Drivers of Hydroperiod in Ephemeral and Permanent Wetlands

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Abstract

Wetlands serve as a habitat for many different plant and animal species that rely on various hydroperiods to survive. Understanding the influences on hydroperiod may help to compensate for any future loss or changes in hydroperiod due to environmental change. Aspects of wetland hydroperiod (min/max depth, seasonal range, mean periodic (six hours) fluctuation, and maximum periodic fluctuation) were related to explanatory geomorphic variables (surface area to volume ratio, basin size, wetland area, and elevation). Permanent (PW) and ephemeral pond (EP) hydroperiod characteristics were compared for wetlands in Chippewa County, Wisconsin. Pressure transducer data loggers were placed in paired PWs and EPs to collect water depth data. In EPs, canopy cover was negatively related to maximum depth, because trees decrease water depths through interception and/or transpiration. Seasonal range was positively correlated with EP area and negatively correlated to peat depth. Larger EPs may have had a larger seasonal range because they both captured and evaporated more water. EPs in larger basins had both higher mean and maximum periodic fluctuations, because larger basins result in more runoff from precipitation. Range and maximum fluctuation were significantly higher in EPs than PWs. Mean periodic fluctuation was not significantly different because PWs were both filling up and evaporating whereas EPs were mostly evaporating with occasionally dramatic increases due to precipitation. PWs that were smaller and lower in elevation with smaller basins tended to have more variable hydroperiods than larger PWs due to a lack of water storage in the basin.

Keywords: wetlands, ephemeral ponds, hydroperiod

Introduction

Ephemeral ponds (EPs) are defined by the Wisconsin Department of Natural Resources as depressions in forests that contain water after snowmelt and dry out during summer (Epstein, Judziewicz, & Spencer, 2002). The unique characteristics (hydroperiods, size, lack of fish, and forested landscapes of EPs) make them important habitats and breeding locations for a variety of plants and animals. Some of the organisms that benefit from EPs are sedges, wood frogs, blue spotted salamanders, and many invertebrates including dragonflies, mosquitos, and predacious diving beetles. Due to the array of plants and animals supported by EPs, they also contribute to the biodiversity of the forested landscape.

The hydroperiod of an EP is the length of time the pond contains water, from the time it fills (usually from snow melt in the spring) to the time it dries up, typically in midsummer (Brooks & Hayashi, 2002). The length of the hydroperiod can vary significantly from pond to pond, based on several hydrologic characteristics. This discrepancy in hydroperiod between ponds is important as it provides multiple varying habitats for the occupying organisms. Snodgrass, Komoroski, Bryan, & Burger (2000) found that different hydroperiod lengths support different sets of species, meaning that short and long hydroperiods cater to unique sets of organisms.

Despite their contributions to biodiversity, the hydroperiods and general water depth fluctuations in EPs remain understudied in comparison to those of permanent wetlands (PWs). Colburn (2004) proposed a general classification scheme for EP hydroperiods, including variation in duration and seasonal timing in water retention, but has little detailed quantitative data. In addition, few studies examine factors that influence EP hydroperiod (drivers). Brooks and Hayashi (2002) found only weak relationships between wetland hydroperiod and morphological features, such as basin depth and maximum volume. They suggested that features such as groundwater connectivity and evapotranspiration should also be investigated. Interannual weather variability in snowpack, mean groundwater levels, and precipitation influence EP hydroperiods (Brooks, 2004), but do not explain why different EPs and PWs in the same local area have different hydroperiods and water depth fluctuations. No study explicitly compares water depth fluctuations in EPs to those of PWs.

The specific objectives of this study included understanding how wetland hydroperiod characteristics vary between PWs and EPs, and discovering what environmental and landscape-level factors had the most influence on wetland water depth and water depth fluctuations. We hypothesized that drainage basin size, elevation, canopy cover, and peat depth would influence wetland water depth and fluctuations, and water depth fluctuations would be greater in EPs than in PWs.

Methods

Site description

Wetlands were located in the Chippewa Moraine State Recreation Area (45° 13′ 13.32″ N, 91° 24′ 39.7″ W) in Chippewa County, Wisconsin. This area contained many forested wetlands that were formed during the Wisconsin Glacial Episode. We studied 11 wetlands, five which were wet the entire year (PWs) and six EPs. In order to better compare wetlands with similar geomorphic and local climate settings, a majority of the wetlands were grouped into five pairs of adjacent PWs and EPs, each pair of wetlands is contained in the same system (area of forest). One system did not contain any PWs so only one EP was studied from that system. All wetlands were located within a 20 km^2 area (Figure 1).

