Species Status Assessment Report
for the
Page Springsnail
Version 1.0

Bass House Spring. Photo by Mike Martinez, USFWS.

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Species Status Assessment Report For
Page Springsnail (*Pyrgulopsis morrisoni*)

Prepared by the Arizona Ecological Services Field Office
U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

This species status assessment reports the results of the comprehensive biological status review by the U.S. Fish and Wildlife Service (Service) for the Page springsnail (*Pyrgulopsis morrisoni*) and provides a thorough account of the species' overall viability and, therefore, extinction risk. The Page springsnail is a small aquatic snail endemic to a complex of springs along Oak Creek and Spring Creek in Yavapai County, central Arizona.

To evaluate the biological status of the Page springsnail both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). The Page springsnail needs multiple resilient populations widely distributed across its range to maintain its persistence into the future and to avoid extinction. A number of factors influence whether Page springsnail populations will grow to maximize habitat occupancy, which increases the resiliency of a population to stochastic events. These factors include (1) adequate spring discharge (water quantity), (2) sufficient water quality, (3) free-flowing spring ecosystems, and (4) sufficient substrate and aquatic vegetation quantity within the springs. If spring ecosystems provide reliable flow, coupled with appropriate water depth, substrates, and suitable water quality, we anticipate springsnails will survive and thrive in abundance (Table ES-1). As we consider the future viability of the species, more populations with high resiliency distributed across the known range of the species are associated with higher overall species viability.

The Page springsnail currently occurs in ten springs in Yavapai County, Arizona; two populations are believed to be extirpated. Maintaining those populations provides redundancy, and the species is currently represented across most of the known geographic extent of the species. We have assessed the Page springsnail's levels of resiliency, redundancy, and representation currently and into the future by ranking the condition of each population (Table ES-1). Rankings are a qualitative assessment of the relative condition of spring ecosystems based on the knowledge and expertise of Service staff, Arizona Game and Fish Department, and other technical experts and resource professionals.

The most significant stressor to Page springsnail is the future loss of spring ecosystems that individuals and populations need to complete their life history. The primary cause of historical habitat loss within the range of the Page springsnail is related to anthropogenic modification of spring ecosystems and/or water quality. Any action that generally removes suitable habitat can contribute to the potential decline or extirpation of local populations. The Arizona Game and Fish Department (AGFD) has implemented conservation measures under a Candidate Conservation Agreement with Assurances (CCAA), which have resulted in the majority of Page springsnail populations being secure from spring modification, aquatic vegetation removal, and water contamination. The primary source of potential future habitat loss is groundwater

depletion resulting in reduced or eliminated spring flow. Groundwater withdrawal will continue to affect base flow in the Verde Valley, although there is a high level of uncertainty regarding the extent to which spring flows will be affected. Nonnative snails could also invade the springs and affect Page springsnail populations, although it is difficult to reliably predict if or when this may occur.

The viability of the Page springsnail depends on maintaining multiple resilient populations over time. Given our uncertainty regarding if or when springs occupied by Page springsnail will experience a reduction or elimination of spring flow in the future, we have forecasted what the Page springsnail may have in terms of resiliency, redundancy, and representation under three future plausible scenarios:

(1) All or most springs occupied by Page springsnail experience **no measureable drop** in spring flow;
(2) Spring flow in springs occupied by Page springsnail is **reduced but not eliminated**; and
(3) All or most springs occupied by Page springsnail experience an **extreme reduction or elimination** of spring flow.

We used the best available information to forecast the likely future condition of the Page springsnail. Our goal was to describe the viability of the species in a manner that will address the needs of the species in terms of resiliency, redundancy, and representation. We considered a range of potential scenarios that may be important influences on the status of the species, and our results describe this range of possible conditions in terms how many and where Page springsnail populations are likely to persist into the future (Table ES-1).

Table ES-1. Cndition of Page springsnail populations, now and in 50 years under spring flow scenario 2.

Spring/Population	Current Condition	Future Condition
Drain Pipe	Moderate	Low
Cave	High	High
Ash Tree	Moderate	Low
Rusty Pipe	Low	Low
Bog	Moderate	Low
Bubbling Outflow	High	High
Bass House Pond	High	Moderate
Bass House Weir	High	Moderate
Spring Creek	High	Moderate
Lo Lo Mai Outflow	High	Moderate

Management actions undertaken via the CCAA with AGFD have ameliorated the bulk of the risks to Page springsnail populations, although they do not remove the potential effects of groundwater depletion. These management actions play a large role in the future viability of the Page springsnail. If populations lose resiliency due to decline of spring flow, their persistence will likely depend on habitat enhancements and potential future reintroductions conducted by

AGFD. Spring flow is the largest factor affecting future persistence of the Page springsnail; while management cannot affect the rate of spring flow, it can affect how resilient populations are to spring flow fluctuations.

Table ES-2. Overall species status assessment summary for the Page springsnail.

3Rs	Needs	Current Condition	Future Condition (Viability)
Resiliency: Population (Large populations able to withstand stochastic events)	• Adequate spring discharge • Sufficient water quality • Free-flowing spring ecosystems • Appropriate substrate and aquatic vegetation	• 10 populations across range of 12 total known populations • 6 assessed to have high resiliency • 3 assessed to have moderate resiliency • 1 assessed to have low resiliency	Projections based on spring flow scenarios: • **No change**: All populations are likely to remain extant into the future • **Spring flow is reduced**: Most populations are expected to experience some level of decline in resiliency • **Spring flow is extremely reduced or eliminated**: All populations experience a large decline in resiliency, with some extirpated.
Redundancy (Number and distribution of populations to withstand catastrophic events)	Multiple populations throughout the range of the species	• 2 populations have been extirpated • The remaining 10 are isolated from one another	Projections based on spring flow scenarios: • **No change**: All populations are likely to remain extant into the future • **Spring flow is reduced**: 4 populations would be vulnerable to extirpation because of low resiliency; the remaining 6 would have moderate or high resiliency • **Spring flow is extremely reduced or eliminated**: Most populations would be vulnerable to extirpation
Representation (genetic and ecological diversity to maintain adaptive potential)	• Genetic variation exists between populations • No known ecological variation	• 2 populations have been extirpated • Remaining 10 exhibit some level of genetic variation	Projections based on spring flow scenarios: • **No change**: All populations are likely to remain extant into the future, maintaining current genetic variation • **Spring flow is reduced**: 4 populations would be vulnerable to extirpation, reducing genetic representation somewhat • **Spring flow is extremely reduced or eliminated**: Most populations would be vulnerable to extirpation, severely limiting genetic variation

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CHAPTER 1. INTRODUCTION

The Page springsnail is a small hydrobiid snail that is currently found in a complex of springs along Oak Creek and Spring Creek in Yavapai County, central Arizona. Members of the family Hydrobiidae are strictly aquatic and often occur in abundance within suitable spring habitats. The Page springsnail has been a candidate for listing under the Endangered Species Act of 1973, as amended (Act), since 1989 (54 FR 554). The Species Status Assessment (SSA) framework is intended to be an in-depth review of the species' biology and threats, 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 from Candidate Assessment to Listing to Consultations to Recovery. 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 Page springsnail is intended to provide the biological support for the decision on whether to propose to list the species as threatened or endangered and, if so, whether to and where to propose designating critical habitat. Importantly, the SSA Report does not result in a decision by the Service on whether this taxon should be proposed for listing as a threatened or endangered species under the Act. Instead, this SSA Report provides a review of the available information strictly related to the biological status of the Page springsnail. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the *Federal Register*, with appropriate opportunities for public input.

For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in natural spring ecosystems beyond a biologically meaningful timeframe, in this case, 50 years. We chose 50 years because it is within the range of the available hydrological and climate change model forecast (see Garner et al. 2013, IPCC 2014, and Jaeger et al. 2014). Additionally, because of the short generation time of the Page springsnail, 50 years encompasses approximately 30-40 generations, which is a relatively long time in which to observe effects to the species. Using the SSA framework (Figure 1.1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf et al. 2015, entire).

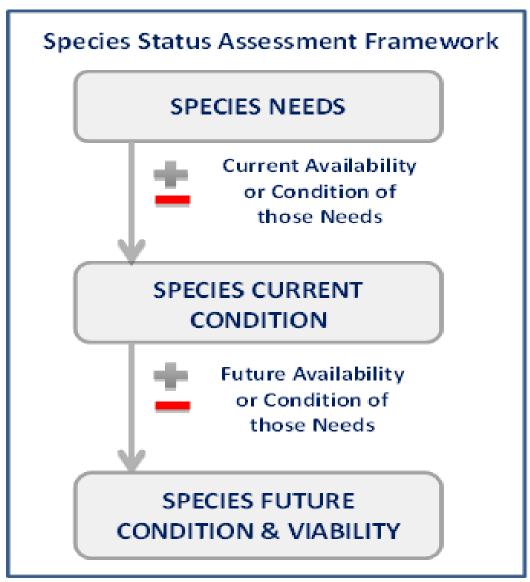

Figure 1.1 Species Status Assessment Framework

- **Resiliency** is having sufficiently large populations for the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

- **Redundancy** is having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk and can be measured through the duplication and distribution of populations across the range of the species. The greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

- **Representation** is having the breadth of genetic makeup of the species to adapt to changing environmental conditions. 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 and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range.

To evaluate the biological status of the Page springsnail both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). This SSA Report provides a thorough assessment of biology and natural history and assesses demographic risks, threats, and limiting factors in the context of determining the viability and risks of extinction for the species.

The format for this SSA Report includes: (1) the resource needs of individuals and populations (Chapter 2); (2) the Page springsnail's historical distribution and a framework for what the species needs in terms of the distribution of resilient populations across its range for species viability (Chapter 3); (3) reviewing the likely causes of the current and future status of the species and determining which of these risk factors affect the species' viability and to what degree (Chapter 4); and (4) concluding with a description of the viability in terms of resiliency, redundancy, and representation (Chapter 5). This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to the Page springsnail.

CHAPTER 2 – INDIVIDUAL NEEDS
BIOLOGY AND BIOGEOGRAPHY

In this chapter, we provide basic biological information about the Page springsnail, including its physical environment, taxonomic history and relationships, morphological description, and reproductive and other life history traits. We then outline the resource needs of individuals and populations. Here we report those aspects of the life history of the Page springsnail that are important to our analysis. For further information about the Page springsnail refer to Hershler and Landye (1988) and Hershler (1994).

2.1. Biology and Life History

2.1.1. Taxonomy and Genetics

The Page springsnail was originally identified by Landye (1973, pp. 29, 35) as two separate *Fontelicella* species from springs at Page Springs and Tavasci spring, Yavapai County, Arizona. Landye (1981, p. 6, 33) and Williams et al. (1985, p. 19) later recognized two species of undescribed *Fontelicella* from Tavasci springs, Lo Lo Mai springs, Bubbling Pond, and Page springs. The species was fully described by Hershler and Landye (1988, pp. 21, 23) as *Pyrgulopsis morrisoni* from specimens collected from Tavasci Springs and Page Springs. The morphological validity of this description was confirmed by Hershler (1994, pp. 52-53). Using phylogenetic analyses, Hurt (2004, pp. 1176) confirmed the taxonomy of the species based on examination of specimens from Page Springs and Bubbling Spring. The taxonomy of the species has not been disputed, and the best available information indicates *P. morrisoni* is a valid taxon. The currently accepted classification is:

Class: Gastropoda
Order: Neotaenioglossa
Superfamily Rissooidea
Family: Hydrobiidae
Species: *Pyrgulopsis morrisoni*

The Page springsnail is one of approximately 170 known species in the United States that are members of the family Hydrobiidae. This family is one of the largest of small aquatic snails and exhibits high diversity and broad distribution within the group (Kabat and Hershler 1993, p. 1). Within this family, the genus *Pyrgulopsis* exhibits high phylogenetic diversity across the landscapes within which they occur (Liu and Hershler 2005, pp. 292-293). Springsnails can exhibit high levels of genetic divergence between geographically close conspecific populations, as well as substantial genetic variation within some populations (Hurt and Hedrick 2004, pp. 411-412; Hurt 2004, pp. 1182-1186). Importantly, in some cases there is evidence of extremely low genetic diversity within populations, consistent with genetic drift and severe bottlenecking related to small population isolation over geologic time (Johnson 2005, pp. 2307-2308).

There is limited genetic information available for Page springsnail. Based on genetic analysis by Hurt and Hedrick (2003, p. 12-13) and Hurt (2004, p. 1179), the species displays four different mitochondrial haplotypes at Bubbling Springs and one at Page Springs, suggesting the existence of some genetic distance between populations at these two sites. These results also indicate greater genetic diversity within the Bubbling Springs population versus Page Springs where there is a dearth of diversity. However, within-site genetic diversity at Bubbling Springs is still not particularly large. Whether these observations are a product of genetic drift or some other event causing a bottleneck is difficult to determine. Additionally, although there exists some small genetic distance between Page Springs and Bubbling Springs, Hurt and Hedrick (2007, pp. 23-26) found that isolation of the two populations is too recent to observe significant divergence, suggesting gene flow has occurred in the recent past. Additionally, catastrophic disturbance resulting in population crash and rebound has led to enhanced levels of within population genetic diversity of springsnails (Wilmer et al. 2011, pp. 9-12).

2.1.2. Morphological Description

Hershler and Landye (1988, pp. 21, 23) describe the Page springsnail as a medium sized snail with a shell height of 0.07 to 0.11 inches (in) (1.8 to 2.9 millimeters (mm)) (Figure 2.1). The shell is ovate or ovate-conic in shape characterized by slightly convex whorls. The inner lip of the shell is thin and usually adnate (two unlike parts are closely attached) to the body whorl. The aperture is less than half of the body whorl height and the umbilicus is open. For a more detailed description and thorough review of the morphological characteristics of Arizona hydrobiid snails, see Hershler and Ponder (1998) and Hershler (1994).

Figure 2.1 Photos of Page springsnail: next to nickel (courtesy of Dan Cox); close-up (courtesy of Stuart Wells)

2.1.3. Reproduction

The sexes are separate in Hydrobiids, and females are noticeably larger than males. Although empirical data and definitive observations of Page springsnail reproduction were limited, early researchers provided some informative insight into the reproductive biology of the species.

Preliminary data collected by the Arizona Game and Fish Department (AGFD) suggested seasonal fluctuation in population of Page springsnail (Sorensen et al. 2002, p. 6-8), with an uptick in late spring to early summer. The Phoenix Zoo noted evidence of reproduction, marked by the first record of a newly hatched snail (≤ 0.04 mm in length), beginning in mid-to-late July and continuing until the end of November in both 2010 and 2011 (Pearson et al. 2014, p. 65; Wells et al. 2013, p. 72; Pearson 2011, p. 3). The peak reproductive period, based on observed number of newly emerged snails, appears to be from mid-August through September, with a gradual reduction of new juveniles beginning in mid-October and continuing through the end of November (Pearson et al. 2014, p. 65). Based on laboratory observations, Pearson et al. (2014, p. 66) suggests that a female Page springsnail deposits one egg approximately every 8-10 days.

Environmental cues often influence the reproductive seasonality of organisms, and may play a role for Page springsnail. We suspect that factors such as photoperiod, water temperature, water quality, or food availability may serve as cues initiating reproduction.

2.1.4. Survival, Growth, and Longevity

The average lifespan of Page springsnail is unknown, though Pearson et al. (2014, p. 64) estimates their lifespan to be one year. This seems like a reasonable estimate given that the lifespan of most aquatic gastropods is usually 9 to 15 months (Pennak 1989, p. 552), and the survival of one species in the genus *Pyrgulopsis* in the laboratory was nearly 13 months (Lysne et al. 2007, p. 3).

Among many prosobranchs (snails with gills), the larval stage is completed in an egg capsule and upon hatching tiny snails crawl out into their adult habitat (Brusca and Brusca 1990, p. 759; Hershler and Sada 2002, p. 256). The Page springsnail is similar, except the species lays single eggs rather than a capsule. Pearson et al. (2014, p. 66-67) reported observed development rate of Page springsnail in a laboratory setting, noting that growth was rapid during the first two weeks but reduced as snails approached adult size (Figure 2.5). The average adult had a shell height of 2.8 mm (0.1 in.), with the largest adult observed having a shell height of 3.9 mm and width of 1.7 mm.

Mobility is limited, and significant migration likely does not occur, although aquatic snails have been known to disperse by becoming attached to the feathers of migratory birds (Roscoe 1955, p. 66; Dundee et al. 1967, pp. 89–90).

2.2. Habitat

In the arid Southwest, springsnails are typically distributed across the landscape as geographically isolated populations exhibiting a high degree of endemism (found only in a particular area or region) (Bequart and Miller 1973, p. 214; Taylor 1987, pp. 5–6; Shepard 1993, p. 354; Hershler and Sada 2002, p. 255). Hydrobiid snails occur in springs, seeps, spring runs, cienegas, and a variety of diverse aquatic systems, but particularly spring ecosystems that produce running water.

