



Analysis of Soils at the National Park Service Weippe Prairie Site

Final Report Under Rocky Mountain Cooperative Ecosystem Studies Unit Cooperative Agreement H1200090004

Natural Resource Technical Report NPS/NEPE/NRTR—2014/914



ON THE COVER

Camassia quamash (Pursh) Greene at the Weippe Prairie, Idaho
Photograph by Anita L. Falen, University of Idaho

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Executive Summary

This project (H120009004) was initiated to provide baseline information about soils of the Nez Perce National Historical Park (NEPE) Weippe Prairie site. In the Fall 2011, three sites representing a range in landscape position and camas density were described and sampled for a suite of chemical, physical, mineralogical analyses. In addition, equipment was installed at all three sites to monitor seasonal changes in soil moisture content at 15- and 40-cm depths, soil temperature at 15-cm, and water table levels. Six sites installed in the Fall 2007 under RM-CESU Cooperative Agreement No. H2000040001 continued to have hydrological monitoring and data collected showing temporal changes in soil moisture and temperature as well as water table levels along with the three new sites.

Results indicate that soils of the Weippe Prairie are primarily of alluvial and lacustrine origin. Because they occupy a broad, relatively low-lying plain, they are often waterlogged during the winter and spring months. This is due, in part, to the presence of dense, slowly permeable subsoil horizons that impede drainage and help create perched water tables. Laboratory analyses revealed that these soils tend to have textures dominated by silt and clay, and are very strongly acid. Kaolin is the predominant mineral found in the clay fractions of these soils, which have also been influenced by more recent additions of volcanic ash and loess.

Hydrological monitoring indicates that all soils have water tables present for approximately 5-7 months per year. At the wettest sites, water tables are very near or above the soil surface for the majority of time during which the soils are saturated.

Results of this project do not indicate that a specific soil property is related to observed differences in camas density at the Weippe Prairie. It may be that factors such as disturbance and past management are more influential than edaphic factors in this regard. However, this project does provide site-specific, baseline information about soils of the NEPE Weippe Prairie site. This information can, in turn, be used to guide informed management strategies and contribute to a better understanding of the edaphic factors related to camas ecology in the region.

Acknowledgments

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Introduction

Camas (*Camassia quamash* [Pursh] Greene) is a plant of considerable cultural and historical significance in National Park Service (NPS) Nez Perce National Historical Park (NEPE). Because of this, a camas monitoring protocol has been developed by the Upper Columbia Basin Network Inventory and Monitoring Program in cooperation with NEPE staff to track population status and trends (Rodhouse and Jocius, 2009). This protocol specifically targets the existing site camas populations and has been designed to provide the park with information on the health of this focal species.

Any effort to monitor and evaluate ecological trends should include careful consideration of soil resources. Soils of the NPS Weippe Prairie site have been mapped by the Natural Resources Conservation Service as part of the Soil Survey of the Clearwater Area, Idaho. However, the map scale is not suitable for site-specific interpretations, nor does the survey provide detailed soil characterization data. Therefore, as a contribution to the camas monitoring effort, NEPE has sought a better understanding of the nature and condition of soils of the Weippe Prairie site. The project described in this report was initiated in Fall 2011 to address this need and to augment ongoing camas monitoring efforts. The overall goal of the project was to build on previous soil/hydrology work done at the Weippe Prairie study site.

Specific objectives of this research were to:

- Characterize the important morphological, chemical, physical, and mineralogical properties of soils at three additional sites.
- Monitor temporal changes in soil water table levels and soil moisture content at the three additional soils/sites.
- Continue to monitor soil water table levels and soil moisture content in already established sites.

This report summarizes the new information gained about soil resources at the Weippe Prairie during the course of this research project. It also summarizes the hydrological monitoring conducted at all sites from Fall 2007 to Summer 2014, a portion of which was presented in the 2010 project report (RM-CESU Cooperative Agreement No. H2000040001).

Methods

Site Selection

In Fall 2011, 3 additional locations at the National Park Service Weippe Prairie Site were selected for soil sampling, laboratory characterization, and monitoring of soil moisture and water table levels. Locations were chosen to represent the range in soil drainage and camas density observed across the site (Table 1). The sampling/monitoring locations selected for this project (hereafter referred to as sites) are shown in Figure 1.

Table 1. Sampling/monitoring sites with GPS coordinates, drainage, and camas management zone.

Site	Latitude °N	Longitude °W	Drainage ¹	Camas management zone ²
7	46.359611	115.924222	moderately well	E
8	46.360194	115.923389	poor	E
9	46.350806	115.926167	somewhat poor	C

¹ based on soil morphology and Soil Survey Staff (2008)

² after Rodhouse and Jocius (2009)

Field Sampling

At each site, a soil pit was excavated by hand. Sod was carefully removed and set aside in an effort to minimize disturbance to camas and other vegetation. Soils were described and sampled using standard methodology (Schoeneberger et al., 2002) and photographed. Bulk samples were collected from each of the genetic horizons for laboratory analyses.

Installation of Monitoring Equipment

Duplicate soil moisture sensors (Model EC-5, Decagon Devices, Pullman, WA) were installed horizontally at depths of 15 cm and 40 cm in each soil. The 15-cm depth was chosen because it represents the depth below which camas bulbs were generally not observed. The 40-cm depth was chosen because it represents the bottom of the zone containing the bulk of plant roots. A soil/air temperature sensor (Decagon Devices, Pullman, WA) was also installed at a depth of 15 cm. All sensor wiring was covered with a rodent-proof plastic sleeve. At each site, all sensors were connected to a data logger (Model Em5b, Decagon Devices, Pullman, WA) mounted on a steel fence post (Figure 2a). Soil pits were refilled and the sod saved from the excavation was replaced at the surface.

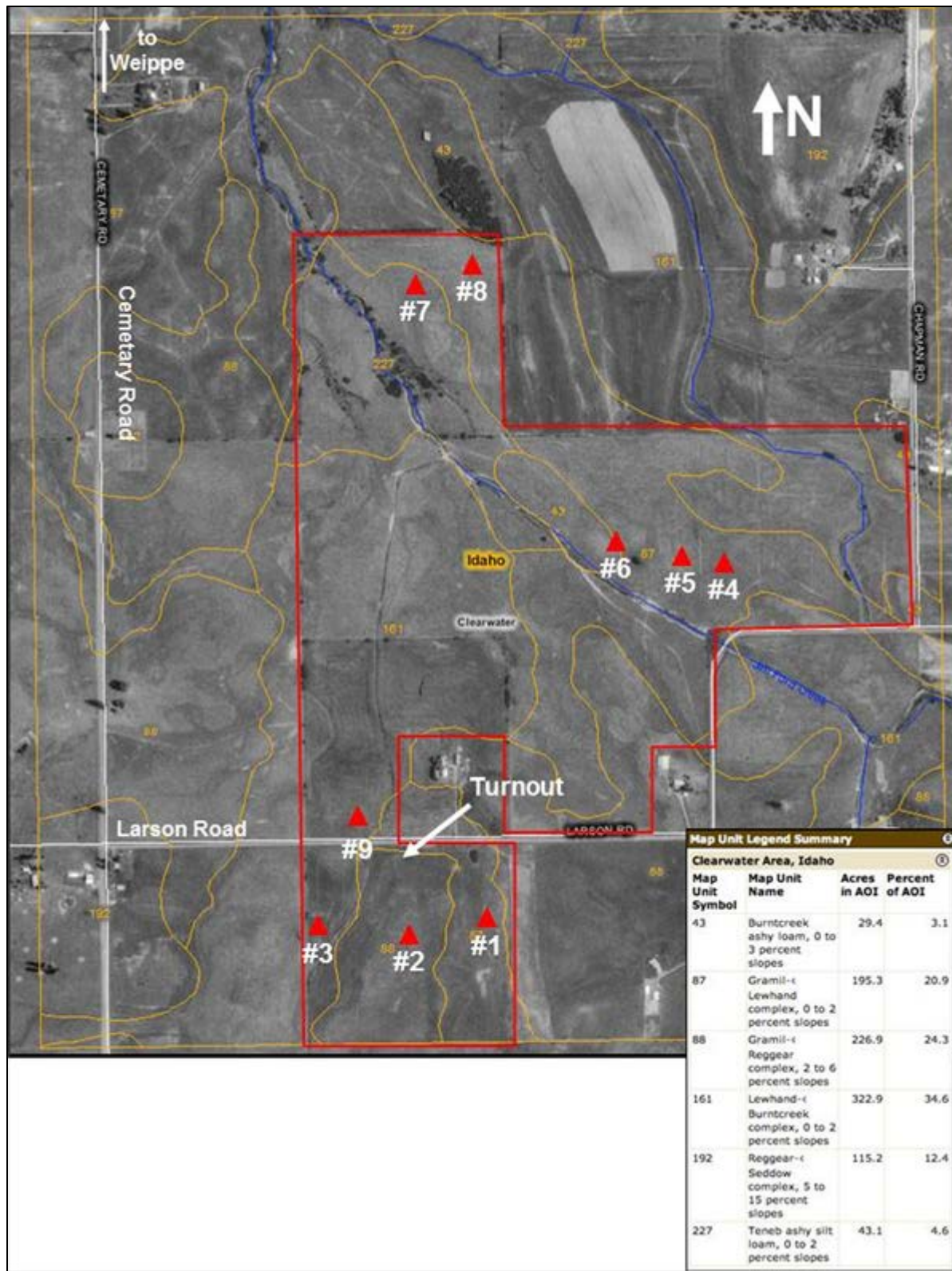


Figure 1. Location of sampling/monitoring sites at the National Park Service Weippe Prairie Site, ~3 km SE of Weippe, ID. The barometric logger is located at Site #3.

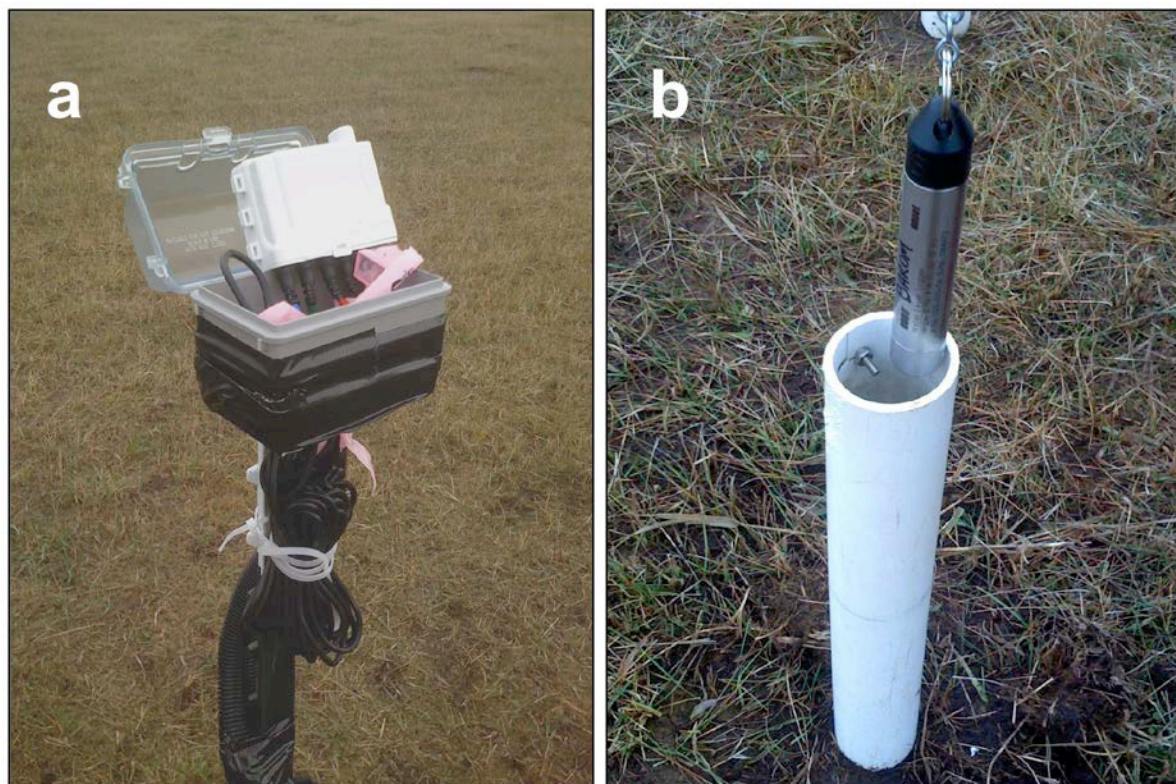


Figure 2. Monitoring equipment used at Sites 7-9.(a) Data logger connected to 4 soil moisture probes and a temperature probe. (b) Water table logger being installed in shallow well.

Shallow wells were installed at each site to allow monitoring of water tables. Wells were constructed of 2.5-inch-diameter PVC pipe. Slotted pipe was used for the below ground portion of the well; solid pipe was used for the riser. A HOBO water table logger (Model U20-001-04, Onset Computer Company, Pocasset, MA) was then inserted into each well at a depth corresponding to a hydraulically restrictive soil layer, if present, or a depth of ~75 cm (Figure 2b). Loggers were programmed to record water table levels every 12 hours. A solid well with a sealed bottom was installed at Site 3 and equipped with a well logger to monitor barometric pressure – this was used to correct all well logger readings for changes in barometric pressure and calculate water table levels. All wells were covered with a loose-fitting plastic cap to prevent entry of precipitation and evaporation losses.

Laboratory Analyses

Samples were collected from genetic horizons of the soils at each of the 3 monitoring sites. A total of 14 samples were transported back to the Pedology Laboratory at the University of Idaho where they were logged in, allowed to air-dry, and stored. Air-dried samples were then analyzed for various chemical, physical, and mineralogical properties. A detailed description of laboratory procedures used and references is contained in Appendix I.

The following physical properties were determined for all samples: bulk density; particle-size distribution (% sand, silt, and clay); textural class; and water retention at tensions of -0.03 and -0.5 MPa to simulate conditions of field capacity and wilting point. Chemical analyses performed

included: pH (H₂O and NaF); organic carbon, nitrate and ammonium; exchangeable bases; exchangeable acidity, cation exchange capacity; base saturation; ammonium oxalate (AOD) and sodium citrate, sodium bicarbonate, and sodium dithionite (CBD) dissolution analysis; and phosphorus retention. For mineralogical properties, X-ray diffraction (XRD) was used to determine crystalline clay mineral components of selected horizons. Sand fractions of these horizons were observed under a polarizing microscope to determine the presence of volcanic ash and other mineral components.

