Hydroperiods of constructed and natural vernal pools in central Ohio and comparison of their depth and duration of inundation

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Introduction

Vernal pools are a special type of ephemeral wetland often found in forests in the eastern USA. Few comprehensive studies have been carried out on eastern vernal pools, and the relationship between precipitation, surface runoff, groundwater exchange and vernal pool inundation is not quantified (Colburn, 2004). Vernal pools usually fill with water in the cooler and wetter fall and winter months and dry out during the summer (Brooks, 2004).

Direct precipitation, evaporation and ground-water exchange (Brooks and Hayashi, 2002) make up most of a vernal pool's water balance. Vernal pools are isolated from other water bodies most of the time, and vernal pool microwatersheds contribute little water to pools during most precipitation events (Pyke, 2004). However, surface flow to and from vernal pools may occur during spring snowmelt or heavy precipitation events (Brooks, 2004) and surface water often flows out of vernal pools to lower elevation streams during part of the wet season (Rains et al., 2003). In perched aquifers, especially, groundwater recharged by rainfall can flow through vernal pools, discharging to the pool on the upside and being recharged on the downside as the water flows down-gradient to streams (Rains et al., 2003).

The hydroperiod of eastern vernal pools has been found to be affected by a pool's surface area, volume, depth, and connection to groundwater (Cole and Brooks, 2000; Cole et al., 1997; Gay, 1998). Pools that receive groundwater inputs are inundated more often than those that do not (Gay, 1998; Hunt et al., 1999). Groundwater has a greater effect on smaller pools with their greater perimeter-to-area ratio as groundwater exchange occurs in general along the perimeter (Shaw and Prepas, 1990).

A bathymetric study of 34 vernal pool was used to estimate maximum pool depths, surface areas, perimeters, volumes and basin profile coefficients (Brooks and Hayashi, 2002). A weak relationship between pool morphometry and hydroperiod was found. Pool with depths greater than 0.5 m, maximum surface area greater than 1000 m2 and maximum volume greater than 100 m3 held water more than 80% of the time. Brooks (2004) evaluated the relationship between precipitation and hydrology over a ten-year period in four New England vernal pools. Using the water balance equation to represent the pool's hydrology:

$$\Delta W = PPT - ET +/- GW \quad (1)$$

where

ΔW = change in pool water depth
PPT = precipitation
ET = evapotranspiration
GW = ground water addition/subtraction

The study found that precipitation and evapotranspiration explained between 40-70% of the weekly water level changes in the vernal pools, with precipitation having a greater effect than evapotranspiration. Groundwater exchange was not considered in the study but the results indicated a loss of water additional to that from ET, most likely from groundwater.

Vernal pools are recognized as difficult to create (National Research Council, 2001), as they are shallow and ephemerally ponded and so require a careful balance between water storage and loss. There have been problems in the past with constructed pools not being able to retain water and improper construction (National Research Council, 2001) and only some mitigation projects have been successful (DeWeese, 1998). A study of 15 vernal pool creation projects in New England found that created pools often failed to replace lost pool functions (Lichko and Calhoun, 2003).

The goal of this study was to investigate the success of duplicating natural vernal pool hydroperiods in vernal pools created to mitigate the loss of forested vernal pools in central Ohio.

Materials and Methods

Study Site Descriptions

Both sites are in the eastern half of Franklin County, Ohio, near Columbus, and are located in the Upper Scioto watershed. Both sites are mature forested wetlands.

New Albany Schools mitigation site

This 16-ha site is across the road from the High School and Middle School in New Albany (Latitude 40° 05' 09.3", Longitude 82° 49' 10.7") and consists of 9.4 ha of replaced or restored wetlands and 6.6 ha of upland buffer (Figure 1a). It was created to compensate for impacts to 10 ha of wetlands destroyed in the relocation and widening of State Route 161. The wetlands destroyed consisted of a mix of palustrine emergent, palustrine open water and palustrine-forested wetlands.

The mitigation site was designed to have a combination of open water and wetland habitats interspersed with upland buffer areas. Construction was completed in 1996. It has three main areas: 1) a large open water area, surrounded by a wetland fringe and upland buffer; 2) an emergent wetland with smaller and shallower open water areas; and 3) a complex of 10 vernal pools integrated into the existing forested area. The vernal pool area is the region utilized in this study and takes up two ha of the mitigation site. The soils consist of Pewamo silty clay loam, Bennington silt loam and Cardington silt loam (U.S. Soil Conservation Service 1980). Pewamo soils are classified as hydric soils while Bennington and Cardington silt loams are non-hydric with hydric components.