Springsnails are strictly aquatic, and respiration occurs through internal gills. They are restricted to perennial waters for their entire life cycle. As such, survival of individual snails is critically tied to the presence and persistence of spring water. The Page springsnail occurs in springs, seeps, marshes, cienegas, spring brooks, spring pools, outflows, and diverse lotic (flowing) waters, supported by water discharged from a regional aquifer. The most common habitat is a spring emerging from the ground as a flowing stream. Firm substrates that consist of cobble, gravel, woody debris, and aquatic vegetation are predominant; though sand, silt, and muddy substrates are not uncommon. These spring sites mostly exist under substantial tree canopy, which may serve to regulate water temperatures through shading and contribute organic nutrients in the form of leaf litter.

2.2.1. Microhabitat Requirements

Based on our current knowledge of habitat and life history of the Page springsnail, important characteristics of its habitat include: 1) permanent free-flowing springs; 2) relatively shallow unpolluted water; 3) coarse firm substrates such as pebble, gravel, cobble, and woody debris; 4) aquatic macrophytes, algae, and periphyton; and 5) few or no nonnative predatory species.

The best habitats for springsnails are typically unmodified spring ecosystems exhibiting natural integrity that are generally free-flowing. Spring ecosystems occupied by Page springsnail include a variety of aquatic environments, including springs that emerge from the ground and flow freely for short distances, boggy seeps, spring ponds, pond outflows, concrete spring boxes, and a concrete-lined artificial spring run. Several habitat parameters, such as substrate, dissolved carbon dioxide, dissolved oxygen, temperature, conductivity, pH, and water depth, have been shown to influence the distribution and abundance of *Pyrgulopsis* snails (O'Brien and Blinn 1999, pp. 231–232; Mladenka and Minshall 2001, pp. 209–211; Malcom et al. 2005, p. 75; Lysne et al. 2007, p. 650; Tsai et al. 2007, p. 2006; Martinez and Rogowski 2011, pp. 218–220). Dissolved salts such as calcium carbonate may also be important factors for springsnails because salts are essential for shell formation (Pennak 1989, p. 552). Martinez and Thome (2006. pp. 12–15) found significant correlations between Page springsnail presence and density, and several habitat variables including substrate, dissolved oxygen, conductivity, and water depth (Figures 2.2 and 2.3). Additionally, ongoing research at the Phoenix Zoo indicates that calcium plays and important role in juvenile development, and copper appears to adversely affect recruitment of Page springsnail (S. Wells, pers. comm.), though the mechanism is not known.

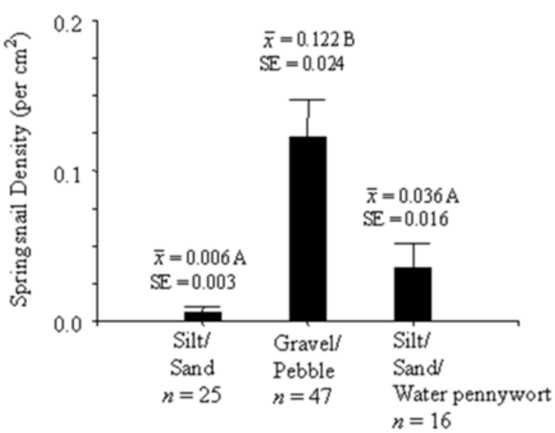

Figure 2.2. Mean values for Page springsnail density across three different substrate types.

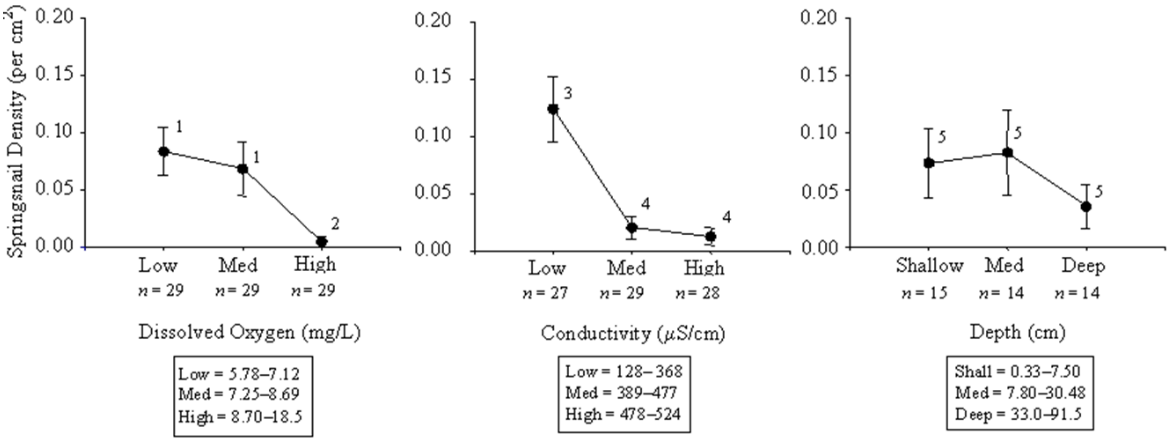

Figure 2.3. Mean values for Page springsnail density (mean±SE) in relation to three different environmental variables in 2001. Values with same number did not differ when tested with a Kruskal-Wallis one-way ANOVA on ranks at α=0.05. Low, medium, and high categories were created using the lower, medium, and upper 33rd percentiles of data within the independent variables.

Proximity to springheads, where water emerges from the ground, plays a key role in the life history of springsnails, and Martinez and Thome (2006, p. 14) noted that Page springsnail appear to be more abundant near spring vents. Many springsnail species exhibit decreased abundance farther away from spring vents, presumably due to their need for stable water chemistry and flow provided by spring waters (Hershler 1984, p. 68; Hershler 1998, p. 11; Hershler and Sada 2002, p. 256; Tsai et al. 2007, p. 216). They are sensitive to water quality, and each species is usually found within relatively narrow habitat parameters (Sada 2008, p. 59).

Importantly, springs exhibiting natural integrity tend to be characterized by gravel and pebble substrates, relatively shallow water, and appropriate water quality. In modified habitats, spring vents are often inundated with deep water and the substrate around spring vents is dominated by sand and silt. In modified springs, water velocity often increases in outflow areas, where sand and silt give way to larger substrates. Martinez and Thome (2006, pp. 8, 14) speculated that water velocity plays an important role in maintaining springsnail habitat by influencing substrate composition and other variables. Typically, snails in the genus Pyrgulopsis are rarely found in mud or soft sediments (Hershler 1998, p. 14) and are typically more abundant in gravel-to cobble-size substrates (Frest and Johannes 1995, p. 203; Malcom et al. 2005, p. 75; Martinez and Thome 2006, pp. 12–13; Lysne et al. 2007, p. 650), though we recognize that Page springsnails do survive in limnocrene habitats, or ponds. In limnocrene systems, *Pyrgulopsis* snails can be found on or at the base of wetland vegetation (Hershler 1998, p. 14).

Page springsnails prefer to attach to firm substrates such as cobble, rocks, woody debris, and aquatic vegetation. Firm substrates provide a suitable surface for springsnail feeding and egg laying (Taylor 1987, p. 5; Hershler 1998, p. 14). Hard surfaces are believed to provide a suitable environment for the production of periphyton and algae, the primary food source of springsnails. In a habitat study, Page springsnails occurred more often, and in greater densities, in gravel and pebble substrates and in shallower water that was relatively lower in dissolved oxygen and conductivity (Martinez and Thome 2006, pp. 8, 11-13).

Although abundant near spring vents, the species is also found in spring outflow channels. For instance, the outflow channel below Bubbling Springs Pond is inhabited by significant numbers of springsnails (AGFD 2011 p. 1, AGFD 2012, p. 2, AGFD 2013, p. 2, AGFD 2014, p. 2; Sorensen and Martinez 2015). This is also observed at Bass House Weir where the outflow (artificial spring run) is inhabited by an abundance of springsnails below the small ponded water within the concrete springbox.

2.2.2. Feeding Habits

Like most freshwater gastropods, the Page springsnail is an herbivore or detritivore that consumes periphyton by scraping from hard surfaces with a radula, or tongue. Springsnails in the family Hydrobiidae are known to feed primarily on periphyton, which is a complex mixture of algae, detritus, bacteria, and other microbes that live upon submerged surfaces in aquatic environments (Mladenka 1992, pp. 46, 81; Hershler and Sada 2002, p. 256; Lysne et al. 2007, p. 649).

In a laboratory setting, Page springsnail diet was supplemented by commercial algae wafers. Production of periphyton and algae in a natural spring system is likely tied to water quality, nutrient availability, and exposure to sunlight.

CHAPTER 3 - POPULATION NEEDS AND CURRENT CONDITION

In this chapter we consider the Page springsnail's historical distribution and what the species needs in terms of the distribution of resilient populations across its range for the species to be viable. We first review the historical information on the range and distribution of the species. We next review the conceptual needs of the species, including population resiliency, redundancy, and representation to maintain viability and reduce the likelihood of extinction. Finally we consider the current conditions of the Page springsnail populations.

3.1. Range and Distribution

The Page springsnail has a relatively small historical range and is known from a series of springs and seeps found along Oak Creek and Spring Creek in the Verde River drainage of central Arizona at elevations of approximately 3,510 feet (ft) (1070 meters (m)) (Figure 3.1). The Oak Creek watershed drains a riparian wooded canyon linking Colorado Plateau and upper Sonoran desert biotic communities, as described by Brown (1994).

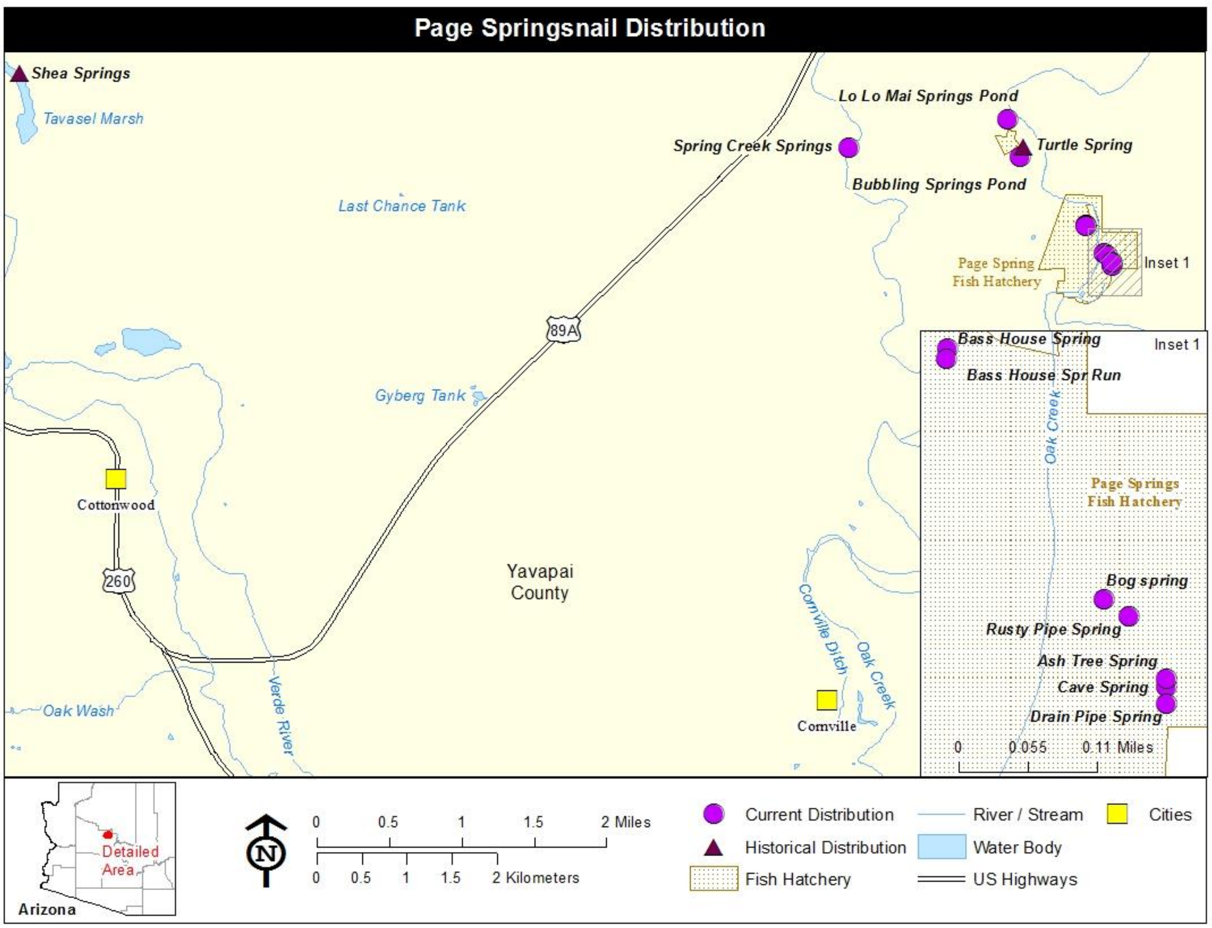

Figure 3.1. Historical and current distribution of the Page springsnail.

The Page springsnail was historically endemic to the upper Verde River drainage of Arizona (Williams et al. 1985, p. 19; Hershler and Landye 1988, pp. 21, 23). The historical distribution includes a number of springs, or spring complexes, located along Oak Creek around the community of Page Springs, Spring Creek, and Tavasci Marsh near the Town of Clarkdale (Figure 3.1). All currently extant populations exist within the Oak Creek Springs complex and springs along Spring Creek. Based on information in our files, springs within which the species is currently known to occur include Cave Spring, Ash Tree Spring, and Drain Pipe Spring which are often referred to collectively as Page Springs; and Bog Spring, Bass House Spring Pond, Bass House Weir Spring, Bubbling Springs pond and outflow, Rusty Pipe Spring, Lo Lo Mai Springs, and Spring Creek Springs. The species was extirpated from Shea Springs at Tavasci Marsh sometime between 1976 and 1980 (Landye 1981, p. 6; Hershler and Landye 1988, p. 23), perhaps due to fluctuating water flows in the marsh that have inundated the springs for long periods of time. The species has not been observed at Turtle Spring since 2008 and is believed to be extirpated from that site as well (J. Sorensen, pers. comm.).

Land ownership is a mix of Federal, State, and private. Lo Lo Mai Springs is owned by Lo Lo Mai Springs Resort. Turtle Springs is partially owned by the Resort and the Arizona Game and Fish Commission (J. Sorensen, pers. comm.). Importantly, the majority of known spring sites are located on State fish hatcheries, including Bubbling Springs, Bass House Spring, the remnants of Page Springs (Drain Pipe Spring, Cave Spring, and Ash Tree Spring), Bog Spring, and Rusty Pipe Spring. Hatchery lands are owned by the Arizona Game and Fish Commission and managed by the AGFD. Several Page springsnail locations occur on private property, including Spring Creek Springs and Lo Lo Mai Springs. A short description of each spring site is provided here:

Drain Pipe Spring (Figure 3.2)

This spring site is one of three which emanate from a west-facing slope between the Page Springs roadway and the hatchery parking lot. Spring flow emanates from the hillside and drains 1.3 m into a culvert and is transported into an underground collection gallery where it is used in hatchery operations. In 2001, the wetted surface area of this site was 2.055 m^2, and water depths ranged from 4-14 cm. Substrate was dominated by gravel, pebble, woody debris, silt, sand, cobble, and aquatic macrophytes. The site is characterized by a substantial tree canopy, including ash (*Fraxinus* sp.) and a shrub understory of blackberry (*Rubus* sp.). This spring provides relatively good habitat for springsnails, which occur in relatively moderate abundance at this site (see Table 3.1).

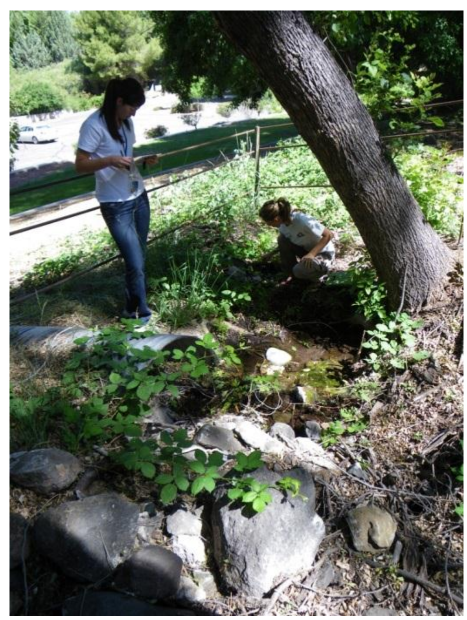

Figure 3.2. Drain Pipe Spring. Photo credit: Jeff Sorensen

Cave Spring (Figure 3.3)

Figure 3.3. Cave Spring. Note small seepage from concrete channel in foreground. Photo credit: Jeff Sorensen

This is one of three springs which emanate from a west-facing slope between the Page Springs roadway and the hatchery parking lot. This spring site exists adjacent to a concrete channel that captures spring discharge from the adjacent hillslope and transports it to an underground collection gallery where it is used in hatchery operations. The majority of the channel does not provide suitable habitat due to high water flows, but springsnails are found in a small 0.35 by 0.7 m seep that leaks under the concrete channel and a 0.6 by 1.2 m slack water area along the north side of the concrete channel. The combined wetted surface area of occupied habitat is approximately 1 m^2. Water depths are shallow at about 6.5 cm and substrate is dominated by gravel, pebble, and woody debris; silt, sand, cobble, and aquatic macrophytes. The site is characterized by a tree canopy of ash and a shrub understory of blackberry. This spring provides relatively good and reliable habitat for springsnails, which occur in relatively high abundance at this site (see Table 3.1).