Results

Soil Morphological Properties

The 3 soils described and sampled at the Weippe Prairie represent 3 NRCS soil survey map units at the Weippe Prairie Site that are contained in the Soil Survey of the Clearwater Area, Idaho (Soil Survey Staff, 2008). Site 7 is located within the Teneb ashy silt loam complex; Site 8 is located within the Gramil-Lewhand complex, and Site 9 is located within a Lewhand-Burntcreek complex map unit (Soil Survey Staff, 2008). Based on this mapping, Sites 8 and 9 represent the wettest parts of the landscape and wet (R009XY0181ID) or semiwet (R009XY019ID) meadow ecological sites.

The Weippe Prairie is a broad, relatively low-relief landscape that is dominated by alluvial and lacustrine sediments. These sediments have been mantled by varying amount of windblown materials, including loess and volcanic ash (Soil Survey Staff, 2008). Because of low relief and very slowly permeable subsoils, most soils at the Weippe Prairie have water tables at or near the surface at some time during the year.

Profile pictures of soils at Sites 7-9 are shown in Figures 3-5; descriptions are given in Tables 2-4. Genetic horizons are shown as well as the locations of soil moisture, temperature, and water table monitoring equipment.

All soils exhibited morphological evidence in the form of redoximorphic features that result from seasonal saturation with water (Vepraskas, 2001). These redoximorphic features include low-chroma colors and Fe concentrations and depletions. Expression of these features varies among the sites and reflects both the duration and positioning of water table within the soil profile. Horizons with low-chroma colors (i.e. horizons with 'g' designation) can be seen in Sites 8 and 9 and indicate these soils are the wettest. Examples of Fe concentrations and depletions can be seen in the E/Bxg horizon at Site 8 (Figure 4, just above blue circle). Site 9 has somewhat better drainage, but nevertheless still shows evidence of seasonal saturation. Site 7 occupies marginally higher parts of the landscape, and this contributes to its somewhat better drainage.

An important feature of many Weippe Prairie Site soils is the presence of hydraulically restrictive subsoil horizons. These are generally dense, high-strength horizons with low porosity, and are identified in the horizon descriptions by the 'x' designation. The ability of these horizons to transmit water is rated as very low to moderately low (≤ 0.06 inch per hour) (Soil Survey Staff, 2008). Previous work in the area indicates that these subsoil horizons perch water for as much as 7 months per year (Rockefeller et al., 2004). All sites in this study except Site 7 appear to have at least a weakly expressed hydraulically restrictive subsoil horizon. These restrictive subsoil horizons were recognized by the exclusion of plant roots from the soil matrix, brittleness, abrupt textural and/or structural differences, and excavation difficulty. Sites 8 and 9 both occupy lower-lying areas of the landscape. It is likely that groundwater tables are also present and may work in conjunction with perched water tables to create seasonal saturation of these soils.

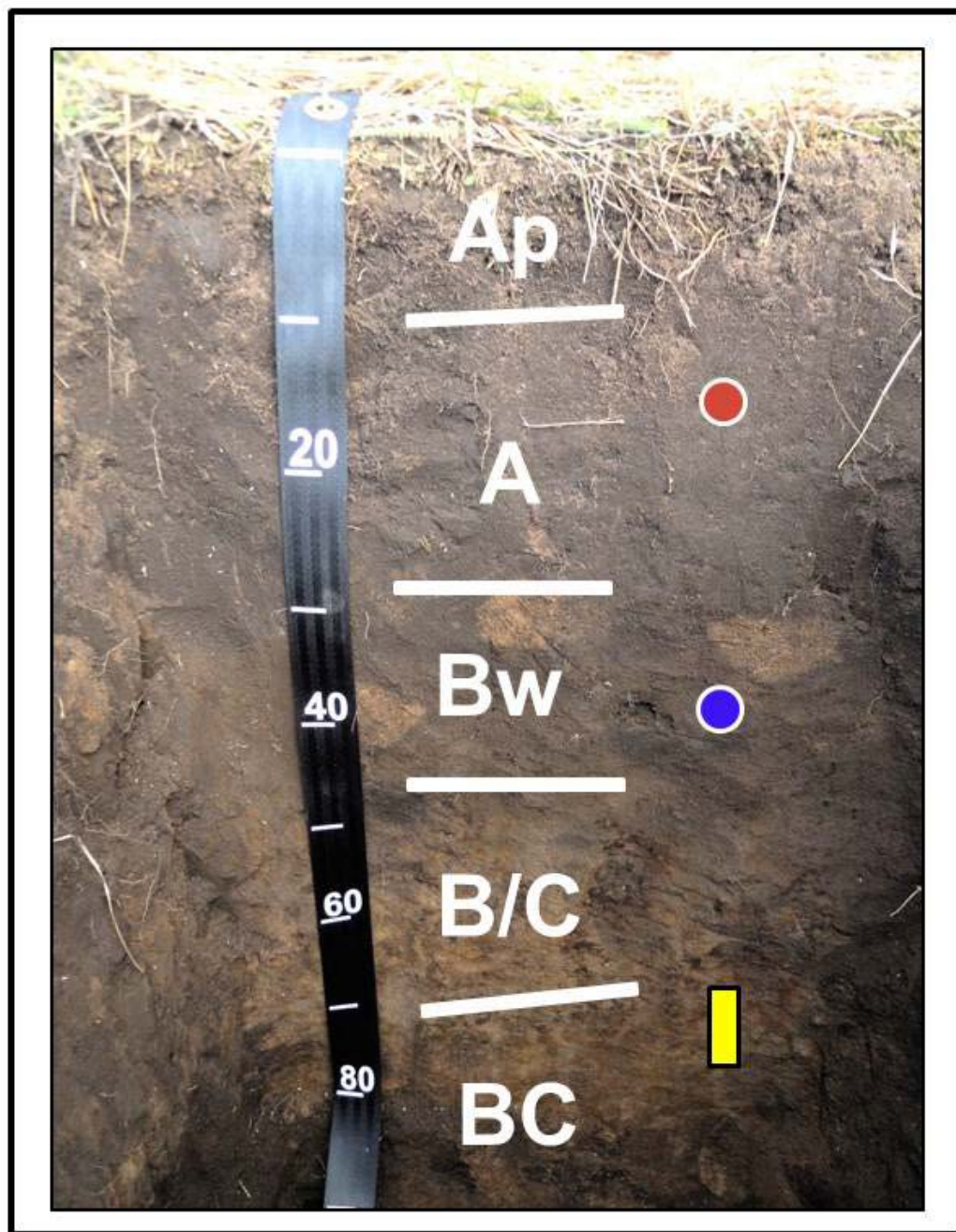


Figure 3. Site 7 (UI Pedon No. 11-ID-18173) profile and genetic horizons. Red and blue circles indicate position of soil moisture probes (15 and 40 cm); yellow rectangle indicates relative position of well logger. Each colored division on scale tape=10 cm (4 inches).

Table 2. Site 7 morphological data – UI Pedon No. 11-ID-18173. All descriptors¹ are taken from Schoeneberger et al. (2002).

UI Lab Sample No.	Horizon	Depth (cm)	Color moist/ dry	Textural class	Structure	Consistence			Notes
						dry	moist	stickiness/ plasticity	
ID1817301	Ap	0-10	10YR2/1 10YR5/1	sandy clay loam	strong, fine, med., & co. subangular blocky	soft	v friable	sl sticky/ sl plastic	
ID1817302	A	10-28	10YR2/1 10YR6/2	sandy loam	strong, fine, med., & co. subangular blocky	soft	v friable	sl sticky/ sl plastic	
ID1817303	Bw	28-45	10YR2/2 10YR6/3	sandy loam	mod., v. fine, fine, & med. subangular blocky	soft	v friable	sl sticky/ sl plastic	
ID1817304	B/C	45-70	10YR4/3 10YR6/4	sandy loam	strong, fine, med. & co. subangular blocky	sl hard	friable	sl sticky/ nonplastic	faint redox (7.5YR5/8) concentrations/ depletions
ID1817305	BC	70-90+	10YR5/3 10YR7/3	sandy loam	strong, med., & coarse subangular blocky	soft	v friable	nonsticky/ nonplastic	faint redox (7.5YR5/8) concentrations/ depletions

¹Abbreviations: v= very; sl = slightly; med = medium; co. = coarse; mod. = moderate(ly)

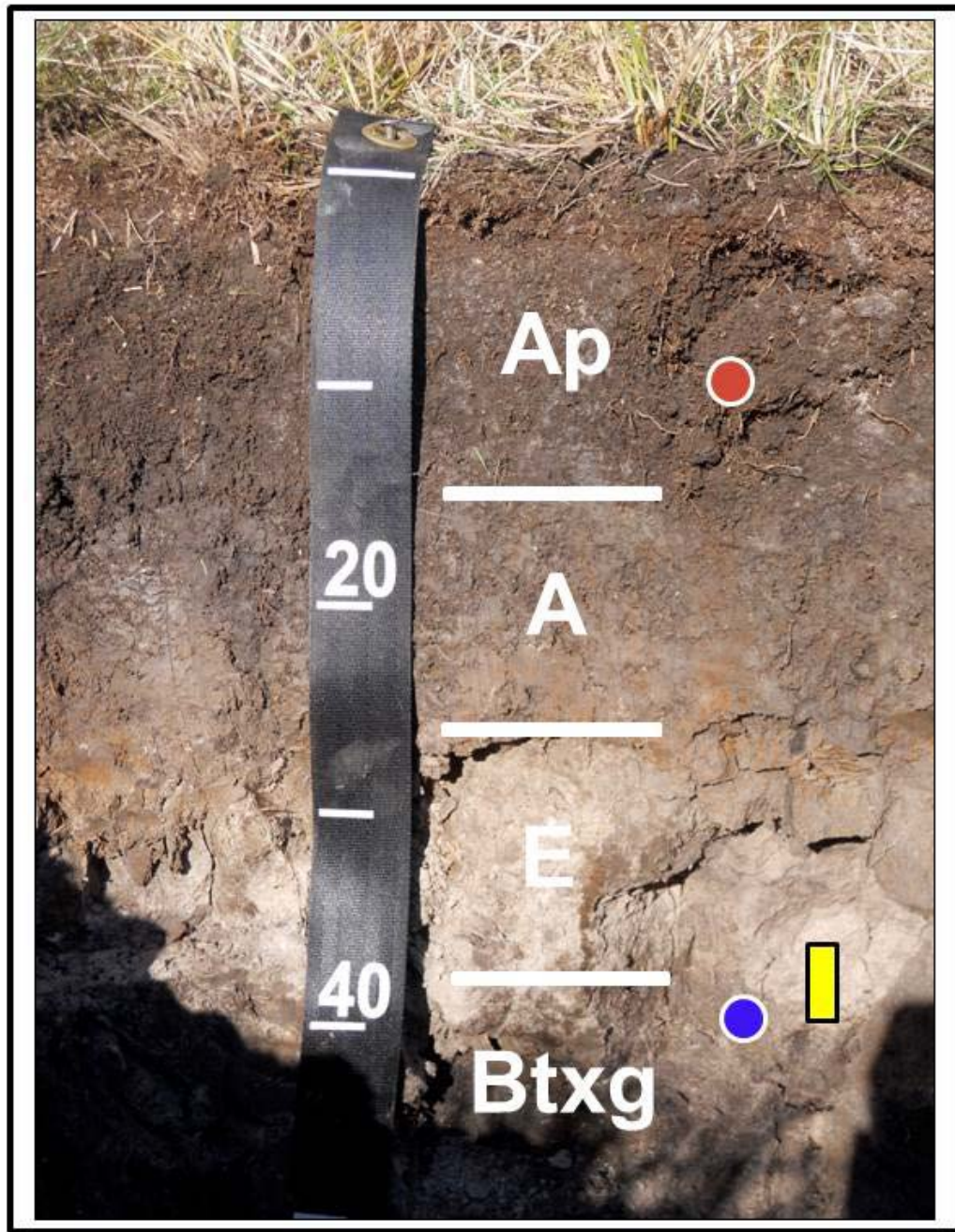


Figure 4. Site 8 (UI Pedon No. 11-ID-18174) profile and genetic horizons. Red and blue circles indicate position of soil moisture probes (15 and 40 cm); yellow rectangle indicates relative position of well logger. Each colored division on scale tape=10 cm (4 inches).

Table 3. Site 8 morphological data – UI Pedon No. 11-ID-18174. All descriptors¹ are taken from Schoeneberger et al. (2002).

UI Lab Sample No.	Horizon	Depth (cm)	Color moist/ dry	Textural class	Structure	Consistence			Notes
						dry	moist	stickiness/ plasticity	
ID1817401	Ap	0-15	10YR3/1 10YR6/1	clay	strong, fine, & med. granular	mod. hard	firm	mod. sticky/ mod. plastic	
ID1817402	A	15-26	10YR4/1 10YR7/1	clay	mod., fine granular/ strong, fine & med. angular blocky	extr. hard	sl rigid	v sticky/ v plastic	faint redox (7.5YR5/8) concentrations/ depletions
ID1817403	E	26-38	10YR5/1 10YR8/1	clay	strong, coarse prismatic	v rigid	v rigid	v sticky/ v plastic	distinct redox (7.5YR5/8) concentrations/ depletions
ID1817404	Btxg	38-53+	10YR4/1 10YR5/2	clay	strong, coarse prismatic	v rigid	v rigid	v sticky/ v plastic	distinct redox (7.5YR5/8) concentrations/ depletions

¹Abbreviations: v= very; sl = slightly; med = medium; co. = coarse; mod. = moderate(ly)