Gahanna Woods state nature preserve

This 23-ha nature preserve is located in Gahanna near the intersection of Havens Corner and Taylor Station Roads (Latitude 40° 00’ 35.5”, Longitude 82° 50’ 14.9”) (Figure 1b). The preserve includes buttonbush swamps and vernal pools surrounded by pin oak-silver maple swamp forest and mature oak-hickory and beech maple forest on uplands. It is believed to have the best remaining complex of buttonbush swamps and vernal pools in central Ohio (Department of Natural Areas and Preserves 2004). This mixed swamp forest supports many native plants and animals and is being used as a reference site in this study. Plant composition and species diversity have been studied by Fineran (1999), who gives a comprehensive history of the site, and Johnson (1999).
3.2.1 Precipitation, stage and groundwater levels

Basin soils consist of Carlisle muck and Pewamo silty clay loam which are both hydric soils (U.S. Soil Conservation Service 1987).

Hydrology

The site’s water sources are believed to be precipitation and runoff from nearby areas (Fineran 1999). The pools in the central area are hydrologically surface connected at least during wet periods. The pools drain to the north into Windrush Creek (Johnson 1999).

Precipitation data were obtained from the Columbus International Airport weather station and from a tipping bucket recording rain gage installed at the New Albany mitigation site.

Groundwater levels in three existing 3-4 m deep wells were measured weekly at the New Albany site using an electric tape. Two of the wells were in the vernal pool area and one was just outside of this area (Figure 1a). Staff gages were installed in 10 created vernal pools at the New Albany site and water levels were recorded weekly from May 2004 through October 2005 .

Water levels were recorded weekly during the same period from six natural vernal pools at Gahanna Woods. Five staff gages at this site were existing while one temporary gage was installed in vernal pool 3 (Figure 1a). At New Albany and Gahanna Woods, weekly photographs were taken at permanent photographic stations to document seasonal changes in the vernal pools.

