Species Status Assessment Report for the Sonoyta Mud Turtle Version 2.0

Juvenile Sonoyta mud turtle from the Rio Sonoyta, Sonora, Mexico. Photo by Glenn Knowles, U.S. Fish and Wildlife Service.

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ASSESSMENT PREPARATION

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EXECUTIVE SUMMARY

This species status assessment reports (SSA Report) the results of a comprehensive biological status review by the U.S. Fish and Wildlife Service (USFWS) for the Sonoyta mud turtle (*Kinosternon sonoriense longifemorale*) and provides a thorough account of the subspecies' overall viability. The Sonoyta mud turtle is an isolated endemic subspecies of the Sonora mud turtle (*Kinosternon sonoriense*) found in southern Arizona and northwestern Mexico. To evaluate the biological status of the Sonoyta mud turtle both currently and into the future, we assessed a range of conditions to allow us to consider the subspecies' resiliency, redundancy, and representation (together, the 3Rs).

The Sonoyta mud turtle is a dark, relatively small-sized (maximum 135 millimeters (mm) (5.2 inches (in)) (P. Holm, pers. comm. 2017), freshwater turtle with a mottled pattern on the head, neck, and limbs (Ernst and Lovich 2009, p. 494). Sonoyta mud turtles live for approximately 10 to 12 years (Rosen 1986, p. 30). Sonoyta mud turtles depend on aquatic habitat with adjacent terrestrial habitat for life-history functions in areas that commonly experiences drought and extreme heat. Aquatic habitat historically consisted of cienegas and streams supported by groundwater-fed springs. Currently aquatic habitat consists of streams and natural and manmade ponds. Sonoyta mud turtles need perennial or near-perennial surface water for feeding, for protection from predators, to prevent desiccation, and for mating. Sonoyta mud turtles are opportunistic carnivores, feeding primarily on aquatic invertebrates that live on emergent and submergent vegetation or the substrate of ponds and streams. Sonoyta mud turtles need aquatic habitat free of problematic nonnative predators and competitors. Sonoyta mud turtles also require terrestrial habitat that maintains soil moisture, which occurs in riparian areas along the banks of ponds and streams, and in intermittently dry sections of stream channels. Riparian habitat provides shadier, cooler, and moister conditions than the adjacent upland areas. Sonoyta mud turtles require moist soil for nesting to prevent desiccation of eggs and for estivation (a state of dormancy) sites to prevent desiccation of hatchlings, juveniles, and adults. Sonoyta mud turtles need accessible shoreline without insurmountable rock or artificial vertical barriers to allow for movement between wetted sites, between aquatic habitat and terrestrial nest sites, and between water and estivation (dormancy during drought) sites.

The most significant stressor for the Sonoyta mud turtle is the loss of aquatic and riparian habitat that individuals need to complete their life history functions; thereby, reducing resiliency in populations. The primary cause of historical habitat loss within the range of the Sonoyta mud turtle is related to above normal drought and anthropogenic groundwater loss. This, combined with lack of connectivity, affects population resiliency, as well as species redundancy and representation. The implementation of conservation measures by the National Park Service and Quitobaquito Rio Sonoyta Work Group has resulted in maintaining the only Sonoyta mud turtle population in the U.S. and should secure one population in Mexico at a new wastewater treatment facility, although it will likely be smaller than the existing population it is replacing. The primary source of potential future habitat loss is groundwater depletion that could result in reduced or eliminated surface water for populations of the Sonoyta mud turtle in the US and Mexico. Groundwater withdrawal will continue to affect base flow in the Rio Sonoyta basin, although we cannot quantify how it will affect the sites that support the subspecies. Increased

drought will also contribute to reduced water availability for Sonoyta mud turtle populations in both the U.S. and Mexico.

The Sonoyta mud turtle needs multiple resilient populations distributed across its range to maintain its persistence into the future and to avoid extinction. Table ES–1 provides a summary of the needs of individuals, populations, and the subspecies as a whole described in terms of resiliency, redundancy, and representation. Several factors influence the persistence of Sonoyta mud turtle's populations: (1) available habitat, (2) recruitment, and (3) connectivity. Conditions that influence these factors include (1) amount of surface water, (2) amount of riparian or riparian analog habitat, (3) amount of aquatic invertebrate prey, and (4) habitat that is free of nonnative predators. As we consider the future viability of the subspecies, more populations with high resiliency distributed across the known range of the subspecies are associated with higher overall subspecies viability.