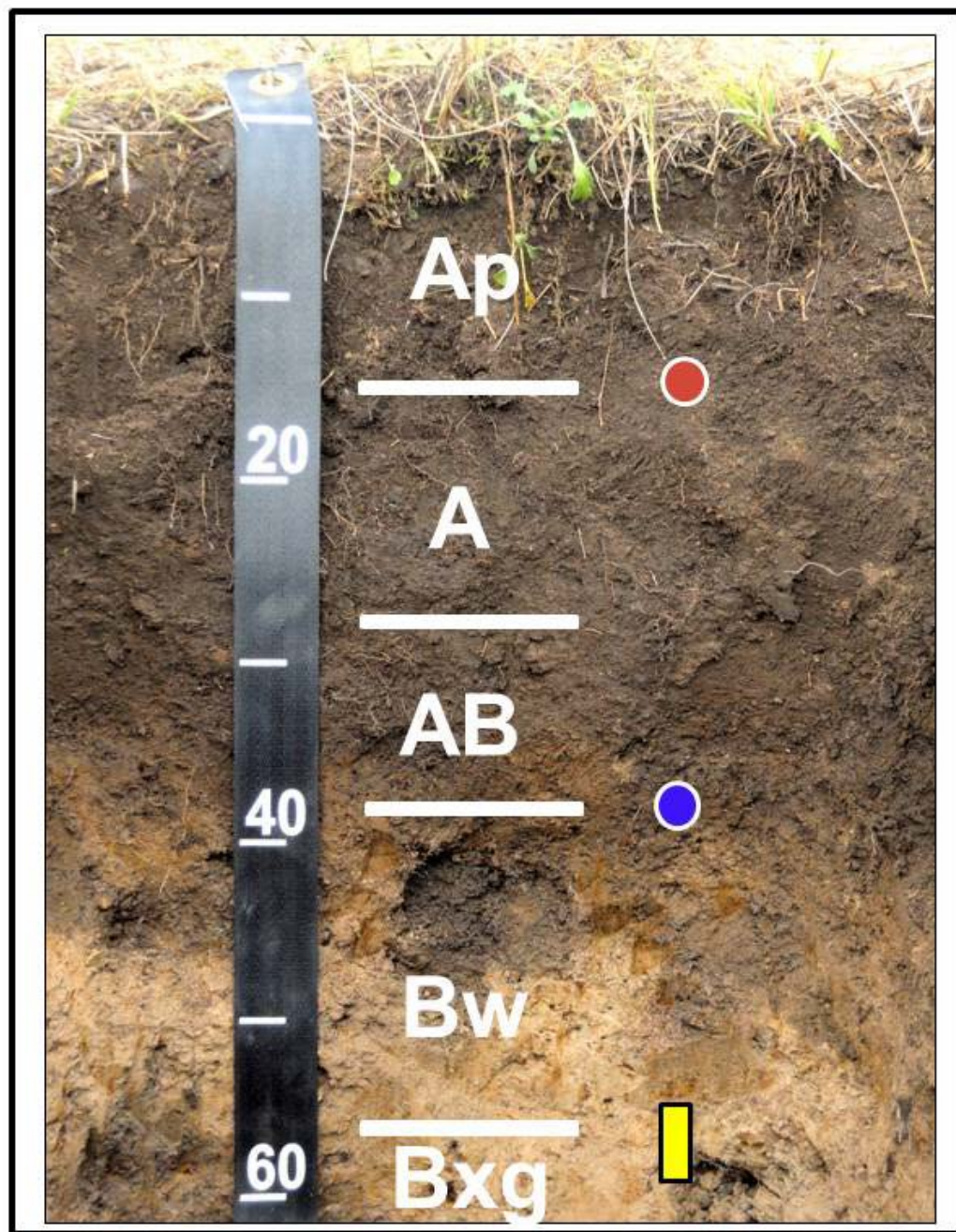


Figure 5. Site 9 (UI Pedon No. 11-ID-18175) profile and genetic horizons. Red and blue circles indicate position of soil moisture probes (15 and 40 cm); yellow rectangle indicates relative position of well logger. Each colored division on scale tape=10 cm (4 inches).

Table 4. Site 9 morphological data – UI Pedon No. 11-ID-18175. All descriptors¹ are taken from Schoeneberger et al. (2002).

UI Lab Sample No.	Horizon	Depth (cm)	Color moist/ dry	Textural class	Structure	Consistence			Notes
						dry	moist	stickiness/ plasticity	
ID1817501	Ap	0-15	10YR3/1 10YR5/2	silty clay	strong, fine granular/ strong, med. & coarse subangular blocky	mod. hard	firm	v sticky/ v plastic	
ID1817502	A	15-28	10YR3/1 10YR5/2	silty clay	strong, fine granular/ strong, med. & coarse angular blocky	hard	v firm	v sticky/ v plastic	
ID1817503	AB	28-39	10YR3/2 10YR6/2	silty clay	strong, fine & med. angular blocky	rigid	rigid	v sticky/ v plastic	
ID1817504	Bw	39-58	10YR5/2 10YR7/2	silty clay loam	strong, med. & coarse subangular blocky	mod. hard	firm	sl sticky/ sl plastic	faint redox (7.5YR5/8) concentrations/ depletions
ID1817505	Bxg	58-70+	10YR3/1 10YR5/2	clay loam	strong, fine & med. subangular blocky	mod. hard	firm	non-sticky/ non-plastic	faint redox (7.5YR5/8) concentrations/ depletions; Mn coatings (10YR2/1)

¹Abbreviations: v= very; sl = slightly; med = medium; co. = coarse; mod. = moderate(ly)

Soil Physical Properties

A summary of soil physical properties of the Weippe Prairie soils is presented in Tables 5 and 6. Particle-size analysis indicates sandy clay loam, silty clay, and clay textures dominate the upper horizons of most of the sampled soils. These textures are typical of soils of the region that have formed in alluvium, loess, and lacustrine sediments.

Highest clay contents (up to 85%) in the Weippe soils are found at Sites 8 and 9, which are not located close to one another; however, they are located on separate broad, low-lying plains. These finer textures appear to reflect a former lacustrine environment in this part of the Weippe Prairie. This interpretation is supported by the presence of diatoms at Site 8, but diatoms are not present in Site 9 (see mineralogy section).

In contrast, Site 7 formed in coarser materials deposited in a higher-energy alluvial environment, and has sandy clay loam and sandy loam textures. These sandy textures coupled with the lack of a hydraulically restrictive subsoil horizon allows for more rapid drainage of water in this soil.

Water retention data in Table 6 illustrate the strong effect of texture on a soil's ability to provide plant-available water. Silty textures are best in this regard, as evidenced by the larger water retention differences. Soils with more clayey or sandy textures generally have lower water retention differences, making them more prone to droughtiness during the growing season. However, given the overall wet condition of the Weippe Prairie at the start of the growing season, it does not appear that water retention differences have much effect on camas density. Site 8, which is characterized by relatively low camas density, has the greatest overall water retention of any of the soils.

Bulk density values for surface horizons are generally within the range considered acceptable for plant growth and therefore likely do not limit camas growth. Subsoil bulk densities at Sites 7, 8 and 9 are borderline to exceed the $\sim 1.5 \text{ g/cm}^3$ threshold that restricts root growth and development (Brady and Weil, 2010). These higher bulk densities are also usually associated with perched water tables in soils of the area (Rockefeller et al., 2004). One notable exception is Site 7 – while the B/C-BC horizon exhibited several of the properties associated with a hydraulically restrictive horizon, the mean measured bulk density value was only 1.21 g/cm^3 . The abundance of volcanic ash in this soil (see mineralogy section) may help explain the relatively low bulk density.

Table 5. Particle-size analysis of Weippe Prairie soils.

Site	Horizon	Depth	VC ¹ Sand	C ¹ Sand	M ¹ Sand	F ¹ Sand	VF ¹ Sand	Sand	Silt	Clay	Textural Class
			2-1 mm	1-0.5 mm	0.5-0.25 mm	0.25-0.10 mm	0.10-0.05 mm	2-0.05 mm	0.05-0.002 mm	<0.002 mm	
		cm	----- % of <2 mm fraction -----								
Site 7	Ap	0-10	1.5	18.0	20.4	14.6	3.5	58.0	21.6	20.4	Sandy Clay Loam
	A	10-28	1.8	18.8	19.5	7.0	13.6	60.7	19.4	19.9	Sandy Loam
	Bw	28-45	1.1	16.9	20.3	15.2	4.2	57.7	23.3	19.0	Sandy Loam
	B/C	45-70	2.0	18.9	20.1	12.0	7.5	60.5	25.3	14.2	Sandy Loam
	BC	70-90+	2.0	19.0	25.9	20.0	5.3	72.1	17.8	10.0	Sandy Loam
Site 8	Ap	0-15	0.0	0.4	0.4	0.4	0.4	1.6	21.4	76.9	Clay
	A	15-26	0.0	0.1	0.0	0.0	0.1	0.2	15.0	84.7	Clay
	E	26-38	0.0	0.0	0.0	0.0	0.1	0.2	19.5	80.3	Clay
	Btxg	38-53+	0.0	0.1	0.2	0.9	0.4	2.7	33.4	64.0	Clay
Site 9	Ap	0-15	4.0	3.8	1.3	1.8	0.6	11.5	41.2	47.4	Silty Clay
	A	15-28	3.6	4.7	2.2	2.1	3.2	15.9	41.4	42.7	Silty Clay
	AB	28-39	5.4	4.4	1.5	1.7	2.7	15.7	40.8	43.5	Silty Clay
	Bw	39-58	4.7	4.4	1.8	2.2	4.6	17.7	54.7	27.6	Silty Clay Loam
	Bxg	58-70+	10.4	11.5	5.3	1.6	8.1	36.9	34.1	29.0	Clay Loam

¹Abbreviations: v = very; f = fine; m = medium; c = coarse

Table 6. Bulk density and water retention data for Weippe Prairie soils.

Site	Horizon	Depth	Bulk Density	Water Retention		
				-0.03 MPa	-1.5 MPa	Difference
		cm	g/cm ³	----- % by weight -----		
Site 7	Ap	0-10	1.16	24.3	12.5	11.8
	A	10-28	1.39	22.7	11.6	11.1
	Bw	28-45	1.16	22.0	9.2	12.8
	B/C	45-70	1.16	21.0	8.8	12.3
	BC	70-90+	1.56	10.0	3.4	6.6
Site 8	Ap	0-15	1.08	56.0	32.1	23.9
	A	15-26	1.25	52.0	35.1	16.9
	E	26-38	1.29	58.1	33.9	24.2
	Btxg	38-53+	1.44	50.6	30.7	20.0
Site 9	Ap	0-15	1.29	34.3	19.4	15.0
	A	15-28	1.37	31.8	18.8	12.9
	AB	28-39	1.38	29.5	18.1	11.4
	Bw	38-58	1.55	28.0	14.1	13.9
	Bxg	58-70+	1.50	26.4	17.3	9.1

Soil Chemical Properties

Results of soil chemical analyses are summarized in Table 7, 8, 9, and 10. pH, carbon, nitrate and ammonium data are contained in Table 7; Table 8 contains exchangeable cation data; Table 9 contains ammonium oxalate (AOD), ODOE, phosphorus retention, and sodium citrate, sodium bicarbonate, and sodium dithionite (CBD) dissolution data; Table 10 contains pH, carbon, nitrate and ammonium data for sites 1-6 from the previous contract (RM-CESU Cooperative Agreement No. H2000040001).

There are several important trends that may have implications for camas growth. Soil pH is considered a 'master variable' in that it strongly influences many chemical and biological properties and processes (Brady and Weil, 2010). All surface horizons are very strongly acid, with pH (H₂O) values ranging from 3.7-4.1. This reflects the relatively large amounts of exchangeable acidity found in surface horizons and relatively low base saturation percentages. As is typical, pH values increase in the subsoils.

Carbon contents of surface A horizons are relatively high for mineral soils, ranging from 3.4 to 5.0%. This is likely due to the seasonal saturation and relatively cold temperatures in the Weippe Prairie soils; both of these factors reduce organic matter decomposition rates. Surface NO₃⁻-N ranged from 1.1 to 2 mg/kg and NH₄⁺-N ranged from 5.0 to 9.7 mg/kg. Table 10 contains nitrate and ammonium data for sites 1-6. The ranges for nitrate and ammonium are typical of a mineral soil A horizon (Brady and Weil, 2010).

With few exceptions, quantities of exchangeable bases (Ca²⁺, Mg²⁺, K⁺) do not vary greatly among the Weippe Prairie soils. Furthermore, quantities of these nutrients do not appear to be sufficiently low to indicate problems for plant growth. However, % base (or nonacid) saturation (i.e. percentage of total cation exchange sites occupied by bases) is relatively low in surface horizons, ranging from 22% at Site 7 to 27% at Site 8. These low values indicate that exchangeable acidity dominates the exchange complex in these soils. However, it should be pointed out that this condition is relatively common in soils of the Weippe area that have been characterized as part of the NRCS soil survey of the Clearwater Area (Soil Survey Staff, 2008).

NaF pH values provide a measure of poorly or nanocrystalline secondary minerals (Soil Survey Staff, 2010). In the Pacific Northwest, these minerals typically result from the weathering of volcanic ash (McDaniel et al., 2005). NaF pH values <~9.4 generally indicate that these minerals are not present in significant quantities, and this is the case for the Weippe soils except for site 7. Examination of samples with a petrographic microscope indicates some volcanic glass is present (Table 11) (see mineralogy section). The volcanic glass is most likely from the eruption of Mt. Mazama ~7600 years ago (Zdanowicz, 1999). Although it is a relatively minor constituent of the soils, its presence is recognized in the taxonomic classification of these soils. In Table 9 the AOD Al +1/2 Fe data indicate the presence of some poorly crystalline minerals and/or metal-humus complexes in Sites 7, 8, and 9. The ODOE and P-retention data show that Site 7 and 9 have some expression of andic soil properties. However, the criteria for andic soil properties were evaluated as part of this project, and Sites 7, 8, and 9 do not meet all the criteria to qualify as *vitrandic* subgroups of Alfisols and Inceptisols (Soil Survey Staff, 2008; 2010). The AOD and CBD data show the depletion of Mn in

site 8 with levels less than 9 mg/kg compared to sites 7 and 9 where the range for AOD was 253-1783 mg/kg and CBD range was 180-1237 mg/kg.

Table 7. pH, carbon, nitrate and ammonium data for Weippe Prairie soils.

Site	Horizon	Depth	pH H ₂ O	NaF pH	Organic ¹ Carbon	NO ₃ ⁻ -N ²	NH ₄ ⁺ -N ²
		cm			%	mg/kg	mg/kg
Site 7	Ap	0-10	4.1	8.6	3.4	1.1	6.1
	A	10-28	4.1	8.9	3.0	1.2	4.2
	Bw	28-45	4.2	9.6	1.6	0.8	3.2
	B/C	45-70	4.4	9.7	0.8	0.5	2.9
	BC	70-90+	4.4	8.2	0.4	0.2	1.3
Site 8	Ap	0-15	3.7	8.0	5.0	2.0	9.7
	A	15-26	3.8	8.1	1.7	0.7	9.3
	E	26-38	4.2	8.0	1.3	0.2	4.4
	Btxg	38-53+	4.6	8.1	0.8	0.3	3.5
Site 9	Ap	0-15	3.9	8.3	3.5	1.1	5.0
	A	15-28	4.0	8.4	2.2	0.3	4.6
	AB	28-39	4.1	8.5	1.5	0.0	3.4
	Bw	39-58	4.4	8.3	0.6	0.1	1.5
	Bxg	58-70+	4.4	8.3	0.6	0.4	2.0

¹ Organic carbon (OC) was determined by rapid dichromate oxidation (Nelson and Sommers, 1982).

