B. Endangered, Threatened, and Rare Species

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EFFECTS OF ROADS ON BULL TROUT (SALVELINUS CONFLUENTUS),
A FEDERALLY THREATENED SPECIES

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Abstract
The bull trout (Salvelinus confluentus) is federally listed as threatened under the Endangered Species Act. Bull trout are apex predators requiring a large prey base and a large home range, and are known to move throughout and between basins in search of prey. However, bull trout are dependent upon very cold, clean waters for spawning (below 9 degrees Celsius) and are typically characterized as spawning in the upper-most reaches of watersheds. Bull trout have four life history forms: resident, fluvial, adfluvial, and in Puget Sound, anadromous. As a result of their varied life histories, bull trout are found in a wide range of habitats.

Dunham and Rieman (1999) found a negative relationship between bull trout occurrence and road density. Direct impacts from roads that can adversely affect bull trout include: increased human access and associated exposure to poaching, angling mortality, and introductions of non-native fish; blocks to passage; erosion and sedimentation; construction disturbance; increased stormwater run-off; and stream channel instability and habitat degradation. Additionally, there are various indirect effects of roads that negatively impact bull trout. These relate to land-use changes stemming from road extension, widening, and other road improvements and upgrades.

We have drawn from the literature and from in-house endangered species expertise to compile a summary and discussion of basic bull trout biology, and how roads affect their various life history forms and habitat requirements. Endangered species biologists use this information when conducting consultations under the Endangered Species Act, and when participating in planning processes for large-scale transportation projects under NEPA. It is important that both transportation specialists and endangered species biologists understand how projects can negatively impact bull trout in order to more effectively minimize the potential adverse effects of projects on the species.
ENVIRONMENTAL CONSIDERATIONS FOR CONSTRUCTION OF BRIDGES AND PROTECTED FRESHWATER MUSSEL SPECIES, A CASE STUDY

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Abstract: The Kennerdell Bridge is located within the Allegheny River National Wild and Scenic River Corridor, approximately 50 miles north of Pittsburgh. The former bridge was identified as being in fair-to-poor condition, with the original main truss spans exhibiting the most serious deterioration. Several bridge replacement options were developed during informal consultation with the United States Fish and Wildlife Service (USFWS) due to the known occurrence of two federally endangered freshwater mussel (Unionidae) species, the clubshell (Pleurobema clava) and the northern riffleshell (Epioblasma torulosa rangiana). The selected option involved the replacement of the former bridge, with the reuse of the existing river piers.

Field surveys of the proposed project area identified a diverse mussel population, including the listed species, around the bridge. The results of the field survey triggered formal Endangered Species Act (ESA) Section (7) consultation with the USFWS, and the development of a biological assessment. The required assessment included a construction/demolition options evaluation, hydraulic and hydrologic analyses, and development and implementation of a mussel relocation program as one mitigation measure to ameliorate impacts to the species.

Overall, 15,737 mussels representing 17 species were recovered and relocated. A total of 529 federally endangered northern riffleshell (Epioblasma torulosa rangiana) and 41 clubshell (Pleurobema clava) mussels were relocated from the primary impact area of the Kennerdell Bridge construction site. A follow-up one-month monitoring of one relocation site indicated good health of the relocated mussels and mortality rates consistent with undisturbed mussel populations. The success of the relocated mussels will be monitored and evaluated by the Biological Resource Division (BRD) of the United States Geological Survey (USGS) for five years.

Introduction
Freshwater mussels (Phylum Mollusca, Class Bivalvia) of the Family Unionidae are commonly known as pearly mussels, bivalves, mussels, naiads, or unionids. About 1,000 species have been identified worldwide, and approximately 297 freshwater mussel species and subspecies occur in the United States. In fact, the continental United States has the world's most diverse mussel fauna, and in the last 100 years, this fauna has suffered a greater decline than any other wide-ranging faunal group. No other widespread group of animals in North America approaches this level of collapse. Nationwide, some mussel species have been reduced to so few and such a small population that the remaining populations are highly vulnerable to extirpation or extinction from random events such as natural disasters or chemical spills.

Mussels are extremely important to freshwater communities as primary consumers and the decline of mussel abundance or the disappearance of mussels from a river or lake may be an indication of deteriorating water and environmental qualities. The presence and abundance or absence of mussels in a historical range usually reflects habitat quality in a watershed. The durability of the shells allows identification habitat once occupied by a species since extirpated, and in some instances the shell material made by the living organism can hold trace elements indicative of the changing water quality.

Mussels are excellent biological indicators of habitat quality in part because of their key position in energy cycling. Mussels, being filter feeders, are directly and immediately affected by their environment and act as important conduits of energy fixed by photosynthesis in phytoplankton to higher trophic levels in the ecosystem. By filtering contaminants, sediments, and nutrients from the water column, mussels help maintain water quality and may also be significant aquatic decomposers.

The decline of mussels is attributed to habitat loss and degradation; pollution, including agricultural run-off that contains nutrients and pesticides; siltation; stream bank erosion and floodplain development; toxic spills; dam construction; dredge, fill, and other channel modifications; heavily used river fords; population isolation;
mining of minerals in watersheds; poaching; and most recently, the introduction of the exotic zebra mussel (
*Dreissena polymorpha*) that outcompetes native mussels for food and habitat.

Most freshwater mussels in the United States occur east of the Rocky Mountains and the greatest diversity of freshwater mussels occurs in the eastern United States. The Upper Mississippi drainage is recognized as supporting a rich mussel community that has been described by biologists as a world-class assemblage. The Ohio River basin supports nearly 127 of the 297 North American species. Regions of endemism and species richness are primarily in the Ohio, Tennessee, Cumberland, and Mobile drainages and other rivers that drain to the Gulf of Mexico and South Atlantic.

North American freshwater mussels have an extraordinary life history and reproductive adaptations. Most have larvae (glochidia) that must attach and encyst, generally on the gills or fins, of specific hosts to complete their life cycle. The glochidia of all unionids, except the salamander mussel (*Simpsonaias ambigua*), use fishes as hosts. Without the proper fish host, the glochidia die. It is this host-fish relation that makes the life cycle of mussels so unique, interesting, and perhaps fragile.

Host fishes have been identified with various degrees of certainty for 33 of 49 genera and for more than 65 species of mussels. Host-specificity is particularly evident among the short-term brooders that release glochidia or conglutinates in summer. Despite the tremendous fecundity of females, few glochidia come into contact with suitable hosts during this critical stage in the life cycle.

To increase the probability of contact by glochidia with the proper fish host, unionids display several adaptations. For example, although glochidial release occurs once a year, the duration of the release is species dependent. Tachytictic mussels (summer brooders) are short-term breeders, whose glochidial development and release take place between April and August, which often corresponds with either migratory periods of anadromous fish hosts or the reproductive and nesting periods of host fish species.

Most bradytictic species (winter breeders) retain the developing glochidia in gill marsupia throughout the year and release them in late spring and early summer. When the glochidia are shed from adult mussels, they are generally bound together by mucus into small packets, which either break apart or are maintained intact as conglutinates of various species-specific colors and forms. Often, the threads of conglutinates are suspended in the water and resemble the food items of their fish hosts. The movement such as waving in the current attracts a fish host. When the fish consumes the conglutinate, it releases the glochidia inside the fish where they can be carried directly to the fish gills by respiratory currents.

The primary advantage of the host fish relation is upstream dispersement of the glochidia into favorable habitats and attainment of energy resources to complete the development from the glochidial stage to the settled juvenile. Although host fish transport increases the probability of dispersal into favorable habitats, it limits the extent of dispersal to that of the host fish, leading to development of highly endemic species. Barriers to fish dispersal, such as dams, are also barriers to unionid dispersal. Most species prefer habitats of less than 4-10m in depth.

Adult mussel survivorship is high, and many species tend to be long-lived. Extended life spans, maturity, low effective fecundity, reduced powers of dispersal, high habitat selectivity, poor juvenile survival, and very long turnover times make freshwater mussels highly susceptible to human disturbances.

**Project Location**  
The Kennerdell Bridge is located within the Allegheny River National Wild and Scenic River Corridor in Venango County, Pennsylvania, approximately 50 miles north of Pittsburgh. Based on a Condition Survey Report prepared for Penn DOT District 1-0, the former bridge was identified as being in fair to poor condition, with the original main truss spans exhibiting the most serious deterioration. Several bridge replacement options were developed during informal consultation with the USFWS due to the known occurrence of two federally endangered freshwater mussel (*Unionidae*) species, the clubshell (*Pleurobema clava*) and the northern riftleshell (*Epioblasma torulosa rangiana*). The selected option involved the replacement of the former bridge, with the reuse of the existing river piers.
Field surveys of the project area identified a diverse mussel population, including the listed species, around the bridge. The results of the field survey triggered formal ESA Section (7) consultation with the USFWS, and the development of a biological assessment. The required assessment included a construction/demolition options evaluation, hydraulic and hydrologic analyses, and development and implementation of a mussel relocation program as one mitigation measure to help ameliorate impacts to the species.

Funding for the Kennerdell Bridge project consisted of 80% federal funds and 20% state funds. This was consistent for all phases of the project: preliminary design and environmental clearance, final design and construction. The initial construction contract was awarded on February 23, 1999, and notice-to-proceed was issued on March 15, 1999. However, physical construction of the project did not begin until April 3, 2000 due to structural steel back-orders and insufficient fabricating capacity of the regional fabricating companies. The new structure was re-opened to traffic on 11/17/00.

Demolition and Construction
From the planning standpoint, the preferred alternative—replacement of the bridge using the existing river piers—caused little concern with the resource agencies relative to the impacts to mussels. This alternative caused minimal new disturbance to the river environment, and had no additional chronic effects, such as contaminated storm water runoff and shading impacts, as compared to the original bridge. A new alignment would require two causeways, one for demolition of the old bridge and one for construction of the new bridge, and have new long-term secondary and cumulative impacts. The focus of the USFWS was the disturbance created by the demolition and construction methodology at the existing bridge site.

The feasibility of alternate construction/demolition methodologies that avoided impacts to mussels was considered. Engineering constraints and unreasonable costs prohibited the use of construction options involving top-down demolition/construction. Demolition involving disassembly of the bridge spans and piecemeal removal from the top was not possible. The simply supported through-truss bridge spans would become unstable at some point and collapse under their own weight.

