

Amphibian Decline in the Mid-Atlantic Region: Monitoring and Management of a Sensitive Resource

Final Report
Legacy Resource Management Program
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Executive Summary

Amphibians have become recognized as sensitive indicators of environmental change. This sensitivity stems from their dual life histories with each individual being exposed to aquatic (as larvae) and terrestrial (as adults) environments, and their possession of a moist, sensitive skin across which most to all respiration takes place.

In contrast to many parts of the world where amphibians are declining and, in some cases, going extinct, the mid-Atlantic region of eastern North America has not yet experienced obvious losses of these animals other than in areas where there has been direct habitat loss. This is the primary cause of amphibian decline in this region. Some populations in this region may be at risk in the near future because acid levels are increasing in some areas. Because populations in this region have not yet reached the crisis stage, scientists are able to obtain baseline data on species occurrence and abundance against which future changes can be assessed. Accumulation of baseline data for future assessments requires that they be obtained from standardized monitoring protocols.

Field research in this three-year Legacy-supported project was conducted in three military bases, Fort Belvoir, Fort A.P. Hill, and Marine Corps Base Quantico, and two national parks, Prince William Forest Park (PWFP) and Shenandoah National Park (SNP). Quantico MCB and PWFP served as a single, combined lowland site. Amphibian populations were studied in seven, isolated low elevation wetlands in each of the military installations and PWFP, and three high elevation watersheds in SNP. Project objectives were to obtain a regional perspective on the status of amphibians in a portion of the mid-Atlantic region of the United States, to evaluate and establish appropriate long-term monitoring methodologies for each military installation and national park targeted by this study, and to obtain a baseline data set on the status and relative abundance of amphibian species occupying these sites.

Several standardized monitoring protocols were established and field tested in 1995-1997. Visual encounter surveys, frog vocalization surveys, and aquatic larval surveys were conducted in the low elevation sites to obtain information on species that breed in ponds and vernal pools. Time-constrained visual encounter surveys and line transects with randomly placed quadrats were used in the high elevation sites to assess streamside salamander assemblages.

Species composition varied considerably among lowland sites, ranging from a low of 3 and a high of 12. There was some year-to-year variation in species occurrence at most sites due to differences in rainfall patterns between years (1995 and 1997 dry, 1996 wet). Although the number of species was relatively similar among years in Shenandoah National Park watersheds, relative abundance estimates varied considerably due to the dry versus wet years. The major flood of 27 June 1995 in the lower Staunton River caused a severe decline of the salamander assemblage that may recover slowly as primary ecological succession takes place.

The results of this study demonstrate the need for continual long-term studies on amphibian populations and the freshwater wetlands they inhabit. Annual variation in weather, single weather events, and the amphibian's responses to them create variation in the composition and relative abundances of amphibians in any one site and on a regional basis. The value of these results is that the baseline data set against which future changes can be measured is now in place and that the protocols used to accumulate the long-term data required for analyses of population trends have been shown to be effective. The information on species composition of each wetland

site, seasonal timing of life history stages (e.g., breeding period, larval period), and apparent health of these environmentally sensitive species will allow resource managers to make informed decisions regarding activities that may affect amphibians and their habitats.

Site-specific management recommendations are provided in this report. General management recommendations for the military installations include: (1) protection of all wetland habitats and their current forest buffers up to a distance of 300 meters, (2) curtailing conversions of hardwood forest habitats to pine plantations, (3) minimize loss and damage of wetlands from draining, filling, and ORV activities, (4) locate and manage all wetlands with GPS and GIS technology; (5) initiate long-term monitoring of wetland chemistry and amphibian populations using standardized protocols, and (6) initiate a review process of the results of number 5 by qualified biologists. Management recommendations for Shenandoah National Park include: (1) ensure continuation of long-term monitoring of salamander assemblages in Long Term Ecological Monitoring watersheds, (2) continue monitoring of amphibians in the lower Staunton River and follow population response to ecological succession, (3) conduct a park-wide inventory of salamander assemblages in all primary Shenandoah National Park watersheds, and (4) develop a database on amphibian distribution and ecology using GIS technology.

Amphibians in the mid-Atlantic region are not declining from any agent known to cause declines in other parts of the world, except for the common and widespread agents of habitat loss and alteration. Potential future causes of amphibian decline in the mid-Atlantic are acid precipitation and introduced disease organisms. No evidence of either problem was discovered during the course of this study. Military bases and national parks in the mid-Atlantic act as preserves for the amphibians in this region. Military training and park recreation activities do not apparently impact amphibian populations adversely, except on a scale that can be controlled by local management. Military bases and national parks serve as vast habitat islands that are fast becoming surrounded by urban and suburban development. Amphibian populations in these areas appear to be secure at this time.

Introduction

Amphibians have received considerable media and scientific attention over much of the past decade because of species extinctions and population declines worldwide. Observations such as (1) the last individual of the Australian gastric brooding frog (*Rheobatrachus silus*) was seen in 1979 (Tyler and Davies, 1985); (2) the golden toad (*Bufo periglenes*) of Costa Rica was last seen in 1989 (Crump et al., 1992); and (3) two species of frogs formerly widespread in the Sierra Nevada of California (mountain yellow-legged frog [*Rana muscosa*] and Yosemite toad [*Bufo canorus*]) have declined precipitously (Bradford et al., 1992) have created a sense of alarm that something was happening on a global level. Examples such as these have been made public since herpetologists compared notes at the First World Congress of Herpetology held in Canterbury, England in 1989. Since then, numerous examples of declines and losses have been published (e.g., Fellers and Droost, 1993; Richards et al., 1993; Vial and Saylor, 1993; Blaustein et al., 1995; Droost and Fellers, 1996; Fisher and Shaffer, 1996; Lips, 1998).

Pin-pointing the causes of these problems has been elusive. In the early phase, scientists were looking for one global smoking gun. The results of studies that have been published since the alarm surfaced, however, indicate that the causes are varied and often local. The most common cause of local population decline continues to be habitat loss caused by a variety of factors, such as timbering, urbanization, and road building. Two physical factors have been implemented as major contributors. Lowering of the pH of ponds and soils by acid precipitation causes amphibian mortality in aquatic systems (Freda and Dunson, 1985; Wyman, 1988) and changes in microdistribution patterns of salamanders in terrestrial environments (Wyman and Hawksley-Lescault, 1987). Increased ultraviolet radiation, apparently due to the thinning of the ozone layer, has been shown to kill developing eggs of the Cascades frog (*Rana cascadae*) and western toad (*Bufo boreas*) (Blaustein et al., 1994a, 1995). The widespread fungus (*Saprolegnia ferax*) introduced into ponds and lakes in the Pacific northwest by introduced fish has caused egg mortality in the western toad (Blaustein et al., 1994b). An unidentified virus carried by introduced fish, such as tilapia, guppies, and carp, is suspected as causing frog decline in Australia (Anderson, 1995). Introduced fish and bullfrogs (*Rana catesbeiana*) have been implicated as causes of amphibian decline in the American west (Hayes and Jennings, 1986; Bradford, 1989; Kiesecker and Blaustein, 1998). Use of aerially-sprayed pesticides in Canadian forests and farmlands has been shown to cause developmental and behavioral problems in several species of frogs (Berrill et al., 1994; Ouellet et al., 1997). More recently, researchers have identified a new chytrid fungus in the skin of amphibians that apparently has

contributed to population decline and loss of species in tropical Australia and Central America (Berger, et al., 1998). This fungus has also been found recently in an endangered species of frog in the United States (Erickson, 1998).

In response to the myriad of examples of amphibian population decline and the need to identify some of the causes, the scientific community has called for the establishment of baseline inventories and long-term monitoring in sites across the United States and around the world (Freda et al., 1991; Pechmann and Wilbur, 1994; Blaustein, 1994). An important problem with assessing amphibian population trends is the lack of published long-term studies on amphibian populations and communities. The longest published studies were an intensive 12 year field census conducted in a Carolina Bay wetland in South Carolina (Pechmann et al., 1991) and a 20 year census of salamander populations in the mountains of North Carolina (Hairston and Wiley, 1993).

These studies demonstrated that amphibian populations, especially frogs, fluctuate over time but that none have become extirpated in these areas. Indeed, amphibian populations in eastern North America have so far apparently escaped the dramatic declines observed in western North America and other parts of the world.

Responding to the need for appropriate data to assess the apparent worldwide problem with amphibians, The Species Survival Commission (SSC) of the World Conservation Union (IUCN) established the Declining Amphibian Populations Task Force (DAPTF). Its goals are to (1) organize a global network of Working Groups to monitor and assess the status of amphibian populations, (2) promote studies of potential causes of decline, (3) recommend uniform protocols for monitoring procedures, and (4) generate appropriate conservation action plans for policy makers, land managers, and scientists and organizations concerned with the maintenance of biological diversity (DAPTF, 1995). Goal three has been addressed by the publication of a book outlining standardized protocols and methodologies for studying amphibian populations (Heyer et al., 1994). This book has become the standard reference for this worldwide effort.

In the mid-Atlantic region, a decline of acid neutralizing capacity (a measure of the buffering capacity of an aquatic system) has been documented in several of the mountain watersheds in Shenandoah National Park and in regions nearby (Lynch and Dise, 1985; Webb et al., 1989a, 1989b, 1994). The cause is acid deposition from acid-laden air masses from the midwestern United States. Research to date has demonstrated varied biotic responses to low pH in fish and invertebrates in these sites (Camuto, 1991; Feldman and Conner, 1992; Bulger et al., 1993). Studies elsewhere have shown that amphibians are sensitive to acid deposition (Clark and Hall, 1985; Freda, 1986; Freda et al., 1991). Because

acid precipitation occurs in the mid-Atlantic region and because fish and several invertebrate species have experienced population decline and extinctions, we would expect that at least some amphibian species are being affected by acid deposition in this area.

The immediate problem in addressing this concern, however, is that there are few to no baseline data available on amphibian species occurrence or on any population parameter for any watershed in the mid-Atlantic region. Military bases and national parks offer excellent places to conduct long-term monitoring of these sensitive resources because many of these areas contain habitats that are protected from the forces that cause permanent habitat loss.

Project Objectives

The objectives of this Legacy Resource Management Program project are to (1) obtain a regional perspective on the status of amphibians in a portion of the mid-Atlantic region of the United States, and (2) to evaluate and establish long-term monitoring methodologies for each DoD installation and national park targeted by this study.

Objective 1 has been addressed by conducting inventories and monitoring surveys of amphibian communities in three US Department of Defense installations during 1995-1997: Fort Belvoir, Fort A.P. Hill, Marine Corps Base Quantico (and its immediate neighbor Prince William Forest Park (National Park Service)), and during late-1994-1997 in Shenandoah National Park (Figure 1).

Objective 2 was addressed by developing monitoring protocols that (1) work effectively in each military installation and national park and (2) follow the protocols outlined in Heyer et al. (1994). In this way, the information and data accumulated during the course of this project will be useful to and assist with the larger amphibian monitoring programs being established across the United States.

The Report

The results of the Legacy Resources Management Program project presented in this report are divided into two primary sections based on the ecological and faunal differences that occur between the three military bases and Shenandoah National Park. The wetlands containing amphibians on military bases consist largely of ponds and vernal pools, whereas the wetlands containing amphibians in Shenandoah National Park are mountain streams. These two contrasting habitats support different groups of amphibians: (1) ponds and vernal pools with frogs and pond-breeding salamanders and (2) mountain streams

with largely streamside salamanders. Therefore, monitoring techniques and protocols differed substantially between these two areas. The two sections of this report reflect this dichotomy.

This report covers the period of 1 September 1994 through 15 October 1997. The field season started late in 1994 because the authorization to establish an agreement with a private university was not finalized until late-summer 1994 and because funds were not transferred until 30 September 1994.

I have used scientific names of the amphibians recorded in this study throughout this report. All common and scientific names of the species used here in are in Appendix 1.

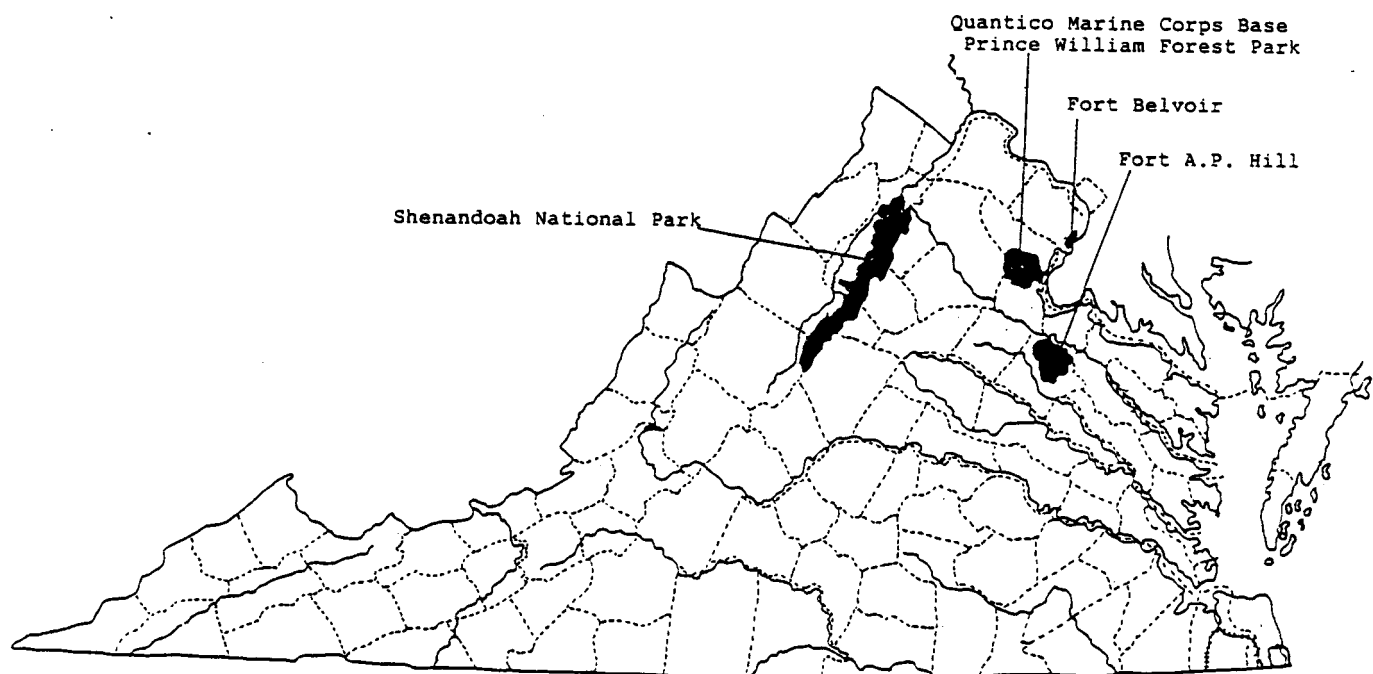


Figure 1. Map of Virginia illustrating the geographic locations of the federal installations within which this study was conducted.

Part 1

Amphibian Populations on Fort Belvoir, Marine Corps Base Quantico, Prince William Forest Park, and Fort A.P. Hill

Introduction

Numerous factors determine the presence or absence of an amphibian species in the landscape. In general, tolerance limits to physical environmental parameters, such as sunlight and temperature, and biological parameters, such as the availability of appropriate prey for all life history stages, influence the distribution patterns of frogs and salamanders. The occurrence of most of the amphibian species (except terrestrial salamanders) in a particular region is correlated with the types of wetlands available, their distribution, and their quality (e.g., Forester, 1993). In the mid-Atlantic region, three factors influence the composition of amphibian communities within wetlands - length of time the wetland holds water (the hydroperiod), acid levels in the aquatic system, and the presence or absence of predatory fish.

Acid levels in the region of northern Virginia that include Fort Belvoir, Prince William Forest Park, Marine Corps Base Quantico, and Fort A.P. Hill have not been well studied. I am unaware of any studies on wetlands in this particular region that allow an evaluation of the trends in acidity. However, continent-wide studies (Wisniewski and Kinsman, 1988) and those in nearby Shenandoah National Park (see below) demonstrate that acid levels have increased and the ability of natural systems to buffer these perturbations has decreased. Amphibians are sensitive to low pH levels and respond behaviorally (Kutka, 1994), physiologically (McDonald et al., 1984; Freda and Dunson, 1985; Pierce, 1985; Freda, 1986), and ecologically (Pough and Wilson, 1977; Clark, 1986; Freda and Dunson, 1986; Freda et al., 1991).

Many species of amphibians, especially treefrogs, breed almost exclusively in fish-free habitats such as vernal ponds and ephemeral rain pools (Bradford, 1989; Hopey and Petranks, 1994). Others, such as bullfrogs (*Rana catesbeiana*) and green frogs (*Rana clamitans*) are able to reproduce and grow in habitats harboring fish. The latter group avoids or reduces predation by producing noxious secretions or by occupying microhabitats inaccessible to fish. The mosaic of wetland habitats in the three military bases included in this study offer a broad spectrum of habitat types. Some of them contain fish and some do not. The length of the hydroperiod affects fish presence. Wetlands that harbor fish usually support water year-round, whereas those that dry up seasonally (usually in summer), do not have fish. These wetlands are used extensively by frogs such as wood frogs (*Rana sylvatica*), Cope's gray treefrogs

(*Hyla chrysoscelis*), spring peepers (*Pseudacris crucifer*), and spotted salamanders (*Ambystoma maculatum*). Amphibians breeding in temporary wetlands must have short enough larval periods so that the larvae can metamorphose before the pool or pond dries out.

The amphibian fauna in the geographic area encompassing the military installations and national park (PWFP) in this study is composed of some 17 frogs and toads and 16 species of salamanders (Tobey, 1985; Mitchell, unpublished). Due to the factors outlined above, each installation would be expected to encompass a unique subset of the total list of species because of differences in the number and extent of wetland habitats available for amphibians in each of these areas. Habitats common to all three installations include man-made ponds with shoreline and emergent vegetation, beaver ponds, freshwater marshes, and vernal pools. Different sets of amphibians occupy each of these habitats. Thus, an inventory of the amphibian fauna of a specific area requires that several habitats be included in the project's design so that all of the species expected may be encountered.

In this section, I compare the results of three years of baseline inventory of and data from standardized monitoring protocols on the region's amphibian fauna. Site descriptions and the results for each military base are presented separately. The results for Prince William Forest Park (one ephemeral wetland site) are included with the section on Marine Corps Base Quantico.

Site Selection

Seven wetland sites were selected on each military base: Fort Belvoir, the Prince William Forest Park and Marine Corps Base Quantico area, and Fort A.P. Hill (Figure 1). Site selection began in September 1994. Each site is described in the narrative for each of the three study areas.

The following criteria were used to select sites: (1) accessibility - sites had to be near a road or parking area accessible to a passenger car and had to be within 5 minutes of walking time, (2) minimal interference from military training activities and vice versa, (3) the site had to be expected to harbor several species of amphibians, (4) the site was expected to persist as a wetland for the foreseeable future, and (5) the majority of sites should be located in the same watershed for consistency within this study.

During each site visit, my field assistants and I checked in with Range Control, Training, or appropriate personnel in the environmental section to reduce potential interactions with military training activities.

Protocol

Field protocols for frogs and toads are fundamentally different from those for salamanders. Frogs and toads, like nearly all frogs worldwide, vocalize their presence during the breeding season. Males produce species-specific vocalizations that are used to attract females and to advertise and defend territories. Although females lack the ability to vocalize, they select males based on body size and differences in call structure. Vocalizations allow us to inventory frog and toad populations without having to catch each individual for identification. Such inventories are always conducted at night, the primary time of calling activity.

Salamanders, on the other hand, do not vocalize. Inventories of salamander populations require that the investigator actually encounter adults during the season of primary activity. This usually means that each individual must be captured for positive identification.

The larval stages of both groups (tadpoles and salamander larvae) in the wetlands included in this study are also seasonal in their occurrence and require capture for positive identification.

The protocols used in this project focused on the nighttime calling activities of adult frogs and toads, on the daytime activity patterns of frogs and aquatic salamanders, and the capture of aquatic tadpoles and salamander larvae during the day. Use of the three primary field protocols -- visual encounters, assessment of nighttime vocalizations, and dipnetting for larvae in the daytime -- ensured that the majority of species expected for each wetland study site were encountered.

Three amphibian monitoring protocols were selected for use on the three military bases and Prince William Forest Park: visual encounter survey, frog call survey, and larval survey. The visual encounter survey was incorporated into the latter two methodologies by recording all observations of amphibians in addition to the data recorded during the execution of the frog call and larval surveys.

The frog call surveys required following the road circuit that connected all seven sites in each of the military bases on a weekly basis. The following procedures were followed at each wetland site: (1) record start and end time, air and water temperature (°C), relative humidity, cloud cover, relative wind speed, and relative water turbidity on the data sheet, (2) record all species heard and observed, along with their relative chorus size and microhabitat using the scale provided on the data sheet, (3) include information on all life history stages observed, and (4) record the species calling during a 10 minute

(1995) or 5 minute (1996, 1997) time period on a hand-held cassette recorder. These data sheets (1 per site/installation/week) and the backup cassette tape used for verification formed the information base on the amphibian fauna based on the nighttime surveys. With exceptions for two bases in 1997, frog call surveys began in mid-March and continued on a weekly basis through the first week of September. This time period covered all amphibian species that are primarily active in the early spring and those who are primarily active in late spring and summer. Frog call surveys on Fort Belvoir and Marine Corps Base Quantico in 1997 started later than desired because of funding delays and organizational delays associated with base access.

The following people assisted with the frog call surveys during 1995-1997: (1) Fort Belvoir: T'Shaka Toure, Graduate Student, Howard University, Washington, D.C. (1995-1997); (2) Marine Corps Base Quantico and Prince William Forest Park: Michael Killian, High School Science Teacher, Spotsylvania Co. Virginia and Dr. Werner Wieland, Department of Biology, Mary Washington College, Fredericksburg, Virginia (1995-1997), and (3) Fort A.P. Hill: 1995 - Mark Dunaway and John Walter, Undergraduate Biology majors, Randolph-Macon College, Ashland, Virginia (1995), and C. Todd Georgel, recent biology graduate of East Carolina University currently residing in Richmond, Virginia (1996-1997).

The larval amphibian survey was conducted at approximately biweekly intervals on the three military installations from mid-April through mid-September 1995 and 1996; monthly in 1997 during April-July due to extreme drought conditions. Each wetland site was surveyed for tadpoles and larval salamanders with a hand-held D-ring dip net. In order to provide some quantitative measure of relative abundance, I assessed the total time it would take to complete a survey of all seven wetland sites in one day. Effort per unit area was taken into consideration. The following numbers of approximately 1-meter sweeps by the dip net were deemed appropriate for the wetland types available in this project: (1) small vernal pools <5x10 meters in size (e.g., logging road ruts) were sampled with 5 sweeps of the dipnet, (2) larger vernal pools were sampled with 10 sweeps of the dipnet, and (3) large ponds and marshes were sampled with 20 sweeps of the dipnet. Where possible, dipnet samples were taken $\geq$ 5 meters apart to help ensure independent samples (Heyer et al., 1994).

All dipnet sweeps were conducted along the shoreline of each wetland. The dipnet was usually held in contact with the substrate during the sweep. Larvae were identified and counted in the field, although several specimens of each species were collected for voucher specimens and to ensure that the species was correctly identified. All other individuals were released. All species and

environmental data were recorded on standardized data sheets.

In 1996 and 1997, I obtained information on acid levels (pH) of the study sites in the three military bases and PWFP in two ways. I collected water samples periodically with Nalgene™ bottles that had been rinsed with hydrochloric acid and rinsed and stored with de-ionized water. These samples were analyzed by an undergraduate chemistry student at the University of Richmond. Laboratory based pH readings were obtained with an Accumet 950 pH meter. In 1997 I collected water samples that were processed by Dr. D. Downey, Chemistry Professor, James Madison University, Harrisonburg, VA. Samples were obtained twice in 1997, once in spring and once in summer. During both years, I also obtained pH measurements in the field with a Hanna HI9023C portable pH meter. The results of both measurements are presented in the appropriate tables.

Results and Conclusions

Site descriptions, results, conclusions, and site-specific management recommendations are presented separately for each military installation and national park.

Results for Fort Belvoir

Fort Belvoir Military Reservation (U.S. Army) is located in southeastern Fairfax County, Virginia, approximately 15 miles south of Washington, D.C. The reservation is bordered to the south by Pohick Bay Regional Park and Mason Neck National Wildlife Refuge, to the east by the Potomac River, to the north by Huntley Meadows Park, and to the west by urban Fairfax County. Fort Belvoir consists of 8,419 acres of which 59% (4,961 acres) are devoted to training, recreation, and environmentally sensitive areas. The latter is comprised of 3,381.9 acres, about 40% of which are wetlands. The post is becoming the administrative center for the United States Army in the National Capitol Region and provides space for over 90 tenant activities. Ernst et al. (1997) provided a summary of the natural history of the amphibians of Fort Belvoir and vicinity.

The seven wetland study sites on Fort Belvoir were located within the Accotink Creek, Dogue Creek, and Pohick Creek watersheds (Figure 2), all of which form tributaries of the Potomac River. Sites 1-5 are located on Fort Belvoir's South Post and sites 6-7 on the base's North Post. South Post is located in the Coastal Plain physiographic province and the North Post is located in the eastern margin of the Piedmont. Descriptions of each amphibian monitoring site follow.

Site Descriptions

Site 1 (Accotink Bay) - This site is located within Accotink Bay Wildlife Refuge and Nature Study area (in Training Area W-2 on the map of the reservation). The refuge encompasses over 1,315 acres of marshes, streams, beaver ponds, and slopes with mixed hardwood trees. The study area is an open wetland that parallels a portion of the paved, Wetlands Trail adjacent to the Pohick Road handicapped parking area.