² Nitrate and ammonium were analyzed on the 2500 Flow Injection (FIALab) instrument and FIALab protocols for reagents and color development specifications (Keeney and Nelson, 1982).

Table 8. Cation exchange capacity (CEC) and exchangeable cation data for Weippe Prairie soils.

Site	Horizon	Depth cm	Exchangeable Cations						CEC ¹	% Base sat. ²
			Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Sum of bases	Acidity (H ⁺ + Al ³⁺)		
			----- cmol(+)/kg -----							
Site 7	Ap	0-10	4.5	1.1	0.2	0.0	5.9	21.4	25	22
	A	10-28	3.9	0.5	0.1	0.0	4.5	20.5	24	18
	Bw	28-45	2.0	0.3	0.1	0.2	2.5	16.9	14	13
	B/C	45-70	1.8	0.3	0.1	0.2	2.4	13.7	12	15
	BC	70-90+	1.7	0.4	0.1	0.1	2.2	4.6	5	33
Site 8	Ap	0-15	7.4	3.7	0.3	0.3	11.7	32.3	53	27
	A	15-26	9.7	4.8	0.3	0.4	15.1	24.1	51	38
	E	26-38	10.0	4.9	0.2	0.4	15.5	16.9	39	48
	Btxg	38-53+	10.7	5.1	0.2	0.4	16.4	10.9	35	60
Site 9	Ap	0-15	7.2	1.9	0.2	0.2	9.5	26.9	33	26
	A	15-28	7.3	2.1	0.2	0.2	9.7	21.0	31	32
	AB	28-39	7.6	2.5	0.2	0.2	10.5	18.2	32	33
	Bw	39-58	6.3	2.5	0.1	0.2	9.0	12.8	19	33
	Bxg	58-70+	7.1	3.0	0.1	0.2	10.4	10.7	28	45

¹ CEC = Cation Exchange Capacity (pH 7)² % Base Saturation = (sum of cations/sum of cations + acidity) x 100

Table 9. Ammonium oxalate (AOD), ODOE, phosphorus retention, and CBD data for the Weippe Prairie soils.

Site	Horizon	Depth	AOD Dissolution ¹								P Retention	CBD ³		
			Al	Fe	Al + ½ Fe	Mn	P	Si	Ti	ODOE ²		Al	Fe	Mn
		cm	----- % -----			----- mg/Kg -----					%	----- % -----		
7	Ap	0-10	0.35	0.52	0.61	481.7	753.9	404.9	340.2	0.24	47.3	0.29	0.81	472.2
	A	10-28	0.38	0.57	0.64	498.1	828.5	408.9	375.6	0.21	38.7	0.29	0.81	495.5
	Bw	28-45	0.39	0.58	0.68	396.5	611.3	849.1	398.6	0.17	46.8	0.28	0.90	478.4
	B/C	45-70	0.45	0.63	0.77	688.3	459.9	1595.9	450.4	0.16	49.4	0.23	0.84	637.1
	BC	70-90+	0.08	0.43	0.30	253.1	194.6	316.1	185.9	0.07	23.3	0.07	0.73	278.2
8	Ap	0-15	0.46	0.45	0.68	9.9	547.7	533.5	83.1	0.13	60.2	0.24	0.47	9.1
	A	15-26	0.44	0.68	0.78	0.0	265.5	650.9	62.3	0.09	63.0	0.19	0.96	0.0
	E	26-38	0.32	0.79	0.72	0.0	161.8	1047.1	60.0	0.08	50.9	0.10	0.99	0.0
	Btxg	38-53+	0.19	0.52	0.45	3.0	123.6	806.7	39.5	0.05	38.7	0.09	0.76	2.5
9	Ap	0-15	0.37	1.08	0.91	440.1	593.9	564.9	447.2	0.26	54.5	0.27	1.35	311.4
	A	15-28	0.37	1.17	0.96	342.5	557.1	669.7	501.2	0.21	52.4	0.23	1.38	179.7
	AB	28-39	0.30	1.17	0.89	259.1	435.9	703.7	498.0	0.20	51.2	0.20	1.39	245.4
	Bw	39-58	0.15	1.08	0.69	408.3	242.9	690.5	467.2	0.21	41.4	0.12	1.41	415.0
	Bxg	58-70+	0.21	1.44	0.93	1782.5	380.3	942.1	519.6	0.24	48.9	0.14	1.52	1237.1

¹AOD = ammonium oxalate extraction is used to estimate poorly crystalline minerals and/or metal-humus complexes

²ODOE = optical density oxalate extraction

³CBD = sodium citrate, sodium bicarbonate, and sodium dithionite extraction is used to estimate total secondary forms of Al, Fe, and Mn

Table 10. pH, carbon, nitrate and ammonium data for Weippe Prairie soil sites 1 thru 6.

Site	Horizon	Depth	pH H ₂ O	NaF pH	Total ¹ Carbon	NO ₃ ⁻ -N ²	NH ₄ ⁺ -N ²
		cm			%	mg/kg	mg/kg
Site 1	A	0-20	4.7	7.7	3.8	0.7	11.4
	Bw	20-44	5.1	7.9	1.0	0.0	3.9
	E	44-58	5.4	8.0	0.5	0.2	1.8
	Btxg	58-75+	5.5	7.9	0.3	0.0	0.6
Site 2	A	0-10	5.0	7.8	4.0	0.7	8.9
	AB	10-27	5.1	8.0	2.8	0.1	5.2
	E	27-61	5.2	8.1	0.8	0.3	1.8
	Btx	61-81+	5.4	8.0	0.3	0.0	0.0
Site 3	A	0-16	5.0	7.8	4.5	2.8	13.2
	AB	16-30	5.1	7.8	3.2	0.6	11.2
	Bw	30-50	5.2	7.7	2.5	0.3	5.9
	BE	50-76+	5.5	8.0	0.4	0.1	1.2
Site 4	A	0-23	4.6	7.7	3.2	3.3	10.6
	E	23-31	4.8	7.7	1.6	0.8	8.1
	E/Bxg	31-50	5.1	7.8	1.1	0.2	3.7
	Btxg	50-65+	5.6	7.9	0.7	0.3	5.0
Site 5	A	0-10	4.7	7.7	3.7	0.0	13.7
	AB	10-21	4.8	8.0	2.7	0.0	10.4
	BE	21-37	5.1	8.0	1.2	0.2	4.1
	E	37-54	6.2	7.8	0.2	0.2	0.2
	E/Bxg	54-76+	6.6	8.0	0.2	0.0	0.9
Site 6	A1	0-16	4.8	7.8	3.8	0.4	13.5
	A2	16-40	4.9	8.3	2.2	1.1	6.3
	Bw1	40-77	5.5	7.7	0.4	0.1	1.5
	Bw2	77-90+	5.6	7.7	0.2	0.0	1.2

¹ Total carbon (C) was analyzed by dry combustion (Nelson and Sommers, 1996) using an Elementar CNS analyzer.

² Nitrate and ammonium were analyzed on the 2500 Flow Injection (FIALab) instrument and FIALab protocols for reagents and color development specifications (Keeney and Nelson, 1982).

Soil Mineralogical Properties

X-ray diffraction (XRD) patterns for all clay fractions analyzed can be found in Appendix II. XRD and sand fraction data are summarized in Table 11. Overall, kaolin is the dominant crystalline clay mineral. An abundance of kaolin, a 1:1 layer silicate, is generally indicative of more intense weathering environments and/or older soils (White and Dixon, 2003). It is likely that much of this kaolin formed in a warmer environment than exists today at the Weippe Prairie, such as during the Miocene. The kaolin-rich sediments have accumulated on the Prairie during the Holocene and Pleistocene (Lewis et al., 2007), and serve as the predominant parent material for the modern-day soils. Weippe Prairie soils have largely formed in these pre-weathered sediments.

In contrast, soils of the nearby Palouse Prairie region of eastern Washington and northern Idaho have formed in late Pleistocene and Holocene loess – their mineralogy is dominated by mica, vermiculite, and in some cases, smectite; kaolin is only present in minor amounts (McDaniel and Hipple, 2010). The presence of vermiculite and mica in Weippe Prairie soils suggests that there have also been additions of more recent sediment, perhaps from a similar source and timing as the Palouse loess. Windblown materials including volcanic ash and loess both appear to have influenced soil mineralogy, but to a much lesser extent than the alluvial and lacustrine deposits.

Abundant diatoms were observed in the sand fractions of soil horizons at Site 8, and none were found at Site 7 or Site 9. Diatoms are commonly found in shallow, freshwater environments (Monger and Kelly, 2002) and indicate that at least part of the Weippe Prairie Site was a lakebed at one time.

Table 11. Summary of mineralogical properties of Weippe Prairie soils.

Site	Horizon	Clay mineralogy	Sand fraction features
7	A	kaolin dominant, minor vermiculite and smectite	~5% volcanic glass, mostly quartz
	B/C	kaolin, vermiculite, mica; amorphous pattern	~10% volcanic glass, no diatoms
8	A	kaolin dominant; minor mica, vermiculite,	~1% ash fragments, some phytoliths, 90% diatoms
	Btxg	kaolin dominant; minor vermiculite and smectite; amorphous pattern	~5% volcanic glass, 50% quartz, some diatoms
9	A	kaolin dominant, vermiculite; minor smectite, mica	1-2% volcanic glass; no diatoms
	Bw	kaolin, mica co-dominant; minor vermiculite, smectite	trace to 1% volcanic glass fragments, no diatoms

Soil Moisture/Temperature Monitoring

Graphs summarizing temporal changes in soil moisture and temperature at Sites 7-9 over the 2011-14 monitoring period are shown in Figures 6a-8a. Graphs summarizing temporal changes in soil moisture and temperature at Sites 1-6 over 2007-14 monitoring period are shown in Figures 9a-14a. These graphs illustrate the overall seasonal soil wetting and drying patterns as well as several general trends that are consistent across all of the sites.

Soils achieve and maintain maximum moisture contents during the winter and spring months. The relatively flat portions of soil moisture curves seen during this period correspond to periods of saturation. As temperatures warm in late spring and evapotranspirational demand increases, moisture contents decrease rapidly over a period of 1-2 months. The exact timing of this dry-down varies somewhat, but generally begins sometime in June.

Following the rapid dry-down period, a few spikes in moisture content at 15 cm occur during the summer and fall in response to precipitation. These spikes are absent or less pronounced at the 40-cm depth, indicating that most of the growing season precipitation is lost via evapotranspiration and typically does not reach subsoil horizons. Rapid increases in soil moisture occur in the fall, depending on the timing and amount of precipitation received.

Some differences in soil moisture patterns are seen across the sites. For example, Site 4 and 8 does not dry down as much as the other sites. Even during the driest part of the summer, moisture content at 40 cm remained above 30%. In contrast, moisture content at 40 cm at Site 6 and 7 dropped to ~13%. This difference is likely due to the textures of the lower-most horizon at these sites: the Btxg horizon at Site 4 and 8 contain 48% and 85% clay while the Bw2 horizon at Site 6 and 7 contain 11% and 19% clay.

Overall, there do not appear to be significant soil temperature differences among the sites. Maximum soil temperatures of ~18-22 °C (64-72 °F) were reached during July and August. These maximum temperatures generally coincided with the rapid decline in soil moisture content.

Water Table Monitoring

Temporal changes in water table levels are shown in Figures 6b-8b for the 2011-12 and 2012-13 water years for Sites 7-9. Temporal changes in water table levels are shown in Figures 9b-14b for the 2008-09, 2009-10, 2010-11, 2011-12, 2012-13 water years for Sites 1-6. Unfortunately, data are not available for the 2007-08 water year for Sites 1-6 due to failure of the well logger used to monitor barometric pressure; although well loggers were operational, we were not able to apply the barometric correction to the readings in order to obtain water table levels.

As predicted from soil morphology, Site 8 experienced the longest duration of saturated conditions (Table 12). In addition, the water table is within 15 cm of the soil surface for most of the time when a water table is present at site 8. This is likely significant as most camas bulbs observed in these soils were present depths of ~5-15 cm. Site 7 experienced fewer days of saturated conditions during the year. However, the biggest difference is that these sites have water table levels within 15 cm of the

soil surface for considerably less time than does Sites 8. In addition, water never ponded at Site 7 and Site 9.

Sites 7 and 8 were initially selected because they are in close proximity to one another and occupy similar landscape positions, but differ markedly in camas density – Site 8 supports lower densities while Site 7 supports some of the higher densities measured at the Weippe Prairie site (Rodhouse and Jocius, 2009). A comparison of water table data in Table 12 indicates that water table levels differ considerably between the two sites. A water table was rarely within 15 cm of the surface at Site 7 and ponding was not observed. Site 8 had a water table within 15 cm of the surface for more than 150 days and had ponding for 36 day during the 2012-13 water year. These differences may, in part, reflect the combined effects of microtopography, drainage ditches that are present in the area, and differences in soil texture. Further investigation may be warranted to identify the conditions that result in ponding across the site and its relationship with camas density.

Close examination of the moisture content and water table level graphs (Figures 6-8) indicates excellent agreement between data obtained from moisture sensors and water table loggers. The ‘plateaus’ seen in moisture content readings correspond with periods when water table levels are measured at those depths. This allows information about water table levels to be reliably inferred from moisture sensor data.