Lifting the individual truss spans in one piece during the demolition work would require two stationary cranes because of the 80 to 85 meter span lengths. A causeway would be needed for removal of the lowered spans. The need for a temporary causeway regardless of the demolition and construction method negated the idea of top-down demolition and construction. The selected demolition option was controlled detonation of the spans and removal of the debris from the river by a temporary work causeway. The area under the bridge was included in the direct mussel impact area.

For construction options, the preferred bridge structure consisted of continuous steel plate girders joined onsite to reach the required span lengths. Delivery of long span materials such as prestressed concrete girders was considered problematic due to the local terrain and rural roads to the site. Two construction options, top down construction involving tower cranes or the use of cantilevered concrete segmental bridge construction, could not be used in conjunction with the existing stone piers without strengthening the foundations or building temporary work causeways for the construction of additional support piers. No advantage would be gained with these construction methods.

The apparent need for a temporary work causeway demanded an analysis of potential options that minimized the causeway interface with the riverbed. These construction concepts included variations that used barges, half-pipes, and partial-width causeways. Barge options were found to be infeasible due to the contact points between the floating barges and the causeway fill. Variations in the water stage elevation would require continuous reworking of the contact point between the moored barge construction platforms and the causeway to provide an even grade for beam delivery and safe construction access, potentially delaying construction.

In addition, pontoon barges have a maximum draft of 4 feet when loaded. Barges resting on the bottom would create an unstable and unsafe work platform and impact shallow water areas of the project. Also, barges would be required to be certified free of zebra mussels. This condition required that watercraft used for construction either had to prove that they came from areas free of zebra mussel infestation, or be thoroughly decontaminated according to procedures outlined by the USFWS.
The use of half pipes set on the riverbed would decrease the impact interface by creating a series of arches over the bottom sediments. However, the amount of fill needed to achieve ring compression for half pipes would be higher than that required for full pipes. The height of fill would increase the area covered by this type of causeway and would increase the impact area. The additional height of the fill would also create hydrologic design issues, since typical causeway designs allow high flows to pass over the causeway. The analysis also indicated that increased scour would impact the riverbed within the pipe area negating the benefits of the half-pipe concept.

Partial-width causeways of various configurations were investigated to minimize the footprint of the impact to the riverbed, and the hydraulic interaction with the river while providing the necessary accessibility for construction equipment. The preferred alternative was a combination of partial-width causeways accessible by temporary bridges. Causeway fill sections were underlain with large diameter full pipes to achieve linear stream flow and minimize stagnant pooling water. The selected option allowed construction equipment full access to the existing bridge for demolition and construction, and minimized direct and secondary disturbances to the riverbed.

**Hydrologic and Hydraulic Analysis**

Numerous designs for temporary work causeways were analyzed in an effort to minimize potential secondary impacts to prime mussel habitat. Reducing the hydrologic interaction of the causeway with the river, and reducing the hydraulic effect to adjacent mussel habitat areas was the main focus of the study. Various construction concepts that minimized contact with the riverbed were studied including the use of barges, half-pipe causeways, partial-width causeways, temporary bridges, and various combinations of these alternatives.

Minimizing the effects of sedimentation and maintaining stream flow over the broadest possible area was of prime importance. The potential for slack water upstream of the project area due to a full width causeway was a key factor in the selection of the preferred causeway layout. The analysis showed that some causeway designs had effects up to 600 meters upstream. This was particularly apparent during the seasonal low stage months of August and September, and increased the potential that reduced current velocities and low dissolved oxygen in the water column upstream of the causeway would adversely affect mussel filter feeding and potentially increase the mussel impact zone. The inclusion of pipes through the causeway fill pads and bridges between partial width causeways helped to minimize these tail water effects by maintaining at least a minimum flow across the river.

Overtopping of the causeway by floodwaters was also a consideration. A scour analysis was conducted on the various designs to determine the amount of scour that would occur at various river stages, and the potential locations of sediment deposition due to the scour. This analysis revealed that water velocities capable of transporting sediments in the coarse sands to fine gravels range had a 75% chance of being exceeded in any given year. This flow rate had occurred nearly every year for the past 23 years. Bottom sediments are significantly reworked during the yearly flood cycle. The implications were the existing mussel population was adapted to and had survived these scour conditions. Any sedimentation effects to adjacent mussel habitat due to the construction would be short-term, and the physical condition of nearby mussel habitat was expected to return to normal conditions following a seasonal flood cycle.

**Mussel Relocation**

Temporal considerations for the relocation of mussels and causeway construction required coordination with task scheduling. The seasonal changes in the river stage and winter weather conditions demanded that construction be completed within one summer season. Winter river stage elevations would overtop the construction causeway and potentially cause flooding and downstream sedimentation. This would delay construction and potentially cause damage to adjacent mussel habitat. Relocation of freshwater mussels is also recommended during more seasonal weather. Stresses from both heat and cold should be avoided during any relocation effort to minimize unnecessary stress and potential mortality. Lower metabolic functions during colder weather can result in lower survival of mussels at relocation sites due to the inactivity and inability of the mussels to adjust to changed conditions. Cold conditions are also difficult for divers to work in and can result in lower mussel recovery.
Overall, 15,737 mussels representing 17 species were recovered and relocated. A total of 529 federally endangered northern riffleshell mussels (Epioblasma torulosa rangiana) and 41 clubshell mussels (Pleurobema clava) were relocated from the 5,346 square meter primary impact area of the Kennerdell Bridge construction site. The northern riffleshell was found to be the fifth most abundant mussel at the site occurring in 40% of the relocation grid cells. A total of 69 juveniles were among those relocated indicative of reproduction of this species in the area. The greatest density and number of northern riffleshell was found in mid-river areas (1.5-2.1 meter), stressing the importance of assessment surveys that cover all depths and habitats. Clubshell mussels were almost always found in habitat that included organic matter, silty sand, muddy substrates in relatively shallow water (less than 1 meter) and slow current velocities.

The overall abundance of mussels at the Kennerdell Bridge relocation site was 2.9 mussels per square meter; significantly lower than the 9.8 mussels per square meter that was anticipated based on previous mussel surveys conducted in the area. Substrate variability and stream flow effects due to the bridge piers at the site probably account for the discrepancy. It was estimated from quality assurance sampling that a 95 percent recovery rate was achieved at the relocation site. This exceeded the USFWS stated goal in the biological opinion by 25 percent.

A follow-up one-month monitoring of one translocation site indicated good health of the relocated mussels and mortality rates consistent with undisturbed mussel populations. The success of the relocated mussels will be monitored and evaluated by the Biological Resource Division (BRD) of the United States Geological Survey (USGS) for five years.

Biographical Sketch: David Reutter, A.I.C.P., Senior Ecologist, has been active within the environmental community for the past 16 years involving environmental issues related to infrastructure development throughout the eastern seaboard, the mid-west, and the Caribbean. Primarily concerned with restoration ecology, mitigation design, NEPA documentation, environmental permitting and assessments, David is well versed in all aspects of biotic community interactions, functional assessments, and the myriad levels of federal and state regulatory processes regarding environmental issues.

For the past nine years with Parsons Brinckerhoff, David has been involved with the documentation and environmental assessment of regional highway systems, airport facilities, signature bridges, and telecommunication facilities requiring federal funding and state or local approval. He has facilitated environmental permitting at the federal, state, and local levels for both private and public entities.

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Abstract: Protecting the natural environment while fostering local development is one of the main challenges that engineers face today. New species are added to the federally threatened and endangered species lists as their habitats are altered or destroyed by development. The bog turtle ( Clemmys muhlenbergii ) is threatened by new development that damages not only its wetland habitat, but the upland areas that store and discharge water into the wetlands. The bog turtle is one of the smallest North American turtles with the adults reaching only 10 to 11 centimeters in length. They are a fresh water turtle that inhabits open wet meadows, shallow water marshes, spring seeps, flood plain wetlands, bogs, and fens. Destruction of habitat and illegal capture have caused significant declines in turtle populations. The bog turtle was listed as federally threatened in 1997. Protection of bog turtle habitat is a concern to many state and local governments because the bog turtle’s habitat is often located in prime land slated for commercial, residential, and transportation related development. Until recently, there was little information available about the source water that feeds these wetland habitats. The Maryland State Highway Administration (MDSHA), in conjunction with other Maryland and federal agencies, has formed a biological assessment team in order to develop a protection plan for one such bog turtle habitat by investigating the hydrology associated with bog turtle habitats.

The hydrologic assessment conducted by Parsons Brinckerhoff and the MDSHA had five primary components: 1) field monitoring; 2) surface water modeling; 3) groundwater modeling; 4) evaluation of hydrologic impacts of proposed development scenarios; and 5) recommendations to minimize the impacts of development on the wetlands and to maintain the hydrology of the bog turtle wetlands.

Although there has been much recent research on the habitat, genetics, and movements of bog turtles, this is the first large scale study of the hydrology of the bog turtle habitat. An extensive field monitoring network has been installed throughout the 1.9 km² watershed, including 15 mechanically dug monitoring wells (approximately 15 meters deep), 42 shallow, hand-dug piezometers (1.2 to 2.8 meters deep), six streamflow gages with low flow weirs, two precipitation gages, and an evaporation pan. The field data were used to set up and calibrate the groundwater and surface water flow models. Low flow weirs constructed at a series of gaging stations allowed the computation of both baseflow and stormflow conditions. Although the surface and groundwater modeling of the wetland habitat is complete, field monitoring at the site will be ongoing until after the completion of the proposed highway bypass.

The bog turtle habitats within the project area are predominately groundwater fed. Although the proposed highway bypass and associated development does not directly contact the bog turtle wetlands, the secondary and cumulative impacts resulting from the loss of groundwater recharge do. The hydrologic impacts on the bog turtle wetlands were determined for three proposed development scenarios. The first scenario analyzed was the construction of the highway bypass only. The roadway construction with proper stormwater management was determined to have a minimal effect on the hydrology of the bog turtle wetlands. The MDSHA was considering the construction of a flyover ramp in order to provide access from the proposed bypass to a proposed industrial park in trade for right-of-way donation. Thus, MDSHA had to consider the secondary and cumulative impacts of the industrial park development on the sensitive bog turtle wetlands. The second scenario was the industrial development located east of the proposed bypass and the third scenario was the industrial development located both east and west of the proposed bypass and near the sensitive wetlands. Groundwater and surface water models were developed for each modeling scenario. The results of the groundwater and surface water modeling showed that construction of the proposed industrial park may be potentially harmful to the sensitive wetland habitats.