The wetland is in a shallow, crescent-shaped area, with emergent grasses and pickerel weed (*Pontederia cordata*). The substrate is highly organic and deep. Within the loop of the crescent is an area of saturated soils dominated by young willows (*Salix* sp.) and grasses. The entire area is surrounded by a relatively mature hardwood forest. Red oak (*Quercus rubra*), birch (*Betula* sp.), and tulip poplar (*Liriodendron tulipifera*) dominate the western slope. Beech (*Fagus grandifolia*) and red oak, with an understory of dogwood (*Cornus florida*), dominate the forest on the northern and eastern slopes. An area of red maple (*Acer rubrum*) and hickory (*Carya* sp.) occurs along the Wetland Trail in a seasonally saturated forested wetland to the south, and beech trees

Fort Belvoir

Amphibian Research Sites

- | | |
|-----------------|----------------------|
| 1. Accotink Bay | 5. Lower T-9 |
| 2. Poe Road | 6. Dogue Creek Field |
| 3. Pohick Creek | 7. Dogue Creek Marsh |
| 4. Upper T-9A | |

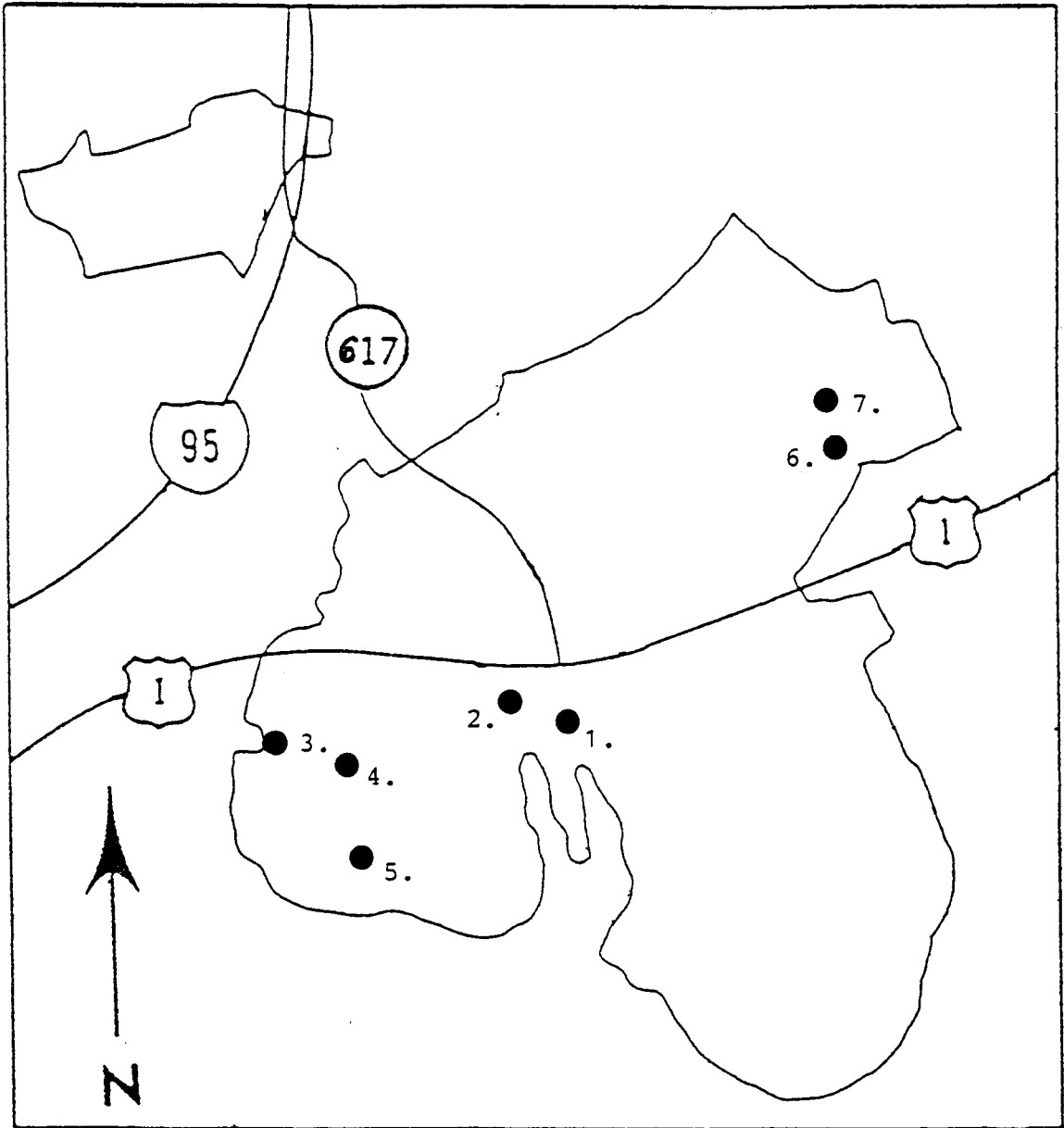


Figure 2. Map of Fort Belvoir, Fairfax County, Virginia illustrating the location of the seven amphibian monitoring sites. Numbered sites on the map correspond with those described in the text and in the following tables.

essentially dominates the forest to the southeast near the Accotink Creek channel. Standing water disappeared from this site during late August because of the drought conditions that prevailed in the summer of 1995. The weather in 1996 was wet, in stark contrast to that in 1995, and this site did not dry that year. This site contained water when first studied in April 1997 but by the end of May the wetland had nearly dried out and contained only shallow, muddy water. This condition prevailed through the summer.

Site 2 (Poe Road) - This site is located about 30-40 meters south of Poe Road and 300 meters west of its junction with Accotink Creek at the north end of W-1. It consists of two small, shallow, ephemeral wetland pools within a grassy area on the edge of a stand of planted loblolly pine (*Pinus taeda*). Several small red maple and hickory trees were present in the understory. Both pools at this site dried up completely by 10 June 1995. Only one of the pools dried completely in 1996. The pool that contained water for all of 1996 had water in April 1997 but was down to a 3x4 m pool in late May. It was dry in June and remained so the rest of the summer. The other pool in this site was dry when first visited in April 1997 and never filled that year.

Site 3 (Pohick Creek) - Site 3 is located in the floodplain of Pohick Creek in the westernmost section of the Accotink Bay Wildlife Refuge at the upper end of F-1 between the end of Poe Road and Pohick Creek. The main section contains two channels that are periodically inundated with water from the main stream channel. Isolated pools form in these channels when water levels are low. The floodplain is almost entirely covered with thick mats of grasses and sedges with several scattered cattails (*Typha* sp.) stands and young sycamore trees (*Platanus occidentalis*). Mature sycamores, red maples, and tulip trees are located at the northern end of the floodplain, on the adjacent slope, and on the eastern side of the creek. These trees, plus river birch (*Betula nigra*) and black gum (*Nyssa sylvatica*) dominate the forest along the southeastern slope. White oak (*Quercus alba*) and tulip poplar occur along the southern end. Beavers inhabit the area and have created several small ponds at the upper end. The intermittent channels and isolated pools nearly dried in August 1995 but refilled late that month from a rain storm. All pools retained water throughout the study period in 1996. In 1997, many of the pools that occur as isolated pockets during dry periods had dried out completely by the end of June. Only a small rivulet in the main creek channel and a small pool contained water in summer 1997.

Site 4 (Upper T-9A) - This site consists of a small, shallow pool located within a stand of young sweetgum (*Liquidambar styraciflua*) at the northern end of training area T-9A. Other trees in the area are red maple, sycamore, black gum, black locust (*Robina pseudoacacia*) and black cherry (*Padus serotina*). The substrate at the main pool supports sphagnum and several grasses in the drier areas. A low, broad depression characterizes the topography of this area. It contains the approximately 15x25 meter pool that usually holds water in late winter and early spring. This area, in addition to the pool, supports amphibian populations. The entire area was completely dry by 10 June 1995. It did not dry completely in 1996. This site contained water in spring 1997 but by June it had dried down to two small pools. The site dried completely in July and remained so the rest of the summer.

Site 5 (Lower T-9) - This site is part of a large beaver pond complex located at the lower end of training area T-9. The main pond is relatively shallow (<1.5 meters) and contains young tulip poplar, sweetgum, sycamore, river birch, and willow oak (*Quercus phellos*). Attached to this pond to the northeast is a series of smaller, shallow beaver ponds and on the north side of this area is a very large beaver meadow-pond complex. I included all but the large complex in the study site. The forest surrounding the series of beaver ponds, except for the southwestern portion, consists primarily of red maple, sweetgum, sycamore, and willow oak. These trees and loblolly pine form a tree line along the southern and eastern rim of the main pond. The southwestern portion of this study area contains mostly grasses with patches of green briar (*Smilax rotundifolia*). Blackberry (*Rubus* sp.) and a stand of Virginia pine (*Pinus virginiana*) and red cedar (*Juniperus virginiana*). This site nearly dried by early September 1995 but retained water throughout 1996. In 1997, this site held water throughout most of the summer but due to the drought conditions, nearly dried by mid-July. Only two small pools of water remained in each of the two portions of this site at this time; tadpoles of two species were found. It dried out completely in August.

Site 6 (Dogue Creek Field) - Site 6 is a shallow depression in a field adjacent to the trail along the western margin of the Jackson M. Abbot Wetland Refuge on the North Post of Fort Belvoir in the Dogue Creek watershed in W-4. The vegetation in the field is dominated by a variety of grasses, sedges, and composites, with a small stand of cattails in the lowest portion. The surrounding forest is comprised of loblolly pine and red cedar to the east, black locust, red maple, and red cedar to the south and southwest, willow oak and red oak to the west, and black locust and mimosa (*Albizia julibrissin*) to

the north. This site dried completely by late July 1995 but did not dry completely in 1996. In 1997, the site retained water through June, despite the drought. It was dry the rest of the summer.

Site 7 (Dogue Creek Marsh) - This is the largest of the monitoring sites on Fort Belvoir. The area consists of a large, shallow marsh within the refuge in W-4. An abundance of pickerel weed, water-lily (*Nymphaea odorata*), utricularia, and algae occurs in the marsh proper. The actual amphibian monitoring site is a cove on the western edge bordered by loblolly pine/sweetgum woods to the south, a red maple, sweetgum, red oak, black gum, Virginia pine forest to the west, and a long terrestrial spit with red maple trees to the north. Emergent grasses occur along the northern and southern margins. Access to the cove is through the forest along the western margin of the refuge. The drought of the summer of 1995 caused the water level to drop substantially, but the area did not entirely dry up. It retained water throughout the entire marsh during all of 1996. In 1997, the site retained water throughout the year, but drought conditions that summer caused water levels to drop and the size of the marsh to shrink. The low water was choked with *Utricularia* that summer.

Results

The number of amphibian species recorded for the seven wetland sites varied from 10 to 12 in 1995, 9-12 in 1996, and 4-9 in 1997 (Table 1). None of the three protocols used alone encountered all species in all sites. However, the nighttime frog call survey, in which all species seen and heard were recorded, registered 80-100% of the total known for individual sites. The use of larval dipnetting and daytime encounter surveys registered about 25-75% of the total recorded for individual sites. Results in Table 2 demonstrate that both the nighttime frog call survey and larval dipnetting survey techniques must be used together to ensure that all species are encountered. All frogs in each wetland site were registered during the frog call surveys. None was recorded solely with other protocols. Many frog species, although not all, were also registered during the larval dipnetting surveys. Salamanders were not encountered during frog call surveys. Only dipnetting during daytime sampling periods and visual encounters discovered these species. These overall results demonstrate that there is considerable variation in species composition in the wetlands of Fort Belvoir and that the use of multiple protocols is the best approach for an inventory and monitoring program.

Results in Tables 3-9 demonstrate conclusively for each wetland that frogs exhibit strong seasonal variation in the timing of male vocalizations and

when the larvae are present. Several species are reproductively active in early spring (e.g., spring peepers [*Pseudacris crucifer*], chorus frogs [*Pseudacris triseriata*], pickerel frog [*Rana palustris*]) and others are active primarily in late spring and summer (e.g., bullfrogs [*Rana catesbeiana*], green frogs [*Rana clamitans*], northern cricket frog [*Acris crepitans*]).

The results also show that the larvae (tadpoles) of some species have a higher catchability than others. Those in the genus *Rana* (e.g., bullfrogs, green frogs) and genus *Bufo* (toads) were encountered more often than those of other species groups. This is probably due to the microhabitats selected by different species and our ability to capture them when dipnetting along the edge of a wetland. These tadpoles are also larger and, in the case of ranid frogs, often overwinter, making them available essentially year-round. The tadpoles of some species of *Rana*, especially bullfrogs and green frogs, may take a year or more to reach metamorphosis and consequently remain in some of these wetlands over winter.

Compared to other military installations and wetlands studied in this project (see below), the methods used in this study suggests that Fort Belvoir does not appear to support a diverse salamander fauna. Only three species (marbled salamander [*Ambystoma opacum*], spotted salamander [*Ambystoma maculatum*], northern two-lined salamander [*Eurycea bislineata*]) were recorded in five of the seven wetland sites during all three years of study (Table 10). The first two species breed in ephemeral, vernal pools and woodland ponds, the third is primarily a stream salamander. Spotted salamanders laid eggs all three years in 3 wetland sites and two out of the three years in 2 others. Marbled salamanders reproduced in 2 locations in 1995 and one location in 1996. They were not encountered in 1997. Two-lined salamanders were found in only one location in 1996 and were not encountered in 1995 or 1997. Several other species are known for the base (C.H. Ernst, personal communication) and Fairfax County (Tobey, 1985; J.C. Mitchell, unpublished) but they were not encountered in 1995-1997 in the locations selected for this study.

Wetland Acidity Levels

Of the seven study sites on Fort Belvoir, only Site 4 remained acidic with pH values between 4.9 and 5.7 throughout 1996 (Table 11). In 1997, this site had less acidic readings between 5.5 and 6.1. This site was a small, woodland depression with abundant sphagnum. The remaining sites were near or above pH 6.0 for 1996 and 1997. Thus, acidity levels in the Fort Belvoir area do not appear to be at levels to warrant concern relative to the impact of acid deposition on amphibians.

The two types of approaches used to obtain pH caused variations in the

readings (laboratory and field). Some of the variation observed among sites and between years may be due to field instrument error, delays in taking the pH readings of samples brought to the lab, and calibration error. There are no obvious correlations in the readings taken by the different instruments. Thus, the pH values provided by both techniques should be viewed as the range experienced by each wetland site. Both laboratory and field pH measurements support the observation that wetlands on Fort Belvoir are apparently not experiencing highly acidic.

Seasonal variation in dissolved oxygen (DO) readings vary among sites and seasons (Table 12). DO readings in spring are higher than those taken later in the year for several wetland sites. Only in Site 5 did DO readings climb from April to May, although they decreased sharply in June. Site 6 was the only site in which DO readings were high throughout spring and summer. This is an open field with abundant grass vegetation and shallow water.

Water samples were collected twice in 1997 for analysis of cations, anions, and acid neutralizing capacity (Table 13). In all sites, ANC was well above the cutoff of 100 $\mu\text{eq/l}$, values below which are considered to be indicative of poor neutralizing conditions. Most sites have high calcium and sodium levels, indicative of salt content. Such salts are usually derived from road surfaces and potentially contaminate wetlands. How they affect amphibian adults or larvae is unknown.

Conclusions

Overall results for Fort Belvoir suggest that the field work conducted in 1995-1997 using the standardized protocols described above allowed a full inventory of the frog fauna and an incomplete inventory of the salamander fauna. These results are indicative of the true composition of the frog assemblages in each of the seven wetlands. The results for the salamanders may reflect actual assemblage composition for each wetland studied here but do not reflect the salamander fauna throughout all of this military base. Despite the fact that the 1995 and 1997 seasons were dry and the 1996 season was wet, the phenological patterns exhibited by the frog communities were similar (Tables 3-9). Several species persisted in spring and others in late spring and summer. The drought conditions that prevailed in the summer of 1995 did not curtail substantially the breeding periods of most species. They did, however, appear to affect breeding activities in 1997. This was most likely due to the fact that dry conditions prevailed earlier in the year (May) in 1997 than in 1995 (June).

The results from this three-year study should be viewed as the baseline

for a long-term monitoring project. Long-term studies is the only way to fully assess the true population status of each of the amphibian species on Fort Belvoir.

The combined use of the two standardized protocols (frog call surveys, larval surveys), along with visual encounter surveys, proved to be effective and useful approaches to inventory and monitor the majority of amphibians of Fort Belvoir. Future studies of these animals in the wetlands on this installation should use these protocols in the manner described here so that the results can be compared across years. Without the use of standardized protocols, the ability to determine trends in community composition and whether these amphibians are in a declining trend will be diminished.

The frog fauna of Fort Belvoir does not appear to be in any danger of immediate decline. No malformations were found on any animals examined, and most species appeared to be relatively numerous whenever sufficient water was present to allow breeding and larval development. The information available for the salamander fauna is too meager to make any decision about the status of any species. Spotted and marbled salamanders breed in several locations each year but may not be abundant in any location.

Current acidity levels in wetlands on Fort Belvoir are not of concern because they are well above the level (pH 4.5) where studies have shown amphibians to be at risk. The chemical nature of these wetlands is altered by salt and possibly other chemical contamination from the surrounding urban environment. These conditions have apparently not had a serious affect on local amphibians. However, continuation of the amphibian monitoring program on Fort Belvoir should continue, along with chemical assessment, to be able to identify effects on these sensitive animals. Results derived from this study provide the initial baseline against which future changes in water chemistry and frog populations can be assessed.

Management Recommendations for Fort Belvoir

1. Maintain all wetland habitats for amphibian breeding requirements and buffers of the surrounding forest habitat remaining at this time. A buffer of at least 300 meters is recommended based on studies that evaluate terrestrial movement patterns in amphibians.
2. Destructive activities, such as draining, filling, bulldozing, and ORV intrusion, should be avoided. Construction activities that destroy any of these wetland should be avoided.

3. Mitigation of wetland losses due to future projects should be done to increase protection of other wetlands and their 300 m buffers on the base for the long term. Codify these protected areas into set-aside preserves.
4. All wetland sites should be monitoring annually for beaver activities, causes of siltation, and other perturbations so that prevention and restoration projects can be undertaken early.
5. Site 6 is a unique habitat for amphibians on this base and should be monitored closely. It contains species rich populations of dragonflies, frogs, and salamanders despite its shallow topographic features. Biological interactions between dragonfly and amphibian larvae in this site are unlike any other on base and should be studied. Maintenance of this site requires maintaining the field habitat and the prevention of natural succession. The patches of cattails should be monitored as they may affect the hydrological characteristics of this site.
6. Water chemistry variables should be evaluated annually in all wetlands to determine whether road salt and other forms of urban pollution are increasing.
7. Amphibian populations should be monitored with the standard protocols used in this study for at least 20 years.

Table 1. Number of amphibian species recorded for the seven amphibian monitoring sites on Fort Belvoir by three techniques in 1995, 1996, and 1997: Night Vocalizations = frog call survey, Larval Sampling, and Visual Encounter Survey (including frog calls).

Technique	1	2	3	Site 4	5	6	7
1995							
Night Vocalizations	11	8	10	8	11	10	10
Larval Sampling	5	2	5	3	7	5	6
Visual Encounter Survey	5	3	3	4	7	4	8
Total No. Species	11	10	11	10	12	12	11
1996							
Night Vocalizations	10	8	10	10	11	9	10
Larval Sampling	5	6	7	4	5	4	4
Visual Encounter Survey	4	3	4	3	6	3	4
Total No. Species	10	9	11	12	12	10	10
1997							
Night Vocalizations	6	2	2	2	4	5	7
Larval Sampling	4	2	5	3	4	3	3
Visual Encounter Survey	4	3	4	1	5	3	6
Total No. Species	8	5	8	4	7	7	9

Table 2. Amphibian species in each of seven amphibian monitoring sites on Fort Belvoir, Virginia. Abbreviations: species identified by vocalizations (V), by identification of frog larvae (tadpoles) and adult and larval salamanders collected by dipnet (L). Common names of all amphibian species are in Appendix 1.

Species	SITE						
	1	2	3	4	5	6	7
1995							
Frogs:							
<i>Acris crepitans</i> (Ac)	V	V	V	V	V	V	V
<i>Bufo americanus</i> (Ba)	V	V	VL	V	VL	V	V
<i>Bufo fowleri</i> (Bf)	VL	V	VL	V	V	V	V
<i>Hyla chrysoscelis</i> (Hch)	VL	V	V	VL	VL	VL	V
<i>Hyla cinerea</i> (Hci)	V		V		V	V	V
<i>Pseudacris crucifer</i> (Pc)	V	V	V	V	VL	VL	VL
<i>Pseudacris triseriata</i> (Pt)	V	V		V	V	V	
<i>Rana catesbeiana</i> (Rca)	VL	V	VL		VL	V	VL
<i>Rana clamitans</i> (Rcl)	VL		VL		VL	V	VL
<i>Rana palustris</i> (Rp)	VL	V	L	V	VL		VL
<i>Rana sphenoccephala</i> (Rs)	V		V	V	V	VL	VL
Salamanders:							
<i>Ambystoma maculatum</i> (Am)		L		L	L	L	L
<i>Ambystoma opacum</i> (Ao)		L		L		L	
1996							
Frogs:							
<i>Acris crepitans</i> (Ac)	V	V	V	V	V	V	V
<i>Bufo americanus</i> (Ba)		VL	VL	V	VL	VL	
<i>Bufo fowleri</i> (Bf)	V	VL	VL	VL	V		V
<i>Hyla chrysoscelis</i> (Hch)	VL	VL	VL	VL	VL	VL	VL
<i>Hyla cinerea</i> (Hci)	V	V	V	V	V	V	V
<i>Pseudacris crucifer</i> (Pc)	VL	VL	VL	VL	VL	VL	VL
<i>Pseudacris triseriata</i> (Pt)	V	VL	V	V	V	V	
<i>Rana catesbeiana</i> (Rca)	VL		VL		V		V
<i>Rana clamitans</i> (Rcl)	VL	VL	VL	VL	VL	VL	VL
<i>Rana palustris</i> (Rp)	V		VL	V	VL	V	VL
<i>Rana sphenoccephala</i> (Rs)	V		V	V	V	V	V
Salamanders:							
<i>Ambystoma maculatum</i> (Am)		L		L	L	L	
<i>Ambystoma opacum</i> (Ao)				L			
<i>Eurycea bislineata</i> (Eb)			L				

Table 2 continued

1997

Frogs:

<i>Acris crepitans</i> (Ac)	V	V	V		V	V	
<i>Bufo americanus</i> (Ba)			VL		V		
<i>Bufo fowleri</i> (Bf)			L			V	V
<i>Hyla chrysoscelis</i> (Hch)	V	V	V		VL	V	V
<i>Hyla cinerea</i> (Hci)	V						V
<i>Pseudacris crucifer</i> (Pc)	L	V	L	L	VL	L	L
<i>Rana catesbeiana</i> (Rca)	VL		VL				V
<i>Rana clamitans</i> (Rcl)	VL	VL	VL	VL	VL	VL	VL
<i>Rana palustris</i> (Rp)	L		L		VL		VL
<i>Rana sphenoccephala</i> (Rs)	V		V	V	V	V	V

Salamanders:

<i>Ambystoma maculatum</i> (Am)		L		L		L	L
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Table 3. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 1 on Fort Belvoir for 1995-1997. Species order and abbreviations as in Table 2. Abbreviations: "V" = vocalizing males, indicating the breeding period, and "L" = known larval period.

		Species										
Week		Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1995												
March	13						V			L	V	
March	20									L		
March	27						V			L	V	
April	3		V				V			L	V	
April	10						V		L	L	V	
April	17			V			V		L	L	V	
April	24	V					V		L	L	V	
May	1	V					V		L	L	V	
May	8			V			V		VL	L	VL	
May	15	V					V	V	VL	VL	L	V
May	22	V							VL	VL	L	V
May	29	V							VL	VL	L	
June	5	V			VL				VL	VL	L	
June	12	V							VL	VL	L	
June	19	V		L					VL	VL	L	V
June	26	V		V	V	V			VL	VL	L	
July	3	V							VL	VL	L	V
July	10	V							VL	VL		
July	17	V							VL	VL		
July	24	V							VL	VL		V
July	31	V								VL		
August	7									VL		
August	14	V								VL		
August	21	V								L		
August	28	V										
Sept.	4	V										
1996												
March	17						V	V			V	
March	24						V	V			V	
March	31						V	V			V	
April	7											
April	14						V	V			V	V
April	21										V	V
April	28						L			VL	V	V
May	5						VL			VL	VL	V
May	12	V					L			VL	L	
May	19	V			V	V	L		V	VL	L	V
May	26						L			VL	L	V
June	2	V					L		VL	VL	L	V
June	9	V			V				VL	VL	L	V
June	16	V		V	VL				VL	VL	L	
June	23	V			L	V			VL	VL	L	V
June	30	V			VL	V			VL	VL	L	
July	7	V			L	V			VL	VL		V
July	14	V			VL	V			VL	VL		
July	21	V			L				VL	VL		V
July	28				L				VL	VL		
August	4								L	VL		
August	11								L	VL		
August	18								L	VL		V
Sept	1								L	L		

Table 3 continued

Week	Ac	Ba	Bw	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20						L		L	L		
April 27								L	L		
May 4								VL	VL		V
May 11								L	L		
May 18	V							L	L		V
May 25								L	L	L	
June 1								VL	VL	L	V
June 8								VL	VL	L	V
June 15								L	L	L	
June 22	V			V				VL	VL		V
June 29				V				VL	VL		
July 6	V			V	V			VL	VL		V
July 13								L	L		
July 20				V							
July 27											
August 3											

Table 4. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 2 on Fort Belvoir for 1995-1997. Sampling periods as in Table 3. Species abbreviations as in Table 2. Abbreviations: "V" = vocalizing males, indicating the breeding period, and "L" = larvae.

Week		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rs
							Pc	Pt				
1995												
March	13		V				V	V				
March	20											
March	27						V					
April	3						V					
April	10		V				V	V	V			
April	17						V				V	
April	24						V	V				
May	1	V					V					
May	8				V		V	V				
May	15	V	V				V					
May	22	V			VL		V					
May	29	V			L				V			
June	5	V		V	L							
June	12	V			L							
June	19	V			V							
June	26	V			V							
July	3	V										
July	10	V			V							
July	17	V										
July	24	V										
July	31											
August	7	V										
August	14	V										
August	21	V										
August	28	V										
Sept.	4	V										
1996												
March	17											
March	24						V	V				
March	31		V				V	V				
April	7		V				V	V				
April	14		V				V	V				
April	21										V	
May	5	V										
May	12						VL					
May	19				V		L					
May	26						L					
June	2	V			L	V	L					
June	9				VL				V			
June	16			L	VL							
June	23				L							
June	30				L							
July	7			V	VL							
July	14			V	VL							
July	21				L							
July	28				VL							
July	31				L							
August	4				L							
August	11				L							
August	18				L							
August	25				L							
Sept.	1				L					L		

Table 4 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20											
April 27									L		
May 4									L		
May 11									L		
May 18	V								L		
May 25									L		
June 1									L		
June 8											
June 15											
June 22											
June 29											
July 6											
July 13											
July 20											
July 27											
August 3											

Table 5. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 3 on Fort Belvoir for 1995-1997. Sampling periods as in Table 3. Species abbreviations as in Table 2. Abbreviations: "V" = vocalizing males, indicating the breeding period, and "L" = larvae.

Week		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rs
							Pc	Pt				
1995												
March	13		V				V			L		
March	20									L		
March	27		V				V			L		
April	3						V			L	V	
April	10		V				V			L	V	
April	17		V				V			L	V	
April	24						V			L		
May	1						V			L		
May	8		L		V		V			L		
May	15			V			V			L		
May	22			L	VL		V			VL	VL	
May	29	V		L					V	L	L	
June	5	V		VL						VL	L	
June	12	V		L						VL	L	V
June	19	V		VL	V					L	L	
June	26	V		VL	V	V				VL	L	
July	3	V		L	V					L	L	V
July	10				V	V				VL	L	V
July	17	V			V				V	VL	L	V
July	24	V			V	V				VL	L	V
July	31	V			V					VL		
August	7									VL		
August	14	V							L	VL		
August	21	V							L	VL		
August	28	V							L	VL		
Sept.	4	V							L	L		
1996												
March	17											
March	24						V	V	L	L		
March	31		V				V		L	L		
April	7		V				V		L	L		
April	14		VL				V		L	L	V	
April	21		L				VL	V	L	L	V	
April	28		L				L		L	L		
May	5		L				L		L	L		
May	12		L				L		L	L	L	
May	19			V	V		L		L	L	L	
May	26						L		L	L	L	
June	2			L	L	V	L		L	L	L	V
June	9			VL	VL				L	VL		
June	16			L	VL				VL	L		
June	23			L	VL	V			L	VL		
June	30			VL	VL	V			L	VL		
July	7			L	L				L	L		
July	14			VL	VL				L	VL		V
July	21				VL				L	VL		
July	28				L				L	VL		
August	4								L	VL		
August	11								L	VL		
August	18								L	L		
August	25								L	L		
Sept.	1								L	L		

Table 5 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20		L						L	L		
April 27								L	L		
May 4								L	L		
May 11	V							L	L		
May 18	V							L	L		
May 25								L	L	L	
June 1								L	L		
June 8								L	L		V
June 15			L					L	L		
June 22									L		
June 29									L		
July 6									L		
July 13									L		
July 20											
July 27	V										
August 3											

Table 6. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 4 on Fort Belvoir for 1995-1997. Sampling periods as in Table 3. Species abbreviations as in Table 2. Abbreviations: "V" = vocalizing males, indicating the breeding period, and "L" = larvae.

