Monitoring Hydrologic Factors Influencing Bog Turtle Persistence at a Site in Connecticut

Julie Webb
julief.webb@gmail.com

Recommended Citation
https://opencommons.uconn.edu/gs_theses/1421
Monitoring Hydrologic Factors Influencing Bog Turtle Persistence at a Site in Connecticut

Julie F. Webb

Bachelor of Science, University of Massachusetts Amherst, 2017

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Masters of Science at the University of Connecticut

2019
Approval Page

Masters of Science

Monitoring Hydrologic Factors Influencing Bog Turtle Persistence at a Site in Connecticut

Presented by
Julie F. Webb, BS

Major Advisor ____________________________
Gary Robbins

Associate Advisor __________________________
Lisa Park-Boush

Associate Advisor __________________________
Brian Hess

University of Connecticut
2019
Acknowledgements

I would like to acknowledge Dr. Gary A. Robbins for his endless enthusiasm, support, and guidance. Thank you for all the encouragement, challenges, and laughs. Another special thank you to Dr. Lisa Park Boush for her kindness and wisdom. Thanks are extended to Samantha Walker, Chris Kuveke, Mark Higgins and Ryan Ordung for their assistance in the field. Further thanks to Mark Higgins for his assistance in data analysis. I would also like to thank my collaborators Brian Hess, Dennis Quinn, and Hank Gruner at the Connecticut Department of Energy and Environmental Protection.

I would like to thank my family, Risa Webb, Bill Webb, Nick Webb for their support. Jack Carr, thank you for always believing in me no matter what.

This study was funded by the Connecticut Department of Energy and Environmental Protection under the DEEP/UCONN Cooperative Projects Agreement.
Table of Contents

Approval Page          ii
Acknowledgements       iii
Table of Contents      iv
List of Figures        v
List of Tables         vi
Abstract               vii

Chapter 1: Study Objectives and Literature Review                               1

Chapter 2: Monitoring Hydrologic Factors Potentially Influencing Bog Turtle Persistence       at a Site in Connecticut       10

Chapter 3: Conclusions and Recommendations for Future Research

Appendices                                             Supplementary CD
Appendix A: Raw Data                                  
Appendix B: Analysis Spreadsheets

List of Figures

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Bedrock geology of the study site. (DEEP, 1985)</td>
<td>43</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Quaternary Geology of the study site. (USGS, 2005)</td>
<td>44</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Soil boring log and well construction of the deep well.</td>
<td>45</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Soil drainage classification of the site. (USDA, NRCS, 2009)</td>
<td>46</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Soil series within the study site. (USDA, NRCS, 2007)</td>
<td>47</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Elevation map of the study area and estimated watershed area of the fen. (CRCOG, 2016)</td>
<td>48</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Plant Community of the study site in 2013. (DEEP, 2013)</td>
<td>49</td>
</tr>
</tbody>
</table>
List of Figures

Figure 8 Comparison photos of the study site. Top image shows the site in the summer of 2018, bottom image shows the site in the spring of 1983. Bottom image provided by The Nature Conservancy in Connecticut (1983).

Figure 9 2016 Orthophotography of the site. (CRCOG, 2016)

Figure 10 Discharge rating curve of the stream based on in-situ measurements, used to calculate flow based on continuous measurements of stream gauge.

Figure 11 Daily rainfall and water level from ground surface of the shallow and deep wells.

Figure 12 Daily rainfall and stream height.

Figure 13 Daily rainfall and stream discharge. Top graph displays full range of discharge, bottom graph shows discharge truncated to 0.5 m³/s.

Figure 14 Daily rainfall and floodplain hydraulic head.

Figure 15 Soil moisture and soil temperature.

Figure 16 Daily rainfall, specific conductivity of the stream, and bulk electrical conductivity of the soil.

Figure 17 Daily rainfall and the bulk conductivity measured by the deep and shallow soil moisture probes.

List of Tables

Chapter 2

Table 1 MP20 Measurements – Stream
Table 2 MP20 Measurements – Shallow Well
Table 3 MP20 Measurements – Deep Well
Table 4 Water Chemistry – Stream
Table 5 Water Chemistry – Shallow Well
Table 6 Water Chemistry – Deep Well
Abstract

The population of bog turtles (Glyptemys muhlenbergii) in Connecticut has been in decline over the past decades. A calcareous fen that supported one of the few populations of bog turtles (Glyptemys muhlenbergii) in Connecticut has been shown by the Connecticut Department of Energy and Environmental Protection (DEEP) to have declined with no sittings reported since 2004. Previous studies of the species at other locales have identified site hydrology as an important factor in maintaining environmental conditions conducive to bog turtle population persistence. Maintaining stable spring-fed fen hydrology, mitigating wetland succession, and avoiding pollution have been identified as critical conditions in supporting population persistence. This study evaluates the current hydrology of this site in order to provide insight as to why it may be no longer habitable. Possible reasons for turtle decline identified at the outset of the project included salt contamination from deicing of a state road, periodic flooding from seasonal storms, nutrient and pesticide runoff from the draining farms, potential drying conditions due to succession and changes in water table depth. A one-year monitoring program was instituted to investigate these issues and produce a hydrologic characterization of the site. This study included continuous and periodic monitoring of hydrologic related parameters. Parameters monitored continuously were groundwater depth, stream stage, flood height across the wetland, soil moisture, soil temperature, soil bulk conductivity, stream conductivity, precipitation, and barometric pressure. Measurements made during periodic site visits were depth to groundwater, stream height and width, stream velocity, water quality parameters (temperature, specific electrical conductivity, dissolved oxygen, pH, ORP), and water chemistry parameters (metals, organics, pesticides, fertilizers). The study focuses on the following conditions and how they may have changed over time: extent of stream flooding, surface and subsurface water quality, groundwater discharge, and the impacts of pollution and succession. Observations from
the study conclude that a receding water table, periodic flooding, and a subsurface infiltration of salt are likely causes for disturbance at the site.
Chapter 1

Introduction and Literature Review
Introduction

The research presented in this thesis developed an in-depth hydrologic characterization of a calcareous fen in Connecticut. The fen formerly supported one of the few populations of bog turtles in the state. The study focuses on characterizing the hydrologic conditions and how they may have changed over time and influenced bog turtle population persistence. The concerns and issues established in this study may be applied to future bog turtle conservation efforts.
Literature Review

Numerous studies have tried to decipher the habitat preferences of the federally endangered bog turtle (*Glyptemys muhlenbergii*), but this has proven to be a challenge due to intersite variation, turtles continuing to live in degraded habitat, and the general difficulty in locating bog turtle populations (Kivat, 1993; Lee and Norden, 1996; Copeyon, 1997; Whitlock, 2002; USFWS, 2002). Despite these challenges some general characteristics have been established. Bog turtles occur in fens or wet meadows and bulrush (Kivat, 1993; Carter et al., 1999; Whitlock, 2002; Rosenbalm and Nelson, 2010; Meyers and Gibbs, 2013; Sirois et al., 2014). In their northern range of distribution in Connecticut, sites are underlain by calcareous bedrock and overlain by glacial till (Kivat, 1978; Warner, 1988; Kivat, 1993; Rosenbalm and Nelson, 2010; Meyers and Gibbs, 2013).