Ash Tree Spring (Figure 3.4)

Figure 3.4. Ash Tree Spring. Photo credit: Jeff Sorensen

This spring site is another of three spring sites which emanate from a west-facing slope between the Page Springs roadway and the hatchery parking lot. The spring vent emanates from middle of 10 m channel and flows for distance of about 6.4 m to the base of an ash tree before percolating into the hillside where flow is captured and transported to an underground collection gallery for use in hatchery operations. The entire channel is 10 m because water backs up behind the spring vent. The channel is about 1.5 m wide, providing for a wetted surface area of approximately 15 m^2 and water depths of about 20 cm. Substrate is dominated by gravel, pebble, woody debris, silt, sand, cobble, and aquatic macrophytes. The site is characterized by a tree canopy of ash and a shrub understory of blackberry. This spring provides relatively moderate habitat for springsnails, which occur in relatively moderate abundance at this site (see Table 3.1).

Rusty Pipe Spring (Figure 3.5)

Figure 3.5. Rusty Pipe Spring. Photo credit: Jeff Sorensen

This spring site seeps from a north-facing slope and flows for distance of 2.5 m. It has relatively low discharge. The channel is about 2 m wide, providing for a wetted surface area of approximately 5 m^2 and water depths of about 4 cm. Rusty Pipe Spring has predominately silt substrate, but the snail population has expanded with the addition of hard surface substrates (Sorensen and Martinez 2015, p. 8). The site is characterized by a tree canopy of ash and a shrub understory of blackberry. The habitat at this site is not as good as other sites, largely due to the minimal flow and silt substrates, but the site does harbor springsnails which occur in low abundance (see Table 3.1).

Bog Spring (Figure 3.6)

Figure 3.6. Bog Spring. Photo credit: Mike Martinez

This spring seeps from relatively flat ground and has relatively low discharge. This site consists of a small complex of spring seepages dispersed across a wetted surface area of approximately 22.75 m^2 and water depths of about 5 cm. This spring has predominately silt substrates, and the site has a tree canopy of ash and a shrub understory of blackberry. The habitat at this site is not as good as other sites, largely due to the minimal flow and silt substrates, but the site does harbor springsnails which occur in moderate abundance (see Table 3.1).

Bubbling Springs Pond Outflow (Figure 3.7)

Figure 3.7. Bubbling Springs pond outflow channel. Photo credit: Jeff Sorensen

This spring site is characterized by a large pond with numerous spring vents that drain into a water conveyance channel that transports water to the fish hatchery. The wetted surface area of the pond is approximately 1454.88 m^2 (Sorensen et al. 2002, p. 5), with water depths up to approximately 2 m in the middle of the pond. The primary portion of this site evaluated in this document is the outflow channel. The portion of the channel that provides suitable habitat is about 4 m wide and extends at least 30 m from the pond, until it enters another water conveyance ditch. This ares is characterized by high volume flow, substrates dominated by gravel, pebble, and sand, abundant aquatic macrophytes, water depths of up to 30 cm, and a good tree canopy. Importantly, this channel did not historically provide suitable habitat until after 2006 when AGFD installed a flow meter at the outflow of the pond which changed habitat characteristics within the channel (Sorensen and Martinez 2015, p. 5). The habitat in the outflow channel is considered high quality due to the substantial flow, appropriate substrates, and high springsnail abundance (see Table 3.1).

Bass House Spring Pond (Figure 3.8)

Figure 3.8. Bass House Springs pond. Photo credit: Jeff Sorensen

This spring site is characterized by a small pond contained within an artificial enclosure of cinder block, chain link fencing, and sheet metal roofing that was constructed by AGFD in 2005. The pond is about 3.6 m by 4.4 m providing for a wetted surface area of approximately 15.84 m^2, with water depths at least 0.75 m. The pond drains into a pipe that discharges directly into an adjacent water conveyance ditch. The small pond is characterized slow moving flow, substrates of cobble and gravel that were placed by AGFD personnel, and abundant aquatic macrophytes. After renovation, this site did not harbor springsnails until 2011 (Sorensen and Martinez 2015, p. 5). The habitat in the pond can be considered high quality despite the lack of significant flowing water, largely due to the presence of appropriate substrates and aquatic macrophytes that support high springsnail abundance (see Table 3.1). The species was previously extirpated from portions of Bass House Springs, but has recently recolonized the entirety of this site and has exhibited annual increases in abundance (AGFD 2011 p. 1, AGFD 2012, p. 2, AGFD 2013, p.2, AGFD 2014, p.2; Sorensen and Martinez 2015).

Bass House Weir Spring (Figure 3.9)

Figure 3.9. Bass House Spring concrete box and artificial springrun. Photo credit: Mike Martinez

This spring site is characterized by a small concrete box springhead (dimensions 1 m by 1 m) and an artificial spring run 1 m wide that flows for a distance of approximately 17 m, providing for total wetted surface area of approximately 18 m^2. Flow discharges into the same water conveyance ditch as Bass House Spring Pond. The artificial spring run has swift flow, a concrete substrate with cobble and gravel embedded, and an overstory of grasses and trees. The artificial spring run was constructed in 2005 but did not harbor springsnails until 2011 (Sorensen and Martinez 2015, p. 5). The habitat in the spring run can be considered high quality due to the nature of free flowing water, and the presence of appropriate substrates and aquatic macrophytes that support a high abundance springsnail population (see Table 3.1).

Spring Creek Springs (Figure 3.10)

Figure 3.10. A spring vent at Spring Creek Springs. Photo credit: Jeff Sorensen

This site is characterized by numerous closely situated springs emerging from the banks and draining into the main channel of Spring Creek. Substrates included silt, pebbles, cobble, and aquatic vegetation. This site maintains some natural integrity and is considered a good site for the species. No information is available regarding water depths, water quality, or springsnail abundance, though it appeared to be high quality during a site investigation in 2007. This population was discovered in 2007.

Lo Lo Mai Springs Pond Outflow (Figure 3.11)

Figure 3.11. Outflow at Lo Lo Mai Springs pond. Photo credit: Mike Martinez

Lo Lo Mai Springs Resort is managed as a commercial campground with RV and tent sites available for rent (http://lolomai.com/). The spring site is characterized by a large pond with numerous spring vents that drain into a water conveyance channel. The wetted surface area of the pond is comparable to Bubbling Springs Pond, though we have no specific information on its size or water depths. The primary portion of this site evaluated in this document is the outflow channel. The portion of the channel that provides suitable habitat is less than a meter in width and extends several meters from the pond until it enters another water conveyance ditch. The outflow area is characterized by high volume flow, substrates dominated by gravel, pebble, and sand, abundant aquatic macrophytes, and a tree canopy. The habitat in the outflow channel can be considered high quality largely due to the substantial flow and appropriate substrates. No information is available regarding springsnail abundance.

3.2. Needs of the Page Springsnail

As discussed in Chapter 1, for the purpose of this assessment, we define viability as the ability of the species to sustain populations in the wild beyond a biologically meaningful timeframe. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (the 3Rs). Using various time frames and the current and projected levels of the 3Rs, we thereby describe the species' level of viability over time.

3.2.1 Population Resiliency

For the Page springsnail to maintain viability, its populations, or some portion of its populations, must be resilient. Stochastic events that have the potential to affect Page springsnail populations include weather events, spring habitat modification, shifts in water quality, and changes in spring discharge. Resilient Page springsnail populations occupy habitats of sufficient size to sustain reproducing populations. We have limited information regarding population demographics; though Page springsnails can be locally quite abundant as illustrated by catch-per-unit-effort (CPUE) derived from AGFD monitoring data from 2010-2015 (Table 3.1). However, due to their high fecundity, we assume that if sufficient suitable habitat is available, a springsnail population will reach high densities rather quickly, assuming the population does not reach so low a level that springsnails are unable to find one another for reproduction (S. Wells, pers. comm.).

Table 3.1 Mean CPUE± standard error across spring sites from 2010-2015. CPUE (as described by Gulland 1983) was calculated based on number of snails counted per minute during timed survey efforts from AGFD annual monitoring data. No data for Spring Creek and Lo Lo Mai springs.

Spring/Population	CPUE±SE	Abundance Rank
Drain Pipe	9.88±3.91	Moderate
Cave	11.31±3.42	High
Ash Tree	30.88±10.79	Moderate
Rusty Pipe	4.35±2.63	Low
Bog	2.49±0.53	Moderate
Bubbling Outflow	37.86±9.77	High
Bass House Pond	16.77±6.78	High
Bass House Weir	16.49±5.30	High
Spring Creek Springs	Unknown	Unknown
Lo Lo Mai Outflow	Unknown	Unknown

As a species, Page springsnail populations appear resilient to disturbance and localized reductions in abundance, perhaps due to high fecundity and recruitment rates (Martinez and Sorensen 2008; Sorensen et al. 2002). Page springsnails can be locally quite abundant. High fecundity and resistance to the deleterious effects of genetic bottlenecking would be expected to allow for quick population rebound after population dips or crashes. Additionally, several sites have demonstrated increases in springsnail abundance since the AGFD began annual monitoring (Sorensen and Martinez 2015, entire).

Perennial spring ecosystems provide protection from desiccation, predation, and temperature extremes, as well as food and shelter for both juvenile and adult springsnails. A number of factors influence whether Page springsnail populations will grow to maximize habitat occupancy, which increases the resiliency of a population to stochastic events. These factors include (1) adequate spring discharge (water quantity), (2) sufficient water quality, (3) freeflowing spring ecosystems, and (4) sufficient substrate and aquatic vegetation quantity within the springs (Figure 3.12). If spring ecosystems provide reliable flow, coupled with appropriate water depth, substrates, and suitable water quality, we anticipate springsnails will survive and thrive in abundance. Each of these factors is discussed here.

Adequate spring discharge (water quantity)

The springs inhabited by Page springsnail are sustained by groundwater discharged from a regional aquifer, and this groundwater discharge must occur in perpetuity for the springs to persist. Recharge of the aquifer is critical to the long term maintenance of spring discharge, and this recharge is dependent on winter and spring snowmelt (ADWR 2009). If groundwater discharge is curtailed or eliminated, Page springsnail populations could lose resiliency or be extirpated.

We considered spring discharge level to be functioning at a high level if water is flowing at a rate and depth sufficient to remove most fine-grained sediments, at a moderate level if water is flowing at rate and depth that removes some fine-grained sediments, and at a low level if water is flowing at a rate and depth that is inadequate to remove fine-grained sediments.

Sufficient water quality

Water quality must be sufficient to sustain springsnail populations. Hydrobiid snails are sensitive to water quality and each species is usually found within relatively narrow habitat parameters (Sada 2008, p. 59). The species occurs more often and in greater densities in shallower water characterized by relatively lower levels of dissolved oxygen and conductivity (Martinez and Thome 2006, pp. 8, 11-13). Page springsnail densities were highest in dissolved oxygen levels between 5.78-8.69 mg/L and conductivity levels between 128-368 µS/cm (Martinez and Thome 2006, pp. 8, 11-13).

We considered water quality to be functioning at a high level if water conditions appear to provide appropriate conditions for springsnail occupation, at a moderate level if water conditions appear to provide marginal conditions for springsnail occupation, and at a low level if water conditions appear unable to support springsnail occupation.

Free-flowing spring ecosystems and appropriate habitat quality

The most important feature to maintain habitat is the presence and permanence of free-flowing spring water. Hershler and Williams (1996, p. 1) suggested that efforts to maintain springsnail populations should focus on the maintenance of natural spring head integrity, which will improve water quality and conserve a broad array of spring-dependent organisms. As such, the maintenance of spring water flow within the Oak Creek and Spring Creek springs complexes is critical to the continued persistence of spring ecosystems and the long-term survival and viability of the Page springsnail.

We considered spring water to be free-flowing (high) if it flows without anthropogenic barriers, moderately free-flowing if it flows with partial barriers, and not free-flowing (low) if it is entirely blocked or nearly so.

Sufficient substrate and aquatic vegetation quantity

Substrate characteristics influence the density and productivity of springsnails. Suitable substrates are typically firm, characterized by cobble, gravel, sand, woody debris, and aquatic vegetation such as *Nasturtium officinale* (watercress), *Lemna minor* (duckweed), *Berula erecta* (water parsnip), *Hydrocotyl venicillata* (water pennywort), *Veronica anagalli aquatica* (water speedwell), and *Rumex verticillatus* (dock). The species occurs more often and in greater densities in gravel and pebble substrates (Martinez and Thome 2006, pp. 8, 11-13). Suitable substrates increase productivity by providing suitable egg-laying sites and providing food resources.

We considered substrate and vegetation to be functioning at a high level if they are dominated by hard substrates such as cobble, gravel, pebble, and vegetation suitable for springsnail occupation; at a moderate level if they contain a portion of hard substrates and suitable vegetation; and at a low level if they lack hard substrates and suitable vegetation.

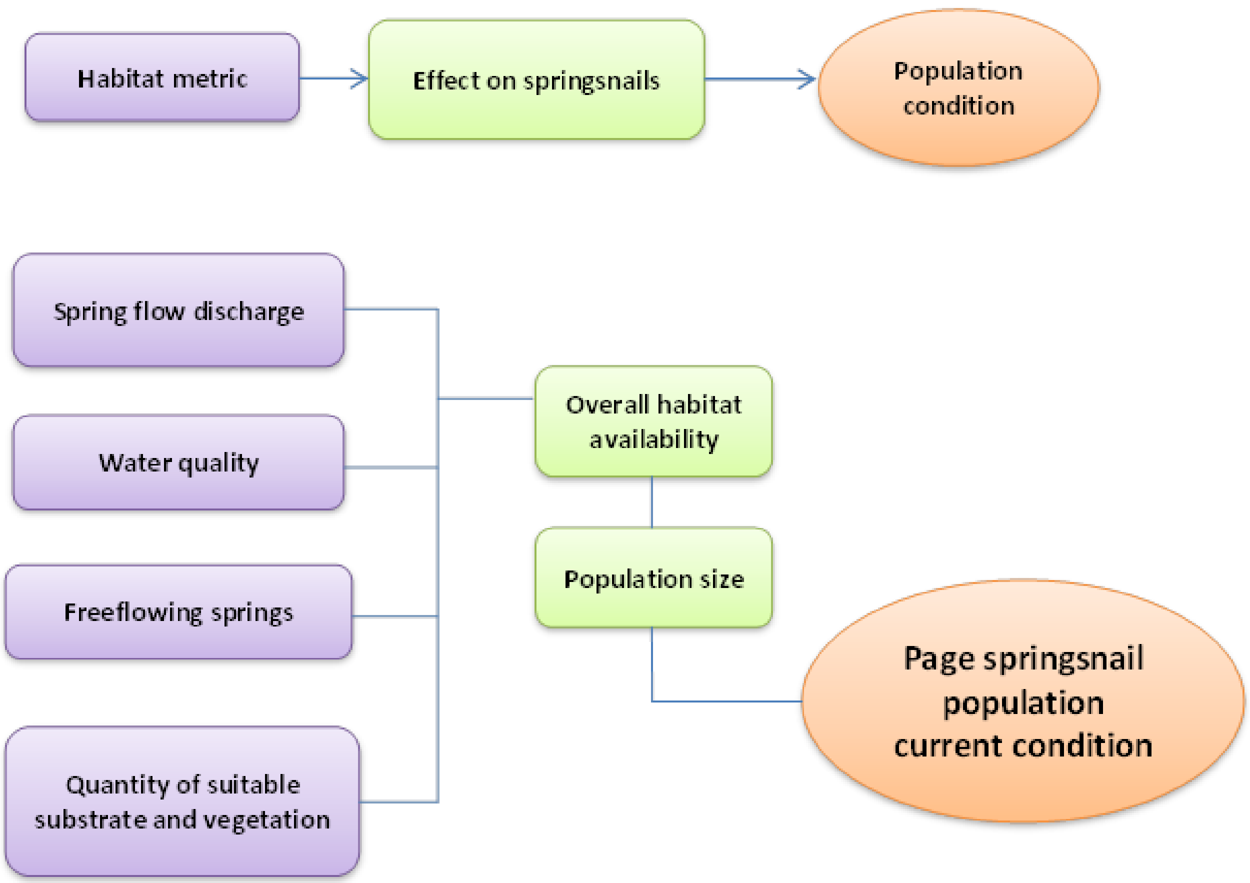

Figure 3.12. Factors influencing the current conditions of Page springsnail populations

3.2.2 Species Redundancy and Representation

The Page springsnail needs to have multiple resilient populations distributed throughout its range to provide for redundancy and representation. The more populations, and the wider the distribution of those populations, the more redundancy the species will exhibit. Redundancy reduces the risk that a large portion of the species' range will be negatively affected by a catastrophic natural or anthropogenic event at a given point in time. Species that are well-distributed across their historic range are less susceptible to extinction and more likely to be viable than species confined to a small portion of their range (Carroll et al. 2012, entire; Redford et al. 2011, entire). All of the Page springsnail populations are essentially isolated from one another, and repopulation of extirpated locations from extant springs is unlikely to occur without active management.

