | Major disturbance assessment point | Minor disturbance assessment point |
|---|---|---|---|---|---|---|---|---|
| Rocky Mountain National Park | 0.00 | 60.48 | 2.62 | 158.761 | 0.00 | 1073.80 | >500 | <250 |
| Florissant Fossil Beds National Monument | 28.66 | 88.67 | 1.35 | 119.471 | 0.00 | 597.67 | >500 | <250 |
| Great Sand Dunes National Park (sandsheet) | 0.00 | 49.35 | 2.14 | 105.368 | 0.00 | 750.12 | >500 | <250 |
| Great Sand Dunes National Preserve (mountains) | 0.00 | 9.89 | 4.41 | 43.624 | 0.00 | 600.00 | >500 | <250 |

*Within Florissant Fossil Beds National Monument*

In FLFO, LDI values ranged from 0 (no disturbance associated with model input layers) to nearly 600 (high disturbance due to multiple landscape stressors; Figure 17). The mean LDI value for the park was 88.7 (Table 8). Given the statewide range, this score suggests a generally low landscape disturbance at the park scale and we classify the park overall as minorly disturbed. The highest landscape disturbance values were in the very southern end of the park where residential roads abut the park boundary. Within the park, the LDI indicated low levels of disturbance in the valley bottoms, with moderate levels immediately adjacent to roads and trails. Surrounding hillsides showed low to no disturbance in the model. However, the LDI does not contain every disturbance that occurs on the landscape, only those for which there are statewide spatial data layers. For example, the LDI does not include grazing or historical land uses, many of which occurred within FLFO. The LDI also does not include hydrologic alteration (we include water diversions and groundwater wells that may impact wetlands in the park in Figure 17).

The Landscape Disturbance Index was notably higher in our sites by both wetland type and sentinel complex (Table 9) relative to the mean value for the park. This suggests that human disturbance may be highest in wetland habitats in FLFO. However, within the statewide context of disturbance, which ranges from urban and agricultural areas to pristine wilderness, LDI in our FLFO wetland sites or sentinel complexes was relatively low.

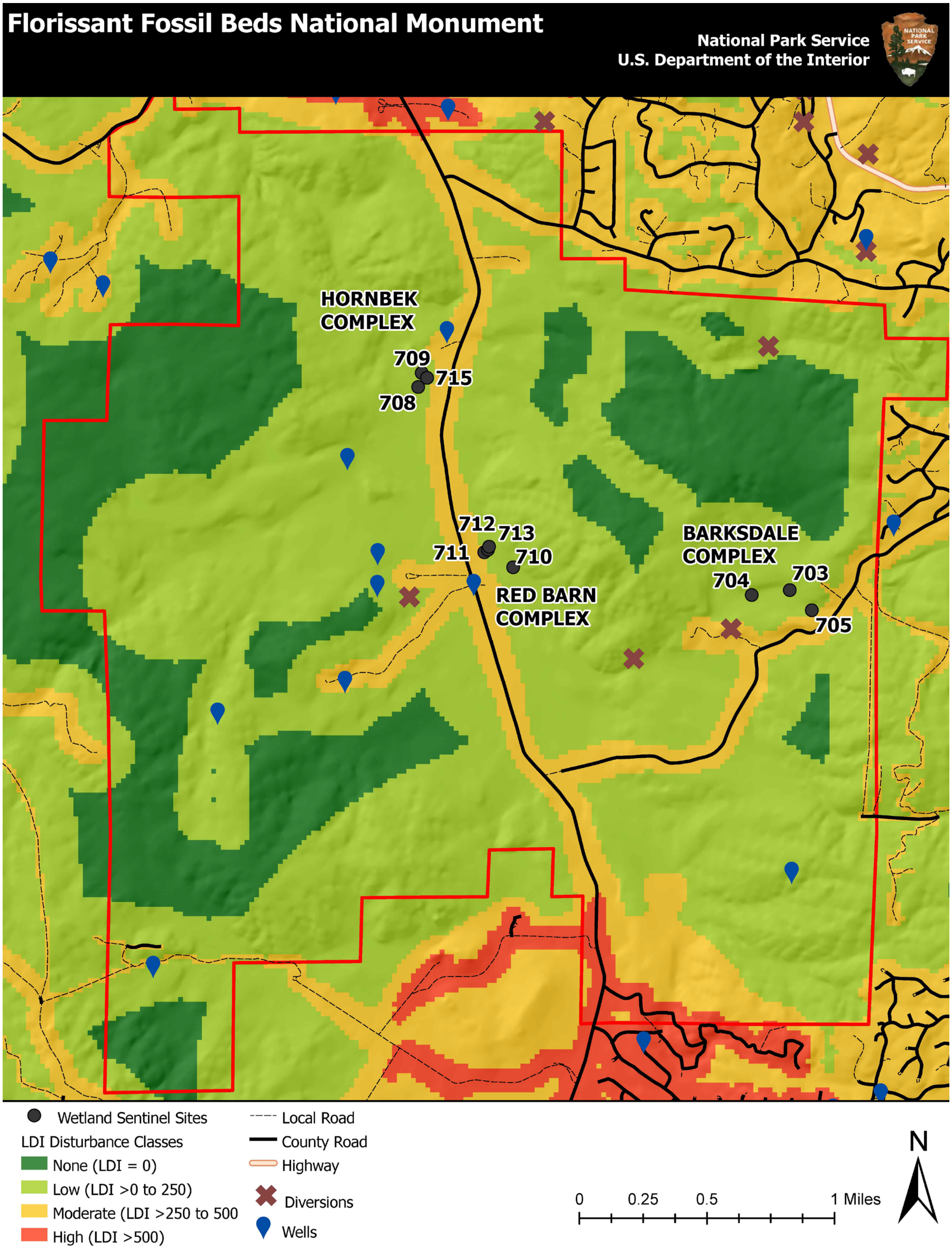



**Figure 17.** Landscape Disturbance Index (LDI) model for Florissant Fossil Beds National Monument, showing wetland monitoring sites and specific disturbances of roads, water diversions, and wells.

**Table 9.** Landscape Disturbance Index (LDI) scores at sentinel sites by wetland type and sentinel complex in Florissant Fossil Beds National Monument, Colorado. Values include coefficient of variation (CV), standard deviation (SD), minimum (min.) and maximum (max.). The Major and Minor disturbance assessment point (AP) columns give assessment points with the greater than (“>”) or less than (“<”) signs indicating where, relative to the assessment point, a disturbance class occurs.

| Wetland type / Sentinel complex | Sample size | LDI median | LDI mean | LDI CV | LDI SD | LDI min. | LDI max. | Major disturbance AP | Minor disturbance AP |
|---|---|---|---|---|---|---|---|---|---|
| Fen | 33 | 118 | 114.12 | 0.11 | 6.688 | 103 | 120 | >500 | <250 |
| Wet Meadow | 36 | 96 | 111.17 | 0.61 | 32.717 | 88 | 181 | >500 | <250 |
| Hornbek | 20 | 103 | 104.2 | 0.13 | 7.223 | 96 | 114 | >500 | <250 |
| Red Barn | 26 | 118 | 122.15 | 0.65 | 35.477 | 88 | 181 | >500 | <250 |
| Barksdale | 23 | 110 | 109.04 | 0.18 | 10.688 | 93 | 120 | >500 | <250 |

*Across wetland type and sentinel complex*

In general, LDI was similar across complexes (Table 9, Figure 18). LDI was also similar across wetland types (Table 9). LDI in wet meadows was lower, largely driven by Red Barn site 710, which was further from a road and other disturbances included in the LDI. All complexes have a long history of human use. The impact of historical uses likely extends into the present and interacts with extant disturbances (i.e., roads remain in the same place, or old land use scars take time to heal—this dynamic is well described for Rocky Mountain National Park in Schweiger et al (2016)). Incised Grape Creek channels also affect both the hydrology and plant communities within these complexes. The Barksdale Sentinel Site complex is situated in a different part of the FLFO landscape. Still along Grape Creek, the site is slightly higher in elevation above the central valley in a narrow opening between forested slopes. Instead of being located along the main park road, this complex is accessed by a spur road to the east. While not in the central valley, the area was still used during the ranching era and there is a stock pond and smaller barn downslope of the complex.

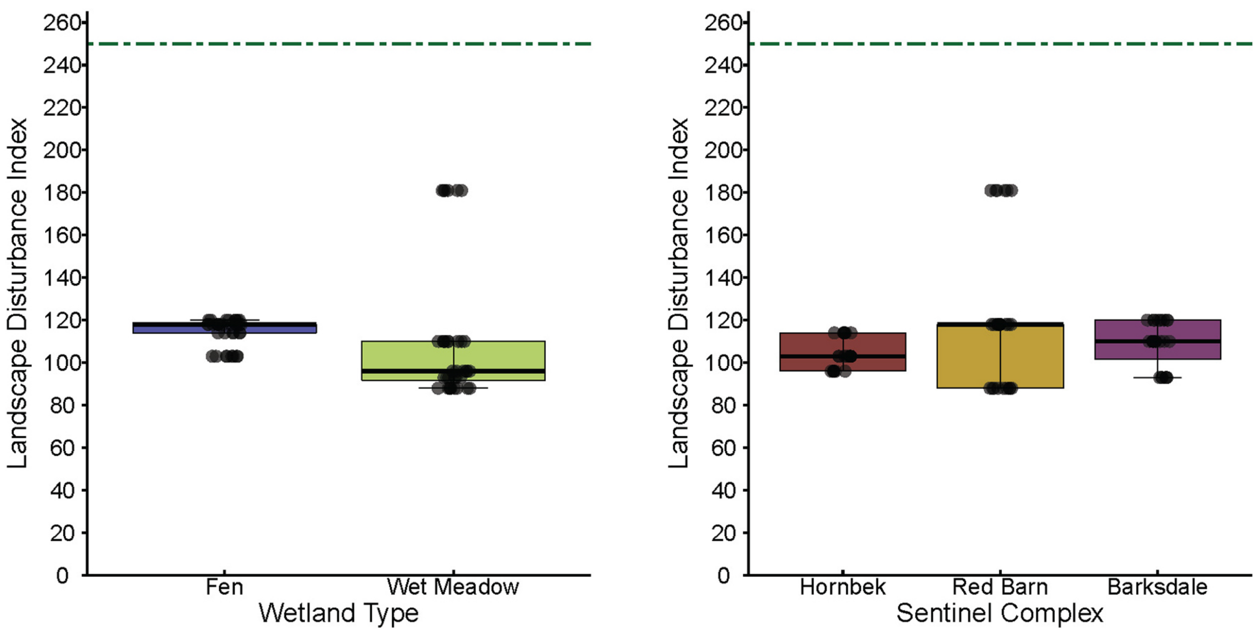



**Figure 18.** Landscape Disturbance Index (LDI) at sentinel sites by wetland type (left panel) and sentinel complex (right panel), Florissant Fossil Beds National Monument, Colorado, circa 2010s. LDI ranges from 0 to 600 (across the entirety of the park). The closest assessment point of 250 for minor disturbance (see Table 9) is shown but a major disturbance assessment point of 500 is omitted as this is well above the range of LDI in the park FLFO. Points are individual LDI values (jittered to reduce overlap).

3.2.3.3 Trend

Given a lack of a temporal element to the LDI (if or until it is redone) there is no distinct or separate baseline for 2009–2011 as used for other indicators and we cannot estimate a trend.

### *3.2.4 Human Disturbance Index*

The Human Disturbance Index (HDI) complements the constraints and strengths of the LDI by providing information about disturbance at finer spatial and temporal scales. In contrast to LDI and

its static GIS data basis, HDI documents observed levels of disturbance at each data collection event (Figure 19). HDI also includes hydrologic disturbances not in the LDI. However, it lacks a "broad view," both in terms of space and time, with the crew collecting data constrained to what they observe in and near each site. The HDI ranges from 0 to 100, with higher scores indicating more potential human disturbance.

**Figure 19.** Site 709 in the Red Barn wetland complex, Florissant Fossil Beds National Monument, Colorado, 2016. Features captured by the Human Disturbance Index are visible in the background of this image, including the namesake barn, power lines, a parking lot, and a road grade. Each of these are indicators of potential disturbance impacting this wetland. (NPS/BILLY SCHWEIGER).

3.2.4.1 Assessment points

Baseline HDI scores were compared to assessment points developed and used by the Colorado Natural Heritage Program for other wetland monitoring applications (Table 10; Rocchio 2007a, 2007b; Lemly and Rocchio 2009). These assessment points split the range of HDI values into simple thirds, scoring major disturbance as above the 67th percentile and minor disturbance as below the 33rd percentile.They place assessment of FLFO disturbance levels into the same scoring schema applied to HDI as used by CNHP in various wetland monitoring applications. These assessment points are useful; however, future work should estimate more relevant assessment points for HDI in

FLFO using undisturbed wetland sites across the state, including in other Rocky Mountain Network parks. These data could be worked up for undisturbed wetland sites much like we do for vegetation and groundwater indicators. This would also allow wetland type specific assessment points.

**Table 10.** Baseline (2009–2011) Human Disturbance Index (HDI) scores at sentinel sites by wetland type and sentinel complex in Florissant Fossil Beds National Monument, Colorado. Reported values include coefficient of variation (CV), standard deviation (SD), minimum (min.), and maximum (max.). Assessment points are given in the in the Major and Minor disturbance assessment point columns, with the greater than (“>”) or less than (“<”) signs indicating where, relative to the assessment point, a disturbance class occurs. Values between these two thresholds are in an intermediate disturbance class. HDI assessment points apply to all wetland types and sentinel complexes.

| Wetland type / Sentinel complex | Sample size | HDI median | HDI mean | HDI CV | HDI SD | HDI min. | HDI max. | Major disturbance assessment point | Minor disturbance assessment point |
|---|---|---|---|---|---|---|---|---|---|
| Fen | 11 | 57.9 | 64.9 | 0.21 | 13.61 | 52.9 | 83.5 | >67 | <33 |
| Wet Meadow | 12 | 55.8 | 57.8 | 0.23 | 13.39 | 39.8 | 83.5 | >67 | <33 |
| Hornbek | 7 | 52.9 | 64.6 | 0.23 | 14.55 | 52.9 | 80.2 | >67 | <33 |
| Red Barn | 9 | 57.9 | 63.9 | 0.26 | 16.39 | 39.8 | 83.5 | >67 | <33 |
| Barksdale | 7 | 54.5 | 54.2 | 0.11 | 5.69 | 42.9 | 61.1 | >67 | <33 |

3.2.4.2 Baseline status (2009–2011)

Table 10 and Figure 20 present summaries of baseline (2009–2011) HDI scores by wetland type and sentinel complex. As with the LDI, HDI is generally consistent across wetland type and complex. HDI is a site-specific measure so we cannot compare results to unsampled locations across the park, but we expect that HDI also is higher in our wetland sites than many other habitats in FLFO, as we see in the LDI.

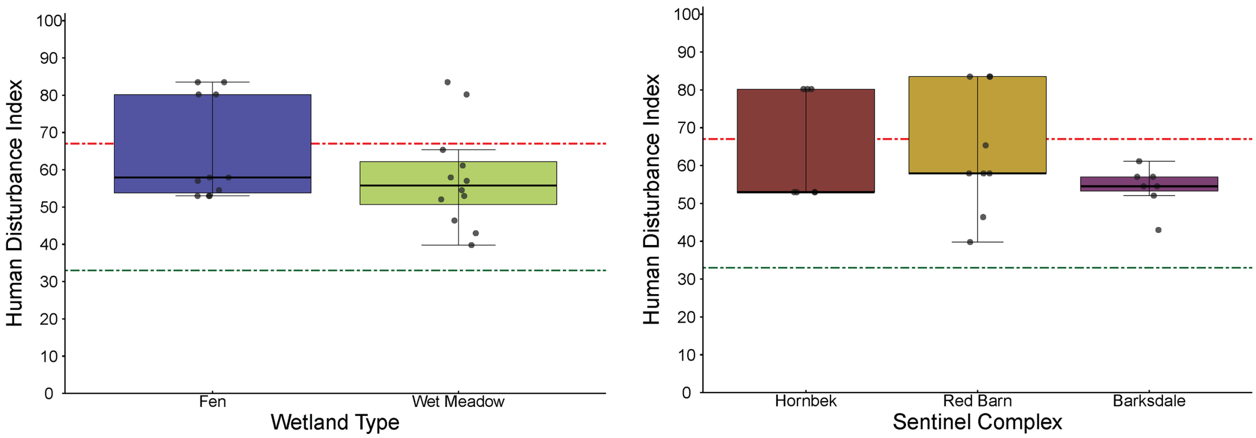



**Figure 20.** Baseline (2009–2011) Human Disturbance Index (HDI) scores at sentinel sites by (left) wetland type and (right) sentinel complex, Florissant Fossil Beds National Monument, Colorado. HDI ranges from 0 to 100. Horizontal lines show the minor disturbance assessment point (green, lower dashed line) and major disturbance (red, upper dashed line), with values below or above these in minor or major disturbance, respectively. Values between these two thresholds are in an intermediate disturbance class. Points are individual HDI values (jittered to reduce overlap). Note that the lines inside the box showing the median values for Hornbek and Red Barn complexes is the same as the bottom of the box and is harder to resolve visually.

FLFO fens had marginally higher baseline median HDI than wet meadows. Hornbek and Red Barn, with more fen sites than Barksdale, also had higher HDI than Barksdale. Variation in LDI across type and complex was relatively similar. Barksdale HDI was more homogenous than the other two complexes.

Median baseline HDI scores fell within the intermediate disturbance range for both wetland types and all three complexes. Patterns across sentinel complex were roughly the same—most complex-specific HDIs were in an intermediate disturbance class with small percentages in a major disturbance class and none at a minor level. In general, Barksdale was the least disturbed complex from 2009 to 2011. This complex is more removed from the main road corridor and the incised portion of Grape Creek.

3.2.4.3 Trend (2009 to 2019)

We first examined general patterns across time in HDI scores. Figure 21 shows a generalized smoothed fit to HDI values that shows non-linear patterns in disturbance levels. The figure also visualizes the disturbance level of each result relative to its assessment point. Across all sites, there is a suggestion of an initial increase in HDI, from 2009 to 2012. Several baseline data points are above

their major assessment point, especially in 2011 and 2012. HDI begins to fall in 2013 or 2014 generally through 2019. This pattern is evident by wetland type and complex, although it less dramatic for the Barksdale complex. Median values set by baseline HDI hover in the mid-50s. These are elevated by higher HDI in the early years of our monitoring. HDI generally decreases below baseline medians values after 2012.

A linear mixed model applied to our HDI data allows statistical tests of overall trend, trend by wetland type, and trend by sentinel complex (Table 11, Figure 22). Model selection resulted in two models with equivalent AIC scores, and we selected the simpler of these. This included sentinel complex and wetland type as fixed predictors but no interaction between time (scaled and normalized to range between 0 and 1, hence the name "scaled date") and wetland type. There was no suggestion of meaningful autocorrelation in the residuals and the relationship between the residuals and fitted values was acceptable. The model explained an acceptable proportion of the variation in HDI scores (adjusted $R^2 = 0.63$).

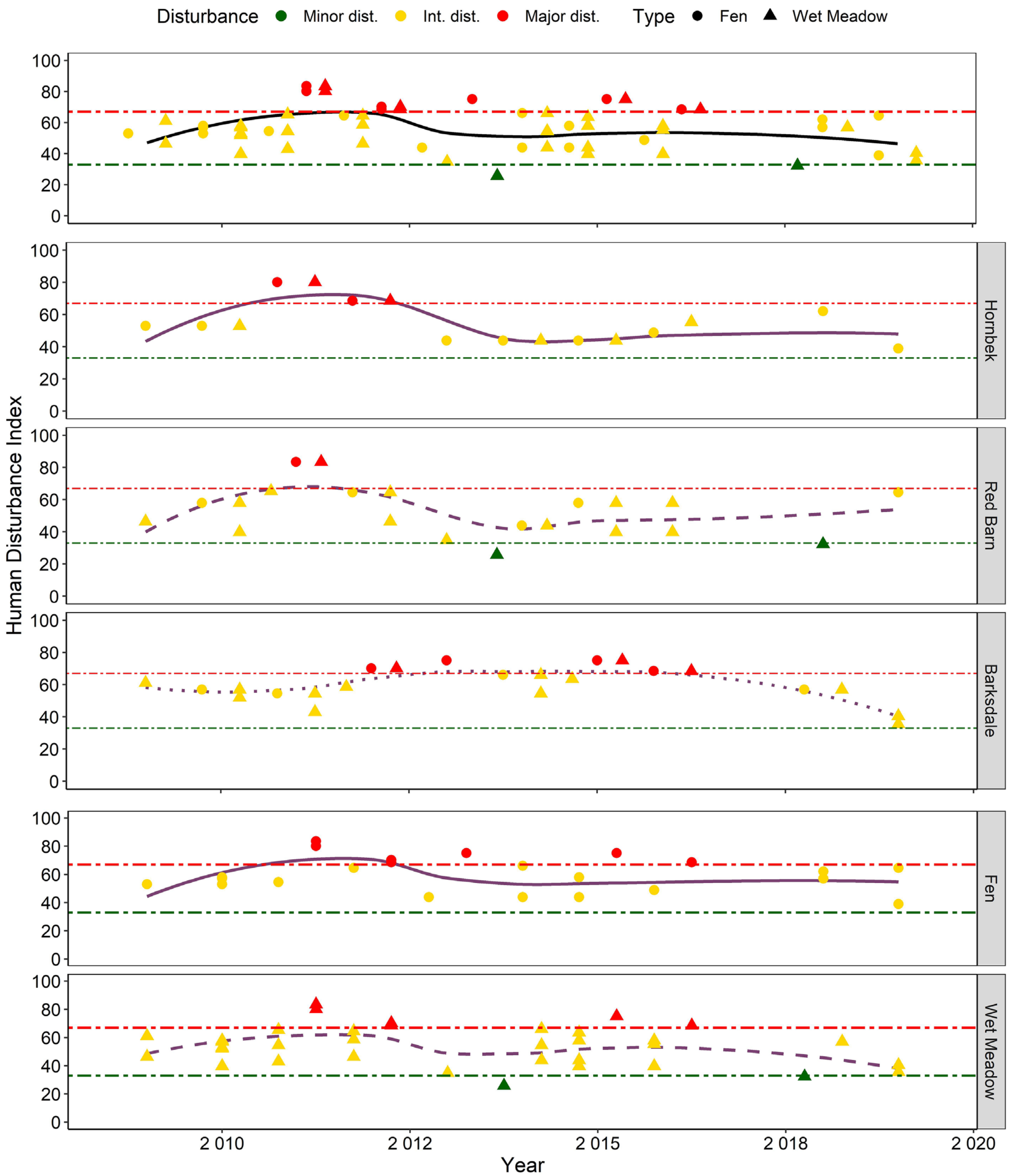



**Figure 21.** Human Disturbance Index (HDI) at sentinel wetland sites for all data (top panel), sentinel complex (three middle panels) and wetland type (bottom two panels), Florissant Fossil Beds National Monument, Colorado, 2009–2019. HDI ranges from 0 to 100, with higher values indicating more disturbance. Fitted lines are via loess smooths, which show general patterns across time. Multiple points within a year correspond to separate sample sites with points jittered to reduce overlap. Point color is determined by relationships to the assessment points shown with horizontal lines in each panel. Green indicates minor disturbance, yellow is intermediate, and red is major disturbance.

**Table 11.** Linear mixed model of Human Disturbance Index scores from all wetland sentinel sites from 2009 to 2019 at Florissant Fossil Beds National Monument, Colorado. Table includes fixed term coefficients, their degrees of freedom (df), t values, upper/lower confidence intervals, and their probability (p). Random terms include each term's standard deviation, a log ratio test statistic, and its probability (as a Chi square). The model had a sample size of 69 values across 10 years (no data were collected in 2017) and 10 sites.

| Type of term | Term | Coefficient | df | t value | Lower CI | Upper CI | p | Standard deviation | Log ratio test | p (as a Chi square) |
|---|---|---|---|---|---|---|---|---|---|---|
| Fixed | **Intercept** [a] | 66.915 | 12.561 | 10.346 | 54.238 | 79.591 | **<0.001** [a] | N/A | N/A | N/A |
| | **Scaled Date** [a] | −2.222 | 25.328 | −2.185 | −4.215 | −0.229 | **0.038** [a] | N/A | N/A | N/A |
| | Sentinel Complex (Red Barn vs. Hornbek) | −0.943 | 8.082 | −0.138 | −14.375 | 12.490 | 0.894 | N/A | N/A | N/A |
| | Sentinel Complex (Barksdale vs. Hornbek) | −1.641 | 7.667 | −0.226 | −15.877 | 12.596 | 0.827 | N/A | N/A | N/A |
| | Wetland Type (Wet meadow vs Fen) | −6.727 | 6.271 | −1.441 | −15.878 | 2.425 | 0.198 | N/A | N/A | N/A |
| | Scaled Date * Red Barn (vs. Hornbek) | 0.442 | 44.644 | 0.410 | −1.669 | 2.552 | 0.684 | N/A | N/A | N/A |
| | **Scaled Date * Barksdale. (vs. Hornbek)** [a] | 1.849 | 43.479 | 1.782 | −0.184 | 3.882 | **0.082** [a] | N/A | N/A | N/A |
| Random | **Year** [a] | N/A | N/A | N/A | N/A | N/A | N/A | 6.266 | 11.551 | **<0.001** [a] |
| | Site | N/A | N/A | N/A | N/A | N/A | N/A | 5.657 | 0.027 | 0.987 |

[a] Terms are significant ($p < 0.10$)(also in bold font).

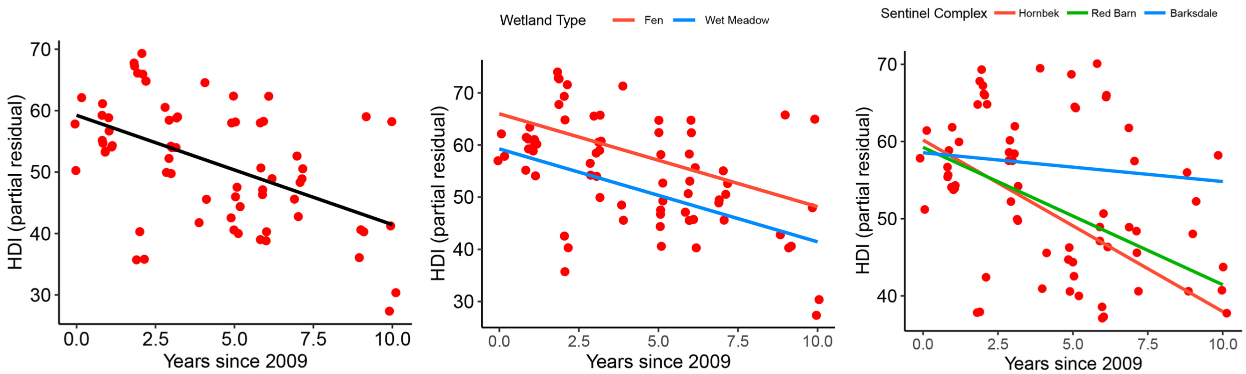



**Figure 22.** Visualizations of trend results for Human Disturbance Index (HDI) in Florissant Fossil Beds National Monument wetland sentinel sites, Colorado, 2009 to 2019. Data points are partial residuals estimated by a mixed model (Table 11). Left panel shows the overall trend across all sites. Middle panel gives trends by wetland type. Right panel gives trends by sentinel complex. Fitted lines show the corresponding estimated linear trend, overall, by wetland type, and by sentinel complex. Y axis scale may be different on some panels given different ranges in the partial residuals. Assessment points are not shown on these figures as partial residuals are not in the same units as raw data.

Overall, there was a strong and significant ($p = 0.038$) negative trend in HDI. As there are no significant interactions with complex or wetland type, we interpret this trend as a general decrease in HDI across the period of record at our sample sites. However, the marginal interaction between scaled date and the Barksdale complex ($p = 0.083$) may suggest that the decreasing trend in disturbance over time was likely different across complexes, with a steeper decline in Hornbek.

The overall decrease in HDI may reflect best management practices put into place by the park between 2009 and 2019. Decreasing HDI is consistent across all complexes and wetland types; however, it may be driven mostly by change in the fens and meadows of the Hornbek complex. This is a relatively large and high-profile wetland that parallels Teller County Road 1, the primary park road. There are several structures in the vicinity and a trail that allows park visitors to access and view the complex. The highest levels of disturbance at Hornbek were recorded in 2011 and 2012, shortly after the network's monitoring sites were installed. Late in 2012, a deeply incised channel within the Hornbek complex was restored by researchers at Colorado State University. The restoration likely raised water levels within a portion of the wetland complex, reducing the degree of hydrologic alteration as scored in the HDI by over 50% from 2013 to 2019. Scores for other components of HDI in Hornbek, such as alterations to the buffer or the wetlands landscape context, remained consistent over time, hence the change in HDI is likely due to the elevated groundwater after 2012. However, it is likely that wetter climate and water balance drivers during these years also elevated water table heights, making it unclear how much of this change was due to climate vs. restoration success.

#### *3.2.5 Summary of patterns among disturbance indicators*

Relationships among HDI and LDI and four GIS based disturbance variables (percent of human land use within 1 km of each site, distance to nearest human land use, road stream crossings in a site's catchment, and the percent of a site's catchment above diversions) are shown in Figure 23. These

should be treated with some caution as bivariate correlations do not account for non-linear relationships or any confounded interactive effects among estimates of disturbance.

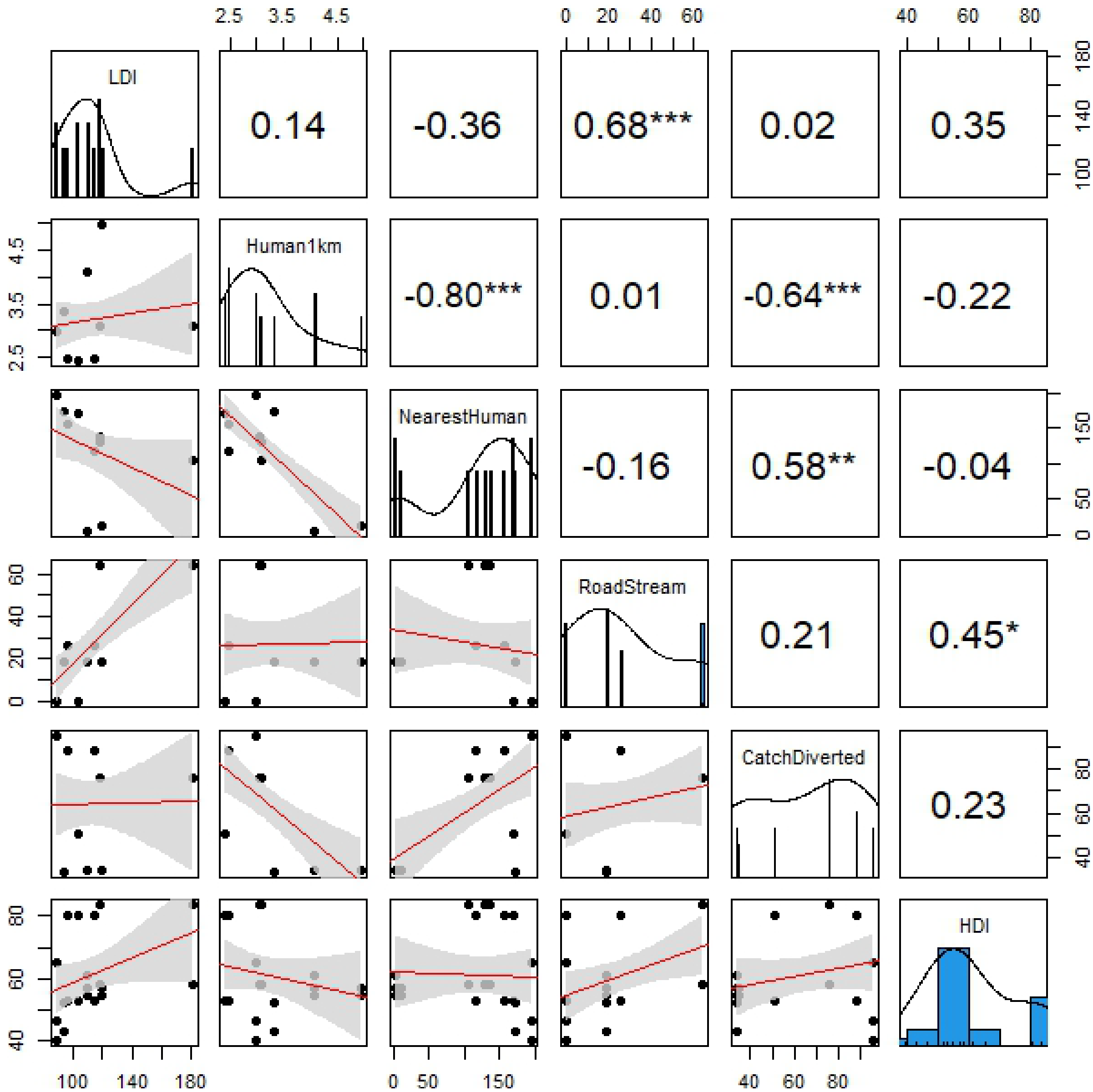



**Figure 23.** Relationships between Human Disturbance (HDI), Landscape Disturbance Index (LDI), Human land use within 1 km, distance to nearest human land use, road stream crossings in a site's catchment, and the percent of a site's catchment above diversions, at sentinel sites, Florissant Fossil Beds National Monument 2009–2011. Matrix shows bivariate scatterplots below the diagonal with linear fits (red lines) and 95% confidence interval (gray shading). The histograms along the center diagonal include a smoothed density plot as a line draped over histograms. Pearson rank correlation coefficients are above the diagonal with significance indicated with a * for $p < 0.05$, ** for $p < 0.01$, and *** for $p < 0.001$. Figures on the bottom most row and correlations in the right most column are for HDI and the five measures of disturbance. Baseline data only used, given a significant trend in HDI.

The two primary disturbance indices, LDI and HDI, were positively correlated (r = 0.35), although scale differences and the lack of a temporal component in LDI likely explain this being a nonsignificant relationship. The pattern may also be driven by outliers in LDI such as Red Barn site 711. The distance to human land use features was negatively related to LDI (r = -0.36) indicating that proximity of a disturbance may have mattered (it was nonsignificant) in the LDI. The density of road–stream intersections was strongly and significantly positively related (r = 0.68) with LDI and HDI (r = 0.45), supporting the well documented role of roads as a source of disturbance to wetlands (i.e., Palomino and Carrascal 2007; Wilbert et al. 2008; Eigenbrod et al. 2009). Finally, the percentage of a site's catchment diverted by dams or other hydrologic modifications had a positive relationship with HDI (r = 0.23) but not with LDI, as there are not explicit hydrologic data in the LDI index. Many of these relationships are intuitive and have congruent patterns. This suggests that these estimates of disturbance are appropriate and reliable indicators, supporting their use in analyses of wetland responses such as hydrology and vegetation.

## 3.3 Hydrology

### *3.3.1 Summary condition*

We begin by summarizing the condition of various depth to groundwater metrics in park wetlands (Table 12) and follow with details for each of the metrics. We specifically discuss patterns among the discrete depth to groundwater metrics and disturbance.

**Table 12.** Summary condition table for groundwater hydrology at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, 2009–2019. These statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not an indicator's absolute value. Summary condition statements are a considerable simplification of the details behind each indicator—they should be used with caution. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

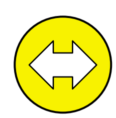
| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Discrete hand measured groundwater depth | Wetland condition is highly influenced by depth to groundwater—without groundwater near the surface, habitat would not be a wetland. Groundwater influences vegetation composition, soil biogeochemistry, and the many species that use these systems.<br><br>FLFO hand-measured (discrete) depth to water across all sites increased or became less negative (that is, sites became wetter) across our period of record, perhaps driven most by increasing wetness in fens, especially in the Hornbek complex. Increased wetness in Hornbek may have been due to site restoration in 2012 and/or the end of a short-term drought. Unraveling these competing causes is complex, but as described in the biology section of this report, patterns in vegetation suggest the Hornbek restoration may have at least enhanced resilience of the site to drought. |  |

**Table 12 (continued).** Summary condition table for groundwater hydrology at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, 2009–2019. These statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not an indicator's absolute value. Summary condition statements are a considerable simplification of the details behind each indicator—they should be used with caution. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

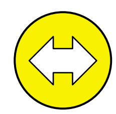
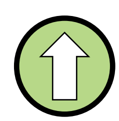
| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Discrete hand measured groundwater depth (continued) | While wetness increased from 2009 to 2019, groundwater levels at our 10 sites were lower than, or drier than, ecoregional assessment points, especially during periods of drought. Dry wetlands generally have a lower ecological condition (i.e., it is more difficult for plants' roots to access water tables and many species cannot survive). The scientific literature includes evidence of interactions between climate driven drying of wetlands and human disturbance. These studies suggest that where or when there are more human disturbances in and around a wetland, groundwater is often farther from the surface and that this interaction will likely be worse as climate change progresses. We see the beginning of these patterns in our FLFO data, and we therefore have an overall rating of caution for discrete groundwater with an intermediate disturbance level.<br>There are important management applications in wetland groundwater maintenance. Clearly FLFO has recognized this given the restoration project at Hornbek, among other actions. This focus should continue, and our long-term monitoring data will help managers understand changes and restoration success.<br>Our confidence in discrete groundwater data itself is high. However, as these data are discrete, the models we apply do not capture patterns across an entire growing season, nor do they include specific examination of climatic and water balance drivers, unlike our site-specific continuous groundwater depth models. Therefore, our overall confidence in this assessment is medium. |  |
| Hornbek Fen Site 708 Continuous growing season groundwater depths | We monitor continuous groundwater levels year-round at three sites in the park. One of those three sites is fen site 708 in the Hornbek complex. Continuous depth to water (DTW) data are ideal for understanding the nuances of the hydrologic regimes in these sentinel wetlands because they may better reflect seasonal patterns that can vary within and across years and, with proper modeling, can reveal non-linear relationships with the climate and water balance drivers of groundwater hydrology. We focus on summer growing season groundwater given the important connection to vegetation in FLFO's wetlands.<br>Site 708 had a stable water table in most years. However, 2011–2013, early in our monitoring period, was unique, with water tables near or above the surface through August but then experiencing a large drop in later summer. This pattern is somewhat unusual for fens that generally have stable groundwater. The years 2010 and 2014–2019 were more typical for a fen, with a largely consistent groundwater elevation near the surface. |  |

**Table 12 (continued).** Summary condition table for groundwater hydrology at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, 2009–2019. These statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not an indicator's absolute value. Summary condition statements are a considerable simplification of the details behind each indicator—they should be used with caution. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

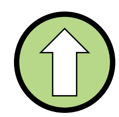
| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Hornbek Fen Site 708 Continuous growing season groundwater depths (continued) | Models relating climate and water balance to groundwater were developed to help explain these patterns. Two water balance variables were included in the final model for site 708: soil moisture and drainage (runoff accumulated across days). Both of these variables had a positive relationship with groundwater level. These terms were not significant, but both are likely ecologically important and have management relevance. Patterns in soil moisture and drainage suggest site 708 is sensitive to changes in the water cycle. The model also showed that groundwater elevations increased from 2010 to 2019 at site 708. Although this change was also not significant, we feel it is meaningful given similar results across other indicators. The assessment points we have are not ideal for continuous groundwater data; they are more relevant for discrete later summer groundwater. However, with this caveat in mind, elevated groundwater (wetter conditions) shifted this site from an intermediate or even major disturbance level into a minor disturbance class over our period of record.<br><br>Restoration work to fill in incised channels was completed in October 2012 at this site. This may have increased water table elevations; however, 2011–2013 was also a drought and without a longer interval of monitoring prior to 2010, it is not clear if the stable and high-water tables we saw at this site beginning in 2014 were due to the 2012 restoration or wetter, non-drought conditions. DTW at site 708 *did not* strongly respond to a shorter drought in 2017–2018, although the other two sites did (see below). It is therefore possible that the restoration increased the resilience of site 708's hydrology. This is suggested by the vegetation data presented in the biology section of this report.<br><br>The complexity in site 708's groundwater has important implications for resource management, perhaps including to temper expectations for success from restoration efforts under a variable and changing climate. Restoration plans might also be designed that incorporate expected climate driven changes in wetland hydrology. These may be important points for the park's interpretive staff to share with the public.<br><br>Future work might forecast water balance estimated drainage and soil moisture based on climate change scenarios to help FLFO management react to and work with possible climate change driven alterations to the hydrology of this wetland. Such research might also provide the park with useful material for climate change interpretive interaction with the public.<br><br>Our continuous groundwater data are high quality and our model for this site was robust and interpretable. Better assessment points for continuous data would be useful. However, overall our confidence is high. |  |

**Table 12 (continued).** Summary condition table for groundwater hydrology at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, 2009–2019. These statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not an indicator's absolute value. Summary condition statements are a considerable simplification of the details behind each indicator—they should be used with caution. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

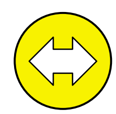
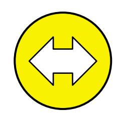
| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Red Barn Wet Meadow Site 710 Continuous growing season groundwater depths | The second site with continuous groundwater monitoring is wet meadow site 710 in the Red Barn complex. Continuous groundwater at this site was highly variable, with a tendency for higher water tables early in the season followed by a drawdown and occasionally a later summer rise. The 2012 and 2013 growing season had lower water tables over several periods—like the other two continuous groundwater monitoring sites, 708 and 705—but in general the two drought periods we see reflected in the hydrographs for these other sites were not evident at site 710.<br><br>A single water balance variable was included in the final model: drainage, with a positive and almost significant relationship with groundwater. The lack of any other water balance term in the final model other than drainage, and the more robust nature of drainage as a predictor, likely reflects important attributes of the site's hydrologic regime and the factors that influence it. The site is adjacent to a portion of Grape Creek that may be more intact (i.e., less historical modification and channelization) than further upstream in Hornbek, where the restoration occurred. It is also closer to a hillslope than other sites, which may contribute more water via drainage than the flatter terrain at the other two sites. It suggests that the site's hydrologic regime may have more of a surface water component as drainage is derived from runoff and runoff is generally surface flow. The importance of this term in this site's model suggests that the site may be sensitive to changes in the water cycle, and future work could forecast water balance estimated drainage, as with site 708 in the Hornbek complex.<br><br>The non-linear trend in the model was highly significant and suggests that DTW dropped across 2010 and 2013 (drought), then returned to a wetter condition through 2017 and then dropped again in 2018 (second drought). This is different than site 708 (Hornbek) and more like site 705 (Barksdale, below), suggesting that the water table in 710 was less resilient to the second drought, unlike the restored Hornbeck site. We give this trend a flat arrow given the lack of a simple linear trend; we also give it a caution assessment given no clear indication that the site's hydrology is stable and given that it may be heavily influenced by annual precipitation patterns.<br><br>Daily groundwater values were rarely in a major disturbance class across the period of record at the site, falling below the threshold only in the drought years of 2013 and rarely in 2011. In most other years groundwater levels at site 710 were above the minor disturbance assessment point or occasionally in an intermediate class.<br><br>Our continuous groundwater data are high quality and our model for this site was robust. However, a simple linear trend would have been more interpretable and a better assessment point for continuous data would be more useful. Overall, our confidence is medium. |  |

**Table 12 (continued).** Summary condition table for groundwater hydrology at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, 2009–2019. These statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not an indicator's absolute value. Summary condition statements are a considerable simplification of the details behind each indicator—they should be used with caution. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Barksdale Fen Site 705 Continuous growing season groundwater depths | The third site with continuous groundwater monitoring is fen site 705 in the Barksdale complex. Continuous groundwater at this site was stable, with high water tables near the surface through August in most years. During the drought in 2012 and 2013, groundwater levels dropped to 20–30 cm below the surface across most of these summers. We saw a similar pattern in fen site 708 (Hornbek) but not in the more naturally variable wet meadow at site 710 (Red Barn). Groundwater in 2011 at 705 was also different, with an oddly low water table in the spring that then became more typical in later June through the end of the growing season. All other years were consistently saturated with water at or near the ground surface elevation, although the site was less wet overall than the Hornbek site after its restoration.<br><br>Two water balance variables were included in the final model for 705: 1) soil moisture, with a positive relationship with DTW, and 2) drainage, also with a positive relationship with groundwater. These terms were not significant, but both are nevertheless ecologically important with management relevance. Patterns in soil moisture and drainage may suggest site 705 is also sensitive to changes in the water cycle, and future work might forecast water balance estimated drainage and soil moisture along climate envelopes as at other sites.<br><br>The non-linear trend in the model was highly significant and had a pattern similar to site 710 (Red Barn), with decreased groundwater levels in response to both drought periods. This suggests the water table was less resilient to drought conditions than the restored site at Hornbek. We give this trend a flat arrow given the lack of a single linear coefficient and a caution assessment given the lack of a single trend of increasing groundwater.<br><br>Daily groundwater values were often in a major disturbance class at this site in late summer, 2011 through 2013, and near this threshold through 2014. In most other years, groundwater levels at the site were in an intermediate disturbance condition.<br><br>Our continuous groundwater data are high quality and our model for this site was robust. However, a simple linear trend would have been more interpretable and better assessment points for continuous data would be more useful. Overall, our confidence is medium. |  |

### *3.3.2 Background and relevancy*

Groundwater hydrology is the primary ecological driver of wetlands, influencing multiple ecosystem processes such as vegetation composition and soil biogeochemistry. Sources of water for wetlands vary and include precipitation, surface flow from streams or lakes, and groundwater input from

outside the wetland. Most wetlands have complex combinations of these sources. Seasonal and annual patterns of groundwater levels in wetlands are related to climate, water balance in the wetland's watershed, and water source. In western US mountainous regions, shallow groundwater tables (water near the surface) tend to occur following snowmelt, with mid to late summer monsoon precipitation also often increasing groundwater levels.

We present and interpret two types of groundwater data: 1) discrete hand measured data collected from each site in each complex mostly in mid to late summer (Figure 24), and 2) continuous data from a logger in one well in each of the three complexes. Discrete depth to water (DTW) data are modeled with linear mixed models, like other wetland ecological integrity data collected once to a few times a year. We apply the Rocky Mountain Network's assessment methods using groundwater depth assessment points developed from ecoregional undisturbed sites. The analyses and assessment approaches for continuous data differ from other wetland ecological integrity (WEI) responses. These data require a more involved non-linear modeling approach (a generalized additive model, see Methods and Appendix 4), which support inclusion of climate and water balance predictors that can increase our understanding of what is driving water table depths. We currently lack assessment points relevant to unique aspects of continuously measured hydrologic data, such as the minimum duration a site needs to be saturated or minimum early season spring water tables when it is difficult to obtain discrete hand measurements. We do make general comparisons to the assessment points developed from discrete data for mid to late summer periods of each time series but caution that these interpretations may not properly deal with or take advantage of continuous groundwater data. However, because continuous DTW can be modeled with climate and water balance, it is possible to interpret how management actions influencing groundwater might interact with changes driven by climate. Thus, long-term monitoring of continuous DTW may have a more useful application to management in FLFO.

Depth to water ranges from larger negative values indicating a deeper water table, up to zero for water at the surface, to positive for inundated sites with standing water. DTW values are thus always relative or scaled to the location of the ground surface at a site. Absolute groundwater or "water table" elevation is also commonly used to describe variation in groundwater position, with terms like "deep groundwater" for a dry site where the groundwater is well below the ground surface, or "high groundwater" for a wet site where groundwater is near or above the surface. We will use both DTW and the terms groundwater or water table elevation to describe a site's groundwater.

**Figure 24.** Measuring groundwater at Site 711 in the Red Barn complex, Florissant Fossil Beds National Monument, Colorado, 2010. This monitoring task seems to make NPS staff very happy. NPS/BILLY SCHWEIGER.

### *3.3.3 Discrete depth to water*

3.3.3.1 Assessment points

Discrete baseline DTW was compared to assessment points derived from ecoregional and Rocky Mountain Network park undisturbed sites (Table 13 and Figure 25) using the 50th and 25th percentiles for minor and major disturbance assessment points, respectively, as summarized in Appendix 5. Median baseline DTW for fens and wet meadows were both in an intermediate disturbance class. In general, Hornbek was the wettest complex from 2009 to 2011, with Red Barn the driest. Highly variable fen DTW in FLFO may reflect marginal hydrologic conditions, variable climate, and/or some uncertainty in our type classifications.

More data may be needed to be certain these assessment points are appropriate for FLFO. However, our current DTW assessment points may be higher (or more positive, indicating a wetter site) than needed for maintenance of wetlands, especially fens in FLFO (see Appendix 5). For example, Faber-Langendoen et al. (2006) and Rocchio (2007b) suggest a minor disturbance DTW for western US fens in later summer is 30 cm below ground level (vs. our assessment point of 7.25 cm below ground for a minorly disturbed site).