Figure 1.

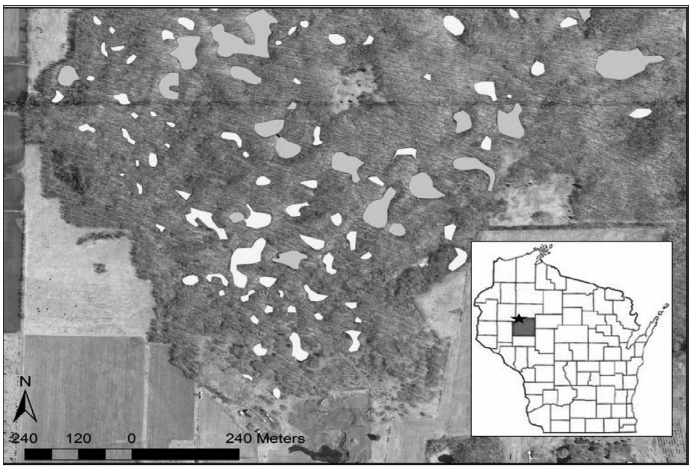

Figure 1. Map identifying a portion of wetlands used in this study (based on aerial photographic interpretation, the yellow spots are ephemeral wetlands and the blue and green spots are permanent wetlands), including a map of Wisconsin with Chippewa County identified in red and a black star over the study sites.

Data collection

HOBO pressure transducer data loggers (Onset Corporation, 2015) were used to record water depth fluctuations. One HOBO logger was installed above water to measure the barometric pressure. The loggers measured water pressure, which was then converted into water depth by correlating readings with actual water depth measurements, using HOBOware (Onset Computer Corporation, 2015). Water depths were logged in six hour increments over the course of about five months (4/23/2015 – 10/17/2015).

We collected a large suite of environmental data in order to determine effects on hydrology. Area of basin, wetland, and elevation were calculated using ArcGIS (ESRI 2014). We assessed canopy cover using spherical densiometers and peat depth using soil probes.

Data analysis

The hydrologic variables processed from the HOBO logger data were mean periodic (six hours) fluctuation, minimum and maximum depths, maximum fluctuation, depth range, mean positive and negative fluctuations, and numbers of rising and falling increments. Mean periodic fluctuation was defined as mean change in water depth per six-hour increment. Minimum and maximum depths were the shallowest and deepest depths in the wetlands, respectively. Maximum fluctuation was the maximum change in water depth per 6 hour increment. Water depth range was calculated by subtracting the minimum water depth from the maximum. Mean positive and negative fluctuations were found by taking the average of the positive (water-depth increase) and negative (water-depth decrease) periodic (six hours) changes in water depth. The numbers of rising and falling increments were simply calculated by counting all the time intervals in which the water depth increased or decreased since the last reading.

Due to small sample size, we did not perform inferential statistics to assess statistical relationships between environmental factors and hydrology. However, we do describe the most important patterns and trends. Because we hypothesized that hydrograph variability would be higher and water depth lower in EPs, we used one-tailed t-tests to compare hydrologic variable means between EPs and PWs.

RESULTS

HOBO logger data show trends between EPs and PWs in paired wetlands. Hydrographs show higher water depth and greater stability of water depth in PWs than in EPs (Figure 2). Some EPs (Figure 2B – D) had negative water depths below ground level, indicating the ponds had gone completely dry.

Figure 2.