The results of the hydrologic modeling were used in conjunction with the results of a separate biological study of the bog turtle to develop an impact mitigation plan. One of the primary components of the mitigation plan was identification of the Zone of Primary Hydrologic Influence. Land use changes within this zone have the potential to cause detrimental impacts to the bog turtle wetlands. Thus, special measures are needed in order to protect the sensitive wetland habitat. Recommendations regarding suggested recharge rates and stormwater management practices within this zone were made to minimize the hydrologic impacts to the bog turtle habitat.

The information gained in this study will be used as input to develop the first major bog turtle preserve in the state of Maryland. It is hoped that the information will also be valuable to other states who are facing similar declines in their bog turtle or other hydrologically sensitive habitats and populations.
Introduction

As part of the biological assessment effort, Parsons Brinckerhoff was commissioned by the Maryland State Highway Administration (MDSHA) to compute a hydrologic analysis of several bog turtle habitats that may be impacted by a proposed highway bypass and commercial/industrial development. Because Maryland is the home to numerous bog turtle wetlands, this study is likely to serve as a model for future studies in determining the hydrological impacts of development on bog turtle wetlands. This project is unique because it provides local planners and regulatory officials with a scientific model that is able to show the impacts that upland development can have on bog turtle wetlands. Although a limited number of modeling scenarios were examined for this study, future land use proposals can be analyzed as they become available.

Bog Turtle Background

Bog turtles are a freshwater species that inhabit shallow spring-fed fens, sphagnum bogs, swamps, open wet meadows, spring seeps, open canopies, pastures that have soft, muddy bottoms, and clear, cool, slow-flowing water often forming a network of rivulets (Shiels 1998, USFWS 1997, Howard 1999). Their habitat is widely scattered across the eastern United States from northern Georgia through the lower New England States. A study by the Maryland Department of Natural Resources (Smith 1994) suggested that there was a 43% decline in bog turtle populations over a fifteen-year period, and recommended that the bog turtle population be listed as threatened by the state of Maryland. Several other states along the East Coast were reporting similar findings (Howard 1999). Therefore, in November 1997, the northern populations of the bog turtle were listed as federally threatened.

Loss of habitat is one of the primary reason for declines in the bog turtle populations in recent years. Land development; draining and filling of wetlands for agricultural, commercial, and residential use; pollution; and other poor land-use practices have all contributed to the decline of turtle populations. At one time, most bog turtle habitats were connected by waterways and wetlands, which allowed individuals in adjoining populations to mingle and maintain the genetic diversity of the species. Bog turtles prefer to live in “early successional” open meadows and fields with open canopies. As open-canopy wetlands are slowly invaded by woody vegetation, they undergo a transition and become closed-canopy, woody swamplands that are unsuitable for habitation by the bog turtle. Historically, as succession occurred, the turtles would move on to other open-canopy wetlands within the adjacent area (NJ FG 2000). However, due to increasing development, the areas in which turtles can migrate have become extremely fragmented.

Site Description

PB examined two primary bog turtle sites in this analysis. Each site is located near perennial streams and numerous groundwater seeps and springs. Bog turtles burrow into the soft, mucky wetland substrate up to 60 cm below the ground surface. The wetlands in this study experience year-round artesian conditions. The artesian conditions create a “quick” mud condition allowing the turtles to easily burrow into the ground. The continuous groundwater flow into the wetland helps to maintain a relatively constant wetland temperature.

Site #1 is located in the northern portion of the study area close to agricultural farmland and a residential subdivision. It contains one bog turtle wetland and is comprised of 10% wetlands and 9% impervious area such as roads and buildings. The contributing watershed area is 0.2 km². A small stream runs directly through Site #1.

Site #2 contains two prime bog turtle habitats (#2a and #2b) and is currently agricultural and forested lands. It is comprised of 4% wetlands and 3% impervious area with a contributing watershed area of 1.5 km². Site #2 contains three streams that join just downstream of the bog turtle habitat #2b (Figure 1).
Fig. 1: Field monitoring network

None of the streams run directly into either bog turtle habitat. Local developers want to convert the current agricultural and forested lands into an industrial park. Because the bypass may include a fly-over ramp that will provide access for the industrial park to the new roadway, the impacts of the industrial park must be included as a secondary and cumulative impact of the roadway.
Project Objectives
The main focus of the overall study was to determine the primary hydrologic sources to the bog turtle wetlands. An extensive field monitoring network was established throughout the study area to provide baseline hydrologic data. Preliminary field data was used to develop conceptual surface and groundwater models of the bog turtle habitats and surrounding areas. The final field monitoring data produced annual values of precipitation, evapotranspiration, recharge, runoff, and baseflow for each of the sub-watersheds. These data was used as inputs to develop existing condition surface and groundwater models. The results of the surface water modeling and field data collection were used as inputs into the groundwater modeling portion of this research. The existing conditions models were modified to incorporate changes caused by the three proposed development scenarios: 1) construction of a highway bypass; 2) construction of a highway bypass and an industrial park in the eastern portion of Site #2; and 3) construction of a highway bypass and an industrial park covering the majority of Site #2.

Field Network
Field monitoring began in May 1999, and continued through late October 2000. The primary objective of the field monitoring was to establish baseline data regarding both surface and groundwater flows in the subject watershed. Fifteen mechanically dug monitoring wells (approximately 15 to 30 meters deep) were installed throughout both project sites. Forty-two shallow, hand-dug piezometers (approximately 1 to 3 meters deep) were nested in and around the sensitive wetlands. Six streamflow gages and low-flow weirs were constructed on the major tributaries at each of the habitat sites. An evaporation pan was located at each site. Two precipitation gages were also located within the study area. Figure 1 shows the locations of the field monitoring devices within the study area.

Site #2 was given the highest priority due to the quality of the wetland, number of bog turtles found at this location, the proximity of the highway bypass, and the potential development of the upland areas into an industrial park. Additional soils testing and water sampling were also performed at this location. Site #1 is similar to Site #2 in that it has a quality bog turtle habitat and is in close proximity to the proposed bypass. However, the contributing watershed of Site #1 is considerably smaller than Site #2.

The deep wells, streamflow gages, and precipitation gages were continuously monitored at fifteen-minute intervals. The piezometer water levels were read on a weekly basis and after major precipitation events. Evaporation pan water levels were measured on a daily basis. A database was created to store all of the hydrologic data for future use.

Hydrologic Inputs
The bog turtle habitats in this study receive their primary water supply from groundwater sources and secondary supply from surface water sources. Although Site #1 has a small stream running directly through the wetland, this stream dries out periodically throughout the year. Site #2 does not have any streams running directly through it. Field observations during the first summer of field monitoring confirmed that groundwater discharges were vital to wetland survival. In 1999, Maryland experienced one of its worst droughts of the century and although the amount of surface water and precipitation supplied to the wetlands dramatically decreased, the wetlands never completely dried up. The drought of 1999 was the third dry year in a row for Maryland, and caused dramatic decreases throughout the region in available water supply in both reservoirs and from groundwater. Because the first year's monitoring demonstrated the importance of groundwater in maintaining the bog turtle wetlands, a detailed groundwater model was developed in order to more accurately simulate the impacts of development on the local wetlands.

Surface Water Modeling
Surface water modeling and calibration was performed based on streamflows measured at the streamflow gages. Baseflow and runoff values obtained at each of the gages were used in the calibration of the groundwater model. The surface water field monitoring network consisted of six weirs and continuously recording water level gages. After defining the existing hydrologic conditions of the study area, runoff estimates were developed for each of the proposed development scenarios. Runoff estimates were developed and distributed using NRCS (1986) methods as a foundation in accordance with standard Maryland procedures.
Surface Water Measurements
At each gage, water surface elevation measurements were continuously recorded at fifteen-minute intervals. Applying the appropriate weir equation to the flow depth results in the determination of a flow rate in the channel at that time. From the discrete flow rate, the flow volumes over the weirs are determined. This flow volume from each gaged basin is transformed into runoff depth over the contributing watershed for the period of the study with weirs in place (April 2000 - October 2000). Two of the flow monitoring gages were in place for the duration of the study, however weirs were not in place at the beginning of the project (May 1999 - March 2000). For this time frame, flow rates were determined from channel rating curves developed in HEC-RAS (v.2.2) based on the measured channel geometry. Knowledge of the flow volumes in these streams allowed for the estimation of the flow volumes at the other gages prior to the construction of their flow gages. The estimated yearly runoff for each gage is summarized in Table 1.

Distribution of Runoff Volume
The groundwater model allows for spatial distribution of runoff values. Therefore, an annual runoff volume for each land-use category within each sub-basin was determined by distributing the measured runoff. This was accomplished by assuming all rainfall becomes runoff for impervious areas. The remaining runoff volume is distributed over pervious areas based on a weighting of the curve number for each land use.

Proposed Condition Surface Water Modeling
Three proposed conditions were considered in this analysis: 1) construction of highway bypass only; 2) construction of highway bypass and an industrial park east of the Site #2 wetlands; and 3) construction of highway bypass and an industrial park both east and west of the Site #2 wetlands. All alternatives were analyzed without the benefit of stormwater management. This assumption was made in order to model the worst case scenario. Innovative stormwater management techniques may reduce the impacts of the proposed development. The annual runoff generated from each proposed land use was estimated in a similar fashion as used for the existing conditions. For all impervious land areas, all rainfall is assumed to become runoff. The runoff from the remaining pervious areas was determined based on a weighting of the land-use curve number compared to the existing conditions for each basin. Table 1 shows the estimated increase in runoff volume due to the development of Sites #1 and #2. The runoff volumes presented here are used in the groundwater model to estimate the potential groundwater recharge.