Bog turtles prefer plant communities of low grasses and sedges and are frequently associated with hummocks of tussock sedge. (Chase et al., 1989; Kivat, 1978; Kivat, 1993; Lee and Norden, 1996; Morrow et al., 2001; Morrow et al., 2001b). Multiple studies have shown that bog turtles avoid areas of tall, dense, woody vegetation and favor areas of open canopy (Klemens and Warner, 1983; Chase et al., 1989; Klemens, 1989; Morrow et al., 2001; USFWS, 2002; Rosenbalm and Nelson, 2010). However, Whitlock (2002) witnessed a northern population of bog turtles using the root structure of woody vegetation as hibernacula. It is suggested that areas of low vegetation are preferred because it promotes turtle mobility, has better penetration of sunlight, and the microclimate maintained by the vegetation (Kivat, 1978; Chase et al., 1989; Morrow et al., 2001). Hummocks form the microtopography used by the turtles. Hummock roots secure mounds of soil and plant matter for basking and nesting, while rivulets used by the turtles for traveling, flow around the root masses (Kivat, 1978; Kivat, 1993; Rosenbalm and Nelson,
The strong preference for low herbaceous vegetation indicates how wetland succession can negatively impact the species. The issue of succession in these habitats was managed in two ways: retarding the growth of upland vegetation or migrating to nearby, interconnected, and more appropriate wetlands (Lee and Norden, 1996; Copeyon, 1997). The later has become less viable for the bog turtle as its habitats become increasingly isolated (Copeyon, 1997). Mitigation is accomplished by herbivore grazers, fires, beaver activity, periodic wet years, and chemical means (Copeyon, 1997; Meyers and Gibbs, 2013). In pre-colonial times grazing would have occurred by wild large herbivores such as bison and elk; after colonial settlement this role was filled by agricultural animals such as cows (Lee and Norden, 1996). Another source suggests that the high mineral content associated with calcareous fens may inhibit plant growth and maintain competition to allow for various early successional plants to remain in the community (Meyers and Gibbs, 2013). Undisturbed calcareous fens also are nutrient poor, limiting plant growth (Goodwin et al., 2002; Picking, 2002; Morgan, 2008).

At the surface, bog turtle habitat is often interspersed with wet and dry patches (Chase et al., 1989; USFWS, 2002). Between the hummocks bog turtles need access to soft and muddy substrate (Kivat, 1978; Chase et al., 1989; Carter, 1999; Rosenbalm and Nelson, 2010). The surface of bog turtle habitats is described as saturated (Kivat, 1978; Warner, 1988; Rosenbalm and Nelson, 2010). Bog turtles submerge themselves in mud to provide thermoregulation, protection from predators, and refuge during hibernation (Ernst et al., 1989; Carter et al., 1999; Feaga, 2010). The preference for a saturated soil surface emphasizes the importance of a shallow water table (Feaga, 2012).

Previous studies in various bog turtle locales have identified broad hydrologic elements that include 1) groundwater recharge, 2) wetland hydrology, and 3) shallow water tables and
saturated surfaces. (Kivat, 1978; Warner, 1988; Tryon and Hermon, 1990 via Lee and Norden, 1996; Rosenbalm and Nelson 2010). Studies of bog turtle habitat, activity, and hibernation indicate that a shallow water table is ideal for bog turtles. While some bog turtles have been found to hibernate deep within mud (45-55 cm), most turtle activity occurs in the shallow layers of mud (5-30 cm) (Ernst et al., 1989; Bloomer, 2004; Pittman and Dorcas, 2009; Feaga, 2010). Feaga (2010) noted that moderately deep hibernacula (25-30cm) were inundated by a water table less than 15 cm deep, showing that even deep hibernacula are accompanied with a shallow water table. Saturated soils appear to help regulate temperature in the hibernacula (Ernst et al., 1989; Pittman and Dorcas, 2009; Feaga, 2010). Feaga (2010) examined water tables among wetlands in the southern range and identified a depth to water of 10 to 15 cm to be preferred by the bog turtles.

Surface waters at bog turtle locations are generally described as shallow, spring-fed and persistent (Chase et al., 1989; Carter et al., 1999; Whitlock, 2002). Flowing water has also been described at sites, but the habitat should not flood when stream levels rise (Lee & Norden, 1996; Whitlock, 2002). Rivulets, very small streams, are important features of these sites as bog turtles frequently submerge and travel within them (Kivat, 1978; Ernst et al., 1989; Whitlock, 2002; Rosenblam and Nelson, 2010). Ernst et al. (1989) describes these rivulets as being no more than 5 to 15 cm deep.

Water quality parameters of bog turtle habitats have not been well studied. Other studies that have focused on calcareous fens near the turtle’s northern range, but not bog turtle habitats specifically, may provide some insight as to the norms of this environment in this region.

The pH of calcareous fen habitats tends to be circumneutral, with some variability in both acidity and alkalinity. Studies of calcareous fens in the northern range suggest a pH range of 6 to

Parameters of dissolved oxygen (D.O.) have not been well studied for bog turtles, but their tendency to hibernate in mud for the winter suggests they may be tolerant to anoxic conditions (Chase et al., 1989; Ultsch, 2006). The painted turtle experiences D.O. concentrations of 0.08 to 13.6 mg/L; the spotted turtle ranges from 1 to 4.7 mg/L (Litzgus et al., 1999; Rollinson, 2008).

Elevated levels of dissolved calcium are the norm for these calcareous fens, but evidence does not agree on a set range. Thresholds of calcium as low as 5 mg/L have been suggested in the western Americas, while studies among the northern range of the bog turtle have higher reporting of 8 to 420 mg/L, though the ranges in individual studies vary (Vitt et al., 1975; Motzkin, 1994; Picking, 2002; Godwin, 2002; Morgan, 2008; Kivat et al., 2010). Ranges of dissolved magnesium are reported at slightly lower values, ranging from 4 to 54 mg/L (Motzkin, 1994; Picking, 2002; Morgan, 2008; Kivat et al., 2010). For sodium, a study of fens in New York suggests a range of 2.3 to 36.34 mg/L (Godwin et al., 2002).

Calcareous fens are nutrient poor. Ortho-phosphate ranges from non-detectable to 1.63 mg/L (Picking, 2002; Morgan, 2008). Nitrates range from non-detectable to 14.26 mg/L (Goodwin et al., 2002; Picking, 2002). Drinking water standards in Connecticut allow up to 10 mg/L of nitrate and 1 mg/L of nitrite; amounts exceeding this may indicate fertilizer runoff or septic contamination (CT DPH, 2017). Picking (2002) reported a mean total organic carbon of 6 mg/L with a range from 1.8 to 64.7 mg/L.
In one study mean chloride concentrations of a calcareous fen range from 2.48 to 43.89 mg/L (Godwin et al., 2002). The EPA designated both a Criterion Continuous Concentration (CCC) and the Criterion Maximum Concentration (CMS) for chloride regarding health of aquatic life, which are 230 mg/L and 260 mg/L, respectively (EPA, 2019).

Picking (2002) recorded alkalinity in a calcareous fen ranging from 76.7 to 115.7 mg/L. Regarding water hardness, Heath (1983) identifies “0 to 60 mg/L as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L very hard.” The location of this study is in a very hard water zone of Connecticut (Omernik et al., 1985).

Organic pesticide contaminants, such as dicamba, 2,4-D, triclopyr and triclopyr butoxyethyl ester may be of concern when near agricultural land use. In 2010, the Connecticut Department of Environmental protection proposed the following ambient freshwater quality criteria (DEEP, 2013):

- Dicamba: Freshwater (acute): 1619 ng/mL; Freshwater (chronic): 180 ng/mL
- 2,4-D: Freshwater (acute): 47 ng/mL; Freshwater (chronic): 5 ng/mL

The EPA (2015) set the following benchmarks for freshwater aquatic life regarding triclopyr and triclopyr butoxyethyl ester:

- Triclopyr: Fish (acute): 58500 µg / L; Invertebrates (acute): 66450 µg / L; Nonvascular Plants (acute): 32500 µg / L
- Triclopyr butoxyethyl ester: Fish (acute): 180 µg / L; Fish (chronic): 26 µg / L; Invertebrates (acute): 850 µg / L; Nonvascular plants (acute): 100 µg / L; Vascular plants (acute): 880 µg / L.