The Sonoyta mud turtle has always been limited in its distribution to the Rio Sonoyta basin in Arizona and Sonora, Mexico. We assume that the historical locations of the Sonoyta mud turtles were in areas of the Rio Sonoyta basin that maintained perennial surface water at all times except during periodic protracted drought periods. There were at least three historical perennial sections of the Rio Sonoyta, including the Sonoyta, Santo Domingo, and Papalote (also referred to as Agua Dulce) reaches (Rosen *et al.* 2010, p. 152). These three distinct perennial reaches of the Rio Sonoyta together likely provided 19 to 27 km (12 to 17 mi) of stream habitat for the Sonoyta mud turtle, from the upstream Sonoyta reach beginning about 4 km (2.4 mi) above the town of Sonoyta to the downstream Papalote reach ending due west or southwest of Quitobaquito Springs. The Sonoyta mud turtle was historically known from five sites in the Rio Sonoyta basin: one site in the U.S. and at least four sites in Mexico. We state "at least four" because of the uncertainty of some of the location information. Some of the historical location information is vague and we used our best professional judgment to determine the locations.

The Sonoyta mud turtle currently occurs in one location in Arizona, and four locations in Sonora, Mexico. One of the historical populations in Sonora is believed to be extirpated (Santo Domingo) and two new populations have been discovered (Quitovac and Sonoyta Sewage Lagoon). Table ES–2 below summarizes the historical and current populations, and the current condition of these populations. The viability of the Sonoyta mud turtle depends on maintaining multiple resilient populations over time. Resiliency of Sonoyta mud turtle populations depends on future surface water availability, amount of riparian habitat and aquatic invertebrates, and continued absence of certain nonnative species that are significant competitors and predators, as well as connectivity. We expect the five extant Sonoyta mud turtle populations to experience changes to all of these aspects of their habitat in different ways under the different scenarios evaluated in this document. Given our uncertainty regarding when habitats of Sonoyta mud turtle will experience a reduction or elimination of surface water and corresponding riparian habitat in the future, we are forecasting what the Sonoyta mud turtle may have in terms of resiliency, redundancy, and representation under three future plausible scenarios over three timeframes, 7–years, 35–years, and 70 years:

(1) Best Case – All habitats occupied by Sonoyta mud turtle experience **no measurable drop** in surface water;

(2) Moderate Case – Surface water in habitats occupied by Sonoyta mud turtle is **somewhat reduced, but not eliminated**; and
(3) Worst Case – All surface water at sites occupied by Sonoyta mud turtle is **extremely reduced or eliminated**.

Each scenario also considered status of aquatic invertebrate prey, riparian habitat condition, potential for nonnative species invasions, and connectivity. Rankings are a qualitative assessment of the condition of occupied habitats based on the knowledge and expertise of USFWS staff, Arizona Game and Fish Department, and other technical experts and resource professionals. We projected the Sonoyta mud turtle's expected future resiliency, representation, and redundancy based on the events that would occur under each scenario, and present projections for the 7–years, 35–years, and 70–year time frame below (Table ES– 2, 3, and 4).

Under scenario 1 – best case, we would expect the Sonoyta mud turtle's viability to be characterized by about the same levels of resiliency, representation, and redundancy that it exhibits under current conditions. We anticipate that all five of the current populations will persist at moderate to low conditions.

Under scenario 2 – moderate case, we would expect the Sonoyta mud turtle's viability to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. We anticipate three populations will persist at moderate to low conditions, two populations will be extirpated (Xochimilco and Papalote reaches), and one population will be replaced by a smaller population (Wastewater Treatment Plant will replace Sonoyta Sewage Lagoon).

Under scenario 3 – worst case, we would expect the Sonoyta mud turtle's viability to be characterized by substantial reductions of resiliency, representation, and redundancy. We would only expect two populations to persist in low condition, three populations will be extirpated (Xochimilco reach, Papalote reach, and Quitovac), and one population will be replaced by a smaller population (Wastewater Treatment Plant will replace Sonoyta Sewage Lagoon).

The moderate case scenario provides a reasonably likely snapshot of the Sonoyta mud turtle's condition over the three time frames (Table 5.4.2). This scenario is the most plausible as it depends on the current long-term drought continuing or recurring, the new Sonoyta wastewater treatment plant coming online, some problematic nonnatives, continued water loss to due groundwater pumping or water diversions, loss of connectivity, and successful implementation of some management actions throughout the range of the subspecies.

Table ES–1. Overall species status assessment summary for the Sonoyta mud turtle.