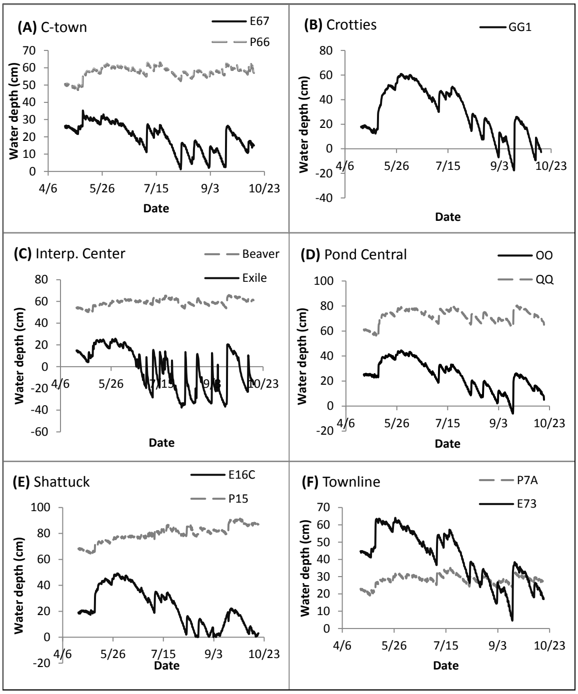

Figure 2: Paired wetland hydrographs. Ephemeral ponds are represented by solid black lines and permanent wetlands by dashed gray lines. A – F show the water depth by date in the six different wetland systems. Negative numbers indicate water depths below the ground surface.

Unsurprisingly, the minimum depth was significantly lower in EPs than in PWs (Table 1), although the maximum depth was not significantly different (P= 0.057). As expected, the range in depth was significantly larger in EPs compared to PWs (Table 1).

The maximum water depth fluctuation was significantly higher in EPs than in PWs (Table 1). The mean periodic (six hours) fluctuation was noticeably different between EPs and PWs, but was not significantly different. Both the mean positive and negative periodic fluctuations were not different. However, the numbers of rising and falling increments were both significantly different; EPs had fewer rising and more falling increments, while PWs had more rising and fewer falling increments (Table 1).

Table 1

Hydrologic Variable	EP	PW	P - value
Minimum depth (cm)	-9.3 (6.5)	47.1 (7.6)	<0.001
Maximum depth (cm)	46.6 (6.0)	67.3 (9.5)	0.057
Range depth (cm)	55.9 (6.1)	22.2 (2.5)	0.001
Maximum fluctuation (cm/hr)	4.15 (0.83)	1.29 (0.20)	0.010
Mean periodic fluctuation (cm/hr)	0.15 (0.03)	0.09 (0.05)	0.069
Mean positive fluctuation (cm/hr)	1.25 (0.39)	0.55 (0.02)	0.066
Mean negative fluctuation (cm/hr)	0.74 (0.98)	0.61 (0.05)	0.137
# of rising increments	274 (23)	368 (13)	0.004
# of falling increments	417 (21)	319 (11)	0.002

Table 1. Comparison of hydroperiod characteristics between permanent and ephemeral ponds. Negative numbers indicate water depths below the ground surface.

Although we investigated all possible relationships between our explanatory and hydrologic variables, we here report on only those showing major trends. In EPs, canopy cover was negatively related to maximum depth (Figure 3C). Seasonal range in EPs had a positive relationship with EP area (Figure 3B), but little relationship to mean peat depth (Figure 3A). For EPs, mean and maximum periodic water depth fluctuation and basin (watershed) size were positively related (Figures 3F and 3D). PWs had a negative relationship between mean periodic fluctuation and elevation (Figure 3E).

Figure 3.

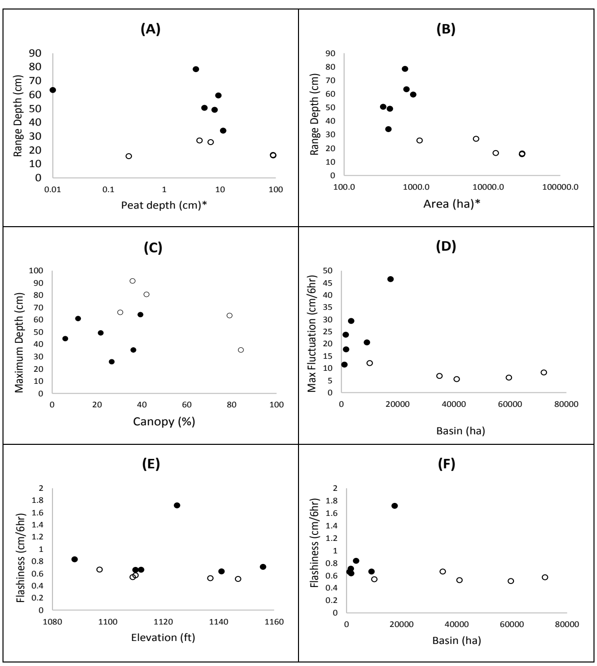

Figure 3. Scatter plots of a variety of explanatory variables and hydroperiod characteristics for relationships with important trends. Ephemeral ponds are represented with black points and permanent wetlands with white. *Axes are on a log scale.