Week		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rs
							Pc	Pt				
1995												
March	13		V				V	V				
March	20											
March	27						V	V				
April	3						V				V	
April	10		V				V	V			V	
April	17						V				V	
April	24	V					V	V				
May	1	V			V		V					
May	8		V		V		VL	V				
May	15	V			V		VL					V
May	22	V		V	VL		VL					V
May	29	V					L					V
June	5	V			V		L					
June	19	V										
June	26				V							
July	3	V		V		V						V
July	10	V			V							
July	17	V			V							
July	24	V										
July	31	V			V					V		
August	7	V			V							
August	14	V										
August	21	V										
August	28	V										
Sept.	4	V										
1996												
March	24						V	V			V	V
March	31						V	V				
April	7		V				V	V				
April	14						V	V				
April	21						V					
April	28						V					
May	5	V	V				V					V
May	12											V
May	19	V			V	V				V		V
May	26									V		V
June	2						L					V
June	9			V	V	V				V		
June	16			L	VL					V		
June	23				L			V				
June	30				L							
July	7				L							
July	14			V	VL							
July	21				VL	V						
July	28			V	VL					VL		
August	4				L					L		
August	11				L					L		
August	18											
August	25											
Sept.	1											

Table 6 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20						L			L		
April 27						L			L		
May 4						L			L		V
May 11						L			L		
May 18						L			VL		
May 25						L			VL		
June 1						L					
June 8						L					
June 15						L					
June 22											
June 29											
July 6											
July 13											
July 20											
July 27											
August 3											

Table 7. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 5 on Fort Belvoir for 1995-1997. Sampling periods as in Table 3. Species abbreviations as in Table 2. Abbreviations: "V" = vocalizing males, indicating the breeding period, and "L" = larvae.

Week	Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rs
						Pc	Pt				
1995											
March 13		V				V	V	L	L	V	V
March 20								L	L		
March 27		V				V		L	L	V	
April 3		V				V		L	L	V	V
April 10	V	V				V	V	L	L	L	V
April 17	V	V	V			V		L	L	VL	
April 24	V					V		L	L	VL	
May 1	V			V		V		L	L	VL	
May 8	V	VL	V	V		VL		VL	VL	L	
May 15	V					V		VL	VL	L	V
May 22	V		V	VL	V	V		VL	VL	L	V
May 29	V			L				VL	VL	L	
June 5	V		V	VL				VL	VL	L	
June 12	V			V				VL	VL	L	V
June 19	V			V	V			VL	VL	L	V
June 26	V			V	V			V	L	L	V
July 3	V		V		V			V	VL	L	V
July 10	V		V	V	V			V	VL	L	V
July 17	V			V	V			V	VL	L	V
July 24					V			V	L	L	V
July 31				V					VL	L	
August 7	V			V					VL		
August 14	V								L		
August 21									VL		
August 28	V								L		
Sept. 4	V								L		
1996											
March 24						V	V			V	
March 31		V				V	V			V	
April 7		V				V	V			V	
April 14		V				V	V			V	
April 21	V					V				V	V
April 28	V	L				VL			L	VL	V
May 5						L		V	VL	L	V
May 12	V	L				L		V	L	L	V
May 19	V			V		L		V	VL	L	V
May 26	V					L		V	VL	L	V
June 2	V		V			L		V	VL	L	V
June 9	V			V	V			V	VL	L	V
June 16				L	V			V	VL	L	
June 23	V			L	V			V	VL	L	V
June 30				L					L	L	
July 7	V			VL	V			V	VL	L	V
July 14	V		VL	VL				V	VL	L	V
July 21	V			VL					VL		V
July 28	V			L	V				VL		
August 4				L					VL		
August 11				L					VL		V
August 18									VL		V
August 25									L		
Sept. 1									L		

Table 7 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20						VL					
April 27						L					
May 4	V					L				V	V
May 11						L			V	V	V
May 18						L			V	V	V
May 25	V			V		L		L	VL		V
June 1	V								VL		V
June 8	V								VL		V
June 15	V								L		
June 22									L		
June 29									L		
July 6									L		
July 13				L					VL		
July 20											
July 27											
August 3											

Table 8. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 6 on Fort Belvoir for 1995-1997. Sampling periods as in Table 3. Species abbreviations as in Table 2. Abbreviations: "V" = vocalizing males, indicating the breeding period, and "L" = larvae.

Week		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rs
							Pc	Pt				
1995												
March	13		V				V	V				V
March	20											
March	27		V				V					V
April	3						V					
April	10		V				V					
April	17						V					
April	24	V					V	V				
May	1	V					V					
May	8	V	V		V		VL					
May	15	V					VL		V			V
May	22	V		V	V		VL					
May	29	V		V	VL		L			V		L
June	5	V		V	VL		L					L
June	12	V			VL							L
June	19	V			VL							L
June	26	V			VL							L
July	3	V			L	V						L
July	10	V			VL					V		L
July	17	V			L							L
July	24	V			L							L
July	31	V										
August	7	V										
August	14	V										
August	21	V										
August	28	V										
Sept.	4	V										
1996												
March	24						V					
March	31						V	V			V	V
April	7						V	V				V
April	14		V				V	V				
April	21						V				V	
April	28		L				VL			L	V	
May	5	V			V		VL			L		V
May	12	V					L			L		V
May	19				V		L			VL		V
May	26						L			VL		V
June	2				L		L			L		
June	9				L	V				VL		
June	16				VL					L		
June	23				VL					L		
June	30				VL					L		
July	7				L					L		
July	14				VL					VL		V
July	21				VL	V				L		V
July	28				L					VL		V
August	4				L					VL		
August	11				L					VL		
August	18									L		V
August	25									L		
Sept.	1									L		

Table 8 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20									L		
April 27									L		
May 4									VL		
May 11	V								VL		
May 18									VL		V
May 25				V		L			L		V
June 1									VL		V
June 8									VL		
June 15						L			L		
June 22											V
June 29											
July 6			V	V							
July 13											
July 20											
July 27											
August 3											

Table 9. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 7 on Fort Belvoir for 1995-1997. Sampling periods as in Table 3. Species abbreviations as in Table 2. Abbreviations: "V" = vocalizing males, indicating the breeding period, and "L" = larvae.

Week of		Ac	Ba	Bf	Hch	Species		Pt	Rca	Rcl	Rp	Rs
						Hci	Pc					
1995												
March	13						V			L	V	V
March	20									L		
March	27						V			L	V	V
April	3						V			L	V	
April	10	V	V				V			L	V	
April	17		V				V			L		V
April	24	V					V			L	V	V
May	1	V					V			L	V	V
May	8	V	V				VL		VL	VL	V	V
May	15	V		V		V			VL	VL		V
May	22	V			V	V	V	V	VL	VL		
May	29	V		V					VL	VL		
June	5	V		V	V				VL	VL		
June	12	V							VL	VL		
June	19	V							VL	VL		
June	26	V		V					VL	VL		V
July	3	V							VL	VL		V
July	10	V			V				VL	L		V
July	17								VL	VL		
July	24	V							VL	VL		
July	31								L	VL		
August	7	V							L	VL		
August	14	V				V			L	VL		
August	21	V				V						
August	28	V				V				V		
Sept.	4	V				V				V		
1996												
March	24						V				V	V
March	31						V				V	V
April	7						V	V			V	V
April	14						V				V	V
April	21						V				V	
April	28						VL			L	V	
May	5				V		VL			L		
May	12	V					VL		V	L	V	V
May	19			V	V		L		V	VL		V
May	26	V					L			VL		V
June	2						L		V	VL		V
June	9			V	V				V	VL		V
June	16				VL					VL	L	
June	23				L			V		VL		V
June	30				L					L	L	
July	7			V	VL			V		VL		V
July	14				VL	V		V		VL		V
July	21					V		V		L		V
July	28							V		VL		
August	4							V		VL		
August	11							V		L		V
August	18							V		V		V
August	25											V
Sept.	1											

Table 9 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20									L	L	
April 27									L	L	
May 4									VL	L	V
May 11									VL	VL	V
May 18								V	VL	L	V
May 25				V		L		V	VL	L	V
June 1								V	VL	L	V
June 8								V	VL	L	V
June 15								V	VL	L	
June 22			V	V				V	VL	L	
June 29				V	V			V	VL	L	
July 6			V	V				V	VL	L	V
July 13				V				V	VL	L	
July 20				V				V	V		V
July 27								V	V		
August 3								V	V		

Table 10. Dates of first and last observations of larval salamanders by site on Fort Belvoir during 1995-1997. The first number is the day and the second is the month following the slash.

Site	<i>A. opacum</i>	<i>A. maculatum</i>	<i>E. bislineata</i>
1995			
1. no salamanders			
2.	27/5	10/3 - 10/6	
3. no salamanders			
4.	13/4 - 11/5	16/3	
5.		13/4	
6.		16/3 - 10/6	
7.		11/5	
1996			
1. no salamanders			
2.		1/5 - 22/6	
3.			1/5
4.	1/5 - 18/5	1/5 - 8/6	
5.		8/6 - 6/7	
6.		1/5 - 6/7	
7. no salamanders			
1997			
1. no salamanders			
2.		24/4	
3. no salamanders			
4.		24/4 - 17/6	
5. no salamanders			
6.		24/4 - 31/5	
7.		24/4	

Table 11. Seasonal variation in acidity in the seven study sites on Fort Belvoir, Virginia, in 1996 and 1997. Except for date (month/day), numbers are pH values. The first number before the slash is pH determined in the laboratory (1996 Accumet 950 pH meter at University of Richmond; 1997 Orion Model 811 pH meter with Ross Glass combination electrode at James Madison University). The second number following the slash is the value obtained with a Hanna HI9023 hand-held pH meter in the field. Dashes indicate no measurement taken and "dry" indicates that no standing water.

Date	Site						
	1	2	3	4	5	6	7
1996							
5/1	5.88	6.37	6.85	5.55	5.84	6.64	6.08
6/8	6.12/6.65	6.19/6.12	6.68/5.54	5.33/5.69	5.91/6.35	5.65/7.17	6.08/6.43
6/22	5.99/6.58	5.89/6.03	6.54/5.39	4.92/5.22	6.07/6.25	-- /6.14	-- /6.74
7/6	6.74/6.77	5.95/6.52	7.00/6.96	5.44/5.36	5.88/6.52	6.17/6.20	6.76/6.98
7/20	6.48	5.49	5.59	5.29	5.98	6.78	6.09
8/3	6.54	5.70	5.32	5.59	6.27	6.99	6.48
8/17	5.88/6.45	5.67/5.54	6.05/5.36	4.94/5.48	5.71/6.28	6.04/6.73	5.99/6.65
9/8	6.24	5.51	5.35	5.40	5.76	6.36	6.19
1997							
4/24	5.69/5.84	7.04/7.49	5.71/5.45	5.62/5.54	6.23/6.37	6.55/6.22	6.52/6.62
31/5	6.37	6.58	5.36	5.97	6.41	6.52	5.76
17/6	6.62/6.38	dry	5.56/5.42	6.08/6.06	6.22/6.36	6.24/6.09	6.77/7.06
18/7	6.94	dry	5.64	dry	6.72	dry	7.06

Table 12. Seasonal variation in dissolved oxygen (DO) content in the seven study sites on Fort Belvoir, Virginia, in 1997. Except for date, numbers are percent DO obtained with a YSI®-95 DO hand-held pH meter in the field.

Date	1	2	Site 3	4	5	6	7
24 April	27.9	37.3	27.9	26.9	8.3	37.4	10.3
31 May	3.5	0.6	19.8	4.7	30.7	33.9	3.4
17 June	3.6	dry	17.8	5.0	6.6	36.5	9.5
18 July	5.5	dry	6.8	dry	1.6	dry	3.6

Table 13. Water chemistry data for the seven study sites on Fort Belvoir, Virginia, in 1997. Chemical tests were performed in Dr. D.M. Downey's laboratory at James Madison University. All values are in $\mu\text{eq/l}$. Abbreviations are ANC = acid neutralizing capacity, Ca^{++} = calcium, Mg^{++} = magnesium, Na^+ = sodium, K^+ = potassium, Cl^- = chloride, NO_3^- = nitrate, SO_4^- = sulfate, Al = aluminum, ND = not determined. Methods: ion chromatography for anions, atomic absorption for metals, two endpoint titration for low ANC and graphite furnace for Al. All methods were done as described in APHA, Standard Methods for the Analysis of Water and Wastewater (D.M. Downey, personal communication).

Site	Date	ANC	Ca^{++}	Mg^{++}	Chemical		Cl^-	NO_3^-	SO_4^-	Al
					Na^+	K^+				
1	4/24	178.8	171.6	200.0	96.5	79.0	242.0	5.0	305.5	51
	17/6	742.3	291.5	197.9	282.0	116.0	301.4	18.8	17.0	22
2	4/24	1300.0	822.5	580.5	130.5	119.6	320.5	5.0	116.0	15
3	4/24	95.8	163.7	154.0	24.0	33.3	112.8	7.0	246.0	45
	17/6	306.7	147.6	150.8	104.5	32.1	117.4	ND	266.6	37
4	4/24	167.6	147.3	135.7	30.7	31.8	82.5	2.3	143.3	12
	17/6	301.1	169.5	162.6	104.5	35.2	121.9	8.0	70.2	25
5	4/24	571.6	222.6	169.5	133.0	36.0	92.1	5.6	12.8	10
	17/6	238.2	125.7	103.5	35.7	33.3	76.3	4.5	26.8	36
6	4/24	127.9	159.1	199.0	43.7	34.3	170.8	3.5	241.5	162
	17/6	302.6	115.8	119.9	87.5	138.0	60.8	10.3	83.0	25
7	4/24	63.7	214.6	119.2	38.3	122.5	57.0	7.0	75.0	82
	17/6	750.0	366.3	256.4	399.0	74.0	459.6	5.2	86.5	39

Results for Marine Corps Base Quantico and Prince William Forest Park

Seven wetlands were selected in two federal installations in this area because they are juxtaposed to each other. These are Prince William Forest Park (PWFP) and Marine Corps Base Quantico (Quantico MCB). Quantico MCB incorporates 60,500 acres of land in Prince William and Stafford counties, Virginia. Of this total, 56,174 acres are owned by the Marine Corps Combat Development Command and 4,262 are owned by the Department of the Interior and placed under the jurisdiction of PWFP. The Marines use this parcel under a Special Use Permit.

All seven amphibian monitoring sites are located within the Chopawamsic Creek watershed (Figure 3). This watershed drains into the Potomac River. Two of these sites are located within the Coastal Plain physiographic region and five are in the eastern Piedmont physiographic region. The site in PWFP is located in the Chopawamsic Back Country Area, imbedded within the Special Use Area, and controlled by park personnel.

Site Descriptions

Site 1 (Buffalo Pond) - This site is located in the Buffalo Pond area of the former Engineering Test Site on Quantico MCB in Training Area TA-4. The pond is a man-made impoundment covering about 5 acres. The southern end has been altered by beavers to form a shallow aquatic area with emergent grasses and a saturated area with grasses and sedges. Attached to the southern end of Buffalo Pond is a series of smaller beaver ponds along Buffalo Creek. These ponds are shallow and are covered by a forest canopy. The forest in the western and southern floodplain and adjacent uplands consist of red maple, sweetgum, tulip poplar, sycamore, birch, and a few Virginia pine. The understory consists of pawpaw (*Asimina triloba*) and ironwood (*Carpinus caroliniana*). The forest on the eastern slope is dominated by white oak with red maple along the edge of the forest near the pond. Although some species of amphibians used the entire pond area (along the margin), most confined their activities to the shallow, southern area and associated beaver ponds. Although water levels decreased in the 1995 drought, the shallow area of Buffalo Pond and the beaver ponds did not dry up. Water levels remained high throughout 1996. Water levels in 1997 fluctuated due to the drought conditions that year but this site did not dry out. One of the small associated beaver ponds dried this year.

Site 2 (Old Rt. 1 right-of-way) - Site 2 is within the Chopawamsic Creek floodplain adjacent to an abandoned stretch of U.S. Route 1 at the northwestern edge of the former Engineering Test Site in TA-4. Access from the main gate to

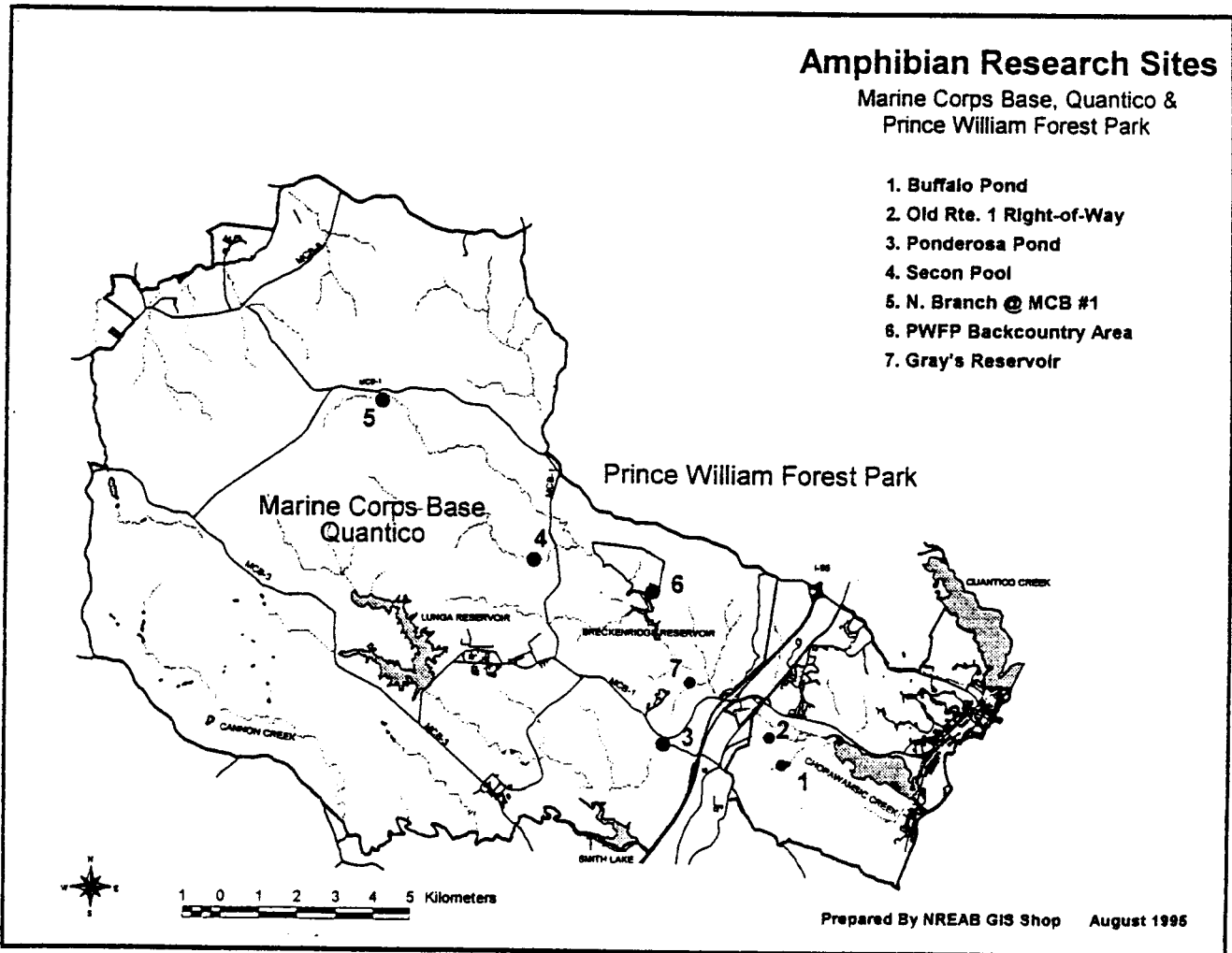


Figure 3. Map of Marine Corps Base Quantico and Prince William Forest Park, Prince William and Stafford counties, Virginia illustrating the location of the seven amphibian monitoring sites. Numbered sites on the map correspond with those in the text and following tables.

the Test Site is along old U.S. 1 and across two channels of the creek. The monitoring site itself consists of shallow floodplain pools on the eastern side of the old road bed within the saturated forested floodplain and a narrow, shallow ditch on the western side. The forest on the eastern side is dominated by sycamore, river birch, and tulip poplar with a variety of low shrubs and herbaceous plants. The floodplain on the western side is primarily an open grassy area with a variety of trees along the margin, especially sycamore, pawpaw, and catalpa (*Catalpa bignonioides*) trees. The floodplain pools dried by August 1995 and the last pool in the ditch dried completely by the end of August that year. The site did not dry in 1996. In 1997, water levels were low by the end of May and the site dried completely by mid-June. A rainfall event at that time provided a shallow layer of water but the condition of the substrate and the lack of amphibians indicated that the pool had dried out earlier that month.

Site 3 (Ponderosa Pond) - This site is called Ponderosa Pond and is located about 300 meters southeast of the junction of Russell Road and MCB-1 at the northern end of Training Area 5-B. The Natural Resources Building is situated <100 meters upslope. The pond is oval in shape and deep (>2 meters). The margin is nearly surrounded by needlerush (*Eleocharis acicularis*) except for an approximately 30 meter section on the northeastern side. Cattails, grasses, and sedges also occur along the margin in patches. A small spring enters the pond at the northwestern end through a wide seepage area. The cattails and sedges are especially prevalent here. Virginia pine with an understory of red maple dominates the forest cover to the east and north. Vegetation on the western slope consists of Virginia pine, loblolly pine, and black locust. The woody vegetation on this slope is trimmed to, apparently, afford a view from the Natural Resources Building. The slope away from the emergent vegetation along the southern margin supports a 10 meter wide strip of mowed grass that is connected to the mowed grassy yard below the building. Behind this strip is a mixture of black locust, red maple, and black cherry. This pond did not dry during the 1995 and 1997 droughts, remaining full or nearly so during all three years of this study.

Site 4 (Secon Pool) - Site 4 is located along the Middle Branch of Chopawamsic Creek at Secon Pool in Training Area-11B. This site consists of three sections, a deep pool in a small spring-fed, forested tributary of Middle Branch, a shallow (<10 cm deep) wetland area in the associated floodplain on the east side of Middle Branch, and the section of Middle Branch above Secon Pool. Middle Branch is a trout fishing stream and is stocked annually. The pool is

located in the floodplain about 5 meters from the main channel of the branch. The floodplain forest on both sides of the branch is dominated by tulip poplar and red maple, with several sycamore and river birch trees and an understory of holly (*Ilex opaca*) and ironwood. The ground cover near the pool is a thick carpet of ferns and skunk cabbage (*Symplocarpus foetidus*). Skunk cabbage dominates the herbaceous cover in the shallow area on the east side of Middle Branch. Secon Pool itself is in an open area with short grasses along the edge at the upper end. Many naked trunks of dead white oak trees (from gypsy moth damage) dominate the forest on the eastern slope. The shallow wetland in the forested floodplain dried by mid-July 1995 and 1997. The pool and mainstem of Middle Branch retained water year round in all three years of this study.

Site 5 (N. Branch at MCB #1) - This site is located at the junction of MCB-1 and Coops Gobbler Road in and immediately north of North Branch in Prince William County. The creek bed contains a narrow, shallow wetland that has been impacted by beavers. Portions of the northern margin are flat and contain open patches of grasses. Tulip popular, red maple, sycamore, and pawpaw dominate the woody vegetation. About 30 meters to the north is located a small (10 x 15 meter) pool (borrow pit) that was apparently created during the construction of Coops Gobbler Road. This pool is shallow (<1.2 meters) and supports emergent grasses and cattails. The surrounding forest is composed of white oak and red maple dominants, with an understory of holly, red maple, sweetgum, and dogwood. This was the primary study site. The pool retained water throughout most of 1995 and 1997, and contained only a small shallow pool in mid-September of both years. It retained water throughout 1996.

Site 6 (PWFP Backcountry Area) - This site is located about 50 meters inside (west of) the gate to the Chopawamsic Back Country Area in Prince William Forest Park in Prince William County. The wetland is within a sweetgum - red maple forest and is only a shallow depression in the forest floor. Virginia pine and a few white oak occur around the depression. Holly and red maple comprise the understory and there are several patches of greenbrier. This site was known to successfully produce at least three species of frogs in previous years but it completely dried early in 1995. No amphibians successfully completed reproduction at this site in 1995 because it dried out before June. In 1997, this site dried out in May. In 1996, this pool retained water until the end of June, allowing successful reproduction of several amphibians.

Site 7 (Gray's Reservoir) - Site 7 lies within Quantico MCB. This is a small reservoir located in the mainstem of Chopawamsic Creek about 1 km west of the

junction of Russell Road and I-95. The reservoir has a concrete dam and a spillway at the southern end. It is largely filled in with silt and supports a great abundance of the aquatic plant *Utricularia*. Other emergent vegetation species occur around the margin of the pond. A sand bar, now covered with grasses, shrubs, small sycamore and birch trees, bisects the upper end of the reservoir. The northern margin is used as a parking area and supports grasses and shrubs where vehicles do not travel. This area has a small, shallow portion within which two species of frogs occurred in early 1995 and 1996. The area below the dam consists largely of gravel deposits and several isolated pools (except in high water). Birch trees occur in this portion of the floodplain. The pools are used by several amphibians for breeding sites. The steep slopes along the southern and western margins of the reservoir are dominated by American beech, sycamore, tulip popular, and tree of heaven (*Ailanthus altissima*). Water levels in the reservoir dropped slightly in 1995 and 1997 but only the area connecting the sand bar to the bank became dry.

Results

The number of amphibian species recorded for the seven wetland sites in the Quantico MCB/PWFP area varied from 3 to 13 in 1995, 5 to 11 in 1996, and 2 to 12 in 1997 (Table 14). These included ten species of frogs and six species of salamanders. None of the protocols used alone encountered all species. The use of the nighttime frog call survey during which all species seen and heard were recorded registered 60-100% of the total known for each site. The use of larval dipnetting and daytime encounter surveys resulted in 10-80% of the total recorded for each site. The differences in numbers of species sampled in these seven wetlands among the 3 years of study (Table 14) probably reflect the differences in rainfall patterns and amount during this period (Appendix 2). Results in Table 15 demonstrate that both the nighttime frog call survey and larval dipnetting survey techniques must be used together to ensure complete coverage and that they need to be carried out over several years in order to encounter all species present.

All but one of the frogs (wood frog [*Rana sylvatica*]) was registered during frog call surveys in 1995. It was recorded in 1996 from three sites, and in 1997 it was not found at all. Wood frogs are early-spring explosive breeders that call for a very short period of time. Calling males may simply have been missed in early 1995 and 1997 because field work started too late to intercept them. Many, although not all, of the frog species were also registered during the larval dipnetting surveys. The wood frog was the only frog recorded exclusively by the larval sampling technique in 1995.

