A Preliminary Evaluation of Seasonal Water Levels Necessary to Sustain Mount Emmons Fen: Grand Mesa, Uncompahgre and Gunnison National Forests

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Introduction

Many wetlands in the Colorado Rocky Mountains are supported by ground water flowing from hillslope aquifers. These seasonal or perennial ground water flows support fens and wet meadows, as well as spring complexes and many small streams. In addition, many larger streams and even our largest rivers may have considerable ground water inputs. Thus, it is critical to understand how ground water flows support wetland and aquatic ecosystems, and how to protect their source waters.

The type of wetland occurring in any location is determined by water table characteristics produced by the seasonal patterns of ground water flow. Where perennial ground water discharges to saturate wetlands all year, dead plant leaves, stems and roots only partially decompose and accumulate to form peat soils, and these ecosystems are fens. Where ground water levels vary seasonally, and long dry periods occur, organic matter production and decomposition are in balance, and wet meadows occur that lack organic soils. Where water discharges at one point in great abundance and with the capacity to erode soils, springs and small streams may form. While the general characteristics of each of these ecosystem types is known, we know very little about the ground water levels or volume of water required to protect the functioning of each of these ecosystem types.

In this report I present the results of an investigation of the Mount Emmons fen, located west of Crested Butte in the Grand Mesa, Gunnison and Uncompahgre National Forest (GMUG). The water table of this fen is perennially near the soil surface, which has allowed organic soils to develop during the Holocene (Fall 1997, Chimner and Cooper 2003). In the Southern Rocky Mountains many fens support rare plant and animal species, and unique communities (Cooper and Sanderson 1997). This is certainly the case for the Mt. Emmons fen, which supports one of only two known populations of *Drosera rotundifolia* (roundleaf sundew) in the southern Rocky Mountain region and is dominated by a rare *Sphagnum angustifolium* moss community. Although fens in the Southern Rocky Mountain region are all ground water fed it is common to find small lakes or pools within them.

Because fen plants are completely dependent upon their water supply and soils for mineral ions and nutrients, the geochemistry of bedrock and quaternary deposits in watersheds supplying water to fens controls the pH and concentrations of dissolved solids reaching fens. Colorado has an extreme range of bedrock types in watersheds supporting fens, ranging from limestone, dolomite or shale bedrock producing water that is basic in reaction (pH 7.0 – 8.5) with a high concentration of dissolved solids (Cooper 1996), to watersheds with granite or metamorphic rocks producing water with low pH (pH 5.0 – 6.5) and low dissolved solids (Cooper 1990, Cooper and Andrus 1994). A very small number of fens in the region have iron pyrite rich bedrock and talus in their watershed. The oxidation of pyrite produces sulfuric acid, which when dissolved in water forms a strong acid that can leach ions from the rock including iron. This produces acid water that also contains high ion concentrations (Cooper et al. 2002). We have termed these ecosystems "iron fens" because dissolved iron from the pyrite is transported to the fen where it oxidizes onto organic matter forming limonite, or bog iron ore, deposits. Iron fens are the only wetland ecosystem type in the region with highly acidic natural water sources. In addition, limonite terraces create landforms unique to iron fens. Key elements of iron fen hydrologic and geochemical regimes include perennial inflow of ground water that maintains saturated and anoxic soil conditions, and complex watershed ground water recharge and flow patterns that produce diverse, yet highly acid and iron rich, geochemical environments in the fen complex. In addition, iron fens support plant communities unique to Colorado.

This report presents field data collected at Mt Emmons fen during the fall of 2002, winter of 2002-2003, and spring, summer and fall of 2003. The goal of this investigation was to: (1) determine the natural range of variability in groundwater levels in the study area, (2) develop an understanding of the linkages between surface water and groundwater, (3) determine the interaction of ground water flow through the fen and the level of the lake within the fen, (4) develop recommendations for hydrologic criteria that could be used to protect plant and aquatic communities and the ecological functioning in the fen.

Methods

Overall Approach: This study focused on quantifying the seasonal variation in ground water levels, piezometric heads, water chemistry and vegetation in the fen. In addition, we present information on the water table response to rain during 2003. We made field and laboratory measures of water pH and water chemical content in the fen and obtained GPS points to identify the boundaries and calculate its area.

Topographic Surveying: I identified the fen boundary, the area with organic soils, which was then surveyed using a high quality GPS unit by Forest Service staff from the Gunnison Ranger District Office. We also used a total station, and a local benchmark, to detemine the elevation, latitude and longitude of all wells, staff gauges and other topographic features in SE portion of the fen.

Precipitation: An Onset Data logging rain gauge, with Hobo Event logger, was used to continuously measure summer precipitation at the site. The goal of monitoring precipitation was to identify whether the water table in any portion of the fen responded to rain events.

Surface water levels: One staff gauge (well 1) was used to measure surface water level in the main pond. The gauge was built using a Global Water WL-15 water level logger installed in a fully slotted PVC pipe. The logger records the height of the water column above the pressure sensor. These data are used to compare lake level changes to ground water level changes elsewhere in the fen.

Ground water levels: Depth to ground water was measured in monitored wells. Wells were constructed by hand augering to approximately 1 m depth using a bucket auger, and casing the well with fully slotted 2” diameter Schedule 40 PVC pipe. A total of 6 wells (wells 2-7) were installed to represent the main study area. Global Water WL-15 water level loggers were installed in each well to continuously record water levels. Water levels were measured at all Mt. Emmons sites from late September 2002 through mid-October 2003, nearly 13 months. One or two piezometers were installed at each well location, other than well 3, to measure the pressure head at depth in the ground water flow system. The data were used to determine whether there were vertical components to ground water flow. In addition, the pH of ground water in piezometers was measured to characterize surface water and ground water at each well site. Piezometers were driven with a steel bar inside ½" inside diameter, PVC pipe. The PVC pipe was open only at the bottom. Wells were developed by bailing until water was clean. Soil stratigraphy at each well site was recorded by depth. Water levels in wells without loggers and in piezometers were measured several times during the study period.

Water chemistry: Water samples for chemical analysis were collected from each well in the fall of 2002. Samples were analyzed at the Soil And Water Testing Laboratory at Colorado State University in Fort Collins, for major cations and anions. Water pH was measured in the field with an Orion Model 250A pH meter, equipped with a combination electrode and calibrated with fresh buffers.

Statistical Analyses: Correlation analysis was used to relate monitoring well water levels to other wells.

Results

Well/Staff Gauges

One staff gauge and six monitoring wells were installed on 27 September 2002. Each well and the staff gauge had a continuous water level recorder. The well casing lengths are listed in Table 1. Ten piezometers were installed and are listed below the well they are adjacent to. All wells and piezometers were installed in thick peat. The location of the wells and lake are shown on Figure 1.

Table 1. Monitoring wells and piezometers installed at Mount Emmons fen. Well number, peat thickness (m), PVC casing length (m), height of casing sticking up above the ground surface (m), and depth of slotted casing below the soil surface for numbered wells (m). P refers to piezometers, which are unslotted and open only at the bottom. Piezometers are located adjacent to the well they are listed below. For example, P1 and P2 are located adjacent to well 1.