<table>
<thead>
<tr>
<th>Site</th>
<th>Avg. Existing condition runoff (in/yr)</th>
<th>Bypass Only Runoff (in/yr)</th>
<th>Percent Increase Over Existing Conditions (%)</th>
<th>Bypass &amp; Half Industrial Park Development Runoff (in/yr)</th>
<th>Percent Increase Over Existing Conditions (%)</th>
<th>Bypass &amp; Full Industrial Park Development Runoff (in/yr)</th>
<th>Percent Increase Over Existing Conditions (%)</th>
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<td>28.2</td>
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Groundwater Modeling
Because groundwater sources play such an integral role in the bog turtle habitat hydrology, groundwater modeling was conducted with the modular finite-difference groundwater flow model (MODFLOW). MODFLOW was developed by the USGS to simulate common features in groundwater systems (McDonald and Harbaugh 1988; Harbaugh and McDonald 1996). MODFLOW can be used to model multi-layer, saturated, steady-state, or transient groundwater flow systems. It is one of the most widely used groundwater modeling programs in the world. Visual MODFLOW (Waterloo Hydrogeologic, v 2.8.2.49) was used to set up and analyze the MODFLOW data sets.
Conceptual Groundwater Model
The study area is located in the Eastern Piedmont province in Central Maryland where groundwater occurs chiefly in fractures in crystalline metamorphic rocks such as schist and phyllite. The area is comprised of two active flow layers representing the topsoil/saprolite and weathered/fractured rock conditions. Although the layer below the weathered/fractured rock zone is not completely impermeable, it is assumed to be a no-flow boundary because the hydraulic conductivities and permeabilities are significantly lower than the adjacent layer.

A decision was made to create one groundwater model to encompass all three bog turtle habitat sites. In the study area, it is typical for the groundwater divides to closely follow the surface water divides (Devilbiss 2000). Figure 1 shows the groundwater modeling area. Ridge lines along the southern and eastern boundaries were taken as no-flow boundaries in the groundwater model. The river that runs west of the three habitats makes the third model boundary.

Groundwater Model Grid Design
The land surface within the model boundaries is relatively steep. The maximum model relief is 282.4 meters at the northeastern boundary and 209.6 meters at the southwestern model boundary for a total relief of 72.8 meters. Because MODFLOW is not designed to handle steep changes in topography, the horizontal cell spacing was set at 15.2 meters by 15.2 meters in order to minimize impacts of steep topography in the study region.

Groundwater Model Inputs
Information for the groundwater model was obtained from several sources including local geologic reports, field measurements, and the surface water analyses. Limited geologic information was available directly inside the model boundaries. Two municipal pumping wells are located in the eastern, central portion of the model. These wells provided the only detailed geologic information in the model area. There were however, numerous geologic studies conducted within a 1 km² radius of the study site. Detailed soils analysis was performed in and around the wetlands in Site #2. In addition, drilling records were available for the 15 deep wells that were installed throughout the project area. The combination of this information was used to make assumptions regarding the model layer thickness and hydraulic properties.

Although there was a large volume of geologic information available within the project area, it was not detailed enough to develop a transient groundwater model. Thus, a steady state groundwater model was developed that analyzes the average annual groundwater elevation for the existing and proposed hydrologic conditions.

Annual recharge was the primary hydrologic input into the groundwater model. Annual recharge for each land use condition was determined by subtracting the annual runoff and annual evapotranspiration from the annual precipitation recorded at the site.

Annual runoff and annual evapotranspiration were determined for each existing land-use condition from the field data. The proposed conditions groundwater model assumes that only the net recharge to the land surface will change for the developed conditions. Due to lack of detailed proposed condition information, changes in surface topography were not directly accounted for in the groundwater model. Increases in impervious area in the developed conditions will increase annual runoff and thus decrease annual recharge.

Groundwater Model Calibration
Matching the observed water budget was the primary focus of groundwater modeling because it was such a critical factor in the sustainability of the wetland habitat. Head values were calibrated using the average annual water level in the 15 deep monitoring wells. Relatively uniform conductivity values were used throughout the model, except in the discharge areas. Because many of the wetlands experience artesian and even “quick-sand” conditions, the vertical conductivities in these regions were assumed to be equal to the horizontal conductivities.

Groundwater modeling was complicated by the presence of drainage tile throughout the lowlands areas. In the early part of the century, the entire model area had been used for agricultural purposes. In order to make the
land suitable for farming, drainage tile had been installed throughout the lowland areas to dry out the surrounding wetlands; the model area was then farmed up to the stream. Historical aerial photographs provide important clues about the location of those drainage tiles. In addition, several tile were encountered during the installation of the shallow piezometers in and around the wetlands. The drainage tile consist of a series of angular rocks laid on top of a series of parallel logs. Although the tiles have become partially clogged with sediment, they still carry a significant portion of the stream’s baseflow. It is believed that the clogging of the drainage tiles has allowed for the development of the wetland habitats. The tributary between streamflow gage SF 2-4 and SF 2-5 loses approximately 80% of its baseflow due to drainage tile immediately below and parallel to the stream. The drainage tile in this region is at least 5m wide and is located 0.6m to 1.2m below the streambed.

The groundwater model accounts for the drainage tile by adding a series of drain nodes at the assumed bottom elevation of the tile with very high conductivity values. Although the locations of some of the drainage tile are known, it is assumed that there are numerous other locations of drainage tile throughout the wetlands. Unknown drainage tile may affect local model variability, but should not have a significant impact on overall model results.

Groundwater Model Results
The calibrated groundwater model produced the Layer #2 head values shown in Figure 2. The majority of the groundwater table is located in Layer #2 - the weathered/fractured rock zone. The model slightly underestimates the baseflow received in the upland areas of Site #2 and slightly overestimates the baseflow received in the downstream sub-basins of Site #2. This may be caused by the steep local gradients and lack of resolution of detailed hydraulic properties in and around the streambeds. In general, the model is simulating approximately 85% of the gaged baseflow.
Groundwater Model
Existing Heads, Layer 2

Fig. 2: Existing condition head values, Layer 2
Proposed Condition Groundwater Modeling

Three proposed conditions were simulated with the groundwater model. The first proposed condition examines the impacts caused by the construction of the highway bypass alone. It does not include any additional development. The second proposed condition evaluates the development of the highway bypass and the construction of the industrial park east of the proposed bypass. The third alternative examines the impacts of the highway bypass and the construction of the industrial park both east and west of the proposed bypass. Although the industrial park plans include the required stream and wetland buffers, they pave over a majority of the upland watershed.

The proposed conditions were modeled by adjusting the runoff, evapotranspiration, and ultimately net recharge received in the affected areas. All precipitation that falls on the impervious portion of the watershed is assumed to be lost as runoff without any benefit of infiltration or stormwater management. While this is an extremely conservative assumption, it was made in order to model the worst case scenario. The impacts of development on groundwater levels may be reduced with innovative infiltration practices.

Proposed condition #1 (bypass only) produced less than a 0.5m change in the local groundwater model. This is negligible when the accuracy of the model is considered. Proposed conditions #2 (bypass and eastern development) and #3 (bypass and full development) produce significant impacts to the groundwater table within the area. In the southeast corner of the study area, the head values drop over 10m in depth. Although the head values are not impacted at the wetlands themselves, the reduction in hydraulic head in the upland areas will dramatically reduce the groundwater discharge throughout the area. Existing artesian conditions in the wetlands may be adversely impacted by reduced head values. Bog turtles frequently burrow up to 60cm into the soft, mucky wetland soils. Reductions in artesian conditions may impact the turtles ability to burrow below the ground surface. The streamflow gage just downstream of the wetland habitat will receive approximately 50% less recharge from the groundwater system. The reduction in groundwater discharge may also influence the temperature of the wetland habitats. Refer to Figures 3 and 4 for anticipated impacts caused by proposed conditions #2 and #3 respectively.
GW Model Results
Drawdown due to East Development
(Drawdown = Existing heads - East heads)

DRAWDOWN (meters)

Note: Model does not account for Stormwater Management. Innovative SWM technologies can improve infiltration.

Fig. 3: Drawdown due to development of eastern industrial park and highway bypass.
GW Model Results
Drawdown due to Full Development
(Drawdown = Existing heads - Full heads)

Note: Model does not account for Stormwater Management. Innovative SWM technologies can improve infiltration.

Fig. 4: Drawdown due to development of full industrial park and highway bypass
It is important to remember that these modeling alternatives represent a worst case modeling scenario. Because an infinite combination of stormwater management, grading, and land-use options exist for the project site, the worst case scenario was developed as a basis for study. Development related impacts may be reduced if the 2000 Maryland Stormwater Design Manual criteria which focus on water quality and quantity control are followed, impervious cover is minimized, and infiltration practices are encouraged.

**Recommendations**

The results of the groundwater modeling portion of this study have shown that extensive development without stormwater management in the upland areas of this study will have a detrimental impact on the bog turtle wetlands. The best way to maintain present hydrologic conditions in any watershed is to not change the land-use or present drainage patterns. In reality, as land values increase, the pressure to develop land increases. The second best way to preserve a hydrologic balance in a watershed is to minimize the effects of land use change through the use of “Best Management Practices” or BMPs. BMPs typically reduce the after development peak discharge rate while providing some water quality benefits. Typical urban BMPs include wet ponds, dry (extended detention) ponds, shallow marsh ponds, infiltration practices, and runoff-filtering practices.

Because the bog turtle wetlands can be adversely affected by changes in hydrology, the BMPs recommended for consideration go beyond the requirements in effect today. To the extent possible, stormwater management plans for any development in the watersheds supporting bog turtle habitats should be comprehensive and watershed-based. The focus of stormwater management in the upland areas should be on pretreatment, infiltration, and maintenance. Infiltration volumes provided after development should meet or exceed the predevelopment recharge volumes determined in this study.

In order to insure the necessary watershed recharge for bog turtle wetland survival, it is recommended that developed sites within the study boundaries generally follow the criteria and procedures found in the 2000 Maryland Stormwater Design Manual with the exception of the Groundwater Recharge Volume, \( R_{w} \), calculation. Because decreases in recharge can have a significant impact on wetland hydrology, within the study boundary the \( R_{w} \) formula should reflect actual predevelopment annual groundwater recharge and actual rainfall depths. The equation should be written as follows:

\[
R_{w} = \frac{(R_{\text{watershed}})(A_{\text{disturbed}})}{(P_{\text{annual}}) \left( \frac{12 \text{ in}}{\text{ft}} \right)}
\]

where:

- \( R_{w} \) = Recommended watershed recharge volume, acre-feet
- \( R_{\text{watershed}} \) = Average annual watershed recharge = 17.6 in / yr
- \( P_{\text{annual}} \) = Average annual watershed precipitation = 41.35 in / yr
- \( A_{\text{disturbed}} \) = Area disturbed during development, acres

**Zone of Primary Hydrologic Influence**

The information obtained in the surface and groundwater modeling will be used by local and state agencies in an effort to protect and sustain the bog turtle habitats. The modeling information was combined with information gained in a biological study of the bog turtle by Frostburg State University and MDSHA (2001) to create a boundary in which special care needs to be exercised in order to sustain the bog turtle wetland habitat. This boundary was called the “Zone of Primary Hydrologic Influence.” The Zone contains a large portion of the upland watershed that drains to the bog turtle habitats. The idea behind the creation of the Zone was to insure that extreme care would be used in any planning and development activities within the Zone in order to maintain the bog turtle wetlands. The creation of the Zone does not inhibit development from taking place, but it does list suggestions for state and local planners to follow when considering any development options. The maintenance of recharge and surface water flows within the Zone are essential to the survival of the bog turtle wetlands. Also, if development does take place, the amount of impervious area must be minimized. State and local agencies are currently trying to purchase or obtain easements for areas
that fall within the Zone to create a bog turtle preserve. This preserve will help ensure that the hydrology of the bog turtle wetlands is maintained.