**Table 13.** Baseline (2009–2011) discrete depth to groundwater (DTW) at sentinel sites by wetland type and sentinel complex in Florissant Fossil Beds National Monument, Colorado. Reported values include coefficient of variation (CV), standard deviation (SD), minimum (min.), and maximum (max.). Assessment points (AP) are given in the Major Dist. AP and Minor Dist. AP columns with the greater than (“>”) or less than (“<”) signs indicating where relative to the AP a disturbance class occurs. Values between these two thresholds are in an intermediate disturbance class. Assessment points are wetland specific and thus do not apply to the mix of types in the three complexes.

| Wetland type / Sentinel complex | Sample size | DTW median (cm) | DTW mean (cm) | DTW CV | DTW SD | DTW min. (cm) | DTW max. (cm) | Major disturbance assessment point | Minor disturbance assessment point |
|---|---|---|---|---|---|---|---|---|---|
| Fen | 89 | −4.4 | −11.7 | 1.59 | 18.62 | −79.9 | 10.5 | < −7.25 | > −0.2 |
| Wet meadow | 84 | −38.9 | −32.0 | 0.88 | 28.17 | −74.8 | 9.2 | < −60.3 | > −23.0 |
| Hornbek | 52 | −4.6 | −14.1 | 1.38 | 19.57 | −51.0 | 10.5 | – | – |
| Red Barn | 68 | −32.8 | −28.9 | 0.77 | 22.29 | −79.9 | 4.7 | – | – |
| Barksdale | 53 | −0.5 | −19.3 | 1.67 | 32.38 | −74.8 | 9.2 | – | – |

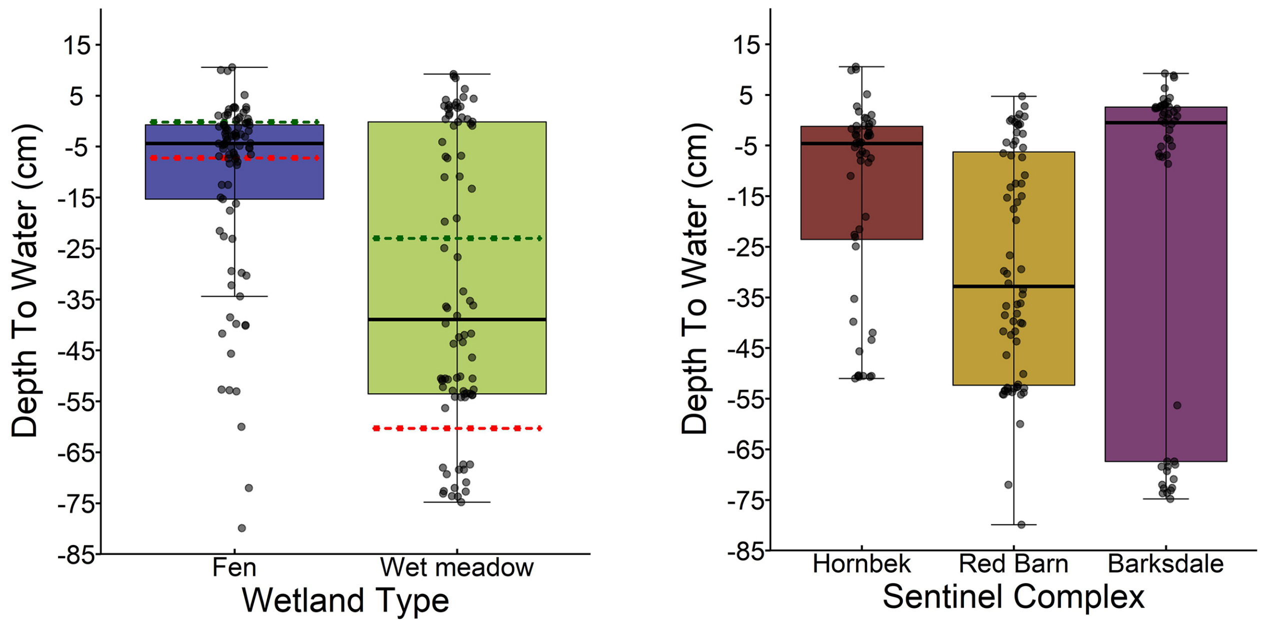



**Figure 25.** Baseline (2009–2011) discrete depth to groundwater (DTW) at sentinel sites by (left) wetland type and (right) sentinel complex, Florissant Fossil Beds National Monument, Colorado. DTW ranges from −80 cm below to 10 cm above ground elevation. Horizontal dotted lines within each box show minor disturbance assessment points (green, upper dotted lines) and major disturbance (red, lower dotted lines) by wetland type, with values above or below these in minor or major disturbance, respectively. Values between these two thresholds are in an intermediate disturbance class. Assessment points are wetland specific and thus do not apply to the mix of types in the three complexes presented in the bottom panel. Points are individual baseline DTW values (jittered to reduce overlap).

3.3.3.2 Baseline status (2009–2011)

FLFO fens had higher baseline groundwater (lower DTW) than wet meadows, but they also had a surprisingly large CV, nearly twice as large as usually more variable wet meadows (Table 13 and Figure 25). Hornbek and Barksdale, with more fen sites than Red Barn, also had the wetter conditions. Fens are naturally wetter and usually have more stable water tables than other wetland types, often because of consistent input from groundwater flow, which can be more independent of climate and water cycle driven fluctuations.

Fens in FLFO are near the lower elevation limit for peat formation (which largely defines the fen wetland type), with some fen sites' vegetation classifiable as either wet meadow or fen depending on the year or sampling variability (Dr. David Cooper, unpublished data). Peat depths and percent organic matter were also marginal for fens (see Appendix 6). Our classification of sites into fen and meadows is likely correct given high and usually consistent water tables and generally fen-like vegetation versus highly variable hydrology and meadow-like vegetation, but the borderline nature of some sites should be considered when assessing relative to DTW assessment points from largely undisturbed sites across the ecoregion.

3.3.3.3 Trend (2009 to 2019)
We examined DTW across time using generalized or smoothed fits to show possible non-linear patterns (Figure 26). Figures also show the disturbance level of each result relative to its assessment point via point color. Across all sites, there is a suggestion that DTW decreased or that there was a drying of sites from 2009 to 2011. Many data points are below their assessment point, especially in 2011. The spread in DTW is also quite large in early years, with high variation during the baseline period (Table 13). Higher variability in groundwater elevations suggests more unsettled or variable hydrologic conditions. DTW begins to recover in 2013 or 2014 with a consistent return to wetter conditions through 2017, followed by a drop again in DTW in some sites during the last two years of the record. This pattern is evident by wetland type and complex, although it less dramatic for fens and in the Hornbek complex.

A linear mixed model applied to our DTW data allows statistical tests of overall trend, trend by wetland type, and trend by sentinel complex (Table 14, Figure 27). Model selection suggested that including all terms and their interactions resulted in a model that fit the data best. The ability to include all interactions in the final model for DTW may be due to the larger sample size than for other responses presented in this report. The trend model explained an acceptable proportion of the overall variation in DTW (adjusted $R^2 = 0.61$). There was no suggestion of meaningful autocorrelation in the residuals and the relationship between the residuals and fitted values was acceptable

Across all wetland types and complexes from 2009 to 2019, water tables became higher, or closer to the surface, resulting in wetter conditions. However, this was not significant ($p = 0.234$) and there was a significant interaction between scaled date and sentinel complex, complicating interpretation. Differences in the patterns across complex were not statistically different. However, the Hornbek complex did have a positive slope (or increased wetness). As discussed in more detail below, this may be due to the restoration in 2012 or a return to non-drought conditions in 2014, or perhaps some of both. The restoration may have increased the resilience of the Hornbek sites to drought that returned in 2017 and impacted the other two complexes (Figure 27). The wetland types were also significantly different, with lower groundwater in wet meadows (i.e., drier) than fens ($p = 0.047$) and a suggestion of increasing water tables in fen and decreasing water tables in wet meadows sites.

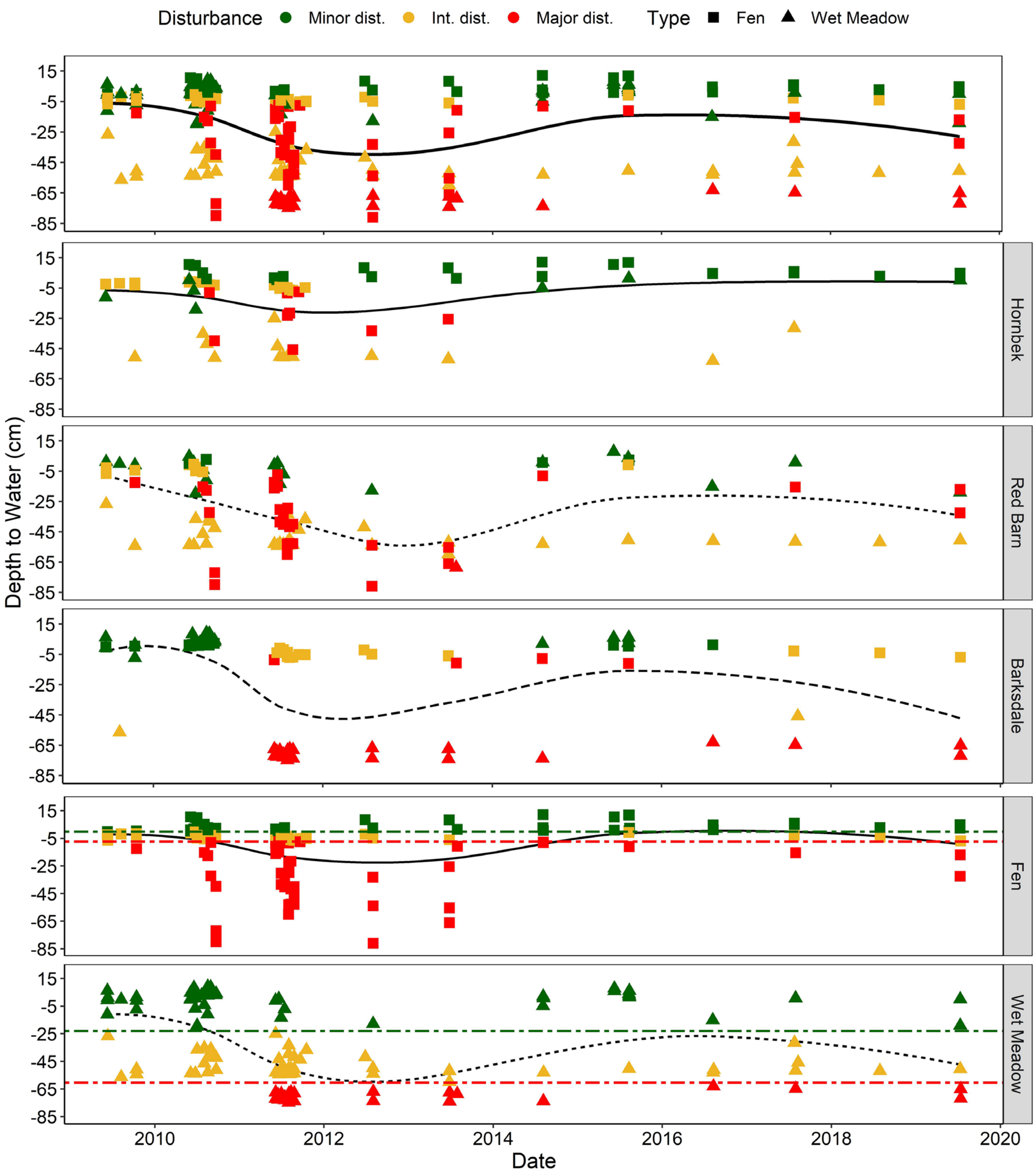



**Figure 26.** Discrete depth to groundwater (DTW) at sentinel sites for all data (top panel), sentinel complex (three middle panels), and wetland type (bottom two panels), Florissant Fossil Beds National Monument, Colorado, 2009–2019. Fitted lines are via loess smooths, which show general patterns across time. Multiple points within a year correspond to separate sample sites, with points jittered to reduce overlap. Point color is determined by relationships to wetland type specific assessment points as shown in the bottom two panels. Green indicates minor disturbance, yellow is intermediate, and red is major disturbance.

**Table 14.** Linear mixed model of hand measured depth to water (DTW) from all wetland ecological integrity sites at Florissant Fossil Beds National Monument, Colorado, 2009 to 2019. Table includes fixed term coefficients, their degrees of freedom (df), t values, upper/lower 95% confidence intervals, and the probability (p) or significance of the term. Random terms include each term's standard deviation, a log ratio test statistic, and its probability (as a Chi square). The model had a sample size of 252 across 10 years and 10 sites.

| Type of term | Term | Coefficient | df | t value | Lower CI | Upper CI | p | SD | Log ratio test | p |
|---|---|---|---|---|---|---|---|---|---|---|
| Fixed | Intercept | −10.872 | 13.842 | −1.038 | -31.410 | 9.666 | 0.317 | N/A | N/A | N/A |
| | Scaled Date | 1.972 | 14.705 | 1.241 | −1.143 | 5.086 | 0.234 | N/A | N/A | N/A |
| | **Wetland Type Wet meadow (vs Fen)** [a] | −18.414 | 6.322 | −2.466 | −33.051 | −3.778 | **0.047** [a] | N/A | N/A | N/A |
| | Sentinel Complex Red Barn (vs Hornbek) | −8.940 | 6.388 | −1.013 | −26.235 | 8.355 | 0.348 | N/A | N/A | N/A |
| | Sentinel Complex Barksdale (vs Hornbek) | 7.251 | 6.243 | 0.754 | −11.587 | 26.088 | 0.478 | N/A | N/A | N/A |
| | Scaled Date*Wetland Type (Wet meadow vs Fen) | −1.354 | 28.856 | −1.405 | −3.241 | 0.534 | 0.171 | N/A | N/A | N/A |
| | Scaled Date* Sent. Complex Red Barn (vs Hornbek) | −1.515 | 30.849 | −1.307 | −3.785 | 0.756 | 0.201 | N/A | N/A | N/A |
| | **Scaled Date* Sent. Complex Barksdale (vs Hornbek)** [a] | −4.213 | 25.175 | −3.517 | −6.560 | −1.865 | **0.002** [a] | N/A | N/A | N/A |
| Random | **Year** [a] | N/A | N/A | N/A | N/A | N/A | N/A | 13.592 | 76.429 | **<0.001** [a] |
| | Site | N/A | N/A | N/A | N/A | N/A | N/A | 10.11611 | 0.627 | 0.7311 |

[a] Terms are significant (p < 0.10)(also in bold font).

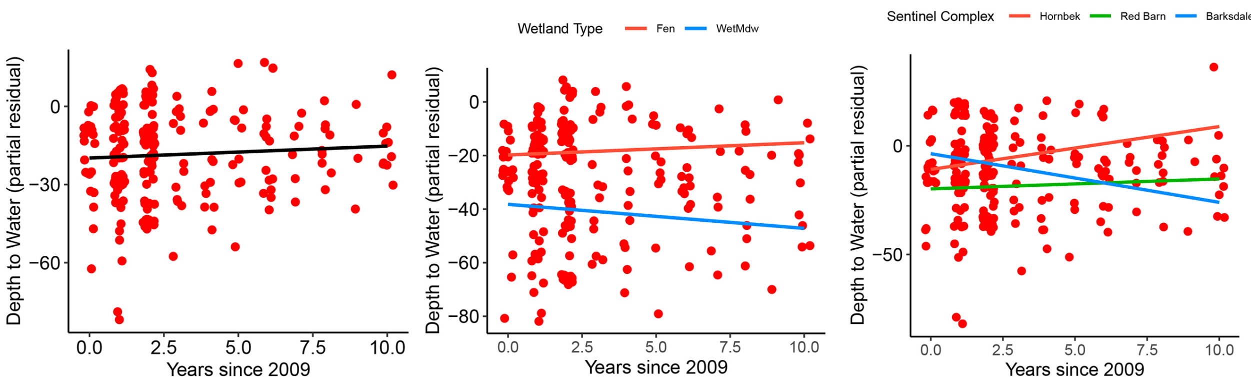



**Figure 27.** Visualizations of trend results for discrete depth to groundwater (DTW) in Florissant Fossil Beds National Monument wetland sentinel sites, Colorado, 2009 to 2019. Data points are partial residuals estimated by a mixed model (Table 14). Left panel shows the overall trend across all sites. Middle panel gives trends by wetland type. Right panel gives trends by sentinel complex. Fitted lines show the corresponding estimated linear trend overall, by wetland type, and by sentinel complex. Y axis scale may be different on some panels given different ranges in the partial residuals. Assessment points are not shown on these figures as partial residuals are not in the same units as raw data.

#### *3.3.4 Summary of patterns among discrete depth to water and disturbance metrics*

Relationships among DTW, HDI, hydrologic alterations (a component of the HDI), and LDI are shown in Figure 28. These should be treated with some caution as bivariate correlations do not account for non-linear relationships or any confounded interactive effects among estimates of DTW and disturbance.

Both measures of human disturbance, HDI and LDI, had nonsignificant and small but possibly meaningful negative relationships (r = -0.13 and r = -0.02, respectively) with DTW, suggesting groundwater is deeper or sites are drier where there is more human disturbance. HDI includes a specific hydrologic component that scores the degree of hydrologic alterations from human activities and the pattern with this element of HDI is stronger (r = -0.26) and significant, suggesting that where or when there are more changes to the hydrology of a site, DTW is lower (drier site). This of course makes sense with altered hydrology generally lowering water tables. This also confirms that the hydrologic alteration piece of the HDI is measuring what it is intended to do. Interpretations of DTW can be broadened and likely made more management relevant by examining simple relationships with disturbance. Many of these relationships are intuitive and have congruent patterns. This suggests that our estimates of DTW and disturbance are appropriate and reliable indicators, supporting their use in monitoring wetlands in FLFO.

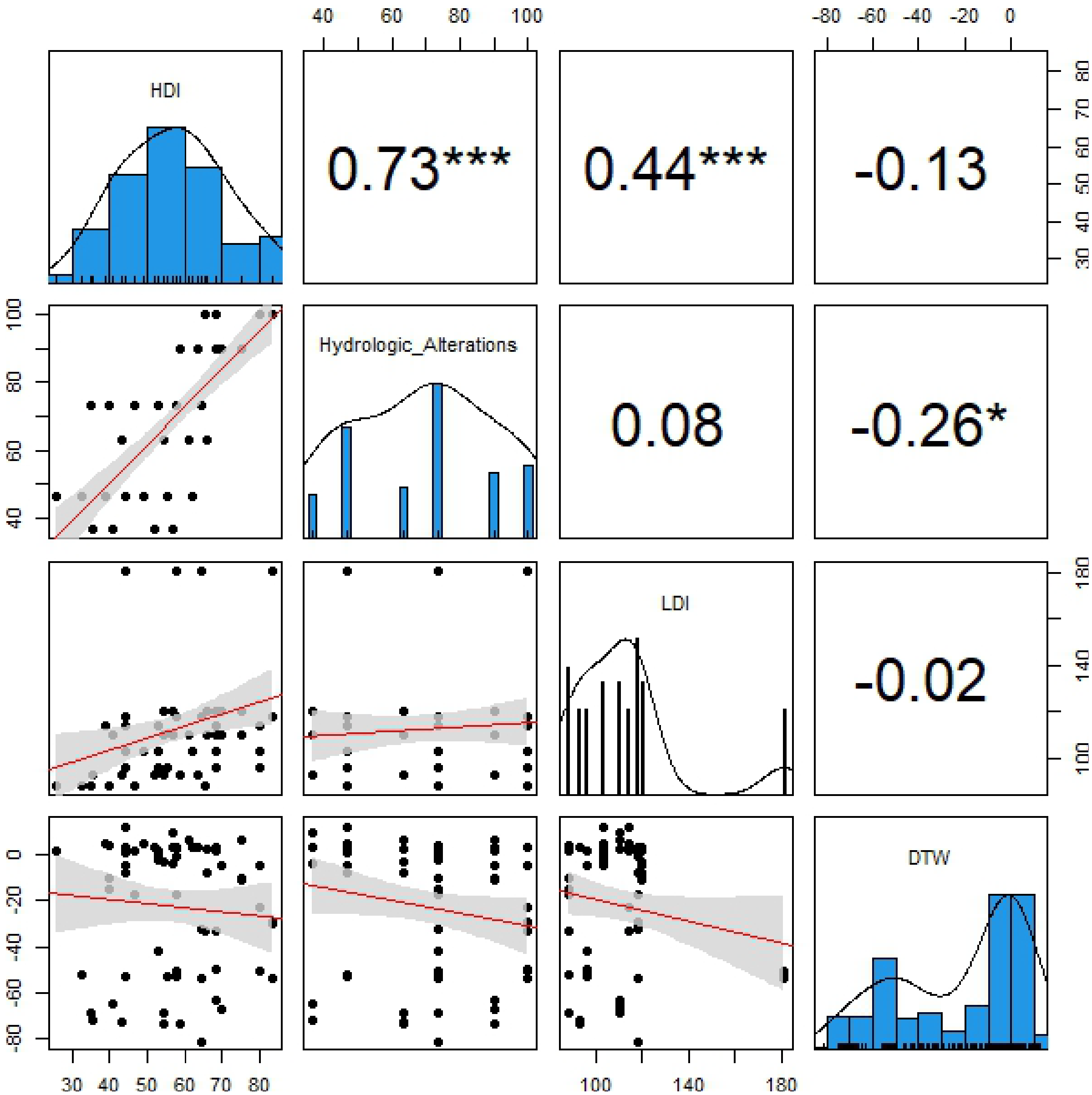


**Figure 28.** Relationships between discrete depth to groundwater (DTW, cm), Human Disturbance (HDI), hydrologic alterations (component of the HDI), and the Landscape Disturbance Index (LDI) at sentinel sites, Florissant Fossil Beds National Monument, Colorado, 2009–2019. Matrix gives bivariate scatterplots in the lower left with linear fit (red lines) and a 95% confidence interval (gray shading); histograms along the center diagonal with a smoothed density plot (line draped over histograms); Pearson rank correlation coefficients (significance indicated with a * for p <0.05, ** for p <0.01, and ** for p < 0.001). Figures on the bottom most row and correlations in the right most column are for DTW and the three measures of disturbance.

### *3.3.5 Continuously logged growing season depth to water*

Models for continuous DTW were challenging to estimate; however, the final versions provide a useful and comprehensive examination of groundwater hydrology within each sentinel complex. All DTW data used were first trimmed to an approximate growing season for FLFO of May 15th to Sept 30th. We do allow predictor data in the models outside a growing season for up to a year (for

example, into the spring or winter prior to a growing season). We present more detail for the first model of site 708 both because of the importance of understanding restoration at the Hornbek complex, and because some of the statistical details are similar among all three sites and are only presented in detail for this first model.

3.3.5.1 Hornbek Site 708 (fen)

Figure 29 shows groundwater depths across each growing season at site 708 in the Hornbek complex from 2010 to 2019 (note that 2020 and 2021 are also shown but will be interpreted in future reports). Three years, 2011–2013, were unique, with water tables near or above the surface through August (as in other years) but then dropping to between 10 to 20 cm below the surface in later summer. This pattern is somewhat unusual for fens that generally have stable groundwater sources driving their hydrology (Gage and Cooper 2013; Driver 2010). The years 2010 and 2014–2019 were more typical for a fen with a largely consistent groundwater elevation near the surface or even inundated with standing water up to 10 cm above the ground surface (Figure 30).

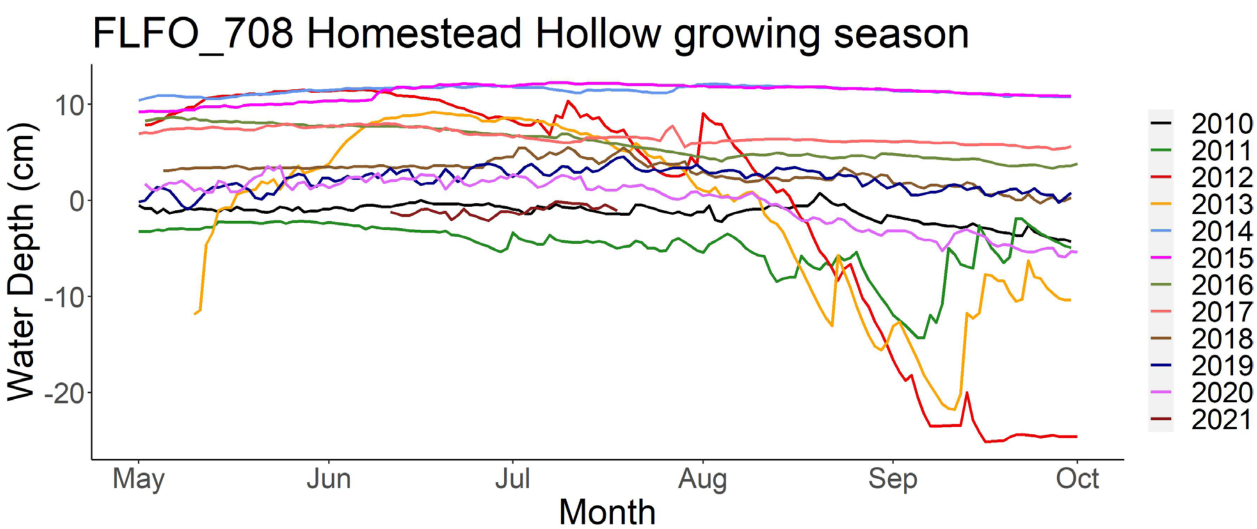



**Figure 29.** Growing season groundwater depth (DTW) by year at Hornbek well 708 in Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. Note that 2020 and 2021 are also shown but will be interpreted in future reports.

**Figure 30.** Fen site 708 in Florissant Fossil Beds National Monument, Colorado, 2017. Standing water is visible in the bottom right foreground of the image. This saturated water table is seen in groundwater data over several years at the site (see Figure 29). NPS/BILLY SCHWEIGER.

*Trend*

To prepare data for this trend model, we calibrated the drainage term in the site's water balance model in two distinct phases or steps that were then combined. First, we adjusted the drainage parameters to better match the more variable hydrograph of the early years, and second, we calibrated to match the more stable hydrograph post 2014. Initial linear models to identify lags indicated that soil moisture was best around a 97-day lag. This also had a positive correlation with DTW, as we would expect. This lagged term was therefore created and included in model selection. Note that this exact lag (97 days) is probably not important—there was a general "swell" of increased correlations around this time frame; this may be best interpreted as somewhere around 100 days in the past on average across our dataset soil moisture had a more pronounced positive interaction with this site's contemporary daily water table.

The final model (Table 15, Figure 31) for site 708 improved substantially (AIC improved by 50%) with water balance variables included. Competing models differed in largely statistical considerations, and decisions on whether to include a given predictor in the model were relatively clear. We chose the final model based on our core objective of estimating an overall (i.e., linear

where possible) trend in continuous groundwater depth. The final model successfully controlled for temporal autocorrelation in the DTW data (i.e., groundwater depths on a *day x* strongly determining those on *day x+1*) via autoregressive terms (known as an "ARIMA" modeling process). It also accommodated strongly non-linear variables, as GAM models are designed to do. The inclusion of the autoregressive terms was key in improving model fit and may have helped in estimating a linear term for scaled date (as noted this is a predictor term for time that is centered and normalized). However, there were two important downsides to the final model: 1) the explained variation was relatively small, with an adjusted $R^2$ of 0.26, and 2) the model included nonsignificant predictors. We expect additional data to fix or help with the explained variation in DTW ($R^2$), and we are not concerned about the nonsignificant predictors—the final set is interpretable and without including these, the model overall was less useful. We attempted several versions of the model to statistically capture the two periods of differing DTW data at 708, but we could not find a structure that did this in an effective way and kept the model interpretable. It is possible the two-phase initial calibration of drainage helped deal with the different forms of pattern in DTW at this site before we even began the GAM—additional work may be needed to further investigate this.

Two water balance variables were included in the final model as linear terms: 1) marginally significant ($p = 0.09$) soil moisture lagged to 97 days with a positive relationship with DTW and 2), drainage (i.e., accumulated runoff), also with a positive but nonsignificant relationship with DTW. These predictors are ecologically important with management relevance even with marginal or a lack of significance.

The lag term in the site 708 model suggests elevated soil moisture appears to take about three months to raise water tables at the site. This likely reflects the complex interactions between the water cycle and the site's groundwater. Soil moisture within our water balance model is largely determined by the difference between water input (from rain or snow melt) and evapotranspiration. This may just take time to manifest as a mechanistic impact on the amount of free water in the soil (i.e., the groundwater we measure in a site's well). There are likely several latent or unmeasured processes that link soil moisture structurally to groundwater, and this complexity is likely reflected in its marginal significance and the lower overall explained variation of the model. Nevertheless, including this term in the model greatly improved it overall. Soil moisture in general may appear in models of DTW (the two fens, this site, and 705) where there is a stronger role of groundwater inputs to a site's hydrology, perhaps because soil moisture often has a less variable pattern across growing seasons that matches the more stable typical hydrograph of fens. The relative importance of soil moisture was the highest of all the terms in the model, further supporting its inclusion and likely strong role in groundwater hydrology. Patterns in soil moisture and drainage may suggest site 708 is sensitive to changes in the water cycle and future work might forecast water balance estimated drainage or soil moisture along climate change scenarios to help FLFO management react to and work with possible climate change driven alterations to the hydrology of this wetland. Such research might also provide the park with useful material to interpret climate change to the public.

**Table 15.** General Additive Model (GAM) of daily mean depth to water (DTW, cm) for Hornbek well 708 at Florissant Fossil Beds National Monument, 2010 to 2019. Table includes parametric term coefficients, their standard errors, t values, and probabilities (p). The non-linear or smoothed term includes the realized number of knots in each smooth (EDF), its F value, and the probability (p) or significance of the term. Relative importance gives the proportion of the total variation explained by each term as approximated by an equivalent model that omits Auto Regressive Integrated Moving Average (ARIMA) adjustments (required to estimate importance).

| Type of term | Term | Coefficient | Std. error | t value | EDF | F value | p | Relative importance |
|---|---|---|---|---|---|---|---|---|
| Parametric | Intercept | −13.081 | 11.272 | −1.160 | N/A | N/A | 0.246 | – |
| Parametric | Scaled Date | 0.973 | 0.755 | 1.289 | N/A | N/A | 0.198 | 0.27 |
| Parametric | Drainage | 0.261 | 0.420 | 0.623 | N/A | N/A | 0.534 | 0.01 |
| Parametric | **Soil Moisture (97-day lag)** [a, b] | 0.020 | 0.012 | 1.686 | N/A | N/A | **0.092** [b] | **0.55** [a] |
| Smooth | **Day of Year** [b] | N/A | N/A | N/A | 4.451 | 6.148 | **0.004** [b] | 0.17 |

[a] Highest importance value (also in bold font).

[b] Terms are significant ($p < 0.10$)(also in bold font).

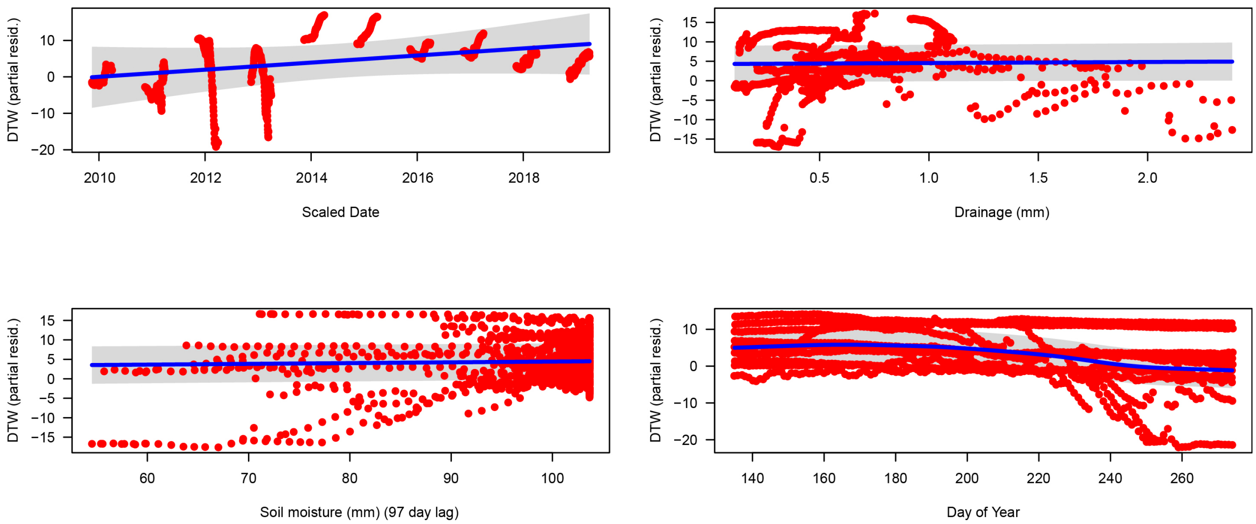



**Figure 31.** Visualizations for the model of daily depth to groundwater (DTW, cm) at Hornbek well 708 in Florissant Fossil Beds National Monument, Colorado, 2010 to 2019. Data points are partial residuals as estimated by a General Additive Model (Table 15). Each panel shows the relationship between each independent term in the model and the partial residual of daily DTW, given that other independent variables are also in the model (e.g., all other variables are controlled for) with (upper left) an overall trend, (upper right) Drainage, (lower left) 97-day lagged Soil Moisture, and (lower right) Day of Year. Y axis scale may be different on some panels given different ranges in the partial residuals. Assessment points are not shown on these figures as partial residuals are not in the same units as raw data. Gray shaded areas give the 95% confidence interval around the fit for each term.

The second water balance variable in the model was runoff-based drainage, with a positive but nonsignificant effect on DTW. Runoff in our water balance model is any remaining water each day after precipitation that is more than soil storage capacity and evapotranspiration. Drainage is accumulated runoff with both base and event (storm) based components, that in a sense, "transfer" runoff from day to day at a site (Croke et al. 2005). It has an intuitive connection to hydrologic regimes as the primary input from a site's catchment into its water table via surface and groundwater sources. At site 708 higher drainage likely led to wetter sites and vice versa) with no meaningful lag, although the effect was likely minor given lack of clear significance.

Two time-based predictors were included in the final model. Day of year (DOY) was best modeled with a highly significant non-linear term. This was more visually clear in earlier versions of Figure 31 when we did not correct for autocorrelation, but it is still marginally evident in the final model. Unremoved correlation structure in alternate models of daily DTW data may contribute to tighter estimates visually but the coefficients from these alternate models are biased. The DOY smoothed fit suggests that, across all years, groundwater levels increased in May or early June and then decreased from July into early September. The second time-based term in the model was time itself, as measured by date—scaled, and normalized to range between 0 and 1 ("scaled date"). At site 708, with all pieces of the model in place as described above, we were able to estimate this as a linear term matching our general objective of estimating an overall trend in DTW. This was only made

possible via the inclusion of the non-linear DOY smooth and especially the control of autocorrelation in scaled date. There was an increasing trend in groundwater levels from 2010 to 2019, although it was not significant ($p = 0.19$). This moved groundwater elevations from an intermediate or even major disturbance level in earlier years into a minor disturbance class in later years.

*Restoration and water balance interaction*

Restoration work was completed on Grape Creek in late summer 2012 that removed incised channels down gradient from site 708. Increased water table elevations at this site evident by spring 2014 and persisting through at least 2016 may reflect this restoration and management success. However, 2011–2013 were also somewhat unique climatically, as reflected in several water balance variables. In 2012 it was hot and dry with the lowest precipitation in our period of record and the highest mean annual temperature. This resulted in a period of high climatic deficit, reduced runoff, and reduced soil moisture levels (i.e., drought; see Figure 14 and Figure 15). Runoff was even lower in 2011 but with less clear connections to base climate (temperature and precipitation). Soil moisture was reduced in 2010 and thus conditions in 2011 may have been driven by a lagged effect from this. We see similar patterns at site 705 (Barksdale, see below), adding to a weight of evidence that climate and water balance were at least part of the reason behind changes in the water table at site 708. Without a longer interval of monitoring prior to 2010, it is not clear if the stable and high water tables we see at this site beginning in 2014 are due to the 2012 restoration or more of a return to a prior, more stable, hydrologic regime, with 2012 and 2013 reflecting drought-like deficit and runoff in these years. There was a shorter drought in 2017–2018 (Figure 14 and Figure 15), and DTW at site 708 *did not* strongly respond to this later drought. It is possible that the restoration increased the resilience of this site, with the post 2012 hydrographs largely flat (and not decreasing). We see similar patterns in several other responses, such as vegetation metrics and the episodic DTW. Models of these responses also suggest that site 708 was more resilient to drought after the restoration. In conclusion, we suspect that both climate and restoration interacted to sustain higher groundwater at the site. This has important implications for resource management, including tempering expectations for restoration success under shifting climate. Additional data and analyses may help better understand this.

*Condition*

Daily DTW values were often in a major disturbance class at site 708 in later summer, 2011 through 2013, falling below 7.25 cm below ground (the major disturbance assessment point). However, in most other years groundwater levels at the site were above the minor disturbance assessment point of −0.2 cm from ground elevation. The trend of increasing water table heights moved the site towards always being in a minor disturbance class from 2014 through 2019. We caution that our assessment points are developed for episodic DTW data and may not be ideal for continuous groundwater data in fens.

#### 3.3.5.2 Red Barn Site 710 (wet meadow)

Groundwater elevations at site 710 from 2010 to 2019 were highly variable, with a tendency for higher water tables early in the season followed by a drawdown and occasionally a later summer rise (Figure 32). The 2013 growing season had lower water tables over several periods—as at sites 708

and 705—but in general the two drought periods we see reflected in other hydrographs are not evident at site 710, or are, in a sense, hidden in the higher level of hydrologic variability in this wet meadow. Growing seasons with a variable water table are typical of wet meadows in the Rocky Mountains, especially if the site has a surface water source other than groundwater (Gage and Cooper 2013; Driver 2010). Figure 33 shows dense sedges at site 710.

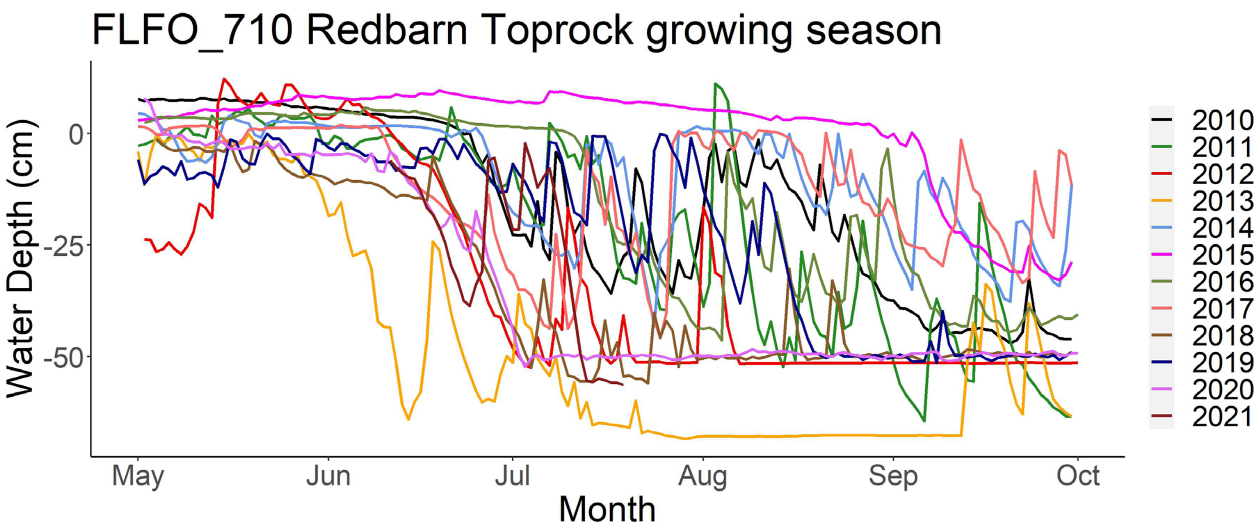



**Figure 32.** Growing season groundwater depth (DTW) by year at Red Barn well 710 in Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. Note that 2020 and 2021 are also shown but will be interpreted in future reports.

**Figure 33.** Wet meadow site 710 in Florissant Fossil Beds National Monument, 2016. This site often supports a dense stand of sedges in years with high water tables that can swallow field technicians whole. NPS/BILLY SCHWEIGER.

*Trend*

Calibration of drainage for this site did not require any special adjustments to distinct phases of DTW as in the other two sites. There were more lags initially estimated for this site (drainage at five days, soil moisture at 76 days, and an interesting combination of AET at 308 and 88 days, where the correlation structure was reversed), but many of these terms were dropped in model estimation. The final model (Table 16, Figure 34) had a large improvement in AIC of 53% from a null model. We were unable to reduce the scaled date term to an acceptable linear approximation as we were for site 708 (Hornbek), and we thus interpreted overall trend at this site visually and without a coefficient or p value. The model did include an autoregressive component, which was key in improving model fit. In contrast with other models, the explained variation for 710 was more acceptable, with an adjusted $R^2$ of 0.74, and there were no insignificant terms.

**Table 16.** General Additive Model (GAM) of daily mean depth to water (DTW, cm) for Red Barn site 710 at Florissant Fossil Beds National Monument, Colorado, 2010 to 2019. Table includes parametric term coefficients, their standard errors, t values and probabilities (p). Non-linear or smoothed terms include the realized number of knots in each smooth (EDF), their F value, and the probability (p) or significance of the term. Relative importance gives the proportion of the total variation explained by each term as approximated by an equivalent model that omits Auto Regressive Integrated Moving Average (ARIMA) adjustments (required to estimate importance).

| Type of term | Term | Coefficient | Std. error | t value | EDF | F value | p | Relative importance |
|---|---|---|---|---|---|---|---|---|
| Parametric | Intercept | −28.208 | 3.524 | −8.005 | N/A | N/A | 0.000 | – |
| | **Drainage (5-day lag)** [a] | 6.680 | 3.735 | 1.788 | N/A | N/A | **0.074** [a] | 0.36 |
| Smooth | **Day of Year** [a, b] | N/A | N/A | N/A | 1.5 | 75.286 | **0.000** [a] | **0.63** [b] |
| | **Scaled Date** [a] | N/A | N/A | N/A | 8.317 | 5.287 | **0.000** [a] | 0.001 |

[a] Terms are significant ($p < 0.10$)(also in bold font).

[b] Highest importance value (also in bold font).

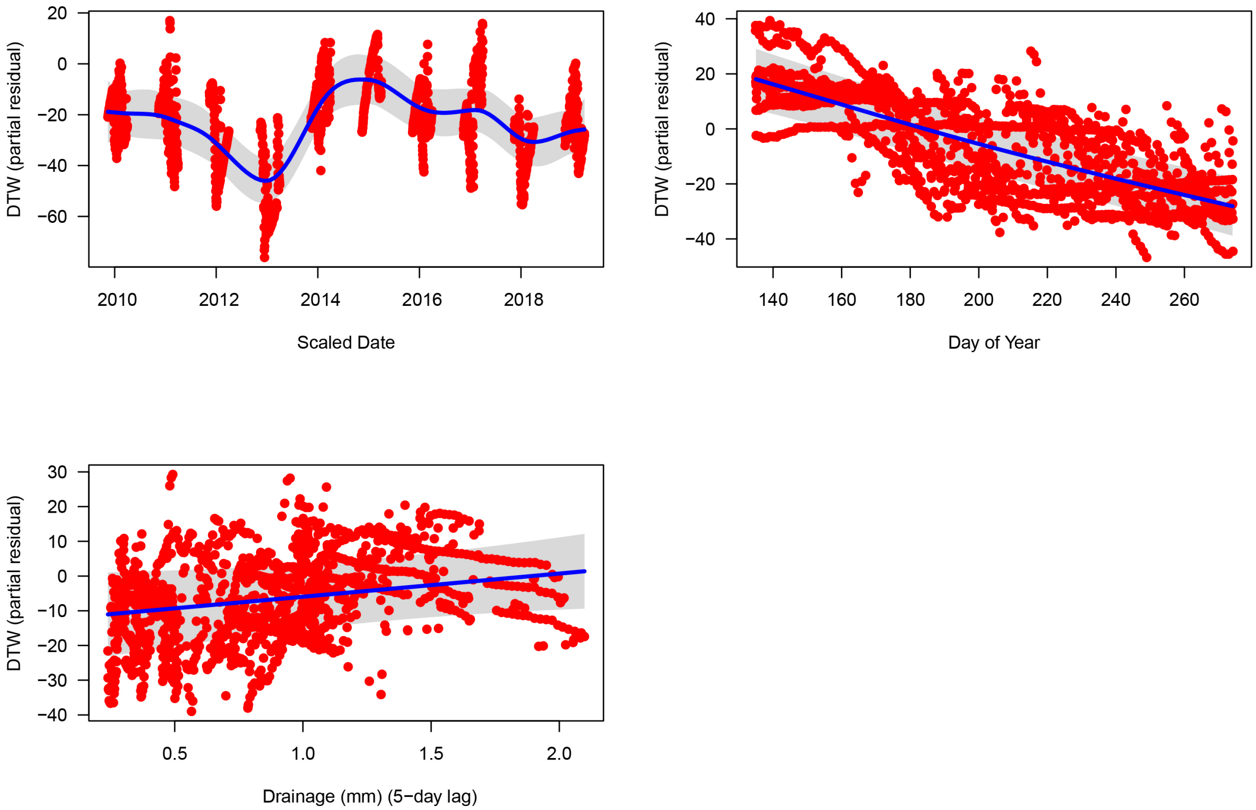



**Figure 34.** Visualizations for the model of daily depth to groundwater (DTW, cm) at Red Barn site 710 in Florissant Fossil Beds National Monument, Colorado, 2010 to 2019. Data points are partial residuals as estimated by a General Additive Model (Table 16). Each panel shows the relationship between each independent term in the model and the partial residual of daily DTW, given that other independent variables are also in the model (e.g., all other variables are controlled for) with (top left) an overall trend, (top right) Day of Year and (bottom), 5-day lagged Drainage. Y axis scale may be different on some panels given different ranges in the partial residuals. Assessment points are not shown on these figures as partial residuals are not in the same units as raw data. Gray shaded areas give the 95% confidence interval around the fit for each term.

A single water balance variable was included in the final model as a linear term: drainage lagged at five days, with a positive and significant ($p = 0.07$) relationship with DTW. The lack of any other water balance term in the final model other than drainage and the more robust nature of drainage as a predictor for site 710 likely reflects important attributes of the site's hydrologic regime and the factors that influence it. This is the only wet meadow site where we log continuous DTW in FLFO, and it has a clearly different hydrologic regime than the two fens, 708 and 705. The site is adjacent to a portion of Grape Creek that may be more intact, with less historical modification and channelization than further upstream at the Hornbek complex sites (where the restoration occurred). It is also closer to a hillslope (Figure 35) than other sites, which may contribute additional water (via drainage) more consistently than the flatter terrain at the other two sites. This site's hydrologic regime may have more of a surface water component since runoff (or drainage in the water balance model) is generally surface flow. Drainage (as runoff) integrates the water cycle—precipitation,

temperature, how water is stored in the soil, and how it is lost through evapotranspiration. Wet meadow sites like 710 often are described as being influenced by a monsoon, with this later summer precipitation elevating the water table. Our drainage predictor is how this monsoon effect is manifested. The importance of this term in this site's model suggests that the site may be sensitive to changes in the water cycle, with decreased drainage likely leading to decreased water tables. Future work should forecast water balance estimated drainage along climate change scenarios to help FLFO management react to and work with possible climate change driven alterations to groundwater in this wetland.

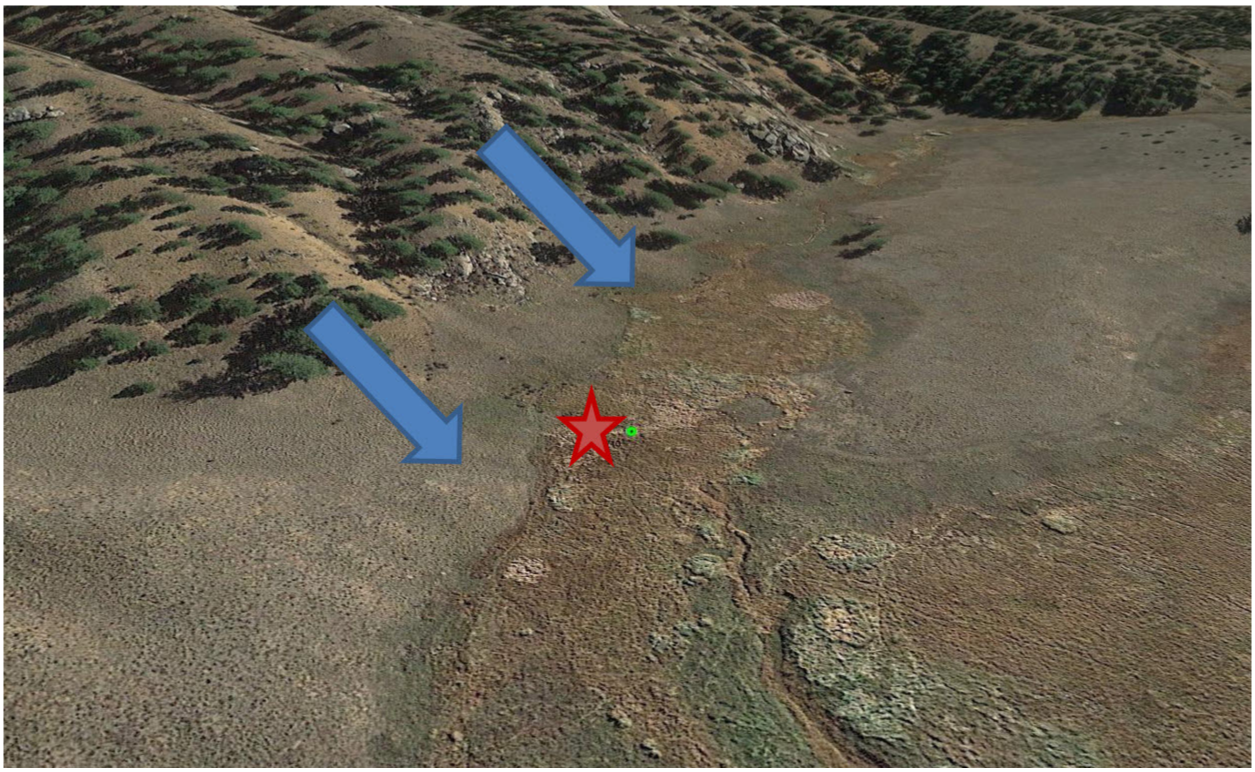


**Figure 35.** Wet meadow site 710 in Florissant Fossil Beds National Monument (red star), Colorado. The site is located near a hillslope that may provide more consistent, largely surface water, drainage (blue arrows).