3Rs	Needs	Current Condition	Future Condition at 70 Years (Viability)
Resiliency: Populations able to withstand stochastic events	• High amount of perennial surface water (volume or extent) • High amount of riparian or riparian analog adjacent to the water • High amount of invertebrate abundance • No presence of nonnative aquatic predators • Connectivity	• 5 of 6 historical populations across range extant • 3 assessed to have moderate resiliency • 2 assessed to have low resiliency	Projections based on surface water scenarios: • **Scenario 1**: All populations are likely to remain extant into the future • **Scenario 2**: All populations are expected to experience some level of decline in resiliency, three are extirpated. • **Scenario 3**: All populations experience a large decline in resiliency, four are extirpated.
Redundancy: Number and distribution of populations to withstand catastrophic events	• Multiple resilient populations throughout the range of the subspecies	• 1 documented population has been extirpated, so 5 of 6 historical populations across range extant • The remaining 5 are isolated from one another	Projections based on surface water scenarios: • **Scenario 1**: All populations are likely to remain extant into the future • **Scenario 2**: 3 populations would be extirpated and 2 vulnerable to extirpation because of low resiliency; the remaining 1 would have moderate resiliency • **Scenario 3**: Most populations would be extirpated or vulnerable to extirpation
Representation: Genetic and ecological diversity to maintain adaptive potential	• Genetic variation exists between populations • No known ecological variation	• 1 population has been extirpated • At least 4 of remaining 5 exhibit some level of genetic variation	Projections based on surface water scenarios: • **Scenario 1**: current genetic variation maintained • **Scenario 2**: only 3 remaining populations, greatly reduce genetic representation due to loss of 2 populations • **Scenario 3**: 2 remaining populations vulnerable to extirpation would severely limit genetic variation

Table ES–2. Projected Sonoyta mud turtle population conditions in 7–years under each scenario.

Country	Population Name	Current Condition	Population Condition in 7 Years		
			Scenario 1 Best Case	Scenario 2 Moderate Case	Scenario 3 Worst Case
U.S.	Quitobaquito Springs	Moderate	Moderate	Moderate	Moderate
Mexico	Papalote Reach (Agua Dulce)	Moderate	Moderate	Moderate	Ø
	Sonoyta Sewage Lagoon	Moderate	Moderate	Low	Ø
	New Sonoyta wastewater treatment plant	Ø	Ø	Moderate	Ø
	Xochimilco Reach (Sonoyta Reach)	Low	Low	Low	Low
	Quitovac	Low	Low	Low	Low

Table ES–3. Projected Sonoyta mud turtle population conditions in 35 years under each scenario.

Country	Population Name	Current Condition	Population Condition in 35 Years		
			Scenario 1 Best Case	Scenario 2 Moderate Case	Scenario 3 Worst Case
U.S.	Quitobaquito Springs	Moderate	Moderate	Moderate	Moderate
Mexico	Papalote Reach (Agua Dulce)	Moderate	Moderate	Ø	Ø
	Sonoyta Sewage Lagoon	Moderate	Moderate	Ø	Ø
	New Sonoyta wastewater treatment plant	Ø	Ø	Moderate	Moderate
	Xochimilco Reach (Sonoyta Reach)	Low	Low	Ø	Ø
	Quitovac	Low	Moderate	Low	Low

Table ES–4. Projected Sonoyta mud turtle population conditions in 70 years under each scenario.

Country	Population Name	Current Condition	Population Condition in 70 Years		
			Scenario 1 Best Case	Scenario 2 Moderate Case	Scenario 3 Worst Case
U.S.	Quitobaquito Springs	Moderate	Moderate	Low	Low
Mexico	Papalote Reach (Agua Dulce)	Moderate	Moderate	Ø	Ø
	Sonoyta Sewage Lagoon	Moderate	Moderate	Ø	Ø
	New Sonoyta wastewater treatment plant	Ø	Ø	Moderate	Low
	Xochimilco Reach (Sonoyta Reach)	Low	Low	Ø	Ø
	Quitovac	Low	Moderate	Low	Ø

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CHAPTER 1. INTRODUCTION

The Sonoyta mud turtle (*Kinosternon sonoriense longifemorale)* is an isolated endemic (restricted to a specific area) subspecies of the Sonora mud turtle (*Kinosternon sonoriense*) found in southern Arizona and northwestern Mexico. It has been a candidate species under the Endangered Species Act, as amended (Act), since 1997 (September 19, 1997, 62 FR 49397). The U.S. Fish and Wildlife Service (USFWS) is using a Species Status Assessment (SSA) framework (Figure 1.1, USFWS 2015, entire) that is intended to support 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. This framework analysis is presented as the SSA Report. 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 Sonoyta mud turtle is intended to provide the biological support for the decision on whether or not to finalize the listing of the subspecies as threatened or endangered. Importantly, the SSA Report does not result in a decision by the USFWS on whether this species 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 Sonoyta mud turtle. The listing decision will be made by the USFWS after reviewing this document and all relevant laws, regulations, and policies, and the results of a decision will be announced in the *Federal Register*.