Conclusions and Future Work
Although the groundwater modeling depicted the worst case development scenario, it clearly demonstrates that extensive development in the upstream watershed areas will have a detrimental impact on the hydrology of bog turtle habitats. The groundwater model was able to physically show that the reduction in recharge due to the development of the upland watershed will hydrologically influence the bog turtle wetland. Although groundwater levels within the wetland should remain unchanged, reductions in upland hydraulic head will cause significant reductions in groundwater discharge to the wetland.

This study was intended to provide an objective hydrologic analysis of the area and does not recommend the prohibition of all development in the upland watershed. However, it does provide local and state agencies with target recharge numbers that must be maintained in order to minimize the impacts of development on the wetland areas. The local and state agencies must work with developers to insure that these levels of recharge are achieved. Because the exact development scenario of the upland watersheds is not yet known, the groundwater model was designed to facilitate the analysis of other potential land uses with ease.

The current analysis used the geologic data that was presently available. The model clearly shows that the development of the industrial park will cause significant impacts to the downstream wetland areas. It is not intended to provide an exact drawdown value, but the general magnitude of impacts on the groundwater table. If more detailed and accurate information regarding the impacts of proposed development is required, additional field information would need to be acquired and added to the current groundwater model.

Although it was assumed that the recharge from the upstream areas is critical for the protection of bog turtle habitats, there are no previous studies showing the range of impacts that development could have on groundwater levels in and around bog turtle habitats. Because a large number of bog turtle habitats experience artesian conditions and are primarily supplied by groundwater flow, this model can be used as a guide in determining the impact zones at other bog turtle locations. The information obtained during this study will be used to develop the first major bog turtle preserve in the state of Maryland. This information should also be valuable to other Mid-Atlantic states who are facing similar declines in bog turtle populations.

Biographical Sketch:
Kelly E. Brennan, P.E., received her B.S. and M.S. in civil engineering, with an emphasis in hydrosystems, from Penn State University. As a water resources engineer for Parsons Brinckerhoff, she has worked on a variety of hydraulic and hydrologic studies throughout Maryland and the eastern U.S. Kelly is active in the American Society of Civil Engineers and is a member of the Urban Stream Restoration subcommittee.

References


Abstract
The U. S. Fish and Wildlife Service (USFWS) listed the Coastal/Puget Sound Distinct Population Segment (DPS) of bull trout (Salvelinus confluentus) as threatened on November 1, 1999, under Endangered Species Act of 1973, as amended (ESA). The bull trout population in the Washington State region is unique in that it contains the only known anadromous life history form of bull trout. This anadromous life form migrates through, and forages in urbanized river and estuarine shorelines of the Puget Sound.

Since more transportation projects occur in urban versus rural areas, and because seemingly minor activities like routine maintenance can adversely affect bull trout, the number of Section 7 ESA Consultations has significantly increased. Stormwater run-off, increased impervious surface, urban growth and the related increases in capacity demands, overlapping regulatory jurisdictions, the lack of opportunity for minimizing impacts, and difficulty in assessing impacts to a degraded baseline are just a few of the issues that both USFWS and the transportation industry currently struggle with during consultation.

Case-by-case review of these projects under the ESA must mesh the regulatory requirements (time-lines and political pressures) with the biological needs of the endangered species. Current efforts are underway to streamline the regulatory process in Washington State. These efforts include the development of tools such as programmatic biological assessments, providing agencies with liaison personnel, and refining guidance on assessing indirect effects. Tracking the overall impacts to threatened and endangered species (as mandated by ESA) resulting from transportation projects is overwhelming, as adequate tools are still lacking.

While perceived conflicts over the needs of people versus ESA species are not new issues, they are amplified in the urban setting. Incorporation of existing tools—such as transportation demand management, high capacity transit, removal of impervious surface and restoration of hydraulic functions—into transportation planning is likely needed to recover listed species in the urban environment, yet remain to be embraced.

We will draw from our experience conducting Section 7 ESA consultations, participating in long-term transportation planning processes under NEPA, and close coordination with Federal, state, and local transportation agencies to provide a discussion of these challenges and suggestions for overcoming them as we move toward recovery planning efforts for bull trout.
SEASONAL MOVEMENTS AND HABITAT PREFERENCES FOR THE SPOTTED TURTLE AND EASTERN BOX TURTLE IN MASSACHUSETTS

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Abstract: Seasonal habitat use and population dynamics of a spotted turtle (Clemmys guttata) population and an eastern box turtle (Terrapene c. carolina) population in southeastern Massachusetts are presented in this paper. The two-year study, conducted between March 1998 and December 1999, was part of a mitigation plan proposed by the Massachusetts Highway Department (MassHighway) and approved by the Massachusetts Natural Heritage and Endangered Species Program (NHESP) to mitigate for 1.0 hectares of direct rare species habitat loss and 1.6 hectares of indirect habitat loss associated with a highway relocation project in Carver, Kingston, and Plymouth, Massachusetts. Sixty individual spotted turtles were captured in a 29-hectare study area consisting of upland and wetland habitat in Carver. Of these, 11 spotted turtles were radio tracked. Thirty-seven box turtles were also captured and 7 were radio tracked. Spotted turtles were observed in wetlands 96 percent of the time, and box turtles 15 percent of the time. During the spring and nesting season, spotted turtles were found exclusively in wetlands. Most activity was observed in an open emergent wetland and a forested vernal pool, with movement between the two habitat types via a stream channel and secondarily via overland travel through the forested wetland. Most turtles estivated in the emergent or forested wetland; only one turtle consistently estivated in forested upland. Hibernacula were found in the forested vernal pool (3) and the emergent wetland (3). The southern ramp of new Route 44 alignment will bisect the spotted turtle population. A proposed 1.8-meter by 1.8-meter box culvert that will convey the stream channel under one of the highway entrance ramps may provide a passageway connecting the emergent wetland to the forested vernal pool; its use will be determined during a future study. Box turtles were generally found in forested upland in the spring, in open upland during the nesting season and summer, with some summer migration to wetlands. Five hibernacula were found, all in forested upland. The new alignment should have less impact on the box turtle population, but will likely result in some loss of nesting habitat and some shifts in home range. Use of nearby replacement nesting habitat will be monitored during a future study. Home ranges averaged 1.43 hectares for spotted turtles and 3.26 hectares for box turtles. For both species, home ranges were larger for males than for females. The population density for spotted turtles was estimated to be 18.8 turtles per hectare, and for box turtles was estimated to be 3.0 turtles per hectare.

Introduction
Over 20 years ago, the Massachusetts Highway Department (MassHighway) undertook a highway relocation project in southeastern Massachusetts to address safety and capacity concerns of Route 44 between Route 58 in Carver and Route 3 in Plymouth. The proposed project involved construction of 12 kilometers of a new four-lane, limited access highway, and resulted in 1.0 hectares of direct habitat loss and 1.6 hectares of indirect habitat loss for three state-listed turtle species. On December 31, 1997, the Massachusetts Department of Environmental Protection (DEP) issued a combined Wetland Variance Decision and Water Quality Certification for the Route 44 Relocation Project, which found that MassHighway had avoided and minimized impacts to rare species to the greatest extent practicable, and that adverse impacts to rare species would be mitigated by a two-part mitigation plan developed by MassHighway and approved by the Massachusetts Natural Heritage and Endangered Species Program (NHESP). The mitigation plan required MassHighway to purchase approximately 11.25 hectares of upland and wetland habitat, and to conduct a two-year study to determine the seasonal movements and habitat preferences for wood turtles (Clemmys insculpta), spotted turtles (C. guttata), and eastern box turtles (Terrapene c. carolina).

Methods
Study Area Definition
The 29.2-hectare, mostly wooded study area is bounded on the west by Route 58, a two-lane roadway, on the north by an upland field, on the east by the Winnetuxet River, and on the south by commercial and residential
The study area includes the Winnetuxet River and associated wetlands and uplands in the vicinity of the new Route 44 alignment. Wetlands mapping from the Notice of Intent, aerial photographs, and field-verification were used to determine 11 different cover types.

Eight of the cover types are wetlands and the remaining three are upland. In the forested wetland, the vegetation is primarily a red maple (Acer rubrum) forested wetland, with smaller areas of forested wetland dominated by red maple and white pine (Pinus strobus) in the canopy, and highbush blueberry (Vaccinium corymbosum), sweet peppercrumb (Clethra alnifolia), and spicebush (Lindera benzoin) in the understory. Wooded upland areas are characterized primarily by white pine and oak (Quercus spp.). The western portion of the study area adjacent to Route 58 is an emergent wetland characterized by soft rush (Juncus effusus) common cattail (Typha latifolia), common reed (Phragmites australis), steeplebush (Spiraea tomentosa), and tussock sedge (Carex stricta). Other open areas include disturbed upland in the MassHighway maintenance depot, a clearcut area in the southern portion of the study area, and two upland fields, one in the northwest corner and one in the southeastern portion of the study area. Two stream channels fed by roadway runoff converge in the emergent marsh in the western portion of the study area. To the east, the stream flows through forested upland and wetland and forms the main tributary to the Winnetuxet River. Several small channels in the forested wetland flow into the vernal pool labeled Turtle Pond during the study; one channel flows from Turtle Pond into the main tributary to the Winnetuxet River. Kettle Pond is a vernal pool in forested upland north of the new alignment.