Two time-based predictors were included in the final model for site 710. First, a highly significant ($p = 0.000$) non-linear day of year term. This fit had little suggestion of the seasonal patterns seen in the annual hydrographs (Figure 32) and instead shows a near linear decrease in DTW across growing season. The lack of a non-linear fit that matches a typical seasonal pattern may be because of the second time-based term, scaled date, that was also highly significant and had a distinct form that may have controlled for much of the non-linearity in the model. This predictor is of primary interest for the WEI protocol in estimating an overall trend. However, for site 710 this must be done visually via its partial plot (Figure 34) as there are no single coefficients for smoothed terms in GAM. The Auto Regressive Integrated Moving Average (ARIMA) term in this model did allow a general smooth that is likely not overfit as can happen in complex GAMs. Visual inspection suggests that DTW dropped

across the 2010 and 2013 period (drought), then returned to a wetter condition through 2017 and then dropped again (second drought). This contrasts with the impression in the raw hydrographs (see above) that the site may not respond to drought and highlights the importance of applying actual models to complex data. This is also different than site 708 (and is more like site 705, below), with the pattern in the scaled date suggesting that the water table in 710 was less resilient to the second drought, unlike 708 that was restored in 2012. Note that while the models don't allow an explicit (i.e., statistical) test of this, it is a consistent pattern across several responses (vegetation, episodic DTW) and therefore we feel it has weight of evidence support.

*Condition*

Daily DTW values were rarely in a major disturbance class across the period of record at 710, falling below 60.3 cm below ground only in the drought years of 2013 and rarely in 2011. In most other years groundwater levels at site 710 were above the minor disturbance assessment point of −23.0 cm from the ground elevation or occasionally in between these values and in an intermediate class. We caution that our assessment points are developed for episodic DTW data and may not be ideal for continuous groundwater data in wet meadows.

3.3.5.3 Barksdale Site 705 (fen)

Figure 36 gives raw DTW across each growing season at site 705 from 2010 to 2019. Two years, 2012 and 2013, were qualitatively unique with water tables near the surface through August as in other years but then a drop to between 20 and 30 cm below the surface and subsequent fluctuation in later summer. We also see this pattern for these years in fen site 708 (Hornbek) but not the more naturally variable wet meadow, 710 (Red Barn). DTW in 2011 was also different, with an oddly low water table in the spring that then became more typical in later June through the end of the growing season. All other years were consistently saturated with water at or near the ground surface elevation, although the site was less wet overall than 708 in Hornbek after its restoration and after the drought in 2011–2013 (compare Figure 29 and Figure 36). Growing seasons with a saturated and stable water table are typical of fens in the Rocky Mountains and a consistent, largely groundwater fed source (Gage and Cooper 2013; Driver 2010). This site's tree cover (Figure 37) is also unique among all sentinel wetlands in the park and the ability of trees to evapotranspire at greater rates than herbaceous vegetation might be a consideration in this site's hydrology.

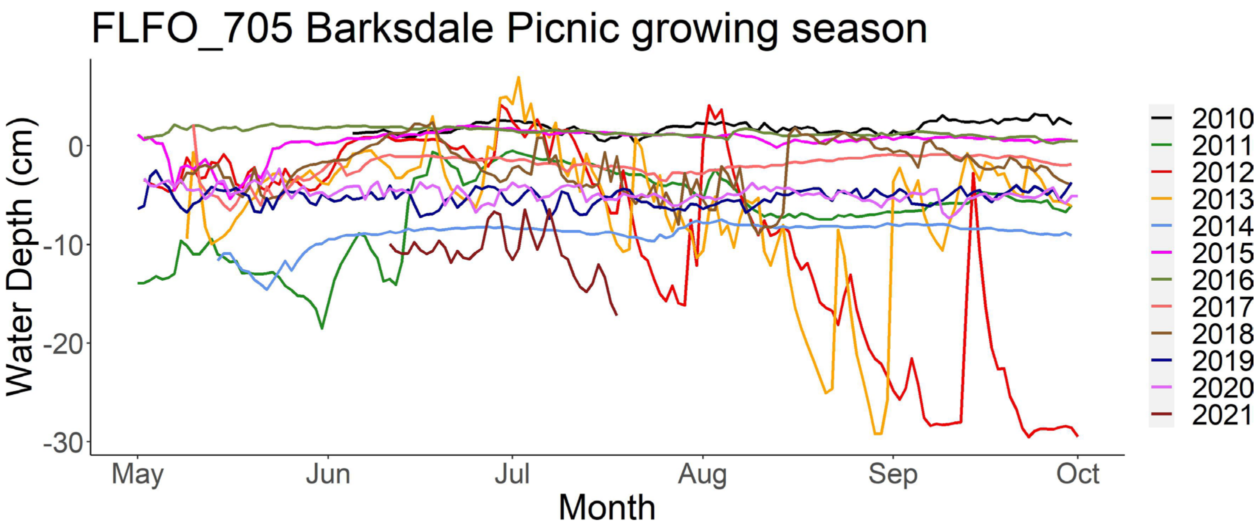



**Figure 36.** Weekly growing season groundwater depth (DTW) at Barksdale well 705 in Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. Individual years are shown with different colors. Note that 2020 and 2021 are also shown but will be interpreted in future reports.

**Figure 37.** Fen site 705 in Florissant Fossil Beds National Monument, Colorado, 2017. The tree cover at this site is unique and indeed may provide habitat for squirrels as this crew member has artfully documented on the placard. NPS/BILLY SCHWEIGER.

*Trend*

As with site 708, we used a two phased or period calibration for site 705 and estimated lags as needed (here, for both drainage at 32 days and soil moisture at 86 days). The final model (Table 17, Figure 38) had a large improvement in AIC from a null model of 56%. We were unable to reduce the scaled date term to an acceptable linear approximation as we were for site 708, and we interpreted overall trend at this site visually and without a single coefficient or p value. The model did include an autoregressive component, which was key in improving model fit. However, as with the models for 708, there were two important downsides in the final model: 1) the explained variation was marginal but verging on acceptable, with an adjusted $R^2$ of 0.42, and 2) the model included nonsignificant predictors. Neither of these were overly problematic.

Two water balance variables were included in the final model as linear terms: 1) marginally significant ($p = 0.10$) soil moisture lagged to 86 days, with a positive relationship with DTW, and 2) drainage (i.e., accumulated runoff), also with a positive but nonsignificant relationship with DTW. Acknowledging the marginal or lack of significance, both predictors are nevertheless important especially as they are repeated in part in all three models. Elevated soil moisture also appears to take about three months to raise water tables at site 705 (as it does in 708 (Hornbek)). Lagged soil moisture does appear to be important in FLFO's wetland sites where there is a stronger role of groundwater inputs (708 and 705). The relative importance of soil moisture was lower at 705, but we feel it still plays a key role. Increased drainage increased DTW (and vice versa), with a lag of 32 days. This may suggest water takes longer to move through this site's catchment than at 708 and 710 (Red Barn), or that there is more of a blending of ground and surface water inputs to the site. Its high importance value (0.77), based largely on the relative value of the coefficients in the model, is indicative of its important role and supports why p values are not the only way to interpret model results. The high importance value may suggest this site could be sensitive to changes in the water cycle and future work might forecast water balance estimated drainage along climate envelopes to help FLFO management react to and work with possible climate change driven alterations to groundwater in this wetland.

Two time-based predictors were included in the final model. Day of year (DOY) was best modeled with a non-linear term, but it was not significant. This may be because much of the non-linearity in the model was controlled by a highly significant ($p = 0.003$) scaled date non-linear term. This predictor is of primary interest for the WEI protocol to estimate an overall trend, but, like for site 710, site 705 must also be done visually via its partial plot (Figure 38). The ARIMA term in this model did allow a general smooth that is likely not overfit as can happen in complex GAMs. Visual inspection of the scaled date fit in Figure 38 suggests that DTW dropped between 2010 and 2013 (drought), then returned to a wetter condition through 2017, and then dropped again (second drought). This is like site 710, suggesting that the water table in 705 was less resilient to the second drought, unlike site 708, which was restored in 2012. Note that while the models do not allow an explicit (i.e., statistical) test of this, it is a consistent pattern across several responses (vegetation, episodic DTW) and therefore we feel it has weight of evidence support.

**Table 17.** General Additive Model (GAM) of daily mean depth to water (DTW, cm) for Barksdale well 705 at Florissant Fossil Beds National Monument, Colorado, 2010 to 2019. Table includes parametric term coefficients, their standard errors, t values, and probabilities (p). Non-linear or smoothed terms include the realized number of knots in each smooth (EDF), their F value, and the probability (p) or significance of the term. Relative importance gives the proportion of the total variation explained by each term as approximated by an equivalent model that omits Auto Regressive Integrated Moving Average (ARIMA) adjustments (required to estimate importance).

| Type of term | Term | Coefficient | Std. error | t value | EDF | F value | p | Relative importance |
|---|---|---|---|---|---|---|---|---|
| Parametric | Intercept | −7.413 | 1.900 | −3.902 | N/A | N/A | 0.000 | – |
| | **Drainage (32-day lag)** [a] | 2.416 | 2.115 | 1.142 | N/A | N/A | 0.254 | **0.77** [a] |
| | Soil Moisture (86-day lag) | 0.028 | 0.017 | 1.638 | N/A | N/A | 0.102 | 0.19 |
| Smooth | Day of Year | N/A | N/A | N/A | 1.62 | 0.204 | 0.695 | 0.02 |
| | **Scaled Date** [b] | N/A | N/A | N/A | 4.16 | 3.939 | **0.003** [b] | 0.02 |

[a] Highest importance value (also in bold font).

[b] Terms are significant ($p < 0.10$)(also in bold font).

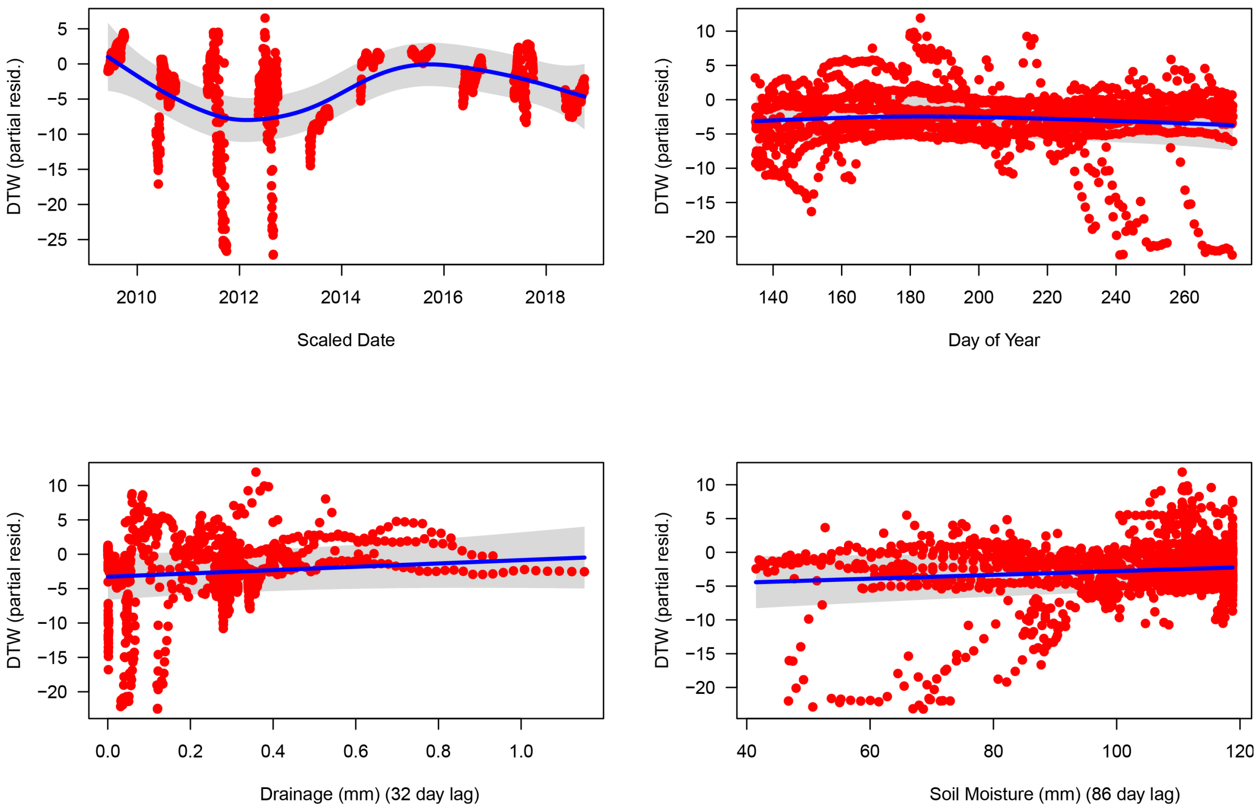



**Figure 38.** Partial plots for the final model of daily depth to groundwater (DTW) at Barksdale well 705 at Florissant Fossil Beds National Monument, Colorado, 2010 to 2019. Each panel shows a relationship between an independent term in the model and the partial residual of the daily DTW response variable given that other independent variables are also in the model (e.g., all other variables are controlled for). Gray shaded areas give the 95% confidence interval around the fit for each term.

*Condition*

Continuous DTW values at site 705 were often in a major disturbance class (more than 7.25 cm below the surface) in later summer, 2011 through 2013, and near this threshold through 2014. In most other years groundwater levels at the site were in an intermediate disturbance (between −7.25 and −0.2 cm below the ground). We caution that our assessment points are developed for episodic DTW data and may not be ideal for continuous groundwater data in fens.

## 3.4 Vegetation

### *3.4.1 Summary condition*

We begin by summarizing the condition of wetland vegetation indicators in the park (Table 18) and follow with details for each indicator. We discuss overall wetland condition as presented by the Vegetation Index of Biotic Integrity, and then end with a summary of patterns among vegetation metrics, disturbance, and groundwater.

**Table 18.** Summary condition table for vegetation at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, in 2009–2019. These statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not an indicator's absolute value. Summary condition statements are considerable simplifications of the details behind each indicator—they should be used with caution. For example, not all sites follow the general pattern we present for a summary condition—these are explained in the main narrative. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

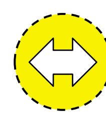
| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Nativity: Relative cover native species | The amount of native species cover in a vegetation community is an important indicator of its condition. Nonnative species can be invasive and can have undesirable effects on ecosystem function.<br><br>Baseline levels of native species in our wetland sites were generally high. However, some sites had nearly 50% total cover of invasive taxa in some years (for example, site 711 in the Red Barn complex).<br><br>We assessed baseline native cover of FLFO wetlands compared to undisturbed sites in similar wetland types in the ecoregion. Fen sites were in a reference condition, while wet meadow sites were in intermediate condition, with native cover at some sites a mild concern. We selected intermediate condition for this indicator overall as a more conservative estimate of native cover, but the condition is likely between intermediate and reference.<br><br>Overall, there was no statistical trend in relative cover of native species, although there is a suggestion of reduced nativity across time and some non-linear patterns suggesting some complexity.<br><br>Natives were more abundant at sites with lower human disturbance and responded positively to wetter conditions—both of which are as expected and show the strong role of human disturbance in wetland condition.<br><br>Nonnative species are the focus of park vegetation management, and we did see some positive changes in nativity that may be related to restoration in the Hornbek complex. Maintaining groundwater levels and reducing impacts from human use of wetlands are two actions that should support higher nativity.<br><br>Our confidence in nativity data itself is high. However, there may be some research needed on selecting the best metric for nativity and in improving assessment points, and our evaluation points to a condition somewhere between reference and intermediate. Therefore, our overall confidence is low. |  |

**Table 18 (continued).** Summary condition table for vegetation at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, in 2009–2019. These statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not an indicator's absolute value. Summary condition statements are considerable simplifications of the details behind each indicator—they should be used with caution. For example, not all sites follow the general pattern we present for a summary condition—these are explained in the main narrative. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

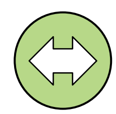
| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Wetland affinity: Relative cover hydrophytic species | Hydrophytic plants are those that persist in or have an affinity for wetlands. Hydrologically stable, high condition wetlands will generally have more hydrophytic species.<br>Fen sites had higher baseline median relative cover of hydrophytic species than wet meadows. Fens have higher water tables that hydrophytic species are well adapted to. Like native cover, sites varied considerably, with Red Barn site 711 and Hornbek site 708 having lower baseline cover of hydrophytic plants.<br>When compared to undisturbed sites in the ecoregion, wetland affinity at FLFO fen and wet meadow sites was in a reference condition.<br>Overall, there was no statistical trend in relative cover of hydrophytic species, although there is a suggestion of a reduction across time and some non-linear patterns. Wetland affinity increased after the 2012 restoration at Hornbek site 708, and the increase in hydrophytes at this site appears to have persisted through 2019. This suggests the restoration of higher groundwater levels had a lasting impact.<br>We also see a general pattern for wetland obligate cover to be higher at sites with lower human disturbance and wetter conditions.<br>Maintaining high groundwater tables, through efforts like the Hornbek restoration, is one way to maintain hydrophytic species composition in wetlands. Hydrophytic species may also provide an integrated indicator of possible decline driven by larger scale human use, for example road density impacts, or climate change driven drought.<br>Our confidence in nativity data itself is high. There may be some research needed in improving assessment points, but our overall confidence is medium. |  |

**Table 18 (continued).** Summary condition table for vegetation at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, in 2009–2019. These statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not an indicator's absolute value. Summary condition statements are considerable simplifications of the details behind each indicator—they should be used with caution. For example, not all sites follow the general pattern we present for a summary condition—these are explained in the main narrative. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

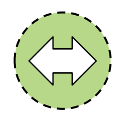
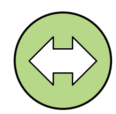
| Indicator | Summary condition | Symbol (description) |
|---|---|---|
| Conservatism: Floristic Quality Index | Conservatism, as estimated by the Floristic Quality Index (FQI), describes a species' fidelity to a specific habitat or range of environmental conditions absent human disturbance. More conservative species are not able to quickly respond to habitat degradation and are often the first to disappear from habitats heavily impacted by human activities.<br>Fen sites had higher baseline median FQI than wet meadows, likely due to their more stable groundwater levels, and thus fewer natural disturbances than wet meadows. Species adapted to wetter conditions often have higher conservatism. In contrast, wet meadows may be more susceptible to disturbances, with less of a "hydrologic buffer" to compensate for human use. Like native and hydrophyte cover, there was considerable variation between sites and a strong effect of species richness. For example, the degraded Red Barn site 711, with higher richness, had less impacted FQI results.<br><br>Assessment of FQI at FLFO wetland sites compared to undisturbed wetland sites in the ecoregion suggested fen sites were in a reference condition while wet meadow sites were in intermediate condition.<br><br>Overall, FQI may have increased from 2009 to 2019 but this was not significant.<br><br>Conservatism is an important component of many other wetland monitoring programs and likely has a strong relationship with management of wetlands. It responds to disturbance, but in a counterintuitive direction at FLFO, perhaps because of confounded species richness (e.g., higher richness via more weedy species can elevate FQI). However, FQI increases with increasing groundwater levels as expected, supporting the park's maintenance of wetland hydrology.<br><br>The FQI may not be an ideal conservatism metric for FLFO given the relationship with species richness. Therefore, our overall confidence is low. |  |

**Table 18 (continued).** Summary condition table for vegetation at Florissant Fossil Beds National Monument (FLFO) wetland sentinel sites, Colorado, in 2009–2019. These statements summarize the status, trend, and our confidence for each indicator. The direction of arrows refers to the change in condition, not an indicator's absolute value. Summary condition statements are considerable simplifications of the details behind each indicator—they should be used with caution. For example, not all sites follow the general pattern we present for a summary condition—these are explained in the main narrative. Key to the status, trend, and confidence symbol: red color = non-reference condition/major disturbance, yellow color = intermediate condition/moderate disturbance, green color = reference condition/minor disturbance; upward arrow = condition is improving, sideways arrows = condition is unchanging, downward arrow = condition is deteriorating, no arrow = unknown trend; heavy border = high confidence, medium-weight border = medium confidence, dashed border = low confidence.

| Indicator | Summary condition | Symbol (description) |
| --- | --- | --- |
| Overall ecological condition: Vegetation Index of Biotic Integrity | We use the Colorado Natural Heritage Program (CNHP) Vegetation Index of Biotic Integrity (VIBI) developed for Colorado wetlands with a classification system like the one used in FLFO. It combines nine metrics in two unique models, one for fens and one for wet meadows.<br>Surprisingly, FLFO fen sites had lower baseline VIBI (poorer condition) than wet meadows. We suspect this is because of a methodological difference with CNHP and Rocky Mountain Network protocols.<br>We use wetland type specific assessment points from CNHP's work in Colorado mountain wetlands. Fens were rated in intermediate condition during the baseline period, while wet meadows were rated in reference condition. These assessment points may compare FLFO wetland sites to a disturbance gradient more pristine in nature and thus may place FLFO in lower condition classes than a more localized set of assessment points would.<br>Overall, there was no statistical trend in VIBI, although there is a suggestion of a reduction across time in VIBI (or a decrease in condition). Some non-linear patterns in VIBI may reflect improvements from the Hornbek restoration, although changes are less persistent than in some other indicators and confounded by wetter conditions following restoration. Patterns in VIBI may also reflect complex effects of changes in water balance drivers across the period of record.<br>The VIBI was negatively related with measures of general disturbance created with large scale data like the LDI but less so with more site-specific disturbance measures like the HDI, suggesting the VIBI may be more responsive to larger scale patterns. This supports the park's continued management of human disturbance levels across the park as a whole.<br>Bioassessment is a useful way to monitor wetland condition, and this metric is closely scaled to the park given the Colorado focus in its derivation by CNHP. Therefore, our overall confidence is medium. |  |

### *3.4.2 Introduction: Bioassessment*

Wetlands are biodiversity hotspots, rich in native plant species and important resources for wildlife. A key aspect of our long-term monitoring of wetlands in FLFO, known as bioassessment, utilizes this biodiversity. It essentially asks why or why not a particular site has the species composition it does

(or does not). Bioassessment assumes that the composition of biological communities reflects the overall ecological integrity of a system. Intact or high condition sites (Figure 39) are characterized by species typical of reference wetlands that maintain processes that support species. Evidence suggests bioassessment can detect stressors that other approaches fail to reveal and that it is an efficient, integrative way of conducting long-term monitoring (Karr and Dudley 1981; Karr and Chu 1999). Bioassessment has become a central element of most federal, state, and other monitoring programs. We use the approach to help meet multiple objectives in FLFO. The following sections present four indicators of vegetation evaluated using a bioassessment approach: nativity, wetland affinity, conservatism, and overall ecological condition.

**Figure 39.** Fen site 710 in the Red Barn complex, Florissant Fossil Beds National Monument, Colorado, 2017. This site was one of the more consistently higher scoring wetlands in the Vegetation Index of Biotic Integrity. NPS/BILLY SCHWEIGER.

#### *3.4.3 Nativity/Invasiveness: Relative cover of native species*

Nativity describes whether a species is found within its area of evolutionary origin and/or arrived without human intervention. Nonnative species are often introduced through intentional or unintentional human action (Pysek et al. 2004; Fertig 2011). Nonnative species can be invasive and can have undesirable effects on ecosystem function (Byers et al. 2002; Levine et al. 2003; Fridley et

al. 2007). They have been linked to reduced overall species diversity (Meiners et al. 2001), altered resource dynamics (Ehrenfeld 2003), and shifted interactions between species (Christian and Wilson 1999). Nonnative species are often the focus of park management of vegetation, including at FLFO.

Of the 151 species documented at our sites, 129 or 85% are natives. Twenty-two (15%) are nonnatives. Important native species in FLFO include *Carex nebrascensis* (Nebraska sedge; Figure 40), *Juncus arcticus* var. *balticus* (mountain rush), and *Deschampsia cespitosa* (tufted hairgrass).

**Figure 40.** Important native species *Carex nebrascensis* (Nebraska sedge) found in the wetlands of Florissant Fossil Beds National Monument, Colorado, such as at Barksdale site 713, where it often has over 80% relative cover. We find that the blue-green hue of Nebraska sedge is nicely enhanced by brown wetland boots. Photo inset by Matt Lavin/Wikimedia Commons/CC BY-SA 2.0; site photo by NPS/BILLY SCHWEIGER.

3.4.3.1 Resolving the best metric

We compared candidate nativity metrics to indices of disturbance (HDI and LDI), examined distributional or statistical properties of each, and evaluated the management relevant interpretability of each. We also considered which nativity metrics are used in other monitoring efforts by NPS, CNHP and the US EPA. A summary of these exploratory analyses is available on request from the Rocky Mountain Network.

Two metrics that floated to the top of our list included those that weighted nonnative species occurrence in a sample by scores of their invasive impact and the more straightforward relative cover of native species. The relative cover of native species responded (as expected) negatively to increasing LDI ($r = -0.67$, see below) but was not related to HDI. The invasiveness impact metrics generally had weaker responses to HDI or LDI even though these metrics are often used in other monitoring programs based on their sensitivity to human disturbance, and they have strong ecological appeal.

We chose to focus on the relative cover of native species but also to include a simpler summary of nonnative invasive taxa as species *not* included in the relative cover of native species metric. Relative cover of native species was also selected because of its relationship to LDI and an assumption that species assemblage processes in our FLFO wetland sites are governed by large scale disturbances that LDI likely does a good job of estimating. Invasiveness metrics are important, but parks like FLFO have focused invasive plant management programs with comprehensive knowledge of invasive plants. We also wanted to broaden the overall understanding of FLFO's vegetation. Relative cover of invasive species also had more zero values (no invasives were present) than relative cover of native species and a relatively small sample size across space in FLFO, making analysis more statistically challenging. Note that our relative cover of native species metric only uses vascular species level data with a known nativity designation; that is, we ignored any portion of a sample that had unknown nativity, was not identified to species, or was a nonvascular plant.

3.4.3.2 Nonnative/invasive species

The most common invasive exotic species found in FLFO wetlands include Canada thistle (*Cirsium arvense*), reed canarygrass (*Phalaris arundinacea*), and butter-and-eggs (*Linaria vulgaris*) (Edwards and Weber 1990; Spackman Panjabi and Anderson 2002). We recorded 23 nonnative invasive taxa across all sample events from 2009 to 2019 (Table 19). Of these, four are state listed noxious weeds and are also species of special concern for the park (*Cirsium arvense*, bull thistle (*Cirsium vulgare*), *Linaria vulgaris,* and quackgrass (*Elymus repens*). FLFO must develop and implement noxious weed management plans designed to stop the continued spread of these taxa. Our data (Table 19) suggest the park may be having some success with these species. *Phalaris arundinacea* is likely the most invasive species we found that is not on the park's list, perhaps because it is a relatively new arrival. It is also not yet widespread, and in our data it was restricted to one site, 705 in the Barksdale complex (adjacent to a parking lot). Of the other taxa we recorded, several are largely naturalized pasture grasses (smooth brome (*Bromus inermis*), Kentucky bluegrass (*Poa pratensis*)) or common lawn weeds (common dandelion (*Taraxacum officinale*)). These taxa are not necessarily wetland species but often do better in wet soils. They represent management challenges, especially when they are irruptive. The park has had some success with managing *Cirsium arvense* in the Hornbek complex, potentially associated with the restoration of Grape Creek in 2012 (see this report's cover photos). We use an Invasiveness Rank (I Rank; Morse et al. 2004) metric as a score of the ecological impact of a species. The metric ranges from 1 to 9, with the impact increasing with score.

**Table 19.** Total mean cover of 23 nonnative invasive species at wetland sentinel sites in Florissant Fossil Beds National Monument, Colorado, 2009 to 2019. The table is sorted from the most likely to be problematic to the least. Cover is averaged across all sample events within a year. Bottom row and right most column give means across taxa and years, respectively. Invasiveness Rank (I Rank) is a score of the ecological impact of the species ranging from 1 to 9, with impact increasing with score. Cells with "–" are taxa/years where a species was not recorded. "Unk" indicates an I-rank score is not known.

| Species | Common name | I Rank | Mean cover | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2021 | 2009–2021 |
| *Phalaris arundinacea* [a] | reed canarygrass | 9 | – | 4.38 | **8.50** [b] | 2.67 | **5.75** [b] | **7.02** [b] | **6.67** [b] | **8.60** [b] | **6.00** [b] | 2.67 | – | – | **5.80** [b] |
| *Bromus inermis* | smooth brome | 8 | – | **21.70** [b] | **13.50** [b] | **11.40** [b] | – | **20.20** [b] | **22.00** [b] | **35.00** [b] | **10.80** [b] | – | 3.00 | 2.50 | **15.57** [b] |
| ***Cirsium arvense*** [c] | Canada thistle | 8 | 1.00 | 2.73 | 1.63 | 1.25 | 0.37 | **8.33** [b] | 0.67 | 1.74 | 0.66 | 0.50 | 0.50 | **11.67** [b] | 2.42 |
| ***Elymus repens*** [c] | quackgrass | 8 | 0.05 | – | – | – | – | **5.50** [b] | 3.17 | 2.00 | 1.00 | – | – | 3.33 | 2.99 |
| ***Linaria vulgare*** [c] | butter and eggs | 7 | – | – | – | 0.05 | – | – | 2.75 | – | – | – | – | – | 1.85 |
| *Poa pratensis* | Kentucky bluegrass | 6 | – | **11.49** [b] | 2.41 | 3.31 | 0.05 | **9.65** [b] | **6.22** [b] | **23.75** [b] | **5.28** [b] | 0.67 | 1.56 | 2.38 | **5.64** [b] |
| *Agrostis gigantea* | redtop | 4 | – | 2.39 | – | – | 0.05 | | 1.50 | 1.50 | **7.00** [b] | 4.40 | – | – | 2.81 |
| ***Cirsium vulgar*** [c] | bull thistle | 4 | – | – | – | – | – | 2.00 | – | – | – | – | – | – | 2.00 |
| *Descurainia sophia* | herb sophia | 4 | – | – | – | – | – | – | – | – | – | – | – | 0.50 | 0.50 |
| *Melilotus officinalis* | sweetclover | 4 | – | – | – | – | – | – | – | – | – | – | – | 0.50 | 0.50 |
| *Tragopogon dubius* | yellow salsify | 4 | – | – | – | – | – | – | – | – | – | – | – | 0.50 | 0.50 |
| *Trifolium hybridum* | alsike clover | 4 | – | – | 0.37 | 0.05 | – | – | 0.88 | 0.50 | 1.88 | – | – | – | 0.69 |
| *Trifolium repens* | white clover | 4 | – | – | – | 0.05 | – | – | – | – | – | 0.50 | – | – | 0.28 |
| *Rumex crispus* | curly dock | 2 | – | – | – | 3.91 | – | – | 0.58 | – | – | – | – | – | 2.24 |
| *Thlaspi arvense* | field pennycress | 2 | 1.00 | 0.28 | 2.58 | 1.93 | – | 2.27 | 2.45 | 2.88 | 0.94 | – | 0.70 | **8.42** [b] | 2.40 |
| *Artemisia biennis* var. *biennis* | biennial wormwood | Unk | – | – | – | 0.05 | – | – | – | – | 0.67 | – | – | – | 0.36 |
| *Axyris amaranthoides* | Russian pigweed | Unk | – | – | – | | – | – | – | – | – | – | – | 0.50 | 0.50 |
| *Erysimum cheiranthoides* | wormseed wallflower | Unk | – | – | – | | 0.76 | – | – | – | – | – | – | – | 0.76 |
| *Lepidium densiflorum* | common pepper weed | Unk | – | – | – | 2.35 | – | – | – | – | – | – | – | – | 2.35 |
| *Persicaria maculosa* | lady's thumb | Unk | – | – | 0.05 | – | – | – | – | – | – | – | – | – | 0.05 |
| *Portulaca oleracea* | little hogweed | Unk | – | 4.70 | 3.00 | – | – | – | – | – | 0.50 | – | – | – | 2.73 |
| *Rumex stenophyllus* | narrowleaf dock | Unk | – | 1.11 | 1.02 | – | – | 2.86 | 1.83 | | 0.58 | – | 0.50 | 1.00 | 1.35 |
| *Taraxacum officinale* | common dandelion | Unk | – | 0.28 | 0.37 | 0.05 | 0.05 | 0.05 | 0.56 | 0.83 | 0.50 | – | 0.50 | 0.50 | 0.34 |
| Mean (all species) | N/A | N/A | 0.68 | 4.96 | 2.68 | 2.11 | 0.97 | **6.64** [b] | 3.16 | **6.35** [b] | 2.22 | 1.54 | 1.15 | 3.88 | 3.39 |

[a] *Phalaris arundinacea* has unresolved nativity but the NPS manages it as an invasive nonnative.

[b] Mean cover value above 5.0 (also in bold red font).

[c] Species of special park concern (also in bold font).

3.4.3.3 Baseline Status (2009–2011)

Baseline relative cover of native species by wetland type and sentinel complex was homogeneous across types and complexes (Table 20, Figure 41). FLFO fen sites had higher baseline median relative cover of native species than wet meadows. Fens are usually more resilient to invasive species due typically to higher groundwater levels, with most nonnative invasive species not well adapted to permanent saturation. Maintaining high groundwater tables is one way to support native species composition in wetlands.

The Red Barn complex had the highest baseline median cover of native species, although the three complexes were quite similar. Most of the nonnative cover was in site 711 from pasture grasses like Kentucky bluegrass and smooth brome, with lower cover of Canada thistle, common dandelion, and alsike clover (*Trifolium hybridum*). Pasture grasses were likely seeded into the meadows of FLFO when the area was actively ranched, and they can be very difficult to eradicate. These grasses are not considered noxious weeds and are often allowed to naturalize, but they are ranked as medium to highly invasive. This site is on the edge of the wetland complex, with a lower water table often below 60 cm from the ground surface (from our episodic hand measurements, see hydrology section). Disturbed areas with variable soil moisture are often more conducive to invasive taxa (Price et al. 2011; Choi and Bury 2003; Galatowitsch et al. 2000).

Interestingly, site 704 in the Barksdale complex had high cover of nonnative species even though it was located farther from the higher human uses such as the picnic area, trail, and parking lot. Over 10 nonnative species were observed within this site, the most common being Kentucky bluegrass, field pennycress (*Thlaspi arvense*), Canada thistle, and narrowleaf dock (*Rumex stenophyllus*). Many of the same nonnatives were found in nearby sites 703 and 705, but at lower cover. This likely reflects complex source dynamics for invasives and historical influences. Site 705 in Barksdale is immediately adjacent to the parking lot, but given its more consistent high-water table, it may be less susceptible to invasion, retaining more natives—with the important exception of reed canarygrass, as noted above.

We assessed the baseline status of FLFO sentinel site relative cover of native species using assessment points derived from a regional dataset of 300 undisturbed fens and wet meadows in Colorado's Southern Rockies (Table 20 and Figure 41). Note that as this indicator is biological in nature, we use the labels reference and non-reference (see Appendix 5). These assessment points are all quite high, indicating that even non-reference wetland sites have a high proportion of native species cover. This is especially the case for fens in reference condition, with nearly all (99%) native cover. At FLFO the median baseline relative cover of native species for fens, but not for wet meadows, was in a reference condition. The non-reference wet meadow baseline was driven by wet meadow site 711 in the Red Barn complex, with only a 57% native cover. This site is near the main park road. It has a higher HDI and a lower water table (average DTW was 50 cm below ground at site 711 compared to an average across all other sites of 19 cm).

**Table 20.** Baseline (2009–2011) relative cover of native species at sentinel sites by wetland type and sentinel complex in Florissant Fossil Beds National Monument, Colorado. Metric ranges from 0 to 100%. Reported values include sample size (N), coefficient of variation (CV), standard deviation (SD), minimum (Min.), and maximum (Max.). Assessment points are given in the Non-reference and Reference assessment point columns with the greater than (“>”) or less than (“<”) signs indicating where, relative to the assessment point, the condition class occurs. Values between these two thresholds are in an intermediate condition class. Assessment points are not relevant for sentinel complex as these include both wetland types.

| Wetland type / Sentinel complex | N | Median % | Mean % | CV | SD | Min. % | Max. % | Non-reference assessment point | Reference assessment point |
|---|---|---|---|---|---|---|---|---|---|
| Fen | 11 | 99.3 | 98.0 | 0.02 | 2.37 | 94.4 | 100 | <90 | >99 |
| Wet Meadow | 12 | 94.3 | 89.8 | 0.16 | 14.32 | 51.70 | 100 | <79 | >96 |
| Hornbek | 7 | 95.3 | 96.50 | 0.03 | 3.28 | 91.2 | 100 | – | – |
| Red Barn | 9 | 99.8 | 91.40 | 0.19 | 17.50 | 51.70 | 100 | – | – |
| Barksdale | 7 | 94.4 | 94.08 | 0.04 | 3.66 | 86.8 | 97.52 | – | – |

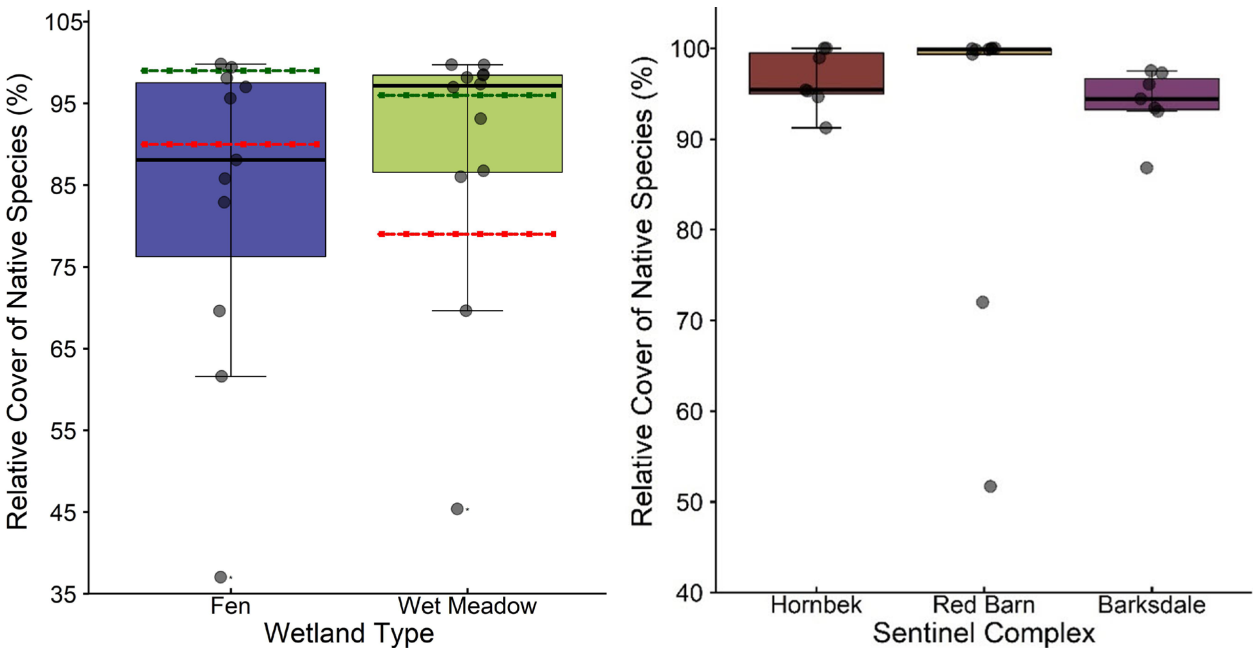



**Figure 41.** Baseline relative cover of native species at sentinel sites by (left panel) wetland type, and (right panel) sentinel complex, Florissant Fossil Beds National Monument, Colorado, 2009–2010. Metric ranges from 0 to 100%. Horizontal lines show the reference assessment point (green) and non-reference assessment point (red) for wetland types, with values above or below these in reference or non-reference, respectively. Values between these two thresholds are in an intermediate condition class. Assessment points are not relevant for sentinel complex as these include both wetland types. Points are individual values (jittered to reduce overlap). Note constrained range in both panels.

3.4.3.4 Trend (2009 to 2019)

We first examine general patterns in relative cover of native species across time and the condition level of individual results (Figure 42). Across all sites (top panel in the figure), there is a suggestion of a small decrease in relative cover of native species from 2009 to 2019. When separated across complexes or wetland types (middle and lower panels in the figure) this decrease persists and appears somewhat non-linear, with small dips in later years, especially in the Red Barn complex and in wet meadows. Many of the non-reference points in the figure are Red Barn wet meadow site 711, with lower nativity. The figure suggests slightly deteriorating conditions, especially overall, but most samples at our FLFO sites were in a reference or intermediate condition, with high levels of native species cover.

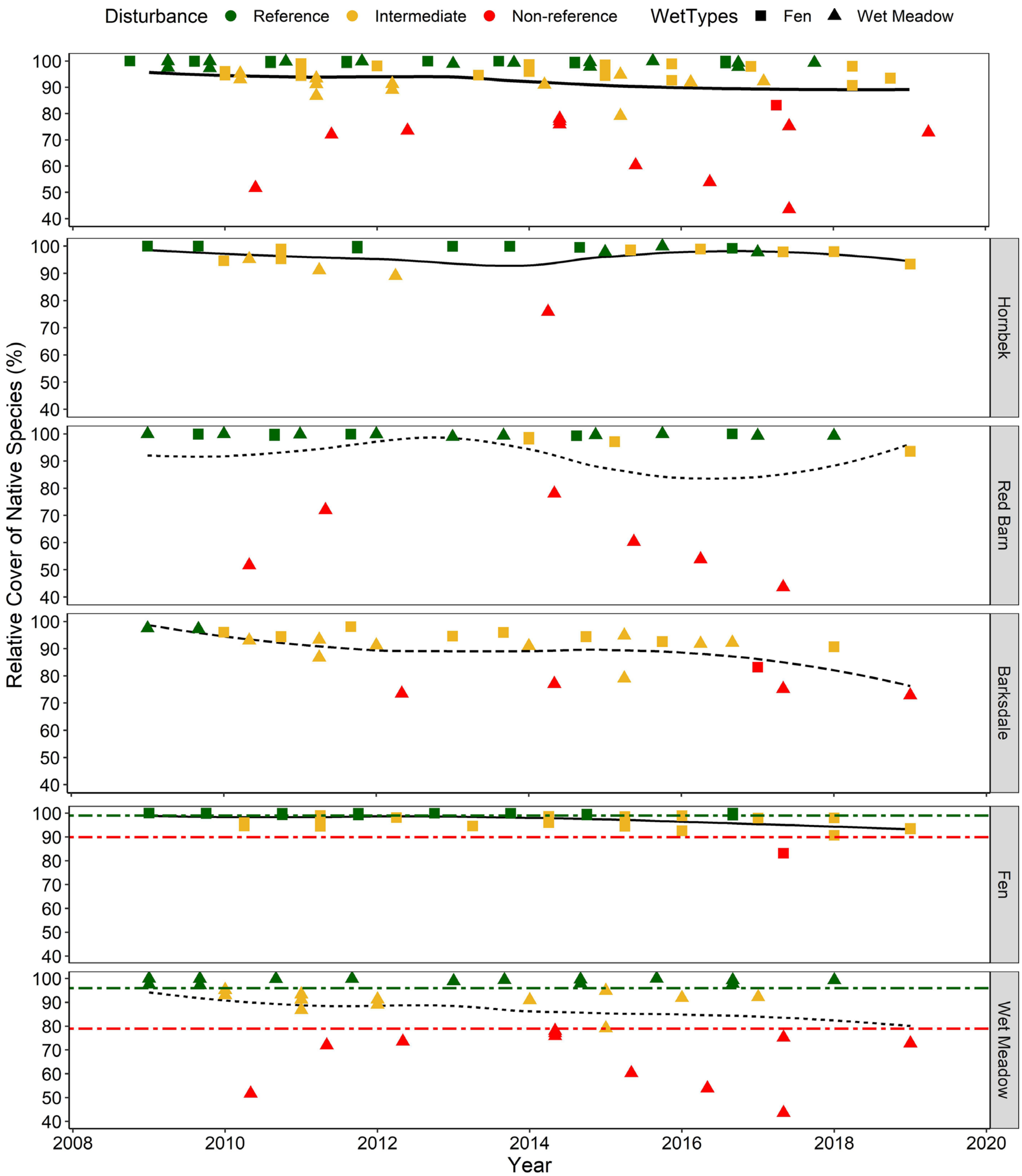



**Figure 42.** Relative cover of native species at sentinel sites for all data (top panel), sentinel complex (three middle panels) and wetland type (bottom two panels), Florissant Fossil Beds National Monument, Colorado, 2009–2019. Fitted lines are via loess smooths, which show general patterns across time. Multiple points within a year correspond to separate sample sites, with points jittered to reduce overlap. Point color is determined by relationships to wetland type specific assessment point (only shown with horizontal lines in bottom panel as other panels mix wetland types). Green indicates reference, yellow is intermediate, and red is non-reference.

A linear mixed model applied to the relative cover of native species allows statistical tests of overall trend, trend by wetland type, and trend by sentinel complex (Table 21, Figure 43). Model selection resulted in a model that fits the data better if the interaction between scaled date and wetland type was removed. The model explained a high proportion of the overall variation in the relative cover of native species (adjusted $R^2 = 0.85$). There was no suggestion of meaningful autocorrelation in the residuals and the relationship between the residuals and fitted values was acceptable.

Overall, there was no trend in relative cover of native species, perhaps in contrast to the suggestion of a slightly decreasing non-linear trend in the loess fit. However, given how the mixed model correctly handles these data, we conclude there is no overall change in relative cover of native species over time, with average values staying high at our sites. There was also no trend within wetland types or complexes, although lower native cover in wet meadows relative to fens approached marginal significance ($p = 0.135$) and had a larger coefficient. There was also a marginally significant interaction ($p = 0.07$) between scaled date and the Barksdale complex, suggesting that there was a steeper declining slope for Barksdale over time relative to Hornbek; however, these coefficient values are small, and this is likely less meaningful.

**Table 21.** Linear mixed model of relative cover of native species from all wetland sentinel sites from 2009 to 2019, Florissant Fossil Beds National Monument, Colorado. Table includes fixed term coefficients, their degrees of freedom (df), t values, upper/lower confidence intervals, and the probability (p) or significance of the term. Random terms include each term's standard deviation (SD), a log ratio test statistic, and its probability (as a Chi square). The model had a sample size of 76 values across 11 years and 10 sites.

| Type of term | Term | Coefficient | df | t value | SD | Log ratio test | Lower CI | Upper CI | p |
|---|---|---|---|---|---|---|---|---|---|
| Fixed | Intercept | 100.514 | 5.954 | 13.345 | N/A | N/A | 85.752 | 115.276 | 0.000 |
| | Scaled Date | 0.099 | 14.745 | 0.215 | N/A | N/A | −0.801 | 0.998 | 0.833 |
| | Sentinel Complex (Red Barn vs. Hornbek) | −2.977 | 6.093 | −0.313 | N/A | N/A | −21.602 | 15.648 | 0.765 |
| | Sentinel Complex (Barksdale vs. Hornbek) | 3.130 | 6.074 | 0.301 | N/A | N/A | −17.248 | 23.508 | 0.773 |
| | Wetland Type (Wet meadow vs. Fen) | −13.771 | 6.247 | −1.716 | N/A | N/A | −29.502 | 1.961 | 0.135 |
| | Scaled Date * Sentinel Complex Red Barn vs. Hornbek | −0.552 | 16.071 | −0.874 | N/A | N/A | −1.790 | 0.686 | 0.395 |
| | **Scaled Date * Sentinel Complex Barksdale vs. Hornbek** [a] | −1.272 | 15.025 | −1.953 | N/A | N/A | −2.549 | 0.005 | **0.070** [a] |
| Random | Year | N/A | N/A | N/A | 0.000 | 0.000 | N/A | N/A | 1.000 |
| | Site | N/A | N/A | N/A | 11.611 | 1.257 | N/A | N/A | 0.533 |

[a] Terms are significant ($p < 0.10$)(also in bold font).