It should be noted that bog turtles are considered semi-aquatic animals, as they spend time much of their time on land and in mud, and thus aquatic life benchmarks may not directly apply to them. Benchmarks applicable to the plant and invertebrate community may be relevant to the health of the habitat and its ability to support bog turtles.
Electrical conductivity varies from fen to fen. Kivat et al. (2010) reported the range of conductivity of groundwater in calcareous fens in New York and adjacent Connecticut to be 0.28 to 0.71 µS/cm. Motzkin (1994) reported a range of 33 to 128 µS/cm in surface waters of Northeastern calcareous fens. Studies of conductivity of groundwater in Northeastern calcareous fens have been reported at higher values, with averages ranging from 75 to 1800 µS/cm. (Goodwin, 2002; Picking 2002). In a broader range, freshwater streams generally may vary from 100 to 2000 µS/cm and potable water from 30 to 1500 µS/cm (CTW, 2004). Recent studies have developed more stringent “aquatic life benchmarks”, or “thresholds at which potential detrimental effects on biotic assemblages may be observed” (Weaver and Nortrup, 2016). The Maryland Biological Stream Survey reported these benchmarks to be <171 µS/cm for fish and <247 µS/cm for macro invertebrates (Morgan et al., 2007). Aquatic life benchmarks for conductivity have been established more specifically in calcareous wetland environments in the Central Appalachians, located in the southern range of the bog turtle, but not the northern range of the bog turtle. The EPA published a report, “Appalachian Region associated with a mixture of salts dominated by Ca+, Mg+, SO 2− 4 , and HCO − 3 at circum-neutral pH”; the benchmark the study presents is 300 µS/cm (Cormier et al. 2011). Again, bog turtles are only semi-aquatic and these standards do not directly apply to them, however, they maybe more applicable to the biota of their environment.

In “Principals of Wetland Restoration” (2018) the EPA discusses the complexity of wetland restoration. The specific points regarding hydrologic factors are summarized below:

“Work within the watershed and broader landscape context. Restoration requires a design based on the entire watershed, not just the part of the waterbody that may be the most degraded
A localized restoration project may not be able to change what goes on in the whole watershed, but it can be designed to better accommodate watershed effects.

**Understand the natural potential of the watershed.** Establishing restoration goals for a waterbody requires knowledge of the historical range of conditions that existed on the site prior to degradation and what future conditions might be. This information can then be used in determining appropriate goals for the restoration project.

**Address ongoing causes of degradation.** Restoration efforts are likely to fail if the sources of degradation persist. While degradation can be caused by one direct impact, such as the filling of a wetland, much degradation is caused by the cumulative effect of numerous, indirect impacts.

"...a wetlands restoration project is not likely to succeed if the hydrological regime that existed prior to degradation cannot be reestablished.” – From “Principals of Wetland Restoration” (EPA, 2018)

Challenges presented in trying to hydrologically restore bog turtle habitat include the lack of historical data regarding hydrologic conditions conducive to healthy bog turtle habitat, the inherent difficulty of addressing problems and solutions on a watershed-wide scale, and the invasive nature of some restoration projects (ex. heavy machinery, excavation). Due to these challenges, conservation efforts should be applied toward determining the hydrologic range of conditions that support bog turtles in their locales and towards upholding those conditions at healthy sites.
Chapter 2

Hydrologic Factors Potentially Influencing Bog Turtle Persistence at a Site in Connecticut
Hydrogeochemical Setting

The study site is located on a small calcareous fen in Western Connecticut. Monitoring equipment was installed towards the north-western of the site, slightly upstream from reported turtle spotings in order to limit potential disturbance. Geology and soils were determined with GIS using state published data. The bedrock geology (Figure 1) is classified as Stockbridge Marble (gray dolomite marble) and Walloomsac Schist (dark, fine grained schist). Overlying material is identified as glacial till (Figure 2). On-site soil borings indicate the following soil layers: (0 to 0.9 m) organic clay-sand top soil, moderately plastic, wet to very moist, saturated at 76.2 cm; (0.9 m to 2 m) gravely till (Figure 3). As shown on Figures 4 and 5, the site soils are classified as moderate to poorly drained and as part of the Mudgepond and Alden series (extremely stony, poorly drained, coarse-loamy till derived from limestone and dolomite / schist, moderate to moderately rapid permeability, high water capacity, neutral to alkaline, very deep to bedrock, seasonal water table 0 to 30.5 cm); and Stockbridge loam (3 to 8 percent slopes, well drained, coarse-loamy till derived from limestone and dolomite and or schist, moderate to moderately low permeability, high water capacity, very deep to bedrock) (NRCS, 2008). All monitoring equipment and onsite measurements were made within the Mudgepond and Alden series.

Figure 6 is an elevation map of the site area. Valley slopes in the wetland vicinity were calculated using a Digital Elevation Model (DEM) in ArcGIS and were found to be between 0 – 12 degrees. Average elevation of the wetland study area was also calculated using a DEM and found to be 242.95 m (797.03 ft). The elevation map was used to define the watershed boundaries for the site.
In a previous flora assessment conducted in 2013 by DEEP, the site was found to contain willows, shrubby cinquefoil, tussock sedge, silky dogwood, sedges (dioecious, inland, yellow), and an old farm field (Figure 7). A flora assessment was not conducted as part of this study, but the site was observed to be dominated by tall, upland species. Collaborators at DEEP familiar with the location (Hank Gruner, Dennis Quinn) have confirmed this shift to upland species through years of visiting the site. A visual comparison can be seen in Figure 8, displaying the habitat in the present day versus 1983.

There are three uphill farms and nurseries that have potential to drain into the wetland. A state road runs adjacent to the wetland and runoff drains to a small stream that dissects the wetland (48 cm wide; 20 cm deep). (Figure 9)

Methodology

Initial site set up began June 26th, 2017 and monitoring continued until August 1st 2018. Parameters monitored continuously were hydraulic head, streamstage, floodplain height across the wetland, soil moisture, soil temperature, stream specific electrical conductivity, soil bulk electrical conductivity, precipitation, and barometric pressure. Periodic measurements made onsite during visits were depth to groundwater, stream height and width, water quality indicator parameters determined with an MP20 (temperature, specific electrical conductivity, dissolved oxygen, pH, ORP), and stream and groundwater water potential contaminants (metals, organics pesticides, fertilizers).

Site set up
During site visits the North East Partners in Amphibian and Reptile Conservation’s (NEPARC) “Disinfection of Field Equipment to Minimize Risk of Spread of Chytridiomycosis and Ranavirus” disinfection protocol was followed before entering the site. A small “weather station” was installed on a metal fence post roughly 30.5 m (100 ft) from the stream. The station included a barometric pressure transducer, a tipping-bucket rain gauge, and two soil moisture probes. Two wells, a floodplain pressure transducer, and a conductivity-pressure transducer in the stream were also installed on site near the weather station.

Rain Gauge

On 7/26/2018 a Hoboware tipping bucket rain gauge was installed at the top a post. At each site visit data was downloaded from the gauge, and the hardware inspected. On two occasions nature interfered with the gauge. On 11/17/18 a spider web prevented the tipping bucket cups from moving properly; the web was removed, and a screen added to the top of the gauge.

The gauge recorded rain events of 0.025 cm. Cumulative daily rain was calculated by summing events for each respective day. Descriptive statistics were calculated in excel.

Soil Moisture

Decagon Devices 5TE soil probes were installed to continuously monitor soil moisture, bulk electrical conductivity (EC), and temperature. On 7/26/2018 two soil probes were installed: one “shallow” 5 cm deep, and one “deep” 26.67 inches deep. Soil moisture was recorded in m³/m³ volumetric water content (VWC); soil electrical conductivity was recorded in milli-Siemens per cm (mS/cm EC); temperature was recorded in Celsius. Data was recorded
continuously in 1-minute intervals and downloaded during site visits. No disruptions in data occurred except for interruptions to download.

*Barometric Probe*

Barometric pressure was monitored on site by a barometric probe installed on the weather station. Initial installation occurred on 7/26, however it was discovered the original probe was not working properly on 10/13/2017. The broken probe was replaced with a Heron pressure transducer on 10/20/2017. Due to this, reliable barometric data was only collected after 10/20/2017. Data was recorded in 1-minute intervals as feet of water (FoW).

*Floodplain Transducer*

A floodplain transducer was installed at ground surface by the stream to detect flooding events. The floodplain probe was installed on 7/26, 1.5 m (5 ft) away from the stream pressure transducer. Pressure (psi) and temperature (°C) were monitored continuously in 1-minute intervals. Original pressure recordings in psi were converted to FoW by multiplying by 2.31 (1 psi = 2.31 feet of head) for ease of comparison with other parameters.