Elevations were determined for staff gages and well

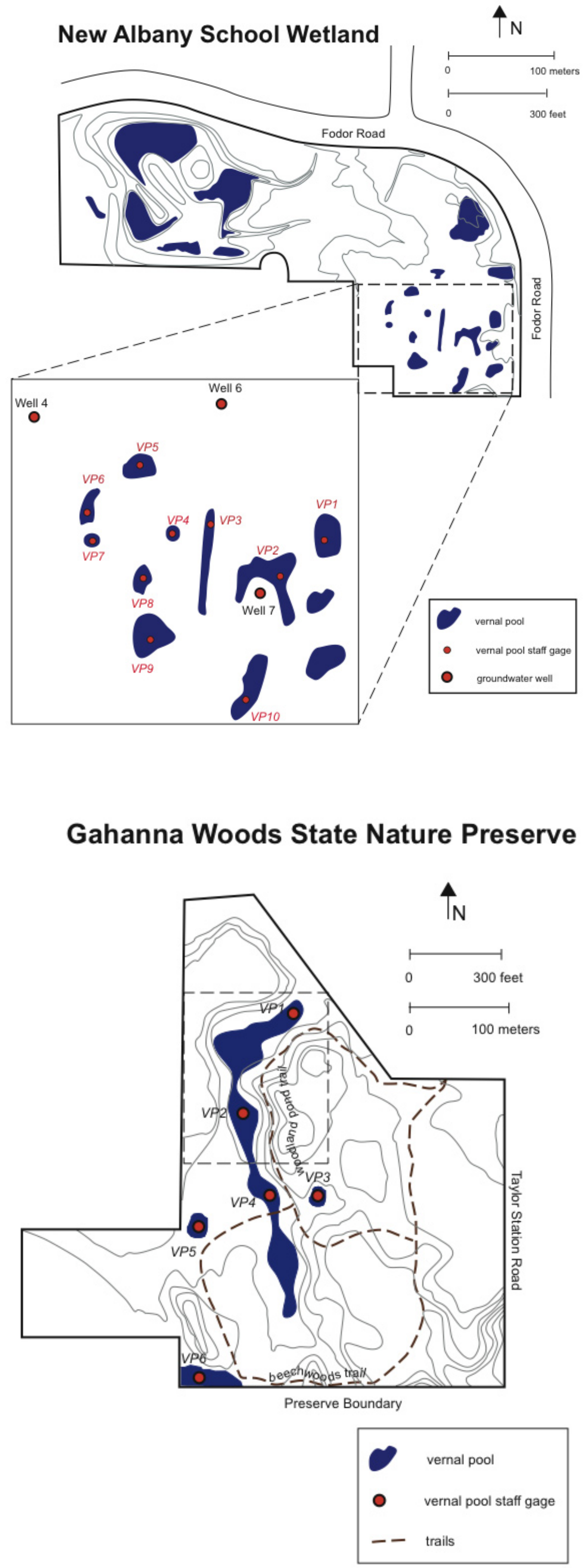

Figure 1. Site maps of (a) New Albany mitigation wetland showing location of vernal pools and groundwater monitoring wells; (b) Gahanna Woods State Nature Preserve showing locations of vernal pools.

Table 1. Summary of surface water measurements (mean, median, minimum and maximum) taken at the study wetlands. Values are ± standard error for the six vernal pools at Gahanna Woods and the ten vernal pools at New Albany.

Site	Ground Surface Elevation (m)	Water Height Above Ground mean	median	min	max
Gahanna Woods vernal pools	272.36 ± 0.27	0.21 ± 0.04	0.20 ± 0.06	0.00 ± 0.00	0.45 ± 0.08
New Albany vernal pools	305.58 ± 0.07	0.28 ± 0.07	0.25 ± 0.07	0.13 ± 0.06	0.47 ± 0.06

locations using a Topcon Positioning Systems, Inc. Model RL-H3C Laser Level.

Statistical analysis

Comparison of vernal pools periods of inundation and depths between New Albany and Gahanna Woods were made using the Mann-Whitney test.

Results

A summary of hydrologic data collected from the 10 created vernal pools at New Albany and 6 natural vernal pools at Gahanna Woods is given in Table 1 and Appendix A, with surface water minimum, maximum, mean and median from each site. The mean, median, minimum and maximum depths at Gahanna Woods vernal pools were lower than the created vernal pools at New Albany. The mean depth at Gahanna Woods had a lower and narrower range (from 5 to 36 cm) than at New Albany (from 12 to 67 cm); the same pattern was reflected in the median level data. The minimum value for all the pools at Gahanna Woods was 0 cm while the minimum value of 13 cm for New Albany reveals that some of its pools did not dry out.

Water elevations in the vernal pools were high in the winter and early spring when evapotranspiration was low and precipitation was high (Figures 2-3). Water levels dropped rapidly in early summer when temperature and evapotranspiration increased. Water levels generally stayed low throughout the summer, reaching their lowest point in the fall. Around November, the pools started to fill again. The pools were located at a greater range of elevations at Gahanna Woods (272.36 ± 0.27 m) than at New Albany (305.58 ± 0.07 m) reflecting Gahanna Woods greater topographic variation (Table 1).

Heavy precipitation events raise the water levels in the pools rapidly. After abundant precipitation in early January 2005, the pools rose and had relatively stable pool levels until early summer when they started to decline. The Hurricane Katrina storm event caused the pools to rise rapidly for a brief period at the end of summer 2005.

Water elevations above sea level do not indicate the pools wetland hydroperiod, so the depth of water in the pools was plotted (Figures 4-5). A zero water level was recorded when no standing water was present in the pool. Water levels in the pools fell faster in 2005 than in 2004 due to less rainfall