Widespread groundwater depletion that diminishes or eliminates the supply of water to the spring ecosystems supporting the species would have large effects on redundancy and representation. The presence of a number of occupied springs should provide refugia from catastrophic events by providing the redundancy required by the species to withstand localized loss of habitat.

Genetic investigations (Hurt 2004) indicate the species exhibits some level of genetic diversity between populations at Bubbling Springs Pond and the remnants of Page Springs. Exchange of genetic material between populations that don't share surface water connection is probably a rare event limited to instances when springsnails might occasionally hitchhike on migratory birds. Based on the diversity within portions of its range, it is possible other populations exhibit some natural variation in genetic diversity across the entire geographic range of the species. As such, maintaining representation in the form of genetic or ecological diversity may be important to the capacity of the Page springsnail to adapt to future environmental change. However, springsnail populations can exhibit genetic drift and bottlenecking (Johnson 2005, pp. 2307-2308), but they are likely predisposed and adapted to this phenomenon by virtue of their natural history.

To measure representation and redundancy, we looked at the number and distribution of Page springsnail populations now and in the future (see Chapter 5, Viability for more information).

3.3 Current Conditions

The available information indicates that the current range of the Page springsnail occurs within at least 10 springs along Oak Creek and Spring Creek. A substantial portion of the spring habitat throughout its current estimated range is managed by the AGFD and is currently relatively intact and protected. These intact habitats contribute to redundancy by providing suitable habitat for 10 populations throughout the range of the species. The spring sources and surrounding land at both the Bubbling Ponds and Page Spring hatcheries have been heavily used for agricultural needs since the 1870s. Despite human use of the springs and surrounding land over approximately the last 100 years, Page springsnails have persisted. Although the primary function of Bubbling Ponds and Page Springs hatcheries is fish production, the management plans for both facilities include provisions to protect endemic invertebrates, including the Page springsnail (AGFD 1997a, 1997b).

As a result of special management considerations, spring ecosystems on the fish hatcheries currently remain intact, thus providing areas for the Page springsnail to persist.

3.4 Summary of Needs

The most important needs of Page springsnail individuals and populations are listed below and summarized in Table 3.1.

<u>Individuals</u>

- permanent free-flowing springs
- relatively shallow unpolluted water
- coarse firm substrates such as pebble, gravel, cobble, and woody debris

- aquatic macrophytes, algae, and periphyton
- few or no nonnative predatory species

Populations

- stable or positive trends in relative abundance
- intact free-flowing spring ecosystems
- sufficient abundance to ensure appropriate encounter rates

Rangewide

- sufficient groundwater to support spring discharge along Oak Creek and Spring Creek

Table 3.1. Current conditions of Page springsnail populations. Rankings are a qualitative assessment of the relative condition of spring ecosystems based on the knowledge and expertise of Service staff, Arizona Game and Fish Department, and other technical experts and resource professionals (see Table 3.2 for more information). High: spring ecosystem is functioning near an optimum level for this resource need and there is little room for improvement. Moderate: spring ecosystem is functioning somewhat well for this resource need and there is room for improvement. Low: spring ecosystem is functioning at a less than optimal level for this resource need and there is significant room for improvement. Overall condition was determined based on an average of the other factors. The factor "Adequate spring discharge" was given twice as much weight as the other factors because we believe it is the most important factor and drives the other factors.

Current Conditions of Page Springsnail Populations

	Factors				
Spring/Population	**Adequate spring discharge**	**Sufficient water quality**	**Free-flowing spring ecosystem**	**Sufficient substrate and aquatic vegetation**	**Current Overall Condition**
Drain Pipe	Low	High	Moderate	Moderate	Moderate
Cave	High	High	High	High	High
Ash Tree	Moderate	High	Moderate	High	Moderate
Rusty Pipe	Low	Moderate	Moderate	Low	Low
Bog	Low	Moderate	Moderate	High	Moderate
Bubbling Outflow	High	High	High	High	High
Bass House Pond	High	High	Low	High	High
Bass House Weir	High	High	High	High	High
Spring Creek	High	High	High	High	High
Lo Lo Mai Outflow	High	High	High	High	High

Table 3.2. Relative condition of factors used to determine Page springsnail population resiliency.

	Condition of Factor		
Population Resiliency Factor	**High**	**Moderate**	**Low**
Adequate spring discharge	water is flowing at a rate and depth sufficient to remove most fine-grained sediments	water is flowing at rate and depth that removes some fine-grained sediments	water is flowing at a rate and depth that is inadequate to remove fine-grained sediments
Sufficient water quality	water appears to provide appropriate conditions for springsnail occupation	water appears to provide marginal conditions for springsnail occupation	water appears unable, or nearly unable, to support springsnail occupation
Free-flowing spring ecosystems	flows without anthropogenic barriers	flows with partial barriers	flow entirely blocked or nearly so
Appropriate substrate and aquatic vegetation	dominated by hard substrates such as cobble, gravel, pebble, and aquatic vegetation	contain a portion of hard substrates and suitable vegetation	mostly lacks hard substrates and suitable vegetation

CHAPTER 4 – FACTORS INFLUENCING VIABILITY

> **Note:** This chapter contains **summaries** of the risk factors. For further information, see the tables in **Appendix A**.

In this chapter, we evaluate the past, current, and future factors that are affecting what the Page springsnail needs for long term viability. We analyzed these factors in detail using the tables in Appendix A in terms of causes and effects to the species. These tables analyze the pathways by which each factor affects the species, and each of the causes is examined for its historical, current, and potential future effects on species' status. Current and potential future effects, along with current expected distribution and abundance, determine present viability and, therefore, vulnerability to extinction. For more information about each of these factors, see Appendix A. Those factors that are not known to have effects on Page springsnail populations, such as overutilization for commercial and scientific purposes and disease, are not discussed in this SSA report.

The two primary factors affecting the future viability of Page springsnail are the modification of spring habitat and the loss of spring discharge. Recent spring management on AGFD property has protected or modified sites such that Page springsnail habitat is maintained or enhanced; therefore, the effect of groundwater decline on spring flow is the factor with the greatest amount of uncertainty regarding the future viability of the species. These and other factors are discussed in more detail here.

4.1. Springhead Modification

Human activity has historically contributed to widespread modification of the species' habitats resulting in the loss of natural springhead integrity and, in some instances, the elimination of the aquatic environment. Covering the springhead reduces natural organic matter input, aquatic vegetation, and algal growth. Diversion of water reduces springsnail habitat. Channelizing and/or landscaping spring runs reduces or eliminates spring habitat. At least seven springs where the species occurs currently or historically have been subjected to some level of modification to meet domestic, agricultural, ranching, fish hatchery, and recreational needs. Springhead modification is unlikely to be a factor in the future for eight of the 10 extant populations due to important management efforts that have been undertaken by AGFD.

4.2. Conversion from Lotic to Lentic Systems

At least five springs currently or formerly occupied by the Page springsnail appear to have been converted, to some degree, from free-flowing systems to ponds which are less conducive to occupation by the species. Impoundments resulting in inundation or pooling above springheads has occurred at several sites, including Lo Lo Mai Springs, Bubbling Springs, Turtle Springs, Shea Springs, and Bass House Springs. Inundation alters springsnail habitat by changing water depth, velocity, substrate composition, vegetation, and water chemistry which can cause population reduction or extirpation. It is important to note that impoundments do not necessarily lead to extirpation, as the Page springsnail persists in several ponded situations, albeit at lower densities. For instance, Page springsnails exhibit lower densities in modified ponded environments versus natural free-flowing environments ($Z = 5.832$, $df = 92$, $P < 0.001$; Service unpublished data). To our knowledge, no further conversion to lentic systems is expected for any of the populations, particularly those managed by AGFD.

4.3. Aquatic Vegetation Removal

Historically, hatchery management activities included periodic vegetation removal from Bubbling Springs Pond and Bass House Springs to improve water flow to the hatchery. Submerged aquatic vegetation is important to Page springsnail persistence because it provides springsnails food and cover. Physical and mechanical removal of emergent and submerged native or nonnative vegetation (including algae) and organic debris can reduce the quality of spring habitats, lowering population numbers. Vegetation removal can result in direct mortality from crushing and desiccation, and indirect mortality through habitat modification and temporary water quality changes. Vegetation removal rarely occurs under current management (J. Sorensen, pers. comm.).

4.4. Water Contamination

Although hydrobiid snails as a group are found in a wide variety of aquatic habitats, they may be sensitive to water quality, and each species is usually found within relatively narrow habitat parameters (Sada 2008, p. 59). Proximity to spring vents, where water emerges from the ground, plays a key role in the life history of springsnails. Many springsnail species exhibit decreased abundance farther away from spring vents, presumably due to their need for stable water chemistry (Hershler 1994, p. 68; Hershler 1998, p. 11; Hershler and Sada 2002, p. 256; Martinez and Thome 2006, p. 14). Several habitat parameters of springs, such as substrate, dissolved carbon dioxide, dissolved oxygen, temperature, conductivity, and water depth, have been shown to correlate with the distribution and abundance of *Pyrgulopsis* (O'Brien and Blinn 1999, pp. 231–232; Mladenka and Minshall 2001, pp. 209–211; Malcom *et al.* 2005, p. 75; Martinez and Thome 2006, pp. 12–15; Lysne *et al.* 2007, p. 650).

Water quality degradation through the use of toxic substances has been identified as a threat to the Page springsnail. The Page Springs and Bubbling Ponds fish hatchery facilities have undergone various chemical and physical treatments to reduce the spread of fish diseases and parasites, including dewatering and disinfection (Landye 1981, p. 33; AGFD 1991, p. 3; 1998, p. 6). These treatments have included the use of rotenone and chlorine. AGFD has greatly reduced the use of chemicals in Page springsnail habitat, and when these chemicals have been used, springsnails have been translocated out of the spring while treatment occurs. Springsnails are then reintroduced back to the habitat once the chemicals have cleared the system. This strategy has been successful in maintaining springsnail populations in these habitats. In addition, Lindberg (2010, p. 1) speculates that unregulated septic leakage could contaminate groundwater through hidden sinkholes within the town of Sedona and lead to contamination of Page Springs, though we have no data to indicate this has actually occurred..

4.5. Reduced Spring Discharge

Oak Creek and Spring Creek occur within the Verde Valley subbasin of the Verde River watershed, and springs and streams in this region are sustained by groundwater discharged from a regional aquifer. The Verde River watershed covers an area of approximately 5,000 square miles in central Arizona, and encompasses part of the Coconino Plateau in the north with the Mogollon Rim to the east. The watershed is characterized by steep canyons, rugged mountains, and broad alluvial valleys in the north and west-central portions. The Verde Valley subbasin is the largest subbasin in the watershed and includes an area of approximately 2,500 square miles (Figure 4.1).

Figure 4.1. Verde Valley subbasin, depicting location of Oak Creek (from Garner and Pool 2013).

The main recharge events for the aquifers in the Verde River watershed and the Verde Valley subbasin are from winter and spring snowmelt, and groundwater enters the subbasin from the Coconino Plateau. Groundwater moves through stream-channel alluvium or discharges at springs and seeps along tributaries of the Verde River, particularly along Oak Creek (ADWR 2009, p. 11). Page Springs is one of the largest spring complexes in the region, discharging about 10,000 gallons per minute (Woodhouse et al. 2002, p. 3). These springs are the primary source of water for perennial flow in Oak Creek (Twenter and Metzger 1963, p. 29).

Arizona Department of Water Resources (ADWR) records show that numerous wells have been drilled in close proximity of Cave Springs (Mitchell 2001, p. 3; AGFD and Service 2009, p. 37). At least two of these wells pump between 1200 and 1500 gallons (4.5 and 5.7 m^3) per minute, and are within 0.75 mi (1.2 km) of Cave Springs. Given their proximity, production rate, and hydrological connectivity, groundwater withdrawal by these wells could have a direct impact on flow at Cave Springs (Mitchell 2001, p. 6). A portion of spring discharge water passes through the fish hatchery, with a portion diverted to downstream users per water rights agreement. Page

Springs Hatchery staff have kept a weekly log of spring flow from Cave Spring since February 12, 1996 and report that discharge at Cave Spring has slowly declined over this 17-year period by approximately 2.3 cubic feet per second (cfs), from 6.5 cfs in 1996 to 4.2 cfs in 2014 (J. Sorensen, AGFD, pers. comm.).

Increases in the frequency or intensity of ecosystem disturbances such as drought have been detected in many parts of the world and in some cases are attributed to climate change (IPCC 2014, p. 51). Climate change over the 21st century is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (IPCC 2014, p. 69). Seager et al. (2007, pp. 1181–1184) analyzed 19 different computer models of differing variables to estimate the future climatology of the southwestern United States and northern Mexico in response to predictions of changing climatic patterns. All but one of the 19 models predicted a drying trend within the Southwest; one predicted a trend toward a wetter climate (Seager et al. 2007, p. 1181). A total of 49 projections were created using the 19 models; all but 3 of the projections predicted a shift to increasing dryness in the Southwest as early as 2021–2040 (Seager et al. 2007, p. 1181). The current prognosis for climate change impacts on the Sonoran Desert of the American Southwest includes fewer frost days; warmer temperatures; greater water demand by plants, animals, and people; and an increased frequency of extreme weather events (heat waves, droughts, and floods) (Overpeck and Weiss 2005, p. 2074; Archer and Predick 2008, p. 24). Models for the Verde River Watershed, where Page springsnail occurs, indicate at 17 percent increase in stream drying events by ~2050 (Jaeger et al. 2014, p. 13895). How climate change will affect summer precipitation is less certain, because precipitation predictions are based on continental-scale general circulation models that do not yet account for land use and land cover change effects on climate or regional phenomena, such as those that control monsoonal rainfall in the Southwest (Overpeck and Weiss 2005, p. 2075; Archer and Predick 2008, pp. 23–24).

Groundwater storage in the Verde River Watershed has already declined due to groundwater pumping and reductions in natural channel recharge resulting from streamflow diversions and inadequate precipitation (Owens-Joyce and Bell 1983, pp. 1, 65; McGavock 1996, p. 67; Blasch et al. 2006, p. 2). Base flow in the Verde River decreased between 1910 and 2005 and is expected to continue to decrease into the future (Garner et al. 2013; Jaeger et al. 2014, p. 13898), and this is likely a result of declining groundwater. Future water levels and stream base flows are expected to continue to decrease along the Verde River and Oak Creek in response to increased pumping, particularly over the next 50 years (Owens-Joyce and Bell 1983, pp. 1, 65; McGavock 1996, p. 67; Blasch et al. 2006, p. 2; Garner et al. 2013).

Groundwater models do not provide the level of specificity necessary to predict the exact nature of the relationship between groundwater levels, Verde River base flow levels, and spring flow discharge. Though we are not certain of the specific relationship between base flow and spring discharge, we presume that declines in groundwater levels in the Verde Valley subbasin and base flow in the Verde River will likely translate to some decline in spring flow. These lowered water levels may lead to reduced spring discharge, although we are unaware of how much groundwater decline will result in a measurable decline in spring flow. Accordingly, we are unaware how much groundwater decline would result in dramatic effects to future levels of spring discharge from spring complexes along Oak Creek and Spring Creek. Nevertheless, we anticipate the effect of groundwater decline on future levels of spring discharge is the primary factor influencing the future condition of the Page springsnail.

4.6. Predation

Many predators occur within the spring systems occupied by the Page springsnail, including fish, waterfowl, and other invertebrates. Remnants of Page springsnail shells have been reported in analyses of stomach content of mosquitofish (*Gambusia affinis*) from the Oak Creek Springs complex (Raisanen 1991, p. 71). Nonnative crayfish (*Orconectis virilis*) are well distributed and abundant in the Verde Valley and were noted near Bubbling Springs Pond in 2001. Crayfish are known predators of mollusks (Fernandez and Rosen 1996, p. 23). Crayfish and the other predators may negatively affect efforts to maintain extant populations of Page springsnails and future efforts to re-establish others. Due to its long-term biogeographic isolation, the Page springsnail may not be evolutionarily adapted to cope with these and other nonnative predators. However, we have no information indicating that crayfish are affecting Page springsnail. Overall, the impact of predators on Page springsnail populations is not known and is presumed to be a minor factor influencing population resiliency.

4.7. New Zealand Mudsnail

The nonnative New Zealand mudsnail (*Potamopyrgus antipodarum*) is an invasive freshwater snail of the family Hydrobiidae that is known to compete with and slow the growth of native freshwater snails, including springsnails (Lysne and Koetsier 2008, pp. 103, 105; Lysne et al. 2007, p. 6). The mudsnail can be easily transported and unintentionally introduced into aquatic environments via birds, hikers, researchers, and resource managers. If introduced into the spring systems harboring the Page springsnail, the effect could be devastating, although management actions could be undertaken to manage their spread and potentially eradicate them from Page springsnail springs. AGFD hatcheries and the AGFD Invertebrate Program implement Hazard Analysis-Critical Control Point plans (HACCP) to minimize the risks of incidentally moving undesirable organisms between waterways. Strict equipment use and cleaning protocols are used in hatchery operations and field sampling of springsnail sites. HACCP planning is an international standard for reducing or eliminating the spread of unwanted species during specific processes or practices or in materials or products based on the Standard Guide for Conducting HACCP Evaluations (http://www.astm.org/Standards/E2590.htm). Additionally, AGFD has identified measures related to nonnative species control in their 10-year Nongame and Endangered Wildlife Conservation Plan and work conducted under State Wildlife Grants (J. Sorensen, pers. comm.)