Well	Peat Thickness	Casing Length	Stick Up	Well depth
1		0.00	0.00	0.00
P1		1.51	0.34	1.16
P2		1.00	0.39	0.61
2	0.69	1.48	0.85	0.62
P3		0.56	0.00	0.00
3	0.91	1.58	0.67	0.91
4	0.91	1.55	0.56	0.99
P4		0.79	0.10	0.69
P5		1.52	0.10	1.42
5	1.52	1.49	0.64	0.85
P6		0.87	0.11	0.76
P7		1.52	0.09	1.43
6	0.84	1.52	0.67	0.85
P8		0.95	0.15	0.80
7	0.49	1.01	0.09	0.91
P9		0.67	0.06	0.61
P10		1.28	0.06	1.22

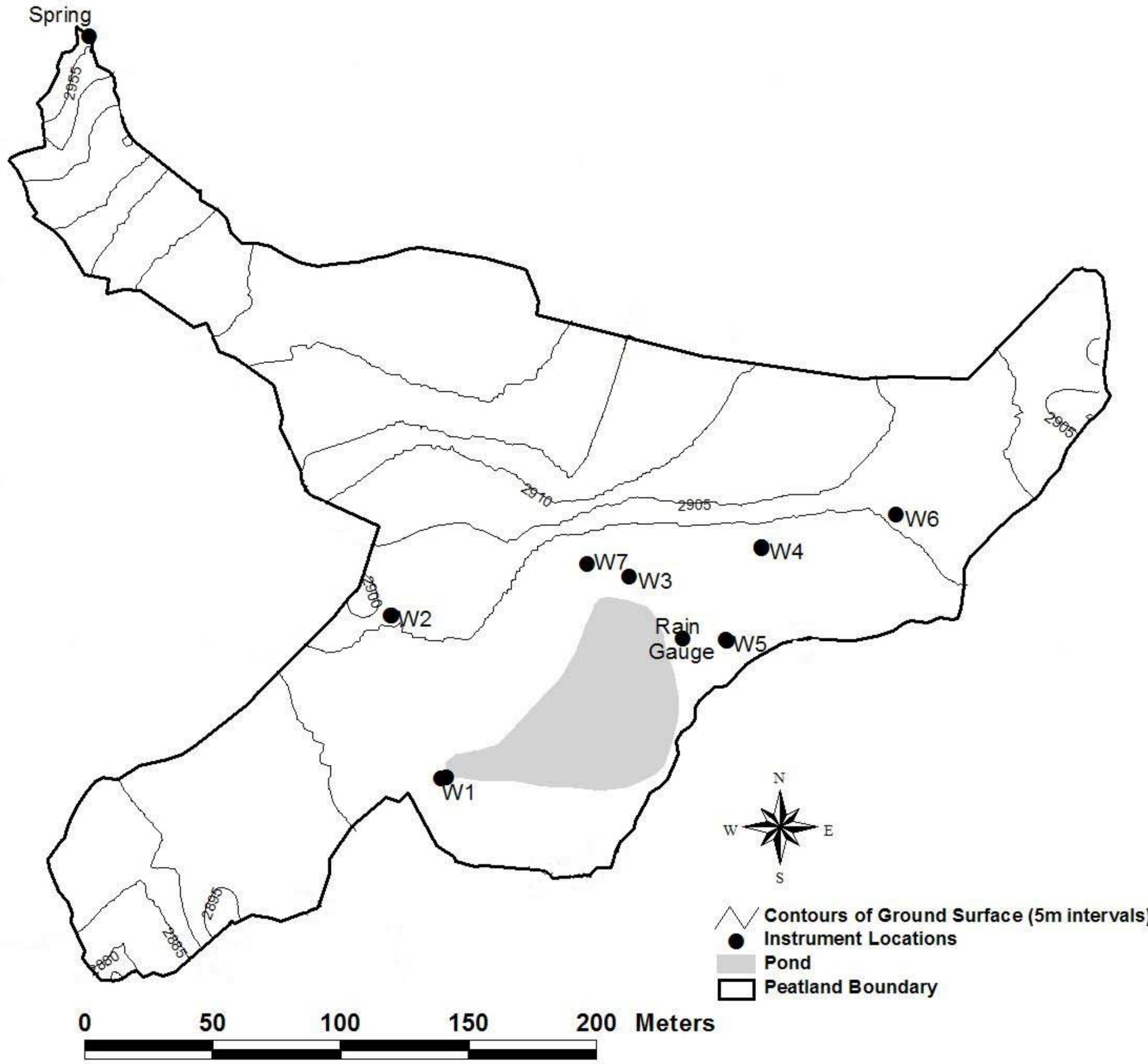


Figure 1. Topographic map of Mt. Emmons fen. Well 1, a staff gauge in the fen pond, is located near the pond outlet. Monitoring wells 2-7 are also shown. Contour interval is 5 meters. The fen is 15.1 acres (6.1 hectares) in size.

Precipitation

Precipitation was measured from early June through 21 October 2003. June and early July 2003 were quite dry, but strong monsoonal flow and regular rains began in late July and continued through mid-September.

Fen Acreage

Mt Emmons fen is 15.1 acres (6.1 ha) in size, and has a Y shape (Figure 1). Water flows from north to south, and at the southern side of the fen converges into a narrow flow path.

Surface and Ground Water levels

The spring and summer of 2002 had very low precipitation, and water levels in wetlands throughout Colorado were extremely low. However, strong monsoonal flow brought significant precipitation to the region in September through November. Unfortunately, heavy rains began just prior to the installation of our wells. Recorded water levels for this period reflect the recent hillslope ground water recharge and water levels were likely higher than they would have been at any point since early spring 2002 (Figure 2).

Mount Emmons lake water levels varied little during the entire study period (Figure 2, 3, 4). Water level was nearly identical from late September through the winter, although it rose slightly in spring. Surface water levels were quite stable all summer. Ground water levels in all wells varied considerably through the monitoring period. Most wells had water levels near the soil surface in late September and early October of 2002 in response to the rain events (Figure 2) and sharply declining water levels through the winter. Water levels rose sharply in spring due to snowmelt recharge of the hillslope aquifers. Water levels at wells 2-6 remained near the soil surface for most of the summer of 2003, while water levels at well 7 declined during the summer.

Data from piezometers installed at the staff gauge and wells 2, 4, 5, 6 and 7 indicate an upward vertical gradient at all sites other than well 7 (Figure 3). Thus, water is discharging vertically toward the soil surface at all monitoring sites including under pond. In addition, surface water sheet flow through the site, and this water has its origin at springs along the northern edge of the fen.