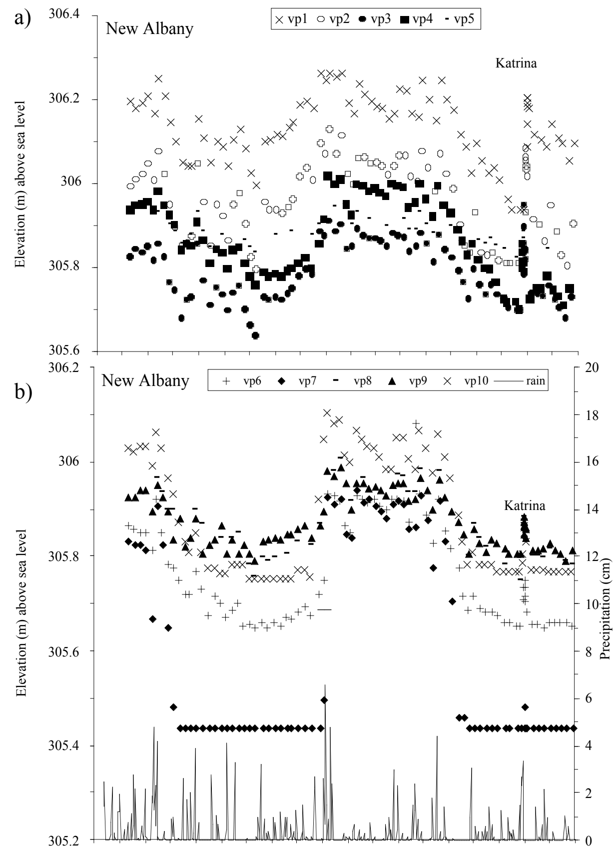

Figure 2. Hydrographs of weekly water levels in New Albany wetland vernal pools (vp) a) 1–5 and b) 6–10. Values are elevation (m) of water above sea level. Measurements were taken weekly. Precipitation data (cm) is on bottom right axis of (b) for comparison.. "Katrina" indicates response to Hurricane Katrina storm event in early September, 2005.

in 2005. At New Albany, pools 5, 8 and 9 are the deepest, and their water levels are more stable over time, never drying out during the reporting period (Appendix A). At Gahanna Woods, the reference wetland, all the pools had seasonal dry periods.

A previous study (Johnson 1999) considered there to be a series of 5 interconnected pools at Gahanna Woods along the west side of the Beachwoods trail (Figure 1b). Water levels in 3 of those 5 pools (Gahanna Woods vernal pools 1, 2 and 4) are reported here (Appendix A). These

Table 2 Comparison of the number of observations of standing water in the vernal pools at New Albany and Gahanna Woods.

Site	Vernal Pool #	Total Number of Observations	Number of Observations with Water	% Observations with Water
Gahanna Woods	1	81	54	67%
	2	83	67	81%
	3	36	22	61%
	4	83	66	80%
	5	81	40	49%
	6	77	61	79%
			Average for Gahanna Woods:	69%
New Albany	1	83	80	96%
	2	83	82	99%
	3	83	82	99%
	4	83	82	99%
	5	83	83	100%
	6	83	80	96%
	7	83	35	42%
	8	83	83	100%
	9	83	83	100%
	10	83	74	89%
			Average for New Albany:	92%

pools become interconnected in late winter/early spring and separate out in the summer when they dry out. VP4 separated from the pool to its immediate south (not monitored in this study) when the water level in VP4 was under 25 cm. VP2 separated from VP4 in this study when the water level in VP2 was under 59 cm. VP1 separated from VP2 in this study when the water level in VP1 was under 45 cm. When the water levels in VP1 were greater than 47 cm, the series of pools were all interconnected and drained to the north into Windrush creek. Water levels were high enough in VP1 for water to run into Windrush creek in 12 out of the 81 weeks of the reporting period.

The percent of observations when water was present in the vernal pools at both sites is listed in Table 2. The average was 92% for New Albany (created pools) and 69% for Gahanna Woods (reference pools). VP3 at Gahanna Woods had no existing staff gage so a temporary one was placed in this pool in 2005 although a photographic record in inundation was kept before that. This pool was one of the first to dry out in 2004 and if depth data had been taken in 2004, it would have made the percent observations with water even less at Gahanna Woods.

The created vernal pools at New Albany were wet significantly longer than the natural vernal pools at Gahanna Woods (Mann-Whitney, α=0.05, p=0.0073). In addition, the median depth at New Albany was significantly higher than the median depth at Gahanna Woods (Mann-Whitney, α=0.05, p=0.005). Vernal pools 5, 8 and 9 (Figure 4) at New Albany were significantly deeper than the rest of the created pools at New Albany and the natural pools at Gahanna Woods (ANOVA, α=0.05, p<0.000).

The depth to the water table in the wells in the New Albany forest were generally considerably lower (0.5 to 2.5 m) than the water elevations of the vernal pools (Figure 6). This disconnect reveals that the deeper wells installed at New Albany do not predict the water table around the vernal pools. Groundwater levels do follow the same pattern as the vernal pools, rising in the winter and spring and declining in the summer and fall, and do respond to storm events such as the "Katrina" storm event blip in late August and early September, 2005.

Discussion

Comparison of the created vernal pools with the natural pools showed that the created pools held water significantly longer than the natural pools. This concurs with the findings of Moore et al. (2001) who found that artificial vernal pools held water longer than the smaller natural pools.