Turtle Capture and Characterization
Turtle capture was initiated on March 24, 1998, during the first year of the study and on March 29, 1999, during the second year of the study. Turtles were caught by hand by visually searching the stream channels and vernal pools, and were trapped in hoop nets and minnow-style traps. Captured turtles were aged, sexed, measured, weighed, photographed, and notched for individual identification as described in Cagle (1939). A triangular metal file was used instead of the square file described by Cagle because the triangular file is less intrusive and produced equivalent notches. Age was determined by counting annuli on each right plastral plate, which is a reasonable estimate of age for many turtle species (Sexton 1959). Turtles were sexed based on eye color, jaw color, vent location, and plastral concavity.

Monitoring
Ten spotted turtles and five box turtles were fitted with radio transmitters (AVM model SM 1-H; 165 MHz) between March and October 1998. Ten spotted and five box turtles were monitored in 1999, using the same transmitter model. Radio transmitters were glued to the right rear side of each turtle’s carapace with a slow-setting epoxy (PC-7) as described in Belzer and Reese (1995). Turtles were released at their point of capture within 24 hours. Each turtle fitted with a radio transmitter was also numbered with a bright orange non-toxic paint pen on its carapace for easier visual observation. Spotted turtles were tracked three times per week in the spring and summer, every 48 hours during the nesting season, and once per month in the fall/winter season. Nine of the ten spotted turtles tracked in 1998 were also tracked in 1999, and three of the five box turtles monitored in 1998 were also tracked in 1999. The tenth spotted turtle was found dead in 1998. Eight turtles were analyzed in 1998; the ninth had fewer than 20 data points and was not included in home range analyses. The two 1998 tagged box turtles, both females, were not found in 1999. Each turtle was tracked to within one meter of its location, and notes were taken on the time, location, behavior, habitat, and, where applicable, the water depth and water temperature where the turtle was seen.

Seasonal habitat use was determined by counting the number of observations recorded in each cover type during each season. For the purpose of this study, seasons were classified as follows: spring (March 15 through May 21); nesting (May 22 through June 30); summer (July 1 through September 30); and fall/winter (October 1 through December 31).

Based on radio tracking data gathered over both field seasons, maps were generated for turtles that had at least 20 observations each year. Home ranges were determined by the minimum convex polygon method in Animal Movement Analysis Arcview Extension (Hooge and Eichenlaub 1997). Population estimates for spotted turtles and box turtles were derived using standard mark-recapture study techniques. The following formula was used to estimate population size:
\[ N = \frac{C_1 C_2}{r} \]
where \( N \) = population size
\( C_1 \) = number captured during first sample (first year)
\( C_2 \) = number captured during second sample (second year)
\( r \) = number of recaptures

**Macroinvertebrate sampling**
On April 30, 1999, a macroinvertebrate sampling was conducted at five sites in the study area: the north channel, south channel, and their confluence in the emergent wetland, Turtle Pond, and the main tributary to the Winnetuxet River approximately 150 meters east of the access path.

**Results and Discussion**

**Wood Turtles**
Two juvenile wood turtles were observed in the study area on three separate occasions in April 1990. Although wood turtles were searched for throughout the study site during the two-year study, both in upland and wetland habitats, none were found. Although there is some habitat in the study area that may support wood turtles, it is likely that the two juveniles observed in 1990 were transients, and did not have established home ranges in the study area.

**Spotted Turtles**
Sixty individual spotted turtles were captured during the two-year study. Including 1998 recaptures, 81 spotted turtles were captured. Table 1 provides new capture frequencies by month, sex, and age. The majority of the captures (82 percent) occurred in open emergent wetland, and 12 percent were captured in a vernal pool in a forested wetland. Two turtles were captured in the main tributary to the Winnetuxet River (3 percent), one adult female was captured as she traveled through upland forest to the open emergent wetland and one turtle hatchling was captured in the MassHighway maintenance depot.

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<table>
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<tr>
<th>Month</th>
<th>1998</th>
<th>1999</th>
<th>Total</th>
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<tr>
<td>March</td>
<td>24</td>
<td>6</td>
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</tr>
<tr>
<td>April</td>
<td>14</td>
<td>12</td>
<td>26</td>
</tr>
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<td>2</td>
</tr>
<tr>
<td>June</td>
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<table>
<thead>
<tr>
<th>Month</th>
<th>1998</th>
<th>1999</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>(60%) (30%)</td>
<td>(50.0%)</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>(35%) (60%)</td>
<td>(43.3%)</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>(2.5%) (5%)</td>
<td>(3.3%)</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>(2.5%) (5%)</td>
<td>(3.3%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Month</th>
<th>1998</th>
<th>1999</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>March</td>
<td>14</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>April</td>
<td>11</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>May</td>
<td>1</td>
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<td>2</td>
</tr>
<tr>
<td>June</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Month</th>
<th>1998</th>
<th>1999</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>March</td>
<td>(35%) (25%)</td>
<td>(31.7%)</td>
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<tr>
<td>April</td>
<td>(27.5%) (35%)</td>
<td>(30%)</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>(2.5%) (5%)</td>
<td>(3.3%)</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>(2.5%) (5%)</td>
<td>(3.3%)</td>
<td></td>
</tr>
</tbody>
</table>

In both years, most turtles were caught in March and April (93 percent). No new turtles were caught from July through December, indicating that spotted turtles are much more active and easily observed during the spring. In 1998, 38 turtles (95 percent) were captured for the first time by hand, and two (5 percent) were captured for the first time in traps. In 1999, 34 turtles (83 percent) were captured for the first time by hand, and seven (17 percent) were first captured in traps.
Seasonal Habitat Use
In 1998, 144 observations were recorded in the spring, 104 in the nesting season, 114 in the summer, and seven in the fall/winter for a total of 369 observations. In 1999, 209 observations were recorded in the spring, 188 in the nesting season, 213 in the summer, and 115 in the fall/winter, for a total of 725 observations. Almost twice the number of observations were recorded in 1999 because ten turtles were analyzed versus eight in 1998, and because observations were continued three times per week through September in 1999, as opposed to one radio tracking in September 1998. During the two years of the study, the majority of the observations (77 percent) occurred in three cover types (Open Stream, Vernal Pool, and Open Wetland).

Overall, 96 percent of the spotted turtle observations occurred in wetlands. Four spotted turtles resided almost exclusively in the emergent wetland, and three turtles resided almost exclusively in Turtle Pond. Three males traveled between wetlands. As with most activity, travel between wetlands occurred primarily in the spring. The main tributary to the Winnetuxet River provided the most-used route between the emergent wetland and Turtle Pond and the forested wetland. Most overland travel was through forested wetland. The Forested Pine/Maple Stream and Scrub-Shrub Wetland cover types were not used. Both unused wetland cover types occur east of a 300-millimeter corrugated metal pipe (CMP) that conveys the main tributary to the Winnetuxet River under an old cart path approximately 50 meters northeast of Turtle Pond. No spotted turtles were observed east of this culvert. The pipe is approximately four meters long, and as water exits the pipe it creates a small waterfall into a one-meter deep scour pool. East of the culvert, the stream flows at a slightly higher velocity, there are more riffles, and the substrate is more stony and gravelly than the stream west of the culvert where spotted turtles were observed.

Table 2
Spotted Turtle Habitat Use *

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Seasonal Use (percent)</th>
<th>Yearly Use (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FO-PM-W</td>
<td>0 0 0</td>
<td>0 3 1.5</td>
</tr>
<tr>
<td>FO-PM-S</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>FO-PM-U</td>
<td>0 0 0</td>
<td>0 5 2.5</td>
</tr>
<tr>
<td>FO-RM-W</td>
<td>26 7 16.5</td>
<td>13 13 13</td>
</tr>
<tr>
<td>FO-RM-S</td>
<td>7 12 9.5</td>
<td>4 5 4.5</td>
</tr>
<tr>
<td>FO-PO-U</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>OPEN-W</td>
<td>45 46 45.5</td>
<td>17 34 25.5</td>
</tr>
<tr>
<td>OPEN-U</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>SCSH-W</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>VP</td>
<td>15 32 23.5</td>
<td>33 24 28.5</td>
</tr>
<tr>
<td>Total (Percent)</td>
<td>100 100 100</td>
<td>100 100 100</td>
</tr>
</tbody>
</table>

* Percent total observations during each season
State-regulated wetland areas shown in bold
FO-PM-W: Forested Pine-Maple Wetland
FO-PM-S: Forested Pine-Maple Stream
FO-PO-U: Forested Pine-Oak Upland
FO-RM-W: Forested Red Maple Wetland
FO-RM-S: Forested Red Maple Stream
FO-PM-U: Forested Pine-Maple Upland
OPEN: Open Stream
OPEN-U: Open Upland
OPEN-S: Open Wetland
SCSH-W: Scrub-Shrub Wetland
VP: Vernal Pool

Spring: Spotted turtles used five wetland cover types in the spring, and no upland habitat. Based on radio tracking observations, the Open Stream cover type accounted for the highest number of observations during the two-year study (45.5 percent), consistent with the Ward et al. (1976) and Graham (1995).
Nesting: Again, during both years, all spotted turtles were recorded in wetlands. Almost 80 percent of the observations occurred in three cover types: Vernal Pool, Open Wetland, and Open Stream. No nests were found during the study, but observations every 48 hours during the nesting season indicate only one female left wetland areas. This individual was found dead on the shoulder of Route 58 (east side) eight days after capture. Five data points noted between her capture point near Kettle Pond and where she was found dead indicate a south-southwest movement through the emergent wetland towards the wetland on the west side of Route 58 (total distance approximately 265 meters).

Summer: Spotted turtles used uplands the most during the summer (10 percent of the time). Open Stream was the most intensively used habitat in 1998 (47 percent), followed by Open Wetland (24 percent). In 1999, Open Wetland was used most heavily (34 percent), and the Open Stream and Forested Red Maple Wetland cover types were used almost equally (26 and 25 percent, respectively). Most studies have shown that turtles migrate to upland areas to estivate in forms during the summer to escape the heat and conserve energy. Perillo (1995) found that spotted turtles left wetlands in the summer to estivate in upland habitat. In Massachusetts, Graham (1997) observed spotted turtles estivating primarily in upland fields, except for one male and one female estivating under a tussock sedge clump in a bog. However, Ward et al. (1976) observed estivation occurring in early successional paludal woods in Maryland. Turtles that resided in Turtle Pond migrated to nearby forested wetland areas during both summers, with rare observances in adjacent uplands. Turtles that resided in the emergent wetland remained in the wetland during both years, buried in the banks of the channel or in forms under clumps of tussock sedge or soft rush, and did not leave the wetland.