4.8. Management Actions

There are a number of conservation actions that have been implemented to minimize threats and maintain or improve the status of the Page springsnail, including a Candidate Conservation Agreement with Assurances (CCAA) with AGFD, originally signed in 2009. The CCAA includes many management actions that have been successful in maintaining Page springsnails at current sites. Future management actions may also include reintroducing them into new sites. Management actions in the CCAA include:

Protect Existing Spring Ecosystems - Because modifications to spring ecosystems can have detrimental effects on Page springsnail populations, AGFD has committed to protect springs known to support, or likely to support, Page springsnails from degradation, modification, or diversion, unless management actions are determined in advance by AGFD and the Service not to negatively affect the species. The benefit identified in the CCAA is that protection of Page springsnail habitat will allow populations to persist and is a crucial part of conserving the species. Through implementation of the CCAA, AGFD has coordinated numerous management activities with the Service, including use of chemicals, aquatic vegetation control, management of non-native fishes, and addition of material into springs.

Restore and/or Create Spring Ecosystems - AGFD has committed to seek opportunities for habitat restoration and/or creation on their lands. Restoration activities include modifying springs, adding substrate preferred by springsnails, and eradicating non-native species. The benefit of creation/restoration of habitat is to enable Page springsnail populations to use the full extent of each site by expanding into habitat that is, or was previously, suboptimal. Creation/restoration of unoccupied sites could be used for translocations. Notably, the AGFD has identified additional opportunities to enhance the springsnail habitat at existing sites (Drain Pipe, Ash Tree, Rusty Pipe, and Bog springs) by several methods, including adding more hard substrates, removing berms that impede spring flow, and creating artificial spring runs to increase the area of suitable habitat. (AGFD 2015). These actions could be accomplished over the next 25 years under the scope of a renewed CCAA.

Implement Monitoring Program - AGFD annually monitors all known springsnail populations and habitats on their lands. The program tracks the effectiveness of the agreed upon management strategies and provides information on abundance and population trends. Annual monitoring plans are provided to the Service and provide important information for evaluating the species' status, trends, and adaptive management needs.

Captive Propagation - The Phoenix Zoo has an active program for captive propagation of Page springsnail. The population at Bubbling Springs pond outflow is represented in captivity, and this refugium was recently augmented from collections during the spring of 2015. This protects the species against catastrophic loss and the threat of extinction.

Population Reestablishment and/or Discovery - AGFD has committed to create (through translocations) or attempt to discover new populations of Page springsnails. Increasing the number of populations would decrease the impact of a catastrophic event at existing sites. Before translocations take place, release sites would be identified and evaluated, project funding secured, donor population(s) located, an AGFD Environmental Action Checklist completed, and transportation guidelines established. Other factors to be considered prior to translocation or re-establishment include the following: presence of non-native species and the ability to remove them, risk of introducing exotic pathogens or parasites, displacement of other endemic aquatic species, likelihood of survivorship, impact on donor populations, economic and cultural impact, and wildlife-recreation conflicts. Notably, the AGFD has already identified two springs/seeps on hatchery property that are not occupied by Page springsnails and will be evaluated for translocations.

The CCAA expired in October 2014. However AGFD has committed to continue the management actions within the agreement while they work towards renewal (J. Sorensen, AGFD, pers. comm.). Additionally, AGFD has expressed their intention to renew the CCAA effort for a longer duration commitment, on the order of 25 years (AGFD 2014).

4.9. Summary

Historical factors affecting Page springsnail viability include spring modification, aquatic vegetation removal, and water contamination. **Future** factors affecting viability include groundwater depletion and potential invasion by nonnative snails.

Figure 4.2 represents our understanding of the factors that influence Page springsnail population resiliency. The most significant stressor to the Page springsnail is the loss of spring ecosystems that individuals and populations need to complete their life history. The primary cause of historical habitat loss within the range of the Page springsnail is related to anthropogenic modification of spring ecosystems and/or water quality. Any action that generally removes suitable habitat can contribute to the potential decline or extirpation of local populations. The implementation of the conservation measures in the CCAA has resulted in securing the majority of Page springsnail populations from spring modification, aquatic vegetation removal, and water contamination. Additionally, although nonnative snails could be unintentionally introduced to springs the implementation of HACCP plans minimizes the potential for spread of New Zealand mudsnail. As such, the primary source of potential future habitat loss is groundwater depletion that could result in reduced or eliminated spring flow. Groundwater withdrawal will continue to affect base flow in the Verde Valley subbasin, although we cannot quantify how it will affect the springs harboring the species.

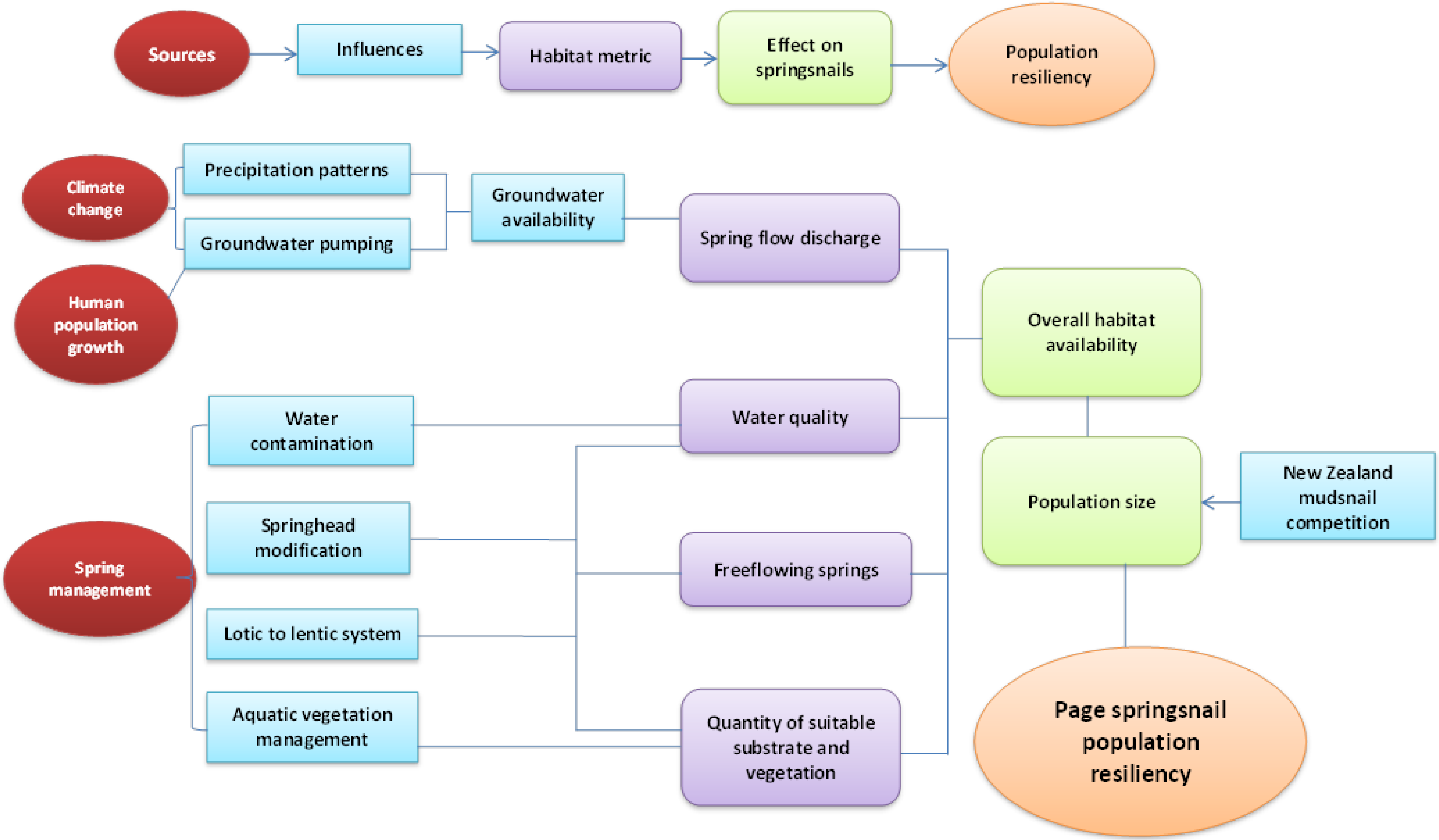

Figure 4.2. Factors affecting Page springsnail population resiliency.

CHAPTER 5 – SPECIES VIABILITY

We have considered what the Page springsnail needs for viability and the current condition of those needs (Chapters 2 and 3), and we reviewed the factors that are driving the historical, current, and future conditions of the species (Chapter 4). We now consider what the species' future conditions are likely to be.

5.1 Introduction

The Page springsnail was historically known from 12 springs and currently occurs at 10 of those locations. Historical actions that modified springs and affected water quality were the primary drivers of habitat and population loss, but these activities have largely been curtailed, primarily due to the CCAA with AGFD for the eight populations they manage. The extant populations currently have primarily moderate to high habitat quantity and quality, and only 2 populations retain some risk due to potential habitat modification from land management activities.

While future impacts from habitat modification are not expected to the majority of extant populations, the risk of groundwater pumping and drought resulting in lowered aquifer levels and a concomitant reduction in spring flow remains a concern. We are relatively certain that climate change and increased human population levels in the Verde Valley will result in lowered groundwater levels (Garner et al. 2013, p. 23; Jaeger et al. 2014, p. 13895), but we are less certain about how and when spring flow would be affected. Groundwater in the Verde Valley is primarily driven by precipitation (ADWR 2009). This was observed when Page Springs experienced a 15 percent decline in flow between 1996 and 2000, a period of drought for the region, which indicated that the spring flow levels may respond to changes in rainfall (Mitchell 2001, p. 1).

Groundwater pumping is also likely to affect aquifer levels. As discussed above, ADWR records show that numerous wells have been drilled in close proximity of springs on hatchery property. Given their proximity, production rate, and probable hydrological connectivity, groundwater withdrawal by these wells could have a direct impact on flow at Cave Springs (Mitchell 2001, p. 6). However, the impact of these wells on the spring cannot be determined without long-term aquifer tests and simultaneous discharge monitoring at Cave Springs (Mitchell 2001, p. 6).

Several long term climate models suggest that the American Southwest may experience a widespread persistent drought in the latter half of the 21st century (Ault et al. 2014, entire; Cook et al. 2015, entire). For the scope of this analysis, this sort of multidecadal megadrought is too uncertain in terms of when and where it may occur and farther into the future than we can reliably forecast for us to make predictions about how and when the Page springsnail populations may be affected.

The viability of Page springsnail depends on maintaining multiple resilient populations over time. Given our uncertainty regarding if and when springs occupied by Page springsnail will experience a reduction or elimination of spring flow in the future, we have forecasted what the

Page springsnail may have in terms of resiliency, redundancy, and representation under three plausible future (over the next 50 years) scenarios:

> (1) All or most springs occupied by Page springsnail experience **no measureable drop** in spring flow;
> (2) Spring flow in springs occupied by Page springsnail is **reduced but not eliminated**; and
> (3) All or most springs occupied by Page springsnail experience an **extreme reduction or elimination** of spring flow.

Because we are not certain of how groundwater decline will specifically affect spring flow, examining how the Page springsnail populations will respond under these three spring flow scenarios allows us to consider the range of future effects of spring flow decline on Page springsnail populations.

5.2. Resiliency

In general, Page springsnails are adapted to the variable and harsh conditions of spring ecosystems. Populations that have experienced extreme reductions have been observed to rebound within one or two breeding seasons (Sorensen et al. 2002). With appropriate habitat and sufficient flow, a short term (~1 year) reduction in population size would not be expected to result in eventual population elimination.

Resiliency of Page springsnail populations is likely to be affected by three primary factors: spring management, the potential introduction of the New Zealand mudsnail, and groundwater decline. As discussed above, AGFD is managing 8 of the 10 populations in a manner consistent with stable or increasing populations; therefore, spring modification is unlikely to lead to population-level effects at most sites.

If New Zealand mudsnails spread to these springs, it would very likely outcompete Page springsnails, dropping resiliency of any population where the nonnative snail was introduced to very low levels or extirpating populations entirely. However, the introduction of the New Zealand mudsnail to springs inhabited by Page springsnail has a low likelihood of occurring. The AGFD implements HACCP plans to minimize the risks of incidentally moving undesirable organisms between waterways. If accidentally introduced into any of the populations that are managed by AGFD, it is likely these sites would be rehabilitated. AGFD has been very successful at translocating populations during chemical treatments to remove other undesired species from the springs, then reintroducing springsnails to the native habitat once the spring becomes inhabitable again. Under the current management, AGFD would likely do the same if New Zealand mudsnails were introduced to the springs they manage.

The remaining factor that may affect Page springsnail resiliency is groundwater decline. We expect that groundwater levels will decline, but there is significant uncertainty over how that will affect spring flows. If spring flows are reduced due to lower aquifer levels from groundwater pumping or prolonged drought, the reduction in available habitat is unlikely to be short term;

therefore, a population rebound would not be expected. Populations would either reach equilibrium at their new, smaller habitat footprint, or they would be extirpated, depending on the extent of the reduction. Because we are not able to predict the extent or location of spring flow reductions, we discuss how population resiliency would vary under each of the three potential spring flow scenarios:

Scenario 1: No measurable drop in spring flow

If expected future groundwater decline does not result in a measureable loss of spring flow over the next 50 years, most Page springsnail populations are expected to maintain their current levels of resiliency. Habitat improvement activities will continue under current management and a renewed CCAA, so resiliency may actually increase in some populations. The two populations not managed by AGFD may lose some resiliency if the landowners modify the springs, though we have no information indicating that those springs will be directly modified.

If a stochastic event occurs that reduces or eliminates a population on land managed by AGFD, management actions would be undertaken by AGFD to attempt to remediate the situation. Actions could include installation of protective features such as fences, habitat creation or restoration, and/or population reintroduction.

The populations would be likely to retain or improve their overall condition, as presented in Table 3.1, with six populations in good condition and therefore with high resiliency, and three populations in moderate condition and therefore moderate resiliency. Populations may experience short term reductions in numbers and density, but given appropriate management actions as outlined in the CCAA, they would rebound or be reintroduced in most cases. At most, the two populations on private land may be extirpated due to stochastic events or land management, but the eight populations managed by AGFD would remain secure.

Scenario 2: Spring flow is reduced but not eliminated

If, over the next 50 years, groundwater decline leads to a reduction (although not dramatic) of spring flows, those populations that experience reduced spring flow will have less resiliency than they currently do. Populations would lose resiliency as they lose habitat. Because these populations are in relatively close proximity to one another, we can presume that if spring flow declines, it would be likely to decline to some degree at all locations. This is to say we expect springs currently characterized by lower discharge would be affected more extremely. A loss or reduction of spring flow across all springs would result in a loss of population resiliency at all locations. Currently, six populations are considered to be in good condition (= high resiliency) and three in moderate condition (= moderate resiliency). Some reduction in spring flow would change the resiliency of populations, so that four populations would have moderate resiliency and four would have poor or low resiliency (Table 5.1).

Key assumption: Due to the proximity of the springs to one another and our uncertainty of the hydrogeology of the springs, we assume that **a drop in spring flow due to a loss of groundwater would occur across all locations approximately equally**.

Scenario 3: Spring flow is extremely reduced or eliminated

Near loss of spring flow would result in loss or near loss of populations. Elimination of spring flow would be catastrophic and likely result in the extirpation of affected populations. If groundwater level reduction translated to a loss of spring flow to this degree, we would expect many, if not all, populations to be extirpated, and any remaining populations would be in poor or low condition.

Table 5.1. Conditions of Page springsnail populations in 50 years under spring flow scenario 2. Rankings are a qualitative assessment of the relative condition of spring ecosystems based on the knowledge and expertise of Service staff, Arizona Game and Fish Department, and other technical experts and resource professionals (see Table 3.2 for more information). High: spring ecosystem is functioning near an optimum level for this resource need and there is little room for improvement. Moderate: spring ecosystem is functioning somewhat well for this resource need and there is room for improvement. Low: spring ecosystem is functioning at a less than optimal level for this resource need and there is significant room for improvement. Overall condition was determined based on an average of the other factors. The factor "Adequate spring discharge" was given twice as much weight as the other factors because we believe it is the most important and drives the other factors.