In EPs the rising and falling increments were more dependent on the surface area to volume ratio (Figure 4A) and percent canopy cover (Figure 4C) of the wetland than in PWs. Surface area to volume ratio and canopy cover had positive relationships with the frequency of falling increments. A weak positive relationship was found between basin size and number of falling increments, (Figure 4B) however, this is likely dominated by one pond.

Figure 4.

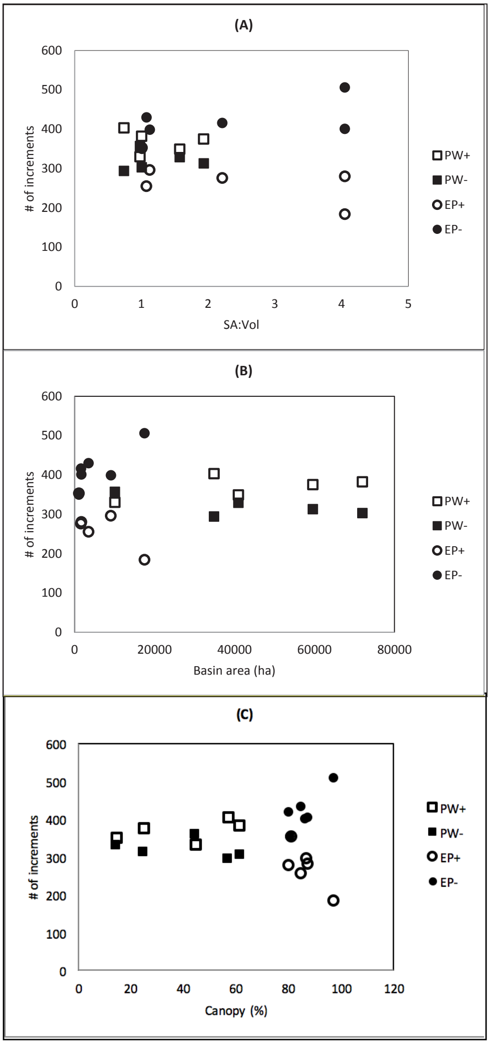

Figure 4. Scatter plots comparing the numbers of rising and falling increments to multiple explanatory variables. PW and EP indicate permanent wetland and ephemeral pond, respectively. + and – indicate rising and falling, respectively.

Discussion

Ephemeral Pond and Permanent Wetland Comparison

In almost all the hydrographs (Figure 2), water depth was clearly lower in EPs than in PWs, with the exception of E73 and P7A (Figure 2F), possibly due to peat accumulation and peat mat formation in P7A. This is consistent with Colburn's (2004) definition of vernal ponds: that they are shallow and their depth peaks in the early spring at about 1 m of water. The PWs tended to have deeper peat, a larger basin size, smaller canopy cover, and larger wetland area, which may have contributed to the higher water depth (Figure 3). The differences in water depths observed on the hydrographs are most likely due to a combination of multiple environmental and landscape characteristics. EPs have more variable hydroperiods than PWs. Both EPs and PWs were affected by the same rain events and drying periods in a relatively small geographic area; however, EPs had higher mean periodic fluctuation. This variability may be due to many of the same environmental characteristics affecting water depth.

EPs had greater seasonal range than PWs (Table 1). Since EPs have a higher perimeter: area ratio, they are more affected by transpiration from surrounding trees (Calhoun & deMaynadier, 2008)). Transpiration may also be affecting ground water, causing decreasing flow into EPs. This wetland water loss may be why seasonal range is much higher in EPs than in PWs. In addition, because HOBO loggers measure water depth at a single location rather than water volume in the wetland, the hydrographs are not completely representative of exactly how much water is gained and lost in a wetland. Although wetlands of different sizes may gain the same depth of water, a wetland with a larger volume gains a larger amount of water than a smaller wetland with the same water depth measurement increase. Evapotranspiration from EPs would result in greater water depth decrease than a similar volume leaving PWs through evapotranspiration. This fact may contribute to the significantly greater seasonal range in EPs.