Table 12. Water table data for Sites 1-9 for the water years 2008-09, 2009-10, 2010-11, 2011-12, and 2012-13

Site	2008-2009			2009-2010			2010-2011			2011-2012			2012-2013		
	Water table present	Water table within 15 cm of surface	Ponded	Water table present	Water table within 15 cm of surface	Ponded	Water table present	Water table within 15 cm of surface	Ponded	Water table present	Water table within 15 cm of surface	Ponded	Water table present	Water table within 15 cm of surface	Ponded
----- Number of days -----															
1	181	155	79	196	174	71	213	201	153	191	160	98	197	164	103
2	156	7	0	163	1	0	193	8	0	150	3	0	166	1	0
3	158	6	5	171	0	0	201	2	0	163	2	0	200	0	0
4	191	166	140	176	166	129	229	208	187	190	171	149	341	179	148
5	197	151	79	198	144	28	245	205	18	211	150	19	336	162	0
6	172	36	0	164	10	0	204	43	0	163	18	0	195	12	0
7	--- ¹	---	---	---	---	---	---	---	---	122	0	0	131	0	0
8	---	---	---	---	---	---	---	---	---	207	152	5	356	168	36
9	---	---	---	---	---	---	---	---	---	142	4	0	141	1	0

¹ No data

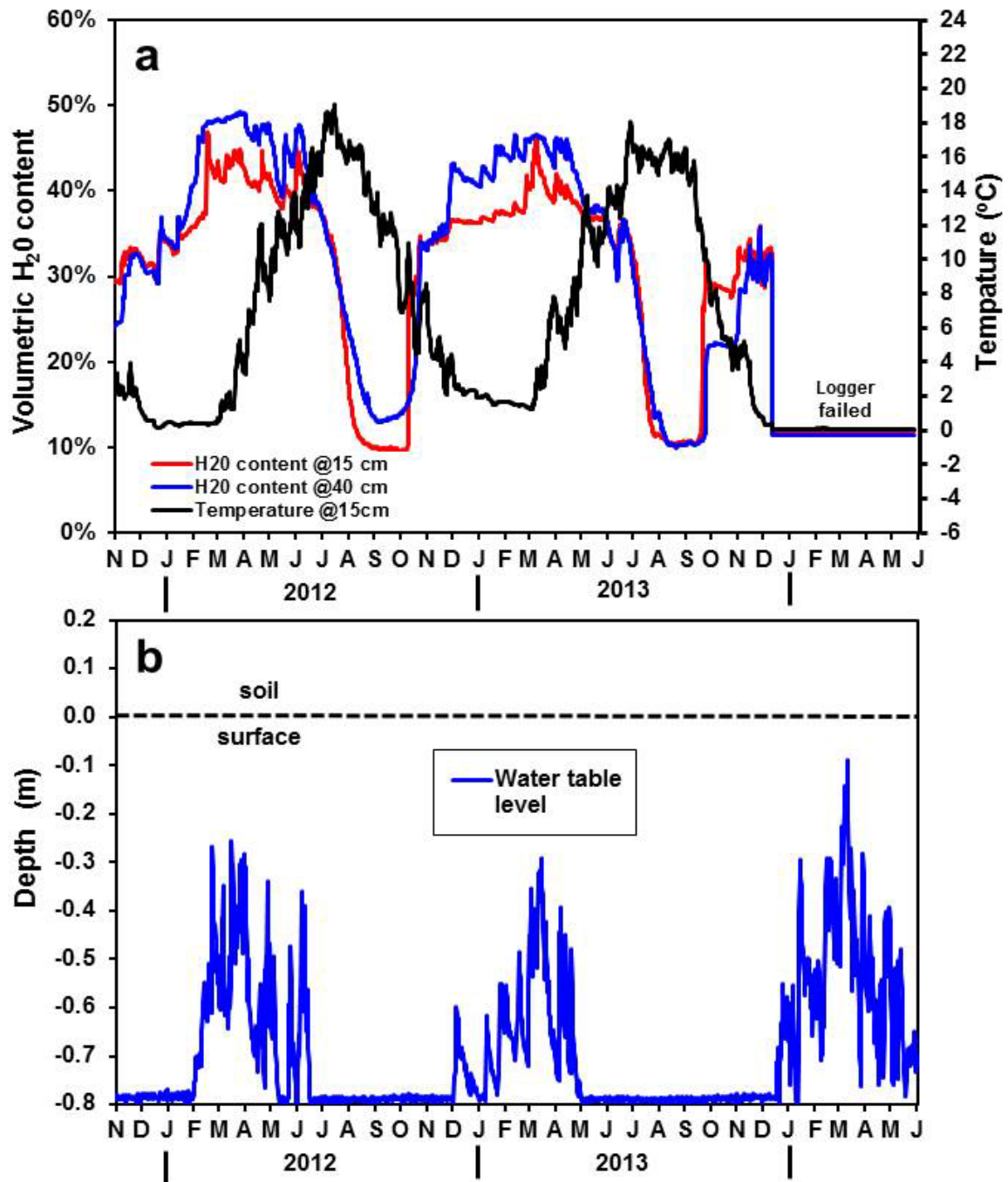


Figure 6. Hydrological data for Site 7 showing temporal changes in (a) soil moisture and temperature and (b) water table levels.

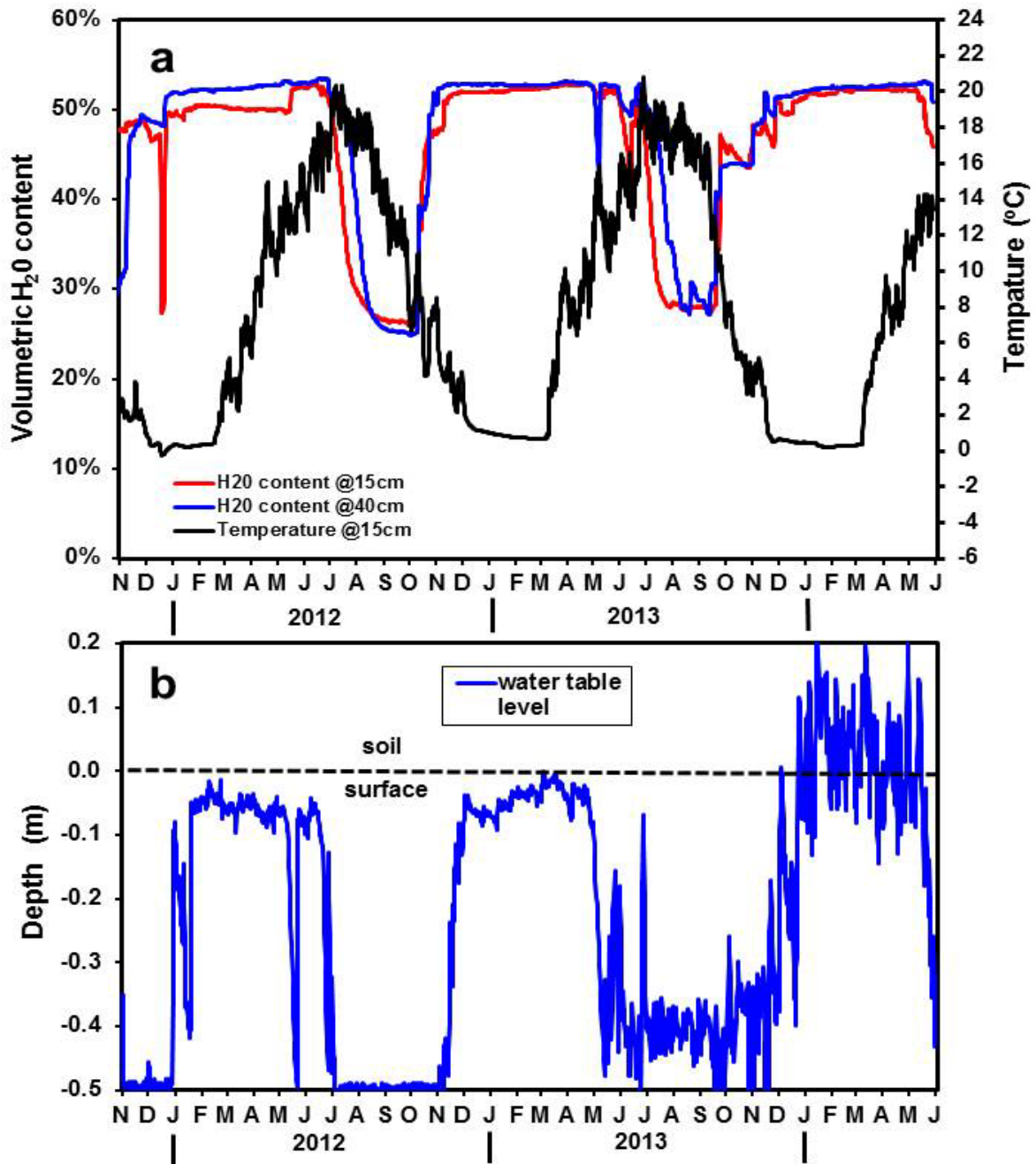


Figure 7. Hydrological data for Site 8 showing temporal changes in (a) soil moisture and temperature and (b) water table levels.

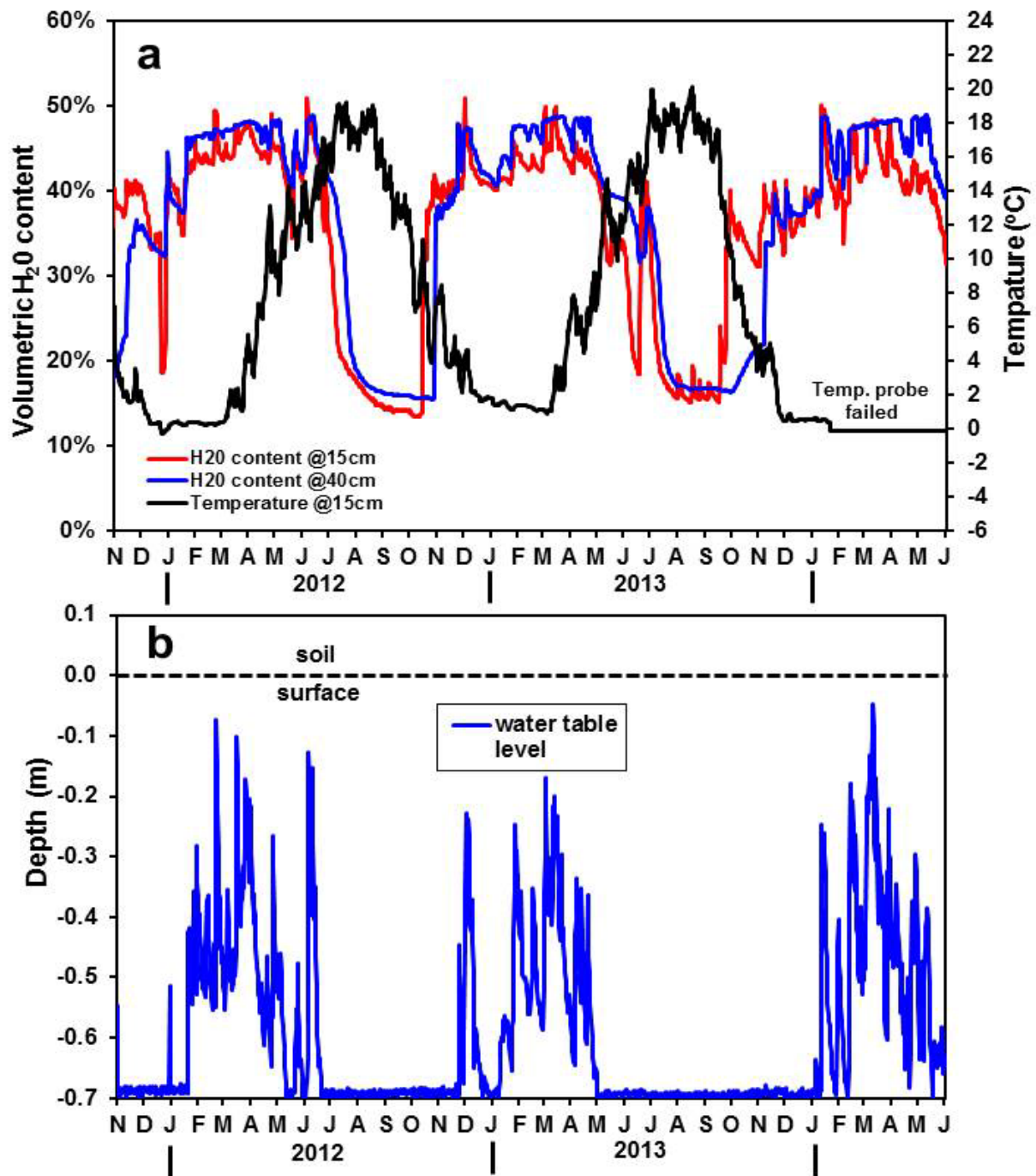


Figure 8. Hydrological data for Site 9 showing temporal changes in (a) soil moisture and temperature and (b) water table levels.

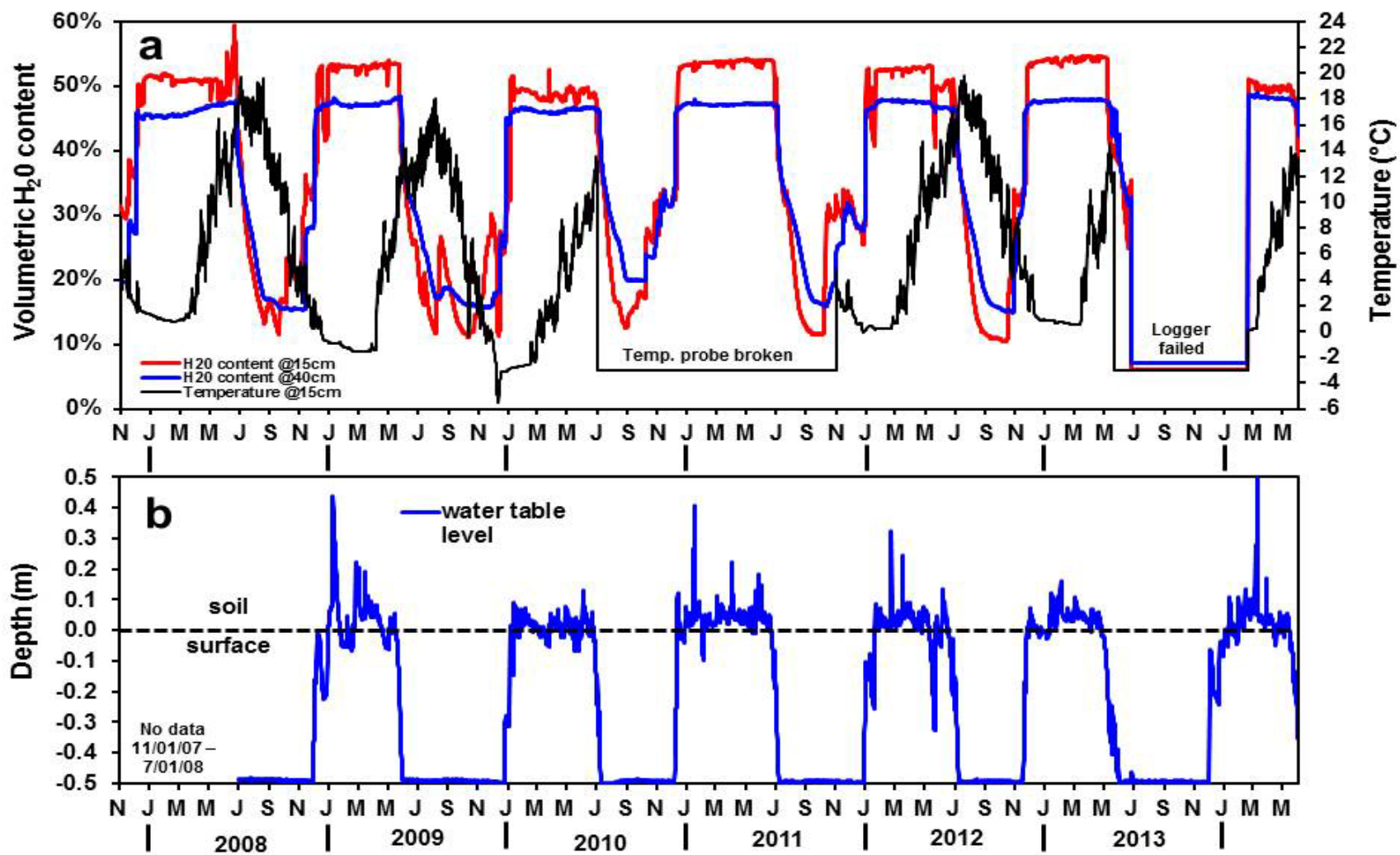


Figure 9. Hydrological data for Site 1 showing temporal changes in (a) soil moisture and temperature and (b) water table levels.