Future Conditions of Page Springsnail Populations (Spring Flow Scenario 2)

	Factors				
Spring/Population	**Adequate spring discharge**	**Sufficient water quality**	**Free-flowing spring ecosystem**	**Sufficient substrate and aquatic vegetation**	**Overall Condition in 50 years**
Drain Pipe	Low	Moderate	Low	Low	Low
Cave	High	High	High	High	High
Ash Tree	Low	Moderate	Low	Moderate	Low
Rusty Pipe	Low	Low	Low	Low	Low
Bog	Low	Low	Moderate	Low	Low
Bubbling Outflow	High	High	High	High	High
Bass House Pond	Moderate	Moderate	Low	Moderate	Moderate
Bass House Weir	Moderate	Moderate	Moderate	Moderate	Moderate
Spring Creek	Moderate	Moderate	Moderate	Moderate	Moderate
Lo Lo Mai Outflow	Moderate	Moderate	Moderate	Moderate	Moderate

5.3. Redundancy

Redundancy is having sufficient numbers of populations for the species to withstand catastrophic events. A catastrophic event is defined here as a rare destructive event or episode involving many populations. The most likely catastrophic event for the Page springsnail would be the loss of spring flow to occupied habitats. Drought and/or an increase in groundwater pumping in and around the Verde Valley could lead to spring flow decline or loss. As an endemic organism, the Page springsnail's range is naturally quite small, so it is not possible for this species to exhibit redundancy over a relatively large geographic area, which would provide some protection from local spring flow decline.

We evaluated redundancy under the same potential spring flow scenarios:

Scenario 1: No measurable drop in spring flow

Under this scenario, spring flow would not decline in response to the projected levels of groundwater depletion, and we would expect most, if not all, populations to persist. The two populations on private land could be extirpated due to stochastic events and the implementation of adverse land management activities. However, with the exception of previously planned residential development adjacent to Spring Creek, we are unaware of currently planned activities at this time. The eight populations managed by AGFD under the CCAA are expected to persist.

Figure 5.1 depicts the current resiliency of Page springsnail populations across the range of the species. The bulk of the populations with moderate or low resliency occur on AGFD lands, where active management is occuring to maintain or increase population condition.

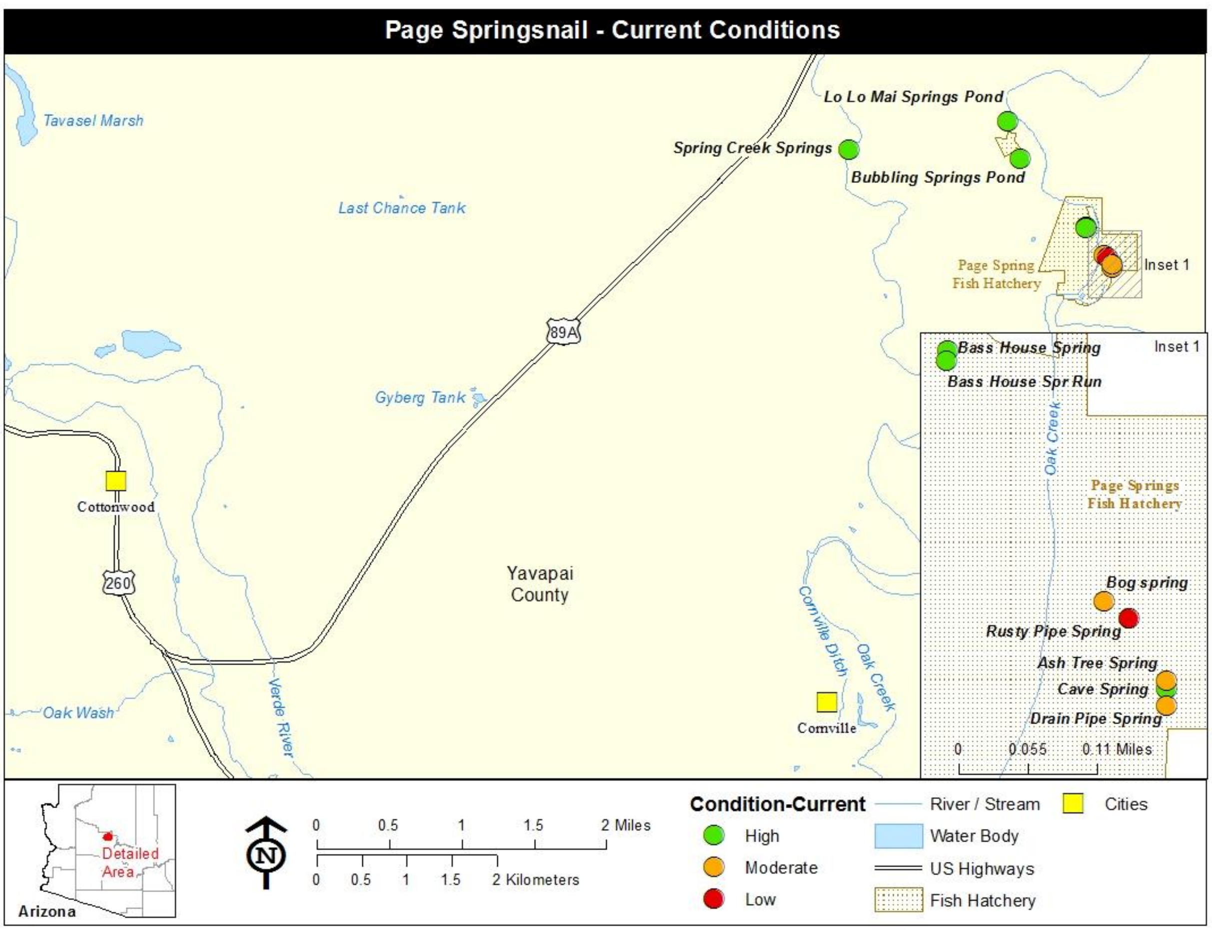

Figure 5.1. Current resiliency of Page springsnail populations rangewide.

Scenario 2: Spring flow is reduced but not eliminated

Under this scenario, we assume that all populations would exhibit some drop in resiliency, such that some springs that currently have high resiliency would have moderate resiliency, and some that currently have moderate resiliency would have low resiliency (Table 5.1). Spring flow decline may result in several populations with low resiliency being extirpated. We expect that the six populations that would likely have high or moderate resiliency would persist. Under this scenario, we project that Drain Pipe, Ash Tree, Rusty Pipe, and Bog springs would likely exhibit low resiliency and have a high likelihood of extirpation. However, these populations are actively managed by AGFD and the loss of resiliency within those populations may be offset by management actions under current management or a renewed CCAA that would help ensure persistence and redundancy (e.g. translocations to spring sites currently unoccupied).

Figure 5.2 depicts the resiliency of the Page springsnail populations in 50 years under this spring flow scenario. Populations not on hatchery land are likely to maintain high or moderate resiliency, and those predicted to have low resiliency are on AGFD lands. The ongoing management by AGFD will help to ensure that those streams with less resiliency will remain flowing and with suitable habitat, reducing the likelihood that they will in fact be in low condition in the future. AGFD's track record of stable or increasing populations under active management lends some security to those populations that we were unable to capture in the habitat assessment.

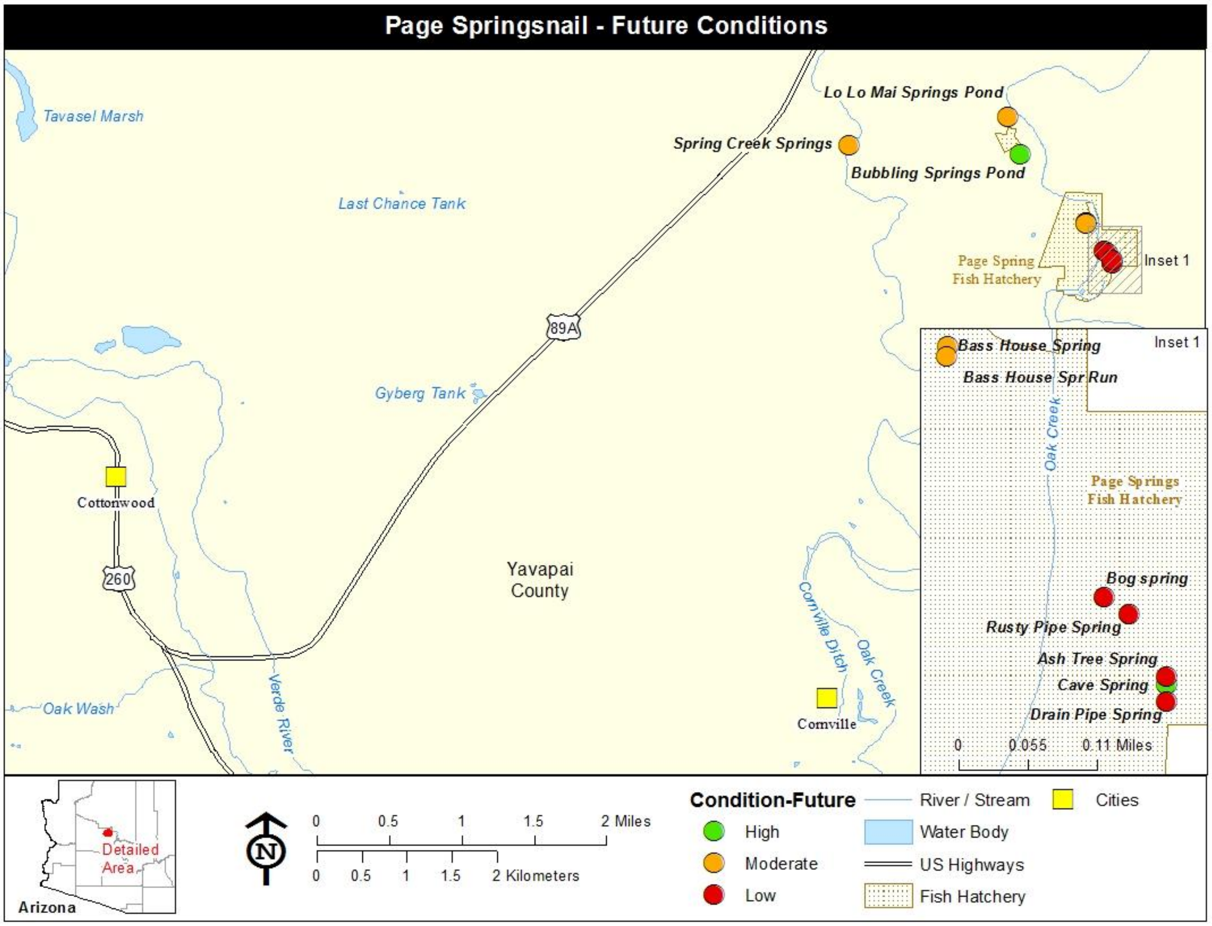

Figure 5.2. Future conditions of Page springsnail populations rangewide, under spring flow scenario 2.

Scenario 3: Spring flow is extremely reduced or eliminated

Under this scenario, the overall condition of most populations is expected to be low, and redundancy would be expected to be greatly reduced as the widespread loss of spring flow results in population extirpations. While we expect that all populations would experience dramatic habitat loss, variations in distance from wells and in groundwater hydrology will likely result in variations in the timing and rates of complete desiccation of springheads and spring runs. However, any Page springsnail populations that persist in locations that retain some level of flow will likely have low resiliency and be extremely vulnerable to extirpation.

5.4. Representation

Representation is having the breadth of genetic and ecological diversity of the species to adapt to changing environmental conditions. The Page springsnail exhibits some genetic diversity between Bubbling Springs and Page Springs, but in general the genetic diversity in this species appears to be limited or unknown. Although we are not aware of any specific ecological diversity across the species' range that might be important for future adaptation, it would be prudent to maintain as much geographic extent of the species' range as possible to maintain any potential, but undetected, ecological diversity. To ensure adequate representation, it may be important to retain populations across the Page springsnail's current range to maintain the species' overall potential genetic and life history attributes, buffering the species' response to environmental changes over time.

We evaluated representation under the same potential spring flow scenarios.

Scenario 1: No measurable drop in spring flow

Under this scenario, spring flows would be maintained throughout the Page springsnail's range over the next 50 years. Representation across the range would be maintained at current levels providing for the preservation of the current level of respresentation.

Scenario 2: Spring flow is reduced but not eliminated

Under this scenario, we assume that several populations would exhibit a drop in resiliency over the next 50 years, such that some springs that currently have high resiliency would have moderate resiliency, and some that currently have moderate resiliency would have low resiliency, as described above. If those populations with low resiliency are extirpated, the Page springsnail would experience a loss of representation. Those populations that may be extirpated are Drain Pipe, Ash Tree, Rusty Pipe, and Bog springs. While these springs are distributed throughout the overall species' range, there are other occupied locations that are expected to persist. The Page springsnail would experience some loss of representation but it would not eliminate the species entirely from a substantial geographical portion of the overall range.

Scenario 3: Spring flow is extremely reduced or eliminated

Under this scenario, we expect that over the next 50 years many, if not all, Page springsnail populations would be extirpated, with perhaps only a few populations with low resiliency remaining. We are unable to predict where any populations would persist, and the species would lose a large amount of representation rangewide.

5.5. Status Assessment Summary

We used the best available information to forecast the likely future condition of the Page springsnail. Our goal was to describe the viability of the species in a manner that will address the needs of the species in terms of resiliency, redundancy, and representation. We considered the possible future condition of the species. We considered a range of potential scenarios that we think are important influences on the status of the species. Our results describe a range of possible conditions in terms of how many and where Page springsnail populations are likely to persist into the future.

With the exception of the risk from groundwater depletion, management actions undertaken via the CCAA with AGFD have ameliorated the bulk of the risks to Page springsnail populations and are expected to continue in the future. These same management actions play a large role in the future viability of the Page springsnail. If populations lose resiliency due to decline of spring flow, their persistence will likely depend on habitat enhancements and reintroductions conducted by AGFD, and captive propagation conducted by the Phoenix Zoo. Spring flow is the largest factor affecting future persistence of the Page springsnail.

Under scenario 1, we would expect the Page springsnail's viability to be characterized by the same level of resiliency, redundancy, and representation that it exhibits under the current condition. We anticipate at least eight of the 10 current populations to persist and perhaps even experience range expansion.

Under scenario 2, it is projected that in 50 years two populations will exhibit high condition, four will exhibit moderate condition, and four will exhibit low condition. It is expected that populations that exist in high and moderate conditions (six of 10) will continue to exhibit adequate levels of resiliency to continue to persist because suitable habitats will continue to be available. Although redundancy will be reduced, members of the genus *Pyrgulopsis* are often characterized by a few isolated populations that continue to persist, perhaps because the genus is evolutionarily adapted to geographic isolation over geologic time. Although representation will likely be reduced, it is expected that Cave/Page Springs and Bubbling Springs will continue to persist. These two sites contain much of the known genetic diversity for the species. As such, we expect in 50 years, under scenario 2, the Page springsnail's viability will be characterized by populations in six springs exhibiting varying levels of resiliency.

Under scenario 3 we would expect the species viability to be characterized by catastrophic losses of resiliency, redundancy, and representation. Many, if not all springs are expected to entirely lose flowing water, resulting in widespread extirpation of populations.

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Appendix A

Evaluating Causes and Effects for Page Springsnail Species Status Assessment

Template for Cause and Effects Evaluation

THEME: ?			
[ESA Factor(s): ?]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	*What is the ultimate source of the actions causing the stressor?*	See next page for confidences to apply at each step.	Literature Citations, with page numbers , for each step.
- Activities	*What is actually happening on the ground as a result of the action?*		
STRESSOR(S)	*What are the changes in evironmental conditions on the ground that may be affecting the species?*		
- Affected Resource(s)	*What are the resources that are needed by the species that are being affected by this stressor?*		
- Exposure of Stressor(s)	*Overlap in time and space. When and where does the stressor overlap with the resource need of the species (life history and habitat needs)?*		
- Immediacy of Stressor(s)	*What's the timing and frequency of the stressors? Are the stressors happening in the past, present, and/or future?*		
Changes in Resource(s)	*Specifically, how has(is) the resource changed(ing)?*		
Response to Stressors: - INDIVIDUALS	*What are the effects on individuals of the species to the stressor? (May be by life stage)*		
POPULATION & SPECIES RESPONSES	*[Following analysis will determine how do individual effects translate to population and species-level responses? And what is the magnitude of this stressor in terms of species viability?]*		
Effects of Stressors: - POPULATIONS [RESILIENCY]	*What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc)?*		
- SCOPE	*What is the geographic extent of the stressor relative to the range of the species/populations? In other words, this stressor effects what proportion of the rangewide populations?*		

Effects of Stressors: **- SPECIES (Rangwide)** **[REDUNDANCY]**	*What are the expected future changes to the number of populations and their distribution across the species' range?*		
Effects of Stressors: **- SPECIES (Rangwide)** **[REPRESENTATION]**	*What changes to the genetic or ecology diversity in the species might occur as a result of any lost populations?*		
RISK OF EXTIRPATION **2065**	*Based on this analysis, how do we characterize the risk of populations being extirpated from this stressor over the next 50 years (by 2065)?*		

This table of Confidence Terminology explains what we mean when we characterize our confidence levels in the cause and effects tables on the following pages.