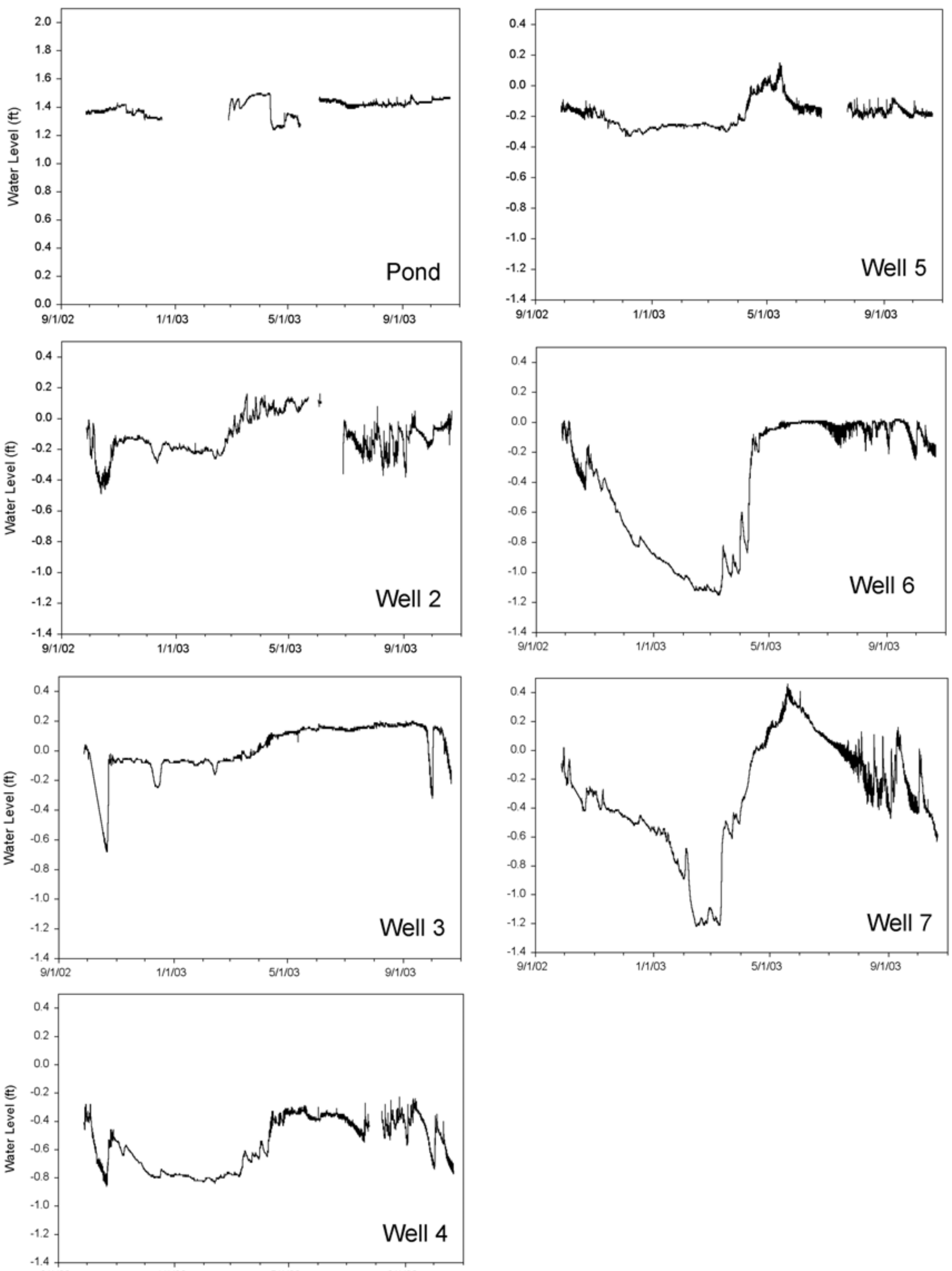


Figure 2. Ground water and lake level measures from late September 2002 through October 2003. Water levels are in feet relative to the ground surface (0 feet). Pond level is relative to an arbitrary datum.

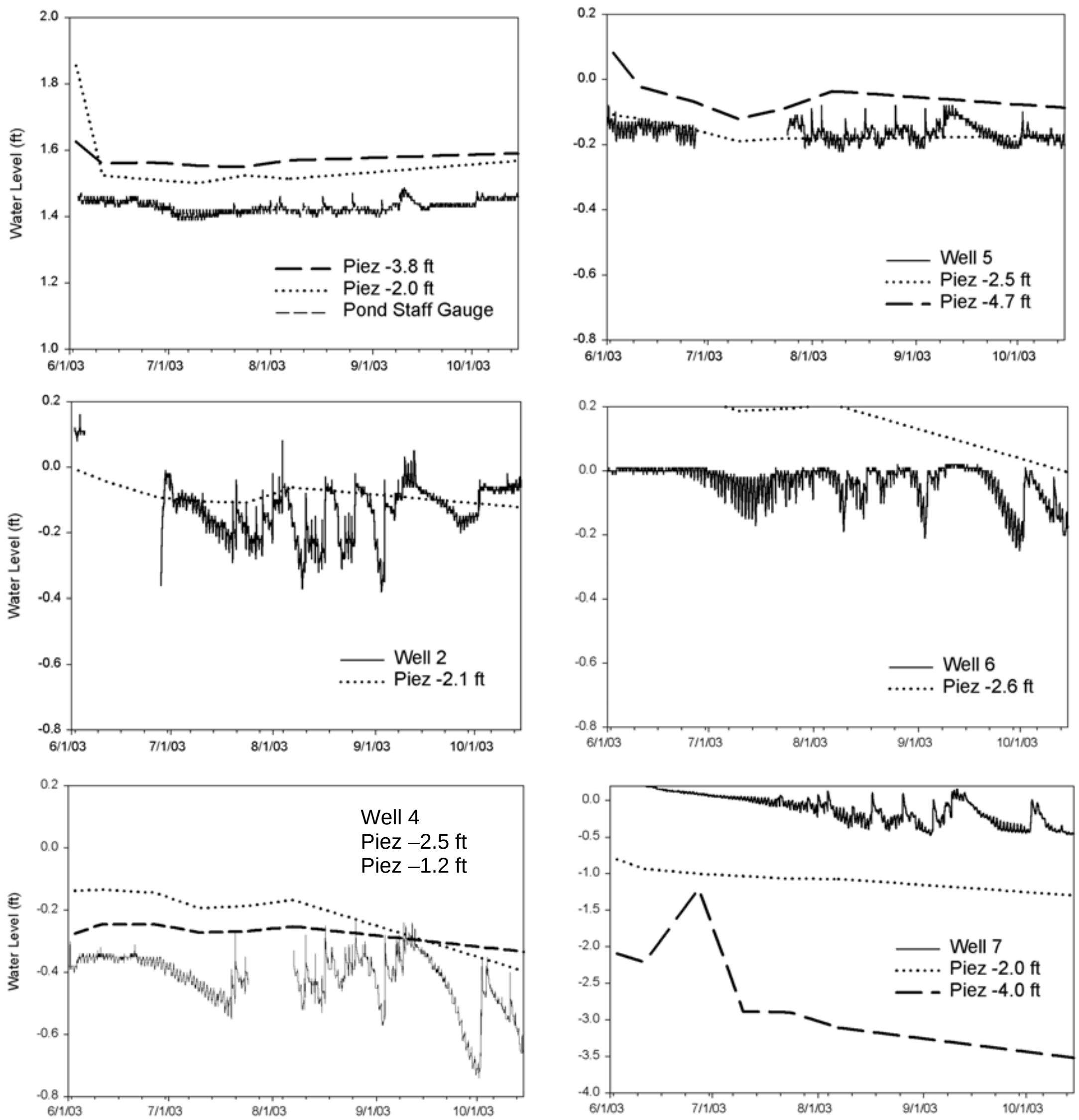


Figure 3. Water levels in pond and ground water monitoring wells (wells 2, 4, 5, 6 and 7) compared with piezometers at the same locations during summer 2003. The piezometers are identified by the depth of their opening. Water levels are in feet relative to the ground surface (0 feet). Piezometers with water levels higher than monitoring well levels indicate an upward flow, while those with lower levels than the well indicate downward flow.

Water Level and Precipitation Relationships

All wells and the pond level responded to summer precipitation events, particular in September 2003 (Figures 4 and 5). Responses varied by well, being greatest at well 7, and least at well 3. However, pond levels varied little in response to rain (Figure 5).