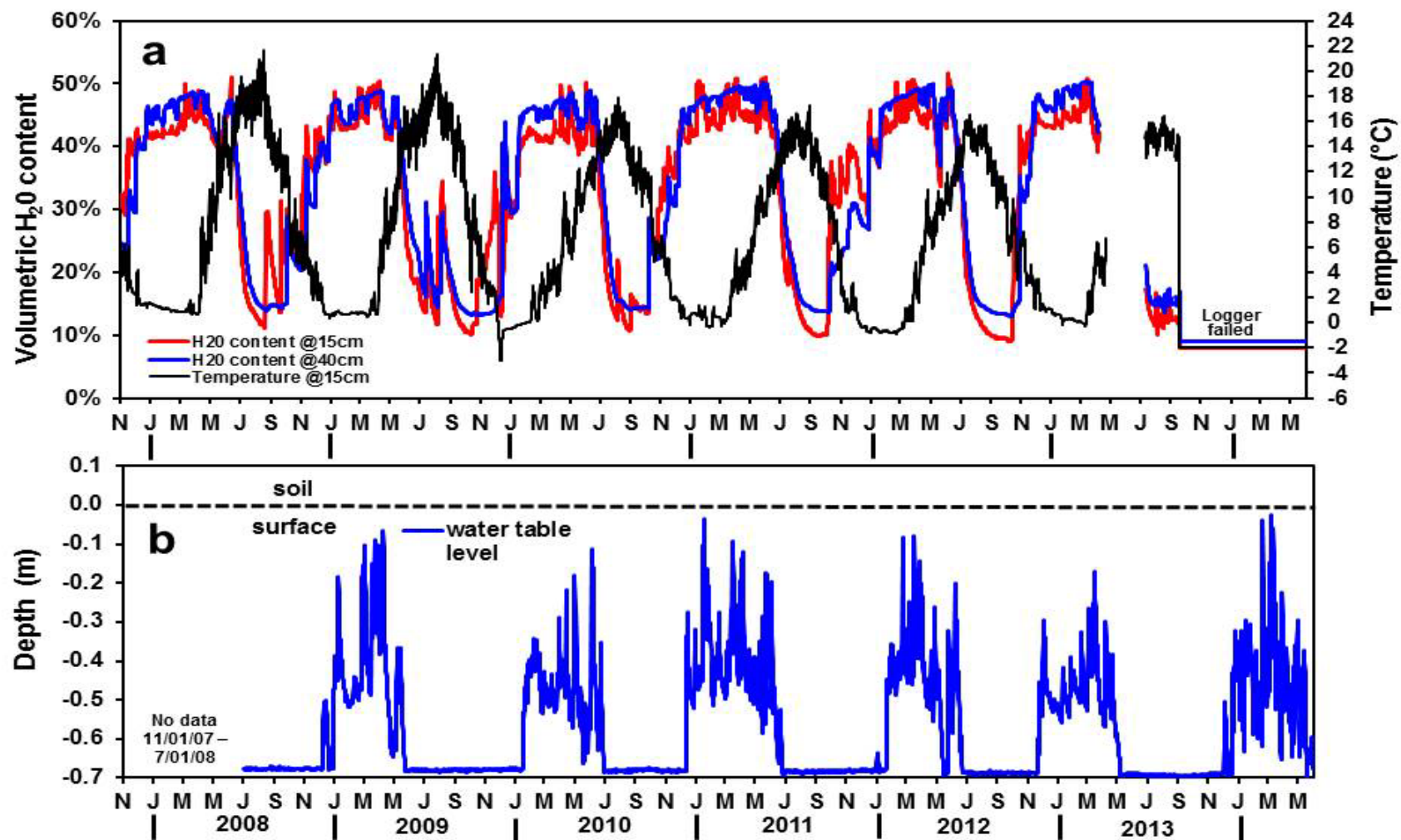


Figure 10. Hydrological data for Site 2 showing temporal changes in (a) soil moisture and temperature and (b) water table levels.

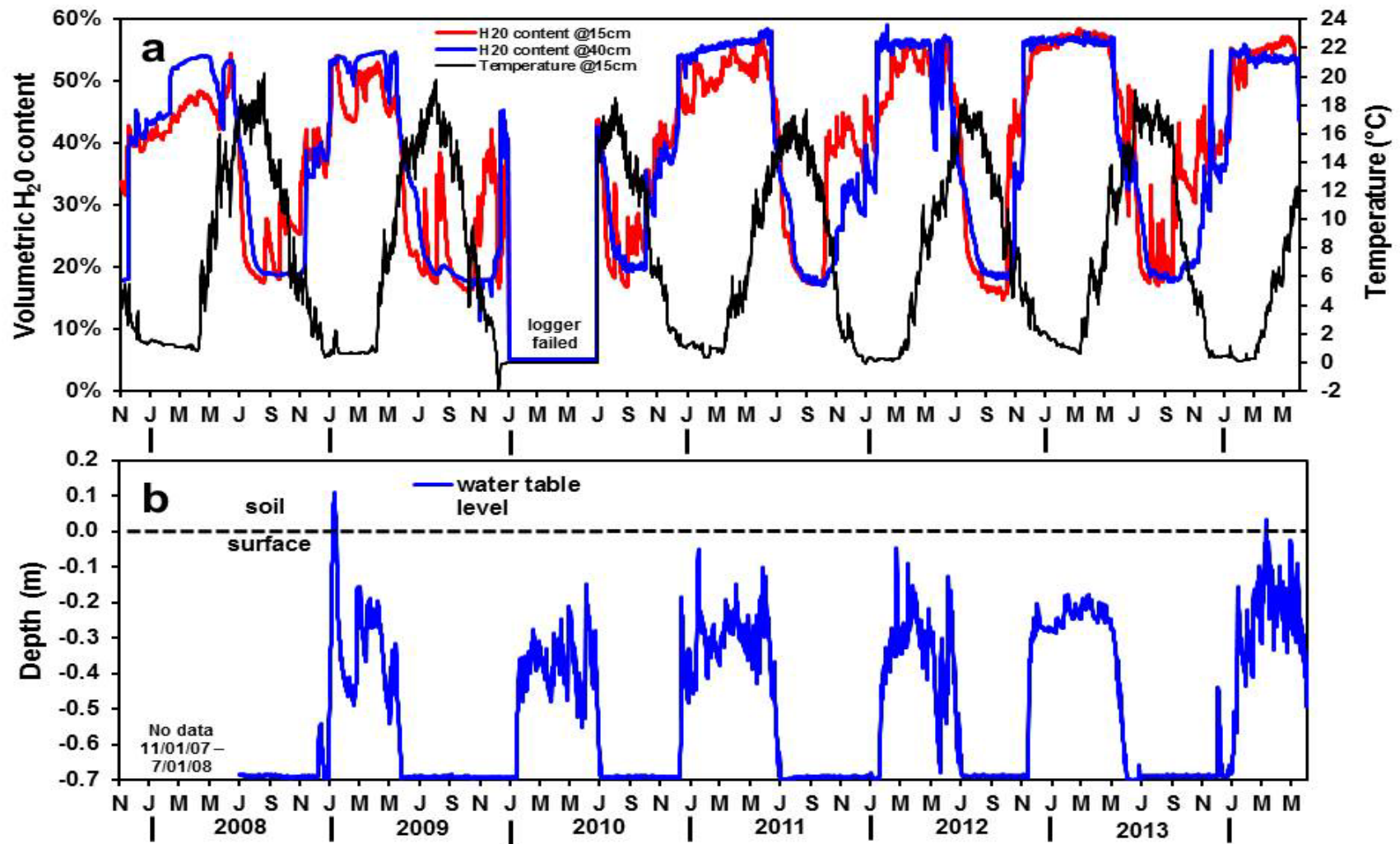


Figure 11. Hydrological data for Site 3 showing temporal changes in (a) soil moisture and temperature and (b) water table levels.

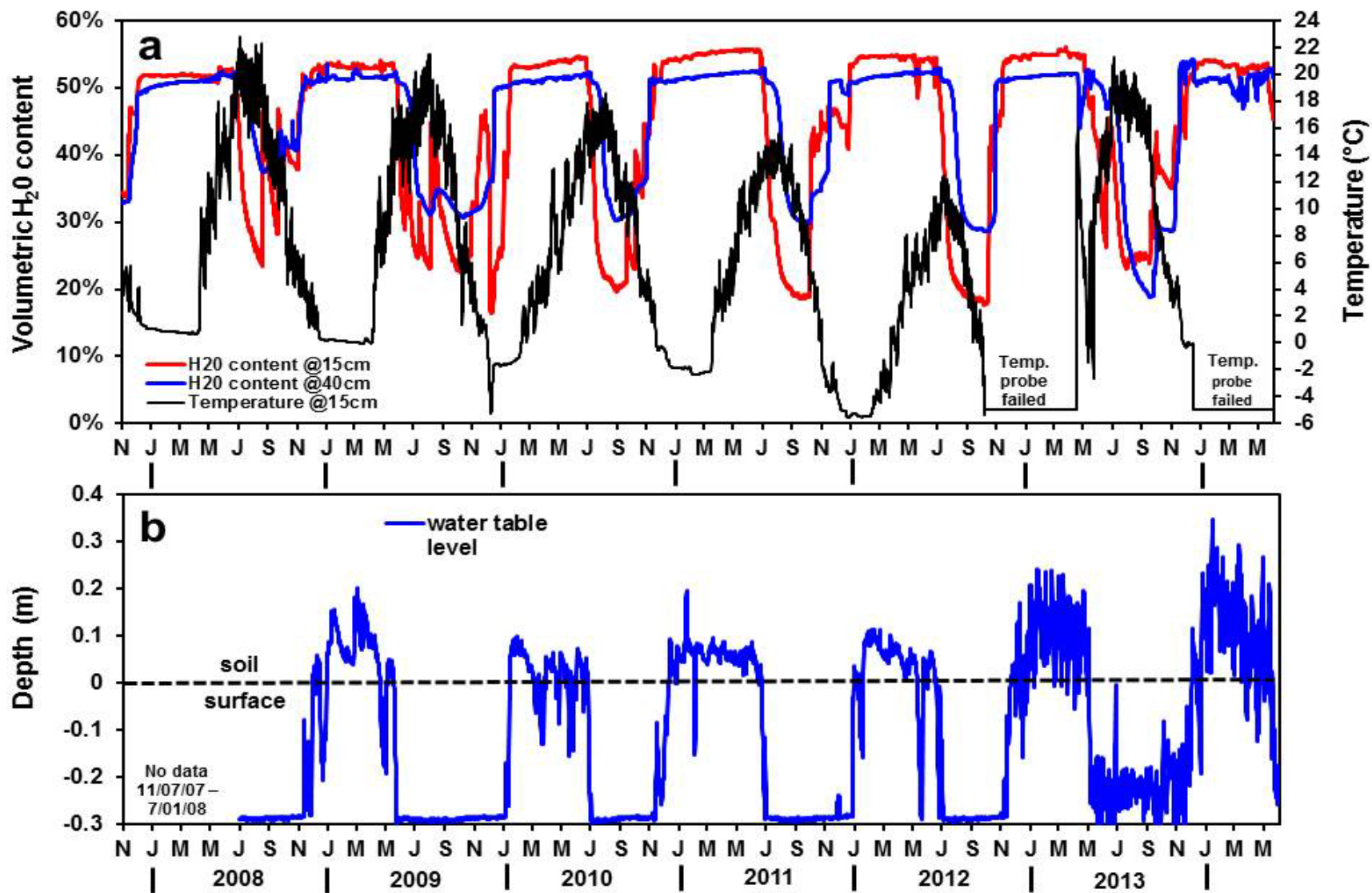


Figure 12. Hydrological data for Site 4 showing temporal changes in (a) soil moisture and temperature and (b) water table levels.

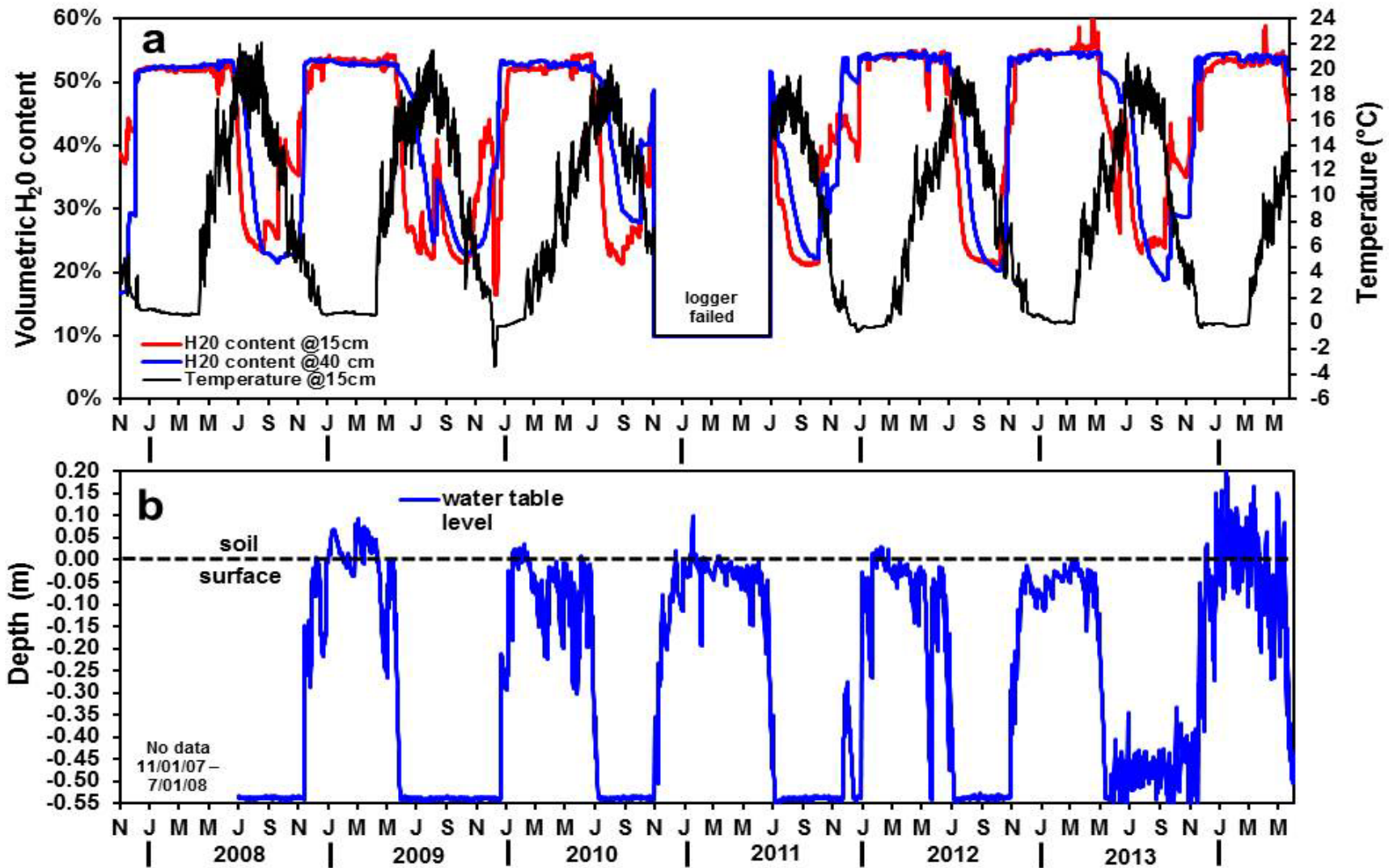


Figure 13. Hydrological data for Site 5 showing temporal changes in (a) soil moisture and temperature and (b) water table levels.