Confidence Terminology	Explanation
Highly Confident	We are more than **90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by documented accounts or research and/or strongly consistent with accepted conservation biology principles.
Moderately Confident	We are **70 to 90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Somewhat Confident	We are **50 to 70% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Low Confidence	We are less than **50% sure** that this relationship or assumption accurately reflects the reality in the wild, as there is little or no supporting available information and/or uncertainty consistency with accepted conservation biology principles. Indicates areas of high uncertainty.

THEME: Springhead Modification			
[ESA Factor(s): E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	The source of spring modification comes from human activity for domestic, agricultural, ranching, fish hatchery, and recreational needs.	**Highly confident**	
- Activities	**Historic:** Human activity has historically contributed to widespread modification of the species' habitats resulting in the loss of natural springhead integrity and, in some instances, the elimination of the aquatic environment. It is reported that the cienega at Turtle Springs had been landscaped with a backhoe in the past, which could have resulted in habitat destruction and/or modification. In the 1950s, a small wooden shed was placed over Bass House Springs to prevent leaves and other debris from clogging the water line that supplies hatchery runways. This cover may have prevented sunlight from reaching the springhead, potentially limiting primary productivity and the production of periphyton, an important food source for springsnails. Portions of the Page Springs complex were diverted into an underground water collection gallery to improve fish production and meet fisheries management needs, resulting in the capping of several springheads and the loss of surface water and springsnail habitat. The AGFD estimated that approximately one acre (0.405 ha) of surface water was lost through collection pond capture and a half acre was lost through field capture, with resulting reduction in springsnail numbers. It is unlikely Page springsnails persist in the underground collection gallery. Page springsnail was previously extirpated from the springhead pool at Bass House Springs but has recently recolonized this site. The species has not been found during recent surveys at Turtle Springs. The species still occupies the remnants of Page Springs on hatchery property. **Current and Future:** Bass House Springs and the remnants of Page Springs are under the management of AGFD and are not expected to be exposed to further modifications. Turtle Springs is located on private property, and we are unaware of the land use plans of the landowner.	**Highly confident** in historic activities resulting in spring modifications **Moderately confident** in the level of modification occurring currently and in the future.	Bills 1993, p. 2 AGFD 1988, p. 2 AGFD 1991, p. 3 Raisanen 1991, p. 71
STRESSOR(S)	Spring modification alters or eliminates habitat for springsnails.	**Highly confident**	
- Affected Resource(s)	Springsnail habitat- water quantity, quality, and substrate		

THEME: Springhead Modification			
[ESA Factor(s): E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Exposure of Stressor(s)	**Historic:** Turtle Springs, Bass House Springs have been modified in the past by human activities. **Current and Future:** We are unaware of any plans to modify springs and we do not anticipate any springs on hatchery property will be modified in the future. Only 2 of the 10 extant springs (those on private land) have any possibility of modification.	**Moderately confident**	
- Immediacy of Stressor(s)	**Historic:** Springs were modified as needed by landowners for various purposes. **Current and Future:** Most Page springsnail springs are located on AGFD lands and are not modified. Additionally, previously modified springs have been restored to suitable habitat under the CCAA. See "Management Actions" tab for a discussion of the actions being taken under the CCAA.	**Highly confident**	
Changes in Resource(s)	Spring modifications that decreased or eliminate habitat quality result in a decreases in population numbers or elimination of populations	**Moderately confident**	
Response to Stressors: **- INDIVIDUALS**	Springsnail densities will decrease in lesser quality habitat or be extirpated if habitat eliminated		
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	Springsnail densities will decrease in lesser quality habitat and could reach levels where populations are lost.	**Moderately confident**	
- SCOPE	**Historic:** Springs were readily modified for various land management and other human needs across the range of the species. **Current and Future:** AGFD has ceased spring modification and has restored several previously modified springs. We do not expect the majority of Page springsnail locations to be modified in the future.	**Historic: Highly confident** **Current and Future: Highly confident** in the low likelihood of spring modification	
Effects of Stressors: **- SPECIES (Rangwide) [REDUNDANCY]**	If populations are lost or reduced in the future, then overall redundancy will decline.	**Highly confident**	
Effects of Stressors: **- SPECIES (Rangwide) [REPRESENTATION]**	Any future loss of populations is expected to reduce overall genetic and ecological diversity of the species and may limit the species' representation.	**Somewhat confident**	

THEME: Springhead Modification			
[ESA Factor(s): E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
RISK OF EXTIRPATION 2065	**Modified springs** have a moderate risk of extirpation. **Unmodified or restored springs** have a very low risk of extirpation. The likelihood of continued modification of spring habitats occupied by Page springsnail is low.The risk of extirpation in the future is extremely low because springsnails are unlikely to be exposed to the detrimental effects of spring modification on a significant scale.		

THEME:Conversion from Lotic to Lentic Systems			
[ESA Factor(s): C,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Human activity to meet water needs for domestic, agricultural, ranching, fish hatchery, and recreational purposes.	**Highly confident.**	
- Activities	**Historic** At least five springs currently or formerly occupied by the Page springsnail appear to have been converted, to some degree, from free-flowing systems to ponds which are less conducive to occupation by the species. Impoundments resulting in inundation or pooling above springheads has occurred at several sites, including Lo Lo Mai Springs, Bubbling Springs, Turtle Springs, Shea Springs, and Bass House Springs. **Current and Future:** These springs continue to exist as ponds and pools, and are expected to remain in this state into the future. No additional springs are expected to be converted to ponds.	**Highly confident** about historic conversion to ponds.	Service 2007 Service 2009
STRESSOR(S)	Inundated springs are typically characterized by pooling over spring vents which results in lowered flow velocity and increased sedimentation with fine substrates. The Page springsnail occurs more often and in greater numbers in gravel and pebble substrates, while occurring less often and in fewer numbers in sand and silt substrates. Analysis of field data demonstrates that density of Page springsnail is lower in pond environments versus free-flowing environments ($Z = 5.832$, $df = 92$, $P < 0.001$). Outflow channels continue to provide good habitat for springsnails. Because springsnails are typically found in shallow flowing water, inundation that alters springsnail habitat by changing water depth, velocity, substrate composition, vegetation, and water chemistry can cause population reduction or extirpation. For example, inundation has negatively affected populations of other springsnails such as Koster's springsnail (*Juturnia kosteri*) and Roswell springsnail *(Pyrgulopsis roswellensis*) at Bitter Lake National Wildlife Refuge and caused their extirpation from a previously occupied spring.	**High confident** that lowered flow velocity and increased sedimentation result in habitat conditions that are correlated with lower Page springsnail densities	Martinez and Thome 2006, p. 8 Service unpublished data New Mexico Department of Game and Fish 2004, p. 33
- Affected Resource(s)	Flow velocity, substrate, water depth, and water quality	**Highly confident**	
- Exposure of Stressor(s)	Lo Lo Mai Springs, Bubbling Springs, Turtle Springs, Shea Springs, and Bass House Springs have been converted to ponds. Within pooled areas, these sites exhibit slower flow and finer substrates, which are typically less conducive to springsnail occupation	**Highly confident**	

THEME:Conversion from Lotic to Lentic Systems			
[ESA Factor(s): C,E]	Analysis	Confidence / Uncertainty	Supporting Information
- Immediacy of Stressor(s)	**Historic:** Although we anticipate that modified springs will be maintained as ponds, it is important to note that the species has continued to survive in these areas, albeit at lower densities. Additionally, several outflow channels at ponds are inhabited by an abundance of springsnails. **Current and Future:** Springs are no longer being converted to ponds. Some outflow channels provide important habitats and refugia, and their maintenance may be critical. See "Management Actions" tab for a discussion of the management of the springs under the CCAA.	**Historic: Highly confident** **Current and Future: Highly confident** that springs will no longer be converted to ponds.	
Changes in Resource(s)	Flow velocity, substrate, water depth, and water quality	**Highly confident**	
Response to Stressors: - INDIVIDUALS	Individuals will not occupy unsuitable habitat. Springsnail density in lentic areas will decrease.	**Highly confident**	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Populations in lentic areas occur at lower densities than those in lotic habitats. These smaller populations are anticipated to be less resilient.	**Moderately confident**	
- SCOPE	**Historic:** Five springs have been converted to ponds. **Current and Future:** We anticipate additional springheads will not be converted to ponds.	**Highly confident**	
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	If springs are converted to ponds, redundancy may decline if those populations are extirpated.	**Moderately confident**	
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	Any future loss of populations will reduce overall genetic and ecological diversity of the species, further limiting the subspecies' representation.	**Moderately confident**	
RISK OF EXTIRPATION 2065	Although smaller populations are typically more vulnerable, these populations have persisted and adapted to current conditions. Any springs converted in the future would have a moderate risk of extirpation. However, the majority of Page springsnail locations are owned by AGFD and were previously covered by the CCAA and will not be converted under current management. We expect current managment that avoids springs conversion to continue into the future; therefore, the risk of extirpation due to springs being converted to lotic systems is low.		

THEME: Reduced Spring Discharge			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Groundwater pumping and drought can reduce aquifer storage and lead to reduced outflow from springheads.	**Highly confident** that groundwater pumping and climate change will reduce groundwater storage and stream base flow in the Verde Valley. **Low confidence** this will result in measurable effects to the loss of water flow from springs.	
- Activities	Municipal and industrial groundwater pumping. Climate change is expected to exacerbate drought conditions, which may lead to less aquifer recharge. Human population growth may lead to increased groundwater pumping.	**Low confidence** that groundwater use will result in reduction of spring flows.	Owens-Joyce and Bell 1983, pp. 1, 65 AGFD 1988, p. 2, 14 Raisanen 1991, p. 71 McGavock 1996, p. 67 Seager et al. 2007, p. 1181 ADWR 2009; IPCC 2014, p. 51
STRESSOR(S)	Groundwater storage in the Verde River Watershed has already declined due to groundwater pumping and reductions in natural channel recharge resulting from streamflow diversions and inadequate precipitation. Base flow in the Verde River decreased between 1910 and 2005 and is expected to continue to decrease into the future. Future groundwater levels in the Verde Valley Basin and stream base flows along the Verde River and Oak Creek are expected to decrease in response to projections of increased pumping. These lowered water levels may lead to reduced spring discharge, although we are unable to predict the future status of spring discharge from spring complexes along Oak Creek. Increases in the frequency or intensity of ecosystem disturbances such as drought have been detected in many parts of the world and in some cases are attributed to climate change. Climate change over the 21st century is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions. Some models indicatae widespread persistent drought in the latter half of the 21st century.	**Highly confident**	Overpeck and Weiss 2005, p. 2074 Blasch et al. 2006, p. 2 Archer and Predick 2008, p. 24 Leake and Haney 2010 Woodhouse et al. 2002 Garner and Pool 2013 Garner et al. 2013 Leake and Pool 2010; IPCC 2014, p. 51, 69 Ault et al 2014 Cook et al 2015

THEME: Reduced Spring Discharge			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Affected Resource(s)	Habitat quantity is reduced or eliminated in springs experiencing a loss or reduction of surface water. Anticipated to effect all springs equally.	**Highly confident**	
- Exposure of Stressor(s)	If pumping of the aquifer were to substantially alter water flow toward the Oak Creek Springs complex, much of the habitat currently occupied by the Page springsnail could be adversely affected. Wells drilled into the aquifer supporting the Oak Creek Springs complex could affect spring flow. An analysis of water flow rate from Page Springs between 1996 and 2000, detected a decline of approximately 1 cfs (2.8 cubic m per second) or a 15 percent decline in flow. Drought conditions and groundwater pumping may have played a role in spring flow declines. Arizona Department of Water Resources records show that numerous wells have been drilled in close proximity of Cave Springs. At least two of these wells pump between 1200 and 1500 gallons (4.5 and 5.7 m^3) per minute, and are within 0.75 mi (1.2 km) of Cave Springs. Given their proximity, production rate, and hydrological connectivity, groundwater withdrawal by these wells could have a direct impact on flow at Cave Springs. However, the impact of these wells on the spring cannot be determined without long-term aquifer tests and simultaneous discharge monitoring at Cave Springs Residential development has been planned near Spring Creek, habitat for the Page springsnail. Groundwater pumping would likely increase as a result. This project is currently on hold. The springs complex formerly known as Page Springs was diverted into an underground water collection gallery to improve fish production and meet fisheries management needs in 1990, reducing surface flow.	**Moderately confident**	Mitchell 2001, pp. 1,6 Overpeck and Weiss 2005, p. 2074 Blasch et al. 2006, p. 2 Archer and Predick 2008, p. 24 Leake and Haney 2010 Woodhouse et al. 2002; Garner and Pool 2013 Garner et al. 2013 Leake and Pool 2010 Owens-Joyce and Bell 1983, pp. 1, 65 AGFD 1988, p. 2, 14 Raisanen 1991, p. 71 McGavock 1996, p. 67 Seager et al. 2007, p. 1181 ADWR 2009; AGFD and Service 2009, p. 37

THEME: Reduced Spring Discharge			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Immediacy of Stressor(s)	**Historic:** Groundwater withdrawal has already affected the hydrologic system of the Verde Valley. As of 2005, annual base flow at the Clarkdale gauge had decreased 4,900 acre-ft/yr due to human stresses to the groundwater system between 1910 and 2005, while the Camp Verde gauge indicated a decrease of 10,000 acre-ft/yr during the same period. Water flow from Page Springs between 1996 and 2000 declined approximately 1 cfs (2.8 cubic m per second) or 15 percent of flow. The 5-year period coincided with a drought period, making it difficult to determine which factors are responsible for the decline in flow. Drought conditions and groundwater pumping may have played a role in spring flow declines, and both of these are expected to increase in the future. **Future:** Climate change is predicted to cause increased drought and temperature, resulting in future surface water loss. It is anticipated that base flow in the Verde Valley will continue to decrease into the future (2005-2110). Climate change is expected to result in greater water demand by people, plants, and animals, and drought will become more likely. Potential decreases in long term preciptation could be detrimental to stream flow and spring discharge, though quantifying these effects is difficult. Although reductions will reduce base flow and groundwater storage in the Verde Valley, there is no information available quantifying the effect on spring discharge along Oak Creek and Spring Creek. Due to the reliance on groundwater, it seems reasonable to assume that spring flow would be negatively affected to some degree. However, the available information does not indicate that spring flow will be signficantly affected or cease altogether. If spring flow continues to be maintained into the future, it is expected to continue to provide habitat for Page springsnail populations.	**Moderately confident**	Overpeck and Weiss 2005, p. 2074 Blasch et al. 2006, p. 2 Archer and Predick 2008, p. 24 Leake and Haney 2010 Woodhouse et al. 2002 Garner and Pool 2013 Garner et al. 2013 Leake and Pool 2010
Changes in Resource(s)	Reduced surface water results in reduced habitat quantity or elimination of habitat.	**Highly confident**	
Response to Stressors: **- INDIVIDUALS**	Fewer springsnails will survive with less habitat available	**Highly confident**	

THEME: Reduced Spring Discharge			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Smaller populations occuring over smaller areas have less resiliency than larger populations over larger areas.	**Highly confident**	
- SCOPE	Municipal and industrial reliance on groundwater is continually growing to meet the demands of an expanding human population in the Verde Valley. Certain characteristics make a spring more or less vulnerable to surface flow loss. In particular, their connection to groundwater in general, and the specific hydrological characteristics of the spring such as discharge rate. As discussed above, groundwater withdrawals and climate change are expected to continue to contribute to reductions in base flow and groundwater storage in the Verde Valley. Although we are unable to predict if or where springs will be affected, or whether or not flow will cease altogether, it seems likely flow will be affected to some degree. Certain models indicate persistent widespread drought may occur towards the end of the 21st century; however, there is significant uncertaintly surround when or where that sort of significant may occur that far into the future.	**Moderately confident**	Jaeger et al 2014 Garner et al 2013 Ault et al 2014 Cook et al 2015
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	If populations are lost due to loss of surface water flow, overall redundancy will decline.	**Highly confident**	
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	Any future loss of populations can reduce overall genetic and ecological diversity of the species, further limiting the species' representation.	**Moderately confident**	

THEME: Reduced Spring Discharge			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
RISK OF EXTIRPATION 2065	**Scenario 1:** Sring flow is maintained and habitat for Page springsnail populations is not decreased due to groundwater pumping or drought. In this scenario, there is a very low risk of extirpation due to loss of spring flow. **Scenario 2:** Spring flow is reduced to some degree, resulting in the loss of habitat for some populations, increasing their risk of extirpation. **Scenario 3:** Spring flow is assumed to be extremely reduced or eliminated, resulting in catastrophic loss of habitat and populations. See the SSA Report, Chapter 5 for our specific projections under each scenario. In the next 35-50 years, we do not expect all populations to be extirpated due to loss of spring flow. The risk increases over time and depends on the hydraulic relationship between the spring and the aquifer.		