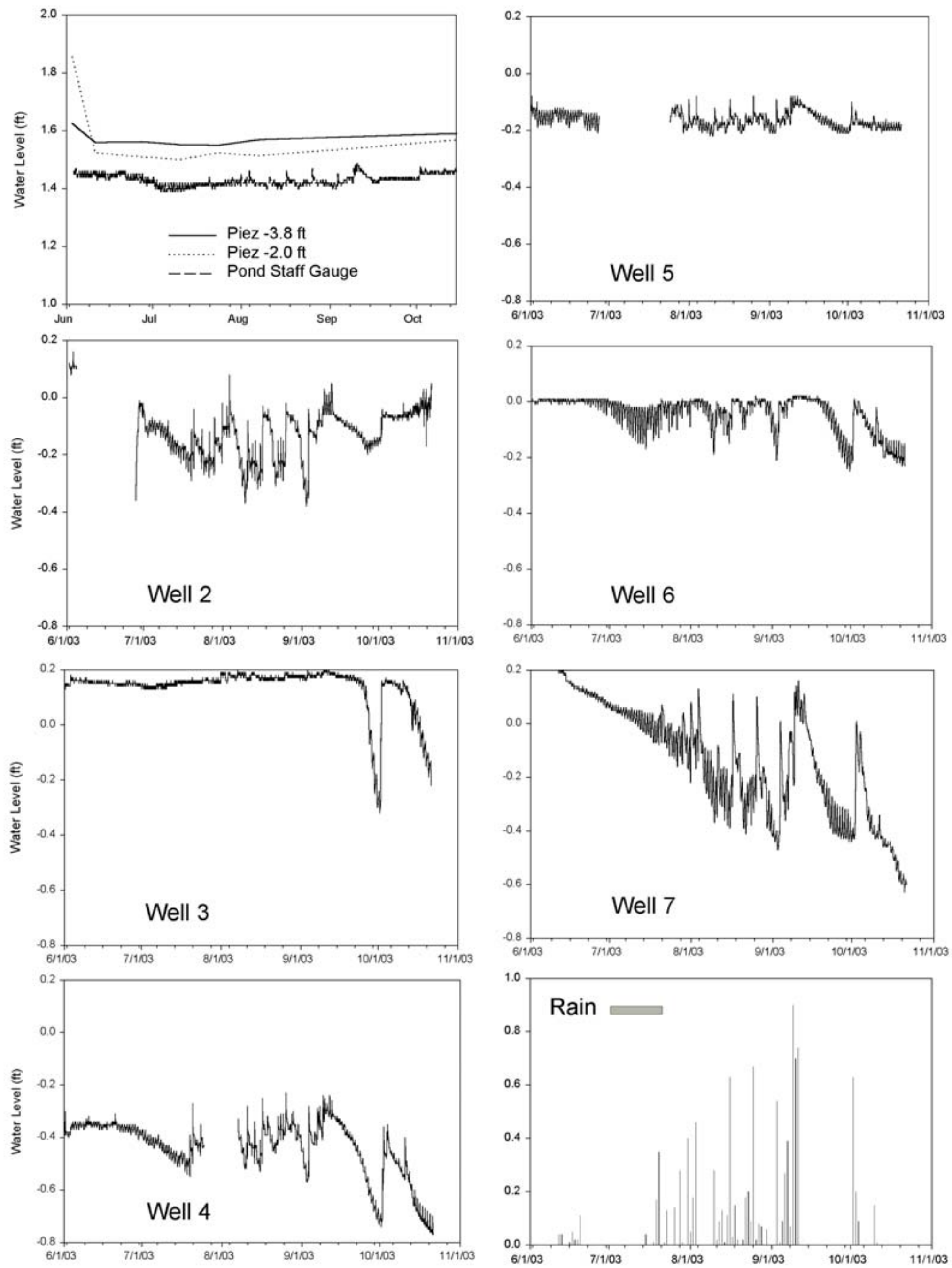


Figure 4. Water levels and daily precipitation totals during summer of 2003.

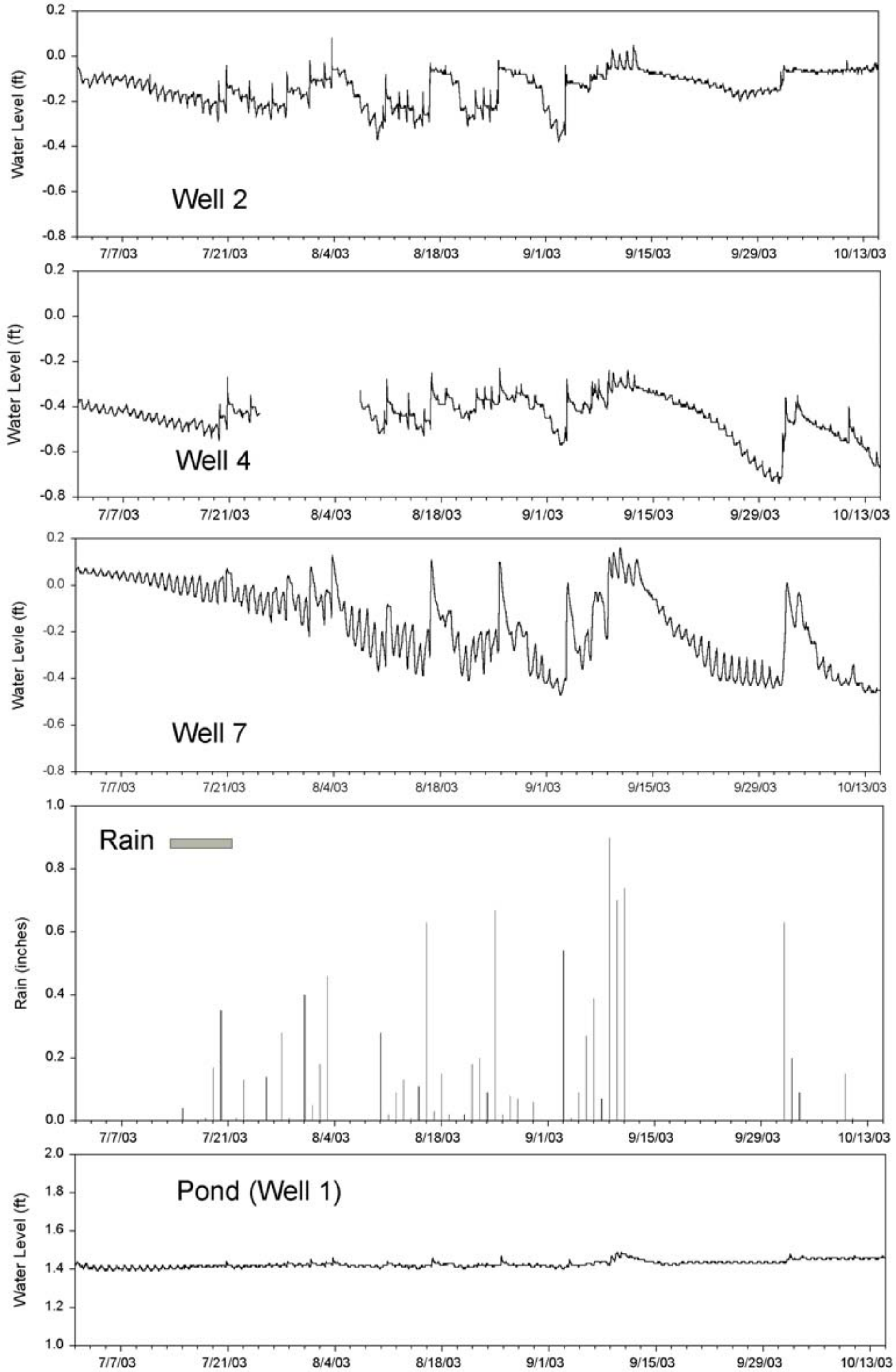


Figure 5. Water levels and precipitation during mid and late summer 2003.