Gibbons (1986) stated that food availability is one factor influencing turtles’ shift from aquatic habitats to uplands as water levels in wetlands fall. Macroinvertebrates collected from this sampling location included crayfish (Cambaridae), backswimmers (Notonectidae), fairy shrimp (Eubranchipus sp.), and scavenger beetles (Hydrophilidae). Caddis fly larva (Hydropsychidae) and one cluster of spotted salamander (Ambystoma maculatum) eggs were also found in the emergent wetland in the spring. Though the streams in the emergent wetland and the main tributary to the Winnetuxet River dried in most areas as the summer progressed, the western portion of the emergent wetland contained standing pools of water throughout the season. Possibly spotted turtles did not need to leave the emergent wetland in search of other food supplies.

Fall/Winter: Spotted turtles were recorded 97.5 percent of the time in wetlands. Six individual spotted turtle hibernacula were located. Three were in the emergent wetland and three were in Turtle Pond. Hibernacula for turtles located both years were found within 6 meters of the previous year’s location. The two hibernacula that were located only in 1999 were also found in the same location as where turtles were captured in the spring, similar to results found by Graham (1995).

Population Dynamics
The population of spotted turtles appears to be healthy, with a relatively equal proportion of males to females (19 males and 18 females), and a substantial number of juveniles (23). Turtles of all ages were captured, ranging from hatchlings to adults greater than 17 years old. Juveniles are often underrepresented in turtle population studies (Ernst 1976), possibly because they are more secretive than their adult counterparts, and also because of higher mortality rates in younger age classes. The high number of juveniles captured indicates substantial recruitment into the population. Males and females were almost equally represented, again indicating a healthy population.

Home Range: Home ranges were determined for the nine turtles that were observed on at least 20 occasions (5 females and 4 males). Home ranges for 1998 are shown on Figure 2 (end of paper), and home ranges for 1999 are shown on Figure 3 (end of paper). Ranges vary from 0.4 to 2.2 hectares for males and 0.03 to 1.3 hectares for females (Table 3).
Table 3
Spotted Turtle Home Range Sizes

<table>
<thead>
<tr>
<th>Turtle</th>
<th>Male Size (hectares)</th>
<th></th>
<th>Female Size (hectares)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1998</td>
<td>1999</td>
<td>Avg.</td>
<td>2-year</td>
</tr>
<tr>
<td>S2</td>
<td>2.2</td>
<td>1.4</td>
<td>1.8</td>
<td>2.3</td>
</tr>
<tr>
<td>S3</td>
<td>2.1</td>
<td>1.9</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>S5</td>
<td>0.6</td>
<td>1.7</td>
<td>1.15</td>
<td>1.7</td>
</tr>
<tr>
<td>S7</td>
<td>0.4</td>
<td>1.1</td>
<td>0.75</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg.</td>
<td>1.33</td>
<td>1.5</td>
<td>1.43</td>
<td>1.95</td>
</tr>
</tbody>
</table>

Spotted turtles were fairly active, particularly in the spring and the early part of the nesting season, and the discrepancies between years may indicate individual points picked up one occasion during one year but not the next. For example, the home range of S2 was more than 25 percent smaller in 1999, but the majority of the use occurred within the same area in both years. During the 1998 nesting season, S2 was found once in the Forested Red Maple Wetland east of the MassHighway depot, and this observation was included within the home range analysis (no data points were deleted for any turtles). S1 was also found in this cover type, and though both turtles were more frequently found there during spring 1998 (and neither one was found there during the 1999 season), the one recorded foray made by S2 into this area greatly enlarged his home range.

The home ranges of turtles are similar to those found by Graham in 1995. Graham also found that females occupied a substantially smaller home range than males. Our study also showed that females’ home ranges were, on average, smaller than males (0.66 hectares and 1.61 hectares, respectively).

Aquatic turtles, such as spotted turtles, are often found in well-defined populations (Gibbons 1968). This was confirmed for spotted turtles in the study area. Spotted turtles showed a great deal of overlap in their home ranges, both with other tagged spotted turtles as well as between-year for the same individuals. All turtles spent a portion of their time in the emergent wetland, and one female was never recorded outside the emergent wetland. Another female was observed most frequently in the emergent wetland, but was occasionally seen in the stream in forested wetland. Most turtles (six of eight) traveled back and forth between Turtle Pond and the emergent wetland, usually swimming or crawling in the main tributary to the Winnetuxet River or, less frequently, through the forested wetland.

Home range lengths and distances turtles moved from their hibernacula were determined for tracked turtles and are presented in Table 4. The data indicate much year-to-year and individual variability in the distance moved.
Table 4
Spotted Turtle Home Range Lengths and Distance Moved from Hibernacula

<table>
<thead>
<tr>
<th>Turtle</th>
<th>Sex</th>
<th>Home Range Length 1 (meters)</th>
<th>Distance Moved From Hibernacula 2 (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>F</td>
<td>280</td>
<td>96</td>
</tr>
<tr>
<td>S2</td>
<td>M</td>
<td>272</td>
<td>272</td>
</tr>
<tr>
<td>S3</td>
<td>M</td>
<td>300</td>
<td>293</td>
</tr>
<tr>
<td>S4</td>
<td>F</td>
<td>102</td>
<td>142</td>
</tr>
<tr>
<td>S5</td>
<td>M</td>
<td>267</td>
<td>304</td>
</tr>
<tr>
<td>S6</td>
<td>F</td>
<td>284</td>
<td>278</td>
</tr>
<tr>
<td>S7</td>
<td>M</td>
<td>193</td>
<td>322</td>
</tr>
<tr>
<td>S8</td>
<td>F</td>
<td>32</td>
<td>105</td>
</tr>
<tr>
<td>S10</td>
<td>F</td>
<td>N/A</td>
<td>364</td>
</tr>
<tr>
<td>S101</td>
<td>F</td>
<td>N/A</td>
<td>288</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>216</td>
<td>246</td>
</tr>
</tbody>
</table>

1 N/A indicates the turtle was not tracked, or less than 20 observations were recorded.
2 Maximum distance from hibernaculum that a turtle was observed. Distance moved from hibernacula are provided for those turtles that were tracked to hibernacula in 1998 and/or 1999. The -- notation indicates that no hibernaculum was located.

The spotted turtle population was estimated to be 78 turtles within the two-year period. The population density is estimated to be 18.8 turtles per hectare in the study area, based on 3.2 hectares of suitable habitat. The estimate is based on an annual sampling period, and therefore may not account for immigration or emigration from the study area. The numbers may be artificially high because suitable habitat was defined as the polygon that encompassed all turtle observation instead of total suitable habitat types available to spotted turtles. The population estimate is higher compared to Graham's assessment of 6.7 spotted turtles per hectare in central Massachusetts. A study reported in Ernst et al. (1994) estimated spotted turtle density for a population in Pennsylvania to be between 39.5 and 79.1 turtles per hectare.

Box Turtles
Thirty-seven individual box turtles were captured during the study. Including 1998 recaptures, a total of 49 box turtles were captured. During the two-year study period, 24 individual males (65 percent), 11 individual females (30 percent), and two individual juveniles (5 percent) were captured. In 1998, 18 males were captured (75 percent), five females were captured, and one juvenile was captured (4 percent). In 1999, 16 males were captured (64 percent), eight females were captured (32 percent), and one juvenile (4 percent) was captured. During the 1999 field season, 26 box turtles were captured and marked; 12 of these were recaptures from 1998.

April represented the highest capture rate for both years (71 percent in 1998 and 54 percent in 1999). Four box turtles were captured in March 1998, while none were captured in March 1999. It is likely that turtles emerged earlier than usual from hibernation in 1998 because of unusually warm temperatures. Evidence of recent emergence from hibernation at the end of March and first week in April was noted as soil caked in the interstices of the scutes and small, fresh cuts on some of the turtles' feet.
Table 5
Box Turtle Capture Frequencies

<table>
<thead>
<tr>
<th>Month</th>
<th>Juveniles</th>
<th>Adults</th>
<th>Total (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>May</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>June</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>August</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>October</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Seven individual turtles were fitted with radio transmitters during the study (five females; two males). Three box turtles (one female and two males) were tracked both years.

Seasonal Habitat Use
In 1998, 108 observations were recorded in the spring, 77 in the nesting season, 86 in the summer, and 9 in the fall/winter for a total of 280 observations. In 1999, 58 observations were recorded in the spring, 88 in the nesting season, 85 in the summer, and 50 in the fall/winter, for a total of 281 observations. Box turtles used seven of the eleven cover types (Table 6).

Table 6
Box Turtle Habitat Use *

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Seasonal Use (percent)</th>
<th>Yearly Use (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FO-PM-W</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>FO-PM-S</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>FO-PO-U</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>FO-RM-W</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>FO-RM-S</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>FO-PM-U</td>
<td>22</td>
<td>57</td>
</tr>
<tr>
<td>OPEN-W</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>OPEN-S</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OPEN-U</td>
<td>35</td>
<td>13</td>
</tr>
<tr>
<td>SCSH-W</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>VP</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

* Percent total observations during each season
1 Wetland areas shown in bold

- FO-PM-W: Forested Pine-Maple Wetland
- FO-PM-S: Forested Pine-Maple Stream
- FO-PO-U: Forested Pine-Oak Upland
- FO-RM-W: Forested Red Maple Wetland
- FO-RM-S: Forested Red Maple Stream
- FO-PM-U: Forested Pine-Maple Upland
- OPEN-S: Open Stream
- OPEN-U: Open Upland
- SCSH-W: Scrub-Shrub Wetland
- VP: Vernal Pool
Fifteen percent of the observations occurred in wetlands. In general, box turtles were found in forested upland in the spring, in open upland during the nesting season and first part of the summer, and moved back into forested areas during the latter half of the summer season; this is consistent with trends noted in the literature. B5 and B2 (both females) were exceptions. One female was never recorded in the Open Upland cover type, and may be representative of a more typical habitat choice of floodplain forests as described by Stickel (1959), though Ernst et al. (1994) include pastures and meadows as secondary habitat. In both 1998 and 1999, another female was found almost exclusively in Open Upland, except for a few observations in the summer, where she was found in Forested Pine-Oak Upland in 1998, and in Forested Pine-Oak Upland in 1999.

As the spring progressed, box turtles were more frequently found in Open Upland in both years. During the nesting season, habitat use shifted to mostly Open Upland, except for one female that was found mostly in forested wetland. Three out of five turtles were recorded north of the main tributary to the Winnetuxet River, but all turtles were most often found south of the Winnetuxet River (and south of the new alignment).