THEME: Aquatic Vegetation Removal			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Fish hatchery management	**Highly confident**	
- Activities	Periodic physical and mechanical removal of emergent and submerged native or nonnative vegetation (including algae) to improve water flow to fish hatchery.	**Highly confident**	
STRESSOR(S)	This activity can result in direct mortality from crushing and desiccation, and indirect mortality through habitat modification and water quality changes.	**Highly confident**	
- Affected Resource(s)	Aquatic habitat (providing breeding, feeding, and sheltering areas). Water with cool temperatures and high dissolved oxygen content.		
- Exposure of Stressor(s)	In the past, vegetation was periodically removed from Bubbling Springs pond and outflow, and Bass House Springs pond to improve water flow to the hatchery.	**Highly confident**	
- Immediacy of Stressor(s)	**Past:** Aquatic vegetation and algae have been removed from springs and outflows to improve water flow to hatchery raceways. **Current and Future:** Vegetation removal does not occur at the same rates nor using the same methods as in the past. AGFD has incorporated measures to reduce the impact of this activity on Page springsnail.	**Highly confident**	J. Sorensen, AGFD, 2012, pers. comm. Raisanen 1991, p. 99 AGFD and Service 2009, p. 15 Service 2007, p. 8
Changes in Resource(s)	Vegetation removal changes the physical attributes of habitat. Vegetation provides shelter and a substrate for foraging and carrying out basic life history functions.	**Moderately confident**	
Response to Stressors: **- INDIVIDUALS**	Crushed springsnails die. Feeding and sheltering habitat is lost overall when aquatic vegetation is removed.	**Highly confident**	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	Removal of aquatic vegetation and organic debris can result in direct snail mortality from crushing and desiccation, and indirect mortality through habitat loss and modification. Loss of individual snails and habitat can result in reduction of population sizes, which reduces population resiliency.	**Highly confident**	
- SCOPE	Vegetation removal has occurred at Bubbling Springs pond and outflow channel, Bass House Springs springhead, and Lo Lo Mai Springs.		

THEME: Aquatic Vegetation Removal			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	Losses of populations will reduce redundancy.	**Moderately confident**	
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	Any future loss of populations can reduce overall genetic and ecological diversity of the species, further limiting the species' representation.	**Moderately confident**	
RISK OF EXTIRPATION 2065	The CCAA calls for landowners, including AGFD, to prevent future detrimental habitat modification that reduces the threat from mechanical removal of vegetation. Specifically, under the CCAA, no more than 10 percent of aquatic, springsnail-occupied habitat is disturbed during management activities, and springsnails that are removed during management are salvaged. Although AGFD may occasionally remove vegetation from the drain gate at Bubbling Springs Pond, they rarely remove algal mats or aquatic vegetation from aquatic habitats occupied by the species (last done in July 2005). When vegetation is removed, they place the vegetation along the banks and in the water to prevent desiccation of individual springsnails. We expect these management actions that reduce the likelihood of deterimental effects to continue into the future, resulting in the risk of extirpation from aquatic vegetation removal being extremely low.	**Highly confident**	

THEME: Water Contamination			
[ESA Factor(s): C]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Historic hatchery management activities.	**Highly confident**	
- Activities	Chemical and physical treatments at fish hatchery facilities to reduce the spread of diseases and parasites. Potential contamination from septic tank leakage.	**Highly confident**	
STRESSOR(S)	The use of rotenone and chlorine harm or kill Page springsnails, as can septic waste.		Linberg 2010
- Affected Resource(s)	Individuals exposed to the chemicals may die.		
- Exposure of Stressor(s)	Any snails in the area of the chemical are exposed.	**Highly confident**	
- Immediacy of Stressor(s)	**Past:** The Page Springs and Bubbling Ponds fish hatcheries have used various chemical and physical treatments to reduce the spread of fish diseases and parasites, including dewatering, and disinfection with rotenone and chlorine. **Current and Future:** The AGFD no longer uses chlorine for treating fish diseases in springs. The AGFD continues to utilize rotenone but implements springsnail salvage and monitoring during treatment operations to reduce negative effects. It is possible that unregulated septic leakage could contaminate groundwater through hidden sinkholes within the town of Sedona and lead to contamination of the Page Springs outflow. Sinkholes are known to occur just over two miles upstream of these spring complexes but we no information indicating contamination	**Highly confident**	Landye 1981, p. 33 AGFD 1991, p. 3; 1998, p. 6 Lindberg 2010, p. 1 Ward et al. 2010
Changes in Resource(s)	Rotenone is a commonly used piscicide that acts as a respiratory inhibitor resulting in physiological suffocation by acting on gills. Chlorine is often used as a water disinfectant and is known to be toxic to aquatic organisms.		Wiley and Wydoski 1993, p. 341 Sprague 1990, p. 506
Response to Stressors: **- INDIVIDUALS**	Physiological suffocation and death to rotenone exposure at or above 2-4 ppm. Toxic shock and death from exposure to chlorine.	**Moderately confident**	Landye 1981, p. 33 Ward et al 2010
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	Loss of individuals may result in reduction of population sizes, which reduces population resiliency. However, if the chemical is cleared from the system in a short period of time, springsnails may be little affected.	**Moderately confident**	

THEME: Water Contamination			
[ESA Factor(s): C]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- SCOPE	To our knowledge, only Bubbling Springs has been exposed to treatment in the recent past.		
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	The loss of populations, if it occurred, would result in a reduction of redundancy.	**Moderately confident**	
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	The loss of populations, if it occurred, would result in a reduction of representation.	**Moderately confident**	
RISK OF EXTIRPATION 2065	Under the CCAA effort, springs are protected from herbicides or other chemicals unless determined in advance by AGFD and Service not to negatively impact the species. We expect this management strategy to continue into the future, greatly reducing the risk of extirpation because springsnails would be unlikely to be exposed to lethal levels of contamination.		

THEME: Predation			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Waterfowl, fish, and crayfish	**Highly confident**	
- Activities	Page springsnails may be predated upon by ducks, other waterfowl, mosquitofish (*Gambusia affinis*), and nonnative crayfish (*Orocnectes virilis*).	**Moderately confident**	
STRESSOR(S)	Springsnails that are eaten die.	**Highly confident**	
- Affected Resource(s)	Individual springsnails		
- Exposure of Stressor(s)	Predators occur at all extant Page springsnail locations. Ducks and other migratory waterfowl are known to utilize Lo Lo Mai Spring Pond and Bubbling Springs Pond. Remnants of Page springsnail shells have been found in analyses of stomach content of mosquitofish from the Oak Creek Springs complex. Nonnative crayfish have been observed near Bubbling Springs Pond and are abundant within the Verde Valley.		Raisanen 1991, p. 71
- Immediacy of Stressor(s)	Predation is a natural phenomenon that we expect is currently occurring and expect to remain at similar levels as in the past.	**Moderately confident**	Fernandez and Rosen 1996, p. 23
Changes in Resource(s)	Springsnails that are eaten die.	**Highly confident**	
Response to Stressors: - INDIVIDUALS	Springsnails that are eaten die.	**Highly confident**	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	It is unlikely predation occurs to a degree that affects population resiliency. We are unaware of any potential link to decreased abundance from predation.	**Moderately confident**	
- SCOPE	Predators occur at all extant Page springsnail locations.	**Highly confident**	
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	We do not expect an effect of predation on the species' redundancy because we do not expect it to occur at levels high enough to affect resiliency.	**Highly confident**	
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	We do not expect an effect of predation on the species' redundancy because we do not expect it to occur at levels high enough to affect resiliency.	**Highly confident**	
RISK OF EXTIRPATION 2065	Predation is not known to be negatively affecting any population of Page springsnail. If this remains the case into the future, the risk of extirpation due to the effects of predation will continue to be minimal.		

Evaluating Cause and Effects for Page Springsnail Species Status Assessment

THEME: New Zealand Mudsnail			
[ESA Factor(s): E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	The New Zealand mudsnail (*Potamopyrgus antipodarum*) is an invasive freshwater snail of the family Hydrobiidae that is known to compete with and slow the growth of native freshwater snails, including springsnails. There is potential for mudsnail invasion into spring ecosystems, because the mudsnail can be easily transported and unintentionally introduced into aquatic environments via birds, hikers, researchers, and resource managers. The mudsnail was first discovered in the United States in the Snake River, Idaho, in 1987, and has since spread to the Colorado River basin in the western United States . Since 2002, New Zealand mudsnails have been detected in Arizona along the Colorado River at Lees Ferry, Diamond Creek, Lake Mead, and Willow Beach Fish Hatchery.	**Highly confident**	U.S. Geological Survey 2002, p. 1 Vinson 2004, p. 9 AGFD 2002, p. 1 Olson 2008, pp. 1–2 Montana State University 2008, p. 1 Sorensen 2010, p. 3
- Activities	**Past:** Spread of non native mudsnail in the western United States. **Current and future:** Potential spread of non native mudsnail into spring ecosystems via birds, hikers, researchers, land managers, and resource managers.	**Highly confident** in historic. **Moderately confident** in current, and future activities	
STRESSOR(S)	The mudsnail is known to compete with and slow the growth of native freshwater snails, including springsnails.	**Highly confident**	Lysne and Koetsier 2008, pp. 103, 105 Lysne et al. 2007, p. 6 Richards et al. 2001, pp. 378–379 Hall et al. 2003, p. 409
- Affected Resource(s)	Mudsnails compete with native springsnails for food and space		
- Exposure of Stressor(s)	No springs have been affected by New Zealand mudsnail at the present time, but exposure could be catastrophic.		

- Immediacy of Stressor(s)	**Historic:** No exposure **Current and Future:** New Zealand mudsnails have been detected in Arizona along the Colorado River at Lees Ferry, Diamond Creek, Lake Mead, and Willow Beach Fish Hatchery. Spread of mudsnails is facilitated by transport via birds and recreationists. Resource agencies, particular AGFD, implement best management practices to reduce the potential for spread of mudsnails, including cleaning equipment and shoes. The [illegible]	**Highly confident**	
Changes in Resource(s)	Mudsnails compete with native springsnails for food and space	**Highly confident**	
Response to Stressors: **- INDIVIDUALS**	The mudsnail has characteristics that enable it to out-compete and replace native springsnails. Mudsnails tolerate a wide range of habitats, and can reach densities exceeding tens of thousands per square meter, particularly in systems with high primary productivity, constant temperatures, and constant flow, though faster moving water seems to limit colonization. Mudsnails can dominate the invertebrate composition of an aquatic system, accounting for up to 97 percent of invertebrate biomass. In doing so, they can consume nearly all microorganisms attached to submerged substrates, making food no longer available for native species, such as springsnails.	**Moderately confident**	Richards et al. 2001, pp. 378–379; Hall et al. 2003, p. 409
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	If New Zealand mudsnails invaded occupied habitat, Page springsnail densities would be expected to decrease, negatively affecting resiliency.	**Moderately confident**	
- SCOPE	No springs have been affected by New Zealand mudsnail at the present time, but exposure could be catastrophic.	**Highly confident**	
Effects of Stressors: **- SPECIES (Rangwide) [REDUNDANCY]**	If populations are lost in the future, then overall redundancy will continue to decline.	**Highly confident**	

Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	Any future loss of populations will continue to reduce overall genetic and ecological diversity of the species, further limiting the species' representation.	**Moderately confident**	
RISK OF EXTIRPATION 2065	Due to the limited current distribution of the New Zealand mudsnail in Arizona, and management attention of the AGFD and other cooperators, particulary through the implementation of HACCP plans, the risk of extirpation is minimial because the likelihood that New Zealand mudsnails will spread into spring habitas occupied by Page springsnail is low.		

THEME: Management Actions			
[ESA Factor(s): E]	**Analysis**	Confidence / Uncertainty	Supporting Information
SOURCE(S)	AGFD is managing springs on their lands to benefit the Page springsnail	**Highly confident**	
- Activities	Protection of exant populations and their habitats, restoration of degraded habitat, consideration of the species in hatchery management, and annual monitoring are examples of conservation actions that have been implemented to minimize threats and maintain or improve the status of the Page springsnail. On October 8, 2009, the AGFD and the Service entered into a 5-year Candidate Conservation Agreement with Assurances (CCAA) to alleviate threats and improve the conservation status of the Page springsnail. Although the CCAA expired on October 8, 2014, the AGFD intends to renew the CCAA, potentially for a 25-year timeframe. The AGFD and Service are currently coordinating to renew the CCAA. Additionally, AGFD continues to implement conservation measures. The objective of the CCAA is to provide protection to the Page springsnail and its habitat, and to provide a framework for addressing its continued conservation. Cooperatively developed conservation measures and strategies have been, and will continue to be, implemented to reduce or remove threats to the Page springsnail. These strategies include the protection and enhancement of extant populations and their habitat, natural history research, restoration of degraded habitat, translocations to restore historical populations, or other activities that improve the status of Page springsnails. Importantly, the CCAA approach provides for adaptive management as new information or empirical data becomes available. The majority of Page springsnail habitats are located on State fish hatchery lands managed by AGFD. These lands are primarily utilized for fish production. However, in addition to conservation practices implemented through the CCAA, the management plans for AGFD hatcheries establish the protection of the Page springsnail and their habitats as an important management goal. Furthermore, in addition to protecting the species on AGFD properties, the CCAA gives AGFD the flexibility to enroll private lands through certificates of inclusion.	**Highly confident**	AGFD 1997a, p. 1 AGFD 1997b, p. 1 AGFD 1998, pp. 6-7 AGFD and Service 2009 AGFD 2013, p. 1 AGFD 2014, p. 1

THEME: Management Actions			
[ESA Factor(s): E]	**Analysis**	Confidence / Uncertainty	Supporting Information
STRESSOR(S)	Habitat quantity and quality have been improved through implementation of the measures in the CCAA.	**Highly confident**	
- Affected Resource(s)	The CCAA called for evaluating the restoration and creation of natural springhead integrity, including springs on AGFD properties. Also, the National Park Service owns the property containing Shea Springs and they have expressed an interest in restoring natural springhead integrity to that site.	**Highly confident**	
- Exposure of Stressor(s)	**Nonnatives:** implement management actions to prevent spread and/or invasion; **Spring restoration** improve habitat conditions to reduce exposure to unfavorable conditions; **Piscicide management** to reduce exposure to chemicals through salvage; **Monitoring** to track success and evaluate need for adaptive management. The CCAA called for landowners, including AGFD, to prevent future detrimental habitat modification that reduces the threat from mechanical removal of vegetation. Specifically, the CCAA called for no more than 10 percent of aquatic, springsnail-occupied habitat be disturbed during management activities, and for springsnails removed during management to be salvaged. Although AGFD may occasionally remove vegetation from the drain gate at Bubbling Springs Pond, they rarely remove algal mats or aquatic vegetation from aquatic habitats occupied by the species (last done in July 2005). And when they do, they place the vegetation along the banks and in the water to prevent desiccation of individual springsnails. In 2006, AGFD installed a flow meter at the outflow of Bubbling Springs Pond to monitor spring discharge. This device tracks seasonal fluctuations in water flow. The benefit of monitoring is to track population trends, assess the success or failure of management activities, and to determine water levels needed for persistence. In March 2001, the AGFD removed the wooden shed and replaced it with a fencing structure to improve springsnail habitat, while still serving the water delivery purpose of preventing debris from clogging the water line. In June 2005, the structure was further modified from a solid surface to an open air surface, to stimulate primary	**Highly confident**	J. Sorensen, AGFD, 2012, pers. comm.; Sorensen and Martinez 2015

THEME: Management Actions			
[ESA Factor(s): E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- Exposure of Stressor(s) continued	productivity and facilitate possible future re-establishment efforts. Within the modified enclosure at Bass House Springs, the aquatic environment remained ponded. In early 2005, the AGFD created an artificial springbrook draining Bass House Springs. In June 2010, over a hundred springsnails were found occupying the artificial springbrook , and in June 2011, springsnails were found in the springhead proper. The species status in Fry Springs and Turtle Springs is unknown. Measure of Success: Habitat and Page springsnail populations will not decrease throughout the duration of the CCAA. Biological measures will be consistent with the survey protocol. Cooperators agree to notify AGFD and USFWS of any modifications that may impact Page springsnails, in writing, at least 30 days in advance. AGFD has conducted habitat restoration activities that have resulted in improved habitat conditions at Bass House Springs, Bubbling Springs, and Ash Tree Springs. These efforts have resulted in increases in the overall quantity of Page springsnail habitat and expansion of springsnails into previously unoccupied habitat.		AGFD 2010, p. 2; AGFD 2011, p. 2
- Immediacy of Stressor(s)	N/A		
Changes in Resource(s)	Populations affected by management actions will remain stable or grow, as management actions reduce the stressors to the population (i.e. habitat restoration, salvage, monitoring).	**Highly confident**	
Response to Stressors: - INDIVIDUALS	Individuals will be exposed to fewer stressors, although the primary response will be at the population level.	**Highly confident**	

THEME: Management Actions			
[ESA Factor(s): E]	**Analysis**	Confidence / Uncertainty	Supporting Information
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Population resiliency will remain stable at some sites and improve at others	**Highly confident**	
- SCOPE	Resiliency will likely remain stable or increase wherever management actions occur	**Highly confident**	
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	The more reslient populations throughout the range of Page springsnail, the more redundancy will increase.	**Highly confident**	
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	Representation will increase as populations are restored and rehabilitated.	**Highly confident**	
RISK OF EXTIRPATION 2065	If management actions and conservation measures designed to avoid spring modifications continue into the future, detrimental effects to the species are expected to be minimized, reducing the risk of extirpation greatly.		