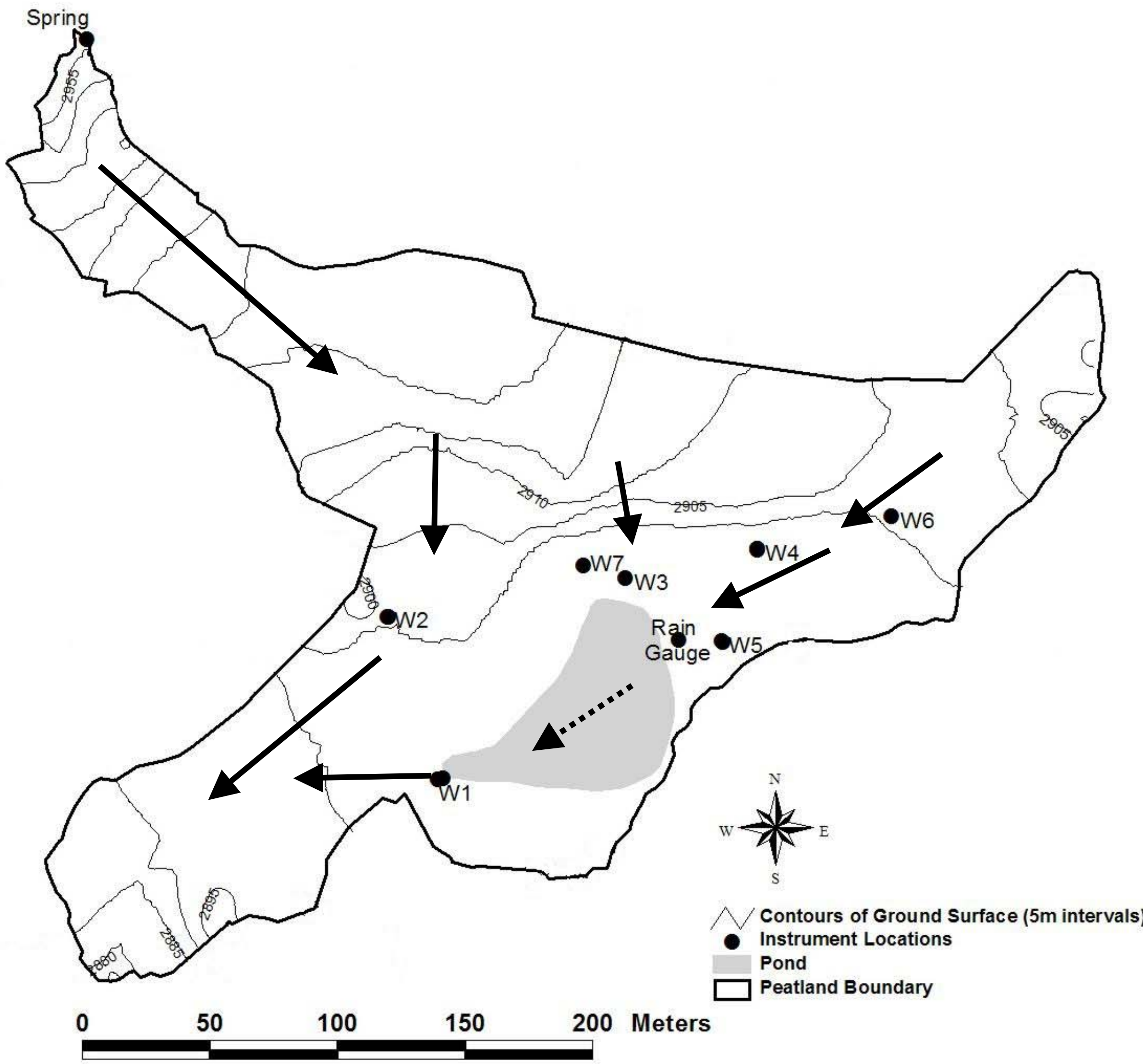


Figure 6. Topographic map (contours are 5 m) of Mt. Emmons fen, with arrows showing principal surface and ground water flow directions.

Surface and ground water flow was from north to south at all times during the study period, and there is a topographic, and hydrologic gradient of ~50 feet (15 meters) from north to south across the fen. This steep gradient controls surface and ground water flow direction. In addition due to the steep gradient, water flow rates are quite high, thus to maintain soil saturation, high flow rates are necessary. Due to the very dispersed ground water inflow, and wide area of surface and ground water flow, flow rates were not quantified.

Well 1, the pond staff gauge was most closely correlated with well 2, which occurs on the pond margin, and poorly correlated with other wells (Table 2). By contrast, well 4 was highly correlated with wells 3, 5, 6 and 7.

Table 2. Correlation coefficients among wells for 2003 water levels. Each row and column represents a well.

	2	3	4	5	6	7
1	0.558	-0.069	0.086	0.268	0.187	0.131
2		0.022	0.167	0.258	0.348	0.281
3			0.654	0.339	0.608	0.283
4				0.647	0.763	0.614
5					0.426	0.467
6						0.637

Water Chemistry: pH

Surface water at Mount Emmons fen is highly acid (Figure 7). The most acid water occurs at well 6, with pH ~3.3. This water flows south down the main limonite water track into the pond. The pond (well 1) water has a pH similar to wells 4 and 5 (Figure 1). The three most westerly wells, 2, 7 and 3, had a higher pH, near 4.5 than other water during the fall of 2002. Wells 2 and 7 had similar higher pH during late June 2003. On the western side of the lake, in June 2003 water at well 3 had a pH of 3.9, yet at the southern lake margin, fen water pH was > 4.0, similar to water at wells 2 and 7. Most striking was that the pH of water in piezometers at wells and the pond, had pH >6.0, even where the lake water and surface water was less than 0.5 m away (Figure 8). This more alkaline water can be seen discharging to the fen surface in many areas. The higher pH of this water allows pH sensitive iron oxidizing bacteria to occur (they are pH sensitive and occur in only very small populations in water with pH < 5.5), and populations of bacteria are seen as a silver slick on surface water. Flocculated iron can also be seen in this location. Thus, two waters of extremely different pH and likely chemical content meet within the fen, and it is the acid water of the springs fed by the Mt. Emmons pyrites that controls the surface water and surface soil chemistry, and controls the presence of acid loving and acid tolerating biota, as well as the formation of limonite landforms.