The created vernal pools were also deeper on average than the natural pools. Brooks and Hayashi (2002) found vernal pools with a maximum depth greater than 0.5 m held surface water more than 80% of the time they were visited. In this study, 4 out of 5 vernal pools having a maximum depth greater than 0.5 m held water more than 80% of the time. Three of these vernal pools were in New Albany and held water 100% of the time, never drying out.

A vernal pool's hydroperiod is significantly related to precipitation and potential evapotranspiration, with precipitation having 2-5 times greater effect than evapotranspiration (Brooks, 2004). The study period had above average precipitation, increasing the duration of inundation in the pools; but for both summers in the study period, the natural vernal pool sites were, on average, drier than the created pools.

Although by name vernal pools are seasonally-wet

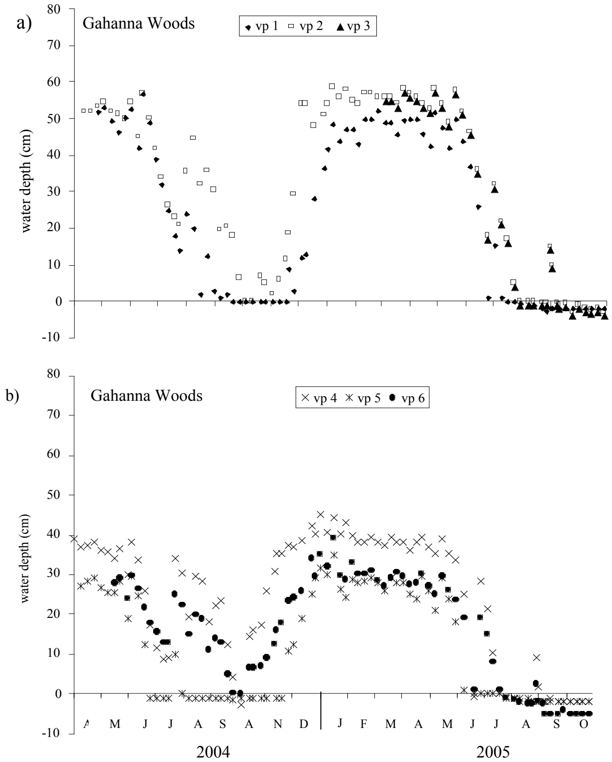

Figure 3. Hydrographs of water levels in vernal pools (vp) (a) 1–3 and (b) 4–6 at the Gahanna Woods State Nature Preserve. Values are elevations (m) of water above sea level (left axis). Measurements were taken weekly. Precipitation data (cm) is on the bottom right axis for comparison. Graph scale starts on April 1, 2004.

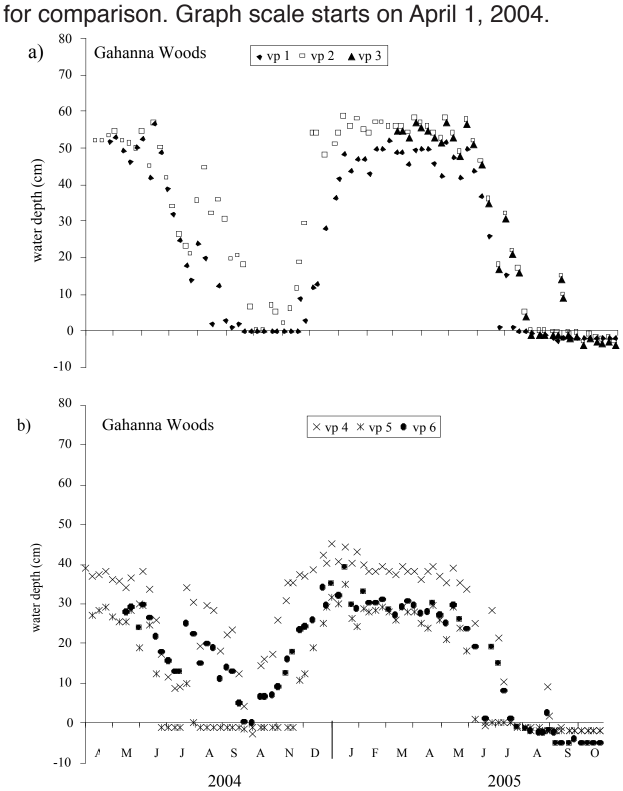

Figure 5 Hydrographs of water level depth taken weekly Gahanna Woods State Nature Preserve vernal pools. Pools 1 through 3 (top) and 4, 5 and 6 (bottom). Measurements were taken weekly.