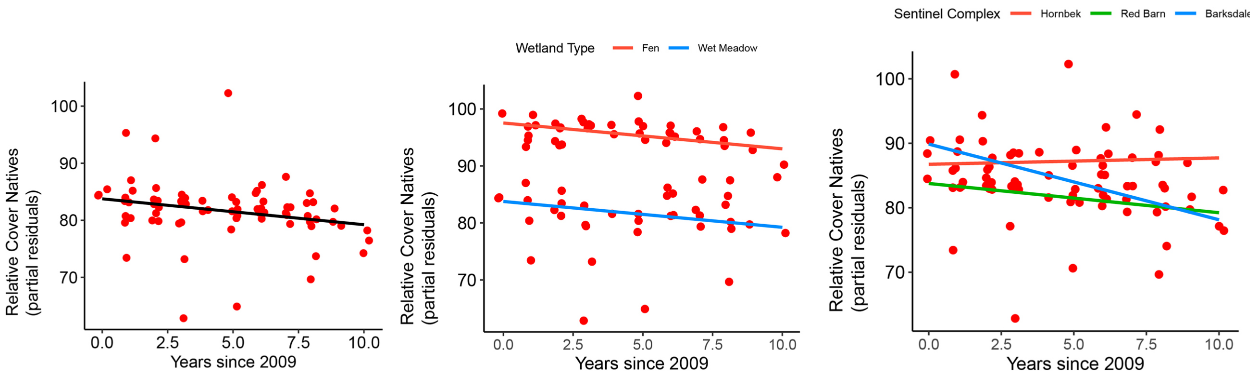



**Figure 43.** Visualizations of trend results for relative cover of native species in Florissant Fossil Beds National Monument wetland sentinel sites, Colorado, 2009 to 2019. Data points are partial residuals estimated by a mixed model (in Table 21). Fitted lines show the estimated linear trend, overall across all sites (left), by wetland type (middle), and by sentinel complex (right). Y axis scale may be different on some panels given different ranges in the partial residuals. Assessment points are not shown on these figures as partial residuals are not in the same units as raw data.

### *3.4.4 Wetland Affinity: Relative cover of hydrophytic species*

Wetland affinity measures the prevalence of species in a community that have a demonstrated ability because of morphological or physiological adaptations and/or reproductive strategies to achieve maturity and reproduce in wetlands. Higher wetland affinity in a sample indicates that vegetation composition includes more wetland obligates and thus likely higher and/or more stable water tables. Because the mix of species at a site responds over time and space to variation in hydrologic regime, wetland affinity integrates seasonal and annual fluctuations in groundwater levels (Grace et al. 2012). It is likely a useful proxy for more complex and expensive measures of groundwater hydrologic regime (Loheide and Gorelick 2007). The indicator we selected to monitor was relative cover of obligate hydrophytic species or those that require wetland soils. We chose this smaller subset of species that require wetlands to focus the metric on a more exclusive vegetation response to wetland conditions.

Of the 151 species documented at our sites, 28 or 18% are strict obligate hydrophytes likely only found in wetland habitat. Another 43 (28%) are facultative wetland species, those that are almost always restricted to wet habitats. Important obligate hydrophytic species in FLFO include water sedge (*Carex aquatilis*) (Figure 44), beaked sedge (*C. utriculata*), and water minerslettuce (*Montia chamissoi*).

**Figure 44.** Water sedge (*Carex aquatilis*) is an important hydrophytic species found in the wetlands of Florissant Fossil Beds National Monument, Colorado. At Hornbek site 709, it often had over 90% relative cover, especially when viewed upside down. Photo inset by Matt Lavin, Wikimedia Commons, CC BY-SA 2.0 license; site photo by NPS/BILLY SCHWEIGER.

3.4.4.1 Baseline Status (2009–2011)

Baseline relative cover of hydrophytic species by wetland type and sentinel complex was somewhat homogeneous, with smaller coefficient of variation across types and complexes (Table 22 and Figure 45). FLFO fen sites had higher baseline median relative cover of hydrophytic species than wet meadows. This was as expected, given fens' generally higher water tables that hydrophytic species are adapted to. Variation across complex likely reflects the different contribution of fens or wet meadows to each complex's median value. The surprising amount of variation in fen DTW we describe above likely occurred over too short of a time to impact hydrophytic species composition, although this may be something to watch. If hydrophytic species decline, it may be connected to the water table dropping. Thus, as with natives, maintaining high groundwater tables is one way to maintain hydrophytic species composition in wetlands. Note that fen site 705 in the Barksdale complex was treated differently with this metric. This was the only wooded site in FLFO, with an overstory of Engelmann spruce, which is not a wetland obligate. To be consistent with other non-wooded sites and to focus on the understory vegetation that responds over shorter time spans, we

removed the cover of spruce from these calculations. With the spruce removed, the baseline status of relative cover of hydrophytic species at site 705 was 86.0%, and the site ranged from 90.2% in 2012 to 62.8% in 2018.

We assessed the baseline status of FLFO sentinel sites' relative cover of hydrophytic species using assessment points derived from the same regional dataset of 300 undisturbed fens and wet meadows used for native species. These assessment points are not as conservative as those for native cover, suggesting wetlands can have lower cover of hydrophytic species and still be considered high quality. Median baseline relative cover of hydrophytic species for both fens and wet meadows was in reference condition. However, two sites, wet meadow 711 in Red Barn and fen 708 in Hornbek, had baseline minima well below the assessment point and site 711 was often below the assessment point over the period of record. This site is generally disturbed and has a dry and variable water table that likely limits the establishment of hydrophytic species that need a more stable hydrologic environment. Site 708's low baseline value in 2009 was somewhat of a surprise. This site has a persistent high cover of moss (nonvascular) taxa (Figure 46), and in 2009 we likely did not identify or locate all mosses correctly as this was our first sample event at the site. Most mountain mosses are wetland obligates (high wetland affinity). Like native cover, our wetland affinity metric only uses cover from vascular plants at the species level, and wetland obligate cover would likely be higher if nonvascular plants were included. The baseline condition for wetland affinity of fens is still in a reference condition, despite the omission of moss cover from the index at some sites. However, we did not include data from site 708 in 2009 in trend visuals and models below to avoid initiating a trend model likely to include incorrectly low values.

**Table 22.** Baseline (2009–2011) cover of hydrophytic species at sentinel sites by wetland type and sentinel complex in Florissant Fossil Beds National Monument, Colorado. Metric ranges from 0 to 100%. Reported values include sample size (N), coefficient of variation (CV), standard deviation (SD), minimum (Min.), and maximum (Max.). Assessment points are given in the Non-reference and Reference assessment point columns with the greater than (">") or less than ("<") signs indicating where relative to the assessment point the condition class occurs. Values between these two thresholds are in an intermediate condition class. Assessment points are not relevant for sentinel complex as these include both wetland types.

| Wetland type / Sentinel complex | N | Median % | Mean % | CV | SD | Min. % | Max. % | Non-reference assessment point | Reference assessment point |
|---|---|---|---|---|---|---|---|---|---|
| Fen | 11 | 98.1 | 89.0 | 0.17 | 15.300 | 49.6 [a] | 99.80 | <62 | >87 |
| Wet Meadow | 12 | 90.2 | 85.6 | 0.21 | 18.310 | 38.50 | 99.80 | <46 | >75 |
| Hornbek | 7 | 89.7 | 85.5 | 0.20 | 17.350 | 49.60 [a] | 99.60 | – | – |
| Red Barn | 9 | 99.2 | 87.9 | 0.26 | 22.678 | 38.58 | 99.86 | – | – |
| Barksdale | 7 | 87.2 | 88.2 | 0.06 | 5.154 | 82.27 | 98.45 | – | – |

[a] Value may reflect methodological issues in data or metric calculation.

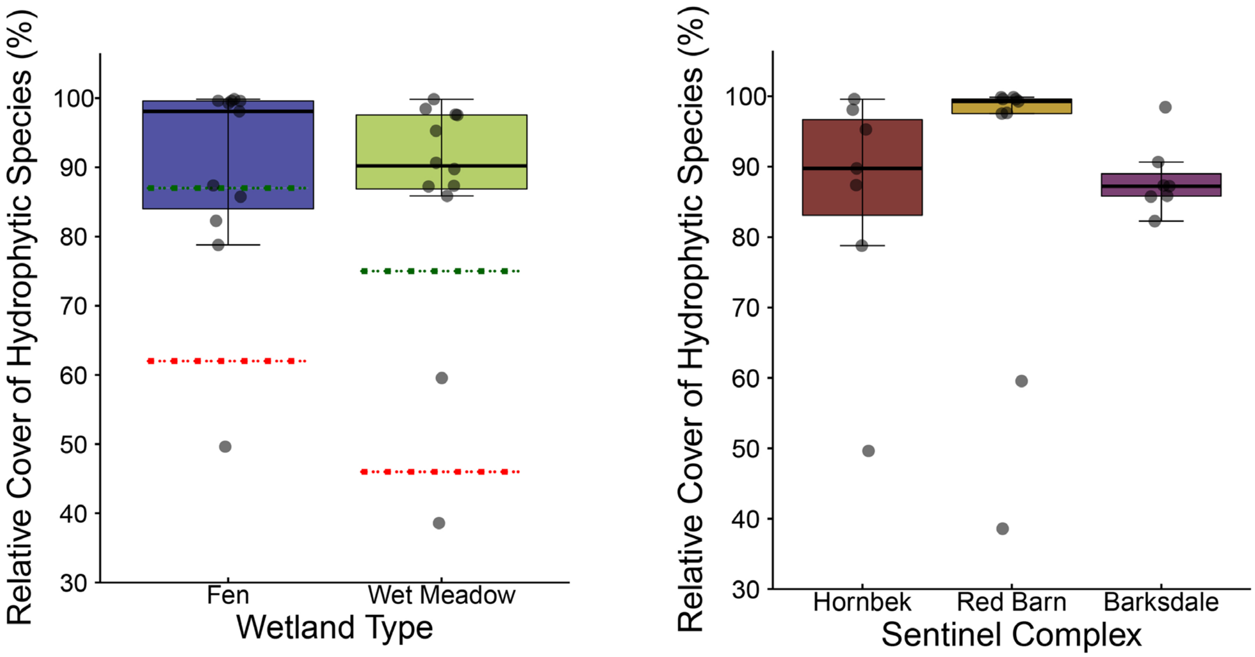



**Figure 45.** Baseline relative cover of hydrophytic species at sentinel sites by (left panel) wetland type, and (right panel) sentinel complex, Florissant Fossil Beds National Monument, Colorado, 2009–2010. Metric ranges from 0 to 100%. Horizontal lines show the reference assessment point (green) and non-reference assessment point (red) with values above or below these in reference or non-reference, respectively. Values between these two thresholds are in an intermediate condition class. Assessment points are not relevant for sentinel complex as these include both wetland types. Points are individual values (jittered to reduce overlap). Note constrained range in both panels and that minima in fens and in the Hornbek complex may contain some inconsistency in the metric calculation, as explained in the text for this section.

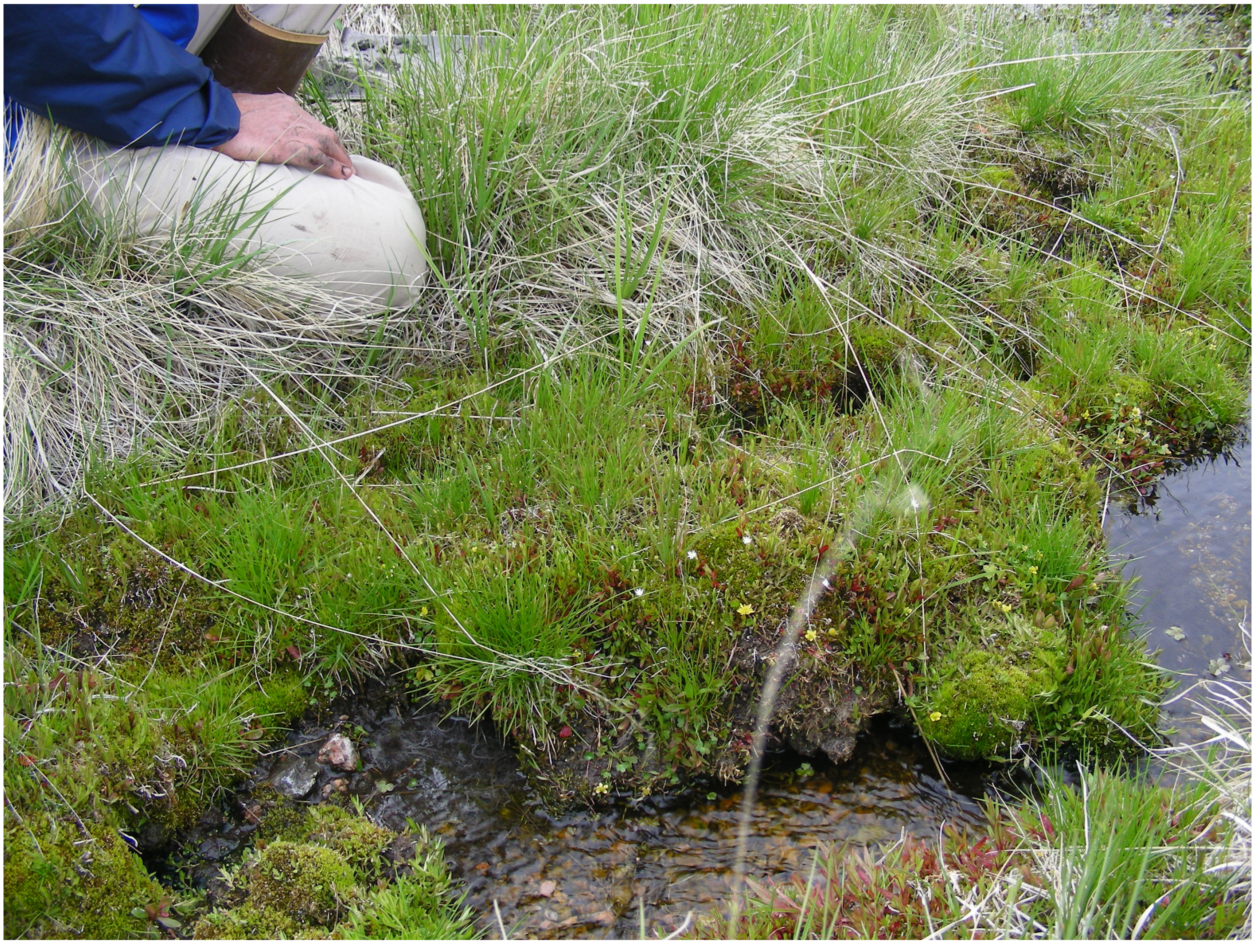


**Figure 46.** High moss cover at Hornbek fen site 708 in 2009 at Florissant Fossil Beds National Monument, Colorado. The often-saturated early summer water table of this site is also evident. Moss also provides a very comfy place to sit. NPS/BILLY SCHWEIGER.

3.4.4.2 Trend (2009 to 2019)

We first examine general patterns in relative cover of hydrophytic species across time and the condition level of individual results (Figure 47). Across all sites (top panel in the figure), the pattern is generally stable with perhaps a slight decrease over the period of record. There is a suggestion of non-linearity with a small decrease in 2012 followed by a slight increase in 2014. This is also seen in fens and the Hornbek and Barksdale complexes but in wet meadows and Red Barn complex there is a drop off in affinity beginning in 2017 (middle and lower panels in the figure). For fens and the Hornbek complex the omission of the suspect 2009 value due to the moss issue described above removes a general increase across the period of record (away from the likely incorrect low value) with wetland affinity instead high and largely consistent (as expected in fens). The dip in wetland affinity from 2012 to 2014 in Hornbek corresponds to the restoration project in the complex. This might also or instead be a climate or water balance driven response, but the decrease in wet meadows and Red Barn affinity in 2017 suggests that the restoration helped the increase in hydrophyte cover to "stick." Red Barn sites showed the greatest variability in hydrophytic cover across time with wet meadow site 711 having consistently low cover (which parallels relative cover of native species). The

nonnative pasture grasses, Kentucky bluegrass and smooth brome, that dominate this site are rated facultative and upland. Facultative species can occur in wet environments but are just as frequent in dry areas. Upland species rarely occur in wet environments.

A linear mixed model applied to the relative cover of hydrophytic species allows statistical tests of overall trend, trend by wetland type, and trend by sentinel complex (Table 23, Figure 48). Model selection resulted in two models with equivalent AIC scores, and we selected the simpler of these. This included sentinel complex and wetland type as fixed predictors but only an interaction between scaled date and sentinel complex. The model explained a high proportion of the overall variation in the relative cover of hydrophytic species (adjusted $R^2 = 0.85$). There was no suggestion of meaningful autocorrelation in the residuals and the relationship between the residuals and fitted values was acceptable.

This model was like the native cover model—not entirely surprising given that most hydrophytic species are also natives. Overall, there was no trend in relative cover of hydrophytic species, despite a suggested decline in the loess fits. There was also no trend within wetland types or complexes, although a decrease in native cover in wet meadows relative to fens approached marginal significance ($p = 0.135$) and this coefficient was on the larger side, so this may be something to pay attention to. There was a marginally significant interaction ($p = 0.051$) between scaled date and the Barksdale complex, suggesting that there was a steeper slope in Barksdale over time (relative to Hornbek); however, for simplicity, we assume this interaction is not meaningful and allow the scaled date term to be interpreted as a stand-alone coefficient.

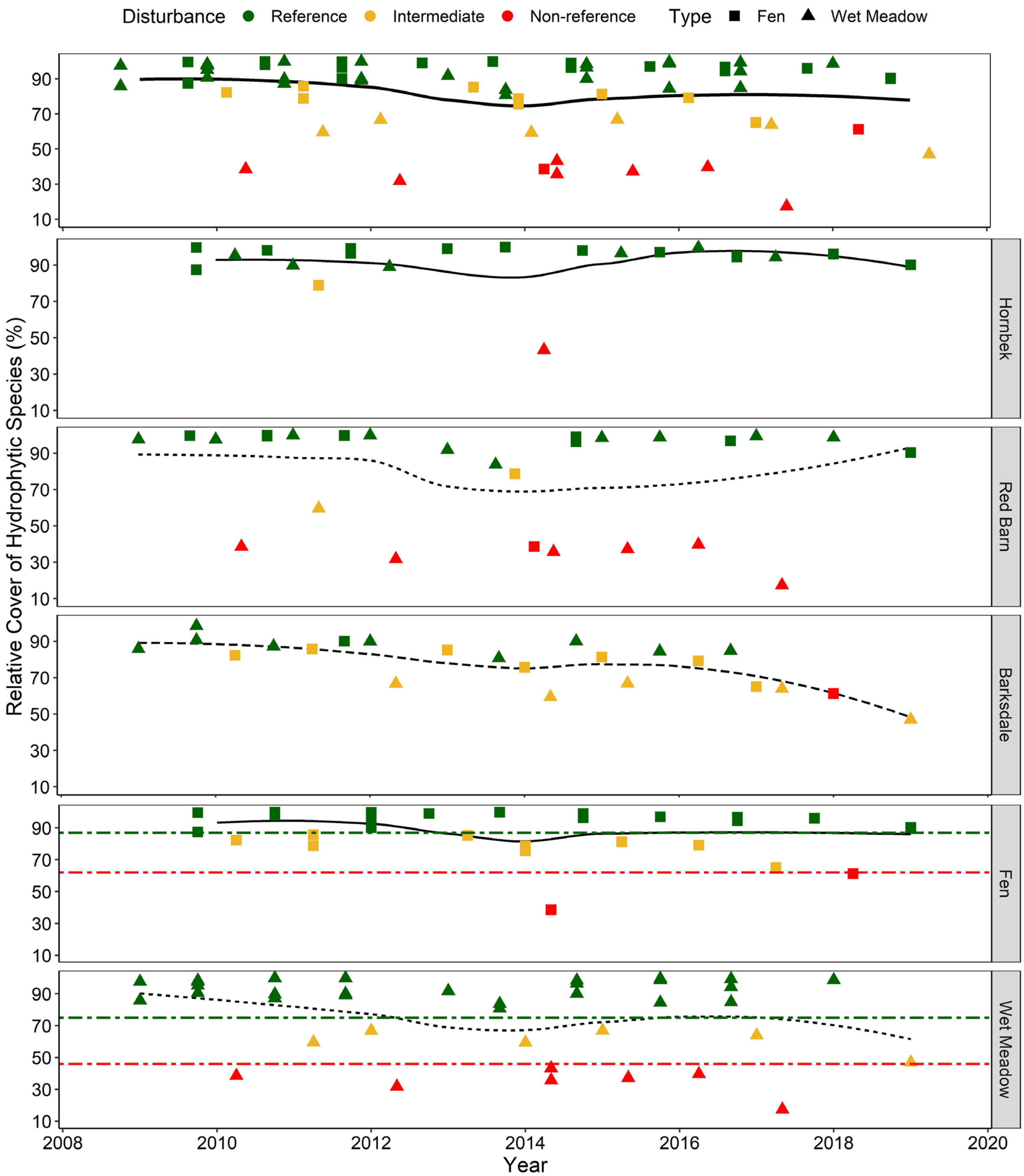



**Figure 47.** Relative cover of hydrophytic species at sentinel sites for all data (top panel), sentinel complex (three middle panels), and wetland type (bottom two panels), Florissant Fossil Beds National Monument, Colorado, 2009–2019. Fitted lines are via loess smooths, which show general patterns across time. Multiple points within a year correspond to separate sample sites, with points jittered to reduce overlap. Point color is determined by relationships to wetland type specific assessment points (only shown with horizontal lines in bottom panel as other panels mix wetland types). Green indicates reference, yellow is intermediate, and red is non-reference.

**Table 23.** Linear mixed model of relative cover of hydrophytic species from all wetland sentinel sites from 2009 to 2019, Florissant Fossil Beds National Monument, Colorado. Table includes fixed term coefficients, their degrees of freedom (df), t values, upper/lower confidence intervals, and the probability (p) or significance of the term. Random terms include each term's standard deviation, a log ratio test statistic, and its probability (as a Chi square). The model had a sample size of 75 values across 11 years and 10 sites.

| Type of term | Term | Coefficient | df | t value | Lower CI | Upper CI | Standard deviation | Log ratio test | p |
|---|---|---|---|---|---|---|---|---|---|
| Fixed | Intercept | 95.024 | 8.171 | 9.296 | 74.990 | 115.057 | N/A | N/A | 0.000 |
| | Scaled Date | 0.279 | 15.237 | 0.249 | −1.912 | 2.469 | N/A | N/A | 0.806 |
| | Sentinel Complex (Red Barn vs. Hornbek) | −2.280 | 6.375 | −0.190 | −25.760 | 21.201 | N/A | N/A | 0.855 |
| | Sentinel Complex (Barksdale vs. Hornbek) | 5.043 | 6.290 | 0.386 | −20.539 | 30.625 | N/A | N/A | 0.712 |
| | Wetland Type (Wet meadow vs. Fen) | −13.582 | 6.899 | −1.362 | −33.131 | 5.968 | N/A | N/A | 0.216 |
| | Scaled Date * Sentinel Complex Red Barn vs. Hornbek | −1.880 | 9.791 | −1.483 | −4.364 | 0.605 | N/A | N/A | 0.170 |
| | **Scaled Date * Sentinel Complex Barksdale vs. Hornbek** [a] | −2.950 | 9.031 | −2.248 | −5.521 | −0.378 | N/A | N/A | **0.051** [a] |
| Random | **Year** [a] | N/A | N/A | N/A | N/A | N/A | 5.620 | 8.686 | **0.003** [a] |
| | Site | N/A | N/A | N/A | N/A | N/A | 13.729 | 3.310 | 0.191 |

[a] Terms are significant ($p < 0.10$)(also in bold font).

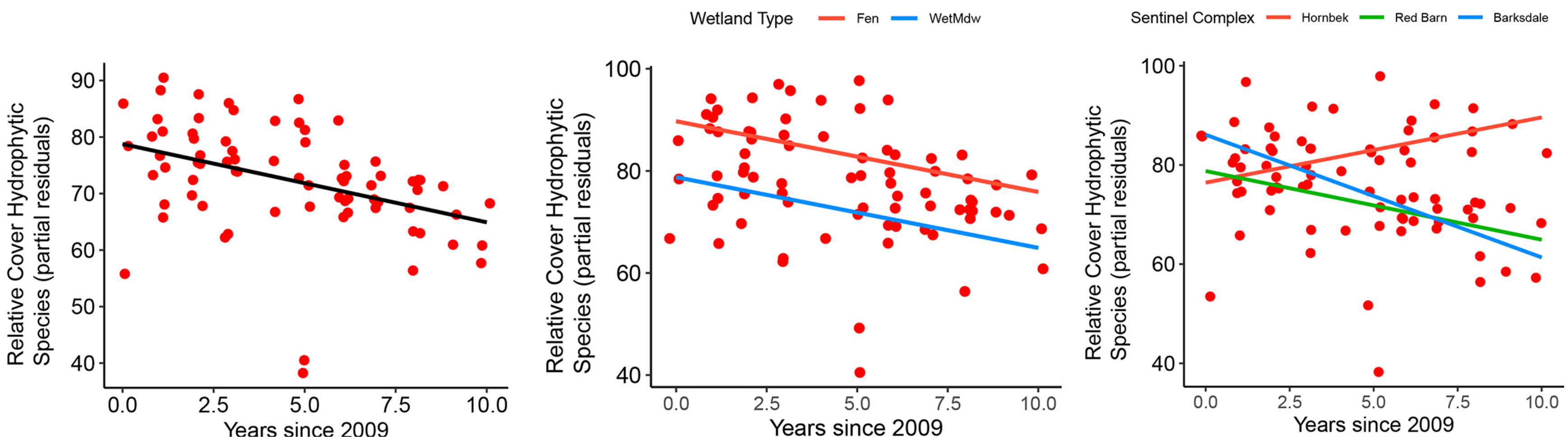



**Figure 48.** Visualizations of trend results for relative cover of hydrophytic species in Florissant Fossil Beds National Monument wetland sentinel sites, Colorado, 2009 to 2019. Data points are partial residuals estimated by a mixed model (in Table 23). Fitted lines show the estimated linear trend, overall across all sites (left), by wetland type (middle), and by sentinel complex (right). Y axis scale may be different on some panels given different ranges in the partial residuals. Assessment points are not shown on these figures as partial residuals are not in the same units as raw data.

### *3.4.5 Conservatism: Floristic Quality Index*

Conservatism describes a species' fidelity to a specific habitat or range of environmental conditions absent human disturbance (Wilhelm and Ladd 1988; Herman et al. 1997; Matthews et al. 2015). Anthropogenic impacts can cause dramatic shifts in ecological processes and habitat conditions and push disturbance regimes outside a natural range of intensity, frequency, and duration. More conservative species are not able to quickly respond to such rapid alterations compared to broad-niche generalists and are often the first to disappear from habitats heavily impacted by human activities. The composition of conservative species at a particular site integrates spatial and temporal impacts and can serve as an indicator of ecological integrity or condition. To assess conservatism, we use metrics based on "coefficients of conservatism" (also known as "C-scores") assigned to the flora of Colorado by a panel of experts following the methods described by Swink and Wilhelm (1994). Colorado C-scores were originally assigned in 2007 (Rocchio 2007b) and updated in 2020 (Smith et al. 2020). C-scores range from 0 to 10 and represent the estimated probability that a plant shows high fidelity to landscapes relatively unaltered from pre-European settlement conditions. Nonnative species are given C-scores of 0 by default. Low C-values are assigned to species that demonstrate little fidelity to unaltered landscapes or have wide ecological tolerances and may be found almost anywhere. High C-values are assigned to species only found in high quality natural areas and that cannot tolerate habitat degradation. Using the C-scores of all or select species present within a site, a suite of metrics can be calculated that convey different aspects of the site's condition and disturbance history. The use of C-scores and their derived metrics is often referred to as Floristic Quality Assessment (FQA).

Of the 151 species in our data, all but two (slenderfruit willowherb (*Epilobium leptocarpum*) and Vreeland's erigeron (*Erigeron vreelandii*)) have a known or assigned C score. This is important as this near complete attribution of C-scores improves any metric that estimates conservatism. The mean C-score for our FLFO sites was 4.54, with a maximum of 9 and a minimum of 0. An important conservative species in FLFO includes the C score = 9 red baneberry (*Actaea rubra*)*,* and a typical low value species is the C score =1 Norwegian cinquefoil (*Potentilla norvegica*) (Figure 49).

**Figure 49.** Important high conservatism species (C score = 9) *Actaea rubra* (red baneberry) (top), and a typical low conservatism value species (C score = 1) *Potentilla norvegica* (Norwegian cinquefoil) (bottom) common in the wetlands of Florissant Fossil Beds National Monument, Colorado. *Actaea rubra* photo by Sheri Hagwood, USDA Plants Database; *Potentilla norvegica* photo courtesy Western New Mexico University Department of Natural Sciences and the Dale A. Zimmerman Herbarium.

3.4.5.1 Resolving the best metric

As with nativity it was important to select from the many ways to estimate conservatism. We explored several metrics, including mean C-scores, various Floristic Quality Indices, and percentages of a sample that were either tolerant or intolerant taxa (based on a C score). We compared metrics to indices of disturbance (HDI and LDI), examined distributional or statistical properties of each, and evaluated the management relevant interpretability of candidates. We also considered the inclusion of metrics in other monitoring efforts by NPS, Colorado Natural Heritage Program, and the US EPA.

Selecting a best metric of conservatism for the FLFO dataset was a challenge. The conservatism of the wetland community at our FLFO sites is fairly constrained in range (or has low variability) and tends to be on the low side. For example, the mean conservatism of FLFO fens was 4.9, while meadows were 3.7, compared to mean C-values of 6.2–6.9 for fens and wet meadows in Great Sand Dunes National Park and Preserve and Rocky Mountain National Park. Lower conservatism is typical for lower elevation systems nested in a more human-influenced matrix like FLFO. The lower variability in conservatism values in our FLFO sites may reduce the ability to resolve a response to human disturbance in our sites' wetland vegetation and may make it harder to resolve the selection of the best conservatism metric.

We decided to overlook these constraints and selected a common conservatism metric, the Floristic Quality Index (FQI) that uses the mean of C-values for all species observed within a sampling event multiplied by the square root of species richness. The FQI ranges from 0 to ~35, with higher values indicating a more conservative community. This metric or close variants are in several Rocky Mountain Network, Colorado Natural Heritage Program, and EPA bioassessment indices (see below), and connecting to these programs via use of the FQI has value. Future work may refine how we include conservatism in FLFO WEI monitoring.

3.4.5.2 Baseline Status (2009–2011)

Baseline median FQI varied meaningfully across types and complexes and had relatively small coefficient of variation values within these groups (Table 24 and Figure 50). FLFO fen sites had higher baseline FQI than wet meadows. Fens are more stable environments with fewer natural disturbances than wet meadows (Gage and Cooper 2013). Many fen species have C-values above 7, which leads to higher FQI values. Fens regionally and within our FLFO sites have higher species richness (115 species were found in our fen sites while 97 occurred in wet meadows). In contrast, wet meadows experience greater fluctuations in water table and higher use by native ungulates (likely of minor importance in FLFO). They may be more susceptible to other natural disturbances and often have greater human use. These factors can all lead to lower potential FQI values in wet meadows.

**Table 24.** Baseline (2009–2011) Floristic Quality Index (FQI) at sentinel sites by wetland type and sentinel complex in Florissant Fossil Beds National Monument, Colorado. Metric ranges from 0 to ~35, with higher values indicating higher condition. Reported values include sample size (N), coefficient of variation (CV), standard deviation (SD), minimum (Min.), and maximum (Max.). Assessment points are given in the Non-reference and Reference assessment point columns, with the greater than (“>”) or less than (“<”) signs indicating where, relative to the assessment point, the condition class occurs. Values between these two thresholds are in an intermediate condition class. Assessment points are not relevant for sentinel complex as these include both wetland types.

| Wetland type / Sentinel complex | N | FQI median | FQI mean | FQI CV | FQI SD | FQI min. | FQI max. | Non-reference assessment point | Reference assessment point |
|---|---|---|---|---|---|---|---|---|---|
| Fen | 11 | 21.1 | 21.6 | 0.24 | 5.115 | 11.8 [a] | 29.7 | <12.8 | >20.6 |
| Wet Meadow | 12 | 14.9 | 14.53 | 0.27 | 3.905 | 7.7 | 20.6 | <9.8 | >16.0 |
| Hornbek | 7 | 16.6 | 18.49 | 0.25 | 4.704 | 11.8 [a] | 24.2 | – | – |
| Red Barn | 9 | 19.6 | 17.91 | 0.24 | 4.331 | 7.7 | 21.1 | – | – |
| Barksdale | 7 | 14.4 | 17.33 | 0.49 | 8.452 | 9.6 | 29.7 | – | – |

[a] Value may reflect methodological issues in data or metric calculation.

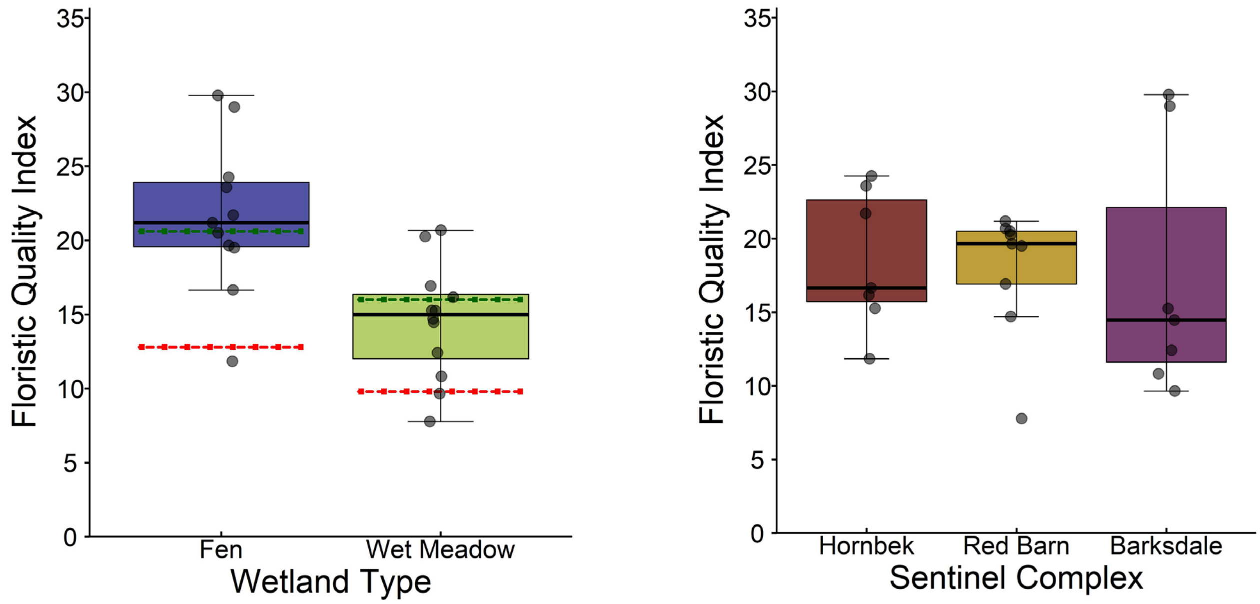



**Figure 50.** Baseline Floristic Quality Index at sentinel sites by (left panel) wetland type, and (right panel) sentinel complex, Florissant Fossil Beds National Monument, Colorado, 2009–2010. Metric ranges from 0 to ~35, with higher values indicating higher condition. Horizontal lines show the reference assessment point (green) and non-reference assessment point (red) with values above or below these in reference or non-reference condition, respectively. Values between these two thresholds are in an intermediate condition class. Assessment points are not relevant for sentinel complex as these include both wetland types. Points are individual values (jittered to reduce overlap). Note constrained range in both panels and that minima in fens and in the Hornbek complex may contain some inconsistency in the metric calculation.

The impact of higher fen FQI also explains differences in baseline results across complexes. Red Barn had more fen sites and thus higher median FQI than the other two complexes. Interestingly, the wet meadow site 710, which had high cover of native and hydrophytic species, had the lowest FQI in Red Barn. This site had lower species diversity and fewer high C-score species, despite its higher cover of natives. FQI for Barksdale sites was more variable than for the Hornbek and Red Barn sites. FQI was lower for Barksdale sites 703 and 704 than all other FLFO sites, even Red Barn site 710. Because nonnative species have a C-value of 0, sites with more nonnative species, like sites 703 and 704, often have relatively low FQI values unless they also have high species richness, like 711. Fen site 705, however, had the highest FQI of all FLFO wetland sites. This small fen was species rich, perhaps in part because of a higher woody component.

We assessed the baseline status of FLFO sentinel site FQI using assessment points derived from the same regional dataset of 300 undisturbed fens and wet meadows used for native and hydrophytic species. Our FQI assessment points are less conservative, suggesting wetlands can have lower FQI scores and still be considered high quality. Median baseline FQI for our fen sites was in reference condition but was intermediate for wet meadows. Fen site 708 in the Hornbek complex again had a low metric value from its 2009 sample and is the only non-reference FQI for fens in our dataset. As

before we retain it in the baseline summary given no impact on the median value but remove it from subsequent trend models. Wet meadows 710 in Red Barn and 704 in Barksdale were also non-reference in the baseline period. These are also the only non-reference wet meadow FQI results in our dataset, but we do not see any methodological reason to question these.

3.4.5.3 Trend (2009 to 2019)

We first examine general patterns in FQI across time and the condition level of individual results (Figure 51). Across all sites, there is a suggestion of a non-linear pattern like the one seen for hydrophytic species and DTW, with a small decrease and slight increase in FQI from 2012 to 2014. Across wetland types and complexes there is a slight suggestion of an overall increasing trend (this was more evident before we removed the problematic results from 2009 in site 708). Overall, there appears to be little change in the numbers of sites in non-reference, intermediate, or reference condition, and there is thus little movement away from baseline median FQI at these sites.

A linear mixed model applied to FQI allows statistical tests of overall trend, trend by wetland type, and trend by sentinel complex (Table 25, Figure 52). Model selection resulted in two models with equivalent AIC scores, and we selected the simpler of these. This included sentinel complex and wetland type as fixed predictors, but no interactions with scaled date. The model explained a high proportion of the overall variation in FQI (adjusted $R^2 = 0.92$). There was no suggestion of meaningful autocorrelation in the residuals and the relationship between the residuals and fitted values was acceptable.

The coefficient for overall trend in FQI across our sites was positive but only approached marginal significance ($p = 0.259$). There was a significant difference between fen and wet meadow sites with higher FQI in fens ($p = 0.039$). There were no differences across sites by complex. As there were no interactions in the model, the scaled date term can be interpreted as a stand-alone coefficient.

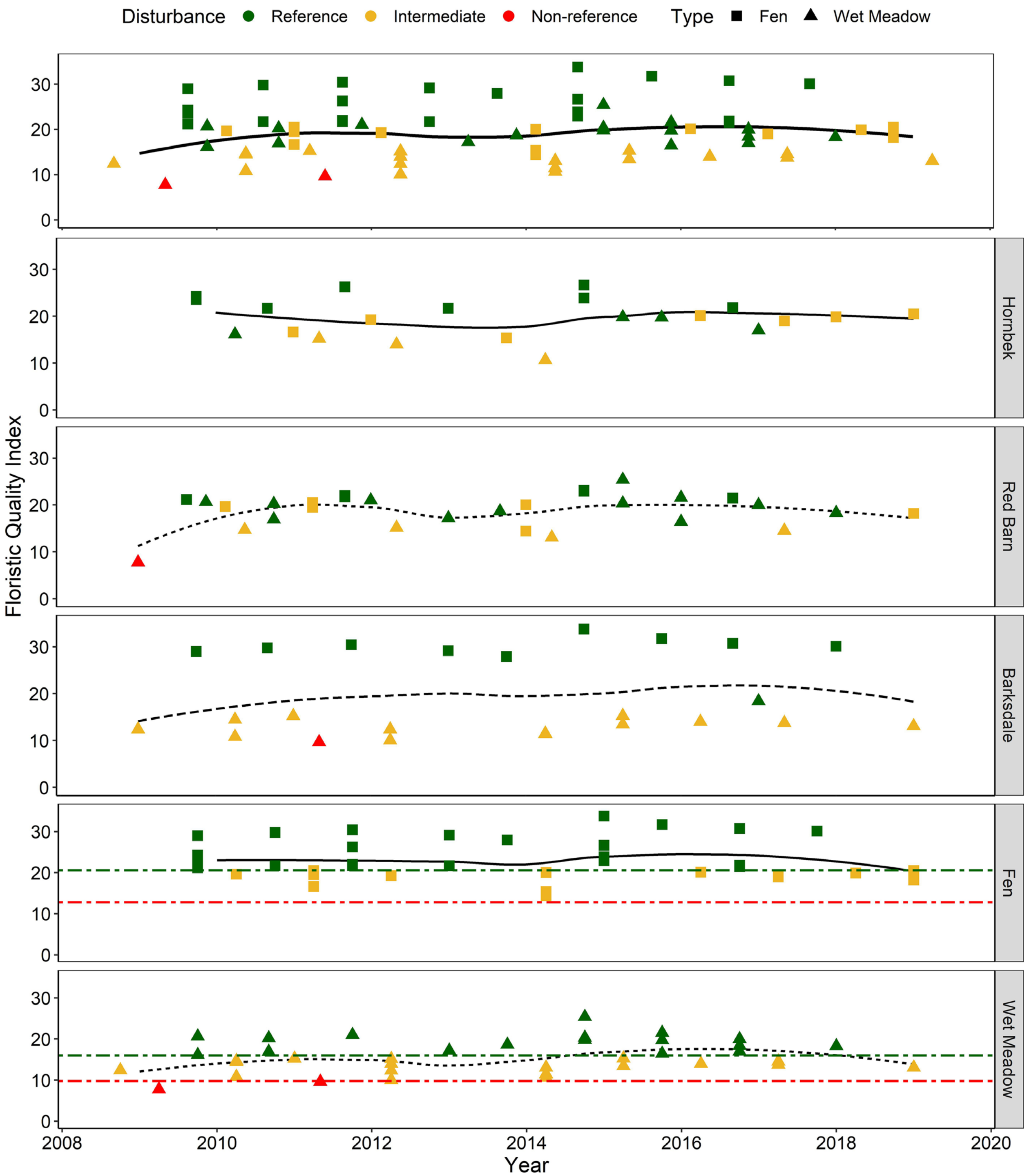



**Figure 51.** Floristic Quality Index at sentinel sites for all data (top panel), sentinel complex (three middle panels), and wetland type (bottom two panels), at Florissant Fossil Beds National Monument, Colorado, 2009–2019. Fitted lines are via loess smooths, which show general patterns across time. Multiple points within a year correspond to separate sample sites, with points jittered to reduce overlap. Point color is determined by relationships to wetland type specific assessment points (only shown with horizontal lines in bottom panel as other panels mix wetland types). Green indicates reference condition, yellow is intermediate, and red is non-reference.

**Table 25.** Linear mixed model of Floristic Quality Index (FQI) from all wetland sentinel sites from 2009 to 2019, Florissant Fossil Beds National Monument, Colorado. Table includes fixed term coefficients, their degrees of freedom (df), t values, upper/lower confidence intervals, and the probability (p) or significance of the term. Random terms include each term's standard deviation, a log ratio test statistic, and its probability (as a Chi square). The model had a sample size of 69 values across 10 years (no data were collected in 2017) and 10 sites.

| Type of term | Term | Coefficient | df | t value | Lower CI | Upper CI | Standard deviation | Log ratio test | p |
|---|---|---|---|---|---|---|---|---|---|
| Fixed | Intercept | 20.613 | 8.065 | 7.042 | 14.876 | 26.350 | N/A | N/A | 0.000 |
| | Scaled Date | 0.239 | 11.115 | 1.190 | −0.155 | 0.633 | N/A | N/A | 0.259 |
| | **Wetland Type (Wet meadow vs Fen)** [a] | −7.536 | 5.999 | −2.630 | −13.153 | −1.920 | N/A | N/A | **0.039** [a] |
| | Sentinel Complex (Red Barn vs. Hornbek | 1.070 | 6.010 | 0.317 | −5.552 | 7.692 | N/A | N/A | 0.762 |
| | Sentinel Complex (Barksdale vs. Hornbek) | 1.649 | 5.987 | 0.446 | −5.599 | 8.896 | N/A | N/A | 0.671 |
| Random | **Year** [a] | N/A | N/A | N/A | N/A | N/A | 2.149 | 21.825 | **<0.001** [a] |
| | Site | N/A | N/A | N/A | N/A | N/A | 4.147 | 0.746 | 0.975 |

[a] Terms are significant ($p < 0.10$)(also in bold font).

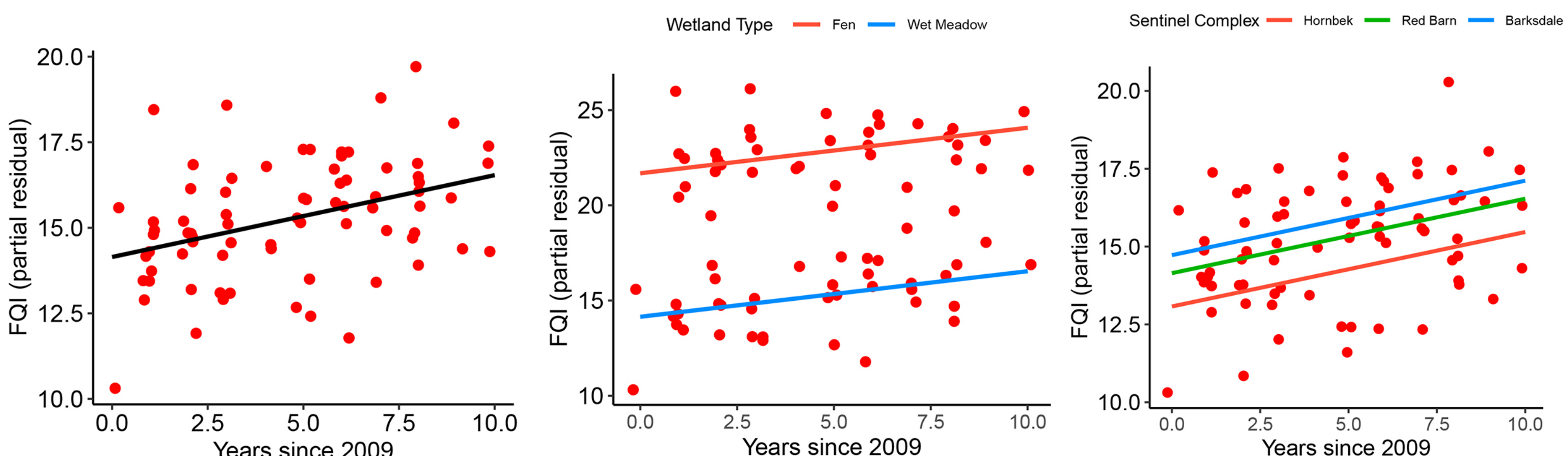



**Figure 52.** Visualizations of trend results for the Floristic Quality Index (FQI) in Florissant Fossil Beds National Monument wetland sentinel sites, Colorado, 2009 to 2019. Data points are partial residuals estimated by a mixed model (in Table 25). Fitted lines show the estimated linear trend, overall across all sites (left), by wetland type (middle), and by sentinel complex (right). Y axis scale may be different on some panels given different ranges in the partial residuals. Assessment points are not shown on these figures as partial residuals are not in the same units as raw data.

### *3.4.6 Overall wetland condition: Vegetation Index of Biotic Integrity*

The final metric type we use is a synthetic index known as an Index of Biotic Integrity or Multimetric Index (MMI). MMIs combine characteristics of biological assemblages that change in predictable ways with human disturbance. MMIs synthesize data from multiple levels of biological organization with the goal of deriving a single index that reflects the overall effects of human disturbance on wetland condition (much like the Dow Jones index is used to understand the performance of the stock market). They have a long history of successful use in bioassessment.

Given the limited number of sample sites in FLFO and thus likely an incomplete sample of the human disturbance gradient across the park, it was determined it was not possible to construct an MMI specific to FLFO (see Schweiger et al. 2016 for an example of this for Great Sand Dunes National Park and Preserve). Instead, we leveraged the work done by other well-established wetland monitoring and assessment programs and estimated at all FLFO sites a 1) fen and a 2) wet meadow Vegetation Index of Biotic Integrity (VIBI) developed by the Colorado Natural Heritage Program for wetland types in Colorado (Lemly and Rocchio 2009; Rocchio 2007a). This MMI combines between four and nine individual vegetation metrics (Table 26) representing different characteristics of the vegetation community composition and structure that respond in predictable ways to human disturbance by changing in interpretable ways with increasing disturbance. Metrics are individually scaled against the range of values found in the development data and then rolled-up into an overall score for the site. Note that the three individual metrics we analyzed in sections 3.4.3 (Nativity/Invasiveness), 3.4.4 (Wetland Affinity), and 3.4.5 (Conservatism) (above) fall into classes of metrics emphasized in this MMI (conservatism, nativity, and wetland affinity). Component metric raw values and scores are given in Appendix 7.

While the VIBI provides additional perspective on the condition of FLFO wetlands, several caveats must be kept in mind. The model was developed with data specific to Colorado and by wetland type, but the development datasets were relatively small (38 fens and 18 wet meadows; see Appendix 5) and may not represent the specific range of variability in FLFO wetlands. In some cases, we revised individual metric thresholds for FLFO wetlands if it was clear FLFO values were beyond the range of the original set of values in the model. We also assume that it is meaningful to combine VIBI scores across types even though the models used to create the index are wetland type specific. One of the intents of MMI models is to create a commonly scaled index to ecological integrity, integrating across system specific differences and we therefore feel this is an acceptable practice. However, we keep the interpretation of these combined scores more general and do not apply assessment points derived from the Colorado Natural Heritage Program at the complex scale when different wetland type VIBI values are combined.