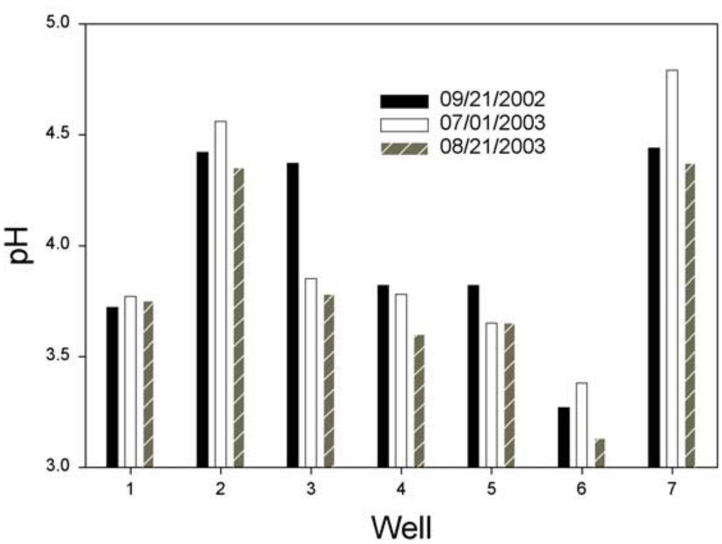


Figure 7. Surface water pH at pond and six wells, Mount Emmons fen.

These data suggest that the northern portion of the fen receives the most acid water and acid concentration decreases by an order of magnitude in the ground water flow system to the west (near well 2) and by two to three orders of magnitude in the area beneath the fen and the pond. Thus, the acidity of water varies spatially, and the concentrations of acids vary by ~1000 times between well 6 at the deeper piezometer at well 6.

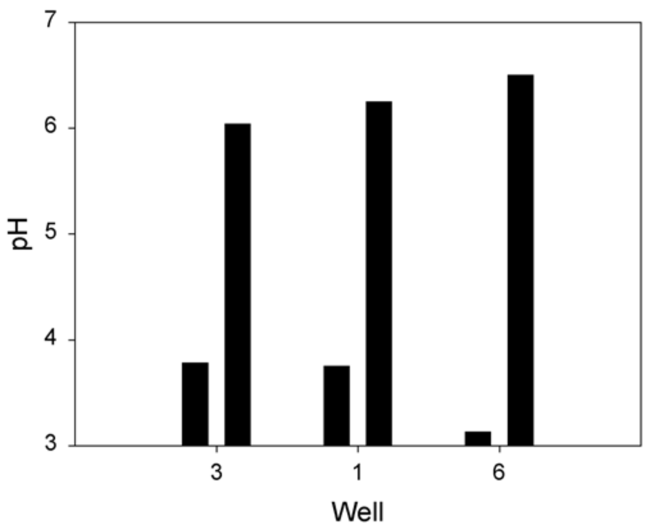


Figure 8. pH values for surface water (lower value) and piezometer water (higher pH value) at wells 3, 1 and 6.

Water Chemistry Mt. Emmons fen: Electrical Conductance and Dissolved Ions

Mount Emmons pond water does not perfectly match any well in its concentration of cations, anions or electrical conductance (Figures 9 and 10, Table 3). The water at all sites is a calcium sulfate (gypsum) type water, and although not measured in this study is also high in dissolved iron. Calcium is typically the most common cation in Colorado fen water sources. Sulfate is typically an abundant anion in water sources originating in bedrock of marine origin, but at Mt. Emmons likely results from the oxidation of pyrite (FeS). Water from the western portion of the fen, near wells 2 and 7, has the lowest EC and ion concentrations, as seen in lower Ca and SO_4 concentrations, likely because lower acid concentrations leaches less material from the aquifer bedrock and colluvium. The water at wells 4 and 5 are most similar yet it is surprising how distinct they are from well 6 located just upgradient a few tens of meters. There was no detectable HCO_3 or NO_3 in any water sample.

Based upon solute chemistry, the Mt. Emmons lake is most similar (in fall 2002) to ground water at well 3, and appears no more similar to the water at wells 2 and 7 (the western side of the fen) than to water at wells 4 and 5 on the eastern side of the fen which have the most similar pH waters. Thus, the lake water chemistry does not reflect any well site water chemistry on this sample date.

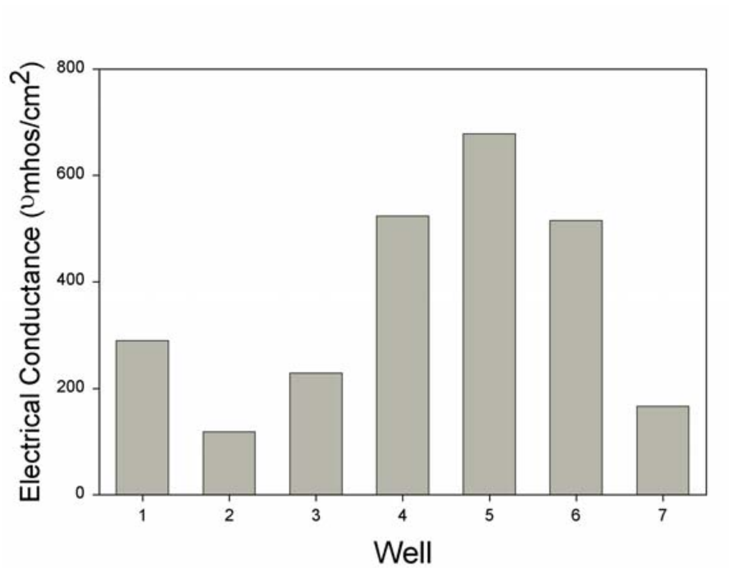


Figure 9. Electrical conductance for surface water at all monitoring stations.