*Wells*

Two wells were installed on site to monitor water table fluctuations and retrieve multi-level groundwater samples. Several attempts had to be made to drill wells due to difficulties drilling through a shallow gravel layer.

On September 8th, 2017 the “Shallow Well” was installed on site and drilled with a borehole diameter of 8.23 cm. Depth to bottom of the well was 42.67 cm, with the bottom 0.3 feet in the gravel layer. The well was constructed with 30.5 cm of prepack screening (2.54 cm in
diameter, PVC # 6 slot). Casing extended 90.8 cm above the ground surface. From the bottom of the well to 12.2 cm below surface the annular space was surrounded by #2 New Jersey sand. From 12.2 cm below surface ground surface the annular space was filled with bentonite clay. After construction the water level was 24.38 cm below surface; 1 hour after construction the depth to water was 22.86 cm below surface.

A borehole log was for the shallow well recorded the following: (0.0 to 30.5 cm) organic clay-sand top soil, moderately plastic, wet to very moist; (30.5 to 61.0 cm) gravelly till; (61.0 cm) refusal.

On October 20\textsuperscript{th}, 2017 the “Deep Well” was installed on site with a Mobile Portable drill rig. The borehole was drilled with a 7.6 cm diameter. Drill refusal occurred at 198.1 cm where a large rock or bedrock was encountered. The well was constructed with a 15.2 cm long screen. Casing extended 128.0 cm above ground surface. The annular space was filled with #2 New Jersey sand until “a few inches above the screen”. From the sand to the surface, the annular space was filled with bentonite.

The borehole log for this well is recorded as the following: (0.0 to 91.4 cm) organic clay-sand top soil, moderately plastic, wet to very moist, saturated at 76.2 cm; (91.4 cm to 198.1 cm) gravelly till; (198.1 cm) refusal, larger rock or boulder (Figure 3).

Each well was equipped with pressure transducer at the bottom to record the height of water in each well. When not being examined, the wells were capped to prevent disturbance.

Pressure was monitored continuously as FoW in 1-minute intervals. Barometric pressure was subtracted from this value to isolate the value of hydraulic head.
During site visits manual depth to water was recorded by a water level sounder, and various water quality indicator parameters measured with an MP20 Sonde. Depth to water was recorded in feet below the top of well casing. Casing height was subtracted from this measurement to determine the depth of water below ground surface. The MP20 Sonde measured temperature (°C), electrical conductivity (mS/cm), dissolved oxygen (mg/L), ORP (millivolts, mv) and pH.

Water quality samples were also taken from both the wells and analyzed by UConn’s University of Connecticut Center for Environmental Sciences and Engineering (CESE) lab to test for metals (metals), fertilizers (nutrients), and pesticides (organics). Samples were only taken at relevant dates (ex: pesticides were not tested for in the middle of winter). A full list of these chemical parameters are as follows:

**Metals**: Na (μg/L), Ca (μg/L), Mg (μg/L),

**Nutrients**: Total Organic Carbon (mg/L), NO₃ (mg/L), NO₂ (mg/L), NOₓ (mg/L), Orthophosphate (mg/L), Alkalinity (mg/L), Cl (mg/L)

**Organics**: Dicamba (ng/mL), 2,4-D (ng/mL), triclopyr (ng/mL), triclopyr butoxyethyl ester (ng/mL)

These parameters were evaluated by the CESE laboratory using the following methods:

**Alkalinity**: EPA 310.1

**Total Organic Carbon**: EPA 415.1

**Chloride**: EPA 300.0

**Nitrite, Nitrite+Nitrate, Orthophosphate**: EPA 353.2, EPA 535.2, EPA 365.1

**Metals on Water by ICP-OES – Ca, Mg, Na**: EPA 200.7
Herbicides (Dicamba, 2,4-D, triclopyr, triclopyr butoxyethyl ester): liquid chromatography tandem mass spectrometry – CESE validated analytical method.

Samples were collected in appropriate containers supplied by CESE and delivered to the lab the same day as collection.

Continuous water level from ground surface was determined by relating hydraulic head to onsite depth to water measurements. Hydraulic head was converted to water level from ground surface by the following equation:

\[-D(t=0) + (P(t=0) - P(t))\] = -D(t)

Where:

\[D(t=0)\] = Onsite measurement of depth to water

\[P(t=0)\] = Hydraulic head of the well the when \(D(t=0)\) was measured

\[P(t)\] = Pressure at any time, \(t\)

\[D(t)\] = Depth to water at any time, \(t\)

\[-D(t)\] = Water level from ground surface at any time, \(t\)

Stream Measurements

An Insitu Aqua TROLL 200 was installed in the stream in the middle of the site, attached to a post. Pressure (PSI) and specific conductance (\(\mu\)S/cm) were continuously monitored by at 1-minute intervals. Pressure was converted into FoW. Barometric pressure was subtracted from the total pressure to isolate stream gauge.
A MP20 Sonde was used to measure temperature (°C), electrical conductivity (mS/cm), dissolved oxygen (mg/L), ORP (millivolts, mv) and pH. Water samples of the stream were collected during site visits and were tested by (CESE) laboratory. Samples were collected in appropriate containers supplied by CESE and delivered to the lab the same day as collection. The chemical parameters and the methods used to evaluate them are the same as those described in the previous section on groundwater.

During each site visit the depth and width of the stream was measured a tape measure. Measurements were taken by the stream transducer for consistency. Stream velocity was determined using a Son-tek Flow Cell; and recorded in cm/sec. Multiple consecutive measurements were made and later averaged together and converted into in/s.

Stream depth and width were used to determine the rectangular cross-section of the stream. Area (cm²) was multiplied by velocity (cm/s) to determine discharge (cm³/s). However, this only provided discrete discharge on site visit days. A stream discharge rating curve was built using discrete measurements across the study period (Figure 10). Continuous stream stage provided by the transducer could then be used in conjunction with the rating curve to determine continuous flow.

Results

Rain History

Rainfall was collected from 7/27/2017 to 8/1/2018, a period of 371 days. No data was collected from 10/9/2017 to 11/17/2017 due to a spider web interfering with the tipping bucket. During the site visit of 8/1/2018, a hornet’s nest was discovered in the bucket and a hornet plugged the bottom funnel. This occurred at some point after the previous site visit on 5/30/2018,
but it is unsure exactly when in the period this developed. Changes in stream height and discharge suggest rain events occurred in mid-June that were not recorded; local weather stations do report precipitation events occurring during this period. This should be considered when examining the data (or lack thereof) beyond 5/30/2018.

Total recorded rainfall from 7/27/2017 to 8/1/2018 (371 days) was 71.68 cm. Of the 371 days, rainfall recorded on 134 days. Average rainfall per day during the recording period was 0.19 cm; maximum recorded rainfall in a day was 3.12 cm.

*Groundwater Levels and Precipitation Response*

Depth to water from the ground surface was monitored and analyzed from 10/27/2017 to 8/1/2018, a period of 279 days. In the shallow well, average depth to water was 0.247 ± 0.002 m. The maximum depth to water was 0.392 m and the minimum depth to water was -0.222 m (negative value indicating water level above ground surface) with a range of 0.614 m. In the deep well, the average depth to water was 0.213 ± 0.119 m. The maximum depth to water was 0.480 m and the minimum depth to water was -0.144m. During wet months (January – May) the hydraulic head of the deep well was greater than that of the shallow well indicating dominance of groundwater recharge during this period. In the drier months (June – December) the shallow well has greater head than the deeper well, indicating a greater influence of surface water recharge. (Figure 11).

*Stream and Precipitation Response*

Stream stage was monitored and analyzed from 10/27/2017 to 8/1/2018, a period of 279 days (Figure 12). Average stream height was 23.4 ± 8.7 cm. Maximum stream height recorded was 75.1 cm and the minimum recorded was 3.1 cm. Stream height was less than 40 cm for 95%
of the time recorded. There were 19 events where stream height exceeded 40 cm. These events are scattered throughout the year. The greatest stream height occurred on 3/20/2018.