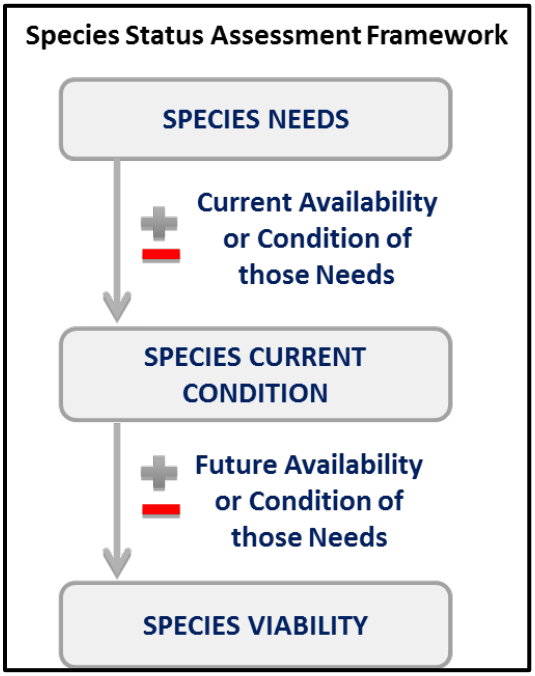


Figure 1.1 Species Status Assessment Framework

For the purpose of this assessment, we generally define viability as the ability of the Sonoyta mud turtle to sustain populations over time. 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).

• **Resilience** describes the ability of populations 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. Highly 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. A catastrophic event is defined here as a rare destructive event or episode involving many populations and occurring suddenly. Measured by the number of populations, redundancy is about spreading the risk and can be measured through the duplication and broad distribution of resilient populations across the range of the species. The more resilient populations the species has, distributed over a larger area, the better chances that the species can withstand or bounce back from catastrophic events.

• **Representation** is having the breadth of genetic makeup of the species to allow for potential future adaptation 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. Theoretically, the more representation, or diversity, the species has, the higher the potential for the species 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 across the geographical range.

To evaluate the biological status of the Sonoyta mud turtle 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, stressors, and limiting factors in the context of determining the viability for the species.

The format for this SSA Report includes: (1) the life history and resource needs of individuals and populations (Chapter 2); (2) the historical and current distributions of the Sonoyta mud turtle and a framework for determining current condition of 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 Sonoyta mud turtle.

Information used in developing this SSA Report is the result of a literature search, a review of recent research and monitoring efforts, and expert information related to the Sonoyta mud turtle from a series of meetings and interviews.

CHAPTER 2. SPECIES INFORMATION & INDIVIDUAL NEEDS

In this chapter, we provide basic biological information about the Sonoyta mud turtle, including its taxonomy, genetics, morphological description, and life history traits. We then outline the resource needs of individuals. For further information about the Sonoyta mud turtle refer to Paredes-Aguilar and Rosen (2003), Iverson (1981), Rosen (1986, 1987), Rosen and Lowe (1996), Rosen *et al.* (2006), and Riedle *et al.* (2012).

2.1. Taxonomy

Currently the Sonoyta mud turtle is classified as *Kinosternon sonoriense longifemorale* (Iverson 1981, entire). The Sonoyta mud turtle was originally described by E.A. Mearns (1907, p. 117) as part of the higher species classification *Kinosternon sonoriense* LeConte (1854, entire). The Sonoyta mud turtle was subsequently described as a subspecies of *K. sonoriense* by Iverson in 1981 (p. 42) based on morphometric analysis of 19 shell measurements of specimens from Quitobaquito Springs in Arizona and sites in the Rio Sonoyta basin in Sonora (Iverson 1981 p. 62). Currently the Sonoyta mud turtle is classified as *K. sonoriense longifemorale* (Iverson 1981, entire), as one of two recognized subspecies of Sonora mud turtle and is considered a valid taxon by the scientific community (Crother 2012, p. 78) based on the morphometric analysis of shell measurements by Iverson (1981, entire) and mitochondrial DNA analysis by Rosen (2003, entire) and Rosen *et al.* (2006, entire). Two genetic analyses support that the subspecies is a recognizable entity compared to the other