**Table 26.** Component metrics of the Colorado Natural Heritage Program Vegetation Index of Biotic Integrity for 1) fens and 2) wet meadows. Response to increasing disturbance is indicated after each metric: (−) = decrease, (+) = increase. C = conservatism and FQI = Floristic Quality Index.

| **Habitat** | **Metric** |
|---|---|
| Fen | Mean C (native species) **(−)** |
| | % Intolerant species (C-value ≥ 7) **(−)** |
| | % Tolerant species (C-value ≤ 3) **(+)** |
| | % Nonnative species **(+)** |
| | Absolute cover native species **(−)** |
| | Absolute cover hydrophytes **(−)** |
| | Absolute cover bryophytes **(−)** |
| | Absolute cover litter **(−)** |
| | Absolute cover bare ground **(+)** |
| Wet Meadow | Cover-weighted FQI (all species) **(−)** |
| | Intolerant species richness **(−)** |
| | Absolute cover native species **(−)** |
| | Absolute cover perennial species **(−)** |
| | Native perennial species richness **(−)** |
| | % Native forb species **(−)** |
| | Absolute cover hydrophytes **(−)** |
| | Relative cover Poaceae **(+)** |
| | Absolute cover bare ground **(+)** |

3.4.6.1 Baseline status (2009-2011)

Baseline median VIBI did not vary meaningfully across types and complexes and had relatively small CV values within these groups (notably less variable that the three individual metrics presented above) (Table 27 and Figure 53). Baseline median VIBI did not vary strongly across types and complexes and had low variability. FLFO fen sites did not have higher baseline VIBI than wet meadows. This is the only metric where fens did not outperform wet meadows. The fen VIBI incorporates ground cover metrics including bryophytes, litter and bare ground (which is also in the wet meadow model). Many FLFO sites scored low on these metrics because they had low cover of bryophytes and litter. However, this may be an artifact of the way the FLFO data were recorded. In the Rocky Mountain Network WEI protocol, ground cover types are mutually exclusive and should add up to 100%, including basal cover, as it is more efficient and precise (crews do not have to look under cover types. In the CNHP data collection protocol used to develop the VIBIs, ground covers across features are not mutually exclusive. For example, moss that occurs under litter can be included in cover estimates. This may make these component metric scores less well-suited to using the VIBI for FLFO wetlands, and more importantly highlights the risks of not developing a custom MMI for FLFO. We feel the impacts of this are likely minor and do not remove any results as with other

metrics. There is still value in the VIBI comparisons across wetland type and complex, but these comparisons should be viewed with some caution.

Among fens, the site with the highest baseline VIBI score was the Barksdale site 705. This site had more bryophyte and litter recorded than other sites, which raised its scores. With more strata of vegetation and dense cover, this site also scored well on the absolute cover of native species metric. The lowest scoring fen sites were Hornbek site 715 and Red Barn site 712. Site 715 had the lowest individual score in 2011, but a much higher score the year previous. When it scored low, site 715 had low cover for the ground cover metrics and metrics related to C-values. These included the percent of species that are tolerant (low C-values) and intolerant (high C-values) of disturbance, two metrics that respond to disturbance in opposite ways. Site 712 also had low cover of bryophytes.

Among wet meadows, the site with the highest baseline VIBI score was Hornbek site 709. This site had high cover of *Poaceae* species, hydrophytic species, and high native forb diversity, all component metrics in the index. The site with the lowest baseline VIBI score was Red Barn site 711, which consistently scored low in all metrics assessed. This site had low diversity of native perennials and forbs, low cover of native species in general, and few species intolerant of disturbance (high C-value).

We used published assessment points (Lemly and Rocchio 2009; Rocchio 2007a) to interpret FLFO VIBI scores. Median baseline VIBI scores for fens were in intermediate condition and in reference condition for wet meadows (there is no intermediate class for wet meadows). These are useful assessment points, but they compare FLFO wetland sites to a disturbance gradient from more pristine wetlands and thus may place FLFO in a lower condition class than a more localized set of assessment points would. As noted above, wet meadow sites were often rated non-reference for metrics related to C-values, including the FQI. FLFO wetlands in general contain few high C-value species. FLFO sites also had lower cover of native species and lower cover of perennial species (see Appendix 7).

**Table 27.** Baseline (2009–2011) Vegetation Index of Biotic Integrity (Colorado Natural Heritage Program) by wetland type and sentinel complex in Florissant Fossil Beds National Monument, Colorado. Index ranges from 0 to 10, with higher values indicating higher condition. Reported values include sample size (N), standard deviation (SD), coefficient of variation (CV), minimum (Min.), and maximum (Max.). Assessment points are given in the Non-reference and Reference assessment point columns with the greater than (“>”) or less than (“<”) signs indicating where, relative to the assessment point, the condition class occurs. Values between these two thresholds are in an intermediate condition class. Note there is only one assessment point for wet meadows. Assessment points are not relevant for sentinel complex as these include both wetland types.

| Wetland type / Sentinel complex | N | Median | Mean | CV | SD | Min. | Max. | Non-reference assessment point | Reference assessment point |
|---|---|---|---|---|---|---|---|---|---|
| Fen | 11 | 5.0 | 4.8 | 0.21 | 1.002 | 3.3 | 6.2 | <3.9 | >6.06 |
| Wet Meadow | 12 | 5.9 | 5.7 | 0.13 | 0.774 | 4.5 | 7.0 | <5.24 | ≥5.24 |
| Hornbek | 7 | 5.6 | 5.2 | 0.25 | 1.338 | 3.3 | 7.0 | – | – |
| Red Barn | 9 | 5.3 | 5.1 | 0.16 | 0.827 | 3.7 | 5.9 | – | – |
| Barksdale | 7 | 5.9 | 5.7 | 0.14 | 0.806 | 4.5 | 6.7 | – | – |

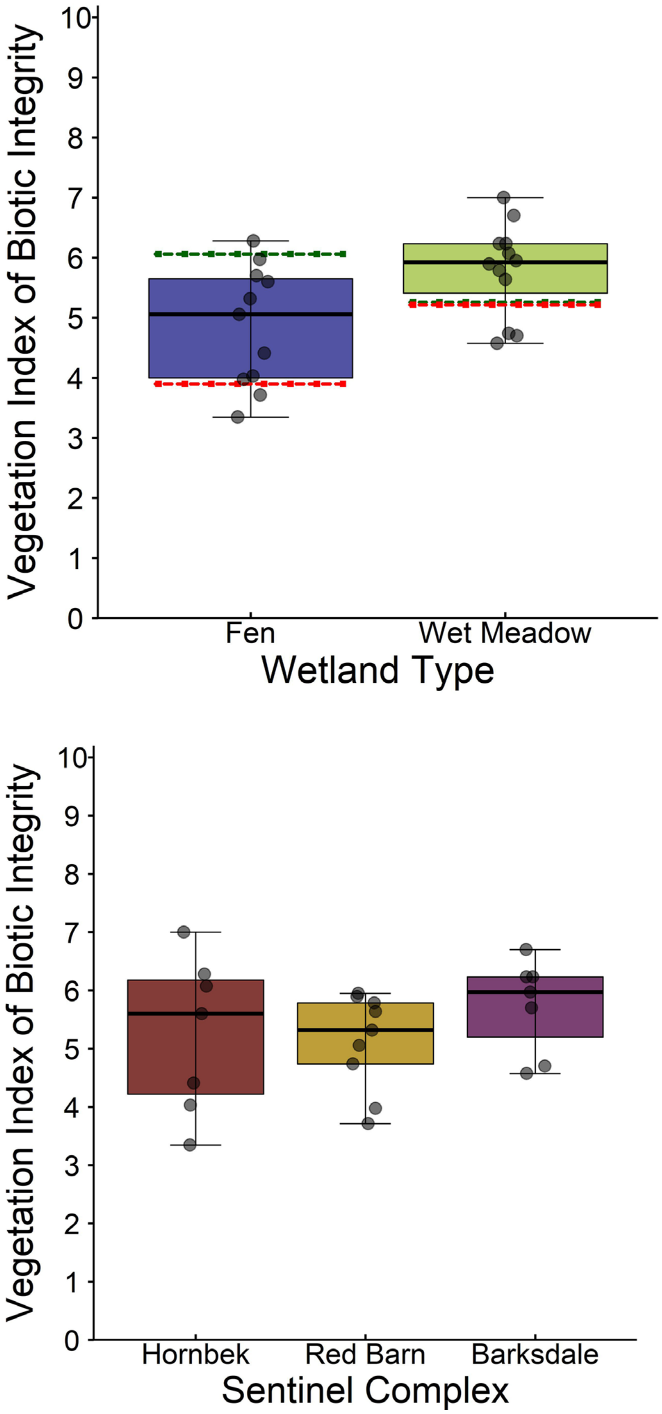



**Figure 53.** Baseline Vegetation Index of Biotic Integrity (Colorado Natural Heritage Program) at sentinel sites by (top) wetland type, and (bottom) sentinel complex, Florissant Fossil Beds National Monument, Colorado, 2009–2010. Index ranges from 0 to 10, with higher values indicating higher condition. Horizontal lines show the reference assessment points (green) and non-reference assessment points (red) with values above or below these in reference or non-reference, respectively. Values between these two thresholds are in an intermediate condition class. Note there is only one assessment point for wet meadows. Assessment points are not relevant for sentinel complex as these include both wetland types. Points are individual values (jittered to reduce overlap). Note constrained range in both panels.

3.4.6.2 Trend (2009–2019)

We first examine general patterns in VIBI across time and the condition level of individual results (Figure 54). Across all sites, there is a suggestion of a small decrease in VIBI through 2013 then an increase that persists for different durations depending on type or complex followed by a general decrease beginning in 2017 through the end of our record. This is largely consistent across wetland types and sentinel complexes. The increase may reflect restoration in the Hornbek complex, although it is less persistent than similar patterns in other indicators for Hornbek. It may also reflect complex effects of changes in water balance drivers across the period of record. Overall, there appears to be little change in the numbers of sites in non-reference, intermediate or reference condition and there is thus little movement away from baseline median values. Non-reference VIBI occurred near the beginning and then again at the end of the period of record.

A linear mixed model applied to VIBI allows statistical tests of overall trend, trend by wetland type, and trend by sentinel complex (Table 28, Figure 55. Model selection resulted in two models with equivalent AIC scores, one of which omitted our main fixed terms of interest. We selected the slightly more complex model that included sentinel complex and wetland type as fixed predictors but no interactions with scaled date. The model explained an acceptable proportion of the overall variation in VIBI (adjusted $R^2 = 0.71$). There was no suggestion of meaningful autocorrelation in the residuals and the relationship between the residuals and fitted values was acceptable.

The coefficient for overall trend in VIBI across our sites was negative but not significant ($p = 0.574$). There was a significant difference between fen and wet meadow sites, with higher VIBI in fens ($p = 0.032$). The composition of the VIBI for fens and wet meadows wetland varies, which might suggest they should not be in the same model. However, we assume that they both estimate the same thing (wetland condition) and that by including a wetland type term this different VIBI structure can be ignored. There were also no differences across sites by complex. As there were no interactions in the model, the scaled date term can be interpreted as a stand-alone coefficient.

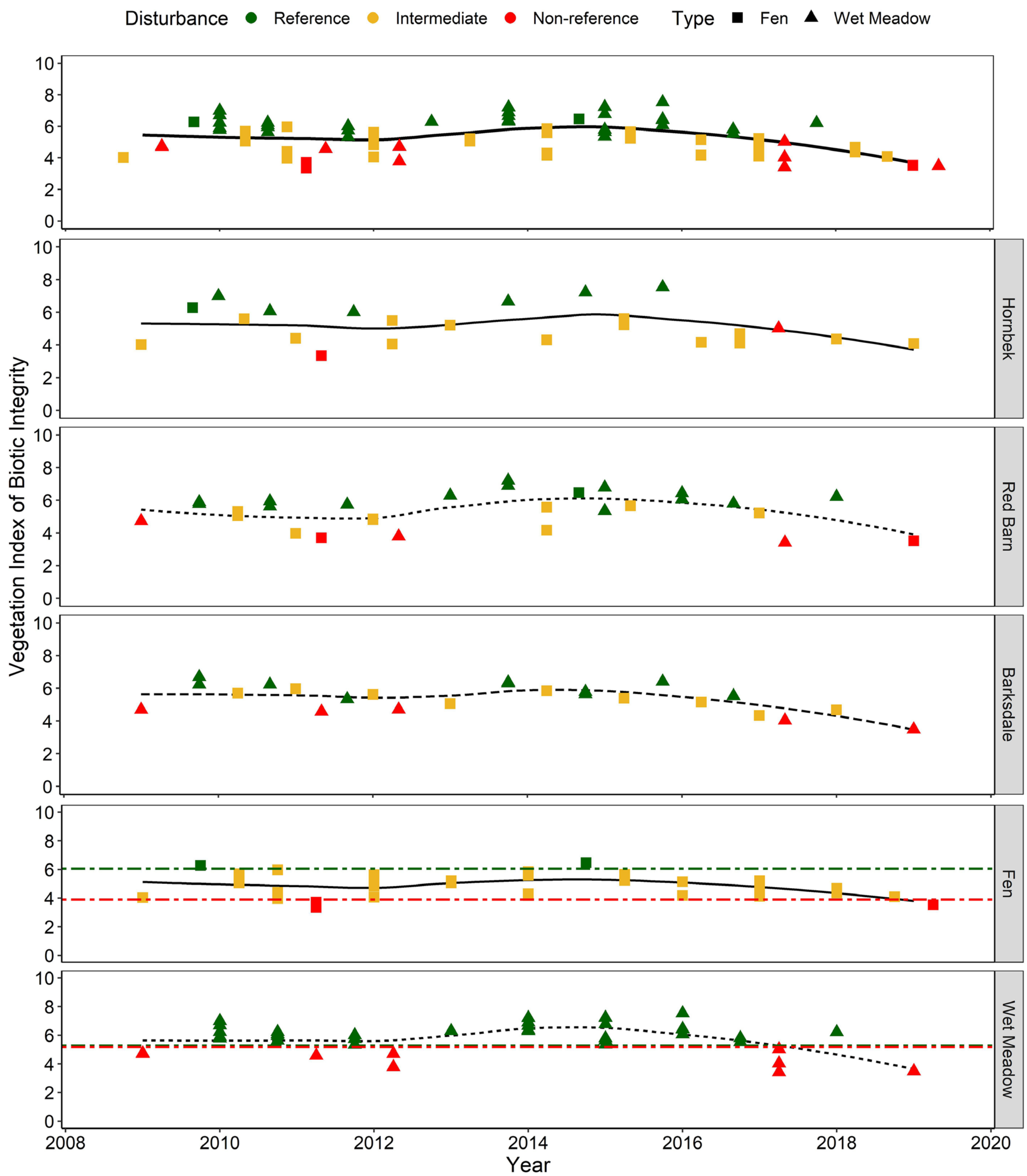



**Figure 54.** Vegetation Index of Biotic Integrity (VIBI) at sentinel sites by (top panel) individual site, (three middle panels) sentinel complex, and (bottom two panels) wetland type, Florissant Fossil Beds National Monument, Colorado, 2009–2019. Index ranges from 0 to 10. Fitted lines in each panel are via a loess smooth, which show general patterns across time. Trend models that account for statistical structure are shown in Table 27 and Figure 53. Points are jittered to reduce overlap. The legend above the top panel applies to all three figures. Point color is determined by relationships to wetland type specific assessment points (shown by horizontal lines in each panel). Green indicates reference condition, yellow is intermediate, and red is non-reference. There is only a single assessment point for wet meadow, so no intermediate class is possible.

**Table 28.** Linear mixed model of Vegetation Index of Biotic Integrity (VIBI) scores from all wetland sentinel sites from 2009 to 2019, Florissant Fossil Beds National Monument, Colorado. Table includes fixed term coefficients, their degrees of freedom (df), t values, upper/lower confidence intervals, and the probability (p) or significance of the term. Random terms include each term's standard deviation, a log ratio test statistic and its probability (as a Chi square). The model had a sample size of 69 values across 10 years (no data were collected in 2017) and 10 sites.

| Type of term | Term | Coefficient | df | t value | Lower CI | Upper CI | Standard deviation | Log ratio test | p |
|---|---|---|---|---|---|---|---|---|---|
| Fixed | Intercept | 5.086 | 12.696 | 10.733 | 4.157 | 6.014 | N/A | N/A | 0.000 |
| | Scaled Date | −0.039 | 9.771 | −0.582 | −0.171 | 0.093 | N/A | N/A | 0.574 |
| | **Wetland Type (Wet meadow vs Fen)** [a] | 0.882 | 6.190 | 2.756 | 0.255 | 1.508 | N/A | N/A | **0.032** [a] |
| | Sentinel Complex (Red Barn vs. Hornbek | −0.310 | 6.214 | −0.824 | −1.049 | 0.428 | N/A | N/A | 0.441 |
| | Sentinel Complex (Barksdale vs. Hornbek) | −0.053 | 6.080 | −0.128 | −0.858 | 0.753 | N/A | N/A | 0.902 |
| Random | **Year** [a] | N/A | N/A | N/A | N/A | N/A | 0.624 | 21.220 | **<0.001** [a] |
| | Site | N/A | N/A | N/A | N/A | N/A | 0.313 | 0.792 | 0.672 |

[a] Terms are significant (p < 0.10)(also in bold font).

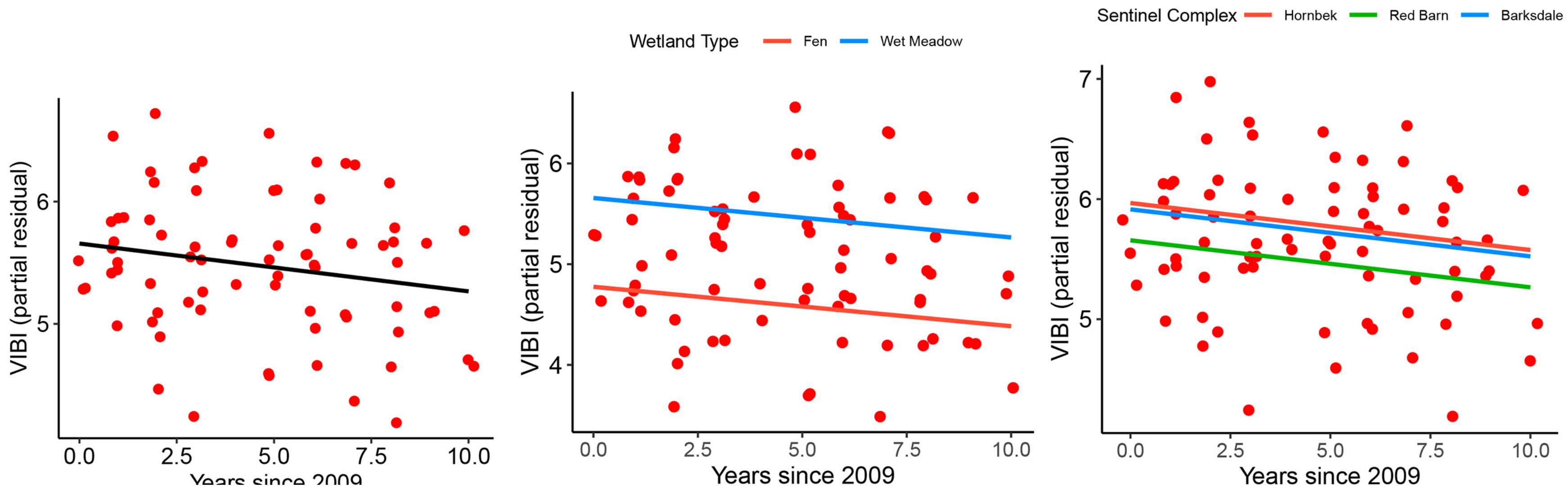



**Figure 55.** Visualizations of trend results for the Vegetation Index of Biotic Integrity (VIBI) in Florissant Fossil Beds National Monument wetland sentinel sites, Colorado, 2009 to 2019. Data points are partial residuals estimated by a mixed model (in Table 28). Fitted lines show the estimated linear trend, overall across all sites (left), by wetland type (middle), and by sentinel complex (right). Y axis scale may be different on some panels given different ranges in the partial residuals. Assessment points are not shown on these figures as partial residuals are not in the same units as raw data.

### *3.4.7 Summary of patterns among vegetation metrics, disturbance, and groundwater*

Relationships among depth to water (DTW), disturbance, and vegetation metrics are shown in Figure 56. These should be treated with some caution as bivariate correlations do not account for non-linear relationships or any confounded interactive effects among these variables.

The pattern in correlation with the four vegetation metrics (native species cover, hydrophytic species cover, Floristic Quality Index (FQI), Vegetation Index of Biotic Integrity (VIBI)) for both synthetic indicators of disturbance, HDI and LDI, was identical. All four relationships were significant with the larger scale LDI, while only the VIBI and HDI had a significant relationship. FQI was counterintuitively positively correlated with disturbance. The other three metrics showed increases in wetland condition with decreases in human disturbance as expected (often in a statistically significant way, which is somewhat surprising given our small sample size). FQI may not be the best metric for conservatism in FLFO. Species richness can be important in the FQI, with a potentially false positive response, as richness has been shown to increase with moderate disturbance (Wilson 1990; 1994). We also evaluated an adjusted Floristic Quality Assessment Index (FQIA; Miller and Wardrop 2006) that corrects for richness but still saw the same pattern. Simpler conservatism metrics that are not impacted by richness at all, such as a percentage of cover of intolerant taxa (high C score), seem to perform better and may be used in the future.

Relationships with direct indicators of disturbance, like road-stream crossing density or distance to nearest human land use, were also generally interpretable. For example, negative and sometimes significant relationships were seen with human land use in a 100-m buffer and native and hydrophytic cover, suggesting that more human land use reduced these important aspects of wetland vegetation. There were also likely meaningful and significant relationships with road–stream crossings and many vegetation metrics—this is perhaps the mechanism behind the pattern with LDI and HDI, as roads are often sources for human use based habitat degradation. The VIBI did have fewer meaningful relationships with specific disturbances. It is interesting that this more derived bioassessment metric responded better to the derived disturbance gradients, HDI and LDI. This may reflect how it was originally constructed from HDI.

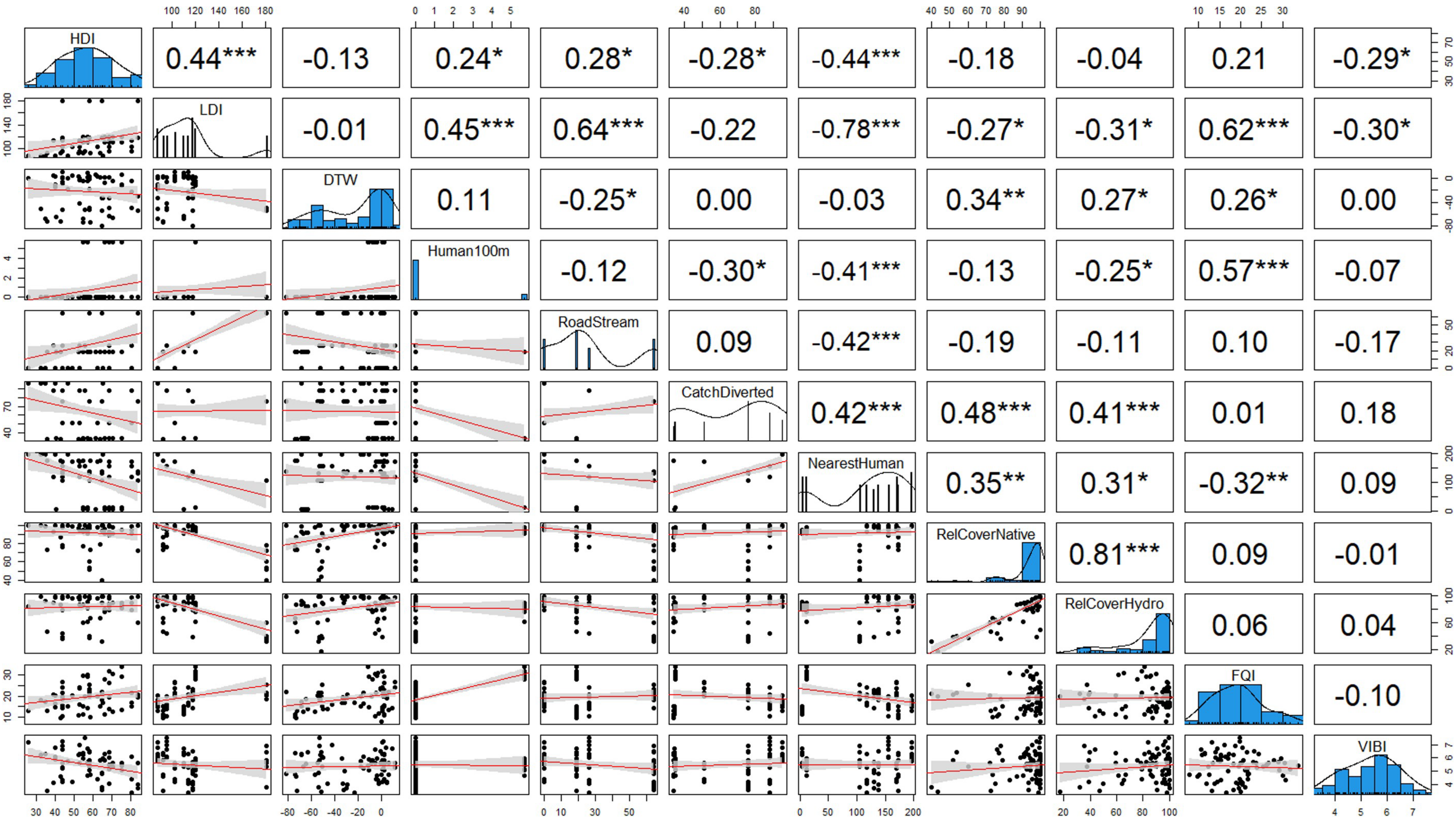



**Figure 56.** Relationships among four vegetation metrics, depth to water, and select disturbance metrics, at sentinel sites, Florissant Fossil Beds National Monument, Colorado, 2009–2019. Matrix shows bivariate scatterplots in the lower left quadrant with a linear fit (red lines) and a 95% confidence interval (gray shading); histograms along the center diagonal with a smoothed density plot (line draped over histograms); and Pearson rank correlation coefficients (significance indicated with a * for p <0.05, ** for p <0.01, and *** for p < 0.001) in the top right quadrant. All data were used given lack of trend in the four vegetation metrics.

# 4 Management Applications and Future Directions

## 4.1 Applications of long-term monitoring results to park management

A fundamental goal of network long-term inventory and monitoring is to provide park managers with information useful for protecting and managing park resources. Our monitoring of wetland ecological integrity can help in several general ways. This information is a baseline for understanding the status and future changes in wetlands in FLFO. Our data can be used to quantify the importance to wetland condition of “stressors” like human use and “drivers” like groundwater hydrology. Protected landscapes such as FLFO do not insulate wetlands from the direct and indirect impacts of a changing climate regime. Management and interpretive strategies should include how changing climate might shift ecological conditions in the park. Our results offer several examples of this, including the likely increased importance of runoff or drainage in maintaining future groundwater as climate shifts. Climate change has important implications for resource management, perhaps including to temper expectations for success from restoration efforts under a shifting climate. More optimistically management should be sure to design restoration strategies with climate change in mind—for example, in the choice of which species to restore. This may be an important point for the park’s interpretive staff to share with the public regarding climate change. These general insights can enhance the understanding of wetland ecology in the park, and this might help resource and interpretive staff communicate to the public about the condition of wetland resources in FLFO. More specific results are also available from our work.

First, we show several connections between human disturbance and wetland condition. A decrease in disturbance over the last decade may reflect best management practices enacted by the park. The park is likely aware of management concerns connected to wetland disturbance and this vigilance should continue, especially under changing climate regimes where problematic disturbance and climate interactions will likely increase. Nonnative species are a focus of park resource management, and we document the occurrence of 23 nonnative plants, some of which are invasive, in the park at our sentinel sites. This represents a management challenge that our data may help with. The park has had some success with managing invasives such as Canada thistle in the Hornbek complex, potentially associated with the restoration of Grape Creek in 2012 (see this report’s cover photos). Maintaining groundwater levels and reducing impacts from human use of wetlands are two actions that should support higher nativity and increase the prevalence of important species like Nebraska sedge and red baneberry.

Second, we show how maintaining high groundwater tables will help maintain wetland hydrophytic and conservative species composition such as *Carex aquatilis*. Hydrophytic species may also provide an integrated indicator of possible change driven by larger scale human use, for example road density impacts, or climate change driven drought. There are real management concerns with wetland groundwater maintenance and clearly FLFO has recognized this in the restoration project at Hornbek. This focus should continue, and our long-term monitoring data will help to understand changes, and to some degree, restoration success.

Third, our models document the condition of individual wetlands, and this can used by park managers in the ongoing restoration of wetland near Grape Creek and to prioritize future wetland for restoration (e.g., a highly degraded wetland) or protection (e.g., carefully protecting a wetland that has high ecological integrity and/or significance). The pilot project to block flow in Grape Creek was implemented in 2012 to determine if stopping surface drainage and raising stream stage would influence groundwater levels, allowing restoration of the native wet meadow hydrologic regime and vegetation. This project successfully demonstrated these two concepts (Figure 57). Raising and maintaining a high water level in wet meadows will create the highest level of ecological resilience to future climate change. Soil saturation can maintain the desired clonal sedge dominance with high below ground biomass and high carbon storage, which also facilitates maintaining saturated soil conditions. An objective should be to restore all eroded channels and human-made dam impacts in the park. This is proposed for restoration projects to be implemented in 2023. Along with the physical restoration, long term monitoring of water table depth and seasonal dynamics, and vegetation composition, are needed to understand the effectiveness of these restoration efforts and the stability and functioning of wetlands in the future. The restoration of FLFO wetlands continues and our data, analyses, and interpretations from wetland ecological integrity monitoring can continue to inform this effort and the adaptive management of wetlands in FLFO to meet NPS mandates and goals over the long term.

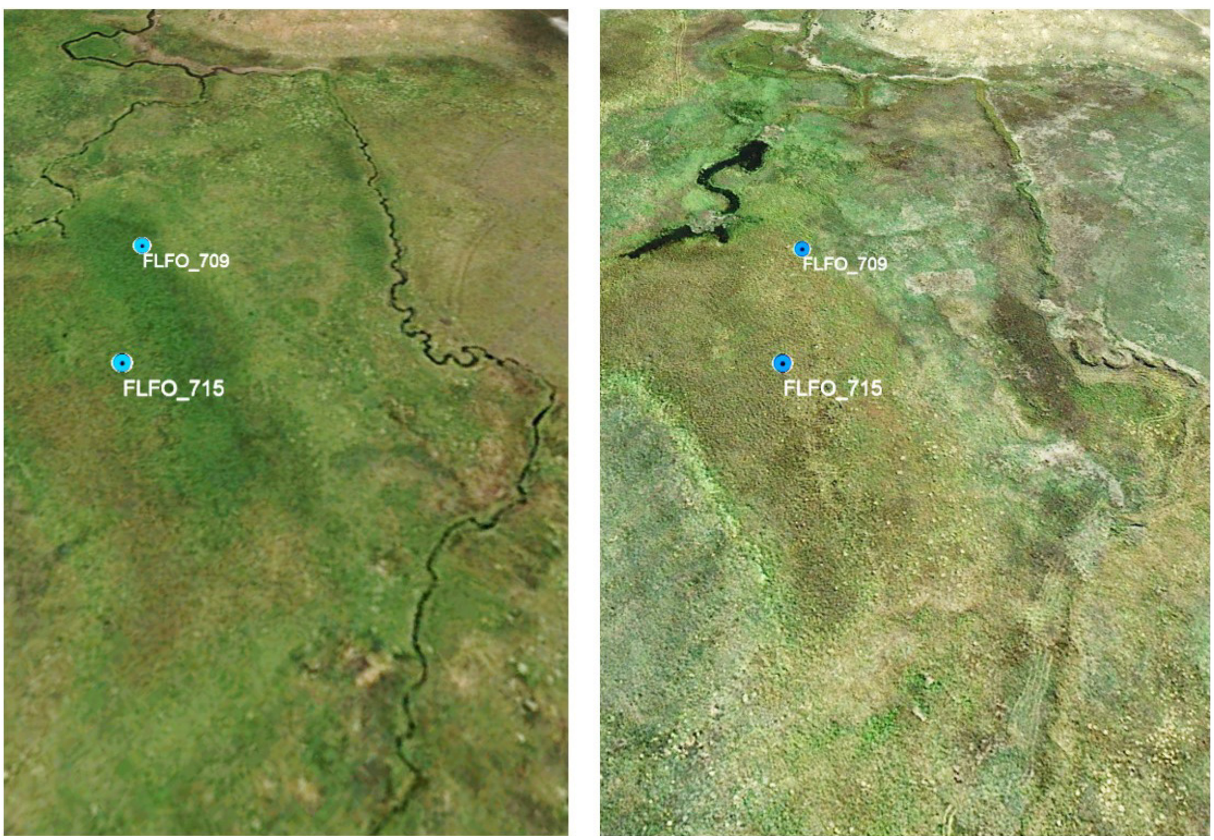



**Figure 57.** Grape Creek near Hornbek sites 709 and 715 in 2009 (left) and 2013 (right)—before and just after restoration, Florissant Fossil Beds National Monument, Colorado. The channel is deeply incised in 2009. In 2013 this had recovered. NPS/BILLY SCHWEIGER

### 4.2 Future wetland monitoring

This effort has been, and will continue to be, a cooperative undertaking between network staff and our partners—most importantly, park management and staff. We believe our results, representing the efforts of dedicated scientists and resource managers over several years, address our objectives, are valid, representative, and in many cases, actionable. However, our data are still relatively "short," and we are still only at the beginning of this effort, even a decade or more in. It will take many more years to have sufficient data to fully understand long-term trends. As we accrue data, we will also continue to improve our understanding of the mechanisms and drivers behind wetland condition in the park. Finally, recent work suggests impact from climate change on biological condition may be offset if other stressors on a system are reduced. This is in a sense paying climatic debt with accrued environmental credit. NPS units like Florissant are well positioned to do this—the park already has a rich bank account full of environmental credit given its protected context. This offers a path forward for park resource management as they work to maintain the park for future visitors.

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# Appendix 1 Wetlands of Florissant Fossil Beds National Monument

Wetlands in Florissant Fossil Beds National Monument (FLFO) are one of the most important ecological resources in the park because they support plant diversity, provide water sources and vegetation for wildlife, and store water that replenishes streams and aquifers integral to the health of the entire valley. Prior to homesteading in the 1870s, the landscape that is now FLFO supported natural wet meadows, fens, and riparian wetlands at points of groundwater discharge or where surface water concentrated. The park is located high in the Grape Creek drainage, a small tributary to Twin Creek that drains to the South Platte River. In this landscape position, saturated groundwater-fed wetlands and headwater streams can be relatively common.

Intensive historical land use and human settlement in the valley has affected FLFO wetlands. During the ranching era, wet meadows and fens were altered to produce hay for cattle forage and ponds for livestock watering. By the time these lands were under federal ownership, the landscape had been significantly impaired and ditches or eroded channels drained portions of the wetlands.

Wetlands are also impacted by current anthropogenic activities and long-term climate change. Over the last decade, the increasing role that climate change plays in altering wetland function and condition has been recognized and wetlands are considered particularly vulnerable to these stressors (Baron et al. 2000). However, many of the effects of climate change may take some time to appear in FLFO wetlands and most will be confounded with other sources of stress on a wetland. In this report we largely focus on more proximate causes of disturbance in wetlands, although many of our results will support future extrapolation of climate driven change in the park's wetland resources.

### Wetland definition

There is no universal definition of "wetland." Rather, multiple regulatory and scientific definitions have been developed for wetland ecosystems because of their high ecological diversity; special legal status under certain federal, state, and local laws; and unique place at the intersection of several scientific disciplines. For example, the definition used by the U.S. Army Corps of Engineers (USACE) to administer section 404 of the Clean Water Act aims to provide consistent and uniform criteria for field delineation (USACE 2008), while the definition used by the U.S. Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI) program was developed for national inventory and mapping efforts (Cowardin et al. 1979).

All definitions recognize, to some degree, the key role of hydrologic processes in wetland formation and the resulting suite of soil and vegetation characteristics. The definition used by the National Research Council (Cowardin et al. 1979) is broad in scope, emphasizing the unique suite of hydrological, chemical, and biological characteristics that differentiate wetlands from uplands. The NWI definition contains elements found in both the USACE and NRC definitions (Cowardin et al. 1979).

The Rocky Mountain Network definition of wetland follows Cowardin et al. (1979), and specifies that wetlands must have two or more of the following three attributes:

1) Vegetation dominated, at least periodically, by hydrophytes.
2) Predominantly undrained hydric soils.
3) Saturated with water or covered by shallow water at some time during the growing season of each year.

The definition of wetland (and its partitioning into distinct types, see below) plays a critical role in the network's wetland ecological integrity (WEI) protocol. As the target population or resource for WEI monitoring, it is one of the key elements of the sample design we use to select monitoring sites and to which monitoring results are extrapolated.

### Wetland classification

There are two common types of wetlands in FLFO as classified by the network using a Rocky Mountain wetland classification system described by Cooper (Cooper 1998; Gage and Cooper 2013). This classification builds upon other systems but is specialized for wetlands in Rocky Mountain Network parks. The approach emphasizes both hydrology and soils. It uses intuitive names that are specific to the landscapes in and around network parks. The two wetland types monitored in FLFO are fens and wet meadows.

#### *Fen*

Fens have two consistent features: 1) stable groundwater-driven hydrologic regimes with high water tables that retard organic matter decomposition, and 2) peat accumulation (Figure 58). Fen soils are composed of organic (peat) soil layers a minimum of 40 cm thick and made up of partially decomposed plant materials. Fens form in a variety of landscape settings and differ widely floristically (Cooper 1996; Bedford and Godwin 2003). Rocky Mountain Network park fens are ecologically diverse and, like all wetlands, support a disproportionate share of a park's biodiversity as well as numerous rare or endemic species (Cooper and Andrus 1994; Cooper and Sanderson 1997; Chadde et al. 1998).


**Figure 58.** (A) Florissant Fossil Beds National Monument fen near Hornbek homestead in early spring. Hummock patterning caused by the bunch grass, tufted hairgrass (*Deschampsia cespitosa*). (B) Close up of peat soil layer from site primarily composed of partially decomposed plant roots and bryophytes. NPS/BILLY SCHWEIGER, 2009.

### *Wet meadow*

Wet meadows are the most abundant wetland type in the western United States and occur from the alpine zone to the plains (Gage and Cooper 2013). Wet meadows typically exhibit seasonally saturated soils but lack the perennial high water tables of fens or the large seasonal and inter-annual water table fluctuations characteristic of marshes (Figure 59). Unlike fens, wet meadow soils are mineral. Wetland hydrology is apparent in the mineral soils by the presence of redoximorphic features (gleyed soil matrices and mottled rhizospheres). Mineral soils often have lower water holding capacity per unit volume than peat, and mineral substrates may drain and dry more readily. The lack of perennial saturation results in aerobic organic matter decomposition during dry periods, which, along with mineral soil throughout the plant root zone, provides higher levels of nutrient availability to wet meadow vegetation (Venterink et al. 2002).


**Figure 59.** (A) Sedge dominated wet meadow near the Red Barn with (B) gleyed and mottled mineral soil. NPS/BILLY SCHWEIGER, 2010.

## Wetland complexes

### *Hornbek*

The Hornbek Sentinel Site Complex is a ~4 ha fen and wet meadow complex between Teller CO Rd 1 and Grape Creek, directly south of the historic Hornbek Ranch (Figure 60). The complex has variable groundwater depths, including perennially saturated areas with deep peat soils. This area has a long history of human use, including high-intensity ranching and homesteading, and is now adjacent to a paved road and a visitor hiking trail. Vegetation is herbaceous and dominated by common wetland grasses and sedges, but several invasive species are often abundant. Some peripheral areas of the wetland are occasionally mowed and sprayed with broadleaf herbicide to control invasive species. Most of the wetland in the complex has flat microtopography, but hummock patterning is also apparent and there is a small spring near the center of the wetland that has distinctive depressional landform and high cover of bryophyte species. Two of the three monitoring

sites within the Hornbek complex (708 and 715) are located in the fen with deep peat soils and the third is located in a wet meadow with more variable soil types (709).

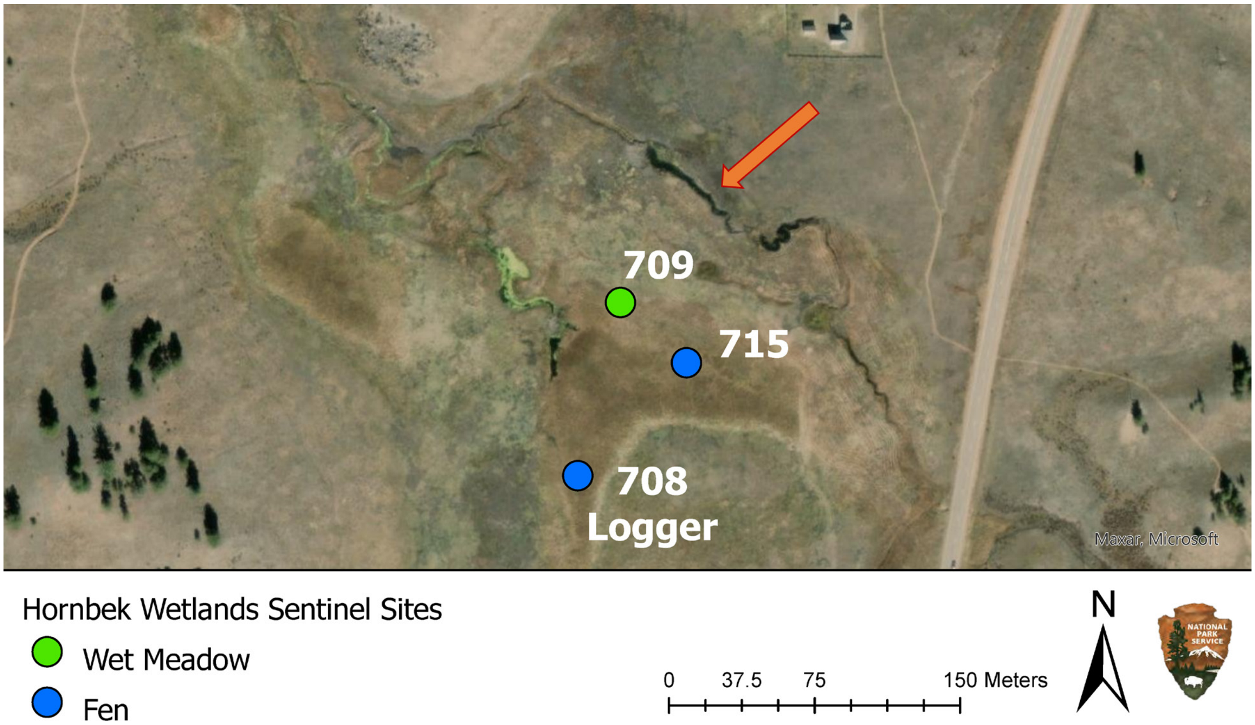


**Figure 60.** Aerial imagery of the three wetland sentinel sites within the Hornbek complex in Florissant Fossil Beds National Monument, Colorado. Note buildings of the Hornbek Homestead north of the wetland complex and the deeply incised channel north of the sites. The red arrow points to the channel that was filled in 2012.

Historical land use and the current main park road likely cause groundwater flow in the site to channelize at the southernmost extent of the wetland. Although commonly mistaken for an incised riparian channel, it is likely that there was no channel present in this wetland historically (Dr. David Cooper, pers. comm.). It is not a riparian wetland, rather a dewatered wet meadow/fen complex with groundwater and surface water flows drained by the channel (Figure 61). It is probable that this channel has lowered the water table throughout the wetland, facilitating invasive plant colonization through soil disturbance and drier conditions. The pilot wetland restoration in 2012 succeeded in filling a portion of the channel, redistributing flow, and restoring water tables to more historical conditions. Rocky Mountain Network monitoring sites are adjacent to the pilot restoration area and monitoring will track the change in conditions because of the restoration efforts.

**Figure 61.** Incised, boot eating, channel running through the middle of the Hornbek wetland complex in Florissant Fossil Beds National Monument, Colorado, 2009. Photo shows erosion and severe channel incision approximately 2 meters deep. Populations of invasive plant species are visible on both banks. Canada thistle (*Cirsium arvensis*) dominates the right bank and butter-and-eggs (*Linaria vulgaris*) is evident in the lower left corner. This channel was filled in 2012 as part of the restoration project. NPS/BILLY SCHWEIGER, 2009.

The Hornbek complex was selected as a Rocky Mountain Network sentinel site because of its importance to FLFO as the largest peat forming wetland in the park and its high-profile location next to the road and the Hornbek Ranch. The wetland is typical for the area because it has been affected by several common anthropogenic and natural disturbances that have negatively affected the condition of the wetland. These disturbances include livestock grazing, homesteading, road construction, exotic species invasion, mowing, and herbicide application.

***Red Barn***

The Red Barn Sentinel Site Complex is a ~6 ha portion of a fen and wet meadow complex parallel to Teller CO Rd 1. It is adjacent to the "Maytag" or "Red" Barn and across from the access road that leads to park headquarters and the visitor center (Figure 62, Figure 63). The sentinel complex is part of a generally continuous wetland corridor that follows CO Rd 1 the entire length of the national monument. Wetlands along this corridor interact with the Grape Creek drainage network. Soil

saturation within the complex is variable, likely related to proximity to points of groundwater discharge. Like Hornbek, vegetation is herbaceous and dominated by common wetland grasses and sedges, but exotic species have invaded several areas. Three of the four monitoring sites within the complex are clustered east of and slightly above Grape Creek. Of these, two are within the fen (712 and 713) and one is in wet meadow (711). The fourth site in the complex is located nearly 200 m to the southeast in a wet meadow closer to the channel of Grape Creek (710). Channel incision in this area may be drying the wetland surrounding site 710.

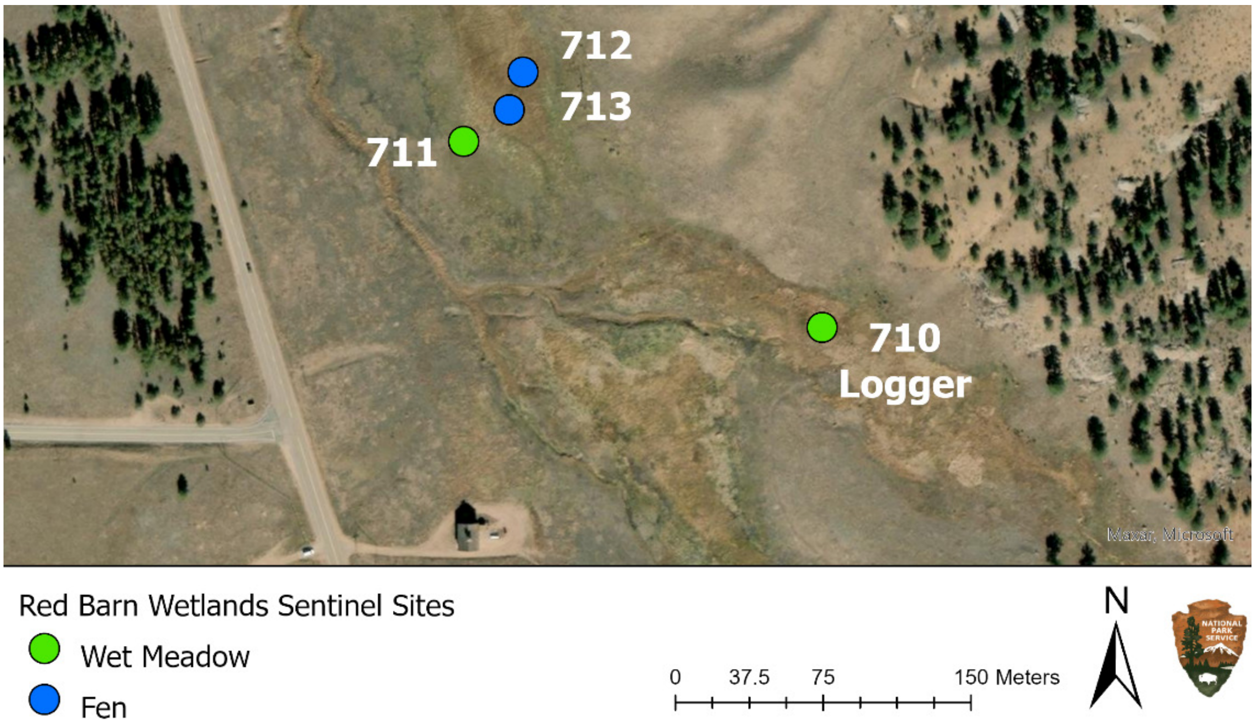


**Figure 62.** Aerial imagery of the four wetland sentinel sites within the Red Barn complex in Florissant Fossil Beds National Monument, Colorado. Note the Red Barn in the southern end of the image.

**Figure 63.** Photo shows Red Barn Sentinel Site Complex. Rocky Mountain Network monitoring sites are installed to the right of the barn in the bright green vegetation between the road and the sagebrush covered hillside. NPS/BILLY SCHWEIGER, 2009.