Average daily stream discharge was $0.21 \pm 0.6 \text{ m}^3/\text{s}$ (Figure 13). Maximum daily stream discharge was $5.7 \text{ m}^3/\text{s}$ and the minimum was $0.000 \text{ m}^3/\text{s}$. Of the 279 days observed, 95.6% of them had an average daily discharge of less than $1 \text{ m}^3/\text{s}$. There were 9 events where average daily discharge exceeded $1 \text{ m}^3/\text{s}$. Of the 9 events, 1 event occurred in October and the remaining 8 occurred between January and May. The greatest discharge event occurred on 1/12/2018.

There were several instances of flooding on the floodplain of the stream (Figure 14). The maximum occurred in January where the floodplain experienced 0.42 meters of head. There were three other occasions where head of the floodplain was greater than 0.1 meters, and they occurred in October, January, and February.

*Soil Moisture and Temperature*

Soil moisture and temperature measurements are shown in Figure 15. The shallow soil (2 in depth) moisture had an average volumetric water content (VWC) of $0.351 \pm 0.161 \text{ m}^3/\text{m}^3$. Minimum soil moisture for the shallow soil was $0.206 \text{ m}^3/\text{m}^3$ and the maximum was $0.656 \text{ m}^3/\text{m}^3$. Average volumetric water content of the deeper soil (10.5 in depth) was $0.344 \pm 0.119 \text{ m}^3/\text{m}^3$. The minimum soil moisture for the deep soil was $0.049 \text{ m}^3/\text{m}^3$ and the maximum was $0.665 \text{ m}^3/\text{m}^3$. From mid-December to mid-April the deeper soil was moister than shallow soil; from late-April to early-December the shallow soil was moister than the deeper soil. Soil VWC is more useful when compared to the available water content of the soil (AWC) than on its own as a value. Soil Data Explorer (UC Davis, 2003) reports that in Mudgepond (dominant component) soils of shallow depths less than 20 cm the AWC is approximately $0.34 \text{ m}^3/\text{m}^3$; in
depths greater than 20 cm the AWC is approximately 0.22 m$^3$/m$^3$. Alden (secondary component) soils list the AWC as 0.22 – 0.24 m$^3$/m$^3$ for depths down to 50 cm (UC Davis, 2009). In comparison to the Alden AWC the soil is saturated at both the shallow and deep depths, however in comparison to the more dominant soil component, Mudgepond, the shallow layers of the soil are not saturated.

Shallow soil temperature was on average 8.12 ± 7.9°C. Minimum shallow soil temperature was -4.10°C and the maximum was 28°C. Deep soil temperature was on average 7.64 ± 6.21°C. Minimum deep soil temperature was 0.80°C and maximum deep soil temperature was 19.6°C (Figure 15).

*Specific Conductivity Bulk Conductivity*

Figure 16 shows how the stream conductance varied with time and precipitation. Average specific conductance for the stream was 522 ± 115 μS/cm. Minimum specific conductance for the stream was 2 μS/cm and the maximum was 1147 μS/cm. Maximum stream conductivity occurred on 2/4/2018. Table 1 displays the stream specific conductance measured on site. Stream conductivity was generally higher in the fall, lower in the winter, higher again in the spring, and low again in the summer (Figure 16).

During site visits field measurements of specific conductivity were made in the deep and shallow wells. Average, minimum, and maximum conductivity of the shallow well can be found in Table 2, and of the deep well in Table 3. Maximum shallow well conductivity occurred in August (Table 2). Maximum deep well conductivity occurred in October (Table 3).

Average bulk conductance for shallow soil was 131.14 ± 83.84 μS/cm. Minimum specific conductance for shallow soil was 0.00 μS/cm and the maximum specific conductance was 340
μS/cm. Maximum conductance in shallow soils occurred on 3/7/2018. Average specific conductance for the deeper soil was 104.44 ± 77.98 μS/cm. Minimum specific conductance for the deeper soil was 10.00 μS/cm and the maximum specific conductance was 280.00 μS/cm. Maximum conductance in deeper soil occurred on 4/8/2018 (Figure 17). Both maximums follow a brief warming period in February. Conductivity briefly rose then fell during the spring melt.

**Water Quality**

Tables 1, 2 and 3 summarize the field water quality measurements determined with the MP20 Flow Cell. Chemical parameters assessed by CESE laboratories are summarized in tables 4, 5, and 6. Dicamba was detected once in the stream at 0.092 ng/mL and was not detected in the stream again during the study. The other organics tested (2,4-D, triclopyr, and triclopyr butoxyethyl ester) were not detected in the stream at any point of the study. No organics tested (dicamba, 2,4-D, triclopyr, and triclopyr butoxyethyl ester) were detected in the shallow well throughout the course of the study (Table 5). 2,4-D was detected once in the deep well at 0.04 ng/mL in April of 2018 and was not detected in the deep well at any other point in the study. Triclopyr butoxyethyl ester, triclopyr, and Dicamba were not detected in the deep well throughout the study (Table 6). The instances of Dicamba and 2,4-D detections were below the ambient water quality standards proposed by the Connecticut DEEP (2010):

- Dicamba: Freshwater acute: 1619 ng/mL Freshwater chronic: 180 ng/mL
- 2,4-D: Freshwater acute: 47 ng/mL Freshwater chronic: 5 ng/mL

**Discussion**

Previous studies in various bog turtle locales have identified 1) groundwater recharge, 2) wetland hydrology, and 3) shallow water tables and saturated surfaces to be key elements of bog
turtle habitat (Kivat, 1978; Warner, 1988; Tryon and Hermon, 1990 via Lee and Norden, 1996; Rosenbalm and Nelson, 2010). Hydraulic head of the deeper well exceeded that of the shallow well for roughly half the year, indicating that groundwater recharge is present at the site for part of the year. Both wells respond quickly to precipitation events suggesting influence from surface water on recharge. The Army Corps of Engineers (2005) defines wetland hydrology as

“inundated (flooded or ponded) or the water table is ≤12 inches below the soil surface for ≥14 consecutive days during the growing season at a minimum frequency of 5 years in 10 (≥50% probability).” The habitat in question maintains a water table within 30.5 cm of the surface for 88.4% of the year and meets the qualification of wetland hydrology. Studies of bog turtle habitat, activity, and hibernation habits indicate that a shallower water table is ideal for bog turtles. Feaga (2010) examined water tables among wetlands in the southern range and identified wetlands with a depth to water of 10 to 15 cm to be preferred by the bog turtle. The water table of this study’s habitat remained within 15 cm of the surface for only 5% of the study period. This may indicated that the water table has become too low to support bog turtle activity or hibernacula.

Comparisons of soil VWC to the AWC of the dominant soil components indicate that the shallow layers of soil are not saturated, suggesting that conditions in the shallow soil are too dry to support the bog turtle.

In addition to apparent dryness, flooding events were recorded at the site. Occasions of stream flooding were indicated by sudden surges in head measured by the floodplain barometer, stream gauge, and stream velocity. Flattened vegetation was observed during site visits following such events. A literature review compiled by Lee and Norden (1996) summarizes that while bog turtle habitats may have small streams, that the habitat should not flood when stream levels rise.
Previous studies of calcareous fens in the New York – Massachusetts – Connecticut adjacent areas report various ranges for conductivity. Motzkin (1994) reported an average of 333 \( \mu S/cm \) with a range of 158 - 478 \( \mu S/cm \); Godwin (2002) reported a range of 75 – 1,800 \( \mu S/cm \), with the average of the sites being 464.64 \( \mu S/cm \); Picking (2002) reported a range of means from 376 to 865 \( \mu S/cm \) with full range over two seasons being 294 to 1,154 \( \mu S/cm \). Aquatic life benchmarks suggested for conductivity are much stricter. The Maryland Biological Stream Survey establishes the freshwater aquatic life benchmark for specific conductivity as $<$171 \( \mu S/cm \); the EPA report “Appalachian Region associated with a mixture of salts dominated by \( Ca^+, Mg^+, SO_2^{-4}, \) and \( HCO_3^- \) at circum-neutral pH” establishes a slightly higher benchmark of 300 \( \mu S/cm \) (Morgan et al., 2007; Cormier et al., 2011). These aquatic life benchmarks do not directly apply to bog turtle is considered semi-aquatic, but can apply to the plant life that supports them.