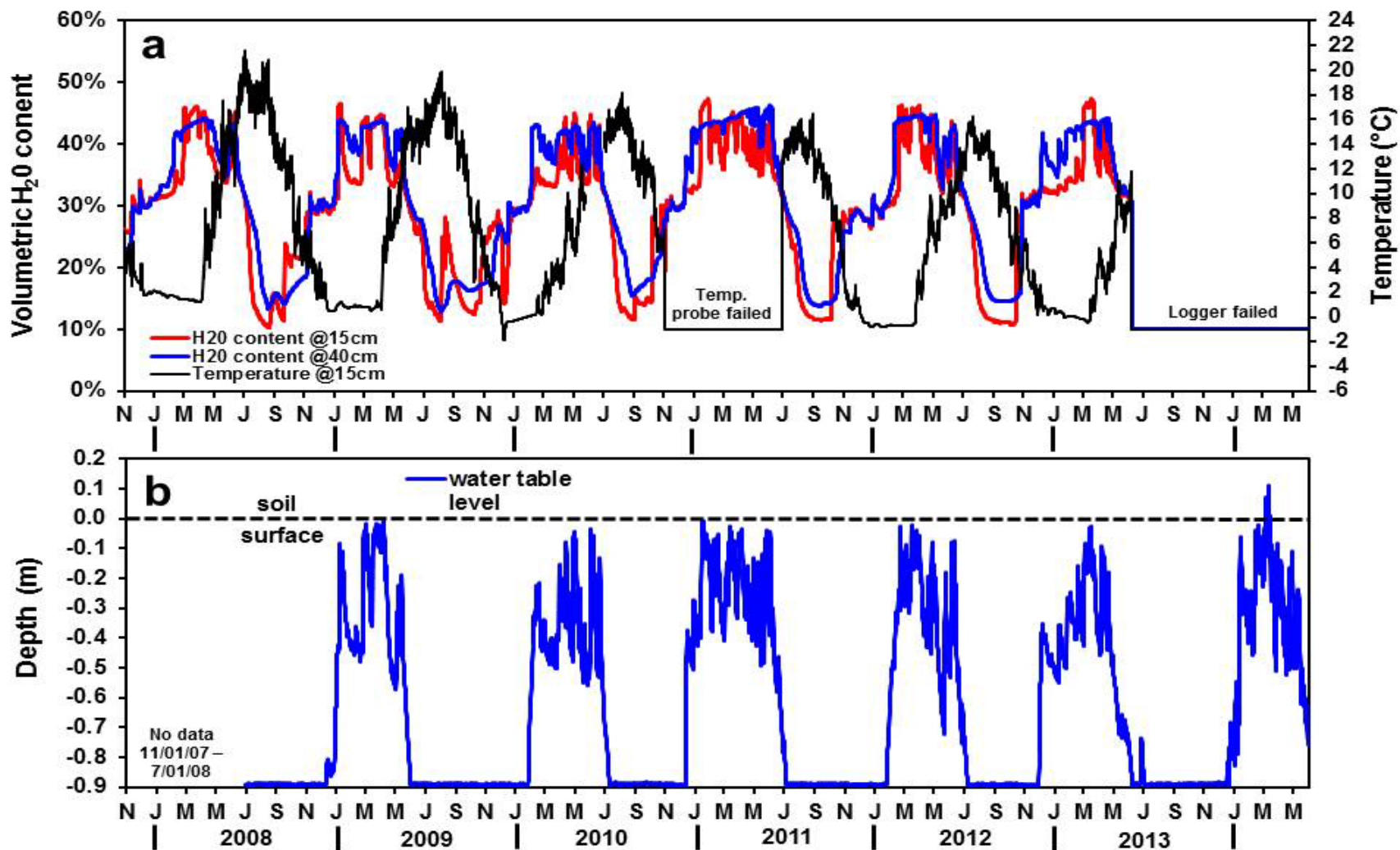


Figure 14. Hydrological data for Site 6 showing temporal changes in (a) soil moisture and temperature and (b) water table levels.

Discussion

Project efforts focused on two objectives: providing detailed soil morphological, physical, and chemical characterization data and monitoring temporal changes in soil hydrology. Sites sampled and monitored as part of this project were selected to represent a range in soil characteristics across the Weippe Prairie site that may be influential in the survival and growth of camas.

All soil profiles exhibited morphological characteristics consistent with a low-lying, alluvial/lacustrine landscape setting. They are characterized by the presence of redoximorphic features, indicating seasonal saturation with water. It is likely that the seasonal saturation of these soils is related to their ability to support camas, which is a facultative wetland species (USDA–NRCS, 2010). An important feature of many Weippe Prairie site soils is the presence of a slowly permeable subsoil horizon that causes a seasonal perched water table. Because these horizons are commonly found at depths of ~0.5 m, they have a strong influence on root-zone soil-water relations.

Soils of the Weippe Prairie tend to have finer textures – silt and clay are the most abundant particle sizes. These textures are indicative of relatively low-energy depositional environments, such as those associated with slow-moving streams and lakes.

Laboratory data indicate that soil chemical properties do not differ markedly across the Weippe Prairie site. All soils are very strongly or strongly acid, a condition that affects many biological and chemical processes. Results also show that reserves of exchangeable base cations (Ca^{2+} , Mg^{2+} , and K^{+}) do not appear to be limiting for plant growth.

Kaolin is the dominant clay mineral found in the soils studied, and its presence generally indicates older, rather intensely weathered soil parent materials. In the case of Weippe Prairie soils, they appear to have formed mainly in pre-weathered alluvial and lacustrine parent materials. There have been additions of younger sediments such as volcanic ash and loess. Additions of these younger materials may help rejuvenate the supply of base cations in these soils and contribute to their fertility.

Hydrological monitoring confirmed the morphological evidence for seasonal wetness. All Weippe Prairie soils studied have water tables for periods in the range of 4-7 months per year. However, two major differences were observed among soils. The first difference is the relative position of the water table within the soil profile – some soils (Sites 1, 4, 5, and 8) were usually saturated within 15 cm of the soil surface during the time when a water table was present. Water tables levels at the other sites (Sites 2, 3, 6, 7, and 9) were typically lower in the soil profile. The second difference was ponding of water. Site 4 remained ponded for 3-4 months, while Sites 2, 6, 7, and 9 were never ponded. Despite these differences, there does not appear to be a consistent relationship between water tables and camas densities.

The results of this project provide valuable baseline information about soils of the Weippe Prairie site. However, they do not identify specific soil or hydrologic properties related to observed camas density differences. This suggests that differences in camas density at the Prairie may be due to factors such as disturbance and past management rather than edaphic factors.

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Appendix I – Laboratory Protocols

Sample Preparation

Samples collected from genetic horizons at each of the field sites were air-dried, gently crushed, and sieved to obtain the <2-mm size fraction for all laboratory analyses (Soil Survey Laboratory Staff, 2004).

Chemical Analyses

1:1 (Soil/H₂O) pH – Twenty grams of soil were weighed into a plastic container and 20-mL of triple distilled water (TDW) was added, mixed, covered, and let stand for 2-hours. pH was read using a standard pH electrode (Soil Survey Laboratory Staff, 2004).

NaF pH – The influence of volcanic ash was measured using 1M sodium fluoride (NaF) solution. One gram of soil was weighed, 50-mL of NaF solution added, and the pH read using a standard pH electrode at 2-minutes after stirring for 1-minute. A NaF pH ≥ 9.4 is a strong indicator that poorly or nanocrystalline minerals (i.e. volcanic ash weathering products) dominate the soil exchange complex (Fieldes and Perrott, 1966).

Exchangeable cations – Exchangeable cations (Ca, Mg, K, and Na) were extracted using 1 M ammonium acetate (NH₄OAc) at pH 7. Soil was weighed, ~35-mL of NH₄OAc added, placed on a hot plate for 2-hours, cooled, and extracted using a Buchner funnel apparatus with suction. Extracts were diluted and analyzed using an inductively coupled plasma (ICP) spectroscopy for Ca, Mg, K, and Na. Cation exchange capacity (CEC) at pH 7 was determined by washing the soil exchange from the exchangeable cation procedure, then removing the ammonium from the exchange using acidified sodium chloride (NaCl). The acidified NaCl solution was diluted and analyzed for ammonium using the automated AE Quickem Lachat spectrophotometer or 2500 Flow Injection (FIALab) instrument. Base saturation percent (B.S. %) was calculated using the sum of cations (pH 7) divided by the sum of cations plus acidity multiplied by 100 (Sumner and Miller, 1996).

Exchangeable acidity – Exchangeable acidity (hydrogen plus aluminum) was extracted using barium chloride (BaCl₂) and triethanolamine (TEA) at pH 8.2. Soil was weighed, ~100-mL of BaCl₂-TEA solution added and soils leached with small additions of BaCl₂-TEA solution after setting overnight using a Buchner funnel apparatus with suction. The leachate was back titrated using standardized hydrochloric acid (HCl) to a pink endpoint (Soil Survey Laboratory Staff, 1996).

Total carbon and nitrogen – Soil samples were analyzed for total carbon (C) and total nitrogen (N) by dry combustion (Nelson and Sommers, 1996) using an Elementar CNS analyzer. Samples were weighed into crucibles and placed in the automated Elementar CNS analyzer to combust at 1000 °C. The C:N ratios were calculated using the total C and N data.

Organic carbon – Organic carbon (OC) was determined by rapid dichromate oxidation (Nelson and Sommers, 1996). The method for determining OC was modified using pre-weighed soil samples according to an estimated amount of OC (Walkley, 1935), digested with dichromate and sulfuric acid

to 150°C. Titration was performed using ferrous sulfate (FeSO_4) to a brown color endpoint to determine the OC present.

Nitrate (NO_3^- -N) and ammonium (NH_4^+ -N) – Soil samples were extracted using 5-grams of air-dried soil and adding 40-mL of 2M potassium chloride (KCl). Samples were placed on a reciprocating shaker for 30-minutes. Samples were filtered using 0.7 μ glass fiber filters placed on a suction apparatus. Clear solutions were analyzed on the 2500 Flow Injection (FIALab) instrument and FIALab protocols for reagents and color development specifications (Keeney and Nelson, 1982).

Ammonium oxalate (AOD) – The selective dissolution procedure ammonium oxalate (pH 3.0) was employed to help characterize the amorphous and short-range components of the soils. Soils were weighed (0.25g) and 25-mL 0.3M ammonium oxalate pH 3.0 solution was added. Samples were placed on a reciprocating shaker for 4-hours in the dark. After adding Superfloc and 1-hour settling, samples were filtered with 0.7 μ glass fiber filters, and diluted 1:4 with double distilled water (DW). Extracts were analyzed for Al, Fe, P, Mn, Si and Ti using inductively coupled plasma (ICP) emission spectroscopy (Jackson et al., 1986 and Soil Survey Laboratory Staff, 2004).

Optical Density Oxalate Extraction (ODOE) – Filtered extracts from the selective dissolution ammonium oxalate (AOD) were used to read the ODOE. Extracts 1:100 were placed in spectrophotometer cuvettes and the absorbance read at 430nm VIS setting and recorded (Soil Survey Laboratory Staff, 2004).

Citrate, Bicarbonate and Dithionite (CBD) Extraction – One gram soil samples were weighed and 45-mL sodium citrate, 5-mL sodium bicarbonate and 1-gram sodium dithionite added. Samples were heated to 80°C in a water bath for 10-minutes and stirred. Another gram of sodium dithionite was added and stirred. After 10-minutes the samples were removed and cooled before centrifuging. Samples were filtered with 0.7 μ glass fiber filters and diluted 1:10 using triple distilled water (TDW). Extracts were analyzed for Al, Fe, and Mn using inductively coupled plasma (ICP) emission spectroscopy (Jackson et al, 1986).

New Zealand Phosphorus Retention (P-retention) – Five gram soil samples were weighed and 25-mL of 1000 $\mu\text{g/mL}$ known phosphorus (P) solution was added. Samples were shaken overnight on a reciprocating shaker and centrifuged. Extracts were analyzed for P retained using a known curve and reading absorbance at 466 nm after color was developed for 30-minutes. P-retained was extrapolated from the standard curve (Blakemore et al., 1981 and Soil Survey Laboratory Staff, 2004).

Physical Analyses

Bulk density – Triplicate 1-3 inch sized aggregates were collected by horizon at each of the field sites. A thin copper wire was tied around the aggregates, oven-dried, weighed, then coated with Saran F-310 lacquer at least 3 times at 15-minute intervals. Aggregate volume was obtained by weighing in water (Blake and Hartge, 1986). Data were averaged for each horizon and reported in g/cm^3 .