Like the Hornbek complex, the Red Barn Sentinel Site Complex was chosen because it is a high-profile wetland adjacent to and visible from the main road. This area also experienced heavy historical use during the ranching period. Heavy historical cattle grazing and likely hydrologic alterations continue to affect the site. Current land use is light. There are no trails immediately adjacent to the wetland, but the road is within 200 m of the monitoring sites. There is also evidence of light elk use.

***Barksdale***

The Barksdale Sentinel Site Complex is distinct from the other two sentinel sites. In contrast to Hornbek and Red Barn, which are large fen and wet meadow complexes dominated by herbaceous vegetation, Barksdale is primarily a narrow linear wet meadow formed along the upper reaches of Grape Creek (Figure 64, Figure 65). The complex runs through an opening between conifer forest from the Barksdale picnic area east towards an old stock pond and a barn. Within the Barksdale complex, the Grape Creek drainage includes wet meadow vegetation in relatively narrow linear patches, likely fed by groundwater discharge and surface runoff, and reaches of intermittent stream

channel. Two of the three Barksdale monitoring sites are within the herbaceous wet meadow (703 and 704), while the third (705) is located in a small fen close to the parking lot and picnic area.

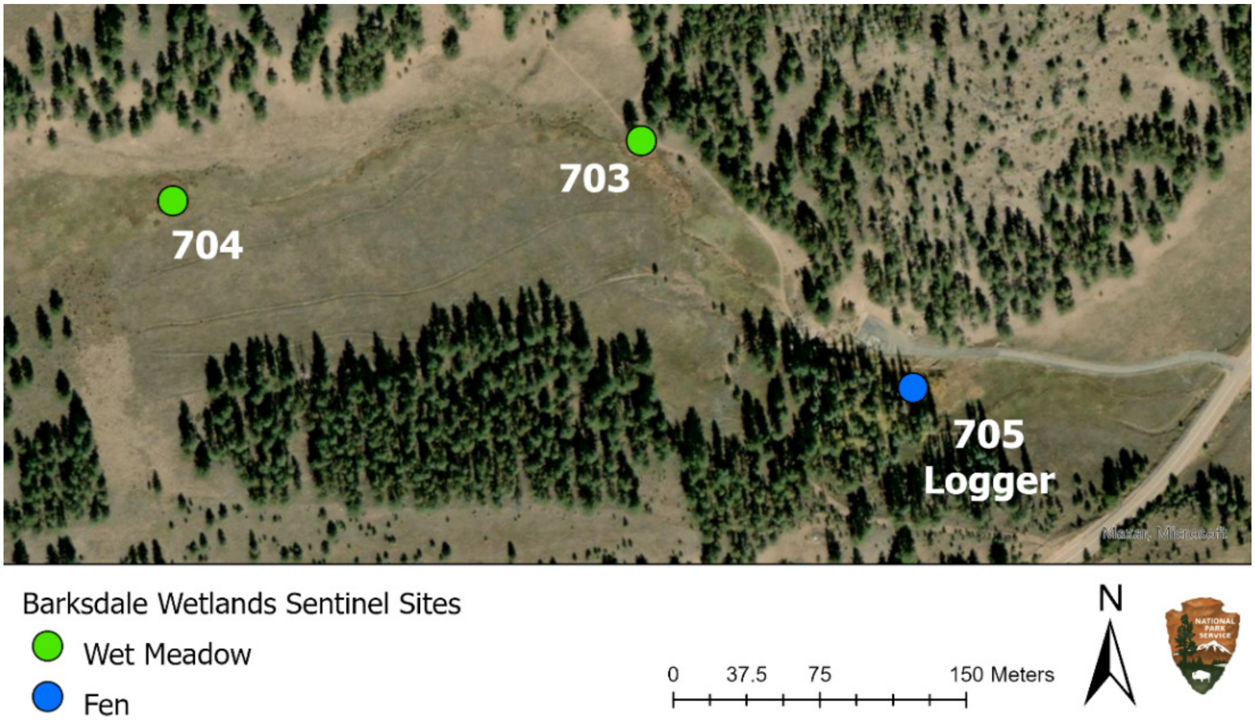


**Figure 64.** Aerial imagery of the three wetland sentinel sites within the Barksdale complex in Florissant Fossil Beds National Monument, Colorado. Note the parking lot near site 705.

**Figure 65.** Photo of one section of the Barksdale Sentinel Site Complex in Florissant Fossil Beds National Monument, Colorado. Rocky Mountain Network monitoring site 703 is along the wet meadow corridor near the center of the photo. NPS/BILLY SCHWEIGER, 2009.

The Barksdale Sentinel Site Complex shows signs of historical land use and the current Grape Creek channel may be an artifact of downcutting within the sloping wet meadow complex, similar to both Hornbek and Red Barn. There are two notable signs of historical land use near the Barksdale complex. South of the Grape Creek channel, a series of shallow, parallel ditches run from the channel across an open meadow. This area was likely irrigated in the spring by water from the Grape Creek drainage. Downslope of the monitoring sites, the complex is interrupted by an excavated stock pond. Current land use is light to moderate for two of the three sites, with minimal visitor interaction. However, the Barksdale picnic area draws visitors and a well-used trail leaving from the parking lot travels adjacent to the wetland for approximately 1 km, passing directly next to monitoring site 703.

# Appendix 2 Sample Effort

The three Florissant Fossil Beds National Monument wetland sentinel site complexes were sampled intensively over a 10-year period from 2009 to 2019. However, not all data types were collected in each monitoring event, depending on conditions in the site and priorities for sampling (Tables 29–31). All 10 monitoring sites were installed in 2009. Soil samples were collected for laboratory analysis in all sites during well installation, and soils were sampled again in 2015 but not in the intervening years. Hand depth to water measurements were most frequent in the first three years of the study (2009–2011), during which time the wells were checked several times a year. Starting in 2012, each well was typically checked for water depth once or twice a year, often in association with additional data collection. Groundwater depth loggers were installed in three monitoring sites, one per sentinel complex, in 2010. The loggers recorded continuous readings of water table depth for these three sites from 2010 to 2019.

**Table 29.** Hand measured depth to water sample effort by year for each sentinel site complex and individual monitoring site, Florissant Fossil Beds National Monument, Colorado, 2009 to 2019.

| Sentinel site complex | Site | Wetland type | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hornbek | FLFO_708 | Fen | 4 | 7 | 10 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | **32** |
| | FLFO_709 | Wet meadow | 2 | 6 | 7 | 1 | 1 | 1 | 1 | 1 | 1 | – | 1 | **23** |
| | FLFO_715 | Fen | 1 | 7 | 8 | 1 | 1 | 1 | 1 | – | 1 | – | 1 | **22** |
| | **All Hornbek** | **N/A** | **7** | **20** | **25** | **4** | **4** | **3** | **4** | **2** | **3** | **1** | **3** | **76** |
| Red Barn | FLFO_710 | Wet meadow | 3 | 7 | 10 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | **31** |
| | FLFO_711 | Wet meadow | 2 | 6 | 8 | 1 | 1 | 1 | 1 | 1 | 1 | – | 1 | **23** |
| | FLFO_712 | Fen | 2 | 5 | 8 | 1 | 1 | 1 | 1 | – | – | – | 1 | **20** |
| | FLFO_713 | Fen | 2 | 7 | 8 | 1 | 1 | 1 | 1 | – | 1 | – | 1 | **23** |
| | **All Red Barn** | **N/A** | **9** | **25** | **34** | **5** | **5** | **4** | **5** | **2** | **3** | **1** | **4** | **97** |
| Barksdale | FLFO_703 | Wet meadow | 3 | 7 | 7 | 1 | 1 | 1 | 2 | 1 | 1 | – | 1 | **25** |
| | FLFO_704 | Wet meadow | 2 | 7 | 7 | 1 | 1 | 1 | 1 | – | 1 | – | 1 | **22** |
| | FLFO_705 | Fen | 2 | 8 | 10 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | **32** |
| | **All Barksdale** | **N/A** | **7** | **22** | **24** | **4** | **4** | **3** | **5** | **2** | **3** | **1** | **3** | **78** |
| **Total** | **N/A** | **N/A** | **23** | **67** | **83** | **13** | **13** | **10** | **14** | **6** | **9** | **3** | **10** | **251** |

**Table 30.** Vegetation and disturbance sample effort by year for each sentinel site complex and individual monitoring site, Florissant Fossil Beds National Monument, Colorado, 2009 to 2019. These represent “full” data collection events.

| Sentinel site complex | Site | Wetland type | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017[a] | 2018 | 2019 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hornbek | FLFO_708 | Fen | 1 | 1 | 1 | 1 | 1 | – | 1 | 1 | 1 | 1 | – | 9 |
| | FLFO_709 | Wet meadow | – | 1 | 1 | 1 | – | 1 | 1 | 1 | 1 | – | – | 7 |
| | FLFO_715 | Fen | – | 1 | 1 | 1 | – | 1 | 1 | – | 1 | – | 1 | 7 |
| | **All Hornbek** | **N/A** | **1** | **3** | **3** | **3** | **1** | **2** | **3** | **2** | **3** | **1** | **1** | **23** |
| Red Barn | FLFO_710 | Wet meadow | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | – | 10 |
| | FLFO_711 | Wet meadow | – | 1 | 1 | 1 | – | 1 | 1 | 1 | 1 | – | – | 7 |
| | FLFO_712 | Fen | – | 1 | 1 | 1 | – | 1 | 1 | – | – | – | – | 5 |
| | FLFO_713 | Fen | – | 1 | 1 | 1 | – | 1 | 1 | – | 1 | – | 1 | 7 |
| | **All Red Barn** | **N/A** | **1** | **4** | **4** | **4** | **1** | **4** | **4** | **2** | **3** | **1** | **1** | **29** |
| Barksdale | FLFO_703 | Wet meadow | 1 | 1 | 1 | 1 | – | 1 | 1 | 1 | 1 | [b] | – | 8 |
| | FLFO_704 | Wet meadow | – | 1 | 1 | 1 | – | 1 | 1 | – | 1 | – | 1 | 7 |
| | FLFO_705 | Fen | – | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | – | 10 |
| | **All Barksdale** | **N/A** | **1** | **3** | **3** | **3** | **1** | **3** | **3** | **2** | **3** | **1** | **1** | **24** |
| **Total** | **N/A** | **N/A** | **3** | **10** | **10** | **10** | **3** | **9** | **10** | **6** | **9** | **3** | **3** | **76** |

[a] Indicates that disturbance data were not collected in 2017.

[b] Iindicates that the Human Disturbance Index, (HDI) data were collected at FLFO_703, but no vegetation data were collected.

**Table 31.** *In situ* water chemistry sample effort by year for each sentinel site complex and individual monitoring site, Florissant Fossil Beds National Monument, Colorado, 2009 to 2019. Water chemistry could only be collected if there was groundwater in the monitoring well.

| Sentinel site complex | Site | Wetland type | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hornbek | FLFO_708 | Fen | 1 | 1 | 2 | 1 | – | – | 1 | 1 | 1 | 1 | – | 9 |
| | FLFO_709 | Wet meadow | 1 | 1 | – | – | 1 | – | 1 | 1 | 1 | – | – | 6 |
| | FLFO_715 | Fen | 1 | 1 | 1 | 1 | – | 1 | 1 | – | 1 | – | 1 | 8 |
| | **All Hornbek** | **N/A** | **3** | **3** | **3** | **2** | **1** | **1** | **3** | **2** | **3** | **1** | **1** | **23** |
| Red Barn | FLFO_710 | Wet meadow | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | – | 11 |
| | FLFO_711 | Wet meadow | 1 | – | – | – | – | – | 1 | 1 | – | – | – | 3 |
| | FLFO_712 | Fen | 1 | 1 | 1 | – | – | 1 | 1 | – | – | – | 1 | 6 |
| | FLFO_713 | Fen | 1 | 1 | 1 | – | – | 1 | 1 | – | 1 | – | 1 | 7 |
| | **All Red Barn** | **N/A** | **4** | **3** | **3** | **1** | **1** | **3** | **4** | **2** | **2** | **1** | **2** | **26** |
| Barksdale | FLFO_703 | Wet meadow | 1 | 1 | – | – | – | 1 | 1 | 1 | – | – | – | 5 |
| | FLFO_704 | Wet meadow | 1 | 1 | – | – | – | – | 1 | – | 1 | – | 1 | 5 |
| | FLFO_705 | Fen | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | – | 10 |
| | **All Barksdale** | **N/A** | **3** | **3** | **1** | **1** | **1** | **2** | **3** | **2** | **2** | **1** | **1** | **20** |
| **Total** | **N/A** | **N/A** | **10** | **9** | **7** | **4** | **3** | **6** | **10** | **6** | **7** | **3** | **4** | **69** |

# Appendix 3 Water Balance

Although temperature and precipitation are often used to characterize the climatic context of a study area, water balance (WB) or water cycle variables have been shown to be stronger indicators of ecological processes than temperature and precipitation alone. WB variables incorporate the interaction of temperature and precipitation with topographic and edaphic (i.e., soil-related) properties that control temporal water availability in wetlands (Dobrowski, 2011; Munson et al., 2015; Thoma et al. 2020). For example, stream flow in much of western North America is controlled by the abundance and timing of snow melt that occurs months after winter precipitation (Hostetler and Alder 2016); vegetation growth is closely linked to soil moisture and water deficit (Daubenmire 1968; Littell et al. 2008; Stephenson 1998), and fire is more closely related to aridity than precipitation (Littell et al. 2016; Williams et al. 2015), although wetting events diminish fire potential (Holden et al. 2018).

The water cycle within a watershed or a wetland site has several intuitive connections to groundwater depths. This is most obvious in wetlands with a surface water driven hydrology strongly influenced by input from adjacent streams or rivers (i.e., site 710 at Florissant Fossil Beds National Monument (FLFO)). It is less obvious in groundwater dominated wetland systems (i.e., site 708 and 705 at FLFO). However, groundwater input to a wetland also ultimately originates from the water cycle in a watershed, although there are likely complex spatial and temporal lags in these connections. For example, groundwater takes more time to move through a watershed through shallow aquifers or via soil moisture dynamics. Therefore, water balance parameters from a previous period may be more relevant to a current day depth to water (DTW) for groundwater dominated sites.

We estimate the components of the water cycle (Figure 66) using equations outlined by Lutz (2010) as implemented in Thoma et al. (2020). We first derive precipitation and temperature from DAYMET version 4 (Thornton et al. 2018) in the 1 $km^2$ grid cell that included each site. The WB model partitions precipitation (P) falling on this cell into rain or snow, following Jennings et al. (2018), the latter of which accumulates until temperatures become warm enough to melt (Hock 2003). Subsequent steps in the WB process treat the movement of water from this grid cell into the wetland sentinel site.

We estimate an initial direct runoff parameter, or the portion of any precipitation that <u>does not</u> enter the water cycle but instead leaves the system, via a USDA Natural Resources Conservation Service (NRCS) curve number (CN) from vegetation type and hydric soil class and methods developed in NRCS (2017). The WB model then calculates a potential evapotranspiration following Oudin et al. (2010) as the amount of water that could be evaporated and transpired with available energy if water was unlimited. Potential evapotranspiration uses slope and aspect summarized across the catchment as derived from a 10-m digital elevation model to better estimate a heat load from solar radiation. We use an estimate of soil water holding capacity as the quantity of water stored in the top meter of soil as defined by NRCS (2021). The model then runs for each day in the period of record using this soil water to estimate actual evapotranspiration, weighted by shade cover estimated from Rocky Mountain Network wetland ecological integrity (WEI) monitoring plots. Daily climatic water deficit

is estimated as the amount of additional water vegetation would use if available, calculated as the difference between actual and potential evapotranspiration (Stephenson 1998). Water that is in excess of soil storage capacity after evapotranspiration creates runoff. Finally, runoff values are used to accumulate a "drainage" term across time following Croke et al. (2005). Drainage is built as a unit hydrograph with coefficients for "quick" or event-based flow and "slow" or base flow that are used as weights on the runoff value for each day.

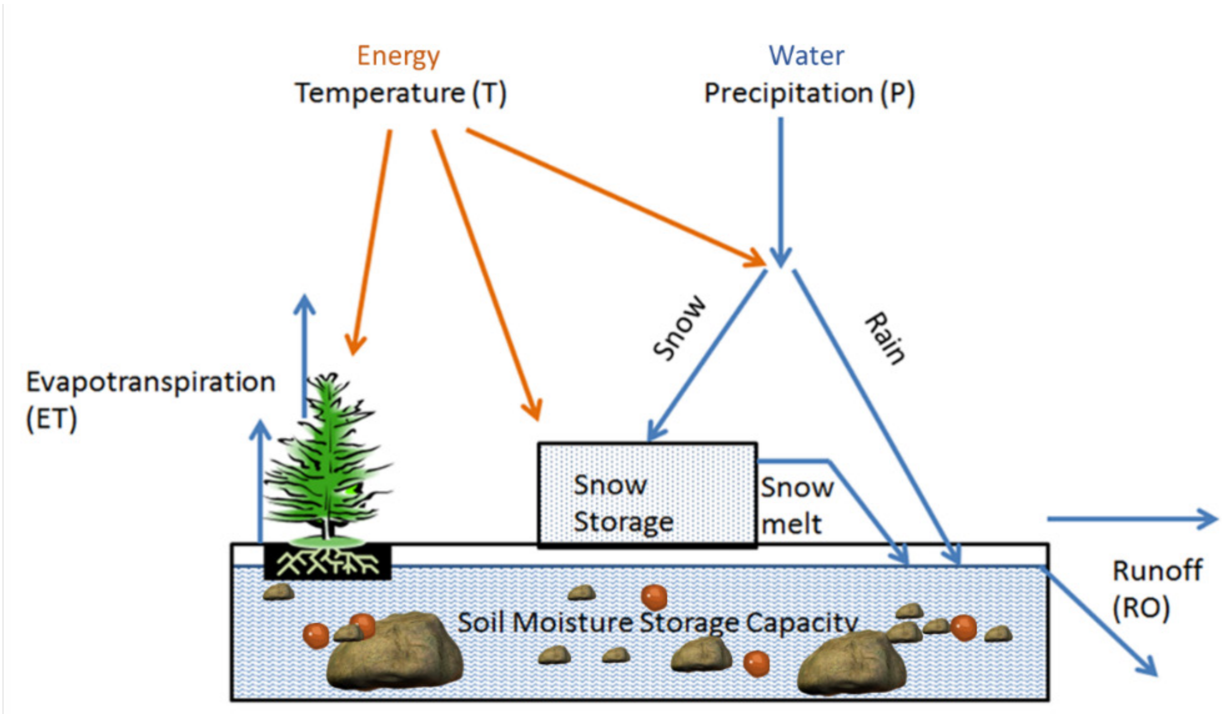


**Figure 66.** Water balance schematic adapted from Gray and McCabe (2010). Soil moisture estimated by the water balance model and water holding capacity taken from the USDA Soil Survey Geographic Database (SSURGO) data are integrated as Soil Moisture Storage Capacity.

Several parameters in the WB model come from readily available GIS data, such as slope or aspect, or field data, such as vegetative cover—these scale the relatively course climate variables (T and P; temperature and precipitation, respectively) from DAYMET to more localized edaphic conditions and improve WB data. We also conduct a series of model calibrations to improve WB output relating drainage or other water balance variables to depth to water. Trial work has suggested that direct runoff and water holding capacity parameters are most sensitive within this calibration. We optimize bivariate fits of these terms to response(s) by iterating these parameters singly and as pairs across a range of values, maximizing adjusted $R^2$. We then do the same for the "quick" and "slow" drainage coefficient to calibrate drainage—these coefficients can have a strong effect on how well drainage fits a response. This calibration may be done in a relatively simple heads-up method using initial conditions that we have seen work well for typical Rocky Mountain Network park wetlands. It may also be done using an optimization routine that steps through all possible combinations of parameters, checking for the best relationship between drainage parameters and depth to water.

# Appendix 4 Trend Analyses Details

## One to several discrete measurements a year: human disturbance, vegetation, and depth to water

Mixed models allow effects to be considered either "fixed" or "random." Fixed effects contribute to the mean of the outcome and random effects contribute to its variance. Following Piepho and Ogutu (2002), we model scaled date (our primary variable of interest for which a trend is estimated) as a fixed effect and site and factor year as random effects. The designation of terms as either fixed or random is an important and complex process; however, Piepho and Ogutu (2002) develop methods that allow site as we use it to be fixed *or* random based on the type of design used. To analyze trends across the full suite of sites at Florissant Fossil Beds National Monument (FLFO), we designate sites as random variables that contribute to the variability around the mean. Replicate samples of sites through time are likely correlated and thus violate a key assumption of simple linear regression—this is the primary reason we use a mixed model. Treating sites as random effects allows for individual site level slope and intercepts (i.e., the parameters are no longer fixed but have variation around their mean values). We treat (factor) year as a random variable given that we only have a small sample of all possible years and thus we assume the years included in our models are realized values of a truly random variable. Finally, Piepho and Ogutu (2002) recommend modeling the intercept as fixed so that convergence problems are avoided and because this optimizes test power when residual variance is large.

We treat years and sites as random effects to control for variation caused by specific sites or years and because these two variables are random samples of all possible years and sites; however, the core or important interpretation of the models focuses on fixed effects. We include time (as a standardized and centered term called scaled date) as a continuous fixed effect predictor by default in all models, given our interest in trends. We then use a model selection approach based on minimizing the Akaike Information Criterion (AIC) to determine if main fixed effects for sentinel complex and wetland type, and interactions of these main effects with scaled date, improved a model. We use the rule of thumb cutoff value of delta AIC > 2, but we also consider model simplicity and interpretation and so this is not hard and fast. The two interactions we include are of interest as they help interpret if a response changes over time differently by wetland types or complex and may contribute to a better test of the main fixed effects. A third interaction between wetland type and sentinel complex was not of interest.

We do not require a predictor or an interaction among independent variables to be significant to be included if the model fit is improved via AIC (*sensu* Murtaugh 2014) thereby allowing marginal effects of terms that improve a model to still be included in coefficient values. We also do not treat it as limiting and interpret p values somewhat loosely and in the context of the magnitude of relevant coefficients. However, we do use p values to determine the potential role of interactions in the interpretation of a main effect. We use treatment contrasts for the categorical wetland type and complex (via the default R conversion to dummy variables) with a reference level of fen and Hornbek for wetland type and sentinel complex, respectively. If there is a significant interaction between scaled date and either wetland type or complex, the estimation of a temporal trend is complex and is based on reference levels of the categorical variables in the interaction(s). However,

if a main effect is not part of a significant interaction, its coefficient corresponds to the average of the individual slopes of subsets of this variable along all remaining categorical variables (i.e., we interpret it as a stand-alone term estimated for the whole dataset, without respect to wetland type or complex).

We explore models that include sentinel complex and wetland type as interactions with scaled date (therefore these are also fixed effects). We use change in the AIC to resolve which model is best. Note that for select responses we also test a limited set of ecological, climate, or hydrologic covariates as additional fixed effect(s). We base these choices on exploratory data analyses and our expectations that a candidate covariate might help us better understand patterns in a response. We keep the inclusion of covariates simple in this report—future work will explore this in more detail. We use tests of the random terms using likelihood ratio tests following Kuznetsova et al. (2017). Finally, because mixed models do not generate a classic model $R^2$, yet this is an intuitive metric of a model's quality, we approximate this using the correlation between fitted and observed values (Xu 2003).

We report fixed effects term coefficients (scaled date, sentinel complex, wetland type) and their 95% confidence intervals. We use Satterthwaite degrees of freedom (Piepho and Ogutu 2002) for the tests of trend and confidence interval construction. We use Fen and Hornbek as the reference classes for wetland type and sentinel complex, respectively. We report p values for fixed and (approximate) random terms but also use the inclusion of zero in a term's 95% confidence as a test of a variable's significance.

To properly visualize the mixed models we use partial residual plots (Larsen and McCleary 1972; Breheny and Burchett 2017). A partial residual plot shows the relationship between each independent variable and the response variable given that other independent variables are also in the model—or a variable's relative importance with respect to the whole model. The plot shows the value of the variable on the x-axis and the partial residual on the y-axis, holding all other variables constant. Linear fits to partial residuals are the visual equivalents to statistical estimates of linear trend but corrected for structure in the data, across all sites and by complex or wetland type. Coefficient values from the mixed model will generally match the relevant partial plots but this depends on how interactive effects influence a given result.

We test and correct for the assumptions of parametric models before running the mixed models, including tests of independent and normally distributed errors with equal variance. We also analyze output from models for violations of model assumptions, including correlation in the residuals. We implement all mixed models in the R libraries lmerTest (Kuznetsova et al. 2017) and lme (Bates et al. 2014).

## Continuously measured depth to water (DTW)

### *Time and lags*

We trimmed all data to an approximate and generalized growing season from May 15th to September 15th and then conducted exploratory work to determine the best time step over which to understand DTW. We estimated draft general additive models (GAM) as described below using daily, weekly,

and monthly intervals. Based on the final predictors and their coefficients and/or shape of the fit with the response, the most interpretable frequency was daily—as long as methods were explored that checked for autocorrelation in residuals from a model. We centered and normalized the daily time series, rescaling days based on the mean, minimum, and maximum date sampled at each site. Scaling improves interpretation of model coefficients for time terms. We refer to time treated in this way as "scaled date."

To determine if there were possibly important lags in the data, we ran exploratory bivariate linear regressions to identify if a WB predictor had a meaningful lagged relationship with depth to water over a range of one to 365 days. If any lagged adjusted $R^2$ was significantly better than a contemporaneous relationship, we created a lagged variable at this time step and included this as a new variable in the estimation of a GAM model. We limited lagged terms to a single instance unless there was a clear indication that two lag structures were present, typically one positive and one negative across two different periods.

***General additive models***

To model depth to water we use generalized additive models (GAM; Wood 2011) in which non-linear or "smooth" functions can be applied to all or a subset of predictor(s) as patterns in data indicate. Smooths are regularized nonparametric functions that can fit simple to very complex non-linear relationships. GAM models may also include predictors with a linear relationship with the response and/or with an *a priori* or expected non-linear relationships, such as a log. All terms in GAMs are estimated simultaneously and then the response predicted by adding these terms up. Smooths do not have to have classic polynomial form, for example they can be complex "wiggly" fits. Moreover, we do not need to know the shape of a given smooth *a priori* as it is derived based on the data during model estimation. The smoothness of a predictor function can be controlled in a GAM to deal with a bias–variance tradeoff and avoid overly wiggly, nonsensical functions. Through the setting of smooth parameters, a GAM can include the prior belief that a given predictive relationships is inherently non-linear (smoothed) even though often data suggest a noisy relationship. This plays an important role in model interpretation as well as in the believability of the results.

Using contemporaneous and lagged versions (if there was a meaningful lagged relationship, see above) of six water balance metrics, as well as air temperature, precipitation, and time-based predictors (day of year, and season), resulted in a large suite of candidate variables. We initially conducted model selection using a combination of hand and automated steps and four model selection criteria (in order of importance): 1) Akaike Information Criterion (AIC; Venables and Ripley 2002); 2) overall model and individual predictor interpretability; 3) adjusted $R^2$ values; and 4) a candidate predictor's p value. However, these models were often quite complex and there was not a clear diagnostic or repeatable solution. We therefore reverted to a more structural approach following Grace and Irvine (2020) and limited predictors to those with likely more direct or readily explainable indirect connections to depth to water. We still employed a model selection process, but it was much simplified with the suite of predictors constrained.

We explored several alternate distributions for the GAM models but determined that a Gaussian distribution with a link identity function worked well and was simplest. Various shape and other

parameters for smoothed terms were explored and set based on changes in our model selection criteria—in the end we used a thin plate spline method but let the basis number in these splines vary. Models were fitted via restricted maximum likelihood estimation.

GAM models assume that errors (residuals) are identically and independently distributed. However, like with any model that includes a temporal component, this is a strong assumption—rarely fulfilled. If autocorrelation (i.e., depth to water in day one predicts depth to water in day two) is not addressed, estimated coefficients and residuals can be negatively biased and p values or confidence intervals wrong. We therefore used the GAMM (general additive *mixed* models) variant on GAMs that allows random predictors and/or an Auto Regressive Integrated Moving Average (ARIMA) component, both of which can deal with correlated residual structure. We determined if a GAMM was required by examining the residuals of candidate models via autocorrelation (ACF) and partial autocorrelation (pACF) function plots (Makridakis et al. 1998). If these suggested a strong pattern in the residuals, we used an automated function in the forecast package in R (Hyndman et al. 2020) to determine the best ARIMA dimensions and estimated a GAMM model with the indicated autoregressive and/or moving average lags. An ARIMA component in a model estimates corrected error terms, helping ensure model coefficients and standard errors are unbiased and correct. An ARIMA adjustment also can affect overfitting (too wiggly) scaled date smooths in a candidate model, even suggesting replacement with a linear term. Linear scaled date terms address most concisely estimating a trend in depth to water, and this was a desirable outcome of the ARIMA adjustment. We also did this when the ARIMA adjusted scaled date smooth was similar to a linear alternative scaled date term. However, if the modeling process indicated that for a given site, trend in a response was non-linear and should not be changed, we fit the scaled date term with a smooth. Smooth terms do not have simple/single coefficients describing a simple trend over the period of record as the slope of fit is potentially different at every point in the time series.

To assist in the interpretation of variables in the final model, we estimated the relative contributions of each of the predictors to a model's total explanatory value. We used a classic (Grömping 2006) approach that averages sequential sums of squares over orderings of regressors (Lindeman et al. 1980). This produces estimates of each predictor’s importance relative to the total amount of explained variance expressed as a simple percentage. These estimates consider both direct effects (i.e., correlations with the response) and effects when combined with the other variables in the model. The method averages over all possible orderings of predictors in a model, thereby dealing with multicollinearity (Grömping 2006).

At all stages of modeling, we performed checks on the distribution of residuals, number of basis dimensions, multicollinearity of linear terms, and concurvity of smoothed predictors. Concurvity is the generalization of collinearity in a GAM, where smooth terms can be approximated by a combination of other smooth terms and can result in unstable estimates. To reduce concurvity in our models we removed variables from pairs with correlations > 0.70, omitting the variables with other issues and/or poorer interpretation. We also examined QQ plots of residuals and determined if the smoothing dimensions (k) was restrictively low using the gam.check function (Wood 2011).

GAM results are presented in a familiar ANOVA format with parametric term coefficients, standard errors, the significance of the term (p value), and relative importance (grouped for factor predictors like season). For smoothed terms we report the estimated degrees of freedom (EDF) that indicate the degree of smoothing in a fit, the F value, and significance of the smoothed fit (p value). We use p values as a model selection criterion (in part); however, we do not require a predictor to be significant to be included if AIC is improved and the term is generally interpretable (*sensu* Murtaugh 2014). Finally, we report the overall adjusted model $R^2$, the change in AIC over a null intercept only model, and the form of any ARIMA term used.

To visualize final model results we use plots of partial residuals (Larsen and McCleary 1972; Breheny and Burchett 2017). A partial residual plot is a graphical tool that shows the relationship between a given independent variable and the response variable given that other independent variables are also in the model. The plot shows the value of the variable on the x-axis and the partial residual on the y-axis, holding all other variables constant (by default, median for numeric variables and most common category for factors). Partial residual plots are also a key feature of linear mixed models used in the Human Disturbance Index (HDI) and vegetation models.

# Appendix 5 Assessment

Assessment is the process by which the condition of an ecological resource, such as a single wetland or a population of wetlands in a park, is placed into classes that describe or interpret condition. We assess the condition of Florissant Fossil Beds National Monument (FLFO) wetlands relative to "assessment points." Assessment points (AP; Bennetts et al. 2007) are numeric values of an indicator where scientists and park managers have agreed to evaluate the status or trend in condition of a vital sign. Assessment points can be defined or set using several methods, including (in general order of preference) 1) direct definition by park management, 2) adoption from regulatory criteria, or 3) via application of ecological theory (which can overlap with the first two methods). However, none of these forms of AP were readily available for the wetland vital signs presented in this report. Therefore, for FLFO wetland indicators, we use two additional methods: 4) development of AP from distributions of indicator data at wetland sites that are known or expected to be undisturbed by human activities (these are known as "ecoregional assessment points"), and 5) AP defined by other authors using a variety of methods.

The following summarizes and updates our approach from previous reports and the wetland ecological integrity (WEI)/ stream ecological integrity (SEI) protocols for application in this report. We focus on how ecoregional assessment points are derived and on the miscellaneous methods developed by other authors that we apply to our data.

### Ecoregional assessment points

For most FLFO vegetation-based indicators and episodic depth to water (DTW), we define AP from distributions of data (i.e., a dataset of a vegetation metric) at wetland sites *known or expected to be undisturbed by human activities* from across the Southern Rockies Ecoregion in Colorado. These undisturbed sites are identified in Figure 67 and are further defined below. The process of identifying undisturbed sites is a key step in the ecoregional assessment point methodology. Stoddard et al. (2006) summarize multiple conceptual considerations and terminology relevant to the process and applied methods are described in various US EPA, CDPHE and Montana Department of Environmental Quality protocols (CDPHE 2012; Stoddard et al. 2006; Suplee et al. 2005). In summary, undisturbed sites are identified via best professional judgement and various statistical models, including relatively simple filtering of sites based on geospatial (i.e., land use) and site level (i.e., soil chemistry) data. Importantly, these filtering tools should not include a known or estimated biological condition of candidate sites to avoid circularity.

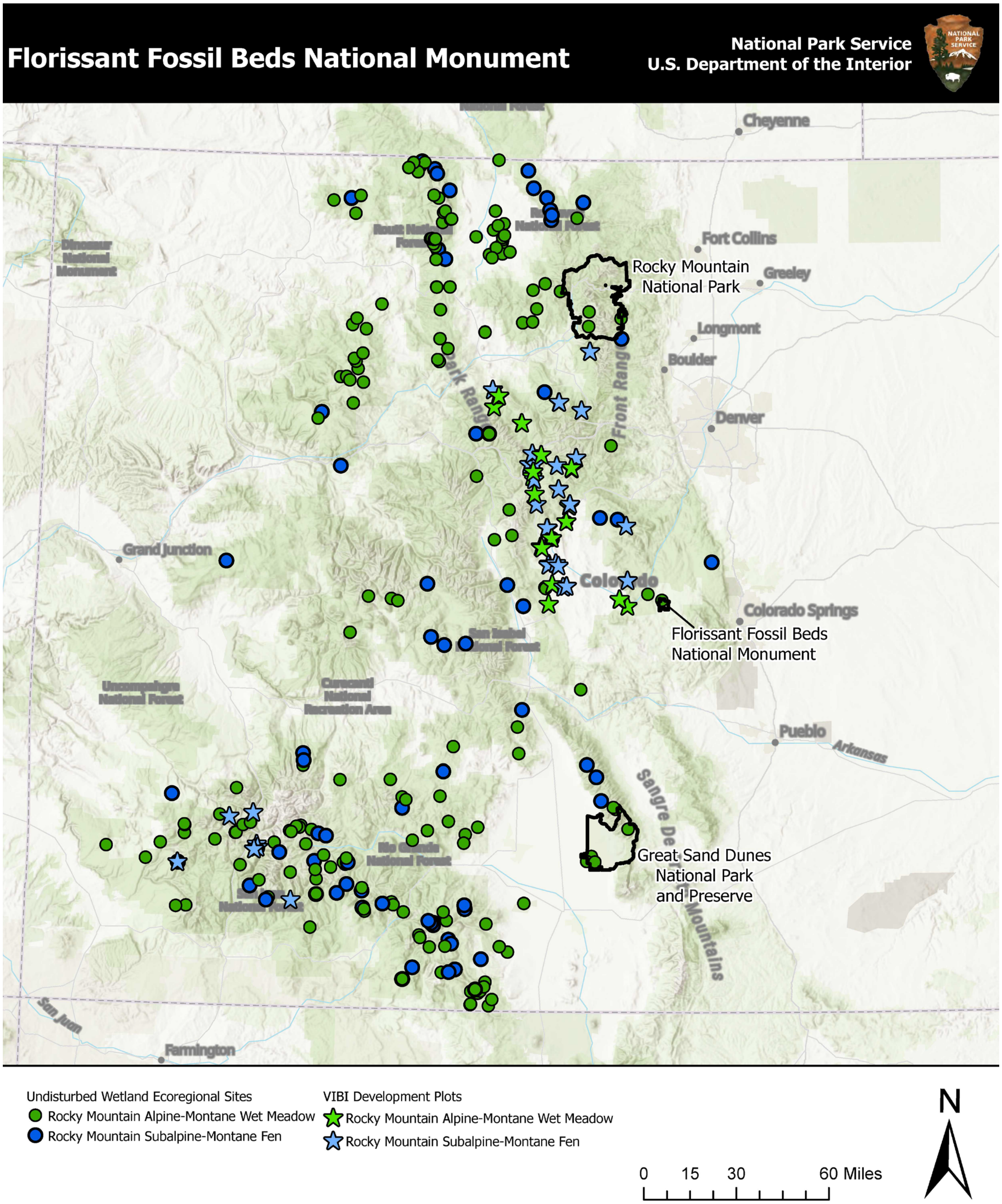


**Figure 67.** Undisturbed wetland sites in the state of Colorado selected from the Colorado Natural Heritage Program (CNHP) Wetland Plots Database that were used to set assessment points for vegetation and groundwater depths (additional sites not shown are also used for groundwater). Sites on private lands are not shown. Stars show wetland sites included in the development of the CNHP Vegetation Indices of Biotic Integrity (VIBI) for fens and wet meadows.

The most salient conceptual consideration from Stoddard et al. (2006) for the process of identifying undisturbed sites is the degree of ambient human disturbance in and around a park. Some parks are embedded in heavily human used landscapes while others are largely surrounded by wilderness. The level of ambient human disturbance in and around a park affects the distribution of data sampled at putatively undisturbed ecoregional (and park) sites (i.e., its shape and location) that in turn impacts how well these sites represent a true undisturbed state. We visualize simulated distributions of data via cumulative distribution functions (CDF) in Figure 68. A CDF (loosely speaking) shows data in increasing order on the x-axis as a percentage of the total on the y-axis. For an indicator collected at sites with more ambient human-caused disturbance (Figure 68, black CDF) and that increases in value with condition (or decreasing human stress), the CDF will likely be expanded or spread out and shifted to the left and further from the undisturbed distribution (Figure 68, red CDF). Less human disturbance (Figure 68, blue CDF) likely reduces overall variance and moves the distribution to the right or towards a less disturbed state. More ambient disturbance also reduces the likelihood that a set of undisturbed sites reflects an undisturbed condition (Figure 68—fewer parts of the black CDF than the blue CDF overlap with the red CDF). Stoddard et al. (2006) and the Rocky Mountain Network WEI and SEI protocols apply the following terms for these two ambient disturbance levels: a context with more human disturbance is labeled a “least disturbed condition (LDC)” (Figure 68, black points), while less disturbance is called “a minimally disturbed condition (MDC)” (Figure 68, blue points). We include these terms here for consistency but have found that given the similarity in “least” and “minimal” they are not so useful and do not emphasize them beyond how we connect our process to the literature and help define decisions points in the ecoregional assessment process.

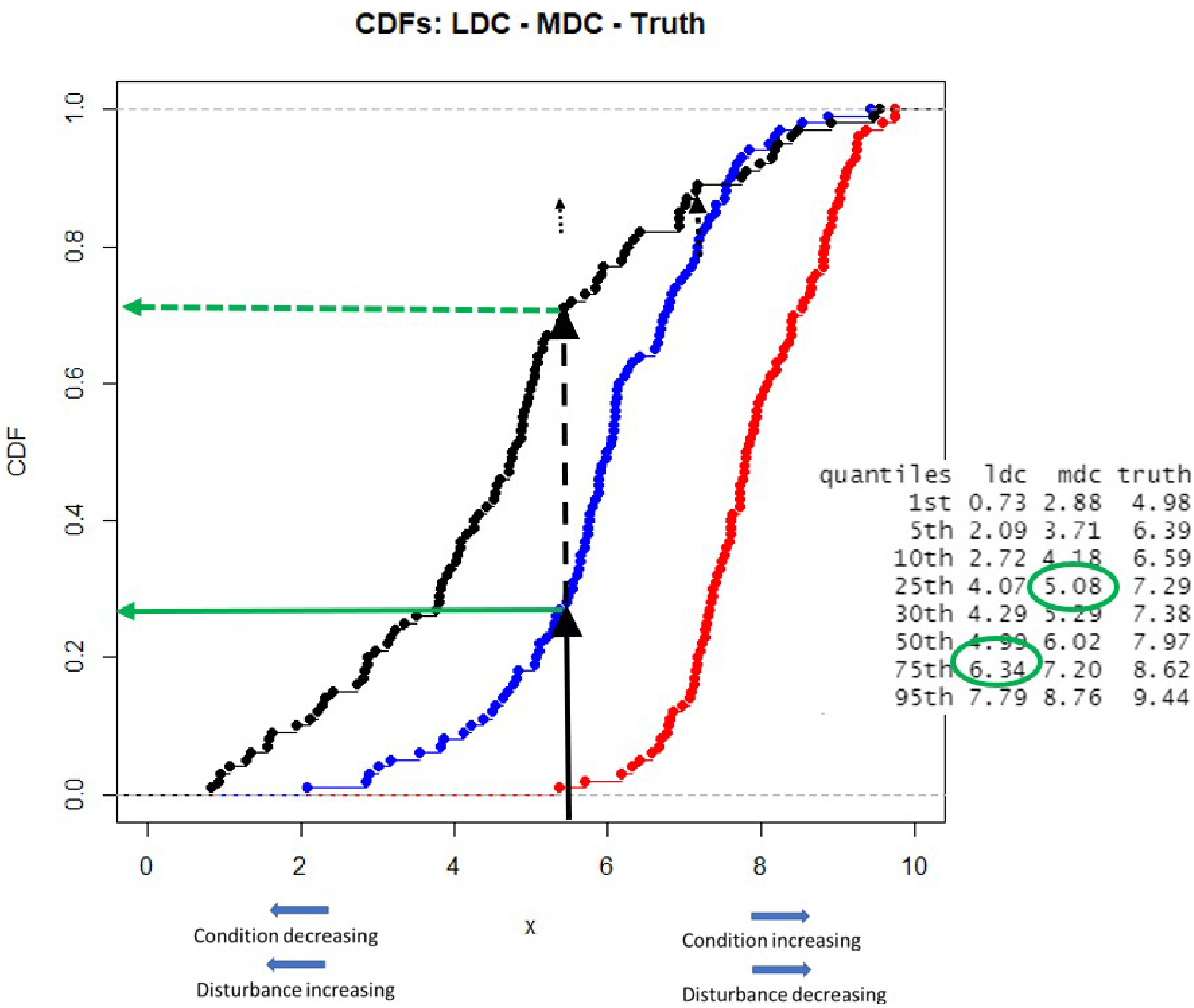


**Figure 68.** Hypothetical empirical cumulative distributions (CDF) simulated from a truncated normal distribution for an example indicator (x) that increases in value as condition increases (or disturbance is reduced). Black points/CDF (the leftmost line) represent a more human disturbed state or the "least disturbed condition (LDC)"; blue points/CDF (the center line) represent less human disturbance or a "minimally disturbed condition (MDC)"; a theoretical completely undisturbed state is shown in the red points/CDF (rightmost line). The table and vertical black arrows give the lookup value at the 25th percentile for the MDC (5.08). For an LDC to match this, the percentile used must be increased to around a 75th percentile. This is similar to when the percentile must be increased to elevate the assessment points generated from a more human influenced distribution of putatively undisturbed sites (i.e., LDC).

Ecoregional AP are defined from distributions of undisturbed site data following US EPA (Stoddard et al. 2006). The method is straightforward and simply defines percentile values as AP that bound disturbance classes in a data set. For example, for an indicator like most vegetation metrics or DTW that increase in value with increasing condition (or decreasing disturbance), the 25th percentile is used to define a "minor" disturbance class while below the 5th percentile is defined as a "major" disturbance class. Indicator values that fall between these two thresholds are considered intermediate in disturbance. For indicators that increase with decreasing condition (or increasing disturbance) such

a most water quality variables or the Human Disturbance Index (HDI), the opposite end of the distribution is used. Values below an assessment point at the 75th are in "minor" disturbance and above the 95th in a "major" disturbance class. Note that we will use indicators that increase in value with increasing condition for the remainder of this discussion, but the pattern as described here for these indicator types is consistent for indicators that increase with decreasing condition.

Our ecoregional AP methodology further defines the choice of the percentile lookup values based on if the undisturbed sites used are taken from a park and/or its ecoregion that are in a highly disturbed (LDC) or less disturbed (MDC) context. Ecoregions (and the parks within them) with less disturbance (MDC) default (following Stoddard et al. 2006) to 5th/25th percentiles as AP for major and minor disturbance classes, respectively. Ecoregions with more disturbance (LDC) use percentiles that are increased above those defined for an MDC. Major disturbance moves from the 5th to the 25th, while the "minor" disturbance class assessment point is increased from above the 25th to the 50th. Increasing the percentiles moves the resulting assessment point closer to the true undisturbed state (i.e., Figure 68) because a more disturbed distribution is likely further away from an undisturbed state and thus more appropriately scores disturbance in landscapes with more disturbance. Stoddard et al. (2006) illustrate this effect using a large sample of undisturbed sites in two different contexts—less disturbed mountain ecoregions and more disturbed plains ecoregions. In the plains, AP are based on higher percentiles, which moves the boundaries of the condition classes closer to what they likely are in a true undisturbed state. Importantly, all of this is specific to a given indicator—some variables will be less affected by disturbance and some more within a single ecoregion. Thus, a park may use assessment point percentiles based on less disturbance (LDC) for one indicator and more for another (MDC).

The choice of percentiles in AP definition is important but is, at its core, arbitrary. Ecoregional AP gain value through consistent application over time as baselines in long-term monitoring and assessment. In addition, if a set of sites are largely, in fact, undisturbed, a minor disturbance class likely estimates condition from the "best of the best" ecoregional sites and this likely has interpretive value as markers of a concept we have yet to introduce—the "*reference condition*"—as discussed next.

***Reference condition***

We have yet to use the term "reference condition." This is intentional because, following Stoddard et al. (2006), we believe this term and its derivatives, like "non-reference," should be restricted to describing a *biological* or *ecological state*. Stoddard et al. (2006) modifies the term "reference condition" to the more explicit "reference condition for biological integrity" or RC(BI), to focus on the biological objectives of the Clean Water Act. For simplicity, we use "reference condition" but intend any "reference" term to apply only to biological indicators like a vegetation metric *sensu* Stoddard et al. (2006).

Undisturbed sites do not best estimate or translate to a reference condition until we sample, model, and assess biological response at these sites. Estimation of a biological condition is accomplished best via a modeling process that uses undisturbed data and a model that "translates" this lack of disturbance to a realized biological condition. However, we lack sufficient data at FLFO to create

bioassessment models and so we instead estimate reference condition AP using the same percentile-based lookup process directly applied to biological metrics as summarized above. While less park-specific and rigorous, this is still a common and well accepted approach.

#### *Undisturbed sites and assessment point percentiles for Florissant Fossil Beds National Monument*

The choice of whether to classify FLFO sites within an MDC or LDC context (setting the AP percentile look up values) is an important step in the assessment process and should ultimately be made by a park in consultation with the network. Unlike in some other Rocky Mountain Network parks, this is a challenging choice for FLFO. The park is in a relatively disturbed immediate landscape context with moderate suburban development, road networks, and a history of moderate to intensive human land use. However, the park is centrally located in the main mountainous corridor in Colorado, and there is a relatively large set of undisturbed sites from across the Southern Rockies ecoregion in Colorado that likely provide a useful and fair comparative context for the park. The details of ecoregional AP estimation vary with indicator type, as presented below.

Undisturbed sites used for assessing FLFO wetland vegetation were drawn from a Colorado Natural Heritage Program (CNHP) database of over 3,000 wetlands and riparian sample events (CNHP 2022). We extracted 374 wet meadows and 174 fen sample events from the CNHP database spanning 1990 to 2018 and subset this to sites rated as excellent or good in terms of their disturbance using CNHP wetland methods (Figure 67; Lemly et al. 2013). These methods are consistent and follow guidelines established by the US EPA (i.e., they do not use biological condition). This reduced the list to 300 reference wet meadows and fens. We do not further subset this list based on covariates like elevation as we feel the wetland typology sufficiently classifies wetland vegetation indicators into comparable groups to FLFO's wetlands, and that late summer vegetation samples integrate well most shorter-term temporal variance. To set AP we assumed that vegetation at these ecoregional sites estimated well a minimally disturbed context and were best characterized using an MDC approach. We therefore defined values above a 25th percentile as in a "reference" class and below a 5th percentile as in a "non-reference" class. Actual assessment point values for vegetation metrics at FLFO are included in the relevant results sections in the main narrative of this report.

For groundwater depths, sites from the CNHP database and a Rocky Mountain Network WEI database were used. Fewer CNHP sites had groundwater data and only 120 wet meadow or fen CNHP events at sites rated excellent/good and sampled between 2008 and 2018 were available. We also used network data from 300 events sampled between 2007 and 2019 at undisturbed sites as defined by the network in Schweiger et al. (2016, 2017; Rocky Mountain Network unpublished data). Undisturbed event groundwater data were further restricted to the late summer months of July–September when water tables are likely most limiting for vegetation production and to sites between 2000 and 3000 m in elevation.