Spring: Most studies indicate box turtles spend at least a portion of the spring in woodlands (Stickel 1950, Ernst et al. 1994).

Nesting: During the nesting season, seven cover types were used. The majority of observations (62 percent) occurred in Open Upland. This is consistent with the literature, which indicates that females search for sunny, well-drained sites to lay eggs. Twelve and one-half percent of the box turtle observations during the nesting season occurred in wetlands. Use of wetlands was predominantly in the Scrub-Shrub and Forested Red Maple Wetland cover type. Open Upland was the most intensively used cover type during the nesting season. Three (depredated) nests were found in the MassHighway maintenance depot (Open Upland) in areas of sandy soils and sparse vegetation.

Summer: During the summer, Open Upland was again the most favored cover type. Other studies (Ernst et al. 1994, Stickel 1950) have found that box turtles estivate in woodlands during the summer to avoid the high heat. Woodlands also offer higher humidity than open areas, which may benefit box turtles by allowing them to conserve water more efficiently. The most time spent in wetlands occurred during the summer, with 19 percent of the observations recorded in wetlands (22 percent in 1998 and 16 percent in 1999).

In 1998, the high frequency of Open Upland use is attributed primarily to two animals (one male and one female). The male spent a substantial portion of the season at the field/forest edge, with occasional forays into the meadow itself. The female spent almost the entire season in the clearcut, but there are many slash piles and downed trees in the clearcut that she was found under, and which may have afforded higher cover and humidity retention than is typically associated with open habitats.

Fall/ Winter: Consistent with the literature, hibernacula were found for five individuals in forested portions of the study area. All were in forested upland habitat (one on an ecotone between Forested Pine-Maple Upland and Forested Red Oak Wetland). One male was tracked to his hibernacula both years, and the hibernacula were located approximately three meters apart from each other. The hibernacula for two turtles were located at the edge of their home ranges, while hibernacula for the remaining three were more centrally located.

Population Dynamics
The study area supports a substantial number of box turtles. Thirty-seven individual box turtles were captured, but it is not known whether they are all residents, or if all or a portion of their home range is within the study area, or how many individuals may be transients. Based on the age distribution and sex ratios, it is likely that the box turtle population is declining.

In contrast to the relatively large number of juveniles in the spotted turtle population, the box turtle population was found to contain only two juveniles. Although it is possible that juveniles were more difficult to find than their adult counterparts, the low percentage of captures (four percent) indicates low recruitment into the population. The heavily skewed adult to juvenile ratio may be influenced by difficulty in finding juveniles because they are smaller, are less active, and are subject to higher predation. The sex ratio and age classes captured are typical of declining populations, where numbers of males heavily outweigh the numbers of
females, and few juveniles are seen. Based on individual captures, the male to female ratio in the population is approximately 2.2:1, and the ratio of adults to juveniles is 18.5:1.

Home Range: Home ranges for 1998 are shown on Figure 4 (end of paper), and home ranges for 1999 are shown on Figure 5 (end of paper). Home ranges vary from 1.2 to 4.3 hectares for females and 2.4 to 7.5 hectares for males (Table 7). Between-year comparisons are available for two males and one female. The home ranges for males varied only 0.1 hectare between years for both males and varied substantially more for the one female (1.8 to 3.4 hectares). The home range of one male overlapped almost exactly between the two years. Average home range sizes were within the range of sizes reported by Schwartz and Schwartz (1991) for three-toed box turtles (Terrapene c. triunguis) in Missouri (between 2.2 and 10.6 hectares). One male was tracked to his hibernacula both years, and the distances traveled from hibernacula differed by only eight meters between 1998 and 1999 (Table 8).

Table 7
Box Turtle Home Range Sizes

<table>
<thead>
<tr>
<th>Turtle</th>
<th>Male Size (hectares)</th>
<th>Female Size (hectares)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>7.3</td>
<td>7.5</td>
</tr>
<tr>
<td>B3</td>
<td>2.5</td>
<td>2.4</td>
</tr>
<tr>
<td>B4</td>
<td>1.8</td>
<td>3.4</td>
</tr>
<tr>
<td>B6</td>
<td>--</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Avg. 4.90 4.95 4.93  Avg. 3.10 3.10 2.6

Table 8
Box Turtle Home Range Lengths and Distance Moved from Hibernacula

<table>
<thead>
<tr>
<th>Turtle</th>
<th>Sex</th>
<th>Home Range Length 1 (m)</th>
<th>Distance Moved From Hibernacula 2 (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Maximum 1998 1999 Mean</td>
<td>1998 1999 Mean Maximum 1998 1999 Mean</td>
</tr>
<tr>
<td>B1</td>
<td>M</td>
<td>402 442 422</td>
<td>937 -- 475 --</td>
</tr>
<tr>
<td>B2</td>
<td>F</td>
<td>267 N/A 134</td>
<td>700 -- 451 --</td>
</tr>
<tr>
<td>B3</td>
<td>M</td>
<td>295 268 282</td>
<td>850 858 503 504</td>
</tr>
<tr>
<td>B4</td>
<td>F</td>
<td>419 N/A 419</td>
<td>-- -- -- --</td>
</tr>
<tr>
<td>B5</td>
<td>F</td>
<td>250 291 271</td>
<td>-- 638 -- 291</td>
</tr>
<tr>
<td>B6</td>
<td>F</td>
<td>N/A 204 204</td>
<td>-- -- -- --</td>
</tr>
<tr>
<td>B7</td>
<td>F</td>
<td>N/A 394 394</td>
<td>-- 773 -- 404</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>327 320 304</td>
<td>829 756 476 399</td>
</tr>
</tbody>
</table>

1 N/A indicates the turtle was not tracked, or less than 20 observations were recorded.
2 Maximum distance from hibernaculum that a turtle was observed. Distance moved from hibernacula are provided for those turtles that were tracked to hibernacula in 1998 and/or 1999. The – notation indicates that the turtle was not tracked to a hibernaculum.

Most studies indicate that box turtles are not territorial and are not aggressive to other members of their species [Stickel 1950, Ernst et al. 1994 (but see Boice 1970)]. One male was observed on two occasions fighting with another male box turtle (on May 5, 1998, and July 23, 1998). Since this animal’s home range overlapped with three other turtles, it is unlikely that he was defending a territory. Ernst (1994) speculated that the aggressive behavior occasionally observed between two males may be mistaken courtship behavior.

Population Estimate: The box turtle population size was estimated to be 50 turtles. Assuming a 16.6-hectare area of suitable habitat, the box turtle population density approximates 3.0 turtles per hectare. Suitable
habitat was defined as the polygon encompassing all turtles' home ranges. Studies conducted in the 1940s in Maryland indicate densities between 8.9 to 12.4 turtles per hectare (Ernst et al. 1994). Subsequent samplings of these same populations indicate a decline in all of them, both in density and proportion of females (ibid.).

**Conclusions**

Federal and state regulations require development projects to avoid impacts to rare species and their habitats. Massachusetts is the third most densely developed state in the United States (Kittredge 1996), and impacts to rare species habitat cannot always be avoided. In these cases, public and private developers must work with state and federal agencies to mitigate unavoidable impacts.

Placement of the western portion of the new alignment was constrained by the existing Route 44 alignment. The emergent wetland adjacent to Route 58 was of particular interest to NHESP for this study because two juvenile wood turtles were observed here on three separate occasions in April 1990. No wood turtles were found in the entire study area during the two-year study, and it is likely that the two juveniles were transients without established home ranges. This wetland proved to be the most productive area for spotted turtles. Although the new highway itself is outside the home ranges of spotted turtles tracked in this study, the southern entrance ramp will bisect the spotted turtle population, isolating the emergent wetland from Turtle Pond. Design features on the entrance ramps will prevent turtles from climbing onto the roadway. Because the study showed the stream channel was the primary means of travel between the two habitat types, MassHighway proposed a 1.8-meter by 1.8-meter box culvert to convey the stream channel under the southern entrance ramp instead of the 600-millimeter reinforced concrete pipe included in the final highway design. Spotted turtle use of the box culvert will be assessed during a future study. A long-term study would also provide data on population trends.

The new alignment is not likely to have as great an effect on the box turtle population, based on the tracked turtles home ranges. One turtles’ home range will be bisected by the southern entrance ramp, as well as altered by the new alignment. Most use of all turtles occurred south of the new alignment in forested upland, open upland, forested wetland, and scrub-shrub wetland. There may be some shifts in box turtles home ranges, since some use was observed north of the proposed alignment. Approximately 100 meters of the Winnetuxet River and adjacent floodplain will be bridged by the new alignment, and it is possible that turtles will continue to pass under the alignment in the area of the new bridge. Changes in box turtle home ranges will be determined during a future study. The forest north of the new alignment contained less woody debris and deadfall than what the box turtles were frequently found under south of the alignment. Open uplands used by box turtles consisted of disturbed, sparsely vegetated areas, particularly the MassHighway maintenance depot. Only one turtle used an open meadow north of the new alignment (during the summer); the meadow was probably not used for nesting because the soil contained dense root materials difficult for nesting.

Biographical Sketches: Delia R. J. Kaye, Senior Environmental Scientist, Vanasse Hangen Brustlin, Inc. Ms. Kaye is a wetlands ecologist and wildlife biologist with VHB and has performed multiple wildlife studies on Cape Cod, the Islands and southeastern Massachusetts. She has received her degree in Wildlife Biology from the University of Vermont and is presently pursuing an M.S. in Biology from Harvard University Extension School. Ms. Kaye served as field supervisor for the rare turtle study for MassHighway in southeastern Massachusetts.

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Christopher Ross, Environmental Engineer, Massachusetts Department of Environmental Protection Wetlands and Waterways Division. Mr. Ross has over 14 years of experience in regulating, by permit, projects within the jurisdiction of the Wetlands Protection Act with an emphasis on Highway projects. As the lead review engineer he coordinated all aspects of the wetland permitting with the State, Federal and local environmental agencies. Mr. Ross holds a Bachelors Degree in Civil Engineering Technology form Northeastern University.

**References**


Fig. 1. Study Area Cover Types
Fig. 2. 1998 Spotted Turtle Home Ranges
Fig. 3. 1999 Spotted Turtle Home Ranges
Fig. 4. 1998 Box Turtle Home Ranges
Fig. 5. 1999 Box Turtle Home Ranges