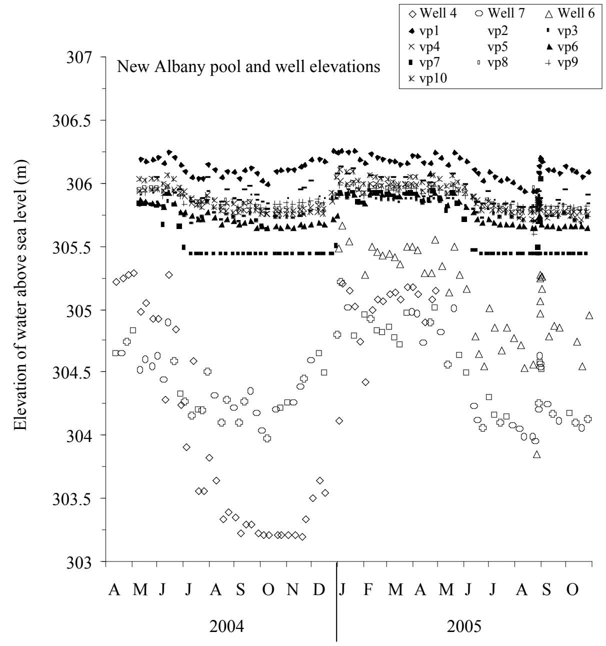

Figure 4 Wetland hydroperiods of water depths in vernal pools (vp) a) 1-5 and b) 6-10 at the New Albany School wetland. Values are depth of water (cm) at staff gage. Measurements were taken weekly. Graph scale starts on April 1, 2004.

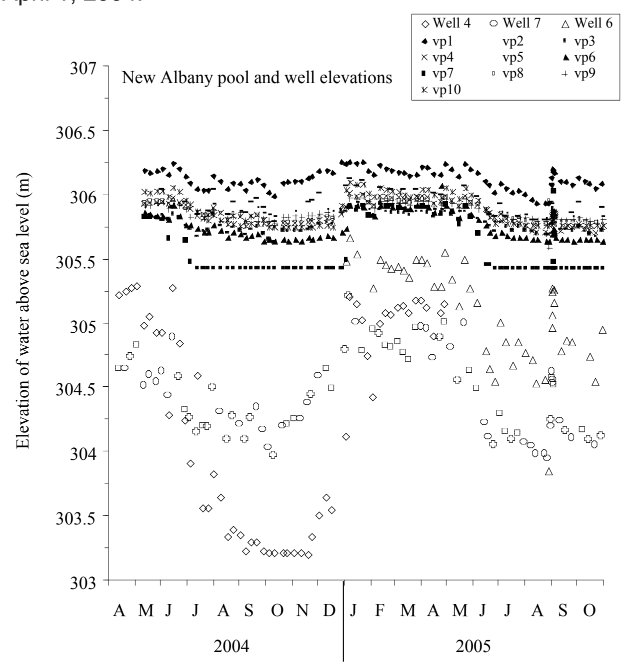

Figure 6. New Albany wetland hydrographs of vernal pools water elevations and well elevations (lower open points) showing that wells were below the water table at the elevation of the vernal pools.

wetlands, and most do dry out sometime in the summer or fall, in actuality vernal pools fall along a continuum from ephemeral pools to permanent pools (Colburn, 2004). Snodgrass et al. (2000) recommended preservation of a diversity of wetlands representing the entire hydroperiod gradient. The constructed vernal pools in this study represented a range of hydroperiods.

The duration of inundation affects the ability of vernal pool animals to complete their reproductive cycle (Brooks and Hayashi, 2002). As a vernal pool's hydroperiod increases, invertebrate richness increases (Brooks, 2000), but predation also increases (Schneider, 1999). Semi-permanent vernal pools which may remain inundated all year provide habitat for species such as green frogs and bullfrogs and some dragonflies which require more than one year to complete their life-cycle (Colburn, 2004). Semi-permanent pools may serve as a refuge for fauna in drought years.

Created wetlands are often constructed to have a permanent hydroperiod to insure compliance with wetland hydrology requirements (Porej, 2003). However, deeper and more permanent vernal pools may not supply the vital habitat needed for species such as wood frogs that breed consistently in the shallowest and least permanent pools (Colburn, 2004). Permanent pools are more likely to have predatory macroinvertebrates and fish (Skelly, 1992; Smith et al., 1999; Woodward, 1983). Predation by fish has been found to change amphibian community composition (Smith et al., 1999) and reduce amphibian diversity (Porej, 2004).

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