Given differences in the rating methodology between CNHP and the Rocky Mountain Network, higher levels of both natural and human use induced variability in groundwater depths, and likely greater measurement variability in collecting groundwater depths, we felt these data likely were poorer estimates of a true undisturbed state and that the proper context for groundwater AP was an

LDC. We therefore define values above a 50th percentile as in "minor" disturbance class and below a 25th percentile as in a "major" disturbance class. An LDC based approach to groundwater generates AP that are "drier" than if MDC based AP had been used. These will result in fewer data values being in a minor disturbance class and more in a major disturbance class. This is a conservative approach to the likely poorer ability of ecoregional sites to estimate a true undisturbed state. Actual AP values are for DTW at FLFO and are included in the relevant results sections in the main narrative of this report.

### Assessment methods adopted by the Rocky Mountain Network

#### *Human Disturbance Index*

In analyses of WEI data in Great Sand Dunes National Park and Preserve and Rocky Mountain National Park, assessment points for HDI were determined based on the distribution of scores in a subset of park sites determined to be undisturbed using LDC and MDC approaches for Great Sand Dunes National Park and Preserve and Rocky Mountain National Park, respectively. Our smaller sample size of HDI in this report precluded replicating this approach with FLFO data. HDI data in undisturbed ecoregion sites are not directly comparable to FLFO given its (disturbed) landscape context, and HDI data from other Rocky Mountain Network parks were not available at time of publication. Therefore, we followed the approach used in the development of wetland assessment tools by CNHP (Rocchio 2007a, b; Lemly and Rocchio 2009). The full range of HDI scores (0–100) was divided into three even bins, with HDI scores of 0–33 labeled as in minor disturbance, HDI scores of 34–66 as having moderate disturbance, and HDI scores of 67–100 as in a major disturbance class. With these assessment points for HDI, disturbance data for FLFO wetlands can be compared using ranges evaluated by CNHP that place FLFO wetlands within a statewide gradient of disturbance.

#### *Landscape Disturbance Index*

The Landscape Disturbance Index (LDI) is a unitless index that ranges from 0 to >2000 (but note that the distribution is very long tailed, with most values less than 600). CNHP describes a score of 0 as no impact, up to 250 as low impact, 250 to 500 as moderate impact, and above 500 as high impact. We use a subset of these breaks as assessment points.

#### *Multimetric indices*

Assessment points for multimetric indices followed methods developed for each index. For the CHNP Vegetation Index of Biotic Integrity (VIBI), we used assessment points defined in Lemly and Rocchio (2009). The VIBI for fens was developed with two thresholds separating reference, intermediate, and non-reference condition. The VIBI for wet meadows, however, was developed with a smaller dataset and the resolution of the data could only distinguish between reference and non-reference. The sites used to develop these assessment points are relevant to wetlands in FLFO. Many are near the park and/or on similar landscape contexts (Figure 67), but the dataset was small.

# Appendix 6 Chemistry: Groundwater and Soil

*Chemistry results are treated as a baseline for future assessment because, as of publication, we lack data and relevant assessment points to assess these data. There is value in the simple treatment presented in this appendix. We will continue to monitor these specific sites over time and will therefore better understand spatial and temporal variability in soil and groundwater chemistry which will support development of assessment points.*

### Soil

Wetland soil is both the medium in which chemical reactions that influence wetland vegetation take place and the primary storage area of available nutrients and chemicals for most wetland plants (Mitsch and Gosselink 2007). Global and local disturbances can alter soil chemistry, which may result in altered vegetation composition. Soil characteristics can provide useful indicators of wetland condition (Sollins et al. 1999). Fens, for example, are distinguished chiefly by the occurrence of organic soils. Certain soil indicators also provide information about hydrologic regime. For example, redoximorphic features (soil attributes influenced by oxidation and reduction processes in the soil), like mottles (blotches of differently colored soil), are most likely to occur in soils that cycle between anaerobic and aerobic conditions. By contrast, strongly gleyed soils (sticky, waterlogged soil, typically colored gray to blue) suggests prolonged anaerobic conditions. Soil organic matter, carbon, pH, and plant nutrient concentrations can provide a powerful index of productivity and ecosystem processes and are often determinants of vegetation structure (Sollins et al. 1999). Various salts can have significant effects on soil properties and plant growth, and these have been well understood for at least half a century by soil scientists (Wong et al. 2010).

Soil chemistry samples were collected from each site twice, once in 2009 with site installation and again in 2015. With only two sample periods, we cannot develop models of trend over time. We instead present results as simple estimates from each time period by sentinel complex (Figure 69, Table 32) and wetland type (Figure 70, Table 33). Results from the two time periods were notably different for several parameters, including organic matter at 20 cm (OM_20cm), cation exchange capacity (CEC), and most ions. For several of these parameters, the 2015 values were double the 2009 values. We do not know if the change has ecological relevance or if it is an artifact of either sampling or laboratory methodological difference between the two time periods, and it may be difficult to resolve this. OM and associated CEC increases may be the result of gradual improvement in wetland hydrology and the release of grazing and agricultural pressure, which are common causes of OM reductions in these systems. It is unlikely that such a dramatic increase would have occurred during the 10 years of this study, however, when the management of the park has remained consistent for decades. Without a better understanding of these differences, we present the two time periods in tables and box plots, but do not analyze the change.

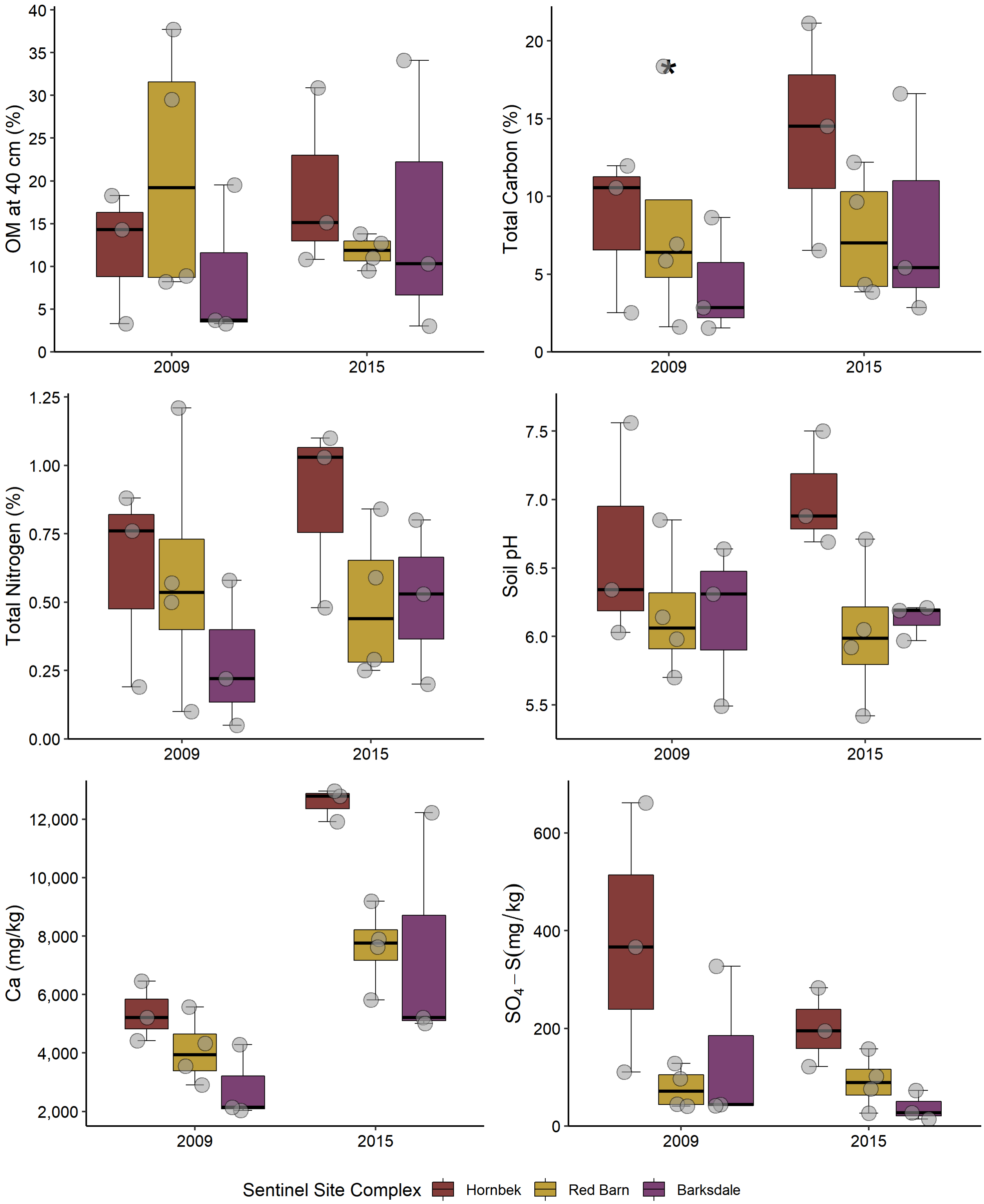


**Figure 69.** Soil chemistry at sentinel sites by sentinel complex, Florissant Fossil Beds National Monument, Colorado, 2009 and 2015. (Top left) organic matter (OM, %) at 40 cm, (top right) total carbon (%), (middle left) total nitrogen (%), (middle right) pH (s.u.), (bottom left) calcium (Ca, mg/kg), (bottom right) sulfate (S04, mg/kg). Whiskers give the interquartile range. Points are individual values (jittered to reduce overlap). Points with a star are outliers (defined as 1.5 times the interquartile range).

**Table 32.** Summary of soil chemistry parameters by sentinel complex, Florissant Fossil Beds National Monument, Colorado. Measurements from 2009 and 2015 sample events are shown separately.

| | | 2009 | | 2015 | |
|---|---|---|---|---|---|
| **Sentinel complex** | **Parameter** | **n** | **Mean ± SE** | **n** | **Mean ± SE** |
| Hornbek | Sand (%) | 3 | 46.7 ± 10.7 | 1 | 48.0 |
| | Silt (%) | 3 | 21.3 ± 6.8 | 1 | 22.0 |
| | Clay (%) | 3 | 32.0 ± 4.6 | 1 | 30.0 |
| | OM_20cm (%) | 3 | 15.4 ± 3.9 | 3 | 28.8 ± 9.9 |
| | OM_40cm (%) | 3 | 12.0 ± 4.5 | 3 | 18.9 ± 6.1 |
| | C, total (%) | 3 | 8.3 ± 2.9 | 3 | 14.1 ± 4.2 |
| | N, total (%) | 3 | 0.6 ± 0.2 | 3 | 0.9 ± 0.2 |
| | pH | 3 | 6.6 ± 0.5 | 3 | 7.0 ± 0.2 |
| | CEC (meq/100g) | 3 | 33.8 ± 4 | 3 | 74.7 ± 1.4 |
| | Al (mg/kg) | 0 | NA | 3 | 3086.0 ± 555.4 |
| | Ca (mg/kg) | 3 | 5365 ± 593.5 | 3 | 12553 ± 325.4 |
| | K (mg/kg) | 3 | 439.3 ± 89.2 | 3 | 515.3 ± 84.1 |
| | Mg (mg/kg) | 3 | 576.1 ± 89.6 | 3 | 1151.7 ± 37.6 |
| | NH4 (mg/kg) | 3 | 15.7 ± 2.4 | 3 | 77.9 ± 22.5 |
| | NO3 (mg/kg) | 3 | 23.0 ± 15.5 | 3 | 1.0 ± 0.1 |
| | P (mg/kg) | 3 | 0.4 ± 0.1 | 3 | 30.5 ± 5.4 |
| | SO4 (mg/kg) | 3 | 379.8 ± 159.1 | 3 | 200.0 ± 46.5 |
| Red Barn | Sand (%) | 3 | 41.3 ± 5.9 | 2 | 32.0 ± 4.0 |
| | Silt (%) | 3 | 21.3 ± 3.7 | 2 | 33.0 ± 3.0 |
| | Clay (%) | 3 | 37.3 ± 5.7 | 2 | 35.0 ± 1.0 |
| | OM_20cm (%) | 4 | 10.4 ± 2.1 | 4 | 27.6 ± 4.6 |
| | OM_40cm (%) | 4 | 21.1 ± 7.4 | 4 | 11.8 ± 0.9 |
| | C, total (%) | 4 | 8.2 ± 3.6 | 4 | 7.5 ± 2 |
| | N, total (%) | 4 | 0.6 ± 0.2 | 4 | 0.5 ± 0.1 |
| | pH | 4 | 6.2 ± 0.2 | 4 | 6.0 ± 0.3 |
| | CEC (meq/100g) | 4 | 24.6 ± 3.3 | 4 | 46.3 ± 3.8 |
| | Al (mg/kg) | 0 | NA | 4 | 3976.8 ± 372.5 |
| | Ca (mg/kg) | 4 | 4092.3 ± 573.4 | 4 | 7632.8 ± 697.6 |
| | K (mg/kg) | 4 | 183.6 ± 35 | 4 | 482.3 ± 18.8 |
| | Mg (mg/kg) | 4 | 382.4 ± 44.4 | 4 | 754.0 ± 37.6 |
| | NH4 (mg/kg) | 4 | 9.4 ± 1.9 | 4 | 70.7 ± 36.1 |
| | NO3 (mg/kg) | 4 | 10.4 ± 5 | 4 | 1.0 ± 0.3 |
| | P (mg/kg) | 4 | 0.2 ± 0 | 4 | 33.7 ± 11.4 |
| | SO4 (mg/kg) | | 77.8 ± 21.2 | 4 | 90.5 ± 27.5 |

**Table 32 (continued).** Summary of soil chemistry parameters by sentinel complex, Florissant Fossil Beds National Monument, Colorado. Measurements from 2009 and 2015 sample events are shown separately.

| Sentinel complex | Parameter | 2009 | | 2015 | |
|---|---|---|---|---|---|
| | | **n** | **Mean ± SE** | **n** | **Mean ± SE** |
| Barksdale | Sand (%) | 3 | 44.7 ± 8.8 | 2 | 44.0 ± 6 |
| | Silt (%) | 3 | 24.0 ± 8.0 | 2 | 33.0 ± 7 |
| | Clay (%) | 3 | 31.3 ± 2.9 | 2 | 23.0 ± 1 |
| | OM_20cm (%) | 3 | 10.3 ± 3.8 | 3 | 16.2 ± 5.3 |
| | OM_40cm (%) | 3 | 8.8 ± 5.3 | 3 | 15.8 ± 9.4 |
| | C, total (%) | 3 | 4.3 ± 2.2 | 3 | 8.3 ± 4.2 |
| | N, total (%) | 3 | 0.3 ± 0.2 | 3 | 0.5 ± 0.2 |
| | pH | 3 | 6.1 ± 0.3 | 3 | 6.1 ± 0.1 |
| | CEC (meq/100g) | 3 | 17.7 ± 4.2 | 3 | 45 ± 13.3 |
| | Al (mg/kg) | 0 | NA | 3 | 3875.3 ± 353.6 |
| | Ca (mg/kg) | 3 | 2823 ± 734.6 | 3 | 7478 ± 2371.4 |
| | K (mg/kg) | 3 | 284.2 ± 45.3 | 3 | 551.0 ± 59.1 |
| | Mg (mg/kg) | 3 | 275.2 ± 45.5 | 3 | 681.0 ± 148.7 |
| | NH4 (mg/kg) | 3 | 15.3 ± 1.7 | 3 | 16.6 ± 6.2 |
| | NO3 (mg/kg) | 3 | 6.9 ± 2 | 3 | 4.0 ± 1.8 |
| | P (mg/kg) | 3 | 1.7 ± 0.4 | 3 | 20.6 ± 1.6 |
| | SO4 (mg/kg) | 3 | 137.6 ± 94.9 | 3 | 38.1 ± 17.9 |
| All sites | Sand (%) | 9 | 44.2 ± 4.4 | 5 | 40 ± 4 |
| | Silt (%) | 9 | 22.2 ± 3.2 | 5 | 30.8 ± 3.3 |
| | Clay (%) | 9 | 33.6 ± 2.5 | 5 | 29.2 ± 2.7 |
| | OM_20cm (%) | 9 | 11.5 ± 1.7 | 10 | 24.5 ± 3.5 |
| | OM_40cm (%) | 10 | 14.7 ± 3.7 | 10 | 15.1 ± 3.1 |
| | C, total (%) | 10 | 7.1 ± 1.7 | 10 | 9.7 ± 2 |
| | N, total (%) | 10 | 0.5 ± 0.1 | 10 | 0.6 ± 0.1 |
| | pH | 10 | 6.3 ± 0.2 | 10 | 6.4 ± 0.2 |
| | CEC (meq/100g) | 10 | 25.3 ± 2.8 | 10 | 54.4 ± 5.8 |
| | Al (mg/kg) | 0 | NA | 10 | 3679.1 ± 253.7 |
| | Ca (mg/kg) | 10 | 4093.3 ± 459.4 | 10 | 9062 ± 1013.7 |
| | K (mg/kg) | 10 | 290.5 ± 45.6 | 10 | 512.8 ± 29 |
| | Mg (mg/kg) | 10 | 408.4 ± 50 | 10 | 851.4 ± 78.4 |
| | NH4 (mg/kg) | 10 | 13.1 ± 1.4 | 10 | 56.6 ± 17 |
| | NO3 (mg/kg) | 10 | 13.1 ± 5 | 10 | 1.9 ± 0.7 |
| | P (mg/kg) | 10 | 0.7 ± 0.2 | 10 | 28.8 ± 4.8 |
| | SO4 (mg/kg) | 10 | 186.3 ± 64.8 | 10 | 107.6 ± 26.9 |

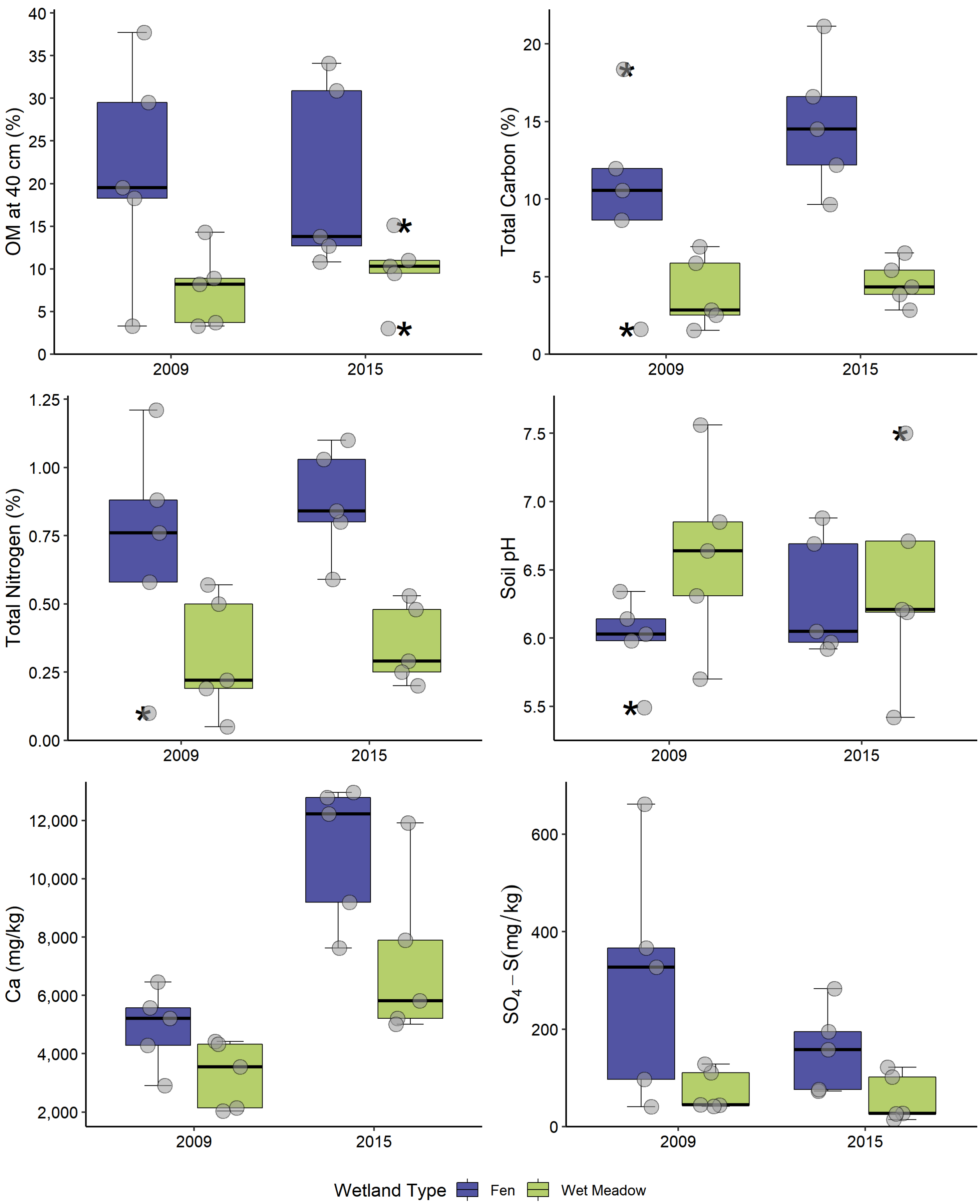


**Figure 70.** Soil chemistry at sentinel sites by wetland type Florissant Fossil Beds National Monument, Colorado, 2009 and 2015: (Top left) organic matter (OM, %) at 40 cm, (top right) total carbon (%), (middle left) total nitrogen (%), (middle right) pH (s.u.), (bottom left) calcium (Ca, mg/kg), (bottom right) sulfate (S04, mg/kg). Whiskers give the interquartile range. Points are individual values (jittered to reduce overlap). Points with a star are outliers (defined as 1.5 times the interquartile range).

**Table 33.** Summary of soil chemistry parameters by wetland type, Florissant Fossil Beds National Monument, Colorado. Measurements from 2009 and 2015 sample events are shown separately.

| | Fens 2009 | | Fens 2015 | | Wet meadows 2009 | | Wet meadows 2015 | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **n** | **Mean ± SE** | **n** | **Mean ± SE** | **n** | **Mean ± SE** | **n** | **Mean ± SE** |
| Sand (%) | 4 | 41.0 ± 9.3 | 0 | NA | 5 | 46.8 ± 3.9 | 5 | 40.0 ± 4.0 |
| Silt (%) | 4 | 26.0 ± 6.7 | 0 | NA | 5 | 19.2 ± 2.4 | 5 | 30.8 ± 3.3 |
| Clay (%) | 4 | 33.0 ± 4.1 | 0 | NA | 5 | 34.0 ± 3.4 | 5 | 29.2 ± 2.7 |
| OM_20cm (%) | 4 | 12.8 ± 3.4 | 5 | 33.8 ± 2.7 | 5 | 10.5 ± 1.7 | 5 | 15.3 ± 2.4 |
| OM_40cm (%) | 5 | 21.7 ± 5.8 | 5 | 20.5 ± 5 | 5 | 7.7 ± 2 | 5 | 9.8 ± 2 |
| C, total (%) | 5 | 10.2 ± 2.7 | 5 | 14.8 ± 2 | 5 | 3.9 ± 1 | 5 | 4.6 ± 0.6 |
| N, total (%) | 5 | 0.7 ± 0.2 | 5 | 0.9 ± 0.1 | 5 | 0.3 ± 0.1 | 5 | 0.4 ± 0.1 |
| pH | 5 | 6.0 ± 0.1 | 5 | 6.3 ± 0.2 | 5 | 6.6 ± 0.3 | 5 | 6.4 ± 0.3 |
| CEC (meq/100g) | 5 | 30.2 ± 3.9 | 5 | 64.9 ± 6.1 | 5 | 20.4 ± 3.0 | 5 | 43.9 ± 7.6 |
| Al (mg/kg) | 5 | NA | 5 | 3301 ± 390.9 | 5 | NA | 5 | 4056 ± 256.0 |
| Ca (mg/kg) | 5 | 4889.2 ± 605.4 | 5 | 10959 ± 1075 | 5 | 3297.4 ± 516 | 5 | 7165 ± 1291.6 |
| K (mg/kg) | 5 | 336.3 ± 76.0 | 5 | 504.8 ± 43.3 | 5 | 244.7 ± 50.2 | 5 | 520.8 ± 43.3 |
| Mg (mg/kg) | 5 | 487.1 ± 78.0 | 5 | 964.8 ± 86.6 | 5 | 329.6 ± 45.1 | 5 | 738.0 ± 117.2 |
| NH4 (mg/kg) | 5 | 13.4 ± 2.4 | 5 | 95.3 ± 22.3 | 5 | 12.7 ± 1.8 | 5 | 18.0 ± 7.0 |
| NO3 (mg/kg) | 5 | 15.4 ± 9.7 | 5 | 1.1 ± 0.2 | 5 | 10.8 ± 3.7 | 5 | 2.7 ± 1.3 |
| P (mg/kg) | 5 | 0.5 ± 0.2 | 5 | 38.5 ± 7.0 | 5 | 0.9 ± 0.4 | 5 | 19.1 ± 2.5 |
| SO4 (mg/kg) | 5 | 298.8 ± 110.5 | 5 | 157.0 ± 39.3 | 5 | 73.9 ± 18.9 | 5 | 58.3 ± 22.3 |

The predominant soil unit within the central valley of FLFO is the Fourmile-Lymaning-Florissant complex, which includes well drained clay loams, sandy loams, and gravelly loams (NRCS 2021). The parent material is alluvium derived from volcanic tuff and shale, which likely contribute to high calcium concentration in the soils. Within the wetland corridor of the Grape Creek drainage, soils are mapped as frequently flooded Platdon loam. This map unit contains finer textured soils than the surrounding uplands and is poorly drained.

#### *Hornbek soils*

Soils in the Hornbek Sentinel Site Complex were composed of both mineral and organic soil layers, depending on wetland type. Wet meadow site 709 had mineral soil layers made up clay loams and sandy clay loams with little organic matter (OM). Organic matter within fen sites 708 and 715 varied by depth and by year. In 2009, OM in site 708 was relatively low (19.4% at 20 cm and only 3.3% at 40 cm); however, OM in the top horizon increased to 31.9% in 2015. This may be related to the restoration project that affected groundwater levels within the Hornbek complex between 2009 and 2015, or it may be related to differences in the sampling or lab analysis. In site 715, thickness of the organic layer was measured at 119 cm in 2009, and this layer was primarily composed of sapric and hemic peat, but the OM at 40 cm was only 18.3%. In 2015, OM in site 715 was 41.0% at 20 cm and 30.9% at 40 cm.

Organic matter measurements from fens in 2015 were more consistent, with true organic soils (histosols) following NRCS (1999). By definition (in brief), histosols must have 40 cm or more of organic soil material in the upper 50 cm or constitute two-thirds or more of the total thickness above the parent material and have no mineral horizon greater than 10 cm. Organic soil material is defined as material that has more than 12–18% organic carbon by weight (depending on clay content). While we do not have measures of organic carbon from FLFO soil samples, published ratios of organic matter to organic carbon range from 1.72 to 2.00, meaning organic matter is roughly half organic carbon (Nelson and Sommers 1996). To meet the definition of a histosol, therefore, OM should be ~24–36% of the soil by weight. The 2015 measurements from Hornbek fens met this criterion. The percent total carbon (both organic and inorganic) from these sites was also high, ranging from 10.6 to 21.1%.

The pH of Hornbek soils ranged from 6.0 to 7.6. The highest pH was measured in the wet meadow site 709. Mean cation exchange capacity (CEC) was 33.8 ± 4 meq/100g in 2009 and 74.7 ± 1.4 in 2015. Values for the dominant cation, calcium, were 5,365 ± 593 mg/kg in 2009 and 12,553 ± 325 in 2015. Hornbeck soils exhibited higher values compared to the other sentinel complexes for several response variables in both sample years, including pH, total carbon, cation exchange capacity (CEC), and the minerals calcium, magnesium, ammonium, and sulfate (Table 32). However, there was considerable variability between sites within a complex and between the two sample years. With so few samples in each complex and time period, we did not test for significance of these differences.

Cation exchange capacity (CEC) is defined as the sum of exchangeable positive ions a soil can hold. It affects the storage and availability of positively charged nutrients important for plant growth. Cation exchange capacity is higher in organic vs. mineral soil layers because organic matter tends to be negatively charged. As the organic content increases, the amount of exchangeable hydrogen ions

also increases (Schaetzl and Anderson 2005; Mitsch and Gosselink 2007). In addition, the CEC of organic soil increases at higher pH (Helling et al. 1964). The higher OM and higher pH values in Hornbek soils compared to the other complexes likely contributed to higher CEC values, which in turn influenced the elevated concentrations of major metal cations (Ca, Mg, K, and Na). In the Hornbeck complex and across all FLFO wetlands and both time periods, there were very tight correlations between OM, CEC, and the ions, especially calcium (Table 32). In general, calcium content was extremely high for all park wetlands with both mineral and organic soils, likely due to the shale deposits and volcanic tuff underlying the park's soils. Calcium values are more than twice as high as those measures in Great Sand Dunes National Park and Preserve or Rocky Mountain National Park (~2,000 mg.kg) in similar sampling (Schweiger et al. 2019; Schweiger et al. 2017).

#### *Red Barn soils*

Soils parameters from Red Barn sites were generally lower than those measured in Hornbek sites but were like those from the Barksdale complex (Table 32). Sites 710 and 711 were classified as wet meadow, in part because they had lower soil organic matter in samples from both 2009 and 2015 compared to fen sites 712 and 713. The clay, clay loam, or sandy clay loam textures and %OM of the upper soil layer at sites 710 and 711 were characteristic of wet meadow wetlands in the Rocky Mountains (Gage and Cooper 2013). Soil samples from fen site 712 had 79 cm of mucky peat soil that was high in OM over deeper clayey mineral soil layers. The measurements of OM at 20 cm for sites 712 and 713 in 2015 were typical of fens (38.9% and 30.5%, respectively). The pH of Red Barn soils ranged from 5.4 to 6.7. The lowest pH was measured in the wet meadow site 710, which is located farther from the other three Red Barn sites. Mean CEC was 24.6 ± 3.3 meq/100g in 2009 and 46.3 ± 3.8 in 2015. Values for the dominant cation, calcium, were 4,092 ± 573 mg/kg in 2009 and 7,633 ± 697 in 2015.

#### *Barksdale soils*

Soil textures at sites 703 and 704 were characterized as sandy clay loam soils, which are typical of wet meadow wetlands in the Rocky Mountains. Site 705 is categorized as a fen wetland with consistently high OM (17.9–34.1%) over sandy clay loam. The pH of Barksdale soils ranged from 5.5 to 6.6. The lowest pH was measured in the fen site 705. Mean CEC was 17.7 ± 4.2 meq/100g in 2009 and 45.0 ± 13.3 in 2015. Values for the dominant cation, calcium, were 2,823 ± 735 mg/kg in 2009 and 7,479 ± 2371 in 2015.

#### *Wetland type*

Nearly all soil parameters except pH were higher in fens than in wet meadows (Table 33). Soil OM at both depths, soil C and N, CEC and all ions were higher in fens during both time periods. Most notable, OM at 20 cm in 2015 was 33.8 ± 2.7% for fens and only 15.3 ± 2.4% for wet meadows. Mean OM at 40 cm was over 20% for fens during both time periods and under 10% for wet meadows. Mean total carbon was over 10% for fens in both time periods and under 5% for wet meadows. Mean CEC, which affects plant available cations, was 30.2 ±3.9 meg/100g for fens in 2009 and 64.9 ±6.1 in 2015. For wet meadows, these numbers were 20.4 ± 3.0 and 43.9 ± 7.6. However, mean pH for fens was 6.0 ± 0.1 in 2009 and 6.3 ± 0.2 in 2015, while mean pH for wet meadows was 6.6 ± 0.3 in 2009 and 6.4 ± 0.3 in 2015.

## Groundwater

Groundwater is an important matrix for chemical reactions that influence wetland vegetation (Mitsch and Gosselink 2007). Groundwater chemistry also reflects large scale and local disturbances and thus may provide useful indicators for wetland disturbance and condition. Four core *in situ* parameters are required by the NPS Water Resources Division as part of all NPS aquatic monitoring protocols. These parameters contribute some consistency to NPS Inventory and Monitoring Division monitoring across parks, and more importantly, they can be key indicators of stress in aquatic systems (NPS 2002). Of the four core parameters, only two are relevant or appropriately measurable in wetland groundwater. First, pH (the measure of water hydrogen ion concentration), has many physical and biological effects in wetland systems. Most plant species occur within specific habitat envelopes of pH conditions, and changes in pH will likely result in changes in vegetation communities. In addition, pH determines the solubility of heavy metals and many salts. Second, specific conductance (the ability of a water body to conduct an electric current used as an index of dissolved ion concentrations in water bodies), also affects important chemical reactions. Changes in conductance also can indicate shifts in major ions or nutrients, such as potassium, calcium, and other anions and cations. We also include groundwater temperature although we have less confidence in these data given the challenge of obtaining a true *in situ* temperature reading.

The following presents a summary of *in situ* groundwater chemistry results as measured in FLFO from 2009 to 2011(Table 34, Figures 71, 72). Results are given by wetland complex and by wetland type.

**Table 34.** Baseline (2009–2011) in situ water chemistry at sentinel sites by wetland type and sentinel complex in Florissant Fossil Beds National Monument, Colorado. Reported values include sample size (N), coefficient of variation (CV), standard deviation (SD), minimum (Min.), and maximum (Max.). Assessment points are still to be determined for these data.

| Metric | Wetland type / Sentinel complex | N | Median % | Mean % | CV | SD | Min. % | Max. % |
|---|---|---|---|---|---|---|---|---|
| pH (su) | Fen | 16 | 6.64 | 6.77 | 0.10 | 0.703 | 5.86 | 8.11 |
| | Wet meadow | 10 | 6.50 | 6.68 | 0.10 | 0.656 | 5.69 | 7.92 |
| | Hornbek | 9 | 6.79 | 6.99 | 0.08 | 0.594 | 6.32 | 8.03 |
| | Red Barn | 10 | 6.26 | 6.40 | 0.10 | 0.643 | 5.69 | 7.92 |
| | Barksdale | 7 | 6.45 | 6.89 | 0.10 | 0.692 | 6.34 | 8.11 |
| Specific conductance (µS/cm) | Fen | 16 | 361.68 | 373.92 | 0.34 | 127.504 | 200.71 | 556.00 |
| | Wet meadow | 10 | 289.64 | 387.82 | 0.60 | 231.255 | 211.93 | 808.86 |
| | Hornbek | 9 | 497.29 | 560.04 | 0.26 | 147.157 | 408.50 | 808.86 |
| | Red Barn | 10 | 284.36 | 316.39 | 0.28 | 87.34 | 212.43 | 493.14 |
| | Barksdale | 7 | 224.57 | 236.66 | 0.16 | 37.564 | 200.71 | 314.86 |
| Groundwater temperature (°C) | Fen | 16 | 13.84 | 13.39 | 0.29 | 3.95 | 7.77 | 20.80 |
| | Wet meadow | 10 | 14.86 | 13.53 | 0.38 | 5.112 | 6.19 | 20.43 |
| | Hornbek | 9 | 13.90 | 13.13 | 0.30 | 3.95 | 7.44 | 17.74 |
| | Red Barn | 10 | 13.34 | 12.34 | 0.33 | 4.047 | 6.19 | 16.77 |
| | Barksdale | 7 | 15.34 | 15.44 | 0.33 | 5.106 | 8.37 | 20.80 |

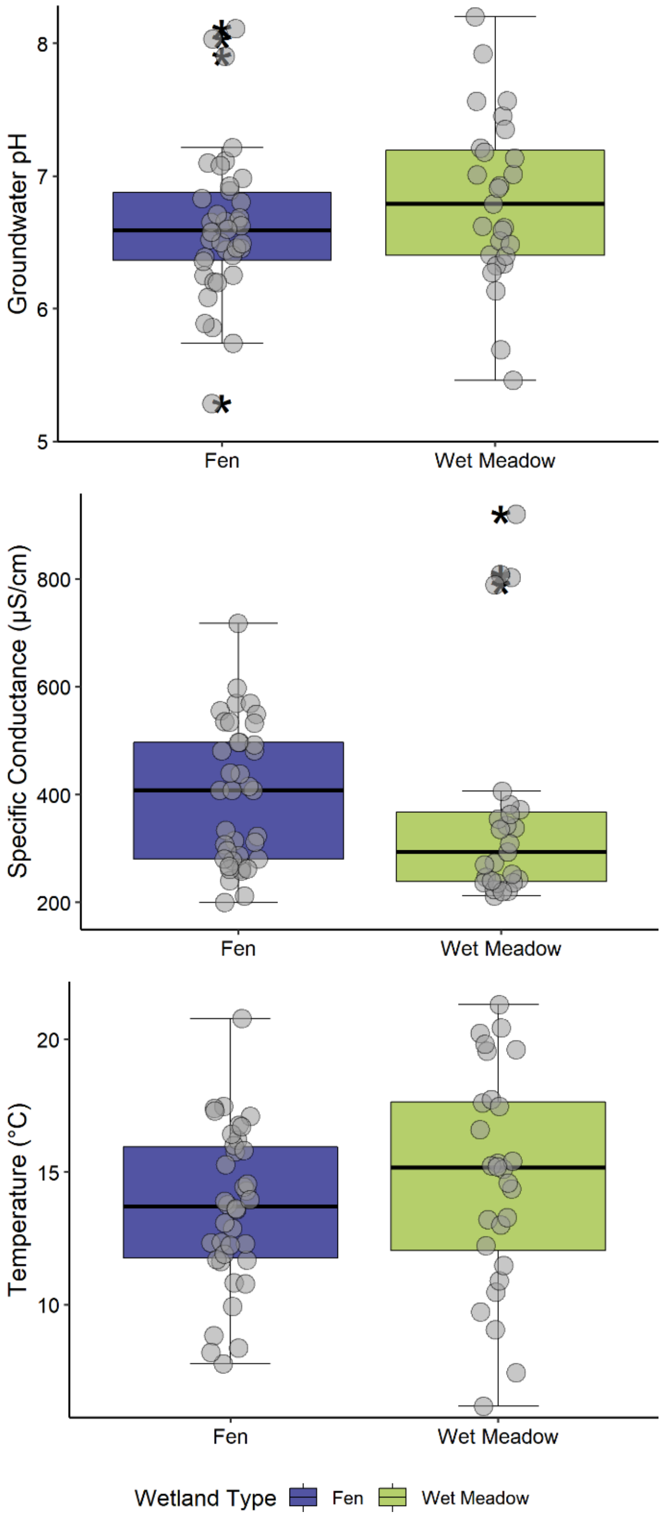


**Figure 71.** Baseline (2009–2011) groundwater pH (s.u.), specific conductance, and tesmperature at sentinel sites by wetland type in Florissant Fossil Beds National Monument, Colorado. Whiskers give the interquartile range. Points are individual values (jittered to reduce overlap). Points with a star are outliers (defined as 1.5 times the interquartile range).

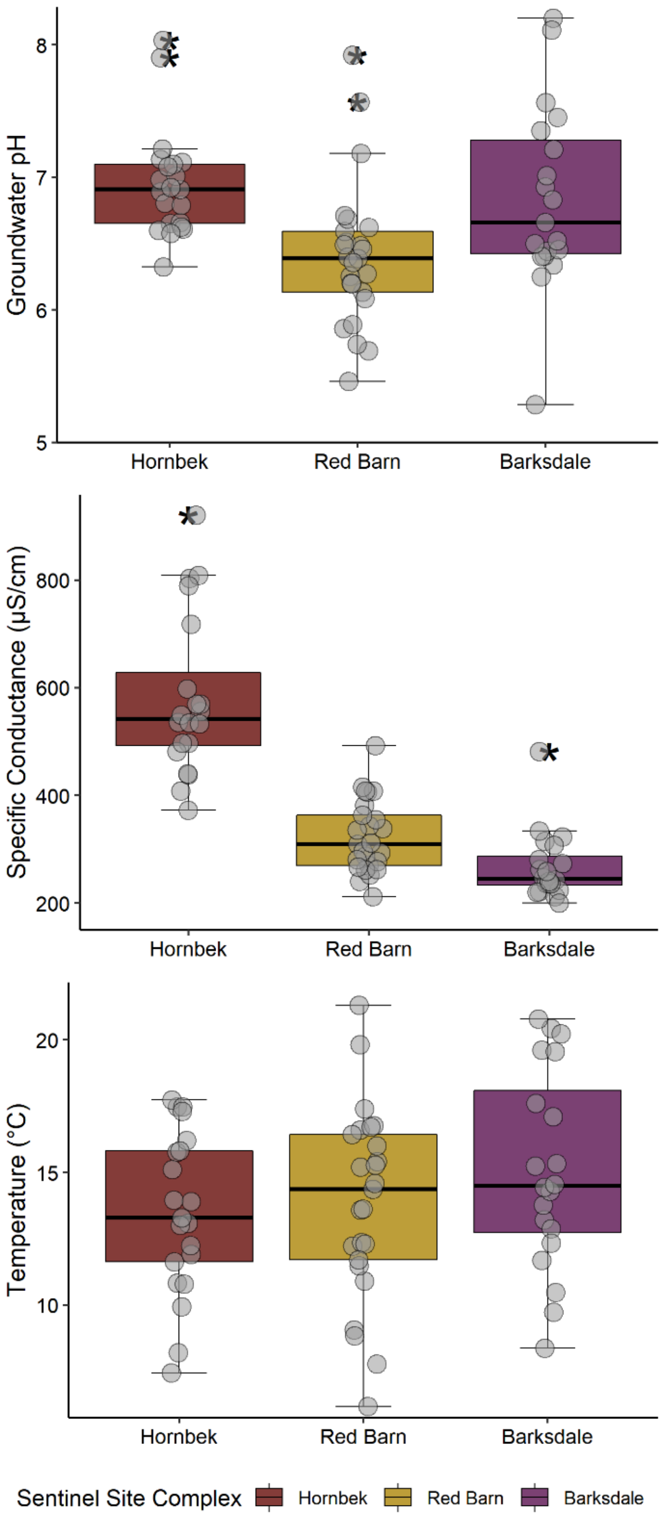


**Figure 72.** Baseline (2009–2011) groundwater pH, specific conductance, and temperature at sentinel sites by sentinel complex, Florissant Fossil Beds National Monument, Colorado. Whiskers give the interquartile range. Points are individual values (jittered to reduce overlap). Points with a star are outliers (defined as 1.5 times the interquartile range).

# Appendix 7 Bioassessment Indices Component Metric Detailed Results

This appendix provides raw metric values and final Vegetation Index of Biotic Integrity scores for fens (Tables 35, 36) and wet meadows (Tables 37, 38), as defined by the Colorado Natural Heritage Program.