Specific conductivity in the stream (Table 1) is greater than that recorded in surface water of outside studies on calcareous fens (but not specifically bog turtle habitats). Specific conductivity of the shallow well (Table 2) and the deep well (Table 3) are elevated compared to the stream (Tables 1) but still within recorded ranges of calcareous fens (but not specifically bog turtle habitats) in the region. Bulk conductance recorded in the shallow soil (mean 131 \( \mu S/cm \); range 0.00 to 340.00 \( \mu S/cm \)) and the deeper soil (mean 104.44 \( \mu S/cm \); range 10 to 280 \( \mu S/cm \)) were lower than those recorded in the stream and wells. This is unexpected as bulk conductance of soil is typically greater than specific conductance of water alone.

The higher conductivity found in the wells may be reflective of the higher concentration of dissolved ions of magnesium and calcium compared to the stream. However, levels of sodium and chloride are also elevated (Tables 5 and 6) compared to the stream (Table 4), suggesting
there may be more road salt dissolved in the groundwater than in the surface water. The comparatively low specific conductivity of the stream, and even lower bulk conductivity of the soil suggests that more road salt is introduced by the subsurface water rather than the surface water. If this is the case, road salt deicing of the adjacent state road may not be of topmost concern but rather the road salt deicing practices of the greater groundwater recharge area of the fen.

Previous studies have identified the mean ranges of dissolved ions in calcareous fens:

- Calcium: Motzkin (1994) 8 to 65 mg/L, Godwin et al. (2002) 10 to 428 mg/L, Picking (2002) 100 to 180 mg/L, Morgan et al. (2008) 26 to 92 mg/L
- Magnesium: Motzkin (1994) 4 to 32 mg/L, Godwin et al. (2002) 0.47 to 35 mg/L, Picking (2002) 20 to 42 mg/L, Morgan (2008) 16 to 54 mg/L.
- Sodium: Godwin et al. (2002) 2.3 to 36.34 mg/L.

Dissolved ions were more concentrated in the wells (Tables 5 and 6) than in the stream (Table 4) and were more concentrated in the deep well (Table 6) than in the shallow well (Table 5). These observations are consistent with the geochemical properties of calcareous groundwater which typically has a greater concentration of dissolved ions, especially of calcium and magnesium. Higher levels of sodium were found in the wells than in the stream, with higher concentrations detected in the shallow well than the deep well. Concentrations of sodium in the wells frequently exceeded those observed in the calcareous groundwater studied in Godwin et al. (2002). This suggests that the concentrations of sodium recorded in the groundwater of this study are not inherent to calcareous fens in this region and may exceed what is normal.
Observed low concentrations of nutrients were consistent with previous studies of calcareous fens. Picking (2002) observed concentrations of orthophosphate ranging from non-detectable to 1.48 mg/L, and Morgan (2008) reported similar results ranging from non-detectable to 1.63 mg/L. The maximum concentrations of orthophosphate reported in the stream (Table 4), shallow well (Table 5), and deep well (Table 6) were below those observed by Picking and Morgan. Godwin et al. (2002) reported nitrates ranging from 0.00 to 14.26 mg/L, Picking (2002) reported a range of means of 0.02 to 0.62 mg/L. Maximum concentrations of nitrate observed in the stream (Table 5) and deep well (Table 6) were below the maximum mean concentration reported in Picking (2002). The maximum concentration in the shallow well (Table 5) was slightly greater than the maximum mean concentration reported in Picking (2002) but less than those observed in Godwin et al. (2002). Nitrites have not been well studied for calcareous fens. The Connecticut drinking water standard is 1 mg/L. Maximum concentrations of nitrite of the stream (Table 4), shallow well (Table 5), and the deep well (Table 6) were below this standard. Picking (2002) reported a mean total organic carbon (TOC) of 6 mg/L in a calcareous fen in Massachusetts. In this study, maximum ranges of TOC observed in the stream (Table 4) and the shallow well (Table 5) are close to or below the average concentration of TOC in calcareous fens observed in Massachusetts by Picking (2002). The deep well had one instance in November 2017 where the TOC was reported to be 64.9 mg/L, however measurements from April and August are 4.2 mg/L and 5.6 mg/L respectively. This maximum of 64.9 mg/L is close to the maximum mean concentration of TOC reported by Picking (2002) of 64.7 mg/L. These observations suggest nutrient runoff is not a prominent issue at the site.

Godwin et al. 2002 reported mean chloride concentrations ranging from 2.48 mg/L to 43.89 mg/L. In this study, maximum chloride observed in the stream (Table 4) was within the
range reported by Godwin (2002). Chloride concentrations in the shallow well (Table 5) and the deep well (Table 6) exceeded the range observed by Godwin (2002) in all measurements throughout the study. All observed concentrations of chloride were below the EPA Criterion Continuous Concentration (CCC) and the Criterion Maximum Concentration (CMS) established for aquatic life, are 230 mg/L and 260 mg/L respectively.

Picking (2002) recorded alkalinity in a Massachusetts calcareous fen ranging from 76.7 to 115.7 mg/L; Heath (1983) describes waters having alkalinity of greater than 180 mg/L as “very hard”. Alkalinity in this study (Tables 4, 5, and 6) suggest the site has very hard waters and a large buffering capacity against changes in pH. High levels of alkalinity are considered a positive attribute in aquatic ecosystems.

There were only two cases across the study in which pesticides were detected in the water. In October, dicamba was detected in the stream, and in April 2,4-D was detected in the deep well. Both pesticide detections were below the ambient water quality standards for dicamba and 2,4-D proposed by the Connecticut DEEP or the EPA.

Studies of calcareous fens in the northern range suggest a pH range of 6 – 8.1, while a study of bog turtle habitats in New York identified a pH range of 5.0 – 8.4. (Motzkin, 1994; Picking and Veneman, 2004; Rosenbalm and Nelson, 2010) In this study, the record of pH in the surface water (Table 1) and groundwater (Tables 2 and 3) are within the previously observed ranges of other Northeastern calcareous fens. Dissolved oxygen is not well studied in either Northeastern calcareous fens or for bog turtles. Chase et al. (1989) and Ultsch (2006) suggest that bog turtles may be tolerant to anoxic conditions over the winter. Studies of other turtle species, such as the painted turtle and spotted turtle, report ranges of dissolved oxygen as 0.08 to 13.6 mg/L and 1 to 4.7 mg/L respectively (Litzgus et al., 1999; Rollinson, 2008). The stream in
this study was well oxygenated (Table 1). Groundwater typically has lower dissolved oxygen than surface water; dissolved oxygen in the wells of this study (Tables 2 and 3) were consistent with this. Both the surface water (Table 1) and groundwater (Tables 2 and 3) showed circum-neutral ORP; oxidizing conditions were the most common with occasional reducing conditions observed. The pH, dissolved oxygen, and ORP observed in this study do not appear to be the source of habitat unsuitability.