Salamanders were not encountered during frog call surveys. Only

dipnetting during day field excursions and visual encounters allowed these species to be registered (Table 15). Most sites supported 2-3 species. These overall results demonstrate that there is considerable variation in salamander species composition in the wetlands in the Quantico MCB/PWFP area and that the use of multiple monitoring protocols is the best approach for the inventory and monitoring program of these sensitive vertebrates.

Results in Tables 16-22 for each individual wetland demonstrate conclusively that frogs exhibit strong seasonal variation in the timing of species-specific male vocalizations and when the larvae (tadpoles) are present in the ecosystem. Several species are reproductively active in early spring (e.g., spring peepers [*Pseudacris crucifer*], pickerel frog [*Rana palustris*]) and others are active only in late spring and summer (e.g., bullfrogs [*Rana catesbeiana*], gray treefrog [*Hyla chrysoscelis*]). Green frogs (*Rana clamitans*) and northern cricket frogs (*Acris crepitans*) had the longest calling periods of all frog species in 1995 and 1996. Overall, the phenology of male vocalizations during 1995 and 1996 was remarkably similar, despite the annual differences in rainfall patterns (with 1995 a dry year and 1996 a wet year). Similar patterns were detected in 1997 in the sites with persistent water levels. However, those wetland sites that dried early due to the 1997 drought supported fewer species that year.

The results (Tables 16-22) also show that tadpoles of some species exhibit a higher catchability than others in the wetlands studied. Those in the genus *Rana* (e.g., bullfrogs, green frogs) and genus *Bufo* (toads) were encountered more often than those of other species groups. This is probably due to the microhabitats selected by different species and our ability to capture them when dipnetting along the edge of the wetlands included in this study.

Quantico MCB/PWFP supports a more diverse salamander fauna than the wetlands of Fort Belvoir studied in this project (see above) but less than that found on Fort A.P. Hill (see below). Two species (marbled salamander [*Ambystoma opacum*], spotted salamander [*Ambystoma maculatum*]) were recorded in three and four of the seven wetland sites, respectively, on Quantico MCB/PWFP (Table 23). These species breed in ephemeral, vernal pools and woodland ponds. Site 2 supported both of these species in 1995, only marbled salamanders in 1996, and neither species in 1997. Spotted salamanders reproduced in sites 1, 4, and 5 each of the three years of study. Marbled salamanders reproduced in 3 sites in 1995, 2 in 1996, and none in 1997. In 1995, red-spotted newts (*Notophthalmus viridescens*) occurred in all wetland sites except the vernal pool in the Chopawamsic Back Country Area (PWFP) that held water for only a short period of time that spring. In 1996, they were found in only 3 of the 7 sites, and in 1997 they occurred in 5 sites. Northern red salamanders (*Pseudotriton ruber*)

were found in the pool habitat in Site 4 in 1995 and 1997. Larval two-lined salamanders (*Eurycea bislineata*) were encountered only in Gray's Reservoir (Site 7) in 1996. Larval three-lined salamanders (*Eurycea guttolineata*) were found in Site 4 in 1996 and 1997, in Site 7 in 1997. Other species are known for the base (J.C. Mitchell, unpublished) but were not encountered in the locations selected for this study.

Wetland Acidity Levels and Chemistry

Acidity levels among wetland monitoring sites varied from a low of pH 4.2 to a high of pH 9.6 in 1996 and from 5.6 to 8.9 in 1997 (Table 24). Acid levels in Sites 1-5 averaged from about 5.5 to 7.2. Site 6 exhibited the lowest pH values in 1996 with an average of about 4.7 to 5.0 depending on the instrument used. This site was ephemeral and dried completely by the end of June 1996 and late May 1997. Site 7 had the highest pH values in both years, often ranging well above neutral. Acidity was lower in the spring season (pH 6.4-6.9) than in the summer season when the water was often warm to the touch (pH 7.1-9.6). Except for certain times in Site 6 when acid-laden rainfall may have caused spikes of low acidity, amphibians in these wetland sites experience a wide range of acidity. Acidity apparently does not drop low enough to cause harmful responses in these animals.

The variation in results from the two instruments used in this portion of the study may be due to a variety of factors, including delay in reading samples in the laboratory, instrument calibration, and variation in pH among microhabitats and water temperature. The three instruments were used to determine pH levels all agreed in general over a two year period, indicating that six of the seven wetlands sites on Quantico MCB/PWFP are not currently experiencing acid levels that are potentially harmful to amphibians. Site 6 on PWFP property should be monitored on an annual basis in the future for acid levels and studies undertaken to determine if low pH in this site affects amphibians and their larvae.

Dissolved oxygen (DO) concentrations in six of the seven sites on Quantico MCB/PWFP vary among sites and seasonally (Table 25). Oxygen levels in sites 1-4 and 7 were all high in spring. Values decreased through the summer in most wetlands (sites 1, 3, 4, 5, 7) as water temperatures increased. DO remained at similar levels throughout spring and summer in Site 3, Ponderosa Pond. DO was low throughout the entire sampling period in Site 5.

Water chemistry values for the seven wetland sites exhibited considerable variation among sites and between sampling periods (Table 26). Acid neutralizing capacity (ANC) values were all above 100 µeq/l, indicating that

these wetlands had considerable capacity to neutralize acid input from atmospheric sources. Salt content (calcium and sodium) was high in sites 2, 3, 4, and 7, indicating that road salt or other salt-containing chemicals were being taken up by these wetlands. The high salt content of these wetlands has an unknown affect on amphibian adults and larvae.

Conclusions

Overall results indicate that the field work conducted in 1995-1997 using standardized protocols described above apparently allowed a full inventory of the frog fauna and a partial inventory of the salamander fauna for the Quantico MCB/PWFP area. Whether these results indicate the true community composition of each of the seven wetlands will be determined by future studies that provide additional information on species occurrences. Each site supports a variable number of species each year depending on water levels, with some species occurring each year and others only during periods of favorable hydrology.

The combined use of the three standardized protocols (frog call surveys, larval surveys, visual encounter surveys) proved to be effective and useful approaches to inventory and monitor the amphibians of the seven sites in Quantico MCB/PWFP. Future studies of these animals in the wetlands of these facilities should use these protocols in the manner described here so that the baseline results obtained in 1995-1997 can be compared across years. Without the use of standardized protocols, the ability to determine trends in community composition and relative population size is diminished.

The results of this study indicate that the frog fauna and at least three species of salamanders in the seven wetlands on Quantico MCB/PWFP are not experiencing population decline. The observed variation in relative abundance was expected to occur because of the variation in rainfall patterns (Appendix 2). Conclusions about the status of the salamander fauna would be premature, but it appears that at least five species are reproducing in these wetlands. The results derived from this study provide the baseline against which future changes can be assessed. All efforts should be made to continue monitoring these sensitive animals.

Management Recommendations for Quantico MCB and PWFP

1. Maintain all wetland habitats used by amphibians and buffers of the remaining surrounding hardwood forest habitat. A buffer of at least 300 meters is recommended for most amphibians.

2. Destructive activities, such as draining, filling, bulldozing, and ORV intrusion, should be avoided. Construction activities that could destroy any of these wetlands should be conducted in other areas.

3. Mitigation of wetland losses due to future projects should be done to increase protection of other wetlands and their 300 m buffers on the base for the long term. Codification of these protected areas into set-aside preserves is highly recommended.

4. All wetland sites should be monitoring annually for beaver activities, causes of siltation, and other perturbations so that prevention and restoration projects can be undertaken early.

5. Site 6 is a unique habitat for amphibians because it (1) dries earlier than any other site, (2) provides habitat for wood frogs and other early-breeding amphibians, and (3) because of its low acidity at times when amphibian larvae are present. It should be protected from all perturbations, especially activities that would alter the sensitive hydrology.

6. Site 7 is an old reservoir that has largely silted in from erosion and runoff upstream. Additional runoff is undesirable. The entire Chopawamsic watershed should be maintained in hardwood forest, especially around the reservoir itself. The surrounding hardwoods provide refugia for many amphibians and helps minimize erosion and siltation.

7. Water chemistry variables should be evaluated annually in all wetlands to determine whether road salt and other forms of urban pollution are increasing in any of the wetlands in this area.

8. Amphibian populations should be monitored with the standard protocols used in this study for at least 20 years.

Table 14. Number of amphibian species recorded for the seven amphibian monitoring sites on Marine Corps Base Quantico and Prince William Forest Park in 1995-1997 by three techniques: Night Vocalizations = frog call survey, Larval Sampling, and Visual Encounter Survey, including frog calls.

Technique	1	2	3	Site 4	5	6	7
1995							
Night Vocalizations	8	7	6	9	7	3	7
Larval Sampling	9	4	6	9	7	1	5
Visual Encounter Survey	7	1	3	4	4	1	3
Total No. Species	11	10	8	13	12	3	8
1996							
Night Vocalizations	9	5	6	5	8	5	8
Larval Sampling	6	2	4	6	6	3	7
Visual Encounter Survey	8	3	5	9	6	3	7
Total No. Species	11	5	8	11	10	7	10
1997							
Night Vocalizations	7	5	5	4	6	2	8
Larval Sampling	5	1	4	7	4	0	5
Visual Encounter Survey	6	2	2	8	7	0	3
Total No. Species	9	5	6	12	9	2	10

Table 15. Amphibian species in each of seven amphibian monitoring sites on Marine Corps Base Quantico and Prince William Forest Park, Virginia in 1995-1997. Abbreviations: species identified by vocalizations and observations (V) and by identification of larvae (L). Common names of species are in Appendix 1.

Species	1	2	3	Site 4	5	6	7
1995							
Frogs:							
<i>Acris crepitans</i> (Ac)	V		VL	V	V		VL
<i>Bufo americanus</i> (Ba)	VL	V	V	VL	VL	V	VL
<i>Bufo fowleri</i> (Bf)	L			V	L		V
<i>Hyla chrysoscelis</i> (Hch)	VL	V		VL	VL	V	V
<i>Pseudacris crucifer</i> (Pc) VL	VL	V	VL	VL	V	VL	
<i>Pseudacris triseriata</i> (Pt)	V	V		V	V		
<i>Rana catesbeiana</i> (Rca)	VL	V	V	VL	V		VL
<i>Rana clamitans</i> (Rcl)	VL	VL	VL	VL	VL		VL
<i>Rana palustris</i> (Rp)	VL	V	VL	V	V		V
<i>Rana sylvatica</i> (Rsy)				L			
Salamanders:							
<i>Ambystoma maculatum</i>	L	L		L	L		
<i>Ambystoma opacum</i>		L		L	L		
<i>Notophthalmus viridescens</i>	L	L	L	L	L		L
<i>Pseudotriton ruber</i>			L				
1996							
Frogs:							
<i>Acris crepitans</i> (Ac)	V		V		VL		VL
<i>Bufo americanus</i> (Ba)	VL	V	V	V	V	VL	V
<i>Bufo fowleri</i> (Bf)	L			V	VL	V	VL
<i>Hyla chrysoscelis</i> (Hch)	VL	V	L	L	VL	V	VL
<i>Hyla cinerea</i> (Hci)	V						
<i>Pseudacris crucifer</i> (Pc) VL	VL	VL	VL	VL	VL	VL	VL
<i>Pseudacris triseriata</i> (Pt)	V			V			
<i>Rana catesbeiana</i> (Rca)	V		L	L	V		VL
<i>Rana clamitans</i> (Rcl)	VL	VL	VL	VL	VL	V	VL
<i>Rana palustris</i> (Rp)	VL	V	VL	L	VL		VL
<i>Rana sylvatica</i> (Rsy)				L	V	V	
Salamanders:							
<i>Ambystoma maculatum</i>	L	L		L	L	L	
<i>Ambystoma opacum</i>					L		
<i>Eurycea bislineata</i>							L
<i>Eurycea longicauda</i>				L			
<i>Notophthalmus viridescens</i>			L				L
<i>Pseudotriton ruber</i>							

Table 15 continued

1997

Frogs:

<i>Acris crepitans</i> (Ac)	V		V	V	V		VL
<i>Bufo americanus</i> (Ba)	V			V			VL
<i>Bufo fowleri</i> (Bf)							V
<i>Hyla chrysoscelis</i> (Hch)	V	V		V	V		V
<i>Hyla cinerea</i> (Hci)			V				
<i>Pseudacris crucifer</i> (Pc)	VL	V	VL	VL	VL	V	VL
<i>Pseudacris triseriata</i> (Pt)					V	V	
<i>Rana catesbeiana</i> (Rca)	V	V		V	V		V
<i>Rana clamitans</i> (Rcl)	VL	VL	VL	VL	VL		VL
<i>Rana palustris</i> (Rp)	VL	V	VL	L	V		

Salamanders:

<i>Ambystoma maculatum</i>	L			L	L		
<i>Eurycea guttolineata</i>				L			L
<i>Notophthalmus viridescens</i>	L		L	L	L		L
<i>Pseudotriton ruber</i>				L			

Table 16. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 1 on Marine Corps Base Quantico for 1995-1997. Species abbreviations as in Table 15. Abbreviations: "V" = vocalizing males, indicating the breeding period, and "L" = larval period.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rsy
							Pc	Pt				
1995												
March	13						V	V		L	V	
March	20						V	V		L	V	
March	27						V			L	V	
April	3						V			L	V	
April	10						V	V		L	V	
April	17						V			VL	V	
April	24						V			VL	V	
May	1						V			VL	V	
May	8	V	VL		V		L		V	VL	V	
May	15	V	L		V				V	VL		
May	22	V	L		V				V	VL		L
May	29	V			V				V	VL		L
June	5	V		L	VL				VL	VL		L
June	12	V			V				VL	VL		L
June	19	V			V				VL	VL		L
June	26	V			V				VL	VL		
July	3	V			V				VL	VL		
July	10	V			V				VL	VL		
July	17	V			V				VL	VL		
July	24								L	VL		
July	31				V				VL	VL		
August	7								VL	VL		
August	14								L	VL		
August	21				V				VL	VL		
August	28											
Sept.	4											
1996												
March	10						V	V		L	V	
March	17						V	V		L	V	
March	24						V	V		L	V	
March	31		V				V			L		
April	7		V				V			L	V	
April	14		VL				V			L	V	
April	21		VL				V			L	V	
April	28		L		V		V		V	VL	V	
May	5		L						V	VL	V	
May	12		VL		V				V	VL		L
May	19	V			V				V	VL		L
May	26	V			V				V	VL		L
June	2	V		L	V		L		V	VL		L
June	9	V			V				V	VL		L
June	16	V			VL	V			V	VL		L
June	23	V			L				V	VL		L
June	30	V			VL				V	VL		L
July	7	V			L				V	VL		L
July	14				V					VL		
July	21				V					VL		
July	28									VL		
August	4									VL		
August	11									VL		
August	18									VL		
August	25									VL		
Sept.	1									VL		

Table 16 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20						V			VL	V	
April 27		V		V		V			VL	V	
May 4									L		
May 11									VL	V	
May 18	V							V	VL		
May 25	V			V				V	VL		L
June 1								V	VL		L
June 8	V			V				V	VL		L
June 15	V			V		L		V	VL		L
June 22	V			V				V	VL		
June 29	V			V				V	VL		
July 6	V			V					VL		
July 13	V							V	VL		
July 20				V				V	V		
July 27								V	V		
August 3									V		

Table 17 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20						V			L	V	
April 27									VL	V	
May 4						V		V	VL		
May 11									L		
May 18									VL		
May 25				V					VL		
June 1											
June 8				V					V		
June 15											
June 22				V							
June 29				V					V		
July 6											
July 13				V							
July 20				V							
July 27											
August 3											

Table 18. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 3 on Marine Corps Base Quantico for 1995-1997. Species abbreviations as in Table 15 and others as in Table 16.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rsy
							Pc	Pt				
1995												
March	13						V			L	V	
March	20						V			L	V	
March	27						V			L	V	
April	3						V			L	V	
April	10		V				V			L	V	
April	17						V			L	V	
April	24	V					V			VL	V	
May	1									VL	V	
May	8	V					VL			VL	V	
May	15	V					VL			VL	V	
May	22	V							V	VL	L	
May	29	V							V	VL	L	
June	5	V								VL	L	
June	12	V								VL	L	
June	19	V								VL	L	
June	26	V								VL	L	
July	3	V								VL	L	
July	10	V								VL	L	
July	17	V								VL		
July	24	V								VL		
July	31	V								VL		
August	7	L								VL		
August	14	L								VL		
August	21	L								VL		
August	28									L		
Sept.	4									L		
1996												
March	10									L	V	
March	17									L	V	
March	24						V			L	V	
March	31						V			L	V	
April	7						V			L	V	
April	14						V			L	VL	
April	21						V			L	VL	
April	28	V					V			L	VL	
May	5	V					V			VL	VL	
May	12	V	V				VL			VL	VL	
May	19	V								VL	L	
May	26	V								VL	L	
June	2	V								VL	L	
June	9	V								VL	L	
June	16	V								VL	L	
June	23	V							V	VL	L	
June	30	V								VL	L	
July	7	V				L				VL	L	
July	14	V							V	VL		
July	21									VL		
July	28									VL		
August	4									VL		
August	11									VL		
August	18									VL		
August	25									VL		
Sept.	1									VL		

Table 18 continued

Week		Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997												
April	20	V					V			L	V	
April	27									VL	V	
May	4						V			VL		
May	11									VL		
May	18	V					L			VL	L	
May	25	V								VL	L	
June	1	V								VL	L	
June	8	V				V				L	L	
June	15	V								VL	L	
June	22	V								VL		
June	29	V								VL		
July	6	V								VL		
July	13	V								VL		
July	20	V								V		
July	27	V								V		
August	3									V		

Table 19. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 4 on Marine Corps Base Quantico for 1995-1997. Species abbreviations as in Table 15 and others as in Table 16.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rsy
							Pc	Pt				
1995												
March	13						V	V				
March	20						V					
March	27						V					
April	3						V				V	
April	10						V			L?	V	
April	17						V			L	V	
April	24						VL			L	VL	L
May	1						VL			L		L
May	8									L		L
May	15	V			V				V	VL		L
May	22		L							VL		L
May	29									VL		L
June	5			V	VL					L		
June	12									VL		
June	19				V					VL		
June	26									VL		
July	3									VL		
July	10									VL		
July	17								VL	VL	V	
July	24								VL	VL		
July	31								L	VL		
August	7								L	VL		
August	14								L	VL		
August	21								L	VL		
August	28								L	L		
Sept.	4								L	L		
1996												
March	10						V	V	L			
March	17								L			
March	24								L			
March	31						V		L			
April	7		V				V	V	L			
April	14		V				V		L	L	L	
April	21						V		L	L	L	
April	28						V		L	L	L	
May	5								L	L	L	
May	12			V			L		L	L	L	
May	19								L	VL		
May	26								L	VL		
June	2			V	L		L		L	VL		
June	9				L				L	VL		
June	16				L				L	VL		
June	23				L				L	VL		
June	30				L				L	VL		
July	7				L				L	VL	L	
July	14								L	VL		
July	21								L	VL		
July	28								L	VL		
August	4								L	VL		
August	11								L	VL		
August	18								L	VL		
August	25								L			
Sept.	1								L			

Table 19 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20						V		L	L		L
April 27						V		L	L		
May 4								L	L		
May 11						V		L	L		
May 18								L	L		
May 25						L		L	VL		
June 1								L	L		
June 8								L	L		
June 15			V			L		L	VL		
June 22				V				L	L		
June 29								L	VL		
July 6								L	VL		
July 13								L	L		
July 20											
July 27									V		
August 3									V		

Table 20. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 5 on Marine Corps Base Quantico for 1995-1997. Species abbreviations as in Table 15 and others as in Table 16.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rsy
							Pc	Pt				
1995												
March	13						V			L	V	
March	20						V			L		
March	27						V			L		
April	3		V				V			L	V	
April	10						V	V		L	V	
April	17						V			VL	V	
April	24	V					V			L	V	
May	1	V					V			L	V	
May	8	V	V				V			VL	V	
May	15			V			L			L		
May	22	V		L						VL	V	
May	29	V		L						L	V	
June	5	V		L	VL				V	VL		
June	12	V		L	VL				V	VL		
June	19	V		L	VL				V	VL		
June	26	V			VL					VL		
July	3	V			VL					VL		
July	10	V			VL					VL		
July	17	V			L				V	VL		
July	24	V			L					VL		
July	31				VL					VL		
August	7									VL		
August	14									VL		
August	21									L		
August	28									L		
Sept.	4									L		
1996												
March	10						V			L		V
March	17									L		
March	24						V			L		
March	31		V				V			L	V	
April	7		V				V			L		
April	14		V				VL			L	V	
April	21						VL			VL		
April	28	V					VL			L		
May	5		V		V		VL			L	VL	
May	12	V	V		V		VL			VL	L	
May	19	V					L			VL	L	
May	26	V			V		L			VL	L	
June	2	V		V	VL		L			VL	L	
June	9	V			VL		L			VL	L	
June	16	V		L	VL		L			VL	L	
June	23	V			VL					VL	L	
June	30	V			VL				V	VL	L	
July	7	V			VL					VL	L	
July	14	V			L					VL	L	
July	21	V			L					VL	L	
July	28	L			L					VL	L	
August	4	L			L					VL	L	
August	11	L			L					VL		
August	18	L			L					L		
August	25	L								L		
Sept.	1	L								L		

Table 20 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20						V	V		L	V	
April 27						V			L		
May 4						V			L		
May 11									L		
May 18									L		
May 25	V					VL			L		
June 1						L			L		
June 8						L			VL		
June 15	V			V		L			VL		
June 22				V					VL		
June 29	V								VL		
July 6									VL		
July 13									VL		
July 20									VL		
July 27									VL		
August 3									VL		

Table 21. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 6 on Marine Corps Base Quantico for 1995-1997. Species abbreviations as in Table 15 and others as in Table 16.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rsy
							Pc	Pt				
1995												
March	13						V					
March	20											
March	27											
April	3											
April	10											
April	17											
April	24											
May	1		V				V					
May	8		V		V		V					
May	15				V		V					
May	22											
May	29											
June	5				V							
June	12											
June	19											
June	26											
July	3				V		V					
July	10											
July	17											
July	24											
July	31											
August	7											
August	14											
August	21											
August	28											
Sept.	4											
1996												
March	10						V					
March	17						V					
March	24											
March	31						V					
April	7		V				V					
April	14		VL				V					L
April	21		L				VL					L
April	28		L				L					L
May	5		L		V		L			V		L
May	12		L		V		L			V		L
May	19		L				L			V		L
May	26		L				L			V		L
June	2		L	V	V		L			V		L
June	9			V	V		L					L
June	16				V		L					L
June	23				V							
June	30											
July	7											
July	14									V		
July	21											
July	28											
August	4											
August	11											
August	18											
August	25											
Sept.	1											

Table 21 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20						V	V				
April 27											
May 4											
May 11											
May 18											
May 25											
June 1											
June 8											
June 15			V	V							
June 22											
June 29											
July 6											
July 13											
July 20											
July 27											
August 3											

Table 22. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 7 on Marine Corps Base Quantico for 1995-1997. Species abbreviations as in Table 15 and others as in Table 16.

Week of		Ac	Ba	Bf	Hch	Hci	Species PcPt		Rca	Rcl	Rp	Rsy
1995												
March	13						V					
March	20											
March	27						V					
April	3		V								V	
April	10						V				V	
April	17		V				V				V	
April	24	V	L				V			V	V	
May	1						V			V	V	
May	8	V	V	V	V		VL			VL		
May	15	V		V					V	VL	V	
May	22	V			V				V	VL		
May	29	V		V	V				V	VL		
June	5	V			V				V	VL		
June	12	V							V	VL		
June	19	V			V				V	VL		
June	26	V			V				V	VL		
July	3	V		V	V				V	VL		
July	10	VL			V				V	VL		
July	17	VL			V				V	VL		
July	24	L								VL		
July	31	VL			V					VL		
August	7	VL								VL		
August	14	L								VL		
August	21	VL								VL		
August	28	L								VL		
Sept.	4	L							L	L		
1996												
March	10									L		
March	17									L		
March	24						V			L		
March	31		V				V			L		
April	7		V				V			L		
April	14		V				V			L	V	
April	21						V			VL	V	
April	28	V	V	V			VL			VL	VL	
May	5	V	V	V	V		VL			L	L	
May	12	V		V	V		L		V	VL	L	
May	19	V							V	VL	L	
May	26	V							V	VL	L	
June	2	V		VL	V				V	VL	L	
June	9	V		V	V				V	VL	L	
June	16	VL		VL					V	VL	L	
June	23	VL		V	V					VL		
June	30	VL		V	V				V	VL		
July	7	VL			L				VL	VL		
July	14	VL							L	VL		
July	21	VL			V				L	VL		
July	28	VL							L	VL		
August	4	VL							L	VL		
August	11	L							L	VL		
August	18	L							L	VL		
August	25									VL		
Sept.	1									L		

Table 22 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
April 20		L									
April 27		V							L	V	
May 4									V	V	
May 11									V	V	
May 18	V								V		
May 25	V		V						VL		
June 1	V								V	V	
June 8	V			V				V	V		
June 15	V		V					V	V	V	
June 22	V								VL		
June 29	V		V	V					V		
July 6	V								V		
July 13	V								V		
July 20	V								VL		
July 27	V								V		
August 3	V								V		
August 10									V		
August 17											
August 24											
August 31											

Table 23. Dates of first and last observations of salamanders by site on Marine Corps Base Quantico and Prince William Forest Park during 1995-1997. The first number is the day and the second is the month. Upper number is first date of observation and second number is last date of observation.

Species	Site						
	1	2	3	4	5	6	7
1995							
<i>A. maculatum</i>	13/3	14/4		13/3	13/3		
	25/6			10/7	8/9		
<i>A. opacum</i>		13/3		14/4	13/3		
					12/5		
<i>N. viridescens</i> (larvae)	10/7		10/7	13/3			15/6
	14/8		21/8	8/9			12/8
<i>N. viridescens</i> (adults)	14/4	12/5	14/4	14/4	28/4		28/4
	8/9		19/7	28/4			8/9
<i>P. ruber</i>				14/4			
				28/4			
1996							
<i>A. maculatum</i>	2/5			2/5	13/3	19/4	
	15/5			5/9	8/9	21/5	
<i>A. opacum</i>		19/4			13/3		
		15/5			12/5		
<i>E. bislineata</i>							2/5
							21/6
<i>E. guttolineata</i>					6/6		
<i>N. viridescens</i> (larvae)	10/7		10/7				9/7
	14/8		21/8				
<i>N. viridescens</i> (adults)	14/4		14/4				
	8/9		19/7				
1997							
<i>A. maculatum</i>	25/4			25/4	25/4		
	29/5			11/9	11/9		
<i>E. guttolineata</i>				29/5			25/4
							16/6
<i>N. viridescens</i> (larvae)			17/7				9/7
<i>N. viridescens</i> (adults)	16/6		25/4	25/4	25/4		25/4
			17/7				
<i>P. ruber</i>				17/7			
				11/9			

Table 24. Seasonal variation in acidity in the seven study sites on Marine Corps Base Quantico and Prince William Forest Park, Virginia, in 1996 and 1997. Except for date (month/day), numbers are pH values. The first number before the slash is pH determined in the laboratory (1996, Accumet 950 pH meter at University of Richmond; 1997, Orion Model 811 pH meter with Ross Glass combination electrode at James Madison University). The second number following the slash is the value obtained with a Hanna HI9023 hand-held pH meter in the field. Dashes indicate no measurement taken and "dry" indicates that no standing water.

Date	Site						
	1	2	3	4	5	6	7
1996							
4/19	4.81	5.23	6.06	5.81	5.42	4.20	6.43
5/2	5.53	6.04	6.26	5.84	5.89	4.86	6.95
6/6	5.15/5.67	5.90/6.24	6.21/6.51	5.74/6.12	6.02/6.40	4.80/5.07	6.55/6.93
6/21	5.23/5.74	6.00/6.24	6.37/6.68	6.29/6.54	5.89/6.18	5.08/4.99	7.08/7.81
7/9	5.75/5.79	6.45/6.50	6.75/7.20	6.51/6.63	6.13/6.71	dry	9.45/9.62
8/5	5.67	6.57	7.15	6.45	6.32	dry	9.29
8/22	5.52/6.22	5.98/6.30	7.42/8.88	6.55/6.79	6.25/6.31	dry	7.07/9.19
9/5	5.76	6.07	6.50	6.27	6.07	dry	7.36
1997							
25/4	5.85	6.20		6.09	5.93	---	6.88
29/5	6.15/5.92	6.81/6.54	6.75/6.21	6.32/6.07	6.45/---	dry	7.45/7.33
15/6	5.92/6.01	6.44/6.48	6.68/6.62	6.50/6.25	6.35/6.28	dry	7.16/8.91
17/7	5.68	dry	6.67	6.60	6.59	dry	9.16

Table 25. Seasonal variation in dissolved oxygen (DO) content in the seven study sites on Marine Corps Base Quantico and Prince William Forest Park, Virginia, in 1997. Except for date, numbers are percent DO obtained with a YSI®-95 DO hand-held pH meter in the field.

Date	1	2	Site 3	4	5	6	7
25 April	34.5	34.8	---	46.2	9.2	---	35.7
29 May	28.3	36.3	38.2	45.1	2.6	dry	50.4
16 June	9.3	36.8	39.9	20.7	5.8	dry	23.9
17 July	3.7	dry	29.7	28.9	3.5	dry	13.4

Table 26. Water chemistry data for the seven study sites on Quantico Marine Corps Base and Prince William Forest Park, Virginia, in 1997. Chemical tests were performed in Dr. D.M. Downey's laboratory at James Madison University. All values are in $\mu\text{eq/l}$. Abbreviations are ANC = acid neutralizing capacity, Ca^{++} = calcium, Mg^{++} = magnesium, Na^+ = sodium, K^+ = potassium, Cl^- = chloride, NO_3^- = nitrate, SO_4^- = sulfate, Al = aluminum, ND = not determined. Methods: ion chromatography for anions, atomic absorption for metals, two endpoint titration for low ANC and graphite furnace for Al. All methods were done as described in APHA, Standard Methods for the Analysis of Water and Wastewater (D.M. Downey, personal communication).

Site	Date	ANC	Ca^{++}	Mg^{++}	Chemical		Cl^-	NO_3^-	SO_4^-	Al
					Na^+	K^+				
1	29/5	137.1	111.6	94.0	89.5	74.5	84.7	1.3	35.9	27
	16/6	80.5	76.8	72.0	73.5	40.5	111.0	4.6	54.8	18
2	29/5	268.0	270.5	180.4	91.6	47.4	120.4	0.8	214.2	36
	16/6	185.5	235.0	166.9	233.0	43.8	244.0	6.1	236.3	43
3	29/5	153.0	257.7	161.8	577.5	60.5	182.0	0.7	102.4	16
	16/6	200.2	254.0	174.7	328.0	74.0	479.9	8.8	51.8	8
4	29/5	272.1	132.2	97.8	122.5	31.7	57.6	0.8	30.3	28
	16/6	271.6	118.0	103.2	48.9	31.1	62.9	ND	23.6	30
5	29/5	154.0	102.3	72.9	51.6	44.3	41.9	0.9	24.1	196
	16/6	338.8	188.0	127.6	46.0	39.4	35.1	5.2	14.4	86
6	29/5	dry								
	16/6	dry								
7	29/5	338.3	194.5	129.8	151.5	32.8	76.3	0.9	53.2	55
	16/6	269.5	178.0	112.6	136.5	7.5	71.0	5.9	14.2	33

Results for Fort A.P. Hill

Fort A.P. Hill was established in 1942 as an installation for training in tactical, artillery, mechanized, and small arms methods. It is composed of 75,944 acres, most of which are in Caroline County, Virginia. The 25,800 acre controlled access area is used for live weapons training and is located on the south side of U.S. Rt. 301. Approximately 80% of the installation is forested with pine (25,832 acres), mixed pine and hardwoods (18,317 acres), and hardwoods (17,532 acres). Fort A.P. Hill is located entirely within the Coastal Plain physiographic province. Fort Belvoir and the Marine Corps Base Quantico/Prince William Forest Park, in contrast, are geographically positioned over two physiographic provinces, Piedmont and Coastal Plain. Mitchell and Roble (1998) recently catalogued the amphibian and reptile fauna of this area.

The geographic position and occurrence of numerous tributaries in Fort A.P. Hill helped to create an environment conducive to beaver activity. Thus, many of the wetland sites in this installation are created or affected by beaver. Six of the eight amphibian monitoring sites (Figure 4) are or were beaver ponds. All of the long-term amphibian monitoring sites occur along the various tributaries of the Campbell Creek watershed. This watershed drains into the Mattaponi River to the west of the installation. The eight amphibian monitoring sites were selected to minimize interference with frequent military training activities and were therefore more concentrated geographically than those in Fort Belvoir and Quantico MCB/PWFP.

Site Descriptions

Site 1 (Toombs Trail) - This site is located within a mixed pine-tulip poplar forest in Training Area 2 off Toombs Trail and consists of four patches of small wetlands derived from tire ruts in a 175 meter long, crescent-shaped, logging road. Grasses occur in the open, sunlit areas, as does sweetgum saplings. A patch of cattails occurs in one of the wetland patches. All of the wetlands are shallow, reaching a maximum depth of 15 cm. The only source of water is rainfall. Consequently, this wetland dries quicker than the other six sites. This site nearly dried by the end of May and completely dried by mid-August in 1995. It dried several times in 1996 but retained water from rain events long enough to support amphibian larvae for periods of time. In mid-May 1997, the site dried completely and remained dried for the rest of the spring and summer. This site will probably not remain viable for the long term because of the increasing shallowness of the tire ruts. (See notes for Site 8.)

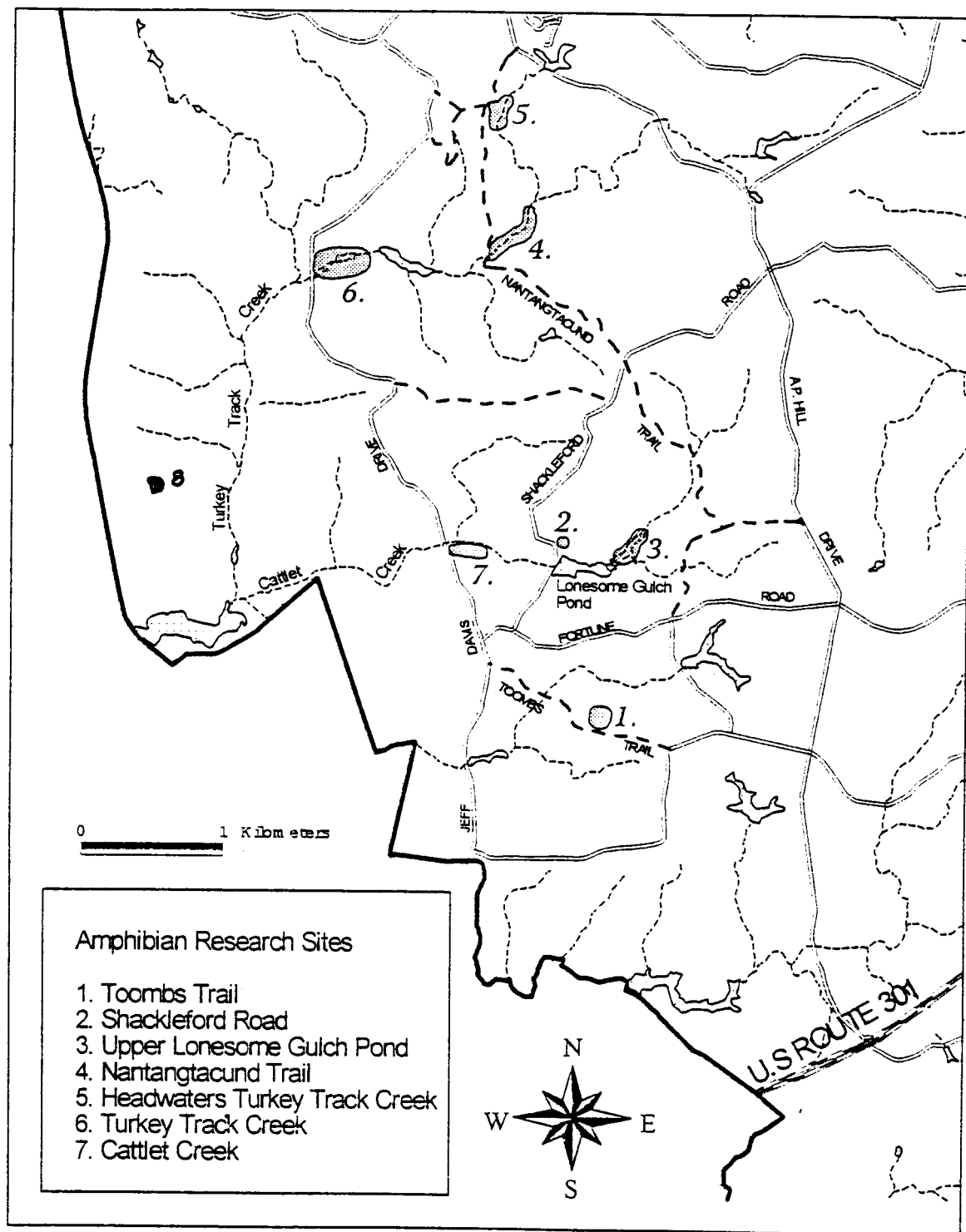


Figure 4. Map of Fort A.P. Hill, Caroline County, Virginia illustrating the locations of eight amphibian monitoring sites. Numbered sites on the map correspond with those in the text and the following tables.

Site 2 (Honeysuckle Gate Road) - Site 2 is a small pool (about 20x35 meters) located on the north side of a dirt road that separates the pool from a cove of Lonesome Gulch Pond in Training Area 3B. A drainage pipe connects the pool to the cove during high water. Virginia pine and mixed oak dominate the eastern slope above the pool, white oak, sweetgum, and tulip poplar occur on the western slope, sweetgum and red maple occur in the upstream floodplain, and tulip poplar forms a strip of woody vegetation along the margin of the road. Greenbrier is abundant around the pool margin. The relatively shallow (<1 m of open water) pool has a deep layer of organic matter, mostly leaves, and supports a population of water lilies (*Nuphar* sp.). This pool nearly dried by late August 1995; there was little standing water. It retained water throughout 1996 and 1997.

Site 3 (Upper Lonesome Gulch Pond) - This site is a large, shallow, beaver pond at the upper end of Lonesome Gulch Pond in Training Area 3B. A large beaver dam, on which grows alder, red maple, and loblolly pine trees, separates the two portions of the pond. The forest on the surrounding slopes consists of mixed oak, loblolly pine, tulip poplar, and red maple. Alder and highbush blueberry (*Vaccinium* sp.) lie along nearly the entire pond margin. A band of grasses occurs along portions of the northern edge. The pond substrate is largely organic. Numerous tree stumps lie just below the water's surface. Populations of water lilies and golden club (*Utricularia aquatica*), which in some areas can be quite dense, occur throughout the pond. The water level dropped substantially in the 1995 drought but the pond did not dry completely. It remained nearly full throughout 1996 and was reduced substantially in size by late summer 1997.

Site 4 (Nantangtacund Trail) - The main portion of this site is an unnamed beaver pond located in Training Area 5A off Talliaferro Road. The large, deep (>2 meters) pond is surrounded by a mixed hardwood forest. The northern slope supports mainly white oaks, whereas the southern slope supports mostly white oak with tulip poplar, sweetgum, and red maple along the margin. Dogwood and holly occur in the understory on both slopes. Alder, emergent grasses, and greenbrier line much of the pond margin. Below the dam to the road the vegetation consists largely of sedges and grasses. Across from the beaver pond is a floodplain with alder, red maple, tulip poplar, and a few loblolly pine. A small depression in the form of a tire rut supports grasses and a few cattails occur in the upper portion of the floodplain near the road. The pond contains large numbers of tree snags and supports a large population of water lilies. The 1995 drought had little effect on this site, except for lowering the water

level slightly and causing the small depression to dry completely. It did not dry in 1996 and decreased in size only slightly in the drought of 1997.

Site 5 (Headwaters Cattlett Creek) - Site 5 is a smaller beaver pond located in a small creek in Training Area 5A. The northeastern slope is dominated by mixed oak, loblolly pine, and Virginia pine. The pines occur primarily near the pond margin in association with alder, various grasses, and *Vaccinium* sp. The southwestern slope supports mainly mixed oaks with red maple and tulip poplar. The downstream habitat is a saturated forested wetland with mostly red maple and blackgum. The beaver dam supports herbaceous plants and alder. Upstream, the forest is dominated by loblolly pine, red maple, and alder. Alder forms a relatively dense stand in the upper, very shallow, end of the pond. Water lilies comprise the primary emergent plant. This pond is littered with the branches and limbs brought in by beavers. The water level dropped during the summers of 1995 and 1997 but the pond did not completely dry up. It retained water throughout 1996.

Site 6 (Turkey Track Creek) - This site is composed of a section of Turkey Track Creek located between Jeff Davis Road and an unnamed beaver pond in Training Area 5C. It is approximately 150 meters long and is surrounded by a forest consisting of oak, hickory, tulip poplar, sweetgum, and red maple, with a few scattered loblolly pine. The site was originally (in 1995) a shallow beaver pond, but Fort A.P. Hill personnel removed the dam that was located inside the road culverts late that year. The site subsequently became single channel with a wide floodplain that supported an expanse of pickerel weed. Water lilies were present in several of the wettest areas. This site supported water in the channel year round in all 3 years, and contained varying water levels due to the construction of a beaver dam in the road culverts and periodic removal of it by maintenance workers in 1996. It remained a channel with some floodplain expansion in early 1997 but the drought conditions that year lowered the water levels such that only the channel contained water after May of that year.

Site 7 (Cattlett Creek) - Site 7 is located to the east of the intersection of Jeff Davis Road and Cattlett Creek in Training Area 5C. It is a large marshy area with a single primary channel in the creek bed. The substrate does not dry completely and access to suitable larval monitoring sites was treacherous because it has deep pockets in many places. Much of the vegetation in the riparian marsh exists as a floating mat on a bed of mix of water and dark organic soil. Most of the surrounding slopes support mixed oaks and tulip

poplar, with a few scattered sweetgum. A band of red maple trees occurs along the southern margin of the site and a band of grasses occurs along the northern margin. The marsh consists of snags, grass mats, and patches of water lilies. The marshy expanse is wetter in the spring than in the summer. Water levels dropped during the 1995 drought, forming a main channel with several areas of lotic water near the beaver dam located next to the road. Water levels were high enough in 1996 to maintain standing water throughout the marsh. Conditions in 1997 mirrored those of 1995. Much of the marsh was dry enough to walk on, although the water level was near the surface and provided holes into which unsuspecting researchers often fell.

Site 8 (Thornton Road) - This site was selected in early 1996 because the tire ruts in Site 1 appeared to be shallower than they were in 1995. It became obvious that Site 1 was not destined to remain in its present condition for the long-term. Site 8 was selected to replace this site once it ceases to support amphibian reproduction. Site 8 is a small, permanent pond (about 50 x 70 m) created by a shallow beaver dam and gravel road (Thornton Road). It is surrounded by a 10-15 year old loblolly pine plantation on three sides. A mixed hardwood forest occurs across Thornton Road. A large stand of cattail occurs in the northwest margin and there are numerous alder shrubs and small trees in the pond itself. It retained water throughout 1996. Drought conditions in 1997 lowered the water level only slightly.

Results

The number of amphibian species recorded for the seven wetland sites on Fort A.P. Hill varied from 9 to 11 in both 1995 and 1996, and from 6 to 10 in 1997 (Table 27). These included eleven species of frogs and five species of salamanders. Neither of the two primary monitoring protocols (frog call surveys and larval surveys) or the visual encounter survey used in this study encountered all species. The nighttime frog call surveys, during which all species seen and heard were recorded, registered 56-90% of the total known for each site, less than those recorded for Fort Belvoir and Quantico MCB/PWFP (see above). The results of the larval dipnetting and daytime visual encounter surveys yielded 10-89% of the total recorded for each site, a more variable rate than that for the other two installations. Results in Table 28 demonstrate that both the nighttime frog call survey and larval dipnetting survey techniques must be used together to ensure that both the frog fauna and salamander fauna were sampled adequately. All frog species recorded during 1995-1997 were done so via the frog call survey protocol. Most of the frog

species were recorded as tadpoles at least once in each site each year in Fort A.P. Hill during the larval survey, although their occurrences within wetlands varied dramatically. Narrow-mouthed toads and southern leopard frog tadpoles were not encountered in 1996 and American toad, spring peeper, and southern leopard frog tadpoles were not found in 1997. No frog species was recorded exclusively by the larval sampling technique.

Salamanders were not encountered during frog call surveys. Only dipnetting during day and visual encounter surveys resulted in these species being registered (Table 27). Two species, three-lined salamander (*Eurycea guttolineata*) and lesser siren (*Siren intermedia*), were discovered only once each in the Cattlett Creek wetland (Site 7) in 1995. The three-lined salamander was not observed in 1996 and the siren was found in two sites (4 and 7). The former was not encountered in 1997 and the siren was found only in Site 5.

Overall results for the three-year study demonstrate that there is considerable variation in amphibian species composition in the wetlands in Fort A.P. Hill and that the use of multiple protocols is an appropriate approach for the inventory and monitoring program.

Results in Tables 29-36 for each individual wetland demonstrate conclusively that frogs exhibit strong seasonal variation in the timing of male vocalizations and when larvae (tadpoles) are present. Several species are reproductively active in early spring (e.g., American toads [*Bufo americanus*], spring peepers [*Pseudacris crucifer*], pickerel frog [*Rana palustris*]) and others are active only in late spring and summer (e.g., bullfrogs [*Rana catesbeiana*], gray treefrog [*Hyla chrysoscelis*]). Green frogs (*Rana clamitans*), carpenter frogs [*Rana virgatipes*], and northern cricket frogs (*Acris crepitans*) had the longest calling periods of all frog species in 1995, 1996, and 1997.

The carpenter frog (*Rana virgatipes*), a special concern species in Virginia (Mitchell, 1991), was recorded for 6 of the 7 wetland study sites in 1995 and 7 of the 8 sites in 1996 and 1997. Fort A.P. Hill contains more populations of this species than anywhere in the state (Fleming and Van Alstine, 1994; J.C. Mitchell, unpublished). The only site lacking this species is Site 1, a series of shallow, ephemeral pools that dry up every year. This site lacks the organic substrate and low pH apparently required by this species.

The results in Tables 29-36 also show that tadpoles of some species are caught more frequently than others in the wetlands studied. Those in the genus *Rana* (e.g., bullfrogs, green frogs) and genus *Bufo* (toads) were encountered more often than those of other species groups. This is probably due to the microhabitats selected by different species and our ability to capture them when dipnetting along the edge of the wetlands included in this study. The

tadpoles of the following species often overwinter before metamorphosing: bullfrog, green frog, and the carpenter frog. All other tadpoles achieve metamorphosis before the cold season. Tadpoles of species other than those in the genus *Rana* are apparently unable to tolerate winter conditions.

The wetlands of Fort A.P. Hill appear to support a similar salamander fauna to that in Quantico MCB/PWFP (Table 37). One species commonly encountered as larvae on the other two military installations (marbled salamander [*Ambystoma opacum*]) was found in Fort A.P. Hill at only one of the eight sites studied, despite the fact that it occurs in numerous other locations on this base (Mitchell and Roble, 1998). The other common pool-breeding species, the spotted salamander (*Ambystoma maculatum*), was recorded in two of the 7 wetland sites in 1995 and 1996 but 3 sites in 1997, 3 over all three years of study (Table 33). Red-spotted newts (*Notophthalmus viridescens*) occurred in all of the wetland sites in 1995 and 1996, but only 4 of the 8 sites in 1997. The completely aquatic lesser siren, (*Siren intermedia*) was obtained by dipnet at 3 of the 8 sites. One three-lined salamander (*Eurycea guttolineata*) was found in Site 7 in 1995 but was not encountered again throughout the remainder of the study. Of the three military base sites, this species is unique to Fort A.P. Hill. At least six other species of aquatic to semi-aquatic salamanders are known to occur on Fort A.P. Hill (Mitchell and Roble, 1998) but they were not encountered in the locations selected for study during 1995-1997.

Water Acidity Levels and Chemistry

In contrast to the wetland sites in Fort Belvoir and Quantico MCB/PWFP the eight wetlands studied on Fort A.P. Hill were all acidic (Table 38). Acidity values were variable among sites and seasons and between years. In 1996, acidity levels ranged from a low of pH 4.06 to a high of pH 6.8. In 1997, the pH values did not appear to be as low, ranging from 5.3 to 6.4. The lowest values were recorded in the spring season and the highest in the summer season. The underlying geology, largely of sedimentary deposits (sand), has limited buffering capacity. Despite the low pH levels, acid concentrations have apparently not yet reached critical levels for amphibian survival.

Dissolved oxygen (DO) concentrations varied among sites and seasons (Table 39). Most wetland sites exhibited higher DO concentrations in spring samples than samples taken in summer. This pattern is apparently correlated with increasing water temperatures as the season progresses. DO in sites 2, 5, 6, 7, and 8 declined from April through July, although it took until July for this to occur in Site 7. DO values in sites 3 and 4 remained relatively high throughout the spring and summer seasons.

Water chemistry parameters varied among sites and between sampling dates (Table 40). Acid neutralizing capacity (ANC) is low ($<100 \mu\text{eq/l}$) in all but Site 5. This site is an active beaver pond surrounded by mixed forest and has at least in part a rocky to gravel substrate. Consequently, the amount of free aluminum in these wetlands is higher than those in the other two installations included in this study. Compared to wetlands in Fort Belvoir and Quantico MCB/PWFP road salt chemicals (Ca, Na) are low in all sites except Site 5. This site does not contain salt concentrations as high as those in the other two installations but they are substantially higher than those in the other wetlands on Fort A.P. Hill.

Conclusions

Overall results of this study suggest that the field work conducted in 1995-1997 using standardized protocols described above provided a full inventory of the frog fauna but an incomplete inventory of the salamander fauna for the 8 sites studied. These results describe the majority of the community composition of each of the eight wetland sites. The results from this 3-year study should be viewed as the baseline data set for a long-term study of amphibians in this area.

The combined use of the three standardized protocols (frog call surveys, larval surveys, visual encounter surveys) proved to be effective and useful approaches to inventory and monitor the amphibians of the wetlands on Fort A.P. Hill. Future studies of these animals should use these protocols in the manner described here so that the results can be compared across years. Without the use of standardized protocols, the ability to determine trends in amphibian community composition and relative abundances will be diminished.

The results of this 3-year study suggest that the frog fauna of Fort A.P. Hill is experiencing no population or species decline. This is probably tied to the apparent health of the wetlands on this installation despite the fact that they are all acidic. Of all the individual amphibians and their larvae we examined in this study, none was deformed or showed signs of ill health. The lack of definitive results on the salamander fauna preclude any meaningful conclusions about population persistence. It is possible to note, however, that spotted salamanders and newts reproduced in each year of study and are apparently persisting in this environment. The results derived from this study provide the baseline against which future changes in at least the frog fauna and selected species of salamanders can be assessed.

Management Recommendations for Fort A.P. Hill

1. Maintain all wetland habitats used by amphibians and buffers of the remaining surrounding hardwood forest habitat. A buffer of at least 300 meters is recommended for most amphibians.
2. Destructive activities, such as draining, filling, bulldozing, and ORV intrusion, should be avoided. Construction activities that could destroy or alter any of these wetlands should be moved to another area.
3. Mitigation of wetland losses due to future projects should be done to increase protection of other wetlands and their 300 m buffers on the base for the long term. Codification of these protected areas into set-aside preserves is highly recommended.
4. All wetland sites should be monitoring annually for beaver activities, causes of siltation, and other perturbations so that prevention and restoration projects can be undertaken early.
5. Site 1 is apparently an ephemeral habitat due to the nature of its configuration. It should be monitored for amphibian activity until it no longer supports these animals. The changing conditions in these shallow pools should be noted so that we can determine when they are no longer suitable for amphibians. This will allow us to recognize other potential shallow wetland sites on base.
6. Site 4 is a large beaver pond maintained partially by the road. The surrounding hardwoods provide refugia for many amphibians and helps minimize erosion and siltation. This site could be silted in from human activities in the watershed. The area immediately south of the site is a bivouac site used extensively by training units. Vehicular and other activities on this site have created mud holes and small-scale erosion problems. Such activities, if allowed to expand, may produce conditions that cause larger erosion problems and loss of forest cover. The entire watershed should be maintained in hardwood forest, especially around the reservoir itself.
7. Site 7 is a high quality biological area that contains sensitive plant species and a diverse amphibian fauna. The hydrology of this site appears to be unique to the base with the thick mat of vegetation on top of a water/organic soil mix. The watershed should be maintained in hardwood forest. No logging

Table 27. Number of amphibian species recorded for the amphibian monitoring sites on Fort A.P. Hill in 1995 and 1996 by three techniques: Night Vocalizations = frog call survey, Larval Sampling, and Visual Encounter Survey, including frog calls.

Technique	1	2	3	Site 4	5	6	7	8
1995								
Night Vocalizations	5	5	9	9	8	8	7	
Larval Sampling	8	4	6	7	6	5	7	
Visual Encounter Survey	3	4	4	5	4	2	5	
Total No. Species	9	9	10	11	9	10	11	
1996								
Night Vocalizations	5	6	7	9	8	8	7	9
Larval Sampling	5	3	6	5	5	5	6	6
Visual Encounter Survey	8	4	6	7	7	4	5	6
Total No. Species	9	9	10	11	9	10	11	11
1997								
Night Vocalizations	1	6	9	8	8	7	6	9
Larval Sampling	1	2	2	1	6	2	4	2
Visual Encounter Survey	5	4	4	7	4	4	3	5
Total No. Species	6	8	9	10	9	8	9	10

Table 28. Amphibian species in each of seven long-term monitoring sites on Fort A.P. Hill, Virginia. Abbreviations: species identified by vocalizations (V), by identification of frog larvae (tadpoles), and adult and larval salamanders collected by dipnet (L). Common names of species are in Appendix 1.

Species	1	2	3	Site 4	5	6	7	8
1995								
Frogs:								
<i>Acris crepitans</i> (Ac)	V	VL	VL	VL	VL	V	VL	
<i>Bufo americanus</i> (Ba)	VL	V	VL	V	V	V	V	
<i>Bufo fowleri</i> (Bf)	L	L	V	VL		V		L
<i>Hyla chrysoscelis</i> (Hch)	VL		V	V	V	V		
<i>Pseudacris crucifer</i> (Pc)	VL	V	V	V	V	V	V	
<i>Rana catesbeiana</i> (Rca)			V	V	VL	VL		V
<i>Rana clamitans</i> (Rcl)	VL	VL	VL	VL	VL	VL	VL	
<i>Rana palustris</i> (Rp)		V	VL	VL	VL	VL	VL	V
<i>Rana sphenoccephala</i> (Rs)		V				VL		
<i>Rana virgatipes</i> (Rv)			VL	VL	VL	VL	VL	
Salamanders:								
<i>Ambystoma maculatum</i> (Am)	L			L				
<i>Ambystoma opacum</i> (Ao)	L							
<i>Eurycea guttolineata</i> (Eg)								L
<i>Notophthalmus viridescens</i> (Nv)	L	L	L	L	L	L		L
<i>Siren intermedia</i> (Si)								L
1996								
Frogs:								
<i>Acris crepitans</i> (Ac)	V	VL	VL	VL	VL	V	VL	V
<i>Bufo americanus</i> (Ba)	VL		V		V	VL	L	V
<i>Bufo fowleri</i> (Bf)	L		VL	V		V		
<i>Gastrophryne carolinensis</i> (Gc)				V				
<i>Hyla chrysoscelis</i> (Hch)	VL	VL	L	V	V	L	L	VL
<i>Pseudacris crucifer</i> (Pc)	V	V		VL	VL	VL	V	VL
<i>Rana catesbeiana</i> (Rca)			V	VL	V	V	V	V
<i>Rana clamitans</i> (Rcl)	V	VL	VL	VL	VL	VL	VL	VL
<i>Rana palustris</i> (Rp)		V	VL	V	V	V	V	VL
<i>Rana sphenoccephala</i> (Rs)							V	V
<i>Rana virgatipes</i> (Rv)		V	VL	VL	VL	VL	VL	V
Salamanders:								
<i>Ambystoma maculatum</i> (Am)	L			L				L
<i>Ambystoma opacum</i> (Ao)								
<i>Notophthalmus viridescens</i> (Nv)	L			L	L		L	L
<i>Siren intermedia</i> (Si)				L			L	

Table 24 continued

1997

Frogs:								
<i>Acris crepitans</i> (Ac)	V	V	VL	V	VL	V	V	V
<i>Bufo americanus</i> (Ba)	V		V				V	V
<i>Bufo fowleri</i> (Bf)			V	V		V	L	
<i>Hyla chrysoscelis</i> (Hch)	V		V	V	VL			V
<i>Pseudacris crucifer</i> (Pc)	V	V		V	V	V	V	V
<i>Rana catesbeiana</i> (Rca)		V	V	V	VL	V		V
<i>Rana clamitans</i> (Rcl)		VL	VL	V	VL	VL	VL	VL
<i>Rana palustris</i> (Rp)		V	V	V	VL	V	V	VL
<i>Rana sphenocephala</i> (Rs)		V	V		V			V
<i>Rana virgatipes</i> (Rv)		V	V	V	V	V	VL	V
Salamanders:								
<i>Ambystoma maculatum</i> (Am)	L							L
<i>Ambystoma opacum</i> (Ao)								
<i>Notophthalmus viridescens</i> (Nv)	L		L	L		L	L	
<i>Siren intermedia</i> (Si)					L			

Table 29. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 1 on Fort A.P. Hill for 1995-1997. Abbreviations as in Table 28.

		Species										
Week of		Ac	Ba	Bf	Hch	Hci	Pc	Rca	Rcl	Rp	Rs	Rv
1995												
March	13						V					
March	20						V					
March	27											
April	3											
April	10		VL				V					
April	17		VL				V					
April	24		L				V					
May	1						V					
May	8						V		V			
May	15				V		VL					
May	22						L					
May	29				VL		L					
June	5				VL		L					
June	12				L							
June	19				VL							
June	26	V			VL				V			
July	3					L				V		
July	10	V		L	VL				V			
July	17				L							
July	24				VL							
July	31				L							
August	7				VL				VL			
August	14								VL			
August	21											
August	28											
Sept.	4											
1996												
March	10						V					
March	17						V					
March	24											
March	31						V					
April	7											
April	14		L									
April	21											
April	28											
May	5			V			V					
May	12			L			VL					
May	19			L			L					
May	26			L			VL					
June	2			L	V							
June	9			L								
June	16	V		L	V		V					
June	23			L								
June	30			L	V							
July	7			L	VL							
July	14				L							
July	21				L				V			
July	28				VL				V			
August	4				L							
August	11				VL				V			
August	18				L							
August	25				L							
Sept.	1				L							

Table 29 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Pt	Rca	Rcl	Rp	Rs
1997											
March 23						V					
March 30											
April 6						V					
April 13											
April 20											
April 27						V					
May 4											
May 11											
May 18											
May 25											
June 1						V					
June 8											
June 15											
June 22											
June 29											
July 6											
July 13											
July 20											
July 27											
August 3											
August 10											
August 17											

Table 30. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 2 on Fort A.P. Hill for 1995-1997. Abbreviations as in Table 28.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rs	Rv
							Pc						
1995													
March	13						V						
March	20						V						
March	27						V				V		
April	3						V				V		
April	10						V				V		
April	17						V					V	
April	24						V				V		
May	1										V		
May	8												
May	15												
May	22												V
May	29	V								VL			V
June	5									VL			
June	12	V								VL			
June	19			L			V			VL			
June	26	V								VL			
July	3	V								VL			L
July	10	V								VL			
July	17	V								VL			
July	24	VL								VL			
July	31	V								VL			
August	7									VL			
August	14									VL			
August	21									VL			
August	28									VL			
Sept.	4									VL			
1996													
March	10						V			L			
March	17						V			L			
March	24						V			L			
March	31						V			L			
April	7						V			L			
April	14						V			L			
April	21						V			L	V		
April	28						V			L	V		V
May	5									L	V		
May	12									VL			V
May	19	V								VL			V
May	26									VL			V
June	2	V								VL			
June	9				V					VL	V		V
June	16	V								L			V
June	23	V								VL			
June	30	V								VL			
July	7	V			L					VL			V
July	14	VL								L			
July	21	L								L			
July	28	L								VL			
August	4	L								L			
August	11	L								L			
August	18	L								L			
August	25									L			
Sept.	1									L			

Table 30 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Rca	Rcl	Rp	Rs	Rv
1997											
March 23						V		L	V		
March 30						V		L	V	V	
April 6						V		L	V	V	
April 13						V		L	V	V	V
April 20						V		L			
April 27								L	V		
May 4	V							VL			
May 11								VL			V
May 18								L			
May 25								VL			
June 1								L			
June 8								VL			
June 15	V							VL			
June 22	V							VL			
June 29	V							L			
July 6	V							VL			
July 13	V							VL			
July 20	V							V			
July 27	V							V			
August 3								V			
August 10											
August 17								V			
August 24											
August 31											

Table 31. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 3 on Fort A.P. Hill for 1995-1997. Abbreviations as in Table 28.

Week of		Ac	Ba	Bw	Hch	Hci	Species		Rca	Rcl	Rp	Rs	Rv
							Pc						
1995													
March	13									L	V		
March	20		V							L	V		
March	27						V			L	V		
April	3		V							L	V		
April	10		VL				V			L	V		
April	17		L								V		
April	24		L								V		V
May	1										V		V
May	8	V											V
May	15	V								V			V
May	22												
May	29	V		V				V	V		L		
June	5	V		V				V	V				V
June	12	V							V				V
June	19	VL		V				V	V				V
June	26	VL		V									V
July	3	VL						V	V				V
July	10	VL		V				V	V				V
July	17	VL							V				V
July	24	VL			V				V				VL
July	31	VL							V				VL
August	7	VL							V				VL
August	14	V							V				VL
August	21								V				VL
August	28								V				
Sept.	4									VL			
1996													
March	10									L			
March	17									L			
March	24		V							L	V		V
March	31									L	V		
April	7									L	V		
April	14									L	V		
April	21	V								L	VL		V
April	28									L	L		V
May	5									VL	L		V
May	12	V		L						VL	L		VL
May	19	V		L				V	V	VL	L		V
May	26	V		L				V	V	VL	L		V
June	2	V		L						L	L		V
June	9	V						V	V	VL	L		V
June	16	V		V						L	L		V
June	23	V						V	V	L	L		V
June	30	V		V				V	V	VL	L		V
July	7	V		V						L	L		V
July	14	V								L			V
July	21									L			
July	28	V								VL			V
August	4	VL								VL			V
August	11	L								VL			
August	18	L								VL			
August	25									VL			
Sept.	1									L			

Table 31 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Rca	Rcl	Rp	Rs	Rv
1997											
March 23		V						L	V		
March 30								L	V	V	
April 6								L	V		
April 13								L	V		V
April 20								L			V
April 27	V							VL			V
May 4	V							L	V		V
May 11								L			V
May 18	V						V	VL			V
May 25	V						V	VL			V
June 1								L			V
June 8	V		V				V	VL			V
June 15	V		V				V	VL			V
June 22	V		V				V	V			V
June 29	V		V	V			V	V			V
July 6	V		V				V	V			V
July 13	VL		V				V	V			V
July 20	V			V			V	V			V
July 27	V						V	V			V
August 3	V							V			
August 10								V			
August 17								V			

Table 32. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 4 on Fort A.P. Hill for 1995-1997. Abbreviations as in Table 28.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rcl	Rp	Rs	Rv	Gc
							Pc	Rca					
1995													
March	13						V			V			
March	20						V			V			
March	27						V						
April	3						V			V			
April	10						V		L	V			
April	17						V		L	V			
April	24						V		L	V		V	
May	1								L	V		V	
May	8	V						V	VL			V	
May	15	V						V	VL			V	
May	22												
May	29	V		V	V			V	VL			V	
June	5	V			V				VL				
June	12	V		V				V	VL			V	
June	19	V						V	VL			V	
June	26	V			V				VL			V	
July	3	VL						V	VL			VL	
July	10	VL			V				VL			VL	
July	17	VL							VL			VL	
July	24	VL		L	V				VL			VL	
July	31								VL			L	
August	7								VL			L	
August	14								VL			L	
August	21								VL			VL	
August	28								L				
Sept.	4								L				
1996													
March	10						V		L				
March	17						V		L				
March	24						V		L	V			
March	31						V		L	V			
April	7								L				
April	14						V		L				
April	21	V					V		L			V	
April	28	V					VL	V	L			V	
May	5	V					L	V	VL			V	
May	12	V							VL			V	
May	19	V						V	VL			V	
May	26	V						V	VL			V	
June	2	V			V			L	VL				
June	9	V						V	VL			V	
June	16	V			V				L			V	V
June	23	V						V	VL			V	
June	30	V		V	V			V	VL			V	
July	7	V		V	V				L			V	
July	14	VL			V			V	VL				
July	21	L						V	L			V	
July	28	L			V				VL			V	
August	4	L							VL			VL	
August	11	L							VL				
August	18	L							VL				
August	25								VL				
Sept.	1								L				

Table 32 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Rca	Rcl	Rp	Rs	Rv
1997											
March 23						V		L	V		
March 30						V		L	V		
April 6						V		VL	V		
April 13								L	V		V
April 20						V		L			V
April 27			V					VL			V
May 4	V						V	VL			V
May 11							V	VL			V
May 18	V						V	VL			V
May 25	V						V	VL	L		V
June 1								L			V
June 8	V		V				V	VL			V
June 15	V			V			V	VL			V
June 22	V		V				V	VL			V
June 29	V			V				VL			V
July 6	V						V	VL			V
July 13	V							VL			V
July 20	V			V				V			V
July 27								V			V
August 3	V							V			V
August 10								V			
August 17								V			

Table 33. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 5 on Fort A.P. Hill for 1995-1997. Abbreviations as in Table 28.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rs	Rv
							Pc						
1995													
March	13						V				V		
March	20		V				V				V		
March	27						V				V		
April	3		V				V				V		
April	10		V				V				V		
April	17		V				V				V		
April	24		V				V						
May	1		V				V				V		V
May	8	V	V				V			V			V
May	15							V	V				V
May	22												
May	29	V			V			V	V				V
June	5	V						V	V				VL
June	12	V						V	V				VL
June	19	V			V			V	VL				VL
June	26	V			V			V	VL				VL
July	3	V						V	VL				VL
July	10	VL						V	VL				VL
July	17	VL							VL				VL
July	24	VL							VL				VL
July	31	V							VL				VL
August	7								VL				VL
August	14								VL				VL
August	21								VL				VL
August	28								VL				
Sept.	4							L	VL				
1996													
March	10						V			L	V		
March	17						V			L			
March	24						V			L	V		
March	31		V				V			L	V		
April	7						V			L			
April	14						V			L	V		
April	21						V			VL	V		V
April	28	V					VL			VL			V
May	5						L			L			V
May	12	V					L	V	VL				V
May	19	V						V	VL				V
May	26	V							VL				V
June	2	V			V				VL				
June	9	V			V			V	VL				V
June	16	V						V	L				V
June	23	V						V	VL				V
June	30	V						V	VL				
July	7	VL			V				VL				L
July	14	VL							VL				V
July	21	L							VL				
July	28	L							VL				
August	4	L							VL				
August	11	L							L				
August	18	L							VL				
August	25								VL				
Sept.	1								VL				

Table 33 continued

Week	Ac	Ba	Bw	Hch	Hci	Pc	Rca	Rcl	Rp	Rs	Rv
1997											
March 23						V		L	V		
March 30						V		L	V		
April 6						V		L	V	V	
April 13						V	L	L	V		
April 20						V	V	L			
April 27	V					V		L			V
May 4								VL			V
May 11								L			V
May 18	V						V	VL			V
May 25	V							L			
June 1								L			
June 8	V			V			V	VL			
June 15	V			VL				VL			V
June 22	V			V				VL			
June 29	V			V			V	VL			V
July 6	V							VL			V
July 13	VL						V	VL			V
July 20	V			V			V	V			
July 27	V						V	V			V
August 3								V			V
August 10								V			
August 17								V			

Table 34. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 6 on Fort A.P. Hill for 1995-1997. Abbreviations as in Table 28.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rca	Rcl	Rp	Rs	Rv
							Pc						
1995													
March	13						V		L	L	V		
March	20		V				V		L	L	V		
March	27						V		L	L	V		
April	3								L	VL	V	V	
April	10						V		L	L	V		
April	17								L	L			
April	24								L	L			V
May	1								L	VL	V		V
May	8	V							VL	VL	V		V
May	15	V							L	VL			V
May	22												
May	29	V		V	V				L	VL		L	V
June	5	V							L	VL			V
June	12	V							L	VL			
June	19	V		V					L	VL			VL
June	26	V							L	VL			VL
July	3	V							L	VL			VL
July	10	V							L	VL			L
July	17	V							L	VL			L
July	24	V							L	VL			L
July	31	V							VL	VL			L
August	7								L	VL			L
August	14								L	V			L
August	21								L	V			L
August	28								L	V			
Sept.	4								L				
1996													
March	10						V			L	V		
March	17						V			L			
March	24		V				V			L	V		
March	31						V			L	V		
April	7						V			L			
April	14						V			L			
April	21	V					V			L			V
April	28	V					VL			VL			V
May	5						L			VL			
May	12	V	L				L	V		VL			V
May	19	V					L	V		VL			V
May	26	V					L			VL			V
June	2	V		V			L			VL			
June	9	V								VL			V
June	16	V								VL			V
June	23	V								VL			V
June	30	V								VL			V
July	7	V				L				VL			V
July	14	V								VL			V
July	21	V								VL			
July	28									VL			V
August	4									VL			VL
August	11									L			
August	18									VL			V
August	25									L			
Sept.	1									L			

Table 34 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Rca	Rcl	Rp	Rs	Rv
1997											
March 23						V		L			
March 30						V		L			V
April 6						V		L	V		V
April 13								L			V
April 20						V		L			V
April 27			V					L			V
May 4								VL			V
May 11								VL			V
May 18	V						V	VL			V
May 25	V							VL			V
June 1								L			
June 8			V				V	VL			V
June 15	V		V					VL			V
June 22	V		V					V			
June 29	V							V			V
July 6	V		V					V			V
July 13	V							V			
July 20	V							V			
July 27								V			
August 3								V			
August 10								V			
August 17								V			

Table 35. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 7 on Fort A.P. Hill for 1995-1997. Abbreviations as in Table 28.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rcl	Rp	Rs	Rv
							Pc	Rca				
1995												
March	13						V		L			
March	20						V		L			
March	27						V		L			
April	3						V		L			
April	10		V				V		L			
April	17						V		L	V		
April	24								L	V		V
May	1						V		L	V		V
May	8								VL			V
May	15	V							VL			V
May	22											
May	29	V							VL			V
June	5	V							VL			VL
June	12	V							VL			VL
June	19	V						V	VL			VL
June	26	V							VL			VL
July	3	V							VL			VL
July	10	V							VL			L
July	17	V							VL			L
July	24	VL						V	VL			VL
July	31	V							VL			L
August	7								VL			VL
August	14								VL			L
August	21				L				VL			L
August	28								VL			L
Sept.	4								L			L
1996												
March	10						V		L			L
March	17						V		L	V		L
March	24						V		L	V	V	L
March	31						V		L	V	V	L
April	7						V		L			L
April	14						V		L	V		VL
April	21								VL	V		VL
April	28						V		VL	V		VL
May	5								VL			VL
May	12	V							VL			VL
May	19	V							VL			VL
May	26	V							VL			VL
June	2	V	L						VL			VL
June	9	V							VL			VL
June	16	V							L			VL
June	23	V						V	VL			VL
June	30	V						V	VL			VL
July	7	V							VL			VL
July	14	V			L				VL			VL
July	21	V							VL			VL
July	28	VL							VL			VL
August	4	L							VL			VL
August	11	L							VL			L
August	18	L							VL			L
August	25								VL			L
Sept.	1								VL			L

Table 35 continued

Week	Ac	Ba	Bf	Hch	Hci	Pc	Rca	Rcl	Rp	Rs	Rv
1997											
March 23						V		L	V		L
March 30						V		L			L
April 6						V		L	V		VL
April 13						V		L			VL
April 20						V		L			VL
April 27		V						L		V	VL
May 4								VL			VL
May 11			L					VL			L
May 18								VL			VL
May 25								VL			VL
June 1								L			VL
June 8								L			VL
June 15	V							VL			VL
June 22	V							VL			VL
June 29	V							L			VL
July 6	V							VL			VL
July 13	V							VL			L
July 20	V							V			
July 27								V			V
August 3								V			
August 10								V			
August 17								V			

Table 36. Seasonal variation in timing of male frog vocalizations and presence of larvae (tadpoles) in Site 8 on Fort A.P. Hill for 1996 and 1997. Abbreviations as in Table 28.

Week of		Ac	Ba	Bf	Hch	Hci	Species		Rcl	Rp	Rs	Rv
							Pc	Rca				
1996												
March	10						V				V	
March	17						V				V	
March	24		V				V			V		
March	31						V			V		
April	7						V			V		
April	14						V			V		
April	21						V		V	V		V
April	28						VL		V	VL		V
May	5						VL		V	L		V
May	12						L		V	L		
May	19	V			V		L	V	V	L		V
May	26						L		V	L		
June	2	V			V		L			L		V
June	9	V			V			V	V	L		
June	16	V			V				V	L		V
June	23	V			V				V	L		V
June	30	V			V				V	L		V
July	7	V			VL				V	L		V
July	14	V			V				V	L		
July	21	V			V				V	L		
July	28	V			V				V	L		V
August	4								VL	L		
August	11								VL	L		
August	18								VL	L		
August	25								VL	L		
Sept.	1								VL	L		
1997												
March	23		V				V		L	V		
March	30								L	V		
April	6						V		L	VL	V	
April	13						V		L	L		
April	20						V		VL	L		
April	27						V		VL	L		
May	4								VL	L		
May	11								VL	L		
May	18								VL	L		
May	25								VL	L		
June	1								L			
June	8	V							VL			
June	15	V							VL			
June	22	V			V			V	VL			
June	29	V			V				VL			
July	6	V						V	VL			
July	13	V			V			V	VL			
July	20	V		V	V	V		V	V			
July	27	V			V			V	V			V
August	3								V			
August	10								V			V
August	17								V			

Table 37. Dates of first and last observations of larval and adult salamanders by site on Fort A.P. Hill during 1995-1997. The first number is the day and the second is the month. Upper number is first date of observation and second number is last date of observation.

Species	1	2	3	Site 4	5	6	7	8
1995								
<i>A. maculatum</i>	14/3 13/5			14/3 13/5				
<i>E. guttolineata</i>							23/6	
<i>N. viridescens</i> (larvae)	9/6 25/7				23/6			
<i>N. viridescens</i> (adults)	14/3	14/4 2/8	14/4	14/4 7/8	9/7 7/8	14/4	14/3 29/5	
<i>S. intermedia</i>							25/7	
1996								
<i>A. maculatum</i>	18/4							
<i>A. opacum</i>								30/4
<i>N. viridescens</i> (larvae)	7/7				7/7 4/8		9/7	5/6 4/8
<i>N. viridescens</i> (adults)	18/4 30/4	18/4 5/8	30/4	18/4 30/4	18/4 5/6	18/4 5/6	30/4 7/7	30/4
<i>S. intermedia</i>				30/4			4/8	
1997								
<i>A. maculatum</i>	22/4			22/4				22/4
<i>N. viridescens</i> (larvae)							9/7	
<i>N. viridescens</i> (adults)		22/4 18/6		22/4		22/4 16/7	18/6	
<i>S. intermedia</i>					16/7		30/5	

Table 38. Seasonal variation in acidity in the eight study sites on Fort A.P. Hill, Virginia, in 1996 and 1997. Except for date (month/day), numbers are pH values. The first number before the slash is pH determined in the laboratory (1996 Accumet 950 pH meter at University of Richmond; 1997 Orion Model 811 pH meter with Ross Glass combination electrode at James Madison University). The second number following the slash is the value obtained with a Hanna HI9023 hand-held pH meter in the field. Dashes indicate no measurement taken and "dry" indicates no standing water.

Date	1	2	3	Site 4	5	6	7
1996							
4/18	4.72	4.06	4.54	4.64	5.01	5.14	4.82
4/30	---	4.72	5.26	5.33	5.72	5.41	5.40
6/5	5.20/6.18	5.20/5.39	5.27/5.76	5.63/5.84	5.83/6.21	5.68/5.89	5.32/5.54
7/7	5.90/6.57	5.29/5.75	5.38/5.96	5.46/6.02	5.69/6.10	5.63/6.09	5.19/5.49
8/4	5.51	5.53	5.69	5.97	6.11	5.95	5.30
8/20	5.18/6.78	5.16/5.83	4.99/5.57	5.33/5.90	5.86/6.20	5.36/5.87	5.02/4.45
9/7	5.49	5.36	5.20	5.64	6.12	5.98	5.33

Date	Site 8
4/18	5.05
4/30	4.89
6/5	5.36/5.55
7/7	5.15/5.52
8/4	5.56
8/20	5.32/5.53
9/7	5.67

Date	1	2	3	4	5	6	7
1997							
4/22	5.35/---	5.43/5.36	5.73/5.64	6.16/5.82	6.40/5.89	6.07/5.65	5.72/5.58
30/5	dry	5.64	5.86	6.06	6.03	5.96	5.57
6/18	dry	5.54/5.78	5.84/5.72	6.14/5.76	6.39/6.08	6.09/5.83	5.73/5.66
7/16	dry	5.67	6.36	6.11	6.30	6.36	5.69

Date	Site 8
4/22	5.72/5.26
30/5	5.50
6/18	5.68/5.48
7/16	5.92

Table 39. Seasonal variation in dissolved oxygen (DO) content in the eight study sites on Fort A.P. Hill, Virginia, in 1997. Except for date, numbers are percent DO obtained with a YSI®-95 DO hand-held pH meter in the field.

Date	Site							
	1	2	3	4	5	6	7	8
22 April	---	36.7	22.4	37.1	14.6	34.7	18.1	11.5
30 May	dry	8.0	16.3	34.2	16.8	27.1	19.0	3.4
18 June	dry	4.1	29.2	13.4	8.4	24.4	20.3	6.8
16 July	dry	3.4	24.5	22.3	6.0	12.9	1.2	13.2

Table 40. Water chemistry data for the eight study sites on Fort A.P. Hill, Virginia, in 1997. Chemical tests were performed in Dr. D.M. Downey's laboratory at James Madison University. All values are in $\mu\text{eq/l}$. Abbreviations are ANC = acid neutralizing capacity, Ca^{++} = calcium, Mg^{++} = magnesium, Na^+ = sodium, K^+ = potassium, Cl^- = chloride, NO_3^- = nitrate, SO_4^- = sulfate, Al = aluminum, ND = not determined. Methods: ion chromatography for anions, atomic absorption for metals, two endpoint titration for low ANC and graphite furnace for Al. All methods were done as described in APHA, Standard Methods for the Analysis of Water and Wastewater (D.M. Downey, personal communication).

Site	Date	ANC	Ca^{++}	Mg^{++}	Chemical		Cl^-	NO_3^-	SO_4^-	Al
					Na^+	K^+				
1	22/4	16.8	85.5	33.6	32.7	75.0	42.8	4.0	162.3	53
2	22/4	13.8	34.4	35.0	34.2	22.8	110.8	5.5	81.8	43
	18/6	67.8	39.9	55.7	63.1	25.9	59.1	1.5	19.5	100
3	22/4	27.5	22.1	24.5	29.2	19.8	78.3	4.8	30.0	69
	18/6	46.4	28.2	42.5	67.6	29.2	61.9	0.5	6.7	192
4	22/4	48.9	46.7	30.9	34.2	19.0	90.8	3.3	59.3	29
	18/6	118.2	78.0	75.4	72/5	28.1	80.8	7.6	8.3	117
5	22/4	161.0	106.6	86.7	38.7	30.3	106.3	5.3	41.0	27
	18/6	317.4	192.4	137.3	70.5	47.4	338.2	6.0	47.2	223
6	22/4	32.6	39.2	52.4	32.5	16.5	75.3	1.8	55.0	43
	18/6	76.9	56.5	62.5	62.4	21.7	64.1	1.1	24.5	45
7	22/4	15.8	21.6	35.1	27.5	21.8	61.3	1.3	38.5	71
	18/6	56.0	36.4	47.3	59.9	16.6	48.7	2.2	9.1	132
8	22/4	54.0	45.7	52.3	39.2	26.3	128.5	3.0	40.3	20
	18/6	67.8	52.5	58.8	126.01	20.4	139.1	4.2	15.7	33

Amphibians on Fort Belvoir, Quantico MCB/PWFP, and Fort A.P. Hill: Conclusions

1. Despite the fact that populations of amphibian species have declined or become extinct in other parts of North America, the amphibian fauna on the three military bases in Virginia, including the portion of Prince William Forest Park included in this study, do not appear to have suffered any noticeable decline or losses of species. With only three years of data it is not possible to determine whether these populations are declining or stable or increasing. Determining population trends require long-term data sets with at least 20 years of continuous information.
2. The accumulation of presence/absence data and information on seasonal variation in timing of male frog vocalizations and occurrence of aquatic larvae for all the species present on the four installations provides the baseline database against which information from future studies can be compared. An assessment of population trends of these sensitive species, that is whether or not they are declining, await the results from similar studies conducted in future years.
3. The two standardized monitoring protocols used in this study, frog call surveys and aquatic larval surveys, along with the visual encounter survey method, were effective methods for amphibian species inventory and population monitoring in these installations. These methods provided results that can be compared among installations and across time for the frog fauna. They incompletely sampled the possible salamander fauna and can serve as the baseline for only the species encountered each year in multiple sites.
4. The frog call survey is a relatively easy protocol to use in the field, as demonstrated by my assistants who have widely varying backgrounds in amphibian biology. The larval survey method, in contrast, is more difficult simply because of the problems with identification of salamander larvae and tadpoles. Effective protocol and identification manuals must, therefore, be developed and training sessions of natural resource personnel must be conducted so that military can conduct the monitoring programs on their own in the future.
5. The research conducted in the three years of this study on the amphibians in the mid-Atlantic region focused primarily on the animals themselves. The habitats in which these amphibians breed, freshwater wetlands, were described at a basic level. The information on the acidity levels of these wetlands show that most of those on Fort Belvoir and Quantico MCB/PWFP are not currently at

pH levels that are harmful to amphibians. In contrast, most the wetland sites on Fort A.P. Hill are acidic, with relatively low pH levels. Current levels, however, do not appear to be harmful to amphibians. Longer term monitoring of acid-base chemistry of these wetlands should undertaken.

6. The information on species composition of each wetland site, seasonal timing of life history stages (e.g., eggs, breeding period, larval period), and apparent health of these environmentally sensitive species allows resource managers to make informed decisions regarding activities that may affect amphibians and their habitats. This information was accumulated throughout this study and should be accumulated throughout the long-term monitoring period. Such knowledge should be incorporated by all resource managers and installation decision makers and used in all evaluations of impacts on sensitive resources and their habitats.

General Management Recommendations

These recommendations pertain to all military bases (and PWFP) and are transferable across base jurisdictions. Other management recommendations specific to each base are included within the section devoted to each installation.

1. Wetland habitats on the three military bases and Prince William Forest Park are important resources used for reproduction by a diversity of amphibian species. Because these animals utilize these wetlands for only a portion of their annual time budget and the remainder in the surrounding forested habitat, both the wetlands and a wide buffer around them should be maintained for the long-term. Amphibians utilize the terrestrial habitat for up to a kilometer or more, but most remain within a 300 meter area around breeding sites (Dodd, 1996; Pauley et al., in press). Loss of populations could occur if the wetland habitat or the majority of the surrounding forested habitat is destroyed. Managed forest habitat may be acceptable to amphibians but clearcutting and elimination of forest cover is not.

2. Conversion of hardwoods to pine plantations and fields will not support viable populations of amphibians. Most amphibians either maintain larger populations in hardwood forests than in pine stands or avoid pine woods altogether (Mitchell, unpublished). Such conversions should be avoided within 300 meters of any wetland, including vernal pools, beaver ponds, and riparian corridors.

3. Off-road vehicles can destroy small wetlands and displace amphibian egg masses and developing larvae. Regulations against encroachment of any wetland of any size by vehicles would help protect these fragile ecosystems and their sensitive inhabitants. Development of base-level or command-level regulations is recommended.

4. Long-term management of wetlands used by amphibians should be coupled with GIS and GPS technology. This management tool requires two approaches. First, each wetland, from small vernal pools and other ephemeral sites to beaver ponds and lakes, should be located and mapped with GPS coordinates and described in detail. Second, the coordinates of each of these sites and the surrounding 300 meter buffer should be computerized and maintained in an electronic data file devoted to this purpose. The benefits of this approach is that it allows all ongoing and planned activities to be overlaid on maps of these sites. Current and future threats can then be evaluated and modified as necessary.

5. Long-term monitoring of amphibian populations, especially frogs, should be maintained on each military installation for at least 20 years. Each base should either have permanent personnel trained and committed to do the job, or they should include in their annual budgets funding to contract the job to outside biologists.

6. Each base should maintain copies of the data accumulated annually data for the 20 year+ study. Copies of all data sheets and electronic copies should be maintained in two or more places, preferably one with the appropriate agency or department on base and one with the primary researcher. A brief annual report should be generated based on these data so that any noticeable changes can be identified quickly.

7. Periodic reviews of the amphibian presence/absence and population data, for example every 3-5 years, should be undertaken by appropriate biologists and staff personnel from all the region's federal installations so that regional trends or obvious changes or problems can be identified quickly.

Part 2

Amphibian Populations in Shenandoah National Park

Introduction

The Appalachian Mountain region was identified two decades ago as an area potentially sensitive to acid deposition (Galloway and Cowling, 1978). Subsequently, studies in Shenandoah National Park in the Blue Ridge Mountains of Virginia, revealed that surface runoff alkalinity concentrations are low throughout the park, indicating an overall sensitivity to atmospheric precipitation containing sulfate and hydrogen ions derived from anthropogenic sources (Lynch and Dise, 1985). Alkalinity is expected to decline in the eastern United States if acid deposition continues at its present level or increases (Galloway et al., 1993).

Biotic responses to the decreases in alkalinity in the Appalachian and Blue Ridge mountains have been studied only on a few taxonomic groups. Feldman and Conner (1992) determined that aquatic invertebrate abundance and species richness are significantly lower in montane streams in Shenandoah National Park with pH levels of 5.8 compared to streams with a pH of 7.1. All of the mayfly fauna (Ephemoptera), an important prey species of brook trout, will decline or become locally extinct in streams that acidify to less than a pH of 6.0. The number of invertebrate taxa in the highly acid-sensitive St. Mary's River in Augusta County, Virginia, south of Shenandoah National Park, declined steadily from 32 in 1936 to 17 in 1988 (Webb et al., 1989b; Camuto, 1991). Likewise, the number of fish species in St. Mary's River declined from 12 in 1976 to 3 in 1995 (Mark Hudy, Fisheries Biologist, George Washington National Forest, personal communication). Webb et al. (1989a) determined that 93% of 344 trout streams in Virginia were sensitive to acid deposition and that 10% were already acidic.

A basic problem with analyses of the effects of acid deposition on montane amphibian communities is that baseline data on these animals often do not exist in those specific watersheds in which water chemistry and the biotic responses of other taxa have been studied. This has been especially true for streams in Shenandoah National Park. Although the general composition of the amphibian fauna of the park is known (Witt, 1993), the distribution of these species by watershed and stream has not been assessed. Thus, one objective of this portion of the study was to obtain baseline data on species composition of the streamside salamander fauna of each of the streams and watersheds studied. A second park objective was to determine species richness of all amphibians in the streams and associated riparian areas in the three watersheds.

Determination of the differences in the amphibian fauna among sites meets the first project objective. Simultaneously, obtaining baseline data on relative abundances of streamside salamanders meets the second objective of the Shenandoah National Park portion of the Legacy study.

This report contains comparisons of data obtained from three watersheds in 1995, 1996, and 1997. Observations from the first excursions into the these areas in late 1994 are included where appropriate. The report also contains comparisons of the results of two different techniques used to assess the relative abundances of the streamside salamanders common to all three watersheds. A separate section describes the results of studies on amphibians following the catastrophic June 1995 flood in Staunton River.

Site Selection and Descriptions

Of the 17 stream sites selected for aquatic sampling in the Long Term Ecological Monitoring (LTEM) System in Shenandoah National Park (Ravlin et al., 1990), three were selected for an analysis of the amphibian fauna. These are Paine Run, Staunton River, and Piney River (Figure 5). These three streams were selected because they represent an alkalinity gradient from low acid neutralizing capacity (ANC, Paine Run), to moderate ANC (Staunton River), to high ANC (Piney River) and because water chemistry parameters and fish and invertebrate communities have been monitored intensely. Physical characteristics of each of these watersheds and streams are compared in Table 31. The bedrock geology is a primary determining component of the ability of the stream to buffer acid precipitation (Webb et al., 1989a, 1994).

The ANC of Paine Run has been consistently lower than the ANC in Piney and Staunton rivers (Bulger et al., 1993; Webb et al., 1993) (Table 41). This is primarily due to the lack of buffering capacity provided by the underlying bedrock, the Hampton formation in Paine Run. The mainstem is approximately 5 km long and covers an elevation range of 424 meters. There are several minor tributaries and one major one that drains Lefthand Hollow on the north side of the watershed near the SNP boundary. The majority of the river margin consists of an abundance of loose, small rock, bank edge with no associated rock cover, large boulders, and patches of rubble and gravel (Table 42). There are reaches of varying length in which the Paine Run passes through bedrock. Several pools and seepages occur within the watershed that serve as breeding locations for amphibians that avoid moving water. A forest canopy was present over most of the stream throughout this study, except for the last 100 meters or so at the SNP boundary.

Staunton River has a moderate capacity to buffer acid deposition and

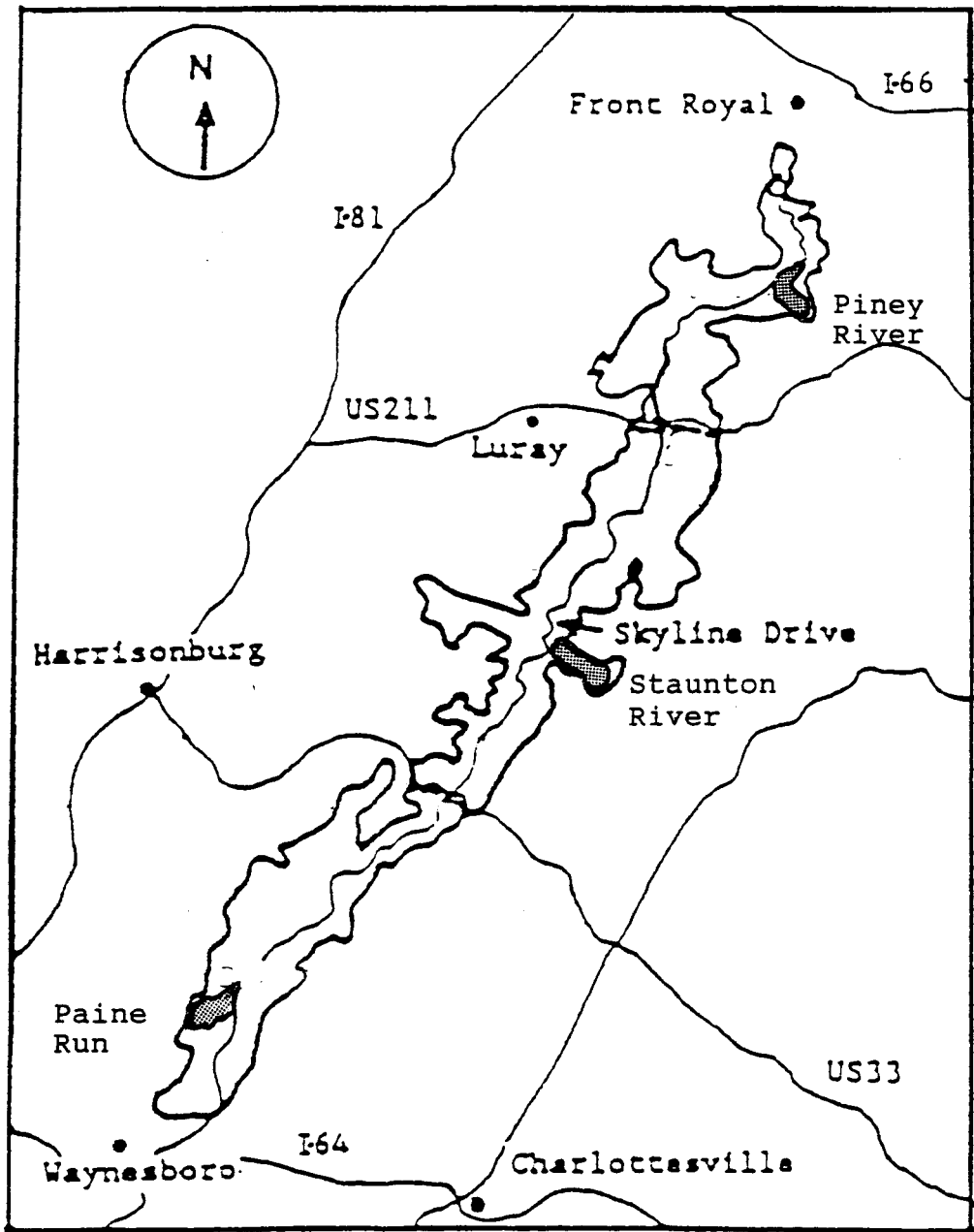


Figure 5. Location of the Paine Run, Staunton River, and Piney River watersheds in Shenandoah National Park.

alkalinity readings have been consistent over the past decade (Webb et al., 1993). The underlying granitic bedrock (mostly Pedlar formation) provides some buffering capacity. The mainstem is approximately 5.5 km long and covers an elevation range of 308 m. There is one primary tributary in the lower reach of the River (Wilson Run), and two smaller tributaries join the river in the middle section. The substrate throughout the mainstem and major tributaries consisted mainly of patches of boulders, large rocks, small rocks, patches of rubble and gravel, and bank margin without cover objects (Table 42). Many of the rocks were covered with mosses. The canopy was complete for nearly the entire length of the watershed until late June 1995 (see below: The Effects of the 27 June 1995 Flood).

Piney River has a high capacity to buffer acid deposition. Alkalinity readings throughout the late 1980s and early 1990s show values well above the danger zone for many aquatic animals ($>100 \mu\text{eq/L}$). The underlying Catoctin Formation, characterized by metamorphosed basalt beds that originated as ancient lava flows (Gathright, 1976), provides high buffering capacity. The mainstem is approximately 6.5 km long and covers an elevation range of 347 m. There are no major tributaries. The substrate throughout much of the mainstem consists of small rock, river bank lacking cover objects, large rocks, boulders, and rubble and gravel bars (Table 32). The canopy over the mainstem was essentially complete throughout the watershed.

Protocol

Streamside salamander assemblages were monitored in the watersheds in two ways, time-constrained visual encounter surveys and randomly-placed quadrants along linear transects. Time-constrained visual encounter surveys (Heyer et al., 1994) were conducted during 1995, 1996, and 1997. Each of the watersheds was searched throughout its length in the stream at least once in 1995 and 1996, usually in the fall. Surface objects were turned over and all microhabitats that might harbor amphibians were searched. All individuals encountered were identified, and relative location (upper, lower reaches [see Figure 6]) and habitat (e.g., seep, tributary, mainstem) noted. Adult and immature life history stages were also recorded for most individuals. These notes were also taken during linear transects so that all species observed would be recorded on data sheets or on field notes. In 1996 and 1997, start and end times during field excursions were noted so that relative abundances in number of individuals per person hour could be obtained (this is the time-constrained visual encounter survey). Non-target species were recorded on all trips so that a species richness list could be developed for each watershed.

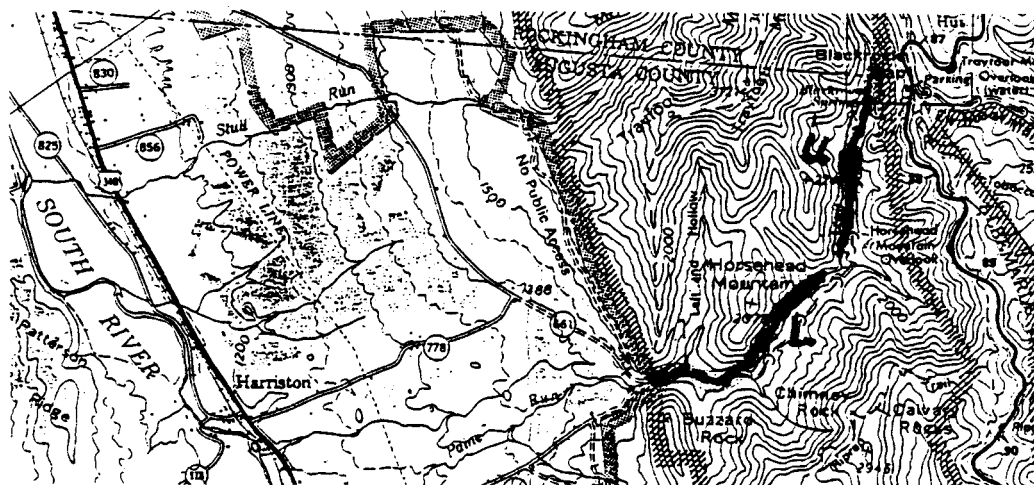
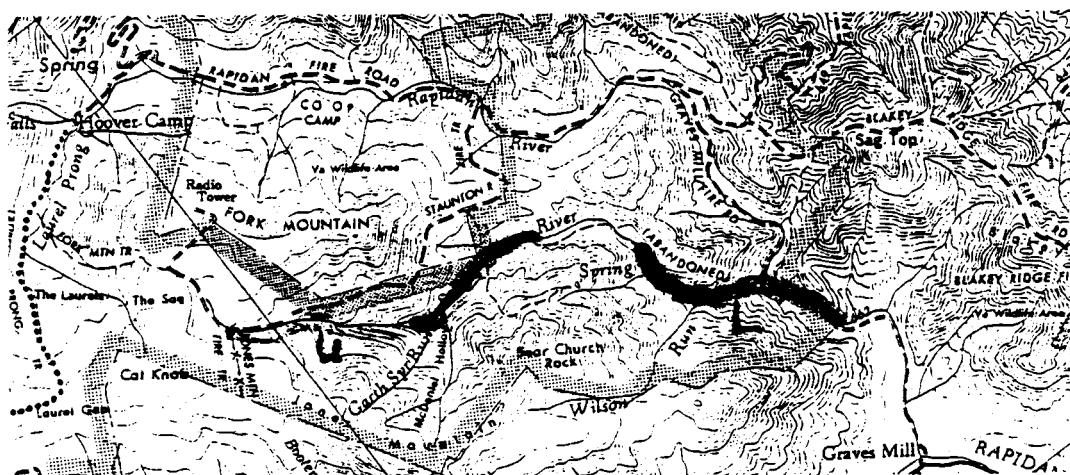
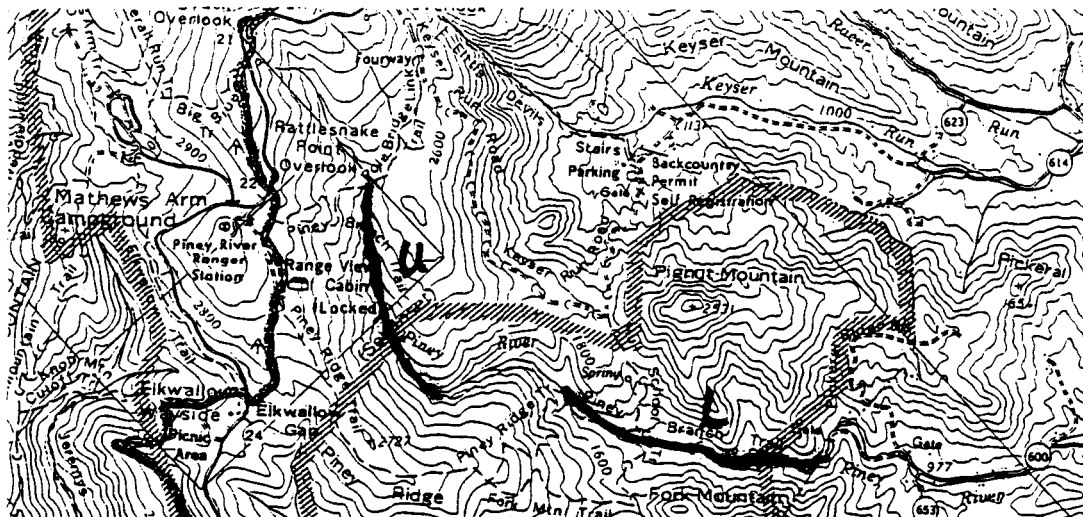


Figure 6. Long-term Ecological Monitoring sites in Shenandoah National Park. Upper panel: Piney River, Middle: Staunton River, Lower: Paine Run. Upper (U) and Lower (L) sections are shaded.

The presence of two species of frogs was determined by me from their species-specific male vocalizations (frog calls).

Linear transects with quadrant sampling (Heyer et al., 1994) were used along stream edges to obtain quantitative information on the abundance of streamside salamanders. A random location was selected within the upper and lower sections of the stream, usually at a trail crossing or other reference point, and a 50 meter tape was deployed upstream along one side. The side of the stream to be surveyed was selected arbitrarily each time. At every 5 meters along the tape a 1 m² quadrant (made of 0.5 inch PCV pipe) was placed on the edge of the open water and positioned over the adjacent substrate. Each quadrant was searched thoroughly by turning over all surface objects, primarily rocks. The gravel substrate, if present, was also plowed to a depth of 4-5 cm to uncover any remaining salamanders. Some salamanders escaped, usually into the water, by using rapid locomotion. This required that the field researcher be able to identify quickly most salamanders on sight. All salamanders were identified, number of individuals were noted, and life history stage (juvenile, adult) were recorded for each quadrant on data sheets. My assistants and I attempted to obtain a total of 100 or more quadrats per stream reach (upper, lower) in each of the three years. Time, water, and air temperatures, and habitat type were usually recorded.

Searching for streamside salamanders is usually best accomplished at night in wet weather when they are foraging. However, in this study searches were conducted during the day because it would have been too dangerous to work the streams at night. Many of the locations are remote and access to some was difficult even in the daytime. This was especially true for the basinwide searches when we hiked from the upper end to the lower end at the SNP boundary.

Dates on which we conducted amphibian inventory and monitoring by LTEM site are as follows: Paine Run - 1994: 9 September, 1995: 8 May, 5 & 18 July, 28-29 August, 6 & 12 September, 19 October, 1996: 17 May, 17 & 25 June, 17 July, 5 October, 1997: 26 July, 4, 10, 23, & 28 August, 10, 16, & 21 September; Staunton River - 1994: 21 September, 1995: 26 April, 16 May, 8 June, 1 August, 13, 19, & 20 September, 17 October, 1996: 7 & 13 June, 1 & 24 July, 25-26 September, 1997: 6 & 29 August, 2 & 12 September, 15 October; Piney River - 1994: 22 September, 1995: 26 April, 22 May, 7 & 17 July, 30 August, 20 September, 1996: 3 May, 14 & 24 June, 25 July, 1997: 8 August, 25 & 26 September, 2, 6, 9, 12, 13 October. Time-constrained visual encounter surveys and density transects were often conducted on the same days.

Results are presented in three ways: presence or absence within watersheds (to ascertain differences in species richness among watersheds; results from all methods combined), number of individuals of each species per

person hour of effort (time-constrained visual encounter survey), and number of individuals of each of the four most common species per m² of each watershed (density protocol with quadrats). Expressing numerical data as number per person hour and per m² allows comparisons among sites when sample sizes differed.

Results

A total of 15 amphibian species were recorded in 1995 for all three LTEM watersheds combined (7 frogs, 8 salamanders) (Table 43). Thirteen species (6 frogs, 7 salamanders) were recorded for 1996, and 10 species were encountered in 1997 (4 frogs, 6 salamanders). The highest total species richness recorded for the project to date occurred in Paine Run (15), whereas the lowest occurred in Piney River (8). Paine Run contained the highest total frog diversity with 9 species. Salamander assemblages were similar among the three watersheds. Four species were found consistently in most years: dusky salamander, seal salamander, two-lined salamander, and spring salamander (Table 43).

In late 1994, the initial survey resulted in observations of nearly all the common salamanders but only two frog species in Paine Run (Table 43).

In 1995, only one frog was recorded for Staunton River (*Rana clamitans*) and two for Piney River (*Rana clamitans* and *Rana palustris*), compared to 6 species for Paine Run. Nearly all these species were encountered in the lowest 200 m of the watershed where the forest canopy is more sparse than upstream. The total number of salamanders was the same (6) for each of the three watersheds. *Plethodon cylindraceus* (White spotted slimy salamander), a terrestrial species, was not discovered in Paine Run in the three years of this study, whereas it was recorded for the other two sites. On the other hand, *Pseudotriton ruber* (red salamander), a species of moist areas and stream margins, was found twice in Paine Run and once in Staunton River. Four species of salamanders were abundant in all three rivers: *D. fuscus* (dusky salamander), *D. monticola* (seal salamander), *E. bislineata* (two-lined salamander), and *G. porphyriticus* (spring salamander). Together, these species comprised the majority of salamanders encountered during this study.

Total species richness was slightly higher in Paine Run in 1996 (10 species) than in Staunton River (9 species) and Piney River (7 species). The number of frog species increased substantially in Staunton River that year (see the section on effects of the 1995 flood below). *Desmognathus fuscus* was not encountered in Paine Run in 1996. The other species were common to uncommon; too few individuals were recorded to note anything more than presence/absence. Juveniles and/or larvae of most species were observed in all three watersheds.

Numbers of species encountered in 1997 were similar to those encountered in previous years. The number of frog species remained low in Piney River for the entire study period. Overall, frog species richness was higher in Paine Run compared to the two other streams, but only three species were encountered in 1997. The salamander fauna was similar across all years of the study.

Relative abundances of the four species common to all three watersheds derived from time-constrained visual encounter surveys (Table 44) demonstrated that *Desmognathus monticola* was the most commonly encountered salamander. Only in lower Piney River in 1997 was another species (*Eurycea bislineata*) found more frequently. There is substantial variation among sites and between years in numbers of salamanders encountered by this method. These results demonstrate that single surveys will not serve as adequate indicators of relative abundance of streamside salamanders in Shenandoah National Park.

Densities of the four most common species of salamanders varied among and within watersheds, as well as among years (Table 45). *Desmognathus monticola* and *Eurycea bislineata* were the two most abundant species in all three sites in 1995, 1996, and 1997. Spring salamander (*Gyrinophilus porphyriticus*) were the third most common species in Paine Run and Staunton River but was not found in quadrants in Piney River in 1995. *Desmognathus fuscus* was uncommon in all three sites except in seepage areas that year; it was rarely found in the mainstem and the larger tributaries. Two-lined salamanders were more common in Paine Run than in Staunton River and Piney River in 1995 and 1996, whereas this species was more abundant in lower Piney River in 1997 than in other sites that year. Salamanders in all three watersheds were much less abundant in 1996 than in 1995 and 1997. This may be attributable to the greater amounts of water in 1996 than in other years. Monthly rainfall was higher in 1996 than in other years (Appendix 3). The result was apparently that salamanders dispersed farther away from the main channel into the adjacent moist forest. When conditions are relatively dry, salamanders remain in the main channel. This effect is likely to occur between seasons as well, more dispersal in spring with higher water levels and less dispersal in fall when streams are typically drier.

Rank-order comparisons of results from the quadrat method 1995- 1997 with those from the time-constrained visual encounter searches are in Table 46. *Desmognathus monticola* was the dominant species numerically in most sections of the watersheds in most years, followed by two-lined salamanders (*Eurycea*). The rank orders of *D. fuscus* and *G. porphyriticus* switched in Piney River when compared to the other two sites. Numbers of salamanders encountered by the time-constrained visual encounter method were substantially higher than numbers recorded by the quadrat technique but yielded similar results when based on ranks.

Species accounts -

Acris crepitans crepitans (Northern cricket frog) - One adult male of this small frog was observed in Paine Run on 19 October 1995.

Bufo americanus americanus (American toad) - One juvenile was observed in the lower portion of Paine Run on 12 September 1995. Two recent metamorphic individuals were found in lower Staunton River on 6 August 1997. One adult was found in upper Staunton on 2 September 1997.

Bufo fowleri (Fowler's toad) - Single juveniles of this toad were observed on the trail in the lower portion of Paine Run on 12 September 1995 and 17 June 1996. A large aggregation of tadpoles and several recent metamorphs of this species was observed in a pool in the lower, inundated portion of Staunton River on 1 July 1996. A large adult female was found in lower Paine Run on 28 August 1997.

Hyla versicolor (Eastern gray treefrog) - Two individual males were heard calling at the upper end of the Paine Run watershed on 17 May 1996. Numerous recently metamorphosed individuals were observed in the lower, inundated portion of the Staunton River among the stagnant and slow-movement pools associated with the mainstem on 1 July 1996.

Pseudacris crucifer crucifer (Spring Peeper) - One male that called three times was heard in the lower portion of Paine Run on 19 October 1995. It was not recorded in 1996.

Rana catesbeiana (Bullfrog) - An adult frog that jumped from a rock into the upper portion of Piney River on 17 July was recorded in the field notes as this species, however, since the identification is tentative, it is not included in Table 33. An immature bullfrog was caught in lower Paine Run on 5 October 1996.

Rana clamitans malanota (Green frog) - This species has been observed in all three LTEM sites. One immature was caught along the stream edge in Paine Run on 17 June 1996. Tadpoles of this species were observed in a pool near the confluence of the Staunton and Rapidan rivers on 17 October 1995. Several aggregations of tadpoles containing up to three size classes (suggesting 3 separate egg-laying events) were recorded in lower Staunton River on 1 July 1996. An adult was observed in a pool in the Piney River floodplain on 22 May

1995. One juvenile was observed in lower Staunton on 20 August 1997 and in lower Paine Run on 28 August 1997.

Rana palustris (Pickerel frog) - This is a relatively numerous frog in Paine Run. Juveniles and adults have been caught under streamside rocks throughout the watershed between 17 June and 5 October. A single adult was caught while it was hiding in a rock crevice adjacent the upper portion of Piney River on 17 July 1995 and one was found under a rock 10 m from the stream edge on 3 May 1996. In 1997, adult pickerel frogs were observed in lower Paine Run on 4 and 28 August, in lower Staunton River on 6 August, and in lower Piney River on 8 August.

Rana sylvatica (Wood frog) - This species is nearly as numerous in Paine Run as pickerel frogs. Adults and juveniles have been caught in both upper and lower portions between 28 August and 5 October. A single recently-metamorphosed individual was caught in the inundated portion of the Staunton River on 1 July 1996, indicating at least one breeding event in this watershed that year.

Salamanders:

Desmognathus fuscus fuscus (Northern dusky salamander) - This is a widespread salamander and is a common inhabitant of mountain streams and tributaries. It prefers shallower water than the seal salamander and occurs less often in flowing water, preferring seepage areas in the park instead of mainstream habitats. It was ranked third to fourth in the three LTEM sites 1995-1997. Only once did it rank second, in upper Piney River in 1997 by the quadrat method (Table 00).

Desmognathus monticola jeffersoni (Virginia seal salamander) - This is an endemic subspecies in the Blue Ridge Mountains of Virginia north of the Roanoke and James rivers (Hoffman, 1951). It is the first to second most abundant streamside salamander in the three LTEM streams in Shenandoah National Park included in this study.

Eurycea bislineata (Northern two-lined salamander) - This species was formerly known as *E. b. bislineata* but was elevated to species level by Jacobs (1987). It is the ecological equivalent to the southern two-lined salamander (*Eurycea cirrigera*). Distributional limits of these sibling species have been unknown. I include all observations of two-lined salamanders under this species name until

results from genetic studies confirms the locations of both species in Shenandoah National Park. Two-lined salamanders were frequently recorded as the second most abundant species in the three watersheds.

Gyrinophilus porphyriticus porphyriticus (Northern spring salamander) - This is an important predator of all other streamside salamanders. It was the third or fourth abundant species encountered in the LTEM sites 1995-1997.

Plethodon cinereus (Red-backed salamander) - Red-backed salamanders are usually the most abundant terrestrial salamander in Appalachian and Blue Ridge forests. My assistants and I found them incidental to searches focusing on streamside salamanders. They were found only in 1995 and 1996.

Plethodon cylindraceus (White-spotted slimy salamander) - This is the largest of the two completely terrestrial species. It was recorded incidentally during searches focusing on the streamside salamanders. It was found in Staunton River and Piney River watersheds, but not the Paine Run watershed.

Pseudotriton ruber ruber (Northern red salamander) - Adults of this species were observed twice in Paine Run in 1995. Adults were found in lower Paine Run on 10 September 1997 and in lower Staunton River on 6 August 1997. None was found in the Piney River watershed.

Effects of the 27 June 1995 Flood in Staunton River

The flood of 27 June 1995, estimated to have resulted from the combination of saturated soils and an approximately 600 mm (24 inches) of rain during a 6-hour period during the morning and early afternoon (Smith et al., 1996), had devastating effects on the lower portion of the Staunton River and the Rapidan River downstream. The estimated discharge of 3,000 cubic meters of water per second (Smith et al., 1996) removed all canopy cover in the approximate lower third of the watershed, caused several debris flows in the area, widened the stream bed by many meters, and eliminated adjacent seepage habitats and all of the soil interstices and streamside biotic habitats. The relative abundance of boulders and large rocks in the mainstem and tributaries increased substantially after the flood (Table 47). The amount of rubble and gravel habitat, usually arranged in linear bars and often used by salamanders, decreased substantially after the flood. These relative amounts of habitat types changed little between 1995 (pre-flood) and 1996 (post-flood) (Table 47).

The species of salamanders known to occur in the lower Staunton River before the flood were *D. fuscus*, *D. monticola*, *E. bislineata*, and *G. porphyriticus*. All four species were encountered during the first survey in the fall of 1994. Three of these were recorded before the flood in 1995 during quadrat surveys (Table 48). My assistants and I were able to gain access to lower Staunton one month following the flood (1 August) because damaged roads, debris flows, and destroyed bridges first needed to be cleared or repaired by the Army Corps of Engineers. Two species of salamanders (*D. monticola*, *E. cirrigera*) were found in the lower Staunton River on 1 August and these, plus one additional species (*G. porphyriticus*), were found on 17 October (Table 48). *Desmognathus fuscus* was not found on 1 August 1995 because the primary habitat in which it occurred prior to the flood event, a large seepage area, was eliminated. Several individuals of each of the other three species were found. All sizes of *D. monticola* (juveniles to large adults) occurred throughout the lower section of the watershed.

In 1996, *Desmognathus monticola* declined to less than half of its previous density levels during or in the months immediately after the flood (Table 48). Post-flood densities of *E. bislineata* and *G. porphyriticus* remained somewhat similar to those of pre-flood densities. All of these salamanders were found under small rocks located at the water-terrestrial (rock) interface. Some of these were also under rocks in sand and water stained by the presence of bacteria associated with the excessive leaching of iron.

A year later, in 1997, there were very few salamanders in the lower Staunton River. *Desmognathus fuscus* was rediscovered in a small seepage area near the confluence of the Staunton and Rapidan rivers at the SNP boundary. Densities of *D. monticola* were substantially less than in August 1995 but were relatively stable in 1996 and 1997 (Table 48). In contrast, densities of *E. cirrigera* were somewhat similar across all collecting periods from August 1995 through 1996. However, densities of this species increased substantially in 1997. No *G. porphyriticus* was found in 1996 and 1997. Results from time-constrained visual encounter surveys (Table 49) provide somewhat different results, with *D. monticola* and *E. bislineata* increasing in relative abundance from 1996 to 1997.

These changes suggest that the salamander fauna in at least the mainstem of the Staunton River continued to decline two years after the flood. The change in the structure and openness of the habitat associated with the mainstem from a cool, closed canopy stream to a relatively warm and open stream has apparently resulted in a modification of the amphibian community inhabiting the lower Staunton River. The number of frogs utilizing this portion of the Staunton River increased noticeably (Table 43). Several species not known to

breed in cool, closed canopy streams produced tadpoles and juveniles in 1996. These include Fowler's toads and eastern gray treefrogs. The lower Staunton River appeared to change in the first year post-flood from a salamander-dominated fauna to a frog-dominated one. However, data from 1997 on the salamanders suggest that the amphibian community is becoming stable with several frog species and the original salamander assemblage that occurs at lower densities than present prior to the flood event.

Table 41. Physical and biological characteristics of the three watersheds containing Long Term Ecological Monitoring sites maintained by the Shenandoah Watershed Study in Shenandoah National Park, Virginia. Adapted from Bulger et al. (1993) and information provided by James R. Webb (Department of Environmental Studies, University of Virginia; personal communication). Alkalinity is measured as $\mu\text{eq/l}$ (values below 50 represent a lack of buffering capacity).

Character	Paine Run	Staunton River	Piney River
Area (km^2)	12.71	10.56	12.66
Catchment aspect	western	eastern	eastern
SNP District	South	Central	North
Major bedrock type	silici-clastic	granitic	basaltic
Bedrock geology	91% Hampton 9% Antietam	82% Pedlar 4% Old Rag	68% Catoctin 31% Pedlar
Vegetation	chestnut oak/ pine - 96%	chestnut oak/ pine - 48%	chestnut oak/ pine - 36%
	hemlock/tulip poplar/cove hardwoods - 2%	red oak/black locust - 11% hemlock/tulip poplar/cove hardwoods - 37%	red oak/black locust - 18% hemlock/tulip poplar/cove hardwoods-42%
Sensitivity to acidification	high	moderate	low
Alkalinity	1992	-7.2- 8.7	44.7-106.9
	1993	-8.0-19.4	35.4-115.3
	1994	-3.8-16.9	45.3-131.2
	1995	-5.5-14.4	43.7-183.2
pH	1992	5.09-6.16	6.03-6.93
	1993	4.98-6.21	6.05-6.99
	1994	5.18-6.25	6.06-7.05
	1995	5.21-6.12	6.17-7.07
	1996-97	5.12-6.27	6.04-7.17

Table 42. Variation in five microhabitat features of the margins of three rivers in Shenandoah National Park, Virginia. All data are from the mainstems of the rivers. Data for Staunton River in 1995 are pre-flood values. Bank refers to the edge of the river that lacks rocks or other features, Boulder refers to rocks larger than 1.5 m, Large Rocks are those 0.5-1.5 m, Small Rocks are those 0.1-0.5 m, and Rubble/gravel refers to a range of rock sizes smaller than 0.1 m and includes gravel and sand. Numbers are percent of total number of meters measured (N). Abbreviations: U = upper half of the watershed, L = lower half, U+L = data for upper and lower sections combined. Abbreviation: gravel = grav.

Feature	Paine Run			Staunton River			Piney River		
	U	L	U+L	U	L	U+L	U	L	U+L
1995									
Bank	24.0	25.2	24.9	6.7	6.7	6.7	3.4	18.6	16.0
Boulder	24.0	18.6	20.0	30.0	36.5	30.9	15.4	0	2.6
Large Rock	0	3.0	2.2	30.3	18.5	28.0	19.7	11.2	12.7
Small Rock	47.6	33.5	37.1	22.5	21.9	22.3	43.3	63.0	59.6
Rubble/grav	4.4	19.7	15.8	9.6	16.2	10.9	18.3	7.2	9.1
N	225	656	881	721	178	899	104	500	604
1996									
Bank	4.1	25.8	12.0	14.7	0	7.1	2.5	13.1	6.4
Boulder	15.7	7.3	12.6	23.4	50.4	37.3	24.7	3.0	16.7
Large Rock	1.2	4.0	2.2	29.4	17.8	23.4	28.8	2.3	19.0
Small Rock	69.4	62.1	66.7	25.1	21.1	23.2	40.6	78.0	54.4
Rubble/grav	9.7	8.1	6.5	7.4	10.3	8.9	3.4	3.5	3.4
N	434	248	682	231	247	478	441	259	700

Table 43. Amphibian species encountered in the three Long-Term Ecological Monitoring (LTEM) watersheds in Shenandoah National Park, Virginia, during 1995-1997 based on all methods used in this study. Abbreviations: A = abundant (>20 individuals), C = common (5-19), U = uncommon (<5). Blank spaces indicate no observations.

Species	Paine Run				Staunton River				Piney River			
	94	95	96	97	94	95	96	97	94	95	96	97
Frogs:												
<i>Acris crepitans</i>		U										
<i>Bufo americanus</i>		U						U				
<i>Bufo fowleri</i>		U	U	U			A					
<i>Hyla versicolor</i>			U				A					
<i>Pseudacris crucifer</i>		U										
<i>Rana catesbeiana</i>		U	U									
<i>Rana clamitans</i>			U	U		U	A	U		U		
<i>Rana palustris</i>	U	C	C	U				U		U	U	U
<i>Rana sylvatica</i>	U	C	U				U					
Salamanders:												
<i>Desmognathus fuscus</i>	U	A		C	A	A	U	C	C	A	A	C
<i>Desmognathus monticola</i>	C	A	A	A	U	A	A	A	A	A	A	C
<i>Eurycea bislineata</i>	U	A	A	A	C	A	C	A	C	A	A	A
<i>Gyrinophilus porphyrit.</i>		A	C	C	U	A	U	C	C	C	U	C
<i>Plethodon cinereus</i>		C	U			C	U		U	C	U	
<i>Plethodon cylindraceus</i>					U			U		U	U	
<i>Pseudotriton ruber</i>		C		U				U				
Total no. frog species	2	7	6	3	0	1	4	3	0	2	1	1
Total no. salamander spp.	3	6	4	5	5	6	5	6	5	6	6	4
Total no. of species		15				13				8		

Table 44. Relative abundance by number per person hour of the four most common species of salamanders in Shenandoah National Park's LTEM sites in 1996 and 1997 based on time-constrained visual encounter survey methodology. Number of person hours ranged from 3.5 to 11 hours per stream section per year.

Species	Paine Run			Staunton River			Piney River		
	U	L	U+L	U	L	U+L	U	L	U+L
1996									
<i>D. mont</i>	18.857	3.815	11.158	12.500	1.648	6.067	12.400	9.500	11.571
<i>D. fusc</i>	0.286	0	0.139	0.833	0.115	0.409	3.600	0	2.571
<i>E. bisl</i>	0.857	2.997	1.953	0.500	0.461	0.477	3.400	1.000	2.714
<i>G. porp</i>	0.571	1.090	0.837	0.667	0.231	0.400	0.400	1.000	0.571
1997									
<i>D. mont</i>	11.636	7.727	9.030	7.167	2.133	4.370	11.897	4.727	8.407
<i>D. fusc</i>	1.091	0.818	0.909	1.667	0	0.741	6.207	0.182	3.274
<i>E. bisl</i>	3.636	5.364	4.788	4.833	2.533	3.556	7.069	10.909	8.938
<i>G. porp</i>	1.273	0.727	0.909	0.333	0	0.148	0.862	0.182	0.531

Table 45. Densities of the four most abundant salamanders in the mainstems of three rivers in the LTEM sites in Shenandoah National Park, Virginia, based on quadrat data. Abbreviations: *D. fusc* = *Desmognathus fuscus* (dusky salamander), *D. mont* = *Desmognathus monticola* (seal salamander), *E. bisl* = *Eurycea bislineata* (northern two-lined salamander), *G. porp* = *Gyrinophilus porphyriticus* (spring salamander). N is the number of m² quadrats searched per stream section. Decimal numbers are the densities per square meter. Only the pre-flood data are presented for the upper and lower Staunton River sections for the 1995 data. The 1996 and 1997 data represent post-flood conditions.

Species	Paine Run			Staunton River			Piney River		
	U	L	U+L	U	L	U+L	U	L	U+L
1995									
<i>D. mont</i>	.250	.236	.241	.206	.240	.218	.182	.307	.273
<i>D. fusc</i>	0	.005	.004	.006	0	.003	.109	.007	.034
<i>E. bisl</i>	.340	.280	.301	.166	.030	.116	.164	.167	.166
<i>G. porp</i>	.010	.055	.039	.057	.030	.047	0	0	0
N	100	182	282	175	100	275	55	150	205
1996									
<i>D. mont</i>	.100	.029	.067	.280	.010	.126	.190	.130	.160
<i>D. fusc</i>	0	0	0	0	0	0	.010	0	.005
<i>E. bisl</i>	.030	.008	.018	0	.020	0	.070	.030	.050
<i>G. porp</i>	0	.016	.009	0	0	0	.010	0	.005
N	100	125	225	75	100	175	100	100	200
1997									
<i>D. mont</i>	.193	.253	.267	.327	.007	.178	.158	.200	.176
<i>D. fusc</i>	.007	.010	.009	0	.007	.003	.019	0	.010
<i>E. bisl</i>	.100	.314	.229	.020	.113	.063	.101	.353	.224
<i>G. porp</i>	.013	.010	.012	0	0	0	.027	.020	.016
N	150	194	344	153	133	286	150	158	308

Table 46. Rank abundance of the four most abundant salamanders in the three LTEM sites in Shenandoah National Park in 1995, 1996, and 1997 by survey method. Abbreviations: m² is rank abundance of the number of individuals per square meter and #/h = rank abundance based on number of individuals observed per person hour for 1996 and 1997. 1995 data are based on observations taken before the June flood.

Species	Paine Run					Staunton River				
	95m ²	96m ²	97m ²	96#/h	97#/h	95m ²	96m ²	97m ²	96#/h	97#/h
<i>D. mont</i>	2	1	1	1	1	1	1	1	1	1
<i>D. fusc</i>	4	4	4	4	3.5	4	3.5	3	3.5	3
<i>E. bisl</i>	1	2	2	2	2	2	2	2	2.5	2
<i>G. porp</i>	3	3	3	3	3.5	3	3.5	4	4	4
Piney River										
	95m ²	96m ²	97m ²	96#/h	97#/h					
<i>D. mont</i>	1	1	2	1	2					
<i>D. fusc</i>	3	3.5	4	2	3					
<i>E. bisl</i>	2	2	1	3	1					
<i>G. porp</i>	4	3.5	3	4	4					

Table 47. Variation in five microhabitat features along the margins of the mainstem of lower Staunton River, Shenandoah National Park, Virginia before and after the 27 June 1995 flood. Descriptions of microhabitat features are in Table 42. Numbers are percent of the total distance measured (N).

Feature	Pre-flood	Post-flood	
	Mainstem	Mainstem	
	1995	1995	1996
Bank	6.7	0.7	0
Boulder	36.5	49.2	50.4
Large Rock	18.5	23.0	17.8
Small Rock	21.9	18.1	21.1
Rubble/gravel	16.2	9.0	10.3
N	178	512	247

Table 48. Densities of three salamander species in lower Staunton River before and after the 27 June 1995 flood. WRn (Wilson Run) is the primary tributary of the lower Staunton River and MSm refers to the mainstem. N is the number of square meter plots searched in each time period. The number for each species is total number of individuals per square meter. Species abbreviations as in Table 35.

Species	Pre-Flood			Post-Flood					
	WRn 5&6/95	MSm 5&6/95	Total	Wilson 8/95	Run 10/95		Mainstem 8/95	10/95	1996 1997
<i>D. mont</i>	.689	.240	.379	.200	.100		.228	.060	.010 .007
<i>D. fusc</i>	0	0	0	0	0		0	0	0 .007
<i>E. bisl</i>	.022	.030	.028	0	.667		.035	.020	.020 .113
<i>G. porp</i>	0	.030	.021	0	.333		0	.020	0 0
N	45	100	145	5	30		57	50	100 133

Table 49. Relative abundance of salamanders in the upper and lower Staunton River in 1996 and 1997 expressed in number of individual salamanders per person hour (#/h). The upper Staunton River is the reach above the major damage from the 27 June 1995 flood and the lower Staunton River is the portion within the impacted area. MSm is the mainstem, WRn is Wilson Run (a tributary of the Staunton River impacted by the flood), and Seep is a small seepage area adjacent to the confluence of the Staunton River and the Rapidan River. Species abbreviations as in Table 45.

Species	MSm	Lower Staunton			1997 MSm	Upper Staunton	
		1996 WRn	1996 Seep	1996 Total		1996 MSm	1997 MSm
<i>D. mont</i>	0.39	5.00	4.00	1.09	2.133	18.67	7.167
<i>D. fusc</i>	0.13	0	4.00	0.33	0	0.83	1.667
<i>E. bisl</i>	0	4.00	0	0.44	2.533	0.33	4.833
<i>G. porp</i>	0.26	0	2.00	0.33	0	0.67	0.333

Amphibians in Shenandoah National Park: Conclusions

1. The number of amphibian species in the three LTEM watersheds during 1994-1997 in Shenandoah National Park range from a low of eight in Piney River to a high of 15 in Paine Run. Paine Run supports a much higher diversity of frogs than the other two systems (9 vs 6 [Staunton] and 2 [Piney]). The number of salamander species is similar, with four streamside species common to all three systems. Juveniles, hatchlings, and/or larvae of most of the species were observed, indicating that all of these species are maintaining reproducing populations in these watersheds during this period.
2. The results of the inventory portion of this study should be considered incomplete for the entire amphibian fauna because the research was conducted in contrasting years, two with droughts and one with frequent rains. The inventory for streamside salamanders is probably complete but the one for frogs requires substantial additional time spent in each watershed. In order to add to our knowledge of the amphibian fauna of these watersheds, all observations of amphibians no matter how basic must be recorded in the future to ensure that a full accounting of all species is made.
3. Despite the fact that Paine Run has low acid neutralizing capacity and the lowest pH values of the three LTEM watersheds, the results of this study reveals that this watershed supports the highest amphibian species richness. The recent low pH values of 4.98-5.21 are apparently not harmful to these species. Thus, acid deposition and the lack of buffering capacity in Paine Run compared to Staunton River and Piney River appears to have had little detrimental affect on the amphibian communities in the three LTEM watersheds in Shenandoah National Park during the 1994-1997 study period. No abnormal individuals or other indications of unhealthy animals, environmental contamination, or genetic damage were noted during this study.
4. Salamander densities varied among watersheds, species, and years. Of the four most commonly-encountered species, seal salamanders (*Desmognathus monticola*) ranked as the most common salamander in all LTEM sites, followed by the two-lined salamanders (*Eurycea bislineata*). The dusky salamander was the least common species in Piney River, whereas the northern spring salamander was the least common in Paine Run and Staunton River sites.
5. The flood of 27 June 1995 that caused extensive landscape change below the Staunton River and that severely damaged and rearranged the lower portion of

that river, had varying effects on the salamanders in the ecosystem. All but one species was found in post-flood searches in 1995. The only species not rediscovered in 1995 was the dusky salamander (*Desmognathus fuscus*). This species had been found only in a seepage tributary that was eliminated by the flood. It was rediscovered in 1997. The densities of the other three species declined and remained low (*D. monticola*, *G. porphyriticus*), or increased (*E. bislineata*). All species found before the flood were found in 1996 but at lower densities. More frog species were found after the 1995 flood event than before the event. The amphibian fauna of the lower Staunton River has apparently changing from a salamander-dominated fauna to one with more frog species and a similar salamander fauna at much lower densities.

6. The most effective and simplest technique of the two monitoring techniques used to date in this study to obtain quantitative estimates of relative abundance of streamside salamanders is time-constrained visual encounter searches, expressed in number of individuals observed or captured per person hour. This technique requires personnel adequately trained in amphibian identification.

Management Recommendations

1. Long-term monitoring of the amphibian species in the three LTEM watersheds using the standardized protocols used here should continue. Such monitoring is essential so that the future effects of the changing acidic conditions of Paine Run can be elucidated and compared with those in Staunton River and Piney River. The current database provides the baseline against which future changes can be assessed. Since amphibians appear to be harmed once pH drops below about 4.5 (e.g., Clark, 1986; Freda, 1986; Whiteman et al., 1995), it is imperative that monitoring of both the water chemistry and amphibian populations be conducted annually for the foreseeable future. Active management options should be reviewed as the pH in Paine Run drops consistently below 5.0.

2. The entire amphibian community in Staunton River should be monitored for the long-term so that we can obtain an understanding of how these species recover after a major natural flooding event. Monitoring should include the same standardized protocols used in this study. Such monitoring should be concurrent with monitoring the recovery of the abiotic (water chemistry) and biotic (plant and other animal communities) components of this riverine ecosystem. The site is going through primary ecological succession. This offers a rare opportunity

to describe such a process.

3. An inventory and assessment of stream distribution patterns of the amphibian fauna in all of the other primary watersheds in Shenandoah National Park should commence at the earliest opportunity. This can be done in a few as two watershed transects, one in spring and one in fall seasons, by personnel who can identify all species on sight. Initial inventories and baseline assessments of these assemblages would provide critical information that cannot be reclaimed once losses occur due to changes in acidity. Such inventories and accumulation of baseline data were recommended strongly by Dr. C. Kenneth Dodd in his 1996 evaluation of the amphibian project in the park. These park-wide inventories need to be conducted before any additional changes in acid levels occur. We cannot determine the status of these animals in the whole of Shenandoah National Park based solely on results from only three LTEM watersheds.

4. All amphibian observational and distributional observations should be maintained in electronic files using GIS technology. All historical records should be captured in this manner and a mechanism of entering all new observations should be established. This data base would provide an important evaluation tool for resource managers in the event of another natural flood or other event (natural or man-made).

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APPENDIX 2

Total monthly rainfall for Fort A.P. Hill and Fort Belvoir for 1995-1997. Data were derived from Climatological Data summaries for Virginia provided by the National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC. The weather station for Fort A.P. Hill is Corbin, Caroline County and for Fort Belvoir is Washington International Airport. Rainfall amounts are in inches. Rainfall data were unavailable from Marine Corps Base Quantico and Prince William Forest Park for this report.

Month	Fort A.P. Hill	Fort Belvoir
1995		
January	4.20	3.22
February	1.48	1.71
March	2.49	2.14
April	2.41	1.89
May	5.28	4.89
June	4.40	2.42
July	6.45	4.03
August	0.97	0.88
September	2.68	3.73
October	7.23	8.65
November	4.23	4.77
December	2.50	2.17
1996		
January	5.26	5.01
February	3.20	1.99
March	3.73	3.60
April	2.69	3.17
May	4.11	4.96
June	3.05	3.14
July	5.74	5.60
August	4.26	2.63
September	4.43	7.79
October	5.83	4.04
November	3.52	3.58
December	5.04	5.51
1997		
January	2.11	2.55
February	3.97	2.43
March	5.26	4.15
April	3.06	2.41
May	1.75	3.04
June	4.21	2.94
July	4.51	1.14
August	2.65	3.51
September	2.23	1.59
October	3.29	3.72
November	6.16	4.60
December	2.55	1.74

Appendix 3

Total monthly rainfall for Shenandoah National Park 1995-1997. Data are from Climatological Data summaries for Big Meadows (3539 ft. Elevation) in SNP (National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC). Rainfall amounts are in inches.

	1995	1996	1997
January	8.04	11.13	2.54
February	1.80	2.62	1.79
March	2.34	2.72	3.31
April	1.71	4.33	2.00
May	5.30	7.45	2.72
June	14.83	4.93	5.63
July	4.42	6.76	3.80
August	4.36	5.72	3.67
September	3.38	19.87	8.26
October	10.02	5.05	2.33
November	5.35	4.48	9.41
December	2.70	4.96	2.18

Cover Illustration Credits

Top left: Northern Red Salamander (*Pseudotriton ruber*)

Top right: View of Paine Run, Shenandoah National Park

Lower left: View of Catlett Creek (Legacy Site 7), Fort A.P. Hill

Lower right: Pickerel Frog (*Rana palustris*)

All photographs by Joseph C. Mitchell