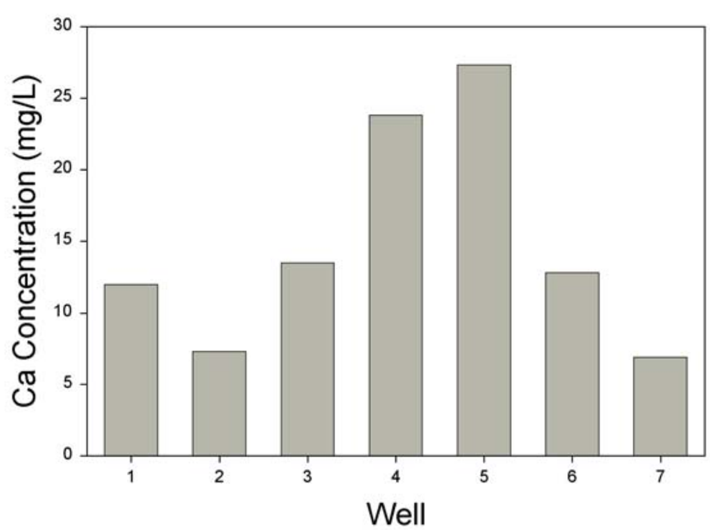
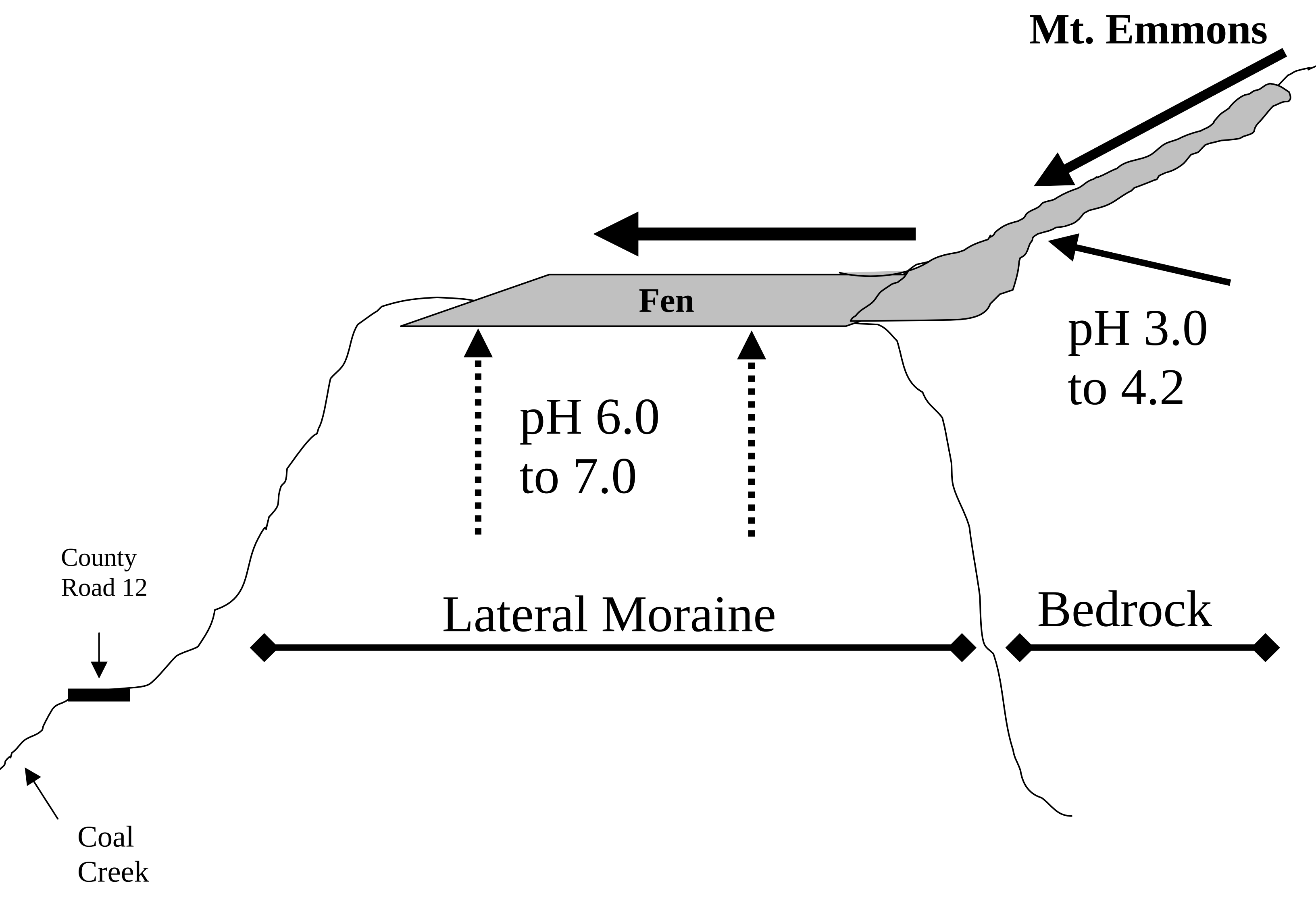


Figure 10. Calcium concentration in surface water at all monitoring stations.

Table 3. Solute chemistry of surface water samples collected in fall 2002, for the area at wells 2-7 and from the lake at Mount Emmons fen (Well 1). E.C. is electrical conductance in μmhos/cm^2, and all other values are in mg/L.

Well	pH	E.C.	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
1		290	12.0	3.6	2.5	2.4	<0.1	50.9	0.4	<0.1
2		118	7.3	2.2	2.7	0.8	<0.1	32.0	0.7	<0.1
3		229	13.5	3.5	3.5	4.6	<0.1	55.2	3.0	<0.1
4		523	23.8	6.6	3.4	4.0	<0.1	95.2	0.3	<0.1
5		678	27.3	7.3	2.9	3.2	<0.1	103.0	1.3	<0.1
6		515	12.8	4.4	2.1	2.0	<0.1	54.3	1.1	<0.1
7		166	6.9	1.9	2.4	1.5	<0.1	30.2	0.7	<0.1

Figure 11. Sketch cross section of Mt. Emmons fen. Bedrock of Mt. Emmons occurs on the right (north) side of the fen (shaded area), and highly acid ground water discharges from the hillslope talus and flows through the fen. The fen sits on a lateral moraine composed largely of circumneutral and alkaline material derived from the West Elk Mountains, and ground water with high pH is discharging from this moraine vertically upward beneath the fen.



Vegetation of Mt. Emmons Fen

Vegetation of the Mt. Emmons fen is dominated by acid tolerant plant species, primarily *Sphagnum fuscum, S. angustifolium, S. russowii, S. fimbriatum, Carex aquatilis, Carex utriculata*, *Betula glandulosa*, *Drosera rotundifolia*, *Vaccinium scoparium*, *Calamagrostis canadensis*, *Pinus contorta* and *Picea engelmannii* (vascular plant species nomenclature follows Weber and Wittmann 2001, and for bryophytes Crum and Anderson 1981). The western portion of the fen is largely a water track, with sheet flowing water, and supports a monoculture of *Carex aquatilis*. The area just west of the lake, and extending north through the center of the fen has an open overstory of *Picea engemannii* and *Pinus contorta* with an understory of *Carex aquatilis* or *Calamagrostis canadensis*. The water track on the eastern side of the fen, which flows into the lake, has numerous small unvegetated pools, with vegetated strings between the pools. *Carex aquatilis* is the main sedge in these areas, and small populations of *Drosera* occur, especially near wells 3 and 5. These areas have a nearly continuous cover of *Sphagnum* mosses, which are acid loving, acid producing, and along with *Carex aquatilis* are likely the main peat formers. The lake with permanent, deep standing water is too deep to support any emergent vascular plant species. Instead it supports a fringe of *Carex utriculata*, one of the tallest sedges in Colorado, which allows it to tolerate deep standing water. The lake center is unvegetated, and cannot be accumulating peat as there is little or no organic matter production. The open pond water likely has sufficient dissolved oxygen to support aerobic decomposition of the submerged peat surface. The lake may have formed from the decomposition of the peat body in this location. The peat likely is decomposing under the lake, while it has been accumulating at a relatively constant rate in most of the fen for the past 8,000 years (Fall 1997). Thus, the lake does not represent the carbon storage function of the majority of the fen.

Discussion

Hydrologic Processes

Ground water discharging from the base of Mount Emmons produces sheet flow and ground water flow that perenially saturates the fen. Water levels during the study period varied by up to 1-2 feet in the monitoring wells, with the lowest water levels occurring during the winter of 2002-2003. During 2003, water levels remained relatively stable at most sites, but declined during the summer at well 7. Maintaining stable ground water levels in this steeply sloping fen indicates that a large volume of ground water discharges from the Mt. Emmons aquifer and flows through the fen. Because the fen has been accumulating peat for more than 8000 years, it is likely that the hydrologic processes occurring today have been relatively intact for an extremely long time.

In the fall of 2002 ground water levels in monitoring wells rose due to rain recharge of hillslope aquifers. Water levels declined during the winter, as precipitation in the form of snow accumulated in the watershed, and little ground water recharge occurred. Rain during mid to late summer 2003 recharged hillslope aquifers and ground water levels in the fen rose in response to each period of rain. The responses of fen water table to precipitation driven recharge, suggests that some shallow and local ground water flow processes can influence fen water tables. However, the fen aquifers are obviously large and complex, with both short and long flow paths, because perennial ground water flow through the fen occurred during the summer of 2002 even under extreme drought conditions.