Elevated levels of chloride, sodium, and specific conductivity in the wells suggest that the subsurface water is contaminated with salt. The greatest levels of chloride and sodium conductivity were detected in the shallow well in comparison to the deeper well and the stream. Specific conductivity was the highest in the shallow well, followed by the deeper well, then the stream. While bulk electrical conductivity in soil is typically higher than specific conductivity observed in water, in this study bulk electrical conductivity of the soil was lower than electrical conductance observed in the surface and groundwaters. The low bulk electric conductivity of the soil does not support surface runoff from the immediately adjacent road as the culprit for salt contamination in the wetland. Rather, the observations in this study suggest that the small stream is catching most the road salt contamination from the adjacent road, but that a more serious contamination of road salt is infiltrating the wetland through subsurface flow around the depth of the water table. Higher levels of chloride, sodium, and conductivity in the shallow well compared to the deeper well indicate that the introduction of salt comes from shallow flow rather than deeper flow, and that water from deeper sources are diluting the deeper well. While the adjacent road may not be the culprit for the salt contamination of the groundwater, salting practices of the greater area could be.
Based on the observations of this study and comparisons with data from other studies, there are two changes that may be responsible for the decline of bog turtles in the habitat: 1) the water table has receded too far to support the habits of bog turtles and 2) subsurface infiltration of road salt to the fen disturbing the plant community. Changes in the water table of a fen impacts both physical and chemical processes that influence plant species composition (Duval and Waddington, 2011). Lack of saturation at the start of the growing season allows taller upland vegetation to be more competitive than the native sedges. (Duval and Waddington, 2011) Road salt contamination also negatively impacts wetland species composition according to studies by Wilcox (1985) and Richburg et al. (2001). Therefore, both of the changes observed in this study can result in the shift from endemic vegetation that has occurred in the site from the 1980’s to the present day.
Chapter 3

Conclusions and Recommendations for Further Study
This study sought to develop an in-depth characterization of a historic, but not occupied bog turtle site to investigate what hydraulic changes may have negatively impacted the species. A yearlong monitoring program was instituted at the site consisting of both continuous monitoring and periodic onsite measurements. After a year of monitoring, it was determined that 1) a lowering water table and dryer soil; and 2) a subsurface infiltration of salt were the two main hydrologic concerns at the site. In addition to being concerns of their own, they may also disturb the composition of the plant community at the site so that it is no longer favorable for the bog turtle. The change in the surface hydrology has led to a loss of rivulets—a crucial hydrologic feature characteristic of bog turtle sites. Addressing hydrologic degradation is made challenging by the lack of historical data on hydrologic conditions conducive to bog turtle persistence, the lack of a singular culprit for drying (ex. draining ditches), and the necessity to address hydrologic problems and solutions on the scale of the watershed as a whole—not just the most degraded site.

The following suggestions for future research and conservation are made to help improve turtle persistence:

- Establishing regional water elevation and saturation norms of healthy bog turtle sites
- Establishing regional water chemistry norms for healthy bog turtle sites
- Continuing existing efforts to mitigate wetland succession of the remaining habitats
- Focusing primary efforts on upholding hydrologically intact habitats with careful monitoring (soil moisture, groundwater level, etc.) and planning rather than saving habitats with damaged hydrology.
• Observe the use of deicing practices in the surrounding area of bog turtle habitats. While the amount of road salt used in state applications is somewhat regulated, private applications (private businesses, property, parking areas, etc) are not.
References


Capitol Region Council of Governments. (2016) *2016 lidar DEM.*


Feaga, J. B. (2010). Wetland hydrology and soils as components of Virginia bog turtle (Glyptemys muhlenbergii) habitat. Virginia Polytechnic Institute and State University.


Picking, D. J. (2002). VEGETATION PATTERNS AND ASSOCIATED HYDROGEOCHEMICAL CYCLES IN A CALCAREOUS SLOPING FEN OF SOUTHWESTERN MASSACHUSETTS (University of Massachusetts Amherst). https://doi.org/10.16953/deusbed.74839


Table 1. MP20 Measurements – Stream

<table>
<thead>
<tr>
<th>Date</th>
<th>Water Temp (*C)</th>
<th>Specific Conductivity (mS/L)</th>
<th>DO (mg/L)</th>
<th>pH</th>
<th>ORP (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-Oct-17</td>
<td>11.31</td>
<td>0.66</td>
<td>8.08</td>
<td>8.04</td>
<td>-73.00</td>
</tr>
<tr>
<td>17-Nov-17</td>
<td>5.30</td>
<td>0.54</td>
<td>11.37</td>
<td>7.40</td>
<td>39.00</td>
</tr>
<tr>
<td>26-Jan-18</td>
<td>1.09</td>
<td>0.39</td>
<td>11.84</td>
<td>6.82</td>
<td>171.00</td>
</tr>
<tr>
<td>23-Mar-18</td>
<td>3.67</td>
<td>0.56</td>
<td>15.00</td>
<td>7.88</td>
<td>82.00</td>
</tr>
<tr>
<td>27-Apr-18</td>
<td>11.19</td>
<td>0.58</td>
<td>10.59</td>
<td>7.73</td>
<td>20.00</td>
</tr>
<tr>
<td>30-May-18</td>
<td>21.06</td>
<td>0.59</td>
<td>7.76</td>
<td>7.66</td>
<td>33.00</td>
</tr>
<tr>
<td>8-Aug-18</td>
<td>22.30</td>
<td>0.62</td>
<td>5.87</td>
<td>7.20</td>
<td>168.00</td>
</tr>
<tr>
<td>Average</td>
<td>10.85</td>
<td>0.56</td>
<td>10.07</td>
<td>7.53</td>
<td>62.86</td>
</tr>
<tr>
<td>St. Dev</td>
<td>8.30</td>
<td>0.09</td>
<td>3.06</td>
<td>0.42</td>
<td>86.48</td>
</tr>
<tr>
<td>Max</td>
<td>22.30</td>
<td>0.66</td>
<td>15.00</td>
<td>8.04</td>
<td>171.00</td>
</tr>
<tr>
<td>Min</td>
<td>1.09</td>
<td>0.39</td>
<td>5.87</td>
<td>6.82</td>
<td>-73.00</td>
</tr>
<tr>
<td>Range</td>
<td>21.21</td>
<td>0.27</td>
<td>9.13</td>
<td>1.22</td>
<td>244.00</td>
</tr>
</tbody>
</table>

Table 2. MP20 Measurements – Shallow Well

<table>
<thead>
<tr>
<th>Date</th>
<th>Water Temp (*C)</th>
<th>Specific Conductivity (mS/L)</th>
<th>DO (mg/L)</th>
<th>pH</th>
<th>ORP (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-Oct-17</td>
<td>13.90</td>
<td>1.02</td>
<td>2.31</td>
<td>7.41</td>
<td>-182.50</td>
</tr>
<tr>
<td>17-Nov-17</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>26-Jan-18</td>
<td>5.11</td>
<td>0.828</td>
<td>6.64</td>
<td>6.49</td>
<td>82.00</td>
</tr>
<tr>
<td>23-Mar-18</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>27-Apr-18</td>
<td>9.82</td>
<td>0.95</td>
<td>3.22</td>
<td>6.42</td>
<td>-26.67</td>
</tr>
<tr>
<td>30-May-18</td>
<td>16.60</td>
<td>0.92</td>
<td>4.09</td>
<td>7.16</td>
<td>45.00</td>
</tr>
<tr>
<td>8-Aug-18</td>
<td>21.44</td>
<td>1.06</td>
<td>3.26</td>
<td>6.70</td>
<td>48.00</td>
</tr>
<tr>
<td>Average</td>
<td>13.37</td>
<td>0.95</td>
<td>3.90</td>
<td>6.83</td>
<td>-6.83</td>
</tr>
<tr>
<td>St. Dev</td>
<td>6.26</td>
<td>0.09</td>
<td>1.65</td>
<td>0.43</td>
<td>105.87</td>
</tr>
<tr>
<td>Max</td>
<td>21.44</td>
<td>1.06</td>
<td>6.64</td>
<td>7.41</td>
<td>82.00</td>
</tr>
<tr>
<td>Min</td>
<td>5.11</td>
<td>0.82</td>
<td>2.31</td>
<td>6.42</td>
<td>-182.50</td>
</tr>
<tr>
<td>Range</td>
<td>16.33</td>
<td>0.24</td>
<td>4.33</td>
<td>0.99</td>
<td>264.50</td>
</tr>
</tbody>
</table>
Table 3. MP20 Measurements – Deep Well