**Table 35.** Raw metric values for the Colorado Natural Heritage Program Fen Vegetation Index of Biotic Integrity (VIBI) at Florissant Fossil Beds National Monument, Colorado. C = Conservatism; OBL = obligate wetland species; FACW = facultative wetland species. Metric scores and overall VIBI score are in Table 36.

| Sentinel site complex | Site | Year | Mean C native | Intolerant species | Tolerant species | Nonnative species | Native species (absolute cover) | OBL & FACW species (absolute cover) | Bryophytes (absolute cover) | Litter (absolute cover) | Bare ground (absolute cover) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hornbek | FLFO_708 | 2009 | 4.83 | 16.7% | 0.0% | – | 41.1% | 41.0% | – | 4.5% | 0.8% |
| | FLFO_708 | 2010 | 5.88 | 33.3% | 16.7% | 5.6% | 82.9% | 76.6% | 31.0% | 42.3% | 2.5% |
| | FLFO_708 | 2011 | 5.71 | 25.0% | 20.0% | 15.0% | 83.9% | 69.3% | 6.7% | 25.5% | 2.2% |
| | FLFO_708 | 2012 | 5.73 | 30.4% | 13.0% | 4.3% | 78.3% | 77.6% | 3.5% | 62.4% | 3.2% |
| | FLFO_708 | 2013 | 5.41 | 22.2% | 16.7% | 5.6% | 86.9% | 86.1% | 5.0% | 60.3% | 0.8% |
| | FLFO_708 | 2015 | 5.95 | 36.4% | 13.6% | 4.5% | 117.3% | 115.5% | 7.5% | 6.8% | 1.3% |
| | FLFO_708 | 2016 | 5.53 | 23.5% | 23.5% | 11.8% | 91.0% | 89.3% | 3.0% | 2.7% | 0.8% |
| | FLFO_708 | 2017 | 5.63 | 29.4% | 17.6% | 5.9% | 64.3% | 62.3% | 6.7% | 41.0% | 9.0% |
| | FLFO_708 | 2018 | 5.47 | 29.4% | 29.4% | 11.8% | 56.9% | 56.3% | 1.7% | 67.0% | 1.0% |
| | FLFO_715 | 2010 | 5.88 | 35.3% | 11.8% | – | 100.2% | 99.8% | 4.0% | 74.0% | 5.7% |
| | FLFO_715 | 2011 | 5.00 | 7.7% | 23.1% | 7.7% | 66.2% | 65.7% | – | 1.3% | 3.2% |
| | FLFO_715 | 2012 | 5.25 | 15.8% | 31.6% | 15.8% | 67.4% | 65.5% | 1.5% | 70.7% | 0.3% |
| | FLFO_715 | 2014 | 5.10 | 18.2% | 27.3% | 9.1% | 106.1% | 106.0% | 4.8% | 15.8% | -- |
| | FLFO_715 | 2015 | 5.60 | 31.8% | 22.7% | 9.1% | 116.1% | 115.5% | 10.4% | 25.2% | 0.4% |
| | FLFO_715 | 2017 | 5.43 | 25.0% | 25.0% | 12.5% | 47.2% | 46.7% | 5.3% | 58.3% | 5.0% |
| | FLFO_715 | 2019 | 5.44 | 22.2% | 22.2% | 11.1% | 14.1% | 13.6% | 30.8% | 58.7% | -- |
| Red Barn | FLFO_712 | 2010 | 5.47 | 26.7% | 13.3% | – | 100.0% | 99.6% | 11.6% | 35.4% | 39.0% |
| | FLFO_712 | 2011 | 5.20 | 18.8% | 25.0% | 6.3% | 71.5% | 71.4% | – | – | – |
| | FLFO_712 | 2012 | 5.39 | 25.0% | 25.0% | 10.0% | 79.5% | 79.4% | – | 73.2% | 0.2% |

**Table 35 (continued).** Raw metric values for the Colorado Natural Heritage Program Fen Vegetation Index of Biotic Integrity (VIBI) at Florissant Fossil Beds National Monument, Colorado. C = Conservatism; OBL = obligate wetland species; FACW = facultative wetland species. Metric scores and overall VIBI score are in Table 36.

| Sentinel site complex | Site | Year | Mean C native | Intolerant species | Tolerant species | Nonnative species | Native species (absolute cover) | OBL & FACW species (absolute cover) | Bryophytes (absolute cover) | Litter (absolute cover) | Bare ground (absolute cover) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Red Barn (continued)** | FLFO_712 | 2014 | 5.00 | 16.7% | 33.3% | 15.4% | 148.8% | 65.1% | – | 42.5% | -- |
| | FLFO_712 | 2015 | 5.53 | 28.6% | 19.0% | 9.5% | 158.8% | 158.3% | 0.8% | 18.3% | 0.3% |
| | FLFO_713 | 2010 | 5.06 | 17.6% | 23.5% | 5.9% | 105.0% | 104.8% | – | 85.0% | – |
| | FLFO_713 | 2011 | 5.12 | 22.2% | 22.2% | 5.6% | 80.4% | 80.3% | – | – | – |
| | FLFO_713 | 2012 | 5.33 | 21.1% | 21.1% | 5.3% | 60.4% | 60.2% | – | 78.8% | 0.2% |
| | FLFO_713 | 2014 | 5.31 | 22.2% | 27.8% | 11.1% | 183.1% | 159.1% | – | 51.7% | – |
| | FLFO_713 | 2015 | 5.30 | 23.8% | 14.3% | 4.8% | 189.3% | 187.8% | 9.2% | 47.3% | 0.8% |
| | FLFO_713 | 2017 | 5.06 | 33.3% | 22.2% | 0.0% | 69.6% | 67.8% | – | 88.7% | 0.2% |
| | FLFO_713 | 2019 | 5.00 | 17.6% | 29.4% | 11.8% | 14.6% | 14.1% | 0.2% | 95.8% | – |
| Barksdale | FLFO_705 | 2010 | 5.42 | 11.8% | 11.8% | 8.1% | 164.9% | 99.7% | 36.7% | 31.7% | 8.3% |
| | FLFO_705 | 2011 | 5.67 | 15.2% | 9.1% | 9.1% | 145.8% | 86.4% | 21.6% | 60.2% | 5.2% |
| | FLFO_705 | 2012 | 5.25 | 15.4% | 17.9% | 7.5% | 144.5% | 92.5% | 4.2% | 75.4% | 0.5% |
| | FLFO_705 | 2013 | 5.32 | 15.4% | 20.5% | 12.5% | 120.6% | 72.7% | 19.3% | 59.5% | 2.0% |
| | FLFO_705 | 2014 | 5.41 | 15.6% | 15.6% | 9.1% | 204.9% | 125.6% | 40.0% | 24.5% | 1.3% |
| | FLFO_705 | 2015 | 5.58 | 20.5% | 15.9% | 9.1% | 155.6% | 98.8% | 39.2% | 5.2% | 11.3% |
| | FLFO_705 | 2016 | 5.65 | 18.9% | 10.8% | 8.1% | 137.0% | 80.2% | 18.3% | 9.3% | 7.2% |
| | FLFO_705 | 2017 | 5.46 | 17.9% | 17.9% | 10.3% | 69.3% | 42.1% | 27.2% | 36.5% | 12.5% |
| | FLFO_705 | 2018 | 5.35 | 18.9% | 18.9% | 7.7% | 73.9% | 24.8% | 9.2% | 78.2%% | 4.2% |

**Table 36.** Metric scores for the Colorado Natural Heritage Program Fen Vegetation Index of Biotic Integrity (VIBI) at Florissant Fossil Beds National Monument, Colorado. C = Conservatism; OBL = obligate wetland species; FACW = facultative wetland species; abs. = absolute. Raw metric values are in Table 35, above.

| Sentinel site complex | Site | Year | Mean C native | Intolerant species | Tolerant species (%) | Nonnative species (%) | Native species (abs. cover) | OBL & FACW species (abs. cover) | Bryophytes (abs. cover) | Litter (abs. cover) | Bare ground (abs. cover) | Overall fen VIBI score | Overall fen VIBI class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hornbek | FLFO_708 | 2009 | 0.01 | 1.29 | 10.00 | 10.00 | 1.93 | 2.59 | 0.00 | 0.53 | 9.90 | 4.03 | Moderate |
| | FLFO_708 | 2010 | 4.48 | 3.70 | 5.50 | 8.46 | 4.92 | 5.00 | 3.65 | 4.98 | 9.71 | 5.60 | Moderate |
| | FLFO_708 | 2011 | 3.73 | 2.50 | 4.59 | 5.83 | 4.99 | 4.51 | 0.78 | 3.00 | 9.75 | 4.41 | Moderate |
| | FLFO_708 | 2012 | 3.82 | 3.28 | 6.47 | 8.79 | 4.59 | 5.08 | 0.41 | 7.34 | 9.63 | 5.49 | Moderate |
| | FLFO_708 | 2013 | 2.48 | 2.10 | 5.50 | 8.46 | 5.21 | 5.66 | 0.59 | 7.10 | 9.90 | 5.22 | Moderate |
| | FLFO_708 | 2015 | 4.78 | 4.14 | 6.31 | 8.74 | 7.38 | 7.65 | 0.88 | 0.80 | 9.84 | 5.61 | Moderate |
| | FLFO_708 | 2016 | 2.99 | 2.28 | 3.64 | 6.73 | 5.50 | 5.87 | 0.35 | 0.31 | 9.90 | 4.18 | Moderate |
| | FLFO_708 | 2017 | 3.38 | 3.13 | 5.23 | 8.37 | 3.59 | 4.04 | 0.78 | 4.82 | 8.94 | 4.70 | Moderate |
| | FLFO_708 | 2018 | 2.71 | 3.13 | 2.05 | 6.73 | 3.07 | 3.62 | 0.20 | 7.88 | 9.88 | 4.36 | Moderate |
| | FLFO_715 | 2010 | 4.48 | 3.98 | 6.82 | 10.00 | 6.16 | 6.58 | 0.47 | 8.71 | 9.33 | 6.28 | High |
| | FLFO_715 | 2011 | 0.72 | 0.00 | 3.76 | 7.86 | 3.73 | 4.26 | 0.00 | 0.16 | 9.63 | 3.35 | Low |
| | FLFO_715 | 2012 | 1.79 | 1.17 | 1.47 | 5.61 | 3.82 | 4.25 | 0.18 | 8.31 | 9.96 | 4.06 | Moderate |
| | FLFO_715 | 2014 | 1.15 | 1.51 | 2.63 | 7.47 | 6.58 | 7.01 | 0.57 | 1.86 | 10.00 | 4.31 | Moderate |
| | FLFO_715 | 2015 | 3.28 | 3.48 | 3.86 | 7.47 | 7.30 | 7.65 | 1.22 | 2.96 | 9.95 | 5.24 | Moderate |
| | FLFO_715 | 2017 | 2.55 | 2.50 | 3.24 | 6.53 | 2.37 | 2.97 | 0.63 | 6.86 | 9.41 | 4.12 | Moderate |
| | FLFO_715 | 2019 | 2.59 | 2.10 | 3.99 | 6.91 | 0.01 | 0.72 | 3.63 | 6.90 | 10.00 | 4.09 | Moderate |
| Red Barn | FLFO_712 | 2010 | 2.71 | 2.74 | 6.40 | 10.00 | 6.15 | 6.57 | 1.36 | 4.16 | 5.41 | 5.06 | Moderate |
| | FLFO_712 | 2011 | 1.57 | 1.59 | 3.24 | 8.26 | 4.11 | 4.65 | 0.00 | 0.00 | 10.00 | 3.72 | Low |
| | FLFO_712 | 2012 | 2.38 | 2.50 | 3.24 | 7.22 | 4.68 | 5.20 | 0.00 | 8.61 | 9.98 | 4.87 | Moderate |
| | FLFO_712 | 2014 | 0.72 | 1.29 | 0.99 | 5.73 | 9.63 | 4.22 | 0.00 | 5.00 | 10.00 | 4.18 | Moderate |
| | FLFO_712 | 2015 | 2.96 | 3.01 | 4.85 | 7.35 | 10.00 | 10.57 | 0.10 | 2.16 | 9.96 | 5.66 | Moderate |
| | FLFO_713 | 2010 | 0.99 | 1.44 | 3.64 | 8.37 | 6.50 | 6.93 | 0.00 | 10.00 | 10.00 | 5.32 | Moderate |
| | FLFO_713 | 2011 | 1.22 | 2.10 | 3.99 | 8.46 | 4.74 | 5.26 | 0.00 | 0.00 | 10.00 | 3.97 | Moderate |
| | FLFO_713 | 2012 | 2.14 | 1.93 | 4.31 | 8.54 | 3.31 | 3.89 | 0.00 | 9.27 | 9.98 | 4.82 | Moderate |

**Table 36 (continued).** Metric scores for the Colorado Natural Heritage Program Fen Vegetation Index of Biotic Integrity (VIBI) at Florissant Fossil Beds National Monument, Colorado. C = Conservatism; OBL = obligate wetland species; FACW = facultative wetland species; abs. = absolute. Raw metric values are in Table 35, above.

| Sentinel site complex | Site | Year | Mean C native | Intolerant species | Tolerant species (%) | Nonnative species (%) | Native species (abs. cover) | OBL & FACW species (abs. cover) | Bryophytes (abs. cover) | Litter (abs. cover) | Bare ground (abs. cover) | Overall fen VIBI score | Overall fen VIBI class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Red Barn (continued) | FLFO_713 | 2014 | 2.05 | 2.10 | 2.49 | 6.91 | 10.00 | 10.62 | 0.00 | 6.08 | 10.00 | 5.58 | Moderate |
| | FLFO_713 | 2015 | 2.00 | 2.32 | 6.14 | 8.68 | 10.00 | 12.57 | 1.08 | 5.57 | 9.90 | 6.47 | High |
| | FLFO_713 | 2017 | 0.96 | 3.70 | 3.99 | 10.00 | 3.97 | 4.41 | 0.00 | 10.00 | 9.98 | 5.22 | Moderate |
| | FLFO_713 | 2019 | 0.72 | 1.44 | 2.05 | 6.73 | 0.04 | 0.75 | 0.02 | 10.00 | 10.00 | 3.53 | Low |
| Barksdale | FLFO_705 | 2010 | 2.51 | 0.59 | 6.82 | 7.75 | 10.00 | 6.58 | 4.31 | 3.73 | 9.02 | 5.70 | Moderate |
| | FLFO_705 | 2011 | 3.56 | 1.08 | 7.54 | 7.47 | 9.41 | 5.67 | 2.54 | 7.08 | 9.39 | 5.97 | Moderate |
| | FLFO_705 | 2012 | 1.79 | 1.11 | 5.15 | 7.92 | 9.32 | 6.09 | 0.49 | 8.87 | 9.94 | 5.63 | Moderate |
| | FLFO_705 | 2013 | 2.10 | 1.11 | 4.46 | 6.53 | 7.62 | 4.74 | 2.27 | 7.00 | 9.76 | 5.07 | Moderate |
| | FLFO_705 | 2014 | 2.48 | 1.14 | 5.78 | 7.47 | 10.00 | 8.34 | 4.71 | 2.88 | 9.84 | 5.85 | Moderate |
| | FLFO_705 | 2015 | 3.17 | 1.84 | 5.70 | 7.47 | 10.00 | 6.52 | 4.61 | 0.61 | 8.67 | 5.40 | Moderate |
| | FLFO_705 | 2016 | 3.48 | 1.62 | 7.08 | 7.75 | 8.78 | 5.25 | 2.16 | 1.10 | 9.16 | 5.15 | Moderate |
| | FLFO_705 | 2017 | 2.67 | 1.48 | 5.15 | 7.15 | 3.95 | 2.66 | 3.20 | 4.29 | 8.53 | 4.34 | Moderate |
| | FLFO_705 | 2018 | 2.23 | 1.62 | 4.89 | 7.86 | 4.28 | 1.48 | 1.08 | 9.20 | 9.51 | 4.68 | Moderate |

**Table 37.** Raw metric values for the Colorado Natural Heritage Program Wet Meadow Vegetation Index of Biotic Integrity (VIBI) at Florissant Fossil Beds National Monument, Colorado. Metric scores and overall VIBI score are in Table 38. FQI = Floristic Quality Index; OBL = obligate wetland species; FACW = facultative wetland species.

| Sentinel site complex | Site | Year | Cover-weighted FQI | Intolerant species (count) | Native perennial species (count) | Percent native forb species | Native species (absolute cover) | Perennial species (absoluteco ver) | OBL & FACW species (absolute cover) | Bare ground (absolute cover) | Relative cover Poaceae |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hornbek | FLFO_709 | 2010 | 18.65 | 4.22 | 1.50 | 2.73 | 6.94 | 8.53 | 9.07 | 10.00 | 10.00 |
| | FLFO_709 | 2011 | 17.87 | 3.96 | 1.50 | 2.73 | 9.52 | 4.89 | 4.96 | 7.10 | 10.00 |
| | FLFO_709 | 2012 | 17.67 | 3.90 | 1.00 | 2.42 | 7.29 | 5.51 | 5.94 | 8.03 | 10.00 |

**Table 37 (continued).** Raw metric values for the Colorado Natural Heritage Program Wet Meadow Vegetation Index of Biotic Integrity (VIBI) at Florissant Fossil Beds National Monument, Colorado. Metric scores and overall VIBI score are in Table 38. FQI = Floristic Quality Index; OBL = obligate wetland species; FACW = facultative wetland species.

| Sentinel site complex | Site | Year | Cover-weighted FQI | Intolerant species (count) | Native perennial species (count) | Percent native forb species | Native species (absolute cover) | Perennial species (absolutecover) | OBL & FACW species (absolute cover) | Bare ground (absolute cover) | Relative cover Poaceae |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hornbek (continued) | FLFO_709 | 2014 | 9.23 | 1.17 | 0.50 | 1.52 | 8.33 | 8.72 | 10.00 | 10.00 | 9.72 |
| | FLFO_709 | 2015 | 22.27 | 5.39 | 1.50 | 4.85 | 7.97 | 10.00 | 10.00 | 10.00 | 5.33 |
| | FLFO_709 | 2016 | 22.85 | 5.57 | 2.00 | 4.24 | 8.33 | 8.94 | 8.99 | 10.00 | 9.78 |
| | FLFO_709 | 2017 | 20.33 | 4.76 | 1.50 | 3.03 | 9.38 | 2.94 | 1.90 | 4.39 | 7.33 |
| Red Barn | FLFO_710 | 2009 | 7.07 | 0.48 | 0.00 | 0.00 | 8.33 | 4.40 | 3.70 | 5.92 | 9.83 |
| | FLFO_710 | 2010 | 17.31 | 3.78 | 0.50 | 2.73 | 8.97 | 8.57 | 8.50 | 10.00 | 0.00 |
| | FLFO_710 | 2011 | 16.86 | 3.64 | 1.50 | 2.73 | 8.97 | 5.22 | 4.66 | 6.83 | 10.00 |
| | FLFO_710 | 2012 | 15.24 | 3.11 | 1.50 | 2.12 | 10.00 | 4.68 | 4.04 | 6.24 | 10.00 |
| | FLFO_710 | 2013 | 17.94 | 3.99 | 2.00 | 2.73 | 10.00 | 5.73 | 5.26 | 7.14 | 10.00 |
| | FLFO_710 | 2014 | 13.67 | 2.61 | 1.00 | 1.52 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| | FLFO_710 | 2015 | 21.32 | 5.08 | 2.50 | 4.24 | 10.00 | 10.00 | 10.00 | 10.00 | 0.00 |
| | FLFO_710 | 2016 | 15.87 | 3.32 | 1.00 | 2.42 | 10.00 | 8.68 | 8.68 | 10.00 | 0.56 |
| | FLFO_710 | 2017 | 15.18 | 3.09 | 0.50 | 2.12 | 8.33 | 5.66 | 5.22 | 7.35 | 9.94 |
| | FLFO_710 | 2018 | 18.19 | 4.07 | 2.00 | 2.73 | 10.00 | 5.77 | 5.30 | 7.48 | 9.89 |
| | FLFO_711 | 2010 | 9.91 | 1.39 | 2.00 | 4.85 | 7.97 | 4.46 | 9.67 | 8.30 | 9.44 |
| | FLFO_711 | 2011 | 15.58 | 3.23 | 1.50 | 4.85 | 8.33 | 4.23 | 5.81 | 5.85 | 10.00 |
| | FLFO_711 | 2012 | 7.64 | 0.66 | 2.50 | 5.15 | 7.64 | 0.42 | 1.95 | 2.78 | 9.83 |
| | FLFO_711 | 2014 | 13.36 | 2.51 | 2.00 | 3.64 | 7.89 | 8.85 | 10.00 | 10.00 | 10.00 |
| | FLFO_711 | 2015 | 15.36 | 3.15 | 2.00 | 7.27 | 7.35 | 3.29 | 5.87 | 4.72 | 9.50 |
| | FLFO_711 | 2016 | 11.64 | 1.95 | 2.50 | 5.76 | 8.33 | 5.53 | 10.00 | 8.91 | 9.89 |
| | FLFO_711 | 2017 | 9.99 | 1.42 | 2.00 | 4.85 | 7.25 | 0.29 | 0.98 | 2.07 | 8.72 |

**Table 37 (continued).** Raw metric values for the Colorado Natural Heritage Program Wet Meadow Vegetation Index of Biotic Integrity (VIBI) at Florissant Fossil Beds National Monument, Colorado. Metric scores and overall VIBI score are in Table 38. FQI = Floristic Quality Index; OBL = obligate wetland species; FACW = facultative wetland species.

| Sentinel site complex | Site | Year | Cover-weighted FQI | Intolerant species (count) | Native perennial species (count) | Percent native forb species | Native species (absolute cover) | Perennial species (absolutecover) | OBL & FACW species (absolute cover) | Bare ground (absolute cover) | Relative cover Poaceae |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Barksdale | FLFO_703 | 2009 | 17.37 | 3.80 | 0.50 | 2.12 | 3.85 | 6.32 | 6.05 | 8.12 | 1.56 |
| | FLFO_703 | 2010 | 15.07 | 3.06 | 0.50 | 2.73 | 8.89 | 8.30 | 9.06 | 10.00 | 7.78 |
| | FLFO_703 | 2011 | 18.00 | 4.01 | 0.00 | 3.33 | 6.25 | 7.17 | 7.28 | 9.18 | 8.89 |
| | FLFO_703 | 2012 | 14.25 | 2.79 | 0.00 | 1.82 | 5.56 | 5.46 | 5.19 | 7.37 | 9.89 |
| | FLFO_703 | 2014 | 13.40 | 2.52 | 0.00 | 1.82 | 3.57 | 9.98 | 10.00 | 10.00 | 8.83 |
| | FLFO_703 | 2015 | 16.77 | 3.61 | 0.00 | 3.33 | 2.78 | 6.85 | 6.96 | 8.93 | 8.33 |
| | FLFO_703 | 2016 | 15.82 | 3.30 | 0.00 | 2.73 | 6.25 | 8.17 | 8.25 | 10.00 | 9.00 |
| | FLFO_703 | 2017 | 20.22 | 4.72 | 1.50 | 5.15 | 8.67 | 3.24 | 2.47 | 4.68 | 9.39 |
| | FLFO_704 | 2010 | 12.97 | 2.38 | 0.00 | 2.12 | 6.41 | 8.96 | 8.20 | 10.00 | 8.39 |
| | FLFO_704 | 2011 | 10.62 | 1.62 | 0.50 | 1.21 | 4.55 | 4.70 | 3.59 | 6.50 | 8.61 |
| | FLFO_704 | 2012 | 10.22 | 1.49 | 0.00 | 0.91 | 5.56 | 3.94 | 4.22 | 6.61 | 9.67 |
| | FLFO_704 | 2014 | 12.11 | 2.10 | 0.00 | 2.12 | 6.86 | 9.39 | 10.00 | 10.00 | 7.89 |
| | FLFO_704 | 2015 | 14.74 | 2.95 | 1.00 | 3.33 | 8.33 | 5.65 | 5.99 | 7.45 | 7.39 |
| | FLFO_704 | 2015 | 14.74 | 2.22 | 0.50 | 3.03 | 6.14 | 2.05 | 1.77 | 4.16 | 9.22 |
| | FLFO_704 | 2017 | 12.47 | 1.91 | 0.00 | 2.42 | 7.50 | 0.84 | 0.01 | 1.98 | 8.39 |
| | FLFO_704 | 2019 | 11.50 | 4.22 | 1.50 | 2.73 | 6.94 | 8.53 | 9.07 | 10.00 | 10.00 |

**Table 38.** Metric scores for the Colorado Natural Heritage Program Wet Meadow Vegetation Index of Biotic Integrity (VIBI) at Florissant Fossil Beds National Monument, Colorado. FQI = Floristic Quality Index; OBL = obligate wetland species; FACW = facultative wetland species. Abs. = absolute. Raw metric values are in Table 37.

| Sentinel site complex | Site | Year | Cover-weighted FQI | Intolerant species (count) | Native perennial species (count) | Native forb species | Native species (abs. cover) | Perennial species (abs. cover) | OBL & FACW species (abs. cover) | Bare ground (abs. cover) | Relative cover Poaceae | Overall VIBI score | Overall VIBI class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hornbek | FLFO_709 | 2010 | 18.65 | 3 | 11 | 41.7% | 104.3% | 109.5% | 109.5% | 0.0% | 2.0% | 7.00 | Higher |
| | FLFO_709 | 2011 | 17.87 | 3 | 11 | 57.1% | 65.4% | 71.6% | 71.6% | 0.0% | 1.4% | 6.07 | Higher |
| | FLFO_709 | 2012 | 17.67 | 2 | 10 | 43.8% | 72.0% | 80.7% | 80.7% | 0.0% | 2.6% | 6.01 | Higher |
| | FLFO_709 | 2014 | 9.23 | 1 | 7 | 50.0% | 106.3% | 160.5% | 160.5% | 0.8% | 1.0% | 6.66 | Higher |
| | FLFO_709 | 2015 | 22.27 | 3 | 18 | 47.8% | 138.5% | 140.0% | 140.0% | 14.0% | 2.6% | 7.23 | Higher |
| | FLFO_709 | 2016 | 22.85 | 4 | 16 | 50.0% | 108.7% | 108.7% | 108.7% | 0.7% | 4.5% | 7.54 | Higher |
| | FLFO_709 | 2017 | 20.33 | 3 | 12 | 56.3% | 44.5% | 43.5% | 45.0% | 8.0% | 1.6% | 5.03 | Lower |
| Red Barn | FLFO_710 | 2009 | 7.07 | 0 | 2 | 50.0% | 60.1% | 60.1% | 60.1% | 0.5% | 0.0% | 4.74 | Lower |
| | FLFO_710 | 2010 | 17.31 | 1 | 11 | 53.8% | 104.7% | 104.2% | 104.7% | 75.8% | 0.7% | 5.89 | Higher |
| | FLFO_710 | 2011 | 16.86 | 3 | 11 | 53.8% | 68.9% | 68.9% | 68.9% | 0.0% | 0.8% | 5.95 | Higher |
| | FLFO_710 | 2012 | 15.24 | 3 | 9 | 70.0% | 63.1% | 63.1% | 63.1% | 0.0% | 2.8% | 5.74 | Higher |
| | FLFO_710 | 2013 | 17.94 | 4 | 11 | 69.2% | 74.3% | 74.4% | 72.0% | 0.0% | 8.5% | 6.29 | Higher |
| | FLFO_710 | 2014 | 13.67 | 2 | 7 | 62.5% | 159.5% | 160.5% | 160.5% | 0.0% | 8.9% | 7.21 | Higher |
| | FLFO_710 | 2015 | 21.32 | 5 | 16 | 64.7% | 127.0% | 127.5% | 127.0% | 30.8% | 13.4% | 6.78 | Higher |
| | FLFO_710 | 2016 | 15.87 | 2 | 10 | 60.0% | 105.9% | 105.9% | 105.9% | 28.3% | 3.1% | 6.07 | Higher |
| | FLFO_710 | 2017 | 15.18 | 1 | 9 | 50.0% | 73.5% | 74.0% | 74.0% | 0.2% | 1.2% | 5.80 | Higher |
| | FLFO_710 | 2018 | 18.19 | 4 | 11 | 61.5% | 74.8% | 74.8% | 75.3% | 0.3% | 17.3% | 6.22 | Higher |
| | FLFO_711 | 2010 | 9.91 | 4 | 18 | 47.8% | 60.8% | 114.9% | 83.3% | 1.7% | 55.8% | 5.78 | Higher |
| | FLFO_711 | 2011 | 15.58 | 3 | 18 | 50.0% | 58.3% | 79.5% | 59.3% | 0.0% | 31.9% | 5.64 | Higher |
| | FLFO_711 | 2012 | 7.64 | 5 | 19 | 45.8% | 17.5% | 43.9% | 29.2% | 0.5% | 62.2% | 3.79 | Lower |
| | FLFO_711 | 2014 | 13.36 | 4 | 14 | 47.4% | 107.7% | 147.3% | 104.5% | 0.0% | 30.0% | 6.89 | Higher |
| | FLFO_711 | 2015 | 15.36 | 4 | 26 | 44.1% | 48.2% | 80.0% | 48.2% | 1.5% | 47.5% | 5.35 | Higher |
| | FLFO_711 | 2016 | 11.64 | 5 | 21 | 50.0% | 72.2% | 133.4% | 89.3% | 0.3% | 46.2% | 6.45 | Higher |
| | FLFO_711 | 2017 | 9.99 | 4 | 18 | 43.5% | 16.1% | 35.0% | 22.2% | 3.8% | 62.1% | 3.42 | Lower |
| Barksdale | FLFO_703 | 2009 | 17.37 | 1 | 9 | 23.1% | 80.6% | 81.6% | 81.6% | 25.3% | 0.4% | 4.70 | Lower |
| | FLFO_703 | 2010 | 15.07 | 1 | 11 | 53.3% | 101.8% | 109.4% | 109.4% | 6.7% | 0.0% | 6.70 | Higher |
| | FLFO_703 | 2011 | 18.00 | 0 | 13 | 37.5% | 89.7% | 92.9% | 91.9% | 3.3% | 0.2% | 6.23 | Higher |
| | FLFO_703 | 2012 | 14.25 | 0 | 8 | 33.3% | 71.4% | 73.7% | 74.2% | 0.3% | 0.0% | 5.34 | Higher |
| | FLFO_703 | 2014 | 13.40 | 0 | 8 | 21.4% | 119.8% | 130.4% | 130.4% | 3.5% | 4.7% | 6.30 | Higher |
| | FLFO_703 | 2015 | 16.77 | 0 | 13 | 16.7% | 86.3% | 90.0% | 89.5% | 5.0% | 0.9% | 5.64 | Higher |
| | FLFO_703 | 2016 | 15.82 | 0 | 11 | 37.5% | 100.4% | 101.9% | 101.4% | 3.0% | 0.7% | 6.41 | Higher |
| | FLFO_703 | 2017 | 20.22 | 3 | 19 | 52.0% | 47.7% | 48.7% | 47.9% | 1.8% | 3.5% | 5.54 | Higher |
| | FLFO_704 | 2010 | 12.97 | 0 | 9 | 38.5% | 108.8% | 101.5% | 111.4% | 4.8% | 9.9% | 6.23 | Higher |
| | FLFO_704 | 2011 | 10.62 | 1 | 6 | 27.3% | 63.3% | 59.0% | 65.7% | 4.2% | 7.7% | 4.58 | Lower |
| | FLFO_704 | 2012 | 10.22 | 0 | 5 | 33.3% | 55.1% | 64.8% | 66.8% | 1.0% | 5.3% | 4.71 | Lower |
| | FLFO_704 | 2014 | 12.11 | 0 | 9 | 41.2% | 113.5% | 140.4% | 130.0% | 6.3% | 15.5% | 6.37 | Higher |

**Table 38 (continued).** Metric scores for the Colorado Natural Heritage Program Wet Meadow Vegetation Index of Biotic Integrity (VIBI) at Florissant Fossil Beds National Monument, Colorado. FQI = Floristic Quality Index; OBL = obligate wetland species; FACW = facultative wetland species. Abs. = absolute. Raw metric values are in Table 37.

| Sentinel site complex | Site | Year | Cover-weighted FQI | Intolerant species (count) | Native perennial species (count) | Native forb species | Native species (abs. cover) | Perennial species (abs. cover) | OBL & FACW species (abs. cover) | Bare ground (abs. cover) | Relative cover Poaceae | Overall VIBI score | Overall VIBI class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barksdale (continued) | FLFO_704 | 2015 | 14.74 | 2 | 13 | 50.0% | 73.5% | 81.1% | 75.0% | 7.8% | 5.1% | 5.79 | Higher |
| | FLFO_704 | 2015 | 14.74 | 2 | 13 | 50.0% | 73.5% | 81.1% | 75.0% | 7.8% | 5.1% | 4.04 | Lower |
| | FLFO_704 | 2017 | 12.47 | 1 | 12 | 36.8% | 34.9% | 42.2% | 42.7% | 2.3% | 29.1% | 3.49 | Lower |
| | FLFO_704 | 2019 | 11.50 | 0 | 10 | 45.0% | 21.9% | 26.1% | 21.4% | 4.8% | 20.1% | 7.00 | Higher |

# Appendix 8 Vegetation Taxa List

A checklist of vascular plants of Florissant Fossil Beds National Monument (FLFO) was created by Edwards and Weber in 1990, following eight years of surveying (Edwards and Weber 1990). The list was updated in 2002 by the Colorado Natural Heritage Program (CNHP; Spackman Panjabi and Anderson 2002). The original species list was very inclusive and documented over 430 taxa in the park. CNHP added a few species to the list and improved documentation on the distribution of rare plants that occur on the unique volcanic ash deposits around FLFO. The park's rare plant species include grassyslope sedge (*Carex oreocharis*), New Mexico cliff fern (*Woodsia neomexicana*), pale blue-eyed grass (*Sisyrinchium pallidum*), and prairie goldenrod *(Solidago ptarmicoides,* syn. *Unamia alba* or *Oligoneuron album*). Additional botanical work has included inventorying and mapping exotic species. The most common invasive exotic species found in FLFO wetlands include Canada thistle (*Cirsium arvense*), musk thistle (*Carduus nutans* ssp. *macrocephalus*), reed canary grass (*Phalaris arundinacea*), and butter-and-eggs (*Linaria vulgaris*) (Edwards and Weber 1990; Spackman Panjabi and Anderson 2002). New exotic species are periodically being discovered in FLFO and are of varying degrees of concern based on invasiveness, difficulty of control, and preferred habitat. Tables 39 and 40 present all vascular and nonvascular taxa, respectively, found in Rocky Mountain Network wetland sampling in FLFO from 2009 to 2019.

**Table 39.** Complete list of vascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. For an explanation of C-value (coefficients of conservatism) and invasiveness (I-rank scores) see sections 3.4.5 and 3.4.3.2, respectively, in the main narrative. Nomenclature follows Ackerfield (2015).

| Family | Taxa | Common name | C-value | I-rank Score | Frequency | Mean absolute cover |
|---|---|---|---|---|---|---|
| Alliaceae | *Allium* | – | – | – | 2 | 0.39 |
| Apiaceae | *Angelica ampla* | giant angelica | 4 | – | 3 | 0.53 |
| | *Cicuta maculata* | spotted water hemlock | 3 | – | 14 | 2.06 |
| | *Heracleum maximum* | common cowparsnip | 6 | – | 5 | 0.77 |
| | *Osmorhiza* | – | – | – | 1 | 0.50 |
| | *Osmorhiza depauperata* | bluntseed sweetroot | 7 | – | 1 | 2.40 |
| Araceae | *Lemna minor* | common duckweed | 2 | – | 2 | 3.85 |
| Asteraceae | *Achillea* | – | – | – | 1 | 0.05 |
| | *Achillea millefolium* | common yarrow | 4 | – | 36 | 1.39 |
| | *Agoseris glauca* | pale agoseris | 7 | – | 1 | 0.50 |
| | *Artemisia biennis* var. *biennis* | biennial wormwood | 0 | – | 2 | 0.36 |
| | *Artemisia frigida* | prairie sagewort | 4 | – | 9 | 0.63 |
| | *Asteraceae* | – | – | – | 1 | 5.21 |
| | *Bidens cernua* | nodding beggartick | 5 | – | 1 | 1.01 |
| | *Cirsium* | – | – | – | 1 | 0.05 |
| | *Cirsium arvense* | Canada thistle | 0 | 8 | 55 | 2.09 |
| | *Cirsium scariosum* | meadow thistle | 6 | – | 23 | 1.63 |
| | *Cirsium vulgare* | bull thistle | 0 | 4 | 1 | 2.00 |
| | *Crepis runcinata* ssp. *runcinata* | fiddleleaf hawksbeard | 6 | – | 2 | 0.28 |
| | *Erigeron* | – | – | – | 1 | 4.60 |
| | *Erigeron flagellaris* | trailing fleabane | 3 | – | 1 | 0.50 |
| | *Erigeron glabellus* | streamside fleabane | 6 | – | 1 | 2.58 |

**Table 39 (continued).** Complete list of vascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. For an explanation of C-value (coefficients of conservatism) and invasiveness (I-rank scores) see sections 3.4.5 and 3.4.3.2, respectively, in the main narrative. Nomenclature follows Ackerfield (2015).

| Family | Taxa | Common name | C-value | I-rank Score | Frequency | Mean absolute cover |
|---|---|---|---|---|---|---|
| Asteraceae (continued) | *Erigeron philadelphicus* var. *philadelphicus* | Philadelphia fleabane | 9 | – | 4 | 0.64 |
| | *Erigeron vreelandii* | Vreeland's erigeron | – | – | 1 | 1.50 |
| | *Packera fendleri* | Fendler's ragwort | 4 | – | 2 | 1.26 |
| | *Packera pseudaurea* var. *flavula* | falsegold groundsel | 7 | – | 10 | 3.13 |
| | *Senecio eremophilus* var. *kingii* | King's ragwort | 4 | – | 7 | 2.15 |
| | *Solidago* | – | – | – | 1 | 0.50 |
| | *Symphyotrichum lanceolatum* ssp. *hesperium* | white panicle aster | 5 | – | 19 | 2.70 |
| | *Taraxacum officinale* | common dandelion | 0 | – | 15 | 0.33 |
| Boraginaceae | *Mertensia ciliata* | tall fringed bluebells | 7 | – | 9 | 3.79 |
| Brassicaceae | *Brassicaceae* | – | – | – | 1 | 1.50 |
| | *Cardamine* | – | – | – | 1 | 0.05 |
| | *Descurainia* | – | – | – | 1 | 0.50 |
| | *Descurainia pinnata* ssp. *brachycarpa* | western tansymustard | 2 | – | 2 | 0.28 |
| | *Erysimum cheiranthoides* | wormseed wallflower | 0 | – | 1 | 0.76 |
| | *Lepidium* | – | – | – | 1 | 0.50 |
| | *Lepidium alyssoides* | mesa pepperwort | 3 | – | 2 | 3.88 |
| | *Lepidium densiflorum* | common pepperweed | 0 | – | 1 | 2.35 |
| | *Lepidium lasiocarpum* ssp. *lasiocarpum* | shaggyfruit pepperweed | 5 | – | 1 | 0.50 |
| | *Lepidium ramosissimum* | manybranched pepperweed | 2 | – | 1 | 0.50 |

**Table 39 (continued).** Complete list of vascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. For an explanation of C-value (coefficients of conservatism) and invasiveness (I-rank scores) see sections 3.4.5 and 3.4.3.2, respectively, in the main narrative. Nomenclature follows Ackerfield (2015).

| Family | Taxa | Common name | C-value | I-rank Score | Frequency | Mean absolute cover |
|---|---|---|---|---|---|---|
| Brassicaceae (continued) | *Lepidium virginicum* | Virginia pepperweed | 2 | – | 1 | 0.50 |
| | *Rorippa* | – | – | – | 3 | 0.31 |
| | *Rorippa curvipes* var. *truncata* | bluntleaf yellowcress | 5 | – | 10 | 1.08 |
| | *Rorippa sinuata* | spreading yellowcress | 4 | – | 14 | 0.76 |
| | *Rorippa sphaerocarpa* | roundfruit yellowcress | 4 | – | 2 | 0.50 |
| | *Thelypodium sagittatum* ssp. *sagittatum* | arrow thelypody | 7 | – | 1 | 0.05 |
| | *Thlaspi arvense* | field pennycress | 0 | 2 | 22 | 1.85 |
| Caryophyllaceae | *Cerastium* | – | – | – | 3 | 2.98 |
| | *Stellaria* | – | – | – | 4 | 8.36 |
| | *Stellaria crassifolia* | fleshy starwort | 7 | – | 2 | 0.76 |
| | *Stellaria longifolia* | longleaf starwort | 7 | – | 4 | 0.73 |
| | *Stellaria longipes* | longstalk starwort | 8 | – | 25 | 2.62 |
| | *Stellaria obtusa* | Rocky Mountain chickweed | 9 | – | 1 | 1.93 |
| Chenopodiaceae | *Chenopodium* | – | – | – | 3 | 0.35 |
| | *Chenopodium leptophyllum* | narrowleaf goosefoot | 5 | – | 1 | 0.50 |
| Cupressaceae | *Juniperus communis* var. *depressa* | common juniper | 6 | – | 9 | 1.39 |
| Cyperaceae | *Carex* | – | – | – | 8 | 25.02 |
| | *Carex aquatilis* | water sedge | 6 | – | 54 | 19.52 |
| | *Carex disperma* | softleaf sedge | 9 | – | 8 | 7.00 |
| | *Carex nebrascensis* | Nebraska sedge | 5 | – | 39 | 21.12 |

**Table 39 (continued).** Complete list of vascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. For an explanation of C-value (coefficients of conservatism) and invasiveness (I-rank scores) see sections 3.4.5 and 3.4.3.2, respectively, in the main narrative. Nomenclature follows Ackerfield (2015).

| Family | Taxa | Common name | C-value | I-rank Score | Frequency | Mean absolute cover |
|---|---|---|---|---|---|---|
| Cyperaceae (continued) | *Carex pellita* | woolly sedge | 6 | – | 9 | 5.43 |
| | *Carex praegracilis* | clustered field sedge | 5 | – | 1 | 0.52 |
| | *Carex simulata* | analogue sedge | 6 | – | 29 | 8.19 |
| | *Carex utriculata* | beaked sedge | 5 | – | 50 | 24.79 |
| | *Eleocharis palustris* | common spikerush | 3 | – | 8 | 0.55 |
| Equisetaceae | *Equisetum arvense* | field horsetail | 4 | – | 9 | 0.55 |
| Fabaceae | *Astragalus* | – | – | – | 6 | 1.02 |
| | *Astragalus alpinus* | alpine milkvetch | 6 | – | 3 | 0.68 |
| | *Astragalus lentiginosus* | freckled milkvetch | 5 | – | 3 | 1.82 |
| | *Oxytropis* | – | – | – | 2 | 0.16 |
| | *Oxytropis splendens* | showy locoweed | 6 | – | 3 | 0.50 |
| | *Trifolium* | – | – | – | 3 | 0.85 |
| | *Trifolium hybridum* | alsike clover | 0 | 4 | 6 | 0.69 |
| | *Trifolium repens* | white clover | 0 | 4 | 2 | 0.28 |
| | *Vicia* | – | – | – | 2 | 0.78 |
| | *Vicia americana* | American vetch | 5 | – | 6 | 0.92 |
| Gentianaceae | *Gentiana fremontii* | moss gentian | 9 | – | 3 | 0.20 |
| | *Lomatogonium rotatum* | marsh felwort | 9 | – | 10 | 0.40 |
| Geraniaceae | *Geranium caespitosum* | pineywoods geranium | 6 | – | 4 | 1.17 |
| | *Geranium richardsonii* | Richardson's geranium | 6 | – | 7 | 1.44 |
| Grossulariaceae | *Ribes inerme* | whitestem gooseberry | 5 | – | 9 | 1.27 |
| Iridaceae | *Iris missouriensis* | Rocky Mountain iris | 4 | – | 7 | 1.71 |

**Table 39 (continued).** Complete list of vascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. For an explanation of C-value (coefficients of conservatism) and invasiveness (I-rank scores) see sections 3.4.5 and 3.4.3.2, respectively, in the main narrative. Nomenclature follows Ackerfield (2015).

| Family | Taxa | Common name | C-value | I-rank Score | Frequency | Mean absolute cover |
|---|---|---|---|---|---|---|
| Juncaceae | *Juncus arcticus* var. *balticus* | mountain rush | 4 | – | 65 | 11.71 |
| | *Juncus longistylis* | longstyle rush | 6 | – | 1 | 0.50 |
| Juncaginaceae | *Triglochin maritima* | seaside arrowgrass | 6 | – | 6 | 0.52 |
| | *Triglochin palustris* | marsh arrowgrass | 7 | – | 8 | 0.90 |
| Lamiaceae | *Dracocephalum parviflorum* | American dragonhead | 3 | – | 4 | 1.01 |
| | *Mentha arvensis* | wild mint | 4 | – | 20 | 1.04 |
| | *Scutellaria galericulata* | marsh skullcap | 7 | – | 24 | 2.58 |
| Linaceae | *Linum lewisii* | Lewis flax | 4 | – | 7 | 1.05 |
| Montiaceae | *Montia chamissoi* | water minerslettuce | 8 | – | 26 | 6.30 |
| Onagraceae | *Chamerion angustifolium* | fireweed | 4 | – | 9 | 0.88 |
| | *Epilobium* | – | – | – | 12 | 2.65 |
| | *Epilobium anagallidifolium* | pimpernel willowherb | 6 | – | 3 | 7.00 |
| | *Epilobium ciliatum* ssp. *ciliatum* | fringed willowherb | 3 | – | 57 | 3.28 |
| | *Epilobium hornemannii* | Hornemann's willowherb | 6 | – | 7 | 2.79 |
| | *Epilobium leptocarpum* | slenderfruit willowherb | – | – | 2 | 3.60 |
| | *Epilobium palustre* var. *gracile* | bog willowherb | 8 | – | 3 | 0.50 |
| Orchidaceae | *Spiranthes romanzoffiana* | hooded lady's tresses | 7 | – | 1 | 0.05 |
| Pinaceae | *Picea pungens* | blue spruce | 6 | – | 9 | 44.47 |
| | *Pinus ponderosa* var. *scopulorum* | ponderosa pine | 5 | – | 2 | 2.75 |
| Plantaginaceae | *Besseya plantaginea* | White River coraldrops | 8 | – | 4 | 0.39 |
| | *Besseya wyomingensis* | Wyoming besseya | 6 | – | 1 | 0.05 |
| | *Linaria vulgaris* | butter and eggs | 0 | 7 | 3 | 1.85 |

**Table 39 (continued).** Complete list of vascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. For an explanation of C-value (coefficients of conservatism) and invasiveness (I-rank scores) see sections 3.4.5 and 3.4.3.2, respectively, in the main narrative. Nomenclature follows Ackerfield (2015).

| Family | Taxa | Common name | C-value | I-rank Score | Frequency | Mean absolute cover |
|---|---|---|---|---|---|---|
| Plantaginaceae (continued) | *Veronica* | – | – | – | 4 | 2.68 |
| | *Veronica americana* | American speedwell | 6 | – | 7 | 0.55 |
| | *Veronica anagallis-aquatica* | water speedwell | 1 | – | 8 | 0.65 |
| | *Veronica peregrina* ssp. *xalapensis* | hairy purslane speedwell | 2 | – | 4 | 0.28 |
| | *Veronica wormskjoldii* | American alpine speedwell | 7 | – | 1 | 0.05 |
| Poaceae | *Agrostis* | – | – | – | 1 | 0.53 |
| | *Agrostis gigantea* | redtop | 0 | 4 | 6 | 2.81 |
| | *Agrostis scabra* | rough bentgrass | 4 | – | 7 | 0.70 |
| | *Alopecurus aequalis* | shortawn foxtail | 4 | – | 8 | 0.80 |
| | *Anthoxanthum hirtum* | northern sweetgrass | 9 | – | 2 | 0.28 |
| | *Beckmannia syzigachne* | American sloughgrass | 4 | – | 7 | 2.90 |
| | *Bromus inermis* | smooth brome | 0 | 8 | 8 | 17.20 |
| | *Bromus porteri* | Porter brome | 5 | – | 1 | 1.00 |
| | *Calamagrostis canadensis* | bluejoint | 6 | – | 14 | 7.98 |
| | *Calamagrostis stricta* | slimstem reedgrass | 7 | – | 24 | 6.76 |
| | *Deschampsia cespitosa* | tufted hairgrass | 4 | – | 44 | 5.57 |
| | *Elymus repens* | quackgrass | 0 | 8 | 8 | 2.94 |
| | *Elymus trachycaulus* | slender wheatgrass | 4 | – | 17 | 1.16 |
| | *Glyceria grandis* | American mannagrass | 6 | – | 5 | 3.95 |
| | *Glyceria striata* | fowl mannagrass | 5 | – | 9 | 4.18 |
| | *Hordeum* | – | – | – | 2 | 1.36 |

**Table 39 (continued).** Complete list of vascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. For an explanation of C-value (coefficients of conservatism) and invasiveness (I-rank scores) see sections 3.4.5 and 3.4.3.2, respectively, in the main narrative. Nomenclature follows Ackerfield (2015).

| Family | Taxa | Common name | C-value | I-rank Score | Frequency | Mean absolute cover |
|---|---|---|---|---|---|---|
| Poaceae (continued) | *Hordeum brachyantherum* | meadow barley | 4 | – | 26 | 2.35 |
| | *Hordeum jubatum* | foxtail barley | 2 | – | 5 | 1.02 |
| | *Koeleria macrantha* | prairie Junegrass | 6 | – | 7 | 0.59 |
| | *Muhlenbergia* | – | – | – | 2 | 0.28 |
| | *Nassella viridula* | green needlegrass | 4 | – | 4 | 0.51 |
| | *Pascopyrum smithii* | western wheatgrass | 5 | – | 12 | 1.15 |
| | *Phalaris arundinacea* | reed canarygrass | 1 | 9 | 9 | 5.80 |
| | *Poa palustris* | fowl bluegrass | 6 | | 31 | 2.81 |
| | *Poa pratensis* | Kentucky bluegrass | 0 | 6 | 36 | 5.82 |
| | *Poaceae* | – | – | – | 4 | 1.32 |
| Polemoniaceae | *Polemonium* | – | – | – | 1 | 0.05 |
| Polygonaceae | *Persicaria amphibia* | longroot smartweed | 4 | – | 5 | 0.44 |
| | *Persicaria maculosa* | spotted ladysthumb | 0 | – | 1 | 0.05 |
| | *Polygonum* | – | – | – | 1 | 1.50 |
| | *Rumex crispus* | curly dock | 0 | 2 | 6 | 2.24 |
| | *Rumex densiflorus* | denseflowered dock | 5 | – | 1 | 0.50 |
| | *Rumex occidentalis* | western dock | 5 | – | 59 | 2.13 |
| | *Rumex stenophyllus* | narrowleaf dock | 0 | – | 9 | 1.38 |
| Portulacaceae | *Portulaca oleracea* | little hogweed | 0 | – | 3 | 2.73 |
| Primulaceae | *Androsace septentrionalis* | pygmyflower rockjasmine | 6 | – | 4 | 0.50 |
| | *Dodecatheon pulchellum* | darkthroat shootingstar | 8 | – | 18 | 0.62 |
| Ranunculaceae | *Actaea rubra* | red baneberry | 9 | – | 3 | 0.35 |

**Table 39 (continued).** Complete list of vascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. For an explanation of C-value (coefficients of conservatism) and invasiveness (I-rank scores) see sections 3.4.5 and 3.4.3.2, respectively, in the main narrative. Nomenclature follows Ackerfield (2015).

| Family | Taxa | Common name | C-value | I-rank Score | Frequency | Mean absolute cover |
|---|---|---|---|---|---|---|
| Ranunculaceae (continued) | *Ranunculus* | – | – | – | 7 | 1.22 |
| | *Ranunculus abortivus* | littleleaf buttercup | 5 | – | 1 | 0.50 |
| | *Ranunculus acriformis* | sharpleaf buttercup | 6 | – | 4 | 0.92 |
| | *Ranunculus cardiophyllus* | heartleaf buttercup | 8 | – | 6 | 0.64 |
| | *Ranunculus cymbalaria* | alkali buttercup | 4 | – | 8 | 0.51 |
| | *Ranunculus hyperboreus* | high northern buttercup | 8 | – | 22 | 1.32 |
| | *Ranunculus macounii* | Macoun's buttercup | 7 | – | 10 | 0.98 |
| | *Ranunculus uncinatus* | woodland buttercup | 6 | – | 1 | 1.21 |
| Rosaceae | *Fragaria* | – | – | – | 4 | 0.40 |
| | *Fragaria vesca* | woodland strawberry | 5 | – | 3 | 0.20 |
| | *Fragaria virginiana* | Virginia strawberry | 5 | – | 4 | 0.28 |
| | *Geum macrophyllum* var. *perincisum* | largeleaf avens | 6 | – | 11 | 1.41 |
| | *Potentilla* | – | – | – | 2 | 1.00 |
| | *Potentilla anserina* | silverweed cinquefoil | 3 | – | 57 | 1.86 |
| | *Potentilla biennis* | biennial cinquefoil | 4 | – | 5 | 1.71 |
| | *Potentilla fruticosa* | shrubby cinquefoil | 4 | – | 17 | 1.73 |
| | *Potentilla norvegica* | Norwegian cinquefoil | 1 | – | 3 | 3.22 |
| | *Rosa woodsii* | Woods' rose | 5 | – | 9 | 1.28 |
| Rubiaceae | *Galium trifidum* ssp. *subbiflorum* | threepetal bedstraw | 7 | – | 19 | 0.46 |
| | *Galium triflorum* | fragrant bedstraw | 7 | – | 1 | 0.50 |

**Table 39 (continued).** Complete list of vascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2019. For an explanation of C-value (coefficients of conservatism) and invasiveness (I-rank scores) see sections 3.4.5 and 3.4.3.2, respectively, in the main narrative. Nomenclature follows Ackerfield (2015).

| Family | Taxa | Common name | C-value | I-rank Score | Frequency | Mean absolute cover |
|---|---|---|---|---|---|---|
| Salicaceae | *Populus tremuloides* | quaking aspen | 5 | – | 1 | |
| | *Salix monticola* | park willow | 6 | – | 9 | 1.55 |
| | *Salix planifolia* | diamondleaf willow | 7 | – | 3 | 1.33 |
| Valerianaceae | *Valeriana edulis* | tobacco root | 7 | – | 7 | 0.38 |
| Violaceae | *Viola* | – | – | – | 4 | 0.43 |

**Table 40.** Complete list of nonvascular taxa documented in wetland monitoring sentinel sites at Florissant Fossil Beds National Monument, Colorado, from 2010 to 2015. Nonvascular species were not sampled in 2016–2019.

| Family | Taxa | Frequency | Mean absolute cover |
|---|---|---|---|
| Amblystegiaceae | *Amblystegium* | 5 | 12.46 |
| | *Campylium chrysophyllum* | 1 | 0.50 |
| | *Conardia compacta* | 1 | 5.60 |
| | *Drepanocladus aduncus* | 2 | 0.54 |
| | *Hygroamblystegium fluviatile* | 1 | 0.58 |
| | *Leptodictyum humile* | 2 | 1.30 |
| Aulacomniaceae | *Aulacomnium palustre* | 5 | 4.17 |
| Bartramiaceae | *Philonotis marchica* | 5 | 21.35 |
| Bryaceae | *Bryum* | 5 | 2.13 |
| | *Bryum argenteum* | 1 | 0.25 |
| | *Bryum pseudotriquetrum* | 10 | 0.92 |
| Climaciaceae | *Climacium dendroides* | 5 | 4.38 |
| Ditrichaceae | *Ceratodon purpureus* | 1 | 0.50 |
| Funariaceae | *Funaria hygrometrica* | 1 | 0.50 |
| Meesiaceae | *Leptobryum pyriforme* | 1 | 0.25 |
| Mniaceae | *Plagiomnium ellipticum* | 6 | 14.00 |
| Pottiaceae | *Pottiaceae* | 1 | 0.25 |
| Pottiaceae | *Tortula* | 2 | 0.04 |

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**Natural Resource Stewardship and Science**
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525