Particle-size Distribution – Particle-size distribution was performed using sieving and sedimentation procedures (Gee and Bauder, 1986). Samples were pre-treated with sodium hypochlorite (NaOCl) to destroy organic aggregating agents (Anderson, 1963; Mikhail and Briner, 1978). Dispersion was completed using a sodium hexametaphosphate solution, mechanical shaking overnight, and sonification. The sand fraction was removed from the suspension by wet sieving and then fractionated by dry sieving. Clay and silt in suspension were stirred and aliquots removed with a pipette at predetermined intervals based on Stokes' law (Kilmer and Alexander, 1949). Aliquots were dried at 110°C and weighed. Sand, silt and clay percentages were calculated from the separate weighing using an EXCEL spreadsheet program. Data was reported to the nearest 0.1 % by weight. The very fine sand fraction was examined under a petrographic microscope to determine volcanic glass content and other features (Drees and Ransom, 1994). Scanning electron microscopy (SEM) was used to image special features found in the very fine sand fraction; this work was performed by Dr. Leslie Baker, Soil Chemistry Research Support Scientist.

Clay Mineralogy – X-ray diffraction analysis was used to determine the crystalline mineralogical components of clays (<2 µm diameter) saved from the particle-size analysis. Treatments included magnesium (Mg) saturation, Mg saturation and glycerol solvation, potassium (K) saturation, and K saturation-heated to 500°C (Jackson, 1975; Whittig and Allardice, 1986). Samples were oriented on glass slides and analyzed on a Siemens D5000 diffractometer instrument using Cu-K α radiation and a continuous scan rate. A formamide treatment to the Mg saturated slide was used to differentiate kaolinite from halloysite (Churchman et al., 1984; Theng et al., 1984).

Water Retention (soil water content at a given soil water tension) – Water retention is useful directly and indirectly as an indicator of other soil characteristics such as drainage, aeration, infiltration, plant available water, and rooting patterns. Soil samples were run by the pressure method (Klute, 1986). Samples were placed in retainer rings on a ceramic plate and equilibrated at 0.33 (field capacity) and 1.5 MPa (wilting point). Pressure was kept constant until equilibrium obtained; gravimetric water content of samples was then determined. The difference between 0.33 and 1.5 MPA is an estimate of plant-available water-holding capacity (U.S. Salinity Staff, 1954; Klute, 1986).

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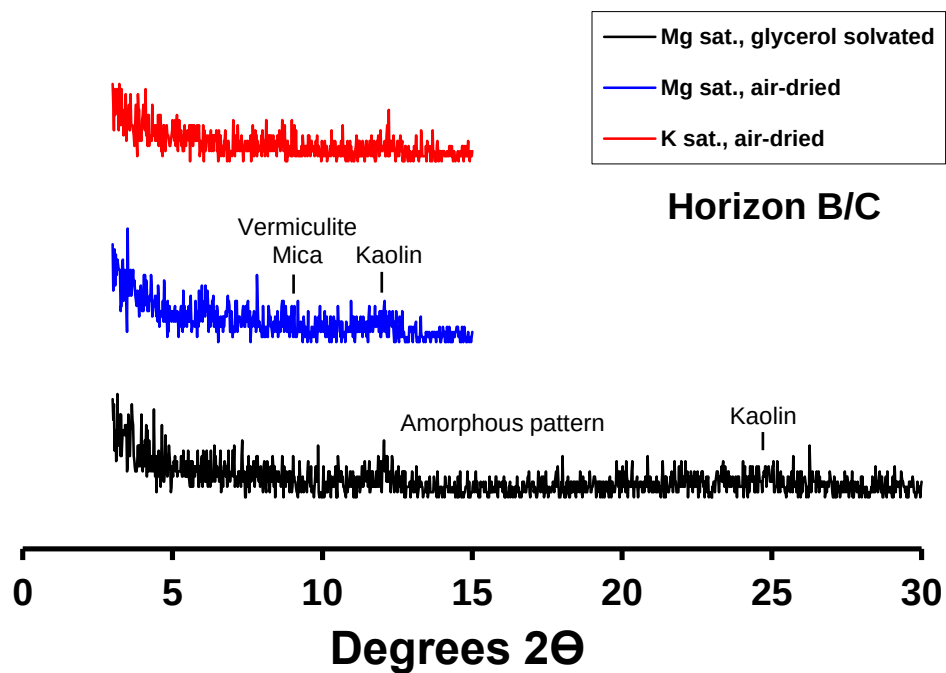
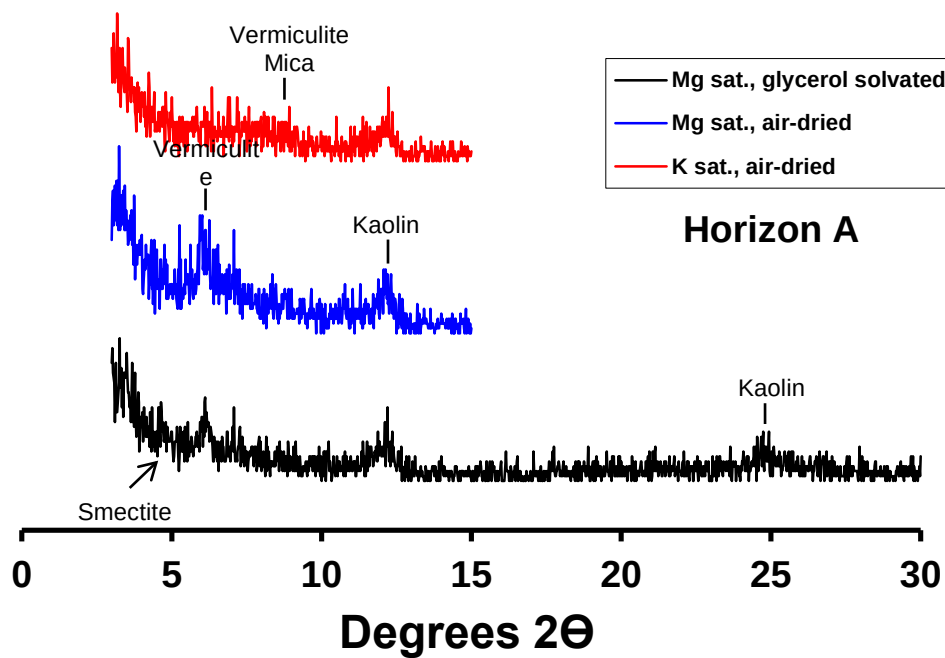
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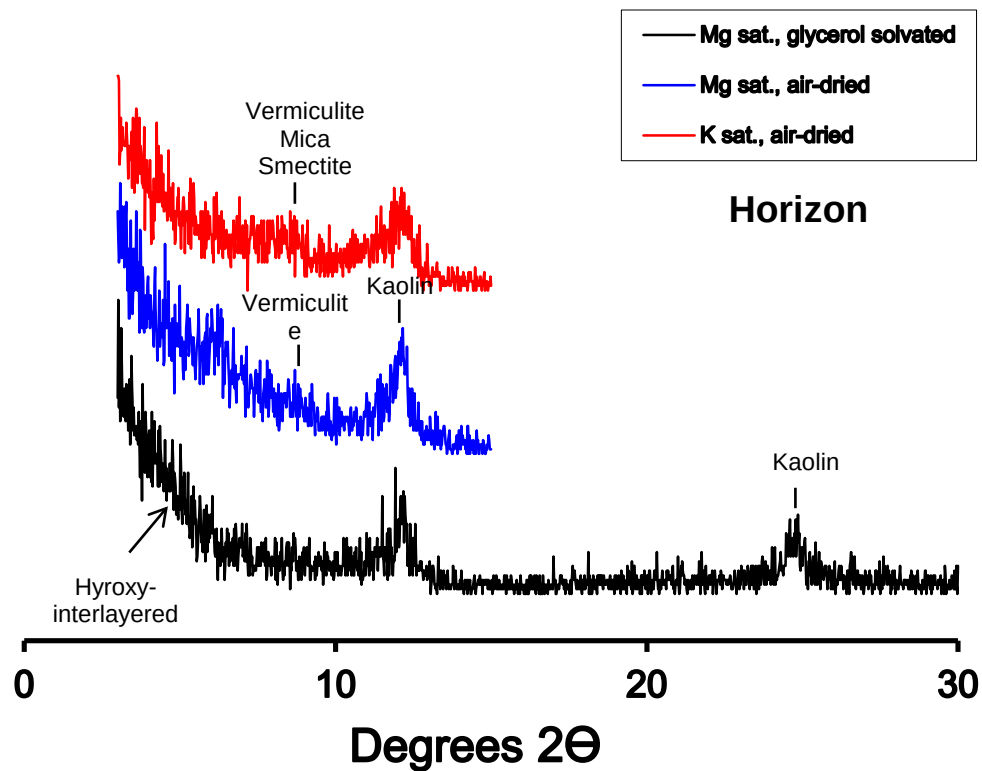
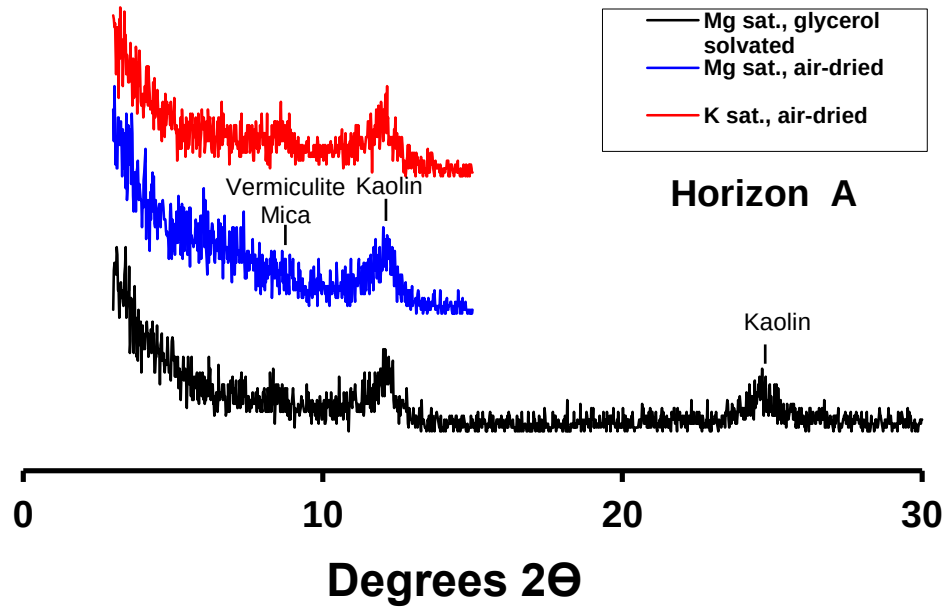
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Appendix II – X-ray Diffraction Patterns

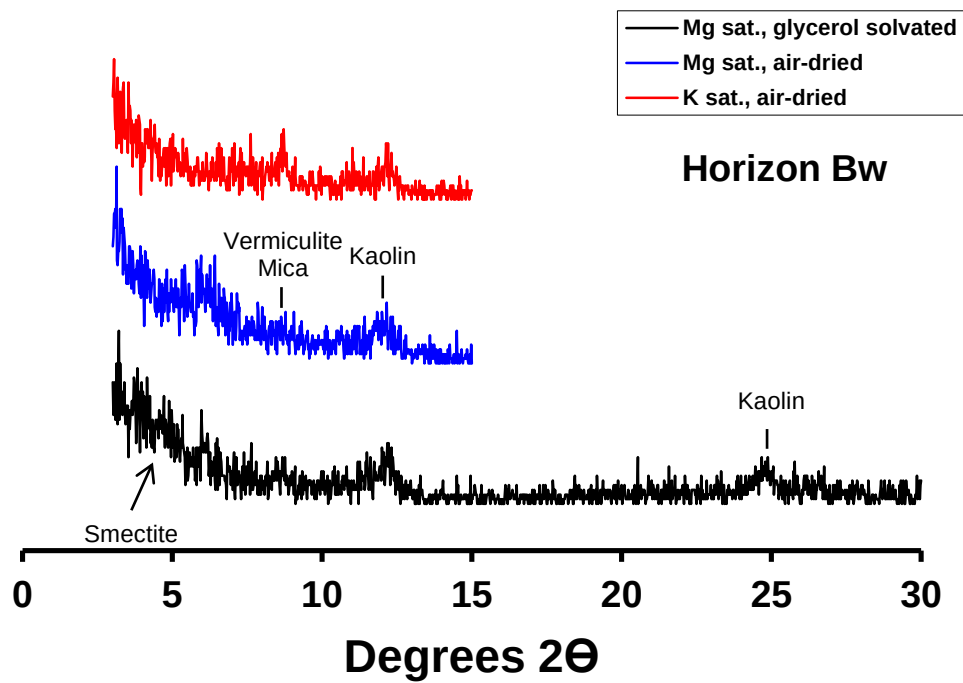
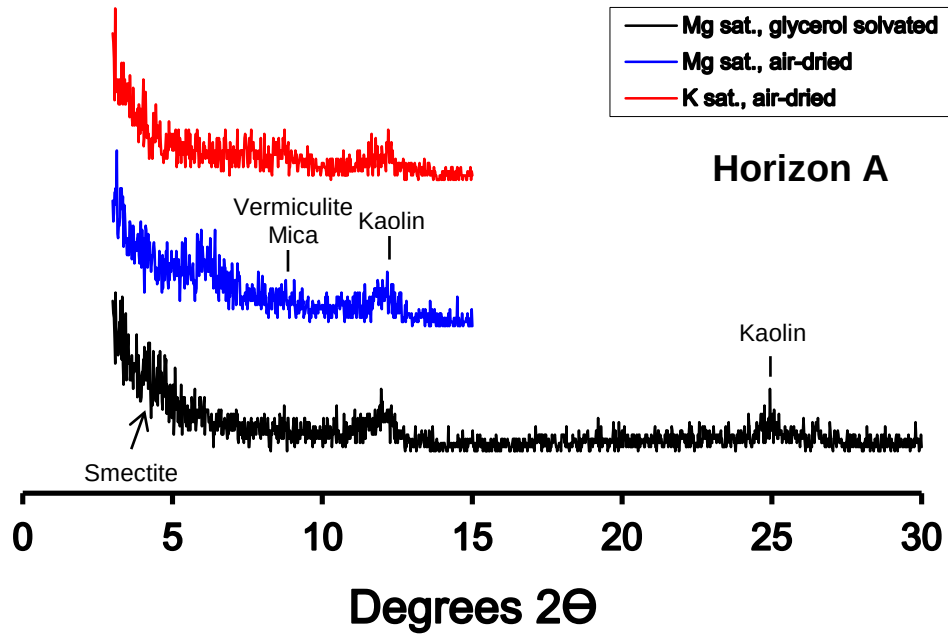
Site 7



Site 8



Site 9



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