<table>
<thead>
<tr>
<th>Date</th>
<th>Water Temp (°C)</th>
<th>Specific Conductivity (mS)</th>
<th>DO (mg/L)</th>
<th>pH</th>
<th>ORP (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-Oct-17</td>
<td>14.45</td>
<td>0.95</td>
<td>1.65</td>
<td>7.37</td>
<td>-165.00</td>
</tr>
<tr>
<td>17-Nov-17</td>
<td>7.45</td>
<td>0.78</td>
<td>6.03</td>
<td>6.50</td>
<td>85.00</td>
</tr>
<tr>
<td>26-Jan-18</td>
<td>5.40</td>
<td>0.66</td>
<td>6.48</td>
<td>6.05</td>
<td>-226.00</td>
</tr>
<tr>
<td>23-Mar-18</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>27-Apr-18</td>
<td>9.71</td>
<td>0.47</td>
<td>4.02</td>
<td>6.57</td>
<td>34.30</td>
</tr>
<tr>
<td>30-May-18</td>
<td>14.48</td>
<td>0.89</td>
<td>4.76</td>
<td>7.30</td>
<td>64.00</td>
</tr>
<tr>
<td>8-Aug-18</td>
<td>18.89</td>
<td>0.93</td>
<td>4.69</td>
<td>7.06</td>
<td>16.00</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.73</td>
<td>0.78</td>
<td>3.70</td>
<td>6.81</td>
<td>-31.95</td>
</tr>
<tr>
<td>St. Dev</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.07</td>
<td>0.19</td>
<td>2.18</td>
<td>0.52</td>
<td>130.33</td>
</tr>
<tr>
<td>Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.89</td>
<td>0.95</td>
<td>6.48</td>
<td>7.37</td>
<td>85.00</td>
</tr>
<tr>
<td>Min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.40</td>
<td>0.47</td>
<td>0.60</td>
<td>6.05</td>
<td>-226.00</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.49</td>
<td>0.48</td>
<td>5.88</td>
<td>1.32</td>
<td>311.00</td>
</tr>
</tbody>
</table>
Table 4. Water Chemistry – Stream

<table>
<thead>
<tr>
<th>Date Collected</th>
<th>Metals (µg/L)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Na (mg/L)</td>
<td>Ca (mg/L)</td>
<td>Mg (µg/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/27/2017</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/17/2018</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/26/2018</td>
<td>10.6</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/27/2018</td>
<td>17.06</td>
<td>60.39</td>
<td>30.61</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/1/2019</td>
<td>30.87</td>
<td>27.8</td>
<td>8.226</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Collected</th>
<th>Nutrients (mg/L)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ALK (mg/L)</td>
<td>Cl (mg/L)</td>
<td>TOC (mg/L)</td>
<td>NO3 (mg/L)</td>
<td>NO2 (mg/L)</td>
<td>NOX (mg/L)</td>
<td>OrthoP (mg/L)</td>
<td></td>
</tr>
<tr>
<td>10/27/2017</td>
<td>286</td>
<td>40</td>
<td>4.8</td>
<td>0.058</td>
<td>ND</td>
<td>0.058</td>
<td>0.011</td>
<td></td>
</tr>
<tr>
<td>11/17/2018</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>1/26/2018</td>
<td>n/a</td>
<td>24.1</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>4/27/2018</td>
<td>246</td>
<td>38.3</td>
<td>3.8</td>
<td>0.151</td>
<td>0.008</td>
<td>0.159</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>8/1/2019</td>
<td>245</td>
<td>n/a</td>
<td>6.4</td>
<td>0.077</td>
<td>0.004</td>
<td>0.081</td>
<td>0.013</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Collected</th>
<th>Organics ng/mL</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dicamba</td>
<td>2,4-D</td>
<td>triclopyr</td>
<td>triclopyr butoxyethyl ester</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/27/2017</td>
<td>0.092</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/17/2018</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/26/2018</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/27/2018</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/1/2019</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reporting Limit</td>
<td>0.036</td>
<td>0.01</td>
<td>0.15</td>
<td>0.125</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 5. Water Chemistry – Shallow Well

<table>
<thead>
<tr>
<th>Date Collected</th>
<th>Na (mg/L)</th>
<th>Ca (mg/L)</th>
<th>Mg (mg/L)</th>
<th>Metals (μg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/27/2017</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>11/17/2018</td>
<td>137.8</td>
<td>72.55</td>
<td>31.35</td>
<td></td>
</tr>
<tr>
<td>1/26/2018</td>
<td>44.5</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>4/27/2018</td>
<td>42.88</td>
<td>86.42</td>
<td>40.81</td>
<td></td>
</tr>
<tr>
<td>8/1/2019</td>
<td>50.8</td>
<td>106.2</td>
<td>48.09</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Collected</th>
<th>ALK (mg/L)</th>
<th>Cl (mg/L)</th>
<th>TOC (mg/L)</th>
<th>NO3 (mg/L)</th>
<th>NO2 (mg/L)</th>
<th>NOX (mg/L)</th>
<th>OrthoP (mg/L)</th>
<th>Nutrients (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/27/2017</td>
<td>354</td>
<td>108.8</td>
<td>1.8</td>
<td>ND</td>
<td>0.013</td>
<td>ND</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>11/17/2018</td>
<td>276</td>
<td>76.5</td>
<td>0.026</td>
<td>0.003</td>
<td>0.029</td>
<td>0.007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/26/2018</td>
<td>n/a</td>
<td>80.2</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>4/27/2018</td>
<td>299</td>
<td>113.9</td>
<td>0.094</td>
<td>0.865</td>
<td>0.003</td>
<td>0.868</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>8/1/2019</td>
<td>359</td>
<td>n/a</td>
<td>2.4</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>0.004</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Collected</th>
<th>dicamba</th>
<th>2,4-D</th>
<th>triclopyr</th>
<th>triclopyr butoxyethyl ester</th>
<th>Organics ng/mL</th>
<th>Reporting Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/27/2017</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>0.036</td>
</tr>
<tr>
<td>11/17/2018</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>0.01</td>
</tr>
<tr>
<td>1/26/2018</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>0.15</td>
</tr>
<tr>
<td>4/27/2018</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>0.125</td>
</tr>
<tr>
<td>8/1/2019</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
</tr>
</tbody>
</table>
Table 6. Water Chemistry – Deep Well

<table>
<thead>
<tr>
<th>Date Collected</th>
<th>Metals (μg/L)</th>
<th>Nutrients (mg/L)</th>
<th>Organics ng/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Na (mg/L)</td>
<td>Ca (mg/L)</td>
<td>Mg (mg/L)</td>
</tr>
<tr>
<td>11/17/2018</td>
<td>31.35</td>
<td>137.8</td>
<td>72.55</td>
</tr>
<tr>
<td>1/26/2018</td>
<td>29.6</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>4/27/2018</td>
<td>34.89</td>
<td>79.27</td>
<td>42.6</td>
</tr>
<tr>
<td>8/1/2019</td>
<td>45.03</td>
<td>292.9</td>
<td>162.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Collected</th>
<th>dicamba</th>
<th>2,4-D</th>
<th>triclopyr</th>
<th>triclopyr butoxyethyl ester</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/17/2018</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>1/26/2018</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>4/27/2018</td>
<td>nd</td>
<td>0.04</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>8/1/2019</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
</tbody>
</table>

Reporting Limit: 0.036, 0.01, 0.15, 0.125
Figure 1. Bedrock geology of the study site (DEEP, 1985).
Figure 2. Quaternary Geology of the study site (USGS, 2005).
Figure 3. Soil boring log and well construction of the deep well.
Figure 4. Soil drainage classification of the site (USDA, NRCS, 2009).
Figure 5. Soil series within the study site (USDA, NRCS, 2007).
Figure 6. Elevation map of the study area and estimated watershed area of the fen (CRCOG 2016).
Figure 7. Plant Community of the study site in 2013 (DEEP, 2013)
Figure 8. Comparison photos of the study site. Top image shows the site in the summer of 2018, bottom image shows the site in the spring of 1983. Bottom image provided by The Nature Conservancy in Connecticut (1983).
Figure 9. 2016 Orthophotography of the site (CRCOG, 2016).
Figure 10. Discharge rating curve of the stream based on in-situ measurements, used to calculate flow based on continuous measurements of stream gauge.
Figure 11. Daily rainfall and water level from ground surface of the shallow and deep wells.
Figure 12. Daily rainfall and stream height.
Figure 13. Daily rainfall and stream discharge. Top graph displays full range of discharge, bottom graph shows discharge truncated to 0.5 m³/s.
Figure 14. Daily rainfall and floodplain hydraulic head.
Figure 15. Soil moisture and soil temperature.
Figure 16. Daily rainfall and specific conductivity of the stream.
Figure 17. Daily rainfall and the bulk conductivity measured by the deep and shallow soil moisture probes.