The high mean periodic fluctuation within EPs may be due to increased response to precipitation, which may have resulted from separation of the wetland from the groundwater table. This can happen when the wetland is "perched" on an impermeable layer, such as clay. These wetlands were formed as a result of melting ice fragments from glaciers, so they may never have been dependent on the larger regional groundwater pool. In these cases, the only water input into the wetland is precipitation and surface runoff. The water then leaves the wetland through evaporation or transpiration (Brooks & Hayashi, 2002). Due to this dependence on precipitation events, it is possible for these ponds to completely dry and be refilled multiple times throughout the summer. This unique hydroperiod provides habitat for plant and animal species that are not supported by ponds that dry once a year (Colburn, 2004), and is demonstrated most clearly by "Exile" (Figure 2C).

Although both mean positive and negative fluctuations were not different, the numbers of rising and falling water depth increments were significantly different between EPs and PWs (Table 1). Water loss was more frequent in EPs while PWs had more instances of water gain. We expected this for multiple reasons. The more frequent water loss in EPs could be due to the lower water depths, which means higher temperatures and more evaporation. Another explanation for the water loss in EPs could be the higher number of surrounding plants transpiring water out of the wetland. The water depth increases in the PWs may be because PWs receive more precipitation with each rain event due to their larger sizes and larger watersheds.

Environmental Drivers

Because larger wetlands have the opportunity to both capture more direct rainfall and evaporate more water due to higher surface area, larger EPs tended to have larger seasonal ranges. However, this relationship is only important for EPs. PWs often have a larger area than EPs but a much lower seasonal range, which indicates that there are many other important contributing factors determining seasonal range for PWs.

EP seasonal range is also affected by peat depth. Peat accumulations may decrease the seasonal range due to the water holding properties of peat (Boelter, 1968). Since peat can store water for the wetland, it may be less likely for a wetland with large amounts of peat to lose water due to infiltration into the groundwater or evapotranspiration. However, this relationship is circular in that the deep peat depth is also a result of the low seasonal range of some wetlands. Peat requires an anaerobic environment to form. A wetland with a high seasonal range may become too shallow to provide the right environment for peat to form, making a relatively "stable" water depth a good characteristic for forming peat. There was no relationship between peat depth and water depth fluctuations in PWs, which could be a result of peat stabilization in higher elevation wetlands and groundwater stabilization in low elevation wetlands with little peat.

Basin size influences the mean periodic water depth fluctuation of an EP. Similar to the impact on the maximum fluctuation, this could be due to an increase in runoff from precipitation. In PWs, as the elevation increases, the mean periodic water depth fluctuation decreases. Higher elevation wetlands also tend to have smaller basin size, making the pond less influenced by precipitation events.

The rising and falling increments tended to be more dependent on pond morphology in EPs than in PWs. In EPs, a higher number of falling increments was common in ponds with a larger surface area to volume ratio (Figure 4A), perhaps due to the large surface area providing more opportunity for evaporation. Another factor influencing the frequency of falling increments is the percent canopy cover of the EP (Figure 4C). As the canopy cover increases the number of falling increments also increases. The canopy may be intercepting rainfall causing rising increments to be more uncommon, while the increased plant life may be causing water loss due to transpiration.

Some of our wetlands, such as QQ, may be semi-permanent. Two years of above-average antecedent precipitation may have caused the regional groundwater table to rise, resulting in some of our study sites intersecting the local groundwater table.

Future studies should investigate groundwater storage. Continuing the study in more normal precipitation years would provide data that could help explain how changes in precipitation patterns affecting the regional groundwater table might alter the hydrology of EPs. These data could also be used in understanding the differences of hydrologic characteristics when the ponds do and do not intersect the groundwater table. In order to help support some of the speculations made here, other hydrology measurements should also be studied in future years, including evaporation and transpiration rates, precipitation gauges, volume of runoff, and interception by trees.

Understanding which environmental characteristics have the most impact on wetland hydrology can serve as an important consideration when determining conservation techniques. Many of the plants and animals that inhabit wetlands are dependent on the length of hydroperiod (Snodgrass, Komoroski, Bryan, & Burger, 2000). If drivers of hydroperiod were better understood, we could better predict which wetlands would have hydroperiods that benefit the most diverse or high priority set of plant and animal species.

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