The presence of perennial ground water inflow is critical to drive hydrologic and geochemical processes that lead to peat formation, and the creation of the fen. However, Mt. Emmons fen is geochemically and ecologically unique, and the processes that have led to the formation of the fen's landforms, biota, and communities must be understood. Patricia Fall's (1997) paleoecological analysis of Mt. Emmons fen indicated that *Sphagnum* spores were abundant in peat that was deposited from 8,000 and 6400 years before present (BP), and from 4400 years BP to the present. Since *Sphagnum* species are relatively uncommon in Colorado wetlands, and occur abundantly primarily in iron fens, it suggests that this wetland has been supported by the perennial flow of acidic ground water from Mt. Emmons for most of the past 8,000 years. This acidic water has produced a hydrologic, geochemical and ecological refugium for *Drosera rotundifolia, Sphagnum angustifolium, Betula glandulosa* and other acid loving species, and the persistence of these species and the communities they form, is dependent upon the perennial flow on acidic water.

Understanding both the patterns of ground water flow from Mt. Emmons, and the chemistry of water that supports the biota and ecological communities of the fen is critical when put in the three dimensional perspective of ground water flow into the fen. Ground water of distinctly higher pH, and likely distinct chemical content is present in the lateral moraine that underlies the main fen body. This water has sufficient head to reach near the peat surface throughout the fen, and discharges to the ground surface at several points within the fen. Were this the only water flowing into the fen, it would support a distinctly different type of fen, that we call a rich fen, and rich fens are quite common in Colorado. At Mt. Emmons fen the acid waters flowing from Mt. Emmons neutralize the effects of the circumneutral water, maintain the highly acid conditions throughout the fen, and support habitat for *Sphagnum angustifolium* and other acidiphiles that characterize iron fens. Any reduction in the flow of the acid water would likely increase the influence of the circumneutral water on fen geochemistry, and would alter site geochemical conditions, and lead to the death of the *Sphagnum*, *Drosera, Betula* and other acidiphiles. Since these species have likely persisted in the acid refugium of Mt. Emmons fen for many thousands of years, local extinction of these species would result in the loss of the plant communities that make Mt. Emmons fen regionally unique. In addition, there is no potential for replenishment of these unique populations (Cooper et al. 2002).

Surface Water/Groundwater Interactions

Several of the data sets presented here make it clear that the pond is the least representative portion of the fen from a hydrological or ecological perspective. During the study period pond water levels varied little and remained relatively stable during all seasons of measurement, winter, snowmelt runoff, dry mid summer and wetter rainy late summer period. Therefore, pond water level variablility does not reflect ground water flow dynamics at our 6 fen monitoring well sites. The pond has a single outlet that controls its level whether the flow of surface water through the lake is high or low. The amount of water flowing into the fen varies seasonally, driven by surface and ground water flow from Mt. Emmons. Even during periods when surface and ground water inflow to the pond is low, little outflow occurs, and pond levels remain stable.

Not all ground water flow paths intersect the pond. For example, the large ground water flow system to the west of the pond, and including well 2, flows largely from north to south, and does not intersect the pond (Figure 6). In addition, most of the fen is upgradient from the pond and up to 10 m of relief within the fen occur above the pond. Thus, maintaining pond water levels would provide little or no influence on ground water flow or soil saturation in the fen above the pond.

Head within the peat body produces an upward flow of water at all sites other than well 7. Any reduction in ground water flow from the northern portion of the fen, through the fen to the south, could allow circumneutral water discharging vertically from the lateral moraine to change the hydrologic and geochemical character of the fen.

Vegetation on the pond margin is dominated by *Carex utriculata*, which in the study site is abundant only in the deep standing water of the lake margins. Thus, the lake vegetation is atypical of the fen. In addition, because much of the lake has no vegetation and little or no organic matter production, it is likely that the peat body under the pond is losing organic matter, while the rest of the fen is gaining peat (Fall 1997).

In summary, data collected during this project indicate five reasons why maintaining the Mt. Emmons pond water level would provide little or no protection to the fen.

(1) Because the lake occurs at the lower end of the fen, its water level does not guarantee water flow through the much larger fen area located above the lake.

(2) The lake water is derived from one portion of the fen, therefore it does not protect the full range of hydrologic and geochemical environments in the fen. The lake may not be a useful indicator of fen conditions because lakes are not important elements of sloping fens in Colorado.

(3) Maintaining the lake water level would likely require only a very small portion of the total amount of water required to maintain soil saturation and peat forming processes in the fen. Thus, much of the fen could be dried up while the lake remains filled to the appropriate water level. Water could be pumped via a pipeline to the lake maintaining its water level while the fen is dried up.

(4) The unique character of the Mt. Emmons fen is produced by acidic mineral rich water flowing from Mt. Emmons. Maintaining the flow of this water type is critical to maintain the fen biota and functioning.

(5) Because the fen is steeply sloping, a large and complex hydrologic system is required

to provide sufficient water to maintain saturated soils through dry and wet periods. Also, the steep fen slopes produce high soil drainage rates, again accentuating the need for perennial inflows of ground water from the northern side of the fen.

Suggested Hydrologic Criteria for Protecting the Mt. Emmons Fen

The most important measurable water level in the fen is ground water level in the fen peat body. Because the fen is steeply sloping a constant inflow of water from the hillslope ground water flow system of Mt. Emmons is required to maintain ground water levels similar to those for wells 2-7, shown in Figures 2-5. Ground water levels should be at or above the soil surface in early summer, may drop during the summer, although they rarely would drop to more than ~50 cm below the soil surface, and typically rise in the mid- to late summer due to monsoon rains. A typical hydrograph, such as that of wells 3, 4 or 5 should be used as the basis for documenting the water levels required for maintaining the fen functioning. In addition, because the Mt. Emmons fen, like many fens, will have multiple water sources, all water sources need to be protected. This could be accomplished by installing wells as in the current study in sufficient density to identify water with different chemical content, and having a ground water monitoring well for use as a reference hydrograph in each water type.

While it is possible to quantify the total water flow into and through the fen, this is extremely complex, has not been accomplished for any fen in North America, would take many years, and the flow volume and rates would vary from fen to fen in Colorado. This quantification would not likely be practicable except in a research setting. . However, the installation of one or more monitoring wells in fens and the routine measure of water levels is quite simple. These water levels could then be compared with reference fens from which an understanding of the natural and historic range of variability would be developed.

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Literature Cited

Chimner, R. A. and D. J. Cooper. 2003. Influence of water table levels on CO2 emissions in a Colorado subalpine fen: an in situ microcosm study. Soil Biology & Biochemistry 35: 345-351.

Cooper, D. J., R. Andrus and C. D. Arp. 2002. *Sphagnum balticum* in a southern Rocky Mountain iron fen. Madrono 49: 186-188.

Cooper, D. J. and J. S. Sanderson 1997. A montane Kobresia myosuroides fen community type in the souther Rocky Mountains of Colorado, USA. Arctic and Alpine Research 29: 300-303.

Crum, H. and L. Anderson. 1981. Mosses of North America. Columbia University Press, New York. Two volumes.

Fall, P. 1997. Fire history and composition of the subalpine forst of western Colorado during the Holocene. Journal of Biogeography 24: 309-325.

Weber, W.A. and R. Wittmann.. 2001. Colorado Flora, western slope. Colorado Associated University Press, Niwot, Colorado.