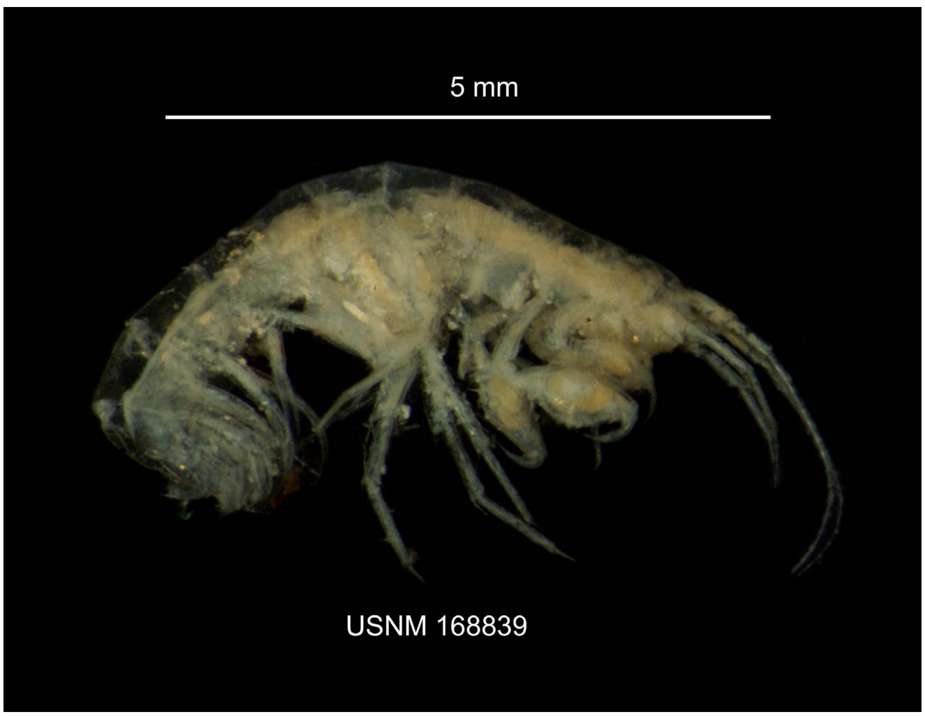
Species Status Assessment (SSA) Report
for the
Northern Virginia Well Amphipod
(Stygobromus phreaticus)
August 2019
Version 1.1



Stygobromus phreaticus. Photo provided by: Michelle Brown, National Museum of Natural History, Smithsonian Institution

U.S. Fish and Wildlife Service
Northeast Region

ACKNOWLEDGEMENTS

The research for this document was prepared by Jacob Osborne (U.S. Fish and Wildlife Service (USFWS)—North Attleboro Fish Hatchery) with technical assistance from Krishna Gifford (USFWS—Northeast Regional Office).

We greatly appreciate the assistance of the following individuals who provided helpful information and/or review of the draft document:

- Chris Hobson and William Orndorff (Virginia Department of Conservation and Recreation, Natural Heritage Program)
- Dorothy Keough, John Pilcicki, Christopher Manikas, and Lindsey David (U.S. Army Garrison Fort Belvoir)
- Robert Denton (Geoconcepts Engineering, Inc.)
- Cindy Schulz , Sumalee Hoskin, Susan Lingenfelser, and Serena Ciparis (USFWS—Virginia Ecological Services Field Office (VAFO)
- Anthony Tur and Jean Brennan (USFWS—Northeast Regional Office)
- Meagan Kelhart (formerly, USFWS—Headquarters)

We also thank our peer reviewers:
- Steve Taylor (Colorado College)
- Dave Culver (American University, retired)
- Dan Fong (American University)
- Olivia DeLee (U.S. Geological Survey, Northeast Climate Adaptation Science Center)

Suggested reference: U.S. Fish and Wildlife Service. 2019. Species status assessment for the Northern Virginia Well Amphipod (*Stygobromus phreaticus*). Version 1.1. August 2019. Hadley, MA. 62 pp.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report summarizes the results of a species status assessment (SSA) conducted for the Northern Virginia well amphipod (NVWA; *Stygobromus phreaticus*) to assess its viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (together, the 3Rs). For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in natural ecosystems within a biologically meaningful timeframe. In conducting the SSA, we compiled the best available scientific information regarding the NVWA's biology; individual, population, and species level needs; and factors that influence the species' viability. We use this information to evaluate and describe the species' current and projected future condition in terms of the 3Rs.

The NVWA is a small, subterranean crustacean occurring in groundwater-related habitat on the U.S. Army's Fort Belvoir Garrison in Fairfax County, Virginia (VA). The species was taxonomically described in 1978, but little is known definitively about its habitat needs and general biology. It was first reportedly collected from a well in Alexandria, VA in 1921 and then from a well in Vienna, VA in 1948; the exact locations of those sampling sites are now unknown (thought to be destroyed by urbanization), as is the status of those populations. Whether the condition of the species at each historical location is extirpated or unknown is a key uncertainty, but for the purposes of this SSA we presume it to be unknown (see *section 2.3 Historical and Current Range, Distribution, and Abundance*). The species was not observed again until specimens were collected in 1996 from a seepage spring during a routine survey in a wooded ravine in the "T-17" area of Fort Belvoir, VA. Efforts to collect the NVWA from that spring and adjacent springs in the T-17 area have yielded a total of 25 individual NVWAs between 1996 and 2013. Because there have been multiple individuals collected over time at the Fort Belvoir capture sites, we do presume that the individuals observed are part of a population, but the size and structure of the presumed extant population is unknown.

Most collections have occurred following significant precipitation events, leading some researchers to suggest that NVWAs are flushed out of a subterranean habitat. Detailed hydrogeological studies throughout the T-17 area suggest that the NVWA may inhabit 'macropores' (cavities and channels within the ravine wall formed when sandy substrates erode while surrounding clay substrate persists) and/or a deep (i.e., non-surficial) aquifer characterized by a unique chemical signature of high conductivity, high dissolved solids, and low organic content. The diet, water quality tolerances, and behavioral traits of the NVWA have not been documented. Reproduction also has not been observed but is thought to be sexual based on reports of both male and female specimens, including females with brood plates indicative of egg laying, in early collections; based on the timing of the collections, we infer that eggs may be laid in late fall-early winter, but it is possible that reproduction may occur year round or at discrete intervals through the year.

We infer, from general principles of conservation biology, general information about other groundwater species, and local information from where NVWA individuals have been observed, that NVWAs need sufficient "space" in which to find food and to reproduce, and that this "space" may equate to either the macropores of the seep/spring areas, the sediments of the deeper aquifer, or both. Although we do not know the specific needs of the NVWA, we infer that a

species generally requires a stable or positive population growth rate to remain healthy. We do not know the species' population size or trend, but instead rely on the best available habitat parameters as a surrogate for population and species health. We infer that the viability of the NVWA would be best supported by multiple (redundancy), self-sustaining (resiliency) populations distributed throughout the geographical extent of its range (representation). We infer, based on the best available information, that it currently has a single population and that the single population is located in suitable subsurface habitat supported by suitable surface habitat.

The primary influencing factors likely to have species-level effects include changes to groundwater quality and quantity, extent of impervious cover in likely recharge zones, and implementation of conservation actions. We lack specific information about the NVWA's population size, as well as the details related to the Installation's research and development activities within the buildings that are closest to the NVWA's spring locations, and how their recreational facilities are maintained. Therefore, we did not evaluate the effects of small population size, Installation research and development activities, and the effects of recreation as part of the species' current or future condition. Amphipod pathogens are generally unstudied and we have no information about disease affecting this species; therefore disease is not evaluated as part of the NVWA's current or future condition. And lastly, the best available information indicates that predation and collection are not having a population- or species-level effect; therefore, we do not evaluate these stressors as part of the species' current or future condition.

Current Condition: The NVWA's population size is unknown. The species is currently known from only one of three historical locations (redundancy). The NVWA was last collected in 2013 from one of two possible habitat types (macropores vs. sediment from deeper aquifers; see *section 2.6* for further details) (representation). However, sufficient suitable surface conditions that support the NVWA's subsurface habitat (such as relatively low impervious surface area) remain, such that we infer that the species persists in its subsurface habitat and retains the ability to withstand stochastic events (resiliency).

Future Scenarios: For the purpose of this assessment, we define viability as the ability of the species to sustain itself in the wild over 25 years. This timeframe is based on the NVWA's approximately 25 years of persistence data, which we deem biologically reasonable to use as a surrogate to project forward a similar amount of time. We also have available development and climate data to reasonably anticipate potential significant effects of stressors (up to 45 years) and ongoing conservation (approximately 18 years) on the species (see chapters 2, 3, and 5 for more details). To assess the viability of the NVWA, we considered three future scenarios that are representative examples from the potential range of plausible scenarios that describe how these stressors and conservation actions may drive changes from the current condition.

Table ES-1. Summary of Future Scenarios (see chapter 5 for detailed information).

Influencing Factor	Scenario A	Scenario B	Scenario C
Climate Projection	RCP 8.5.	RCP 8.5.	RCP 4.5.
Climate Effects	Precipitation is expected to increase 5 to 10 percent by 2065.	Precipitation is expected to increase 5 to 10 percent by 2065.	Precipitation is expected to increase 5 to 10 percent by 2065.
Recharge Zone Impervious Cover	No change.	Increases slightly.	No change.
Water Quantity	Not limiting.	Slight reduction, but not limiting.	Not limiting.
Water Quality	Not limiting, but may be reduced if nuclear power plant decommissioning and deconstruction occurs.	Slight reduction, but not limiting.	Not limiting.
Conservation Actions	2018 Fort Belvoir Integrated Natural Resource Management Plan (INRMP) remains in place, with current Installation mission. Frequency of NVWA monitoring remains as current. National Environmental Planning Act (NEPA) assessment of nuclear power plant decommissioning and deconstruction guides additional conservation action, if needed.	2018 INRMP requires revision to address changes in Installation mission. Potential effects from additional buildings/development within the recharge area or from power plant decommissioning activities.	2018 INRMP remains in place, with current Installation mission. Frequency of NVWA monitoring increases (e.g., increased field collection effort, application of non-destructive eDNA water testing, etc.) providing improved population status information.

Future Condition: Applying the limited information we know about the species' biology, needs, and primary influencing factors to the above representative future scenarios, we predict that: the NVWA will continue to persist (have resiliency) in all three scenarios, will have no redundancy in Scenarios A and B but a potential increase in Scenario C if additional "populations" are discovered in future surveys using the forthcoming eDNA tool, and will retain some level of representation in all three scenarios.

Key Uncertainties: Given the limited information about the species' biology and needs, we made a number of assumptions to complete the SSA analysis. Our assumptions were informed by information from similar species, best professional judgement, and other surrogate data (e.g., surface habitat quality parameters), but may have resulted in us overestimating or underestimating the species' viability. The key uncertainties (chapter 6) include that (1) the species is represented in an underground aquifer as a robust, stable population; (2) the single, isolated population at Fort Belvoir is capable of reaching the surface from multiple nearby openings in the ravine wall; (3) individuals that exit the spring are unable to return to their subterranean habitat; (4) the species has sufficient genetic diversity, due to its representation potential in two habitat types and persistence over time, to adapt to relevant changes in its environment; (5) the continued existence of the species at the two historical locations is unknown; (6) the two historical locations were discrete, separate locations not connected to each other or the Fort Belvoir location; and, (7) the species' total historical range is represented by the current site on Fort Belvoir and the two historical sites.

CHAPTER 1 INTRODUCTION

1.1 Background

The U.S. Fish and Wildlife Service (i.e., Service, we, our) is responsible for identifying species that may be in need of protection under the Endangered Species Act, as amended (Act). The Service recognized the need to investigate the current population status and trends of the Northern Virginia well amphipod (NVWA; *Stygobromus phreaticus*) and the relative effects of both positive and negative influences on the species' viability. At our discretion, we prioritized a status review for the species according to our 2016 Methodology for Prioritizing Status Reviews and added the species to the Endangered Species Program's National Listing Workplan (Workplan). At the time, the Workplan outlined a schedule for the Service to evaluate the status of, and make a listing decision for, petitioned and discretionary status review species through Fiscal Year (FY) 2023. The Workplan is updated annually to reflect, for a 5-year timeframe, the need to respond to new petitions, updated information on the included species, and the Service's budget and staffing resources. Based on this revision process, we intend to make a decision on the NVWA's listing status in FY 2019.

1.2 Analytical Framework

The SSA report, the product of conducting an SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, the SSA report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the Act.

This SSA report for the NVWA is intended to provide the biological support for the decision on whether or not to propose to list the species as threatened or endangered and if so, whether or not to propose designating critical habitat. The process and this SSA report do not represent a decision by the Service whether or not to list a species under the Act. Instead, this SSA report provides a review of the best available information strictly related to the biological status of the NVWA. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and a decision will be announced in the ***Federal Register***.

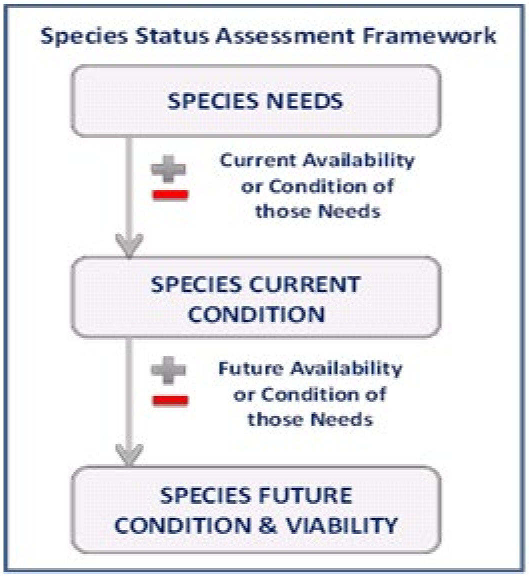


Figure 1. Species Status Assessment Framework.

Using the SSA framework (figure 1), we consider what a species needs to maintain viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (Service 2016, entire; Smith *et al*. 2018, entire). For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in natural ecosystems within a biologically meaningful timeframe: in this case, approximately 30 years. This timeframe is based on the NVWA's approximately 25 years of persistence data, which we deem biologically reasonable to use as a surrogate to project forward a similar amount of time. We also have available development and climate data to reasonably anticipate potential significant effects of stressors (up to 45 years) and ongoing conservation (approximately 18 years) on the species (see chapters 2, 3, and 5).

Resiliency, redundancy, and representation are defined as follows:

Resiliency describes the ability of the species to withstand stochastic events (arising from random factors), which is associated with population size, growth rate, and habitat quality. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), and the effects of human activities.

Redundancy describes the ability of the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations), which is related to the number, distribution, and resiliency of populations. Redundancy is about spreading the risk. Generally, the greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

Representation describes the ability of the species to adapt to changing environmental conditions, which is related to distribution within the species' ecological settings. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range.

Together, the 3Rs, and their core autecological parameters of abundance, distribution and diversity, comprise the key characteristics that contribute to a species' ability to sustain populations in the wild over time. When combined across populations, they measure the health of the species as a whole.

The decision whether to list a species is based *not* on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. Therefore, to inform this assessment of extinction risk, we describe the species' current biological status and assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. We evaluate the current biological status of the species by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation (together, the 3Rs). We then evaluate the future biological status by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species and forecasting the most likely future condition for each scenario in terms of the 3Rs. As a matter of practicality, the full range of potential future scenarios and the range of potential future conditions for each potential scenario are too large to individually describe and analyze. These scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures. This future scenario analysis is intended to inform the determination of the risk that extinction will be the future experienced by the species within each timeframe analyzed.

CHAPTER 2 SPECIES INFORMATION

2.1 Taxonomy and Genetics

Stygobromus phreaticus was first described by Holsinger (1978, p. 98) from historical collections of well water from Alexandria (1921) and Vienna (1948), Virginia (VA), approximately 8 to 20 miles (mi) (13 to 32 kilometers (km)), respectively, outside of Washington, District of Columbia (D.C.). The NVWA is one of 209 described subterranean crustaceans belonging to the family Crangonyctidae. These taxa are found in freshwater caves, seeps, wells, and other groundwater-related habitat types.

The currently accepted taxonomic classification is:

Class: Malacostraca
Order: Amphipoda
Family: Crangonyctidae
Species: *Stygobromus phreaticus*

We currently do not have any information regarding the NVWA's genetic diversity. The Service accepts the above taxonomy as the best available information.

2.2 Species Description

Species in the genus *Stygobromus* "lack eyes and pigment and generally have a gracile appearance" (Holsinger 1978, pp. 7–8; Culver *et al*. 2010). The 1921 and 1948 NVWA paratypes ranged in size from 4.5 millimeters (mm) (0.17 inches (in)) to 7.0 mm (0.28 in) and differ from other *Stygobromus* species because of the spiny abdominal appendages (Holsinger 1978, p. 98). The NVWA can be distinguished from other amphipods based on morphological characteristics such as a notch on the tip of the telson (distinctive structure just above the uropods), relative size of the gnathopods, and overall size of mature animals (Holsinger 1978, p. 98; Hobson 2018a). This species does not exhibit pronounced sexual dimorphism. Figure 2, below, shows the species under magnification.

Figure 2. Lateral head and claw of NVWA at 18x magnification. Photo credit: Michelle Brown, National Museum of Natural History, Smithsonian Institution.

Unlike other amphipods found in the D.C. area, the NVWA is not found in habitats that would be described as hyporheic (interface between a streambed and an aquifer) or hypotelminorheic (a 'wet patch' of forest floor characterized by a perched aquifer and abundant leafy organic matter). It is instead thought to occupy deeper groundwater habitats (Hutchins and Culver 2008, p. 10) and to be observed at the surface only when flushed out when groundwater levels rise suddenly following major precipitation events (Hobson and Orndorff 2013, p. 20). Aquatic species that are limited to subterranean habitats are referred to as "stygobionts" (Culver and Pipan 2014, p. 1).

2.3 Historical and Current Range, Distribution, and Abundance

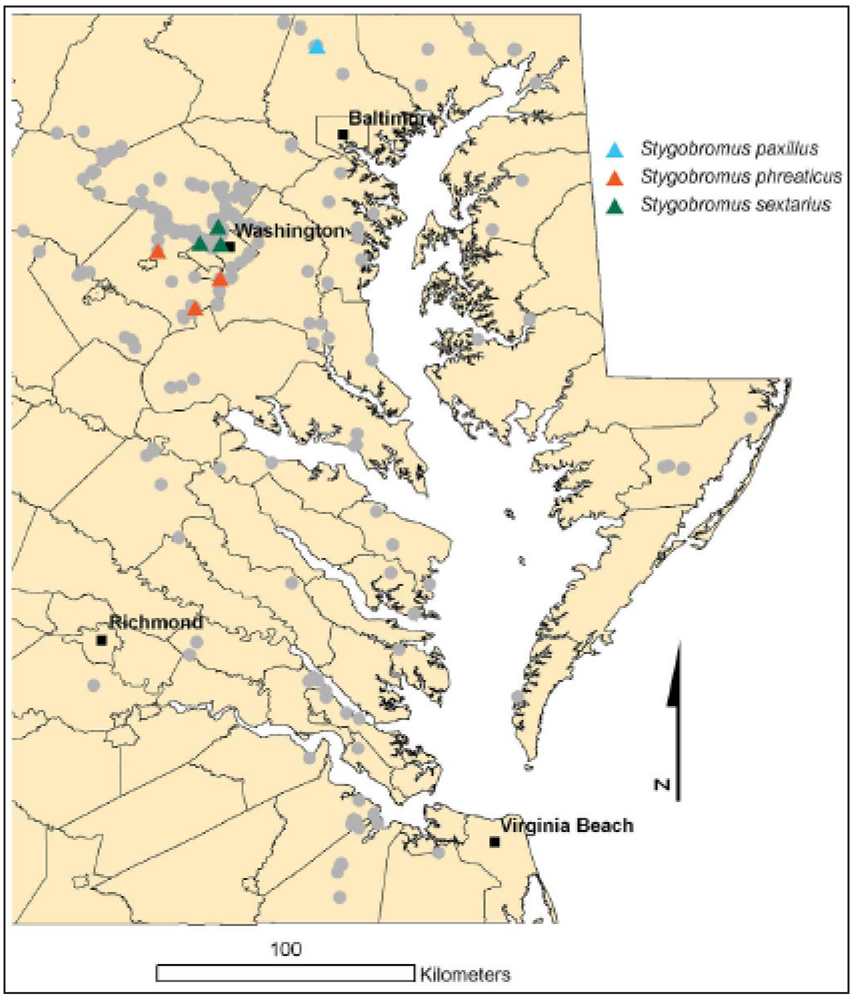


Figure 3. From Culver *et al*. 2012. Distribution of *Stygobromus paxillus* (blue triangle), *S. phreaticus* (orange triangles), and *S. sextarius* (green triangles). Gray dots represent all sampling sites in the study area with stygobionts.

Culver *et al*. (2012, p. 24) denoted the general location of the two NVWA historical sites (1921 from Vienna, VA and 1948 from Alexandria, VA) on their stygobionts survey range map (figure 3). However, "the exact locations of both collection sites are unknown, but they were likely destroyed by subsequent urbanization" (Chazal and Hobson 2003, p. 1). The sampling sites are thus inaccessible, and whether the condition of the NVWA at each historical location is extirpated or unknown is a key uncertainty. For the purposes of this SSA, we presume it to be unknown.

The NVWA was not recorded again until 1996, when 15 specimens were collected at "a series of small lateral seepages… from thick leaf litter and detritus...directly downslope from the border fence at the Belvoir Research and Development Command Center" during a survey in the "T-17" area of the U.S. Army's Fort Belvoir Garrison (Ft. Belvoir, Installation), Fairfax County, VA (Hobson 1997). Two additional NVWA specimens were collected between March and June 2003 at the same site, which was identified as 'S1E-015' (Chazal and Hobson 2003, p. 3), located in a ravine within the T-17 area (see figure 4). This collection is noteworthy because the NVWA was found only at site 'S1E-015' even though surveys were conducted at 44 seepage areas in T-17, 61 seeps outside T-17 but still on Fort Belvoir, and 29 seeps located in Mount Vernon, Mason Neck State Park and Pohick Bay Regional Park, VA (all sites located within a 5-mi (8-km) radius of the NVWA spring) (Chazal and Hobson 2003, p. 3). (Note: throughout this document, we use the terms seep, seepage area, and spring interchangeably, depending on the source of the information.)

Figure 4. Location of Fort Belvoir (inset map) and NVWA spring location (yellow star) within the T-17 area (green line).

A further eight specimens were collected during surveys conducted in 2012 and 2013 (Hobson and Orndorff 2013, p. 18) from a second seepage area several meters downstream of 'S1E-015' (identified as 'S1E-018' in Chazal and Hobson (2003) and as 'Shelf Seep' in Hobson and Orndorff (2013)). A single individual was collected on January 11, 2012. Two more NVWA were collected during subsequent late winter and early spring surveys for a total of three specimens in 2012. In 2013, one individual was found dead on February 7, 2013, and four live specimens[1] were subsequently captured on March 13, 2013 (Hobson and Orndorff 2013, p. 50). The specific seepage area where NVWA were captured in 1996 and 2003 ('S1E-015') could not be sampled again because it was covered by an episode of 'mass slump,' a phenomenon in which a mass of sediment moves downslope as a cohesive unit, that occurred during the interval of the 2003 and 2013 hydrogeologic surveys. No further attempts have been made to collect NVWA since 2013.

Table 1. Summary of NVWA positive sampling events.

Year	Number of Individuals	Location
1921	11(F), 3(M), 2(J)*	Vienna, VA
1948	12 (F)	Alexandria, VA
1996	15	T-17 area, Ft. Belvoir, VA
2003	2	T-17 area, seep 'S1E-015' Ft. Belvoir, VA
2012	3	T-17 area, seep 'S1E-018'/Shelf Seep, Ft. Belvoir, VA
2013	5 (1 dead, 4 live)	T-17 area, seep 'S1E-018'/Shelf Seep, Ft. Belvoir, VA
* F = female, M = male, J = juvenile.		

Rainfall records indicate that all collections of NVWA at Fort Belvoir have occurred after significant precipitation events, leading some researchers to suggest the amphipods are "flushed out" of their normal subterranean habitat by elevated groundwater flows (Hobson and Orndorff 2013, p. 20). This hypothesis is based on best professional judgement because sampling for NVWA and monitoring of groundwater levels and flow rates are not conducted on a regular, year-round basis. If correct, this hypothesis suggests that successful sampling events likely serve as an indicator of presence rather than abundance. We therefore do not have an overall population estimate for the species or know if the population is increasing, decreasing, or stable.

2.3.1 Hydrogeological Setting

Every collection of the NVWA (from historical and current sites) has occurred in areas located in the vicinity of the 'Fall Line,' a zone of geologic transition from consolidated metamorphic bedrock of the Piedmont physiographic province in the west to unconsolidated or poorly consolidated sedimentary deposits of the Atlantic Coastal Plain province in the east. Two of these areas (Fort Belvoir, VA; Alexandria, VA) are located to the east on sediments consistent with the relatively young Lower Cretaceous Potomac Formation of the Atlantic Coastal Plain province, while the third (Vienna, VA) is located further west and underlain principally by much older metamorphosed rock of Cambrian origin from the Piedmont province (Holsinger 1978, p. 101; VA Department of Mines, Minerals and Energy (VDMME) 2018). Detailed geologic maps

[1] Incidentally, these four live specimens were subsequently transferred to Dr. Dan Fong at American University, but were lost to equipment failure and never sequenced for DNA (Hobson 2019). Thus, research is still pending on development of an environmental DNA (eDNA) tool (see section 3.3.2 for additional information).

show the majority of the Vienna area lacks the kind of sand and clay deposits that contain the aquifer habitat in which the NVWA is thought to live (*see section 2.6 below*), but isolated 'islands' of deposits dating to the Miocene epoch are located between Vienna and the Pimmit Hills to the east (Drake and Froelich 1997; VDMME 2018). Geologists currently lack consensus on whether a portion of these deposits may in fact be the westernmost occurrence of the Potomac Formation, and their geologic composition suggests that they might support the same kind of aquifer observed on Fort Belvoir (Denton 2018d). This geologic context suggests that the amphipod specimens noted as being collected from a well in Vienna may in fact have been collected from a well dug on one of these Miocene epoch "islands" or on "the unconsolidated sediments of the Pimmit Hills" to the east (Denton and Scott 2013, p. 39).

2.4 Life History

Holsinger (1978, p. 98) reported two juvenile paratypes in the December 27, 1921, collection by W.S. Abbott from a well in Fairfax County, VA. This information suggests breeding may occur in late fall/early winter. However, we do not know if breeding occurs year round or at discrete intervals through the year (Taylor 2019; Orndorff 2019). Holsinger (1978, p. 101) reported brood plates on females, indicating reproduction occurs via eggs (figure 5). This suggests the female provides limited care/protection via the brood pouch, which in amphipods is comprised of a brood plate (Dick *et al*. 1998, p. 666). Parthenogenesis, a form of asexual reproduction in which embryos develop without fertilization, also has been reported to be a possible life history strategy in *Stygobromus* species (Culver and Holsinger 1969, p. 631; Holsinger 1978, pp. 38, 59; Taylor and Holsinger 2011, p. 42). Male NVWA were reported in the 1921 collection, but the 1948 collection consisted entirely of females, and the sex of subsequent specimens has not been reported. It therefore remains unknown whether reproduction in the NVWA is entirely sexual or whether asexual reproduction occurs as well. We also do not know at what age or size class individuals become sexually mature or how long they may live (Taylor 2019).

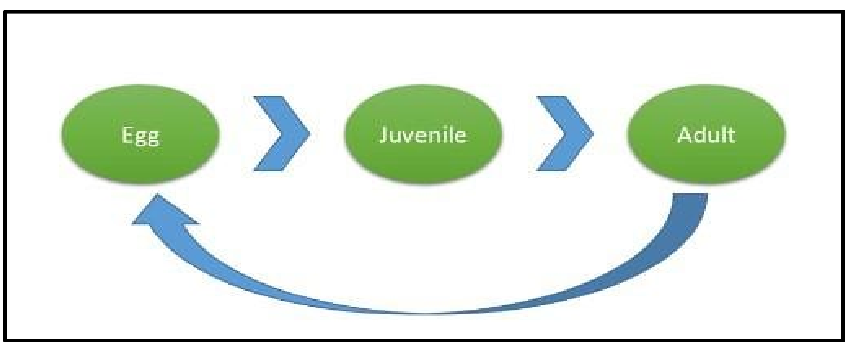


Figure 5. General amphipod life history conceptual model.

The food requirements of NVWA are currently unknown. Attempts to capture NVWA in monitoring wells using traps baited with shrimp (a technique that successfully captured other amphipods) were unsuccessful (Denton and Scott 2013, p. 43) and specimens captured live by hand did not eat in the laboratory (Denton 2018b). The gut of a specimen of a groundwater-dwelling amphipod found in Wisconsin, *Stygobromus putealis,* contained rust-colored particles thought to have been formed by subterranean bacteria feeding on iron in surrounding sediments (Jass and Klausmeier 2011, p. 601). Captive specimens of other amphipods in the genus

Stygobromus have been observed feeding on protozoans, flatworms, organic debris, and plant material (Denton and Scott 2013, p. 42). Insights into the feeding mode (*e.g.*, filter feeder, scraper or predator) and trophic position (*e.g.*, primary consumer or secondary consumer) of amphipods may also be gained through analyses of mouthpart morphology and the ratio of nitrogen isotopes in body tissues, respectively (Hutchins *et al*. 2014, p. 2447). Similar investigations could be applied to the NVWA in the future if sufficient specimens became available for study.

Subterranean habitats such as that thought to be occupied by the NVWA are often nutrient poor, with limited flux of photosynthesis-derived organic material via percolation from overlying sediments (Culver and Pipan 2009, p. 24). In some subterranean habitats (such as caves) this limited flow of nutrients can lead to the development of biofilms (accretions of polysaccharides, microorganisms and organic and inorganic molecules on rocks and sediments; Boston 2004 *In* Culver and Pipan 2009, p. 29), which can serve as the base of a subterranean food web (Simon *et al*. 2003 *In* Culver and Pipan 2009, p. 29). Stable isotope analyses have also shown that chemolithoautotrophic primary productivity, in which organic carbon is fixed to tissues by microbes in the absence of sunlight, may be an important source of carbon for subterranean communities (Hutchins *et al*. 2016, entire). Similar procedures could be applied to the NVWA in the future if sufficient specimens were available for study.

2.5 Behavior

It is unknown whether this species uses a "swimmer" or "crawler" form of locomotion, which would likely affect its abilities to reside in certain sediments or respond to changing water levels (Stump and Hose 2013, p. 7). Both swimming and "walking" have been observed in the hypotelminorheic amphipod *Stygobromus tenuis potomacus* (Gilbert *et al*. 2018, p. 22). The behavioral response of the NVWA to elevated flows, as might happen following a significant precipitation event, or to reduced flows, as might happen during a drought or other drop in water level, is likewise unknown.

Interspecific behaviors, such as predator-prey or competitive interactions, have not been observed. The NVWA has been known to be occasionally associated with other amphipods found in the T-17 area, such as *Stygobromus tenuis potomacus* and *Crangonyx shoemakeri* (Hobson 1997, p. 14; Hobson and Orndorff 2013, p. 50), that are "known from hypotelminorheic seeps, which occur in shallow sand lenses underlain by clay, rich in organic material and occurring no more than 50 cm below the ground surface" (Denton and Scott 2013, p. 1). By contrast, the NVWA is thought to occupy deeper, subterranean habitat (see *section 2.6*). Any predation on the NVWA in surface habitats may be from *Crangonyx* spp. (among other predatory invertebrates) because they are known to be voracious predators and would likely quickly consume any NVWAs that reached the surface (Denton 2018c).

2.6 Individual Requirements (Ecological Setting and Habitat Needs)

As described above, the only known current occurrence of the NVWA is located on Fort Belvoir in VA. The site at which the NVWA has been collected is located in a ravine on the southwestern portion of the Installation, approximately 700 m (2,297 feet (ft)) inland from where an unnamed creek (though referred to in a hydrogeological study and in this SSA, as 'Stream #1' (Lee *et al.* 2003, entire)) in the ravine discharges into nearby Gunston Cove (figure 7). As a whole, Fort Belvoir is set in an urbanized area but the Installation is a mix of developed and undeveloped lands. As of 2014, 65 percent of the Installation was undeveloped (U.S. Army 2014, p. 3.2). The most recent Integrated Natural Resources Management Plan (INRMP), a planning document that allows Department of Defense (DoD) installations to implement landscape-level management of their natural resources in coordination with stakeholders, states that 16 percent of the Installation overall is impervious cover (U.S. Army 2018, p. 3.10), while 18 percent of the subwatershed containing the NVWA spring is impervious cover (U.S. Army 2018, p. 5.20). The ravine and slopes surrounding the NVWA spring location are wooded and undeveloped, but the surrounding uplands support a variety of land uses and management including research and development, waste storage (21st Street solid waste transfer facility), and recreation (ball fields). See chapter 3 for a description of the NVWA's presumed influencing factors and the extent to which we have information on activities upland from the species' location.

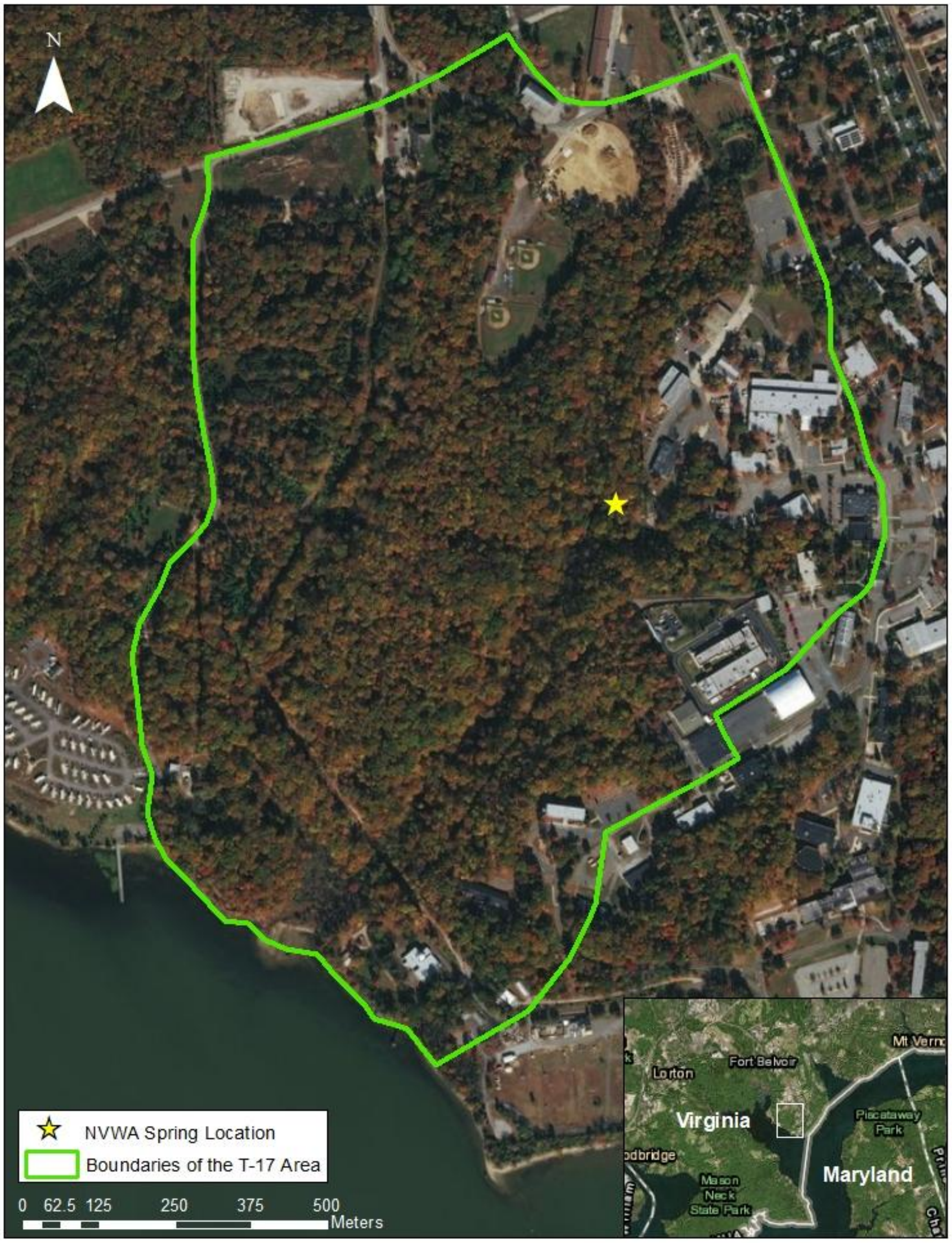


Figure 7. Aerial view of Fort Belvoir (inset), the NVWA spring location, and surrounding landscape.

In 2007, the DoD designated the ravine and presumed surrounding recharge zone, 70 acres (ac) (28.3 hectares (ha)) along Gunston Cove, a "Special Natural Area" to provide special conservation status to the area. The area is referred to as the T-17 Refuge and was designated as a National Environmental Policy Act (NEPA) mitigation commitment for the 2005 Base Realignment and Closure (U.S. Army 2007). This commitment was articulated in the INRMP (U.S. Army 2018, p. 9.1):

> "At Fort Belvoir, 'Special Natural Area' designation protects significant natural resources by encouraging new facilities to be sited away from locations of significant natural resources; by evaluating mission activities for potential impact to significant natural resources and incorporating mitigations to offset unavoidable impacts (e.g., incorporating wildlife crossing structures on roads through the FWC); and prioritizing natural resources monitoring and management efforts on the significant natural resources on post."

The boundaries of this Special Natural Area were delineated to include the groundwater seepage area where NVWA and other rare *Stygobromus* species are encountered, along with an estimated area of influence for groundwater recharge to that seepage area. The boundary delineation took into account installation mission and included the steep-sloped riparian areas and down-slope wetlands (areas that are not suitable for development). For ease of management, the boundary of this Special Natural Area was set at the 100-foot (ft) (33-meter (m)) contour and below, although it is unknown if the extent of this designated area encompasses all relevant surface and subsurface areas.

The ravine containing the NVWA site is formed by Stream #1, which "serves as an [sic] outlet for storm water originating from impervious surfaces located to the northwest" (Denton and Scott 2013, p. 7). One site drained by Stream # 1 is the 21st Street Solid Waste Transfer Facility, a point-source of pollution due to its use as waste storage/disposal and spill history (see *section 3.1.1—Water Quality*). Based on satellite imagery, everything else draining into Stream #1 appears to be a parking lot or buildings. Runoff directed to Stream #1 since at least 1944 has accelerated natural erosion, resulting in the stream's current deeply scoured form and exposing the springs from which NVWA have been collected (Denton and Scott 2013, p. 7).

Our limited knowledge of the habitat required by the species comes from hydrogeological and water quality studies in the T-17 area in the vicinity of NVWA collections. The geology of the Fort Belvoir peninsula as a whole is consistent with the Cretaceous-era 'Potomac Formation,' the oldest of the mostly unconsolidated (e.g., not bedrock) geologic strata in the Atlantic Coastal Plain province (Lee *et al.* 2003, p. 10; Denton and Scott 2013, p. 5). The Potomac Formation contains two regional aquifers, the 'Middle Potomac' and the deeper 'Lower Potomac,' which are separated by a dense clay 'confining unit' that limits the movement of water from shallower aquifers to deeper ones. An analysis conducted by the U.S. Geological Survey (USGS) indicated that the shallower of these two regional aquifers (the Middle Potomac) is likely the one encountered by wells and eroded surface channels on Fort Belvoir (Meng and Harsh 1988, entire; Denton 2018e). The Middle Potomac aquifer on Fort Belvoir does not have a broad confining unit above it (i.e. it is 'unconfined'), but topsoil and other post-Cretaceous sediments ('terrace deposits') are present. Together, "the middle Potomac and terrace deposits act as a single unconfined aquifer, except where there are local clay aquitards" (Grogin 1999, p. 20). It remains unknown whether the Middle Potomac exists under Fort Belvoir as a continuous aquifer through which water flows freely or as smaller sub-aquifers occupying the same strata but isolated from adjacent units by incised channels or other geologic features such that water does not flow between different sub-aquifers (Orndorff 2019).

At the scale of the T-17 ravine, distinct layers of coarse-grained (*e.g.*, sand and poorly consolidated sandstone) and fine-grained (*e.g.*, clay) substrates form two aquifers separated by a layer of clay (Lee *et al*. 2003, pp. 11–12). The shallower aquifer is referred to as 'surficial' and is covered only by terrace deposits while the deeper aquifer is likely part of the 'Middle Potomac' regional aquifer (Denton 2018e). The clay layer is referred to as an 'aquitard' because it slows (or retards) the flow of water from overlying layers of sediment to the layers beneath. Contained within the clay aquitard in the T-17 ravine are bands/pockets of coarser substrate ('sand lenses') thought to be deposited as a result of sequential prehistoric riverine processes such as levee formation and breaching (Lee *et al.* 2003, p. 19; Denton and Scott 2013, p. 29). The coarser substrates in the sand lenses have eroded over time, leaving behind channels and small caves ('macropores') extending up to at least 60 centimeters (cm) (23 in) into the clay bank at observed seeps/springs (figure 8) (Denton and Scott 2013, p. 27).

Figure 8. The seepage spring in the T-17 ravine from which NVWA were last collected. A 12-in (30.48-cm) ruler provides scale. The white PVC pipe protruding from the macropore is used for monitoring *in situ* water quality. Photo taken on February 4, 2019, and provided by John Pilcicki, Fort Belvoir.

Water quality testing of samples taken from exposed seeps/springs throughout the T-17 area and from eight monitoring wells near NVWA collection points (see map in Lee *et al*. 2003, figure 7) indicated that the water exiting through the NVWA spring more closely matched the chemistry of water taken from the deepest of the monitoring wells than from other wells (see Appendix B for more details). A key difference between the deepest well and the others is that it was the only well pumping water from beneath the clay aquitard that separates the two aquifers; all other wells terminated in or above the clay layer (Lee *et al*. 2003, figure 4-5) and thus appeared to pump water only from the surficial aquifer. This evidence suggests that the springs from which NVWA have been collected are connected to the deeper aquifer, possibly via channels created as sand lenses eroded while the surrounding clay remained (Denton and Scott 2013, p. 41, figure 29). It remains unclear whether the NVWA's habitat consists entirely of where the macropores exit the ravine wall (where specimens have been collected) or also includes the full length of the macropores inside the ravine wall and/or the sediments of the associated aquifer.

The complex depositional environment at Fort Belvoir (Manikas 2019) and different interpretations of hydrogeologic and water quality data collected in the T-17 ravine have led to the identification of two potential recharge zones for the NVWA spring. A hydrogeologic study conducted in 2003 concluded that water emerging from the NVWA spring likely originated from the surficial aquifer, and moved to the spring opening “primarily along the two thin, more permeable silty sand lenses, but also...several feet above these lenses, at the contact between the weathered clay aquitard and overlying sandy alluvial/colluvial deposits in the stream embankment” (Lee *et al*. 2003, p. 19). The report suggested that the recharge zone for the surficial aquifer is probably located to the east of the spring, in the vicinity of the research facility, specifically below buildings 332 and 333 (Lee *et al*. 2003, p. 19). A later study concluded the water emerging at the NVWA spring likely originated from the aquifer located below the clay aquitard, and that the recharge zone is probably to the northwest in a band across Fort Belvoir bounded approximately to the northwest by 12th Street and to the southeast by 19th Street (Denton and Scott 2013, p. 34; Denton 2018b). The second hypothesis may be more likely because potentiometric maps (which show the direction groundwater is likely to move based on the shape of the underlying geology) for the Fort Belvoir area indicate subsurface water is likely to move in a south-easterly direction (Johnston and Larson 1977, plates 1 and 2) following the downslope of the Potomac Formation. The depth and lateral continuity of an aquitard clay layer on Fort Belvoir is the subject of an investigation due to be completed in 2020 (Manikas 2019) and should provide insights regarding the spatial extent of the recharge zone of the aquifer supplying the NVWA’s spring (areas without an overlying clay layer are more likely to facilitate recharge of the deeper aquifer). Additional insights could be gained by conducting higher resolution hydrogeological investigations than were conducted previously or through the use of dye tracers (Johnson *et al*. 2010, entire), if appropriate.

In summary, we do not know the specific habitat requirements of the NVWA at the individual level. However, we infer, from general principles of conservation biology, general information about other groundwater species, and local information from where individuals have been observed, that NVWAs need sufficient “space” in which to find food and to reproduce, and that this “space” may equate to either the macropores of the seep/spring areas, the sediments of the deeper aquifer, or both.

2.7 Population Needs

There are no population estimates for the NVWA. Multiple mark-recapture studies have been used to estimate the abundance of the cave amphipod *Stygobromus emarginatus* (Knapp and Fong 1999) and the hypotelminoreic amphipod *S. tenuis potomacus* (Friedel *et al*. 2014), but such approaches have not been applied to the NVWA at Fort Belvoir due to an inability to effectively capture them. However, because there have been multiple individuals collected over time at the ravine sites (*see section 3.1.3 below*), we do presume that the individuals observed are part of a population. We do not know, though, whether the observed NVWA individuals represent an isolated population or may be part of a metapopulation, as has been suggested for hypotelminorheic communities in the vicinity of National Capital Parks East near Washington, D.C. (Keany *et al*. 2018, p. 10). However, we infer, based on general principles of conservation biology, that a species’ abundance should be large enough within its populations and distributed in a way such that local stochastic events do not eliminate all individuals, allowing the overall population to recover from any one event. A larger number of individuals provides a greater chance that a portion of the population will survive. The health of "populations" is generally contingent upon recruitment (an increase in a natural population as progeny grow and immigrants arrive).

2.8 Species Needs

Nothing is known about the tolerance of the NVWA for commonly monitored water quality parameters and pollutants. Table 2 below shows *in-situ* water quality measurements from the springs where NVWAs were collected during sampling in 2003 and 2013 and surface water quality criteria as defined by the Virginia Department of Environmental Quality (VDEQ). The VDEQ criteria are not necessarily directly applicable to the biology of the NVWA, but they are the best information available for providing context for water quality data collected from Stream #1 and the spring. It is also possible that subterranean conditions are less variable than those observed at the spring opening (Orndorff 2019).

Table 2. Recorded 2003 and 2013 *in-situ* quality measurements for the NVWA springs and VDEQ defined water quality criteria.

Parameter	**Units**	**Water Quality Measurements**	**VDEQ Criteria**
Temperature	Celsius/ Fahrenheit (°C/°F)	8.2-14.4 °C/ 46.8-57.9 °F[A,D]	<32 °C/ 89.6 °F[E]
Conductivity	Micro Siemens (µS)	99-233[A,D]	n/a
Dissolved Oxygen	Milligrams/Liter (mg/L)	4-10.1[A,D]	4[E]
pH	n/a	5.4-5.5[A,D]	6.0-9.0[E]
Total Dissolved Solids	mg/L	175-209[B]	500.000[F]
Total Dissolved Carbon	mg/L	2.5-2.7[B]	n/a
Nitrate	mg/L	0.21[C]	10[F]
Total Phosphorus	mg/L	0.21[C]	n/a
Nitrate + Nitrite	mg/L	0.519[C]	n/a

[A] Denton and Scott 2013, Table 6, 7, 8; [B] Denton and Scott 2013, Table 9b; [C] Lee et al. 2003, Table 5; [D] Lee et al. 2003, Table 6; [E] 9VAC25-260-50 (Numerical criteria for dissolved oxygen, pH and maximum temperature [non-tidal waters]); [F] 9VAC25-260-140 (Criteria for Surface Water).

The data in table 2 suggest that the species has persisted following exposure to a relatively wide range of both dissolved oxygen and temperature (as documented at the spring opening), although the recorded values do not necessarily delineate upper and lower physical tolerances. Based on observed patterns of water quality in monitoring wells and at the NVWA spring, Denton and Scott (2013, p. 36) suggested that a combination of relatively high conductivity, high dissolved solids, and low organic content served as a 'fingerprint' for the NVWA's habitat.

Although we do not know the specific needs of the NVWA, we infer that a species generally requires a stable or positive population growth rate to remain healthy. We do not know the species' population size or trend, but instead rely on the best available habitat parameters as a surrogate for population and species health.

In summary, we infer, based on general conservation biology principles, that the viability of the NVWA would be best supported by multiple (redundancy) self-sustaining (resiliency) populations distributed throughout the geographical extent of its range (representation). See chapter 4 for a discussion of the species' current condition.

2.9 Summary of Species Information

Species of *Stygobromus* amphipods are small crustaceans morphologically adapted for life in freshwater caves, seeps, wells and other groundwater-related habitats. The NVWA was taxonomically described in 1978, but little is known definitively about its habitat needs and general biology. It was first reportedly collected from a well in Alexandria, VA in 1921 and then from a well in Vienna, VA in 1948; due to development activities likely physically filling in the wells, the exact locations of both collection sites are unknown, as is the status of those populations. Whether the condition of the species at each historical location is extirpated or unknown is a key uncertainty, but for the purposes of this SSA we presume it to be unknown (see *section 2.3 Historical and Current Range, Distribution, and Abundance*). The species was not observed again until specimens were collected in 1996 from a seepage spring during a routine survey in a wooded ravine in the T-17 area of Fort Belvoir, VA. Efforts to collect the NVWA from that spring and adjacent springs have yielded a total of 25 individuals between 1996 and 2013. Because there have been multiple individuals collected over time at the capture sites, we do assume that the individuals observed are part of a population, but the size and structure of the population in the T-17 area are unknown.

Most collections have occurred following significant precipitation events, leading some researchers to suggest that NVWAs are flushed out of a subterranean habitat. Detailed hydrogeological studies throughout the T-17 area suggest that the NVWA may inhabit 'macropores' (cavities and channels within the ravine wall formed when sandy substrates erode while surrounding clay substrate persists) and/or a deep (i.e., non-surficial) aquifer characterized by a unique chemical signature of high conductivity, high dissolved solids and low organic content. The diet, water quality tolerances, and behavioral traits of the NVWA have not been documented. Reproduction also has not been observed but is thought to be sexual based on reports of both male and female specimens, including females with brood plates indicative of egg laying, in early collections; based on the timing of the collections, we infer that eggs may be laid in late fall-early winter, but we cannot exclude the possibility that reproduction is year-round or episodic.

We infer, based on general principles of conservation biology, general information about other groundwater species, and local information from where NVWA individuals have been observed, that NVWAs need sufficient "space" in which to find food and to reproduce, and that this "space" may equate to either the macropores of the seep/spring areas, the sediments of the deeper aquifer, or both. Although we do not know the specific needs of the NVWA, we infer, that a species generally requires a stable or positive population growth rate to remain healthy. We do not know the species' population size or trend, but instead rely on the best available habitat parameters as a surrogate for population and species health. We presume, based on general conservation biology principles, that the viability of the NVWA would be best supported by multiple (redundancy), self-sustaining (resiliency) populations distributed throughout the geographical extent of its range (representation). See chapter 4 for a discussion of the species' current condition.

CHAPTER 3 FACTORS INFLUENCING VIABILITY

In this chapter, we evaluate the past, current, and future influences that are affecting or could be affecting the current and future condition of the NVWA. These influences are summarized in a conceptual model (figure 9) and discussed in more detail in the section below.

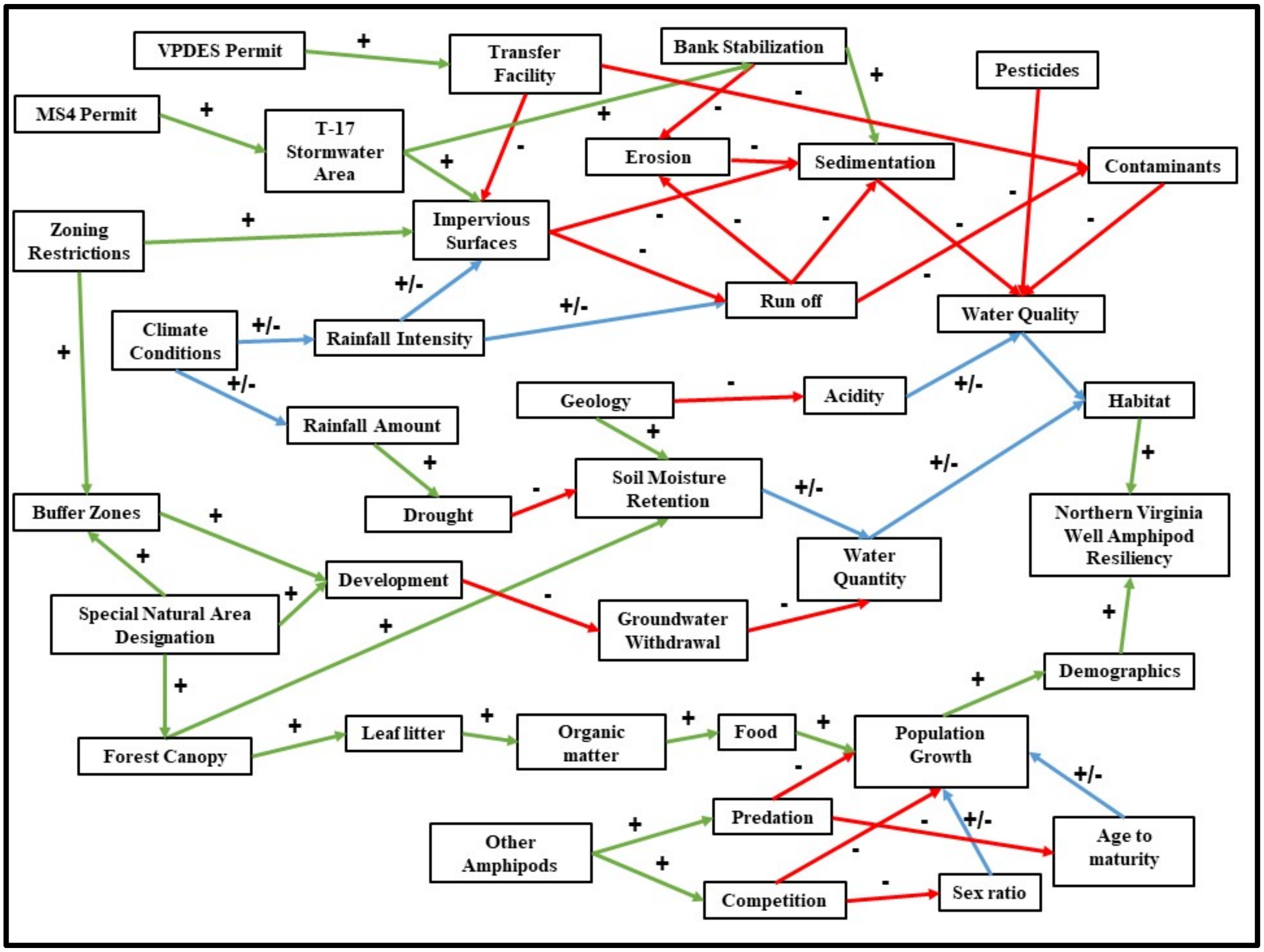


Figure 9. Presumed influence diagram for the NVWA. Green arrows with a plus (+) sign indicate a positive influence, red arrows with a minus (-) sign indicate a negative influence and blue arrows with a plus/minus (+/-) sign indicate a variable or uncertain influence.

3.1 Habitat Loss and Degradation

We do not currently know if the primary habitat of the NVWA is the macropores described above in *section 2.6* or the deep aquifer thought to supply the water emerging from the NVWA spring, or if the species uses both types of habitat. The 2018 Fort Belvoir INRMP identified several potential threats to the amphipod, all of which could degrade both habitat types, including potential threats to water quality (e.g., groundwater or surface water contamination), water quantity (e.g., groundwater withdrawal or impacts to the recharge zones for the local water table), and physical structure of the spring (e.g., slope stability) where NVWAs have been collected (U.S. Army 2018, p. 8.13).

3.1.1 Water Quality

Contamination of groundwater or surface water could occur as the result of spills in the recharge zone, infiltration of polluted stormwater runoff, leakage from underground pipes, or activities associated with subterranean construction. It is also possible that contaminated runoff might inundate the spring opening if water in the stream pooled behind a blockage following a landslide, logjam, or other disruptive event (Denton 2018e). Contaminants associated with stormwater runoff in developed areas include heavy metals, residues of petroleum products, pesticides, salts, and microorganisms such as bacteria and viruses (Pitt *et al*. 1996, pp. 223–224).

The most likely potential source of contaminated runoff in Stream #1 is Outfall 007, a discharge point located at the upstream end of the ravine that drains stormwater runoff from an area that includes the 21st Street Solid Waste Transfer Facility. For example, during an amphipod survey on January 18, 2012, VDCR—Natural Heritage and Installation—Natural Resources staff noticed that "the stream turned dark gray with floating bubbles after being clear with several fish seen swimming in pools upstream and downstream of overhead pipe just minutes before. Followed upstream and found spill/release site at 21St Street facility" (Hobson 2018b). The Natural Resources staff contacted the Installation's Directorate of Public Works Environmental Division staff to report the incident (Hobson 2018b). An investigation revealed the contamination resulted from a release of water and sediment removed by a contractor from trench drains and a manhole in an airfield hanger building. Analyses of water samples from the spill area detected "several compounds of VOC's [volatile organic compounds], SVOC's [semi-volatile organic compounds] and a TPH-DRO [total petroleum hydrocarbons-diesel range organics] result of 114mg/L" (VADEQ 2012). The potential impact on NVWA of exposure to such compounds through contact with contaminated surface water or with contaminated groundwater entering the aquifer from overlying sediments is unknown.

Regular testing of the effluent at Outfall 007 is conducted pursuant to Fort Belvoir's Virginia Pollution Discharge Elimination System Permit (VPDES) Industrial Stormwater Major Permit VA0092771. Table 3 shows results for sampling at Outfall 007 on two representative dates, April 17, 2017, and January 23, 2018.

Table 3. Water quality measurements at Outfall 007.

Parameter	Units	April 17, 2017[A]	January 23, 2018[B]	VDEQ Criteria
Suspended Solids	mg/L	8.82	107	No criteria specified
Total Phosphorus	mg/L	0.17	0.21	No criteria specified
Nitrate + Nitrite	mg/L	0.389	0.519	No criteria specified
Total Hardness	mg/L	42.9	94.8	No criteria specified
Dissolved Copper	Micrograms/ Liter (µg/L)	4.0	28.1	6.05 (2017), 12.78 (2018)*
Dissolved Lead	µg/L	<0.3	0.9	25.42 (2017), 60.93 (2018)*
Dissolved Nickel	µg/L	3.6	4.2	228.8 (2017), 447.6 (2018)*

*[A] Angler Environmental 2017; [B] Angler Environmental 2018; *Hardness-dependent, Acute Exposure. Calculated using an Excel sheet for 'Aquatic Life Criteria' provided by the U.S. Environmental Protection Agency (USEPA) using a default 'Water Effect Ratio' of 1. https://www.epa.gov/sites/production/files/2017-04/aquatic-life-criteria-calculator-beta-wqsa-version.xls.*

The water quality results reported in table 3 meet applicable criteria for dissolved lead and dissolved nickel. Water quality criteria are not established for suspended solids, total phosphorus, nitrate + nitrite, and total hardness under the current permit. There is no information on effects of these parameters to NVWA, however, levels reported in the 2017 and 2018 samples are generally not at levels of concern for other aquatic species. The copper concentration in the January 2018 sample is the only sample tested that exceeds water quality criteria. Amphipods are one of the most sensitive groups of invertebrates to copper toxicity (USEPA 2007). However, more accurate prediction of potential toxicity requires measurement of concentrations of inorganic and organic ligands (USEPA 2007). Thus, we do not know if the measured concentration in January 2018 exceeds the acute toxicity threshold for the NVWA or the potential for exposure of the resident population.

We are unaware of any current routine activities at Fort Belvoir that would likely result in measurable contamination of the aquifer thought to supply the NVWA spring. However, a USGS map classified the T-17 area as having "intermediate risk of groundwater contamination," while adjacent land to the east was classified as having "high risk of ground-water contamination." Our understanding is that the classification was based on local hydraulic gradients resulting from a combination of the type and sequence of different sediment layers (high-permeability sand versus low-permeability clay) and the degree to which those substrates might transmit contaminated water released from a hypothetical waste disposal site (Froelich 1985, plate 4F). This suggests that the susceptibility of the NVWA aquifer to contamination would depend on the composition of sediments in the immediate vicinity of the source of exposure to a pollutant (such as whether a clay layer is located beneath a spill location). We evaluate changes to water quality as part of the species' current and future condition.

3.1.2 Water Quantity

The seepage spring from which NVWAs have been collected is thought to be sustained by groundwater originating in sediments associated with the 'Middle Potomac' regional aquifer. Any local recharge zone(s) for that aquifer could be affected by construction of additional impervious cover, such as roadways, parking lots or buildings, as well as by installation of artificial infiltration basins to handle runoff, which "may induce locally high groundwater recharge rates" (Pitt *et al.* 1999 *In* Datry *et al*. 2005, p. 461). Between 1999 and 2000, 4.4 acres (ac) (1.78 hectares (ha)) of abandoned pavement, Installation-wide, were removed and replanted with native vegetation (U.S. Army 2001, p 7.40). Spatial analyses of ground cover at Fort Belvoir indicate that the percent of area classified as 'developed' increased by 1 percent over most of the Fort Belvoir peninsula but declined by 2 percent within the T-17 Refuge between 2001 and 2011. The fraction of land classified as 'greater than 15 percent impervious' increased by 1 percent both in the T-17 Refuge and the broader Fort Belvoir peninsula during the same period, while the fraction classified as '0 percent impervious' did not change in the T-17 Refuge and declined 1 percent on the broader Fort Belvoir peninsula (see appendix A for additional details). We are unaware of any measurable changes in impervious cover since that time, any significant changes planned in the future, or plans to install artificial infiltration basins.

A drop in the water level in the aquifer supplying the NVWA spring could reduce the amount of habitat available for the species. Such a drop could occur relatively quickly as a result of removal of a significant volume of groundwater through pumping ("abstraction") or more slowly as a result of changing climate conditions (see *section 3.2.1* below). According to a USGS groundwater specialist, "In the absence of locational, hydrogeologic framework, and water-level data, it would be difficult to determine potential impacts on the habitat from groundwater withdrawals. However, considering the thickness and areal extent of potential recharge of the Potomac aquifer, groundwater withdrawals would have to be either in the vicinity of the spring or extremely large to cause water-level drawdowns that encountered the spring or intercept water that would have flowed to the spring" (Nelms 2018). We are unaware of any plans to extract significant volumes of groundwater from the Fort Belvoir peninsula where previous studies suggest recharge of the NVWA spring occurs. It has also been suggested that the springs where the NVWA have been found might be draining the aquifer in which the NVWA are thought to live (Orndorff 2019). We are unaware of any long-term water level monitoring data for any of the wells in the T-17 area that would allow investigation of that hypothesis.

Progressive loss of water in the aquifer, regardless of mechanism, could strand individual amphipods in dry sediments, as was observed in laboratory experiments with copepods (Stumpp and Hose 2013, p. 5), or force individuals to seek deeper sediments with sub-optimal physical or chemical composition (Stumpp and Hose 2013, p. 9). For example, Gilbert et al (2018, p. 22) documented behavioral response of two amphipod species, the wetland amphipod *C. shoemaker* and the hypotelminoreic amphipod *S. tenuis potomacus*, both of which are also found in seep and spring habitats in the T-17 Refuge (Gilbert *et al*. 2018, p. 22). These amphipods burrowed into the clay substrate of experimental containers when exposed to drying habitat conditions in the laboratory. This may be an adaptive response to seasonal drying because clay has high water retention (Heath 1980, p. 9), but it is unknown how long such burrows provide refuge (Gilbert *et al*. 2018, p. 23). It is unknown if the NVWA exhibits similar behavior in response to dewatering of the aquifer and macropores supplying water to the T-17 spring.

While the NVWA is not currently listed as a species of concern or as State-listed species, groundwater management law in VA provides some protection for the species' suggested subterranean habitat. The State of VA manages groundwater withdrawals through the VDEQ and requires permits for any people or entities withdrawing 300,000 gallons or more of groundwater per month (10,000 gallons/day) (VDEQ 2018). Fort Belvoir is located in the Eastern VA Groundwater Management Area (EVGMA), meaning that any large-scale proposed groundwater withdrawals from the installation would be subject to review, monitoring, and regulation by the State of VA. This is a potentially significant measure of protection in light of a report prepared by the EVGMA (2017, entire) stating that "the available groundwater supplies in the EVGMA are insufficient to meet the demands of current and future groundwater users."

We evaluate changes to water quantity as part of the species' current and future condition.

3.1.3 Physical structure of the spring opening

Acute loss or degradation of physical habitat (or at least of the site where NVWAs have been collected) could occur as a result of a significant storm event or routine erosion. Examples of such events include 'mass slump' (*see section 2.3, above*) and collapse of the ravine wall due to a tree fall (figure 10). In the T-17 ravine, an episode of 'mass slump' that occurred during the interval between the 2003 and 2013 hydrogeologic studies covered the original seepage spring at which NVWA had been discovered, yet amphipods were subsequently collected from a second spring found nearby (Denton and Scott 2013, p. 1). This suggests that individuals at the surface are connected to a larger population underground (*see section 2.7, above*), and therefore the population may be either tolerant of, or able to recover from, perturbations to the physical state of the spring opening. We evaluate changes to the physical structure of the spring opening as part of the species' current and future condition.

Figure 10. Sloughing of the ravine wall due to a tree fall immediately downstream of the spring from which NVWAs have been collected. Picture taken on February 4, 2019, and provided by John Pilcicki, Fort Belvoir.

3.2 Climate Conditions

Here, we evaluate the climatological indicators that would most affect NVWA habitat and resource needs. Fort Belvoir is located in a climate subtype of the Köppen Climate Classification System that is "characterized by mild winters and warm, humid summers, and an absence of an annual dry season. During winter, freezes occur, but do not persist for long periods. During summer, warm and wet flows from the tropics result in muggy conditions and frequent thunderstorms" (U.S. Army 2018, p. 4.1). Mean annual precipitation from 1981 to 2017 at nearby Washington Reagan International Airport was approximately 39.97 in (101.53 cm) (range: 29.62 to 60.83 in (75.23 to 154.51 cm)) (National Oceanic and Atmospheric Administration 2018).

It is unknown what effect a change in regional climate would have on the NVWA population at Fort Belvoir. A climatic shift to a regime of more frequent or more intense precipitation events might raise the water table in the aquifer supplying the spring or increase the rate of erosion of the ravine in which the NVWA spring is found, while a shift to a drier regime might result in a long-term decline of the water table.

3.2.1 Projected Changes in Climate Indicators

The climate change projections used in this SSA report are based on Representative Concentration Pathway (RCP) scenarios. The RCPs are the current set of scenarios used for generating projections of climate change and are based on the influences of greenhouse gas concentrations in the atmosphere. There are four RCPs, selected to be representative of the range of theoretically possible atmospheric conditions (measured as "radiative forcing," a reflection of influence on climate) which could exist at 2100, and pathways over this century time for those conditions, as described in more than 100 scenarios in the scientific literature at the time the RCPs were developed (van Vuuren *et al*. 2011, p. 13). For information about the RCP scenarios, see van Vuuren *et al*. 2011 (entire) or Collins *et al*. 2013 (pp. 1044–1047).

In this SSA report, we use climate change projections based on RCP 4.5 and RCP 8.5, the "medium-low" and "highest" scenarios, respectively, in the RCP set. We did not use the "lowest" scenario, RCP 2.6, because it is based on numerous assumptions that are increasingly viewed as being theoretically but not realistically feasible due to a variety of social, economic, ethical, and technological considerations (e.g., Buck 2016, entire; McLaren *et al*. 2016, entire; Smith *et al*. 2016, entire; Williamson 2016, entire; Gambhir *et al*. 2017, entire; Raftery *et al*. 2017, entire; European Academies Science Advisory Council, 2018). The RCP 4.5 and RCP 8.5 scenarios are widely used together in the scientific community, and these scenarios were selected as the basis of projections for assessing climate change impacts, vulnerability, and adaptation responses in the development of the Fourth National Climate Assessments (U.S. Global Change Research Program 2015, entire). Using a range of climate change projections based on outcomes of more than one scenario is a widely recommended practice (Nakicenovic and Swart 2000, pp. 11, 23; Harris *et al*. 2014, p. 8; Mauger *et al*. 2015, pp. 1–4; Kotamarthi *et al*. 2016, p. 16), as it is one way to acknowledge and work with uncertainty that is inherent in modeling and uncertainty about future human actions which influence changes in climate. The precipitation outcomes described for RCP 4.5 and RCP 8.5 are best viewed as providing a technically plausible range, and outcomes closer to the center of this range are more likely than outcomes at either end. Further, we assume, based on current trends in global emissions (Jackson *et al*. 2017, entire) and the long-lasting influence of greenhouse gases already in the atmosphere (Collins *et al*. 2013, pp. 1102–1105; Mauritsen and Pincus 2017, entire), that there is a very reasonable basis for concluding that changes from now through at least mid-century will be much closer to projections under RCP 8.5 than RCP 4.5. However, we did use RCP 4.5 in one of our future scenarios (*see section 5.2*, *below*) to incorporate the suite of plausible scenarios.

3.2.1.1 Projections for Virginia

We used precipitation projections for mid-century (defined as 2036–2065 in the Fourth National Climate Assessment; Vose *et al*. 2017, p. 196), which includes the 25-year timeframe covered by this SSA, when analyzing the potential impacts of climate change on the NVWA. Visualizations of data from the Localized Constructed Analogs dataset, which "uses statistical techniques to correct global climate model data for biases and downscale those data to a 1/16th degree spatial resolution" indicate an increase in annual precipitation in Virginia of 5 to 10 percent when compared to the reference period (1976 to 2005) under both RCP 4.5 and RCP 8.5 (Global Change 2019). The expected annual number of days with precipitation greater than the 99th percentile is expected to increase 20 to 40 percent during the same time under RCP 4.5 and 40 to 60 percent under RCP 8.5 (Global Change 2019). Prior modeling suggested that the frequency of 2-day extreme precipitation events (those exceeding a 5-year return period) in VA is expected to increase approximately 30 percent by 2070 based on RCP 4.5 and approximately 40 percent based on RCP 8.5 (Janssen *et al*. 2014, p. 110–111). It is unknown if these projected changes in total annual precipitation and in the frequency of more intense precipitation events are likely to impact the NVWA, its potential habitat(s) or other influencing factors such as water quality (*see* *section 3.1.1*), water quantity (*see section 3.1.2*), and the condition of the spring opening (*see section 3.1.3*).

We also considered the potential effect of climate change on soil moisture. Warmer air temperatures can increase evapotranspiration, resulting in "drier soils and often less runoff in the long term" (Wehner *et al*. 2017, p. 232). Further, "future decreases in surface (top 10 cm) soil moisture from anthropogenic forcing over most of the United States are *likely* as the climate warms under the higher scenarios" (Wehner *et al*. 2017, p. 247). It is unknown if decreased moisture in surface soils is likely to impact the NVWA given their presumed subterranean habitat, but it is possible that increased evapotranspiration might reduce flows into the aquifer that supplies the spring where they have been collected.

The effects of climate change are evaluated as part of the species' future condition.

3.3 Other Influences Considered

3.3.1 Effects of Small Population Sizes

In general, small populations, especially those that are isolated, tend to exhibit reduced genetic diversity and associated consequences such as inbreeding depression. However, we do not have existing information to help inform estimates of the species' population size or genetic diversity. Therefore, we cannot draw a reasonable conclusion on whether the NVWA is currently experiencing, or may in the future experience, the deleterious effects of a small population size. Thus, we are not evaluating the effects of small population size as part of the species' current or future condition.

3.3.2 Collection

Accurate field identification of amphipods in the genus *Stygobromus* can be a challenge. For example, identification of the Kenk's amphipod (*Stygobromus kenki*) can be done only following field preservation of a specimen in alcohol or other fixing agent and expert review of disarticulated appendages under a microscope (Service 2017 (82 FR 45552)). This procedure removes individuals from the population, but it remains the best scientific method available for that species. Visual identification in the field is possible for some specimens of the NVWA, but we assume that a lethal approach similar to that used for *S. kenki* is required for less obvious specimens. All collections of the NVWA since the species was discovered on Fort Belvoir in 1996 have been from the surface by hand following significant precipitation events or during seasonal aquifer 'high water marks.' This pattern has led some researchers to suggest that the organisms are being flushed out of their habitat and collected opportunistically at the surface, rather than being removed from their habitat during sampling. It is therefore unlikely that the current form of sampling impacts the population within its hypothesized subterranean habitat. Therefore, we are not evaluating collection as part of the species' current or future condition.

Development of an environmental DNA (eDNA) sampling protocol for this species may all but eliminate the need to collect specimens once a protocol is established. Research to support this effort is planned for later in 2019 (Hobson 2018c), once funding is secured. Environmental

DNA, a forensic technique that selectively amplifies DNA fragments of a target species in a water sample, is a powerful tool for detecting species that are cryptic, rare, or difficult to capture. Research by Niemiller *et al.* (2017, entire) demonstrated that eDNA can be a practical tool for detecting and monitoring invertebrates in subterranean ecosystems, including the endangered Hay's Spring amphipod (*Stygobromus hayi*). An identical approach could be applied to the NVWA when sufficient tissues from verified specimens are available for analysis.

3.3.3 Disease

Amphipod pathogens are generally unstudied (Orndorff 2019), and we have no information about disease affecting the species. Therefore, we are not evaluating disease as part of the species' current or future condition.

3.3.4 Predation

Predation on NVWA has not been observed, but other crustaceans found in seeps in the T-17 area, such as *Crangonyx* spp., are known to be voracious predators and "would surely attack and eat them as soon as they could" (Denton 2018c). However, these other species occur closer to the surface than the NVWA does (*see section 2.5 Behavior*). We presume predation is a natural occurrence, and while it may occur on individuals, we have no information to suggest that it is having or is likely to have a population- or species-level effect. Therefore, we are not evaluating predation as part of the species' current or future condition.

3.3.5 Construction Activities

Fort Belvoir's history includes operation of 'SM-1 Nuclear Power Plant,' the first nuclear power plant producing electricity for a commercial grid. It is located to the southeast of the T-17 ravine and operated from 1957 to 1973 as a power generation and training facility. The plant was deactivated during the years 1973 to 1974 and the decommissioning process (facility decontamination, deconstruction of structures, and disposal of contaminated materials and used nuclear fuel) is planned to start as early as late 2020. It is currently unclear whether deconstruction activities and handling of any radioactive wastes might impact ecological resources on Fort Belvoir, but a draft Environmental Assessment (EA) pursuant to the National Environmental Policy Act (NEPA) is under preparation (U.S. Army Corps of Engineers 2019, entire). We evaluate construction activities associated with the decommissioning process as part of the species' future condition.

3.3.6 Research and Development

As discussed in *section 2.6*, the upland areas surrounding the NVWA's spring include facilities that support the Installation's research and development activities. We have been unable to obtain specific information related to these activities and therefore are unable to assess the extent to which these activities may or may not be affecting the NVWA currently or in the future.

3.3.7 Recreation

As discussed in *section 2.6*, the upland areas surrounding the NVWA's spring include facilities that support recreation activities (i.e., approximately 8.5 ac (3.4 ha) of ball fields). The ball fields are located 306 m (1,004 ft) northwest of the NVWA's spring and separated by undeveloped, wooded habitat (see figures 4 and 7). We do not have information on how those recreational facilities are maintained. However, given the physical distance and type of habitat (i.e., buffer) that separates the ball fields from the underground aquifer and the spring opening, we assume that the Installation's recreational activities have minimal impact on the species currently or in the future. Therefore, we are not including recreation as part of our future scenarios.

3.4 Other Conservation Efforts

All DoD installations are required under the Sikes Act (16 U.S.C. 670a-670f, as amended) to develop and implement an INRMP. The INRMPs are planning documents that allow DoD installations to implement and adapt landscape-level management of their natural resources in periodic coordination with appropriate stakeholders (Service, States, and others). They ensure that military operations and natural resources conservation are integrated and consistent with stewardship and legal requirements. The current Installation mission at Fort Belvoir is "to provide installation base support to enable readiness. Fort Belvoir garrison organizations operate and maintain the installation; provide quality installation support and services to its customers and to plan, maintain, and execute mobilization readiness, military operations, and contingency missions. Since the departure of the Engineer School in 1988, the emphasis of Fort Belvoir's mission has shifted from training to providing logistical and administrative support to its tenants" (U.S. Army 2018, p. 3.1).

Based on coordination with the Service—VAFO and the Virginia Department of Conservation and Recreation, Natural Heritage Program, the DoD has addressed the NVWA and its habitat in INRMP documents completed in 2001 (U.S. Army 2001) and 2018 (U.S. Army 2018). Since 2001, conservation-related actions have been applied directly to the NVWA's habitat, or to the surrounding lands on Fort Belvoir, in a manner that we anticipate likely benefits the NVWA and its habitat. Table 4 provides examples of proposed management activities from the 2001 INRMP and examples of follow up actions taken between 2001 and 2018, while table 5 provides examples of management activities proposed in the most recent INRMP update (U.S. Army 2018, p. 8.13).

Table 4. Management Activities Identified in the 2001 INRMP (U.S. Army 2001, pp. 8.9, 12.28–12.31).

Proposed Management Activity	**Activity Completed?**	**Documentation**
Characterize and protect groundwater quality and flow at the T-17 Ravine (p. 8.9).	Yes	Lee *et al*. 2003; Denton and Scott 2013
Develop and implement a study to evaluate the *Stygobromus phreaticus* (NVWA) (p. 12.28).	Yes	Lee *et al*. 2003; Chazal and Hobson 2003; Denton and Scott 2013
Develop and implement a program to monitor rare plant and animal species, and rare ecological communities (p. 12.28).	Ongoing	Hobson and Orndorff 2013
Continue to set aside habitat areas for endangered, threatened, and rare species and rare ecological communities (p. 12.28).	Ongoing	U.S. Army 2007 (p. 29)
Designate part of T-17 as a conservation area within the Tompkins Basin Recreation Area (p. 12.29).	Yes	U.S. Army 2007 (p. 29)
Continue to coordinate with the Service, VDGIF, DCR-DNH, and other appropriate entities regarding protection requirements for, and current population and other information on, bald eagles and wood turtles, other listed and rare species, and rare ecological communities, as they may be encountered on Fort Belvoir (p. 12.28).	Ongoing	Pilcicki 2018b (see numbered bullet points 1, 3 and 4)
Continue to use the installation project and activity review process to incorporate threatened, endangered, and rare species/communities conservation requirements into all phases of facilities siting, construction, renovation, operation, maintenance, and demolition activities; in reviewing and supporting military training and testing activities; and in reviewing and responding to outdoor recreation, environmental education, scientific research and study, and all other types of land area access and use requests (p. 12.30).	Ongoing	Pilcicki 2018b (see numbered bullet points 3, 4 and 5)
Continue to perform agency coordination on installation actions potentially affecting endangered, threatened, or rare species or rare ecological communities (p. 12.31).	Ongoing	Pilcicki 2018b (see numbered bullet points 3 and 4)

Table 5. Management Activities Identified in the 2018 INRMP (U.S. Army 2018, p. 8.13).

Proposed Management Activity	Activity Completed?	Documentation
Continue to use the NEPA process to evaluate, provide alternatives, and if possible, eliminate risks.	Ongoing	Pilcicki 2018b (see numbered bullet point 6)
Continue to maintain Special Natural Area designation of the T-17 Refuge to provide a buffer around the seep and restrict activities in the landscape surrounding the seep.	Ongoing	Pilcicki 2018b (see numbered bullet point 6)
Protect the recharge zones for the aquifer by limiting an increase in impervious surface within 0.5 mi (0.8 km) of the seep if mission allows.	Ongoing	Pilcicki 2018b (see numbered bullet point 7)
Continue to address the 21st Street solid waste transfer facility under the industrial storm water permit program (VPDES - Industrial Stormwater Major Permit VA0092771 Part 1 A.7) and continue testing stormwater samples leaving the facility and entering the drainage in accordance with the permit requirements. Analytic results from water testing under the installation stormwater permits, and responses to any exceedances, will be coordinated with the Service annually.	Ongoing	Pilcicki 2018b (see numbered bullet points 9 and 11)
Continue to manage the 21st Street solid waste transfer facility under the MS4 permit program (VAR040093) to regulate the quantity and condition of the stormwater in accordance with the permit requirements as well as sediment and erosion control measures. Analytic results from water testing under the installation stormwater permits, and responses to any exceedances, will be coordinated with the Service annually.	Ongoing	Pilcicki 2018b (see numbered bullet points 9 and 11)
Monitor other seeps around Fort Belvoir as new seeps are identified or there are potential risks to currently known seeps that are not known to have NVWA to be able to identify if any additional locations or populations can be located. The known seep will be visited and visually inspected on a periodic basis (quarterly and after heavy rain events) to ensure that the habitat has not been impacted by installation operations. If impact is observed, response will be coordinated with the Service.	Ongoing	Pilcicki 2018b (see numbered bullet points 12 and 13)
Continue to monitor the condition of the wells that are surrounding the T-17 seep and used to monitor water quality of the aquifers.	Ongoing	Pilcicki 2018b (see numbered bullet point 13)

Natural resources staff at Fort Belvoir have also taken additional steps not outlined in the INRMPs to limit the impact of base operations on the NVWA's habitat. For example, a 1.2-meter (m) (3.3-foot (ft)) high berm was installed in 2013 at the southern end of the 21st Street solid waste transfer facility to discourage illicit dumping and discharge of liquids from vehicles (Pilcicki 2018b). Staff also recommended changing the course of a planned water/sewer line so that it did not pass through the T-17 ravine (Pilcicki 2018b). We evaluate implementation of the INRMP as part of the species' current and future condition.

3.5 Summary of Factors Influencing the Species

The primary influencing factors likely to have species-level effects include changes to groundwater quality and quantity, extent of impervious cover in likely recharge zones, and implementation of conservation actions. Because we lack specific information about the NVWA's population size, research and development, and recreation we did not evaluate the effects of small population size, research and development, and recreation as part of the species' current or future condition. Amphipod pathogens are generally unstudied and we have no information about disease affecting this species; therefore disease is not evaluated as part of the NVWA's current or future condition. And lastly, the best available information indicates that predation and collection are not having a population- or species-level effect; therefore, we do not evaluate these stressors as part of the species' current or future condition.

CHAPTER 4 CURRENT CONDITION

4.1 Methodology

To assess the biological status of the NVWA across its range, we used the best available information, including professional reports, peer reviewed scientific literature, academic book chapters, and VA State agency species-specific survey data. Additionally, we consulted an interdisciplinary group of experts in fields related to the life history, genetics, and habitat of the species (see Acknowledgements). After reviewing available literature and consulting with the species' experts, we identified the factors (i.e., stressors and ongoing conservation measures to address stressors) most likely affecting the NVWA and constructed a conceptual model illustrating how each of those stressors might affect the species (see chapter 3). We considered only factors that might affect the Fort Belvoir population because it is the only known extant population and it is also the only population of the three ever referenced for which a specific location (including local hydrogeology and degree of development) is known. The sampling sites from which the holotype and paratype specimens were collected are thought to have been destroyed as a result of urbanization, making the status of those populations unknown (see *section 2.3 Historical and Current Range, Distribution, and Abundance*). Whether the condition of the species at each historical location is extirpated or unknown is a key uncertainty, but for the purposes of this SSA we presume it to be unknown. In addition, given there are no estimates of NVWA abundance at Fort Belvoir, and surveying for them has proven difficult, we are relying on observed and assumed habitat conditions and/or parameters as a surrogate for the species' assumed condition in addition to the available, albeit limited, presence-absence data. This approach, based on the best available information, has inherent but unavoidable uncertainties *(see chapter 6—Key Uncertainties*). We considered using another amphipod species as a surrogate for our analysis, but we were advised by a subject matter expert that such an approach would be difficult to justify given the apparently unique habitat of the NVWA and the lack of an appropriate surrogate (Hobson 2018d).

As discussed above in chapter 3, conservation actions to address stressors include survey efforts, genetic research, an INRMP emphasizing protection of the surrounding landscape, and monitoring the physical condition of the single presumed-extant site.

4.2 Current Condition (3Rs)

4.2.1 Resiliency

For a species to maintain viability, its populations, or some portion of its populations, must be resilient. In the case of the NVWA, only the population on Fort Belvoir is known to exist. Stochastic events that have the potential to affect that NVWA population include spring and aquifer modification, changes in water quality (including pollution), and changes in spring discharge. We have no meaningful information regarding population demographics (only limited data on presence/absence), and an appropriate surrogate species has not been identified. However, specimens were collected several times over the period 1996 to 2013, indicating the population persisted for over a decade, and likely longer, of seasonal variations in subterranean water quality/quantity (including runoff from impervious surfaces within the recharge area), erosion-mediated habitat modification, and at least one petroleum distillate spill (see *section 3.1.1—Water Quality*).

Phreatic (permanently saturated) subterranean ecosystems like those in which the NVWA is thought to live (Denton and Scott 2013, p. 39) are assumed to provide food and shelter for all life stages as well as protection from desiccation, temperature extremes, and predation by surface-dwelling organisms. They may also protect organisms from perturbations that might affect surface habitats. Several factors associated with these habitat functions likely influence whether a population of the NVWA will grow to maximize habitat occupancy, which would increase the resiliency of a population to stochastic events. However, information regarding the general biology of the species (or even of the exact nature and spatial extent of its subterranean habitat), is incomplete due to infrequent collections. The last specimen was collected in 2013, and none appeared to be females or have brood plates. Our best assessment of the resiliency of the NVWA at Fort Belvoir is based on the limited information available about the geology in the vicinity of the NVWA spring, and the location and spatial extent of the recharge zone for the aquifer thought to supply water to that spring. If sufficient water of adequate quality passes through the recharge zone into the NVWA aquifer, we anticipate that the population will survive and grow to the carrying capacity of its habitat.

The most recent hydrogeologic study of the T-17 ravine suggested that the recharge zone for the aquifer supplying the NVWA spring is in a band across the Fort Belvoir peninsula to the north (Denton and Scott 2013). A previous study had suggested the recharge zone was likely in the vicinity of buildings to the east (Lee *et al*. 2003, p. 19). Aquifer recharge rates are generally driven by seasonal precipitation (including runoff from impervious surfaces), evapotranspiration in surface soils, and the permeability of sediments. A layer of low-permeability sediments (e.g., clay) may function as an aquitard, slowing the rate at which water in overlying layers infiltrates into a deeper aquifer, where the NVWA population is thought to reside. This may attenuate what might otherwise be a significant pulse of water (such as might occur following seasonal snowmelt or a major storm event) entering subterranean habitats. Low-permeability overlying sediments can also ‘strain’ out colloids, organic particles, and organisms from water as it passes through (Bradford *et al*. 2006 *in* Larned 2012, p. 891), which might prevent surface pollutants from reaching deeper sediment layers and aquifers. Sequential layers or irregular lenses of high- and low-permeability substrates are a common feature of the Potomac Formation and have been documented on Fort Belvoir in the vicinity of the NVWA spring.

Based on the existing suitable habitat parameters and absence of information to the contrary, we presume the NVWA retains its capacity for resiliency.

4.2.2 Redundancy

Most species need to have multiple resilient populations distributed across the landscape to provide for redundancy. The more populations, and the wider the distribution of those populations, the more redundancy a species will exhibit. Redundancy reduces the risk that a large component of a species’ range will be negatively affected by a catastrophic natural or anthropogenic event at a given point in time. A species that is well distributed across its historical range is less susceptible to extinction and more likely to be viable than is a species confined to a small portion of its historical range (Carroll *et al*. 2010, entire; Redford *et al*. 2011, entire). As previously stated, the NVWA population at Fort Belvoir is the only known occurrence. The two historical populations in Alexandria and Vienna, VA may still exist, but the locations of the wells from which specimens were collected are unknown, and the wells themselves are assumed to have been filled in as a result of development. Whether the condition of the species at each historical location is extirpated or unknown is a key uncertainty, but for the purposes of this SSA we presume it to be unknown (see *section 2.3 Historical and Current Range, Distribution, and Abundance*). Based on the best available information, we conclude that the NVWA currently lacks redundancy, although it is possible that other populations exist but have not yet been discovered or are inaccessible.

4.2.3 Representation

Representation refers to the breadth of genetic or environmental diversity within a species and reflects the ability of a species to adapt to changing environmental conditions. The greater the diversity, the more successful a species should be to respond to changing environmental conditions. We currently have no information regarding the genetic diversity of the NVWA. However, two different likely habitats have been identified. One is a deep aquifer isolated from surface sediments by a clay aquitard and characterized by water with relatively low dissolved organic content and relatively high conductivity. The other is the eroded channels, or macropores, observed within the overlying clay layer. It remains unclear whether both geologic features represent distinct habitats capable of supporting the entire life cycle of the NVWA, but these differences may illustrate the species' ability to occur in multiple representative areas. All NVWA specimens at Fort Belvoir have been collected from where the macropores exit the ravine wall. It is possible there may be a third habitat type (Orndorff 2019), aquifers residing in 'islands' of sediments between Vienna, VA and the more easterly Pimmit Hills that may be isolated remnants the Potomac Formation (Denton 2018d); *see section 2.3.1*. Without knowing the exact location of the historical sites, we are not factoring that into our representation assumptions, but we do recognize this area of uncertainty (*see chapter 6*). Currently, the NVWA is known to be represented in one habitat area (macropores), but we infer based on hydrology information that they may also be represented in a second habitat area (deep aquifer).

4.3 Summary of Current Condition (3Rs)

The population size of the NVWA is unknown. The species is currently known from only one of three locations; two are historical (redundancy). The NVWA was last collected in 2013 from one of two possible habitat types (representation). However, sufficient suitable surface conditions that support the NVWA's subsurface habitat (such as relatively low impervious surface area) remain, such that we infer that the species persists in its subsurface habitat and retains the ability to withstand stochastic events (resiliency).

CHAPTER 5 FUTURE SCENARIOS

5.1 Methodology

As discussed in *chapter 1*, for the purpose of this assessment, we define viability as the ability of the species to sustain itself in the wild over 25 years. This timeframe is based on the NVWA's approximately 25 years of persistence data, which we deem biologically reasonable to use as a surrogate to project forward a similar amount of time. We also have available data development and climate data to reasonably anticipate potential significant effects of stressors (up to 45 years) and ongoing conservation (approximately 18 years) on the species (*see chapters 2 and 3*). Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation.

We have considered the NVWA's life history characteristics and identified the individual-, population-, and species-level needs (*chapter 2*), reviewed the factors that may be driving the historical, current, and future conditions of the species (*chapter 3*), and its presumed current condition (*chapter 4*). Next we predict the NVWA's future conditions for a range of plausible future scenarios. We used the demographic and habitat information to predict, for each future scenario, how the species will respond to the primary factors likely to influence its condition in the future. These influencing factors include: water quality and quantity, extent of impervious cover in likely recharge zones, and implementation of conservation actions. Our analysis is limited to three future scenarios, which are representative examples from the potential range of plausible scenarios, and that describe how these stressors and conservation actions may drive changes from the current condition.

5.2 Future Scenarios

We considered three future scenarios to assess the viability of the NVWA at Fort Belvoir; the other two historical locations are considered unknown, thus we did not include them in the future scenarios. We believe these scenarios to be plausible based on the best information available, although a lack of data pertaining to the life history and habitat characteristics of the NVWA required making several assumptions. These assumptions are detailed in *chapter 6*. The projections are forecast 25 years into the future, which includes using the historical timeframes from the NVWA persistence, changes in impervious cover (i.e., development) data, and implementation of the INRMP as surrogates to project forward. It also encompasses the mid-range portion of the 2036 to 2045 climate model mid-Century forecast.

Table 6. Summary of Future Scenarios.

Influencing Factor	Scenario A	Scenario B	Scenario C
Climate Projection	RCP 8.5.	RCP 8.5.	RCP 4.5.
Climate Effects	Precipitation is expected to increase 5 to 10 percent by 2065.	Precipitation is expected to increase 5 to 10 percent by 2065.	Precipitation is expected to increase 5 to 10 percent by 2065.
Recharge Zone Impervious Cover	No change.	Increases slightly.	No change.
Water Quantity	Not limiting.	Slight reduction, but not limiting.	Not limiting.
Water Quality	Not limiting, but may be reduced if nuclear power plant decommissioning and deconstruction occurs.	Slight reduction, but not limiting.	Not limiting.
Conservation Actions	2018 INRMP remains in place, with current Installation mission. Frequency of NVWA monitoring remains as current. NEPA assessment of nuclear power plant decommissioning and deconstruction guides additional conservation action, if needed.	2018 INRMP requires revision to address changes in Installation mission. Potential effects from additional buildings/development within the recharge area or from power plant decommissioning activities.	2018 INRMP remains in place, with current Installation mission. Frequency of NVWA monitoring increases (e.g., increased field collection effort, application of non-destructive eDNA water testing, etc.) providing improved population status information.

5.2.1 Scenario A

The first future scenario we considered is a continuation of current trends in Installation mission, changing climate conditions, and level of conservation and monitoring effort by Fort Belvoir in the T-17 ravine.

Based on the collection of NVWAs on multiple occasions over the past 23 years, we conclude that a continuation of Fort Belvoir's mission (*see section 2.6*) is unlikely to further impact the NVWA, provided any facilities modifications and associated increases in impervious cover do not occur at a level that may affect the aquifer feeding the NVWA's spring or the aquifer's recharge zone(s). One potential source of risk is the decommissioning process for the SM-1 nuclear power plant (*see section 3.3.5*). Decommissioning and deconstruction of the SM-1 nuclear power plant could negatively impact the NVWA spring's aquifer(s) through construction activities, including the operation of heavy equipment adjacent to aquifer recharge areas, the installation of new monitoring wells to assess the impacts of the deconstruction process, the physical dismantling of buildings and foundations, and the removal of utilities (*e.g.* water and sewer lines), contaminated soil, and debris. Natural resources staff on the Installation have suggested that impacts on the NVWA spring from decommissioning and deconstruction activities are unlikely given its location (2,297 ft (700 m) south-west of the spring) and limits on the heavy equipment that may be used given the structural constraints of the base's roadways (Osborne 2019). Fort Belvoir is currently preparing a draft EA, a planning document required by the NEPA that will identify "potential ecological, cultural, water, public health and safety, and waste management effects associated with the decommissioning of the SM-1 facility at Fort Belvoir" (U.S. Army Corps of Engineers 2019, entire).

As discussed in *chapter 3*, current emissions and temperature are consistent with the 8.5 RCP trajectory. Under that projection, precipitation in VA is expected to increase 5 to 10 percent by 2065, and the frequency of intense precipitation events is expected to increase. In addition, as discussed above under *section 3.1.2*, groundwater withdrawal is managed by the EVGMA, and we are unaware of any plans to extract significant volumes of groundwater from the Fort Belvoir peninsula, where previous studies suggest recharge of the NVWA spring occurs. All else being equal, this suggests that water quantity will likely not be a limiting factor for the NVWA population at Fort Belvoir.

Continued implementation of existing habitat conservation and monitoring protocols as detailed in the 2018 INRMP will presumably support the species.

5.2.2 Scenario B

The second future scenario we considered assumes significant changes occur to the structure and function of Fort Belvoir, the condition of the spring habitat, and the degree to which the NVWA or its aquifer might be exposed to contaminants. We assume that water quantity in the form of precipitation would be no different from Scenario A because climate trajectories more extreme than 8.5 RCP have not been developed.

While we have no current indication that Fort Belvoir's mission will change, we conclude, based on broader strategic goals, objectives, and training and security needs, that the possibility exists for the structure and function of military bases to change. For example, the DoD has closed or restructured multiple facilities across the country under the Base Realignment and Closure (BRAC) process to "to reorganize its base structure to more efficiently and effectively support our forces, increase operational readiness and facilitate new ways of doing business" (Office of the Undersecretary for Defense for Acquisition, Technology, and Logistics 2019). This scenario assumes that the mission of Fort Belvoir shifts from logistics and support to field-based training or other activities (such as construction of additional training facilities) that might require significantly greater development, particularly construction of larger areas of impervious surface or encroachment on the T-17 Refuge. Development resulting in significantly larger areas of impervious surfaces in the recharge zone(s) of the aquifer(s) feeding the NVWA spring would likely reduce aquifer recharge rates, possibly lowering the water table and reducing the quantity of habitat available to the NVWA. However, as discussed above under *section 3.1.2*, groundwater withdrawal is managed by the EVGMA and we are unaware of any plans to extract significant volumes of groundwater from the Fort Belvoir peninsula, where previous studies suggest recharge of the NVWA spring occurs.

More impervious surface, if not compensated for by artificial drainage basins or other features to reduce or redirect runoff, might also increase discharge to the ravine in which the NVWA spring is located. That might accelerate erosion of the ravine wall and increase the frequency or severity of mass slumping, which has been previously documented (*see section 2.3*). Such events might cover up the spring site (as seen in past events), making it impossible to assess the presence/abundance of the NVWA, or cause potentially contaminated water to pool and inundate the spring opening. Construction elsewhere on the Installation might also negatively impact the T-17 ravine if support infrastructure such as water pipes or electrical conduit are installed across the ravine.

Additional threats to water quality in the T-17 ravine and to the NVWA spring and aquifer(s) may come from the continued use of the 21st Street Solid Waste Transfer Facility, located at the upslope end of the T-17 ravine. Increased precipitation expected under the 8.5 RCP (see Scenario A) may increase the likelihood or exacerbate the effects of any future contamination events. Water quality at a discharge point near this facility (Outfall 007) is monitored on a regular basis (*see section 3.1.1*).

5.2.3 Scenario C

The third scenario we considered assumes a reduction in global emissions resulting in a climate trajectory consistent with RCP 4.5, as well as developments that might improve our understanding of the viability of the species. As discussed in *section 3.2.1*, whereas proceeding along RCP 8.5 is more likely, RCP 4.5 is still plausible and is used in the Fourth National Climate Assessment. Under RCP 4.5, precipitation in VA is expected to increase 5 to 10 percent by 2065 (the same as under RCP 8.5). In addition, as discussed above under *section 3.1.2*, groundwater withdrawal is managed by the EVGMA, and we are unaware of any plans to extract significant volumes of groundwater from the Fort Belvoir peninsula, where previous studies suggest recharge of the NVWA spring occurs. We therefore expect that precipitation will not be limiting.

Increased frequency and intensity of monitoring efforts might result in the capture of additional live specimens for biological study. Documenting basic aspects of the NVWA's biology, such as longevity, reproductive strategy and capacity, diet, behavior, and tolerance to potential water pollutants, would fill many knowledge gaps and improve long-term management of necessary habitat(s). Installation of a larger monitoring well in the vicinity of the NVWA spring following the specifications recommended by Denton and Scott (2013, p. 43) might enable *in situ* capture of individuals in the deep aquifer that is thought to be their primary habitat. This could provide specimens for study and also permit development of a standard protocol for monitoring the abundance of the NVWA. Development of an eDNA sampling protocol could enable more cost-effective sampling efforts over a wider area to identify other groundwater sources that might contain populations of NVWA, providing valuable data regarding the redundancy of the species.

5.3 Future Condition

5.3.1 Scenario A

5.3.1.1 Resiliency

As previously stated, our best assessment of the resiliency of the NVWA at Fort Belvoir is based on the limited information available about the geology in the vicinity of the NVWA spring and the location and spatial extent of the recharge zone for the aquifer thought to supply water to that spring. If sufficient water of adequate quality passes through the recharge zone into the NVWA aquifer, we anticipate that the population will persist. Given the continuation of current trends, we project that suitable surface conditions that support the NVWA's subsurface habitat will likely remain, such that we infer that the species will persist in its subsurface habitat.

5.3.1.2 Redundancy

As previously stated, there is a single known NVWA population at Fort Belvoir. Given the continuation of current trends into the future, we project that the species will continue to lack redundancy into the future under Scenario A.

5.3.1.3 Representation

Given the continuation of current trends into the future, we project that the species will continue to be represented in one habitat area (macropores), but we assume based on hydrology information that it may also continue to have the potential to be represented in a second habitat area (deep aquifer), or both areas.

5.3.2 Scenario B

5.3.2.1 Resiliency

As stated previously, if sufficient water of adequate quality passes through the recharge zone into the NVWA aquifer, we anticipate that the population will persist. Under Scenario B, the quantity of water reaching the NVWA's aquifer is expected to decrease slightly due to a net increase in impervious surface on Fort Belvoir as a result of a hypothetical shift in base mission to activities requiring more developed area. Additional development might also increase the risk of contamination from vehicles, construction activity and routine operations. These changes would probably impact the surficial aquifer more than the deeper aquifer in which the bulk of the NVWA population is thought to reside, but local recharge rates and water quality of even the deeper aquifer might be reduced without mitigating measures. Ultimately, the regional spatial scale of the Middle Potomac aquifer would probably minimize the impact on the NVWA of any modest changes in impervious cover and associated activities on Fort Belvoir. We therefore project that suitable subsurface habitat will likely remain such that we infer that the species will persist in its subsurface habitat.

5.3.2.2 Redundancy

As previously stated, there is a single known NVWA population at Fort Belvoir. Given the continuation of current trends into the future, we project that the species will continue to lack redundancy into the future under Scenario B.

5.3.2.3 Representation

Given the continuation of current trends into the future, we project that the species will continue to be represented in one habitat area (macropores), but we assume based on hydrology information that it may also continue to have the potential to be represented in a second habitat area (deep aquifer), or both habitats.

5.3.3 Scenario C

5.3.3.1 Resiliency

As stated previously, if sufficient water of adequate quality passes through the recharge zone into the NVWA aquifer, we anticipate that the population will persist. Under Scenario C, the quantity and quality of water reaching the NVWA's subterranean habitat is not expected to differ from that described in Scenario A. We therefore project that suitable surface conditions that support the NVWA's subsurface habitat will likely remain, such that we infer that the species will persist in its subsurface habitat.

5.3.3.2 Redundancy

As previously stated, there is a single known NVWA population at Fort Belvoir. However, implementation of the conservation measures identified in Scenario C, particularly the development of effective eDNA sampling protocols and the resulting increased field collection effort, might result in improved understanding of the species' population status, including the delineation of a larger continuous range on Fort Belvoir, or identification of additional populations both on- and off-Installation. We project that there is a possibility, though unquantifiable, that the redundancy of the NVWA increases.

5.3.3.3 Representation

Given the continuation of current trends into the future, we project that the species will continue to be represented in one habitat area (macropores), but we assume based on hydrology information that it may also continue to have the potential to be represented in a second habitat area (deep aquifer), or both habitats.

5.3.4 Summary of Future Condition

Table 7. Summary of the 3Rs Across Current Condition and Future Scenarios.

	Current Condition	**Scenario A**	**Scenario B**	**Scenario C**
Resiliency	Persistence	Persistence	Persistence	Persistence
Redundancy	None	None	None	Potentially Increases
Representation	Some	Some	Some	Some

CHAPTER 6 KEY UNCERTAINTIES

- We assume that the species is currently represented in an underground aquifer as a robust, stable population. If we are wrong, our analysis overestimates viability.
- We assume that there is a single, isolated population at Fort Belvoir that is capable of reaching the surface from multiple nearby openings in the ravine wall. However, if the individuals observed are part of multiple, connected populations able to move through pores or channels within the sediments of a larger regional aquifer, we may have underestimated viability.
- We assume that individuals that exit the spring are unable to return to their subterranean habitat. If they are able to access the resources of the subterranean habitat, then we may have underestimated viability.
- We assume that the species has sufficient genetic diversity to adapt to relevant changes in its environment. If that assumption is incorrect, we may have overestimated viability.
- We assume that the two historical locations are unknown. However, if the individuals in those populations still exist but are inaccessible, we may have underestimated viability.
- We assume that the two historical locations were discrete, separate locations not connected to each other or the Fort Belvoir location. If they were or are connected, such as through pores or channels within the sediments of a larger regional aquifer, the species may be more abundant and we have underestimated its viability.
- We assume that the species' total historical range is represented by the site on Fort Belvoir and the two historical sites. As discussed in *section 2.3—Historical and Current Range, Distribution, and Abundance*, surveys at spring and seep habitats at 134 sites within a 5-mi (8-km) radius of the Fort Belvoir site did not locate any additional specimens. It remains possible that other populations exist outside that area or that populations within that area were missed. If other populations exist, we have underestimated viability.
- Denton and Scott's (2013) suggested delineation of the aquifer recharge zone is the best available information regarding the potential zone of influence on the T-17 area and the NVWA's seep sites. Our future analysis is based on projected changes to that area. If our assumption about the hydrology is incorrect, we may have underestimated the species' viability.

REFERENCES CITED

Angler Environmental. 2018. Analytical report for water collected at Outfall 007 on February 23, 2018. Report # 24604. 3 pp.

Angler Environmental. 2017. Analytical report for water collected at Outfall 007 on July 6, 2017. Report # 17646. 3 pp.

Buck, H. J. 2016. Rapid scale-up of negative emissions technologies: Social barriers and social implications. *Climate Change*, 139: 155-167.

Carroll, C., J. A. Vucetich, M. P. Nelson, D. J. Rohlf, and M. K. Phillips. 2010. Geography and recovery under the U.S. Endangered Species Act. *Conservation Biology*. 24(2): 395-403.

Cederstrom, D. J. 1945. Geology and ground-water resources of the Coastal Plain in southeastern Virginia. Virginia Geological Survey Bulletin. 63. 384 pages.

Chazal, A. C. and C. S. Hobson. 2003. Surveys for the Northern Virginia well amphipod (*Stygobromus phreaticus)* at Fort Belvoir, Virginia. Natural Heritage Technical Report 03-11. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, Virginia. Unpublished report submitted to USAG Fort Belvoir. 11pp plus appendix.

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Culver, D. C. and J. R. Holsinger. 1969. Preliminary observations on sex ratios in the subterranean amphipod genus *Stygonectes* (Gammaridae). *The American Midland Naturalist*. 82(2): 631-633.

Culver, D. C., J. R. Holsinger, M. C. Christman and T. Pipan. 2010. Morphological differences among eyeless amphipods in the genus *Stygobromus* dwelling in different subterranean habitats. *Journal of Crustacean Biology*. 30(1): 68-74.

Culver, D. C., J. R. Holsinger and D. J. Feller. 2012. The fauna of seepage springs and other shallow subterranean habitats in the mid-Atlantic Piedmont and Coastal Plain. *Northeastern Naturalist*. 19(9): 1-42.

Culver, D. C. and T. Pipan. 2009. The biology of caves and other subterranean habitats. Oxford, UK: Oxford University Press.

Culver, D. C. and T. Pipan. 2014. Shallow subterranean habitats: ecology, evolution and conservation. Oxford, UK: Oxford University Press.

Datry, T., F. Malard and J. Gilbert. 2005. Response of invertebrate assemblages to increased groundwater recharge rates in a phreatic aquifer. *Journal of the North American Benthological Society*. 24(3): 461-477.

Drake, A. A., Jr and A. J. Froelich. 1997. Geologic map of the Falls Church quadrangle, Fairfax and Arlington Counties and the City of Falls Church, Virginia and Montgomery County, Maryland: United States Geological Survey Quadrangle Map GQ-1734, scale 1:24,000.

Denton, R. K., Jr. and H. Scott. 2013. Geological survey of the Lower Cretaceous Potomac Formation of Fort Belvoir, VA and its relationship to the habitat of the northern Virginia well amphipod *Stygobromus phreaticus*. Report by Geoconcepts Engineering, Inc. to Fort Belvoir Directorate of Public Works.

Dick, J. T. A., S. E. Faloon and R. W. Elwood. 1998. Active brood care in an amphipod: influences of embryonic development, temperature and oxygen. *Animal Behaviour*. 56(3): 663-672.

Easterling, D. R., Kunkel, K. E., Arnold, J. R., Knutson, T., LeGrande, A. N., Leung, L. R, Wehner, M. F. (2017). Precipitation change in the United States. In D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, & T. K. Maycock (Eds.), Climate Science Special Report: Fourth National Climate Assessment, Volume I (pp. 207-230). Washington, D.C.: U.S. Global Change Research Program.

Eastern Virginia Groundwater Management Area (EVGMAC). 2017. Report to the Virginia Department of Environmental Quality and Virginia General Assembly. *https://www.deq.virginia.gov/Portals/0/DEQ/Water/GroundwaterPermitting/EVGMAC/GWAC_FinalReport_8.07.17.pdf*. Last accessed October 24, 2018.

European Academies Science Advisory Council. 2018. Negative emission technologies: What role in meeting Paris Agreement targets? European Academies Science Advisory Council. Halle (Saale), Germany: European Academies Science Advisory Council.

Friedel, B. D., J. Williams and D. W. Fong. 2014. Multiple mark and recapture population size estimates of *Stygobromus tenuis potomacus* in a hypotelminorheic habitat. Presentation at the 2014 National Speleological Society convention. Accessed online: *https://www.slideshare.net/BenFriedel/ben-friedel-2014-nss-presentation*.

Froelich, A.J., 1985. Folio of geologic and hydrologic maps for land-use planning in the Coastal Plain of Fairfax County, Virginia, and vicinity. U.S. Geological Survey Miscellaneous Investigations Series Map (IMAP) I-1423. Scale 1:100,000.

Gambhir, A., Drouet, L., McCollum, D., Napp, T., Bernie, D., Hawkes, A., Lowe, J. (2017). Assessing the feasibility of global long-term mitigation scenarios. *Energies*. 10: 89.

Gilbert, H., J. Keany and D. C. Culver. 2018. Response of shallow subterranean freshwater amphipods to habitat drying. *Subterranean Biology*. 28. 15-28.

Global Change. 2019. Scenarios for the National Climate Assessment: LOCA Viewer. Retrieved from: *https://scenarios.globalchange.gov/loca-viewer/*. Last accessed on July 25, 2019.

Harris, R. M., Grose, M. R., Lee, G., Bindoff, N. L., Porfirio, L. L., & Fox-Hughes, P. (2014). Climate projections for ecologists. *Wiley Interdisciplinary Reviews: Climate Change.* 5: 621-637.

Heath, R. C. 1983. Basic Groundwater hydrology. United States Geological Survey Water Supply Paper 2220, Alexandria, 85pp. *https://pubs.er.usgs.gov/djvu/WSP/wsp_2220.pdf*. Last accessed: June 27, 2019.

Hobson, C. 1997. A natural heritage zoological inventory of U.S. Army Fort Belvoir. Natural Heritage Technical Report 97-5. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, VA. Final Report. February 1997. 22pp. Plus appendices.

Hobson, C. 2018a. Email conversation between C. Hobson, field zoologist, Virginia Department of Conservation and Recreation, Natural Heritage Program and Sumalee Hoskin, biologist, U. S. Fish and Wildlife Service. June 5, 2018.

Hobson, C. 2018b. Telephone conversation record between K. Gifford, biologist, U.S. Fish and Wildlife Service and C. Hobson, field zoologist, Virginia Department of Conservation and Recreation, Natural Heritage Program. November 28, 2018.

Hobson, C. 2018c. Email conversation between C. Hobson, field zoologist, Virginia Department of Conservation and Recreation, Natural Heritage Program, Krishna Gifford, biologist, U. S. Fish and Wildlife Service, and Jacob Osbourne, biologist, U.S. Fish and Wildlife Service. October 19, 2018.

Hobson, C. 2019. Email communication between C. Hobson, field zoologist, Virginia Department of Conservation and Recreation, Natural Heritage Program and Northern Virginia Well Amphipod SSA Team, U.S. Fish and Wildlife Service. April 5, 2019.

Hobson, C. S. and W. D. Orndorff. 2013. Surveys for lepidoptera, odonata, freshwater mussels, bats and amphipods during 2011-2013 at U.S. Army Garrison Fort Belvoir, Virginia. *Natural Heritage Technical Report 13-11*. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, VA. Final Report. April 2013. 34pp. Plus appendices.

Holsinger, J. R. 1978. Systematics of the subterranean amphipod genus Stygobromus (Crangonyctidae), Part II: Species of the Eastern United States. *Smithsonian Contributions to Zoology*. 266: 1-144.

Hoskin, S. 2018. Email communication between S. Hoskin, U.S. Fish and Wildlife Service, and J. Pilcicki, U.S. Army Garrison Fort Belvoir. October 29, 2018.

Hutchins B. and D. C. Culver. 2008. Investigating rare and endemic pollution-sensitive subterranean fauna of vulnerable habitats in the NCR. Report to National Capital Region, National Park Service, Washington, DC.

Jackson, R. B., Le Quéré, C., Andrew, R. M., Canadell, J. G., Peters, G. P., Roy, J., and Wu, L. 2017. Warning signs for stabilizing global CO2 emissions. *Environmental Research Letters.*12:110202.

Janssen, E., R. L. Sriver, D. J. Wuebbles, and K. E. Kunkel. 2016. Seasonal and regional variations in extreme precipitation event frequency using CMIP5. Geophys. Res. Lett., 43, 5385–5393, doi:10.1002/2016GL069151.
Wue
Jass, J. and B. Klausmeier. 2011. Presence of the well-dwelling amphipod *Stygobromus putealis* (Crustacea: Crangonyctidae) re-documented in Wisconsin. *Journal of Freshwater Ecology*. 26(4): 599-603.

Johnson, S., G. Schindel and G. Veni. 2010. Tracing groundwater flowpaths in the Edwards Aquifer recharge zone, Panther Springs Creek Basin, northern Bexar County, Texas. Report. 112 pp.

Johnston, R. H. and Larson, J.D. 1977. Potentiometric surface maps and water-level change map, 1960-76, for the lower aquifer of the Cretaceous Potomac Group in Fairfax County, Virginia: U.S. Geological Survey Open-File Report 77-284, 3 pls., scale 1:48000.

Keany, J., M. C. Christman, M. Milton, K. L. Knee, H. Gilbert and D. C. Culver. 2019. Distribution and structure of shallow subterranean aquatic arthropod communities in the parklands of Washington, D. C. *Ecohydrology*. 12(1):e2044.

Knapp, S. M. and D. W. Fong. 1999. Estimates of population size of *Stygobromus emarginatus* (Amphioda: Crangonyctidae) in a headwater stream in Organ Cave, West Virginia. *Journal of Cave and Karst Studies*. 61(6): 3-6.

Kotamarthi, R., Mearns, L., Hayhoe, K., Castro, C. L., and Wuebble, D. 2016. Use of climate information for decision-making and impacts research: State of our understanding. Prepared for the Department of Defense, Strategic Environmental Research and Development Program. Retrieved from *http://www.dtic.mil/dtic/tr/fulltext/u2/1029525.pdf.* Last accessed December 12, 2018.

Larned, S. T. 2012. Phreatic groundwater ecosystems: research frontiers for freshwater ecology. *Freshwater Biology*. 57: 885-906.

Lee, W. L., B. R. Chapman, and G. B. Grose. 2003. Hydrogeologic Report, T-17 Area, U. S. Army Garrison Fort Belvoir, Virginia. Report prepared by Mactec Engineering and Consulting of Georgia, Inc. for Department of the Army, Directorate of Public Works and Logistics, Environmental and Natural Resources Division, For Belvoir, VA.

Mauger, G. S., Casola, J. H., Morgan, H. A., Strauch, R. L., Jones, B., Curry, B., Snover, A. K. 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Seattle: Climate Impacts Group, University of Washington.

Mauritsen, T. and R. Pincus. 2017. Committed warming inferred from observations. *Nature Climate Change*. 7: 652-655.

McLaren, D., Parkhill, K. A., Corner, A., Vaughan, N. E., & Pidgeon, N. F. 2016. Public conceptions of justice in climate engineering: Evidence from secondary analysis of public deliberation. Global Environmental Change. 41: 64-73.

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

Meng, A.A., III, and Harsh, J.F., 1988, Hydrogeologic framework of the Virginia Coastal Plain: U.S. Geological Survey Professional Paper 1404-C, 82 p.

Nakicenovic, N. and Swart, R. 2000. Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge, England, United Kingdom: Cambridge University Press. Retrieved from *https://www.ipcc.ch/site/assets/uploads/2018/03/emissions_scenarios-1.pdf*. Last accessed April 29, 2019.

National Oceanographic and Atmospheric Administration (NOAA). 2018. Monthly precipitation in Washington, DC since 1871. *https://www.weather.gov/media/lwx/climate/dcaprecip.pdf*. Last accessed December 12, 2018.

Niemiller, M. L., M. L. Porter, J. Keany, H. Gilbert, D. W. Fong, D. C. Culver, C. S. Hobson, D. Kendall, M. A. Davis and S. J. Taylor. 2017. Evaluation of eDNA for groundwater invertebrate detection and monitoring: a case study with endangered *Stygobromus* (Amphipoda: Crangonyctidae). *Conservation Genetics Resources*. 10(2): 247-257.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. 2019. Base Realignment and Closure (BRAC). *https://www.acq.osd.mil/brac/*. Last accessed April 5, 2019.

Pitt, R., 1996. Groundwater Contamination From Stormwater Infiltration. Ann Arbor Press, Chelsea, MI, USA.

Pitt, R., S. Clark, and R. Field. 1999. Groundwater contamination potential from stormwater infiltration practices. Urban Water 1:217–236.

Raftery, A. E., Zimmer, A., Frierson, D. M., Startz, R., & Liu, P. 2017. Less than 2 °C warming by 2100 unlikely. Nature Climate Change. 7: 637-641.

Redford, K. H., G. Amato, J. Baillie, P. Beldomenico, E. L. Bennett, N. Clum, R. Cook, G. Fonseca, S. Hedges, F. Launay, S. Lieberman, G. M. Mace, A. Murayama, A. Putnam, J. G. Robinson, H. Rosenbaum, E. W. Sanderson, S. N. Stuart, P. Thomas and J. Thorbjarnarson. 2011. What does it mean to successfully conserve a (vertebrate) species? *BioScience*. 61(1): 39-48.

Runkle, J., K. Kunkel, L. Stevens, S. Champion, B. Stewart, R. Frankson, and W. Sweet, 2017: Virginia State Climate Summary. NOAA Technical Report NESDIS 149-VA, 4 pp.

Smith, P., Davis, S. J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., van Vuuren, D. P. 2016. Biophysical and economic limits to negative CO2 emissions. Nature Climate Change. 6: 64-50.

Smith, D. R., N. L. Allan, C. P. McGowan, J. A. Szymanski, S. R. Oetker and H. M. Bell. 2018. Development of a species status assessment process for decisions under the U.S. Endangered Species Act. *Journal of Fish and Wildlife Management*. 9(1): 302-320.

Stumpp, C. and G. C. Hose. 2013. The impact of water table drawdown and drying on subterranean aquatic fauna in *in-vitro* experiments. PLoS ONE. 8. e78502.

Taylor, S. J. and J. R. Holsinger. 2011. A new species of the subterranean amphipod crustacean genus *Stygobromus* (Crangonyctidae) from a cave in Nevada, USA. *Subterranean Biology*. 8: 39-47.

U.S. Army. 2014. Environmental Assessment Fort Belvoir Elementary School Expansion. 215 pages.

U.S. Army. 2018. Integrated Natural Resources Management Plan. U.S. Army Garrison Fort Belvoir, Virginia.

U.S. Army. 2007. Record of Decision for the Implementation of 2005 Base Realignment and Closure (BRAC) Recommendations and Related Army Actions at Fort Belvoir, Virginia. 52 Pages.

U. S. Army. 2001. Integrated Natural Resources Management Plan 2001-2005. US Army Garrison Fort Belvoir, Virginia

U.S. Army Corps of Engineers. 2019. Presentation: SM-1 deactivated nuclear power plant decommissioning project, Fort Belvoir, VA. *https://www.nab.usace.army.mil/Portals/63/docs/Environmental/HealthPhysics/SM-1/SM-1_Townhall_On_Post_28Jan2019.pdf*. Last accessed April 4, 2019.

U.S. Environmental Protection Agency. 2007. Aquatic Life Ambient Freshwater Quality Criteria – Copper 2007 Revision. Office of Water, Office of Science and Technology, Washington, DC. *http://www.epa.gov/waterscience/criteria/aqlife.html*. Last accessed May 29, 2019.

U.S. Fish and Wildlife Service (Service). 2017. Withdrawal of the proposed rule to list Kenk's amphipod. 82 FR 45551–45574. September 29, 2017.

U.S. Global Change Research Program. 2015. U.S. Global Change Research Program General Decisions Regarding Climate-Related Scenarios for Framing the Fourth National Climate Assessment. Retrieved from: *https://scenarios.globalchange.gov/sites/default/files/External%20memo%20NCA4%20scenarios%20framing_20150506.pdf*. Last accessed April 29, 2019.

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S.K. 2011. The representative concentration pathways: An overview. *Climate Change.* 109(1-2): 5-31.

Virginia Department of Environmental Quality (VADEQ). 2012. Notice of Violation: Unauthorized discharge to unnamed tributary of Accotink Creek at 21st Street Debris Collection Site, U.S. Army Garrison Fort Belvoir, Fairfax County.

Virginia Department of Environmental Quality (VADEQ). 2018. *https://www.deq.virginia.gov/Programs/Water/WaterSupplyWaterQuantity/WaterWithdrawalPermittingandCompliance.aspx*. Last Accessed October 24, 2018.

Virginia Department of Environmental Quality. 2019. Surface Water Standards with General, Statewide Application. Virginia Administrative Code. Title 9 Environment. 9VAC25-260-5.

Virginia Department of Mines, Minerals and Energy (VDMME). 2018. *https://www.dmme.virginia.gov/webmaps/DGMR/*. Accessed October 24, 2018.

Vose, R. S., Easterling, D. R., Kunkel, K. E., LeGrande, A. N., & Wehner, M. F. 2017. Temperature changes in the United States. In D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, & T. K. Maycock (Eds.), Climate Science Special Report: Fourth National Climate Assessment, Volume I (pp. 185-206). Washington, D.C., USA: U.S. Global Change Research Program.

Wehner, M.F., J.R. Arnold, T. Knutson, K.E. Kunkel, and A.N. LeGrande, 2017: Droughts, floods, and wildfires. *In*: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 231-256.

Williamson, P. 2016. Scrutinize CO2 removal methods: The viability and environmental risks of removing carbon dioxide from the air must be assessed if we are to achieve the Paris goals. Nature, 530: 153-155.

APPENDIX A METHODOLOGY

Spatial analyses of land cover type and percent area of impervious cover (such as parking lots, buildings and other developments that inhibit infiltration of precipitation into topsoils) were conducted to determine what changes in these landscape characteristics, if any, have occurred since implementation of the 2001 INRMP. Analyses were conducted for both the T-17 Refuge area and the surrounding landscape of the Installation. Data for 2001 through 2011 (the most recent data available at the time of the analysis) were retrieved from the National Land Cover Database (https://catalog.data.gov/dataset/national-land-cover-database-nlcd-land-cover-collection). Impervious cover categories were based on a similar analysis conducted for Kenk's amphipod (*Stygobromus kenki*).

Figure A. Scope of spatial analyses of ground cover and impervious cover on Fort Belvoir. The green outline indicates the boundaries of the T-17 Refuge. The blue outline includes all land to the southeast of 12th Street, which includes the estimated location for the on-Installation recharge area of the deep aquifer. Changes in land cover of the area encompassed by the blue line illustrate broader development trends on the Fort Belvoir peninsula.

Table A. Land cover in the T-17 Refuge and Fort Belvoir peninsula south of 12th Street.

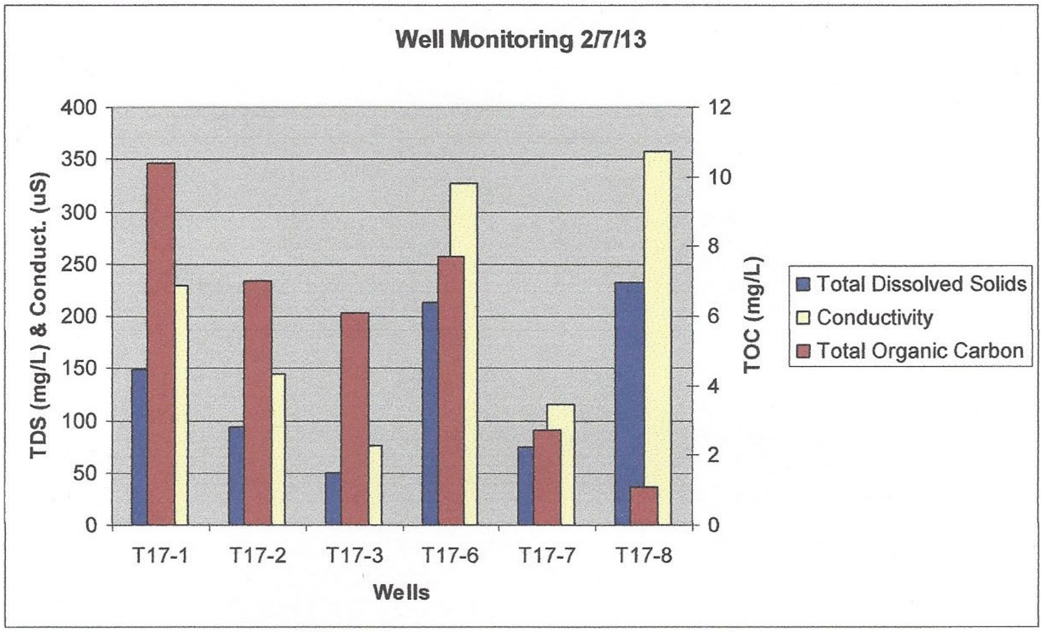
	T-17 Refuge			Ft. Belvoir Peninsula South of 12th Street		
	2001	2011	Change	2001	2011	Change
Open Water	0.10%	0.10%	0.00%	0.63%	0.63%	0.00%
Developed	50.00%	48.00%	-2.00%	56.00%	57.00%	1.00%
Forested	44.00%	45.00%	1.00%	37.00%	36.00%	-1.00%
Cultivated	3.00%	4.00%	1.00%	2.00%	2.00%	0.00%
Woody Wetlands	2.00%	2.00%	0.00%	3.00%	3.00%	0.00%
Herbaceous Wetlands	0.90%	0.80%	-0.10%	0.94%	0.94%	0.00%

Table B. Impervious cover in the T-17 Refuge and Fort Belvoir peninsula south of 12th Street.

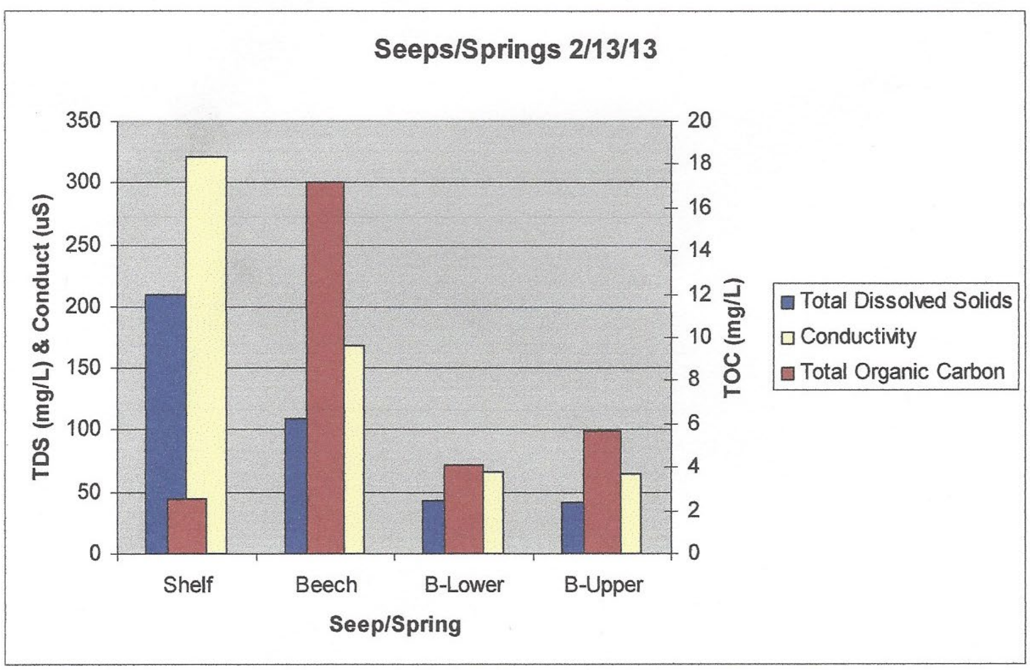
	T-17 Refuge			Ft. Belvoir Peninsula South of 12th Street		
	2001	2011	Change	2001	2011	Change
0% Impervious	52%	52%	0%	44%	43%	-1%
1-15% Impervious	25%	24%	-1%	20%	19%	-1%
>15% Impervious	24%	25%	1%	37%	38%	1%

APPENDIX B SUPPLEMENTARY WATER QUALITY DATA

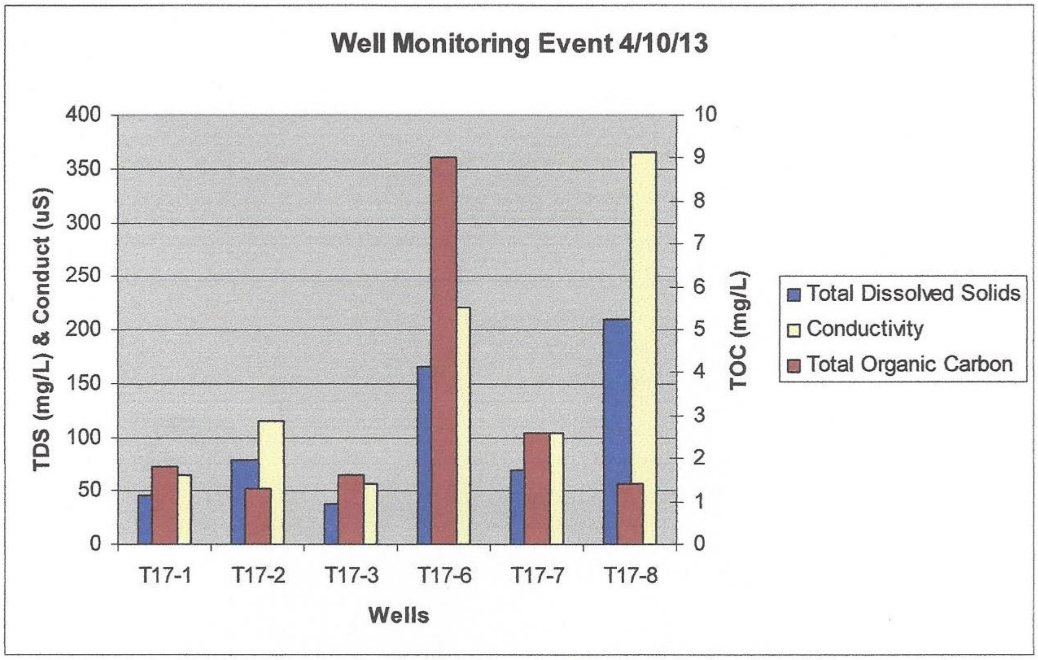
Graphs of selected water quality parameters for samples collected from monitoring wells and seeps/springs located throughout the T-17 area. Vertical axis scales differ between graphs. Source: Denton and Scott 2013, graphs 1-4 on pages 37-38.



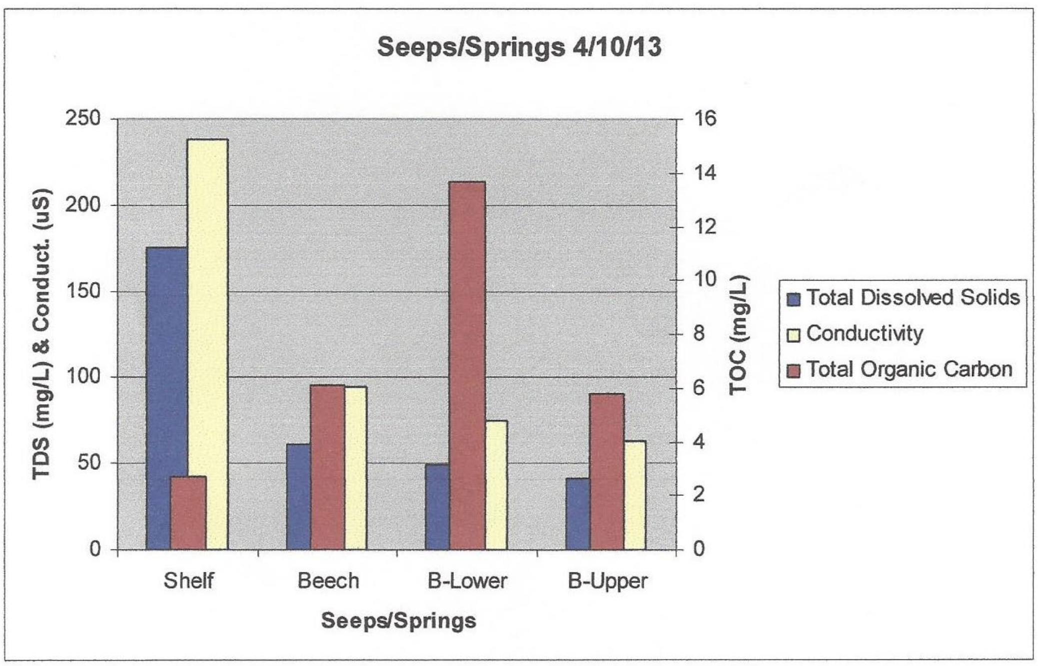
Graph 1. TDS, Conductivity and TOC date for the 2/7/13 well monitoring event.



Graph 2. TDS, Conductivity and TOC date for the 2/13/13 seep/spring monitoring event.



Graph 3. TDS, Conductivity and TOC date for the 4/10/13 well monitoring event.



Graph 4. TDS, Conductivity and TOC date for the 4/10/13 spring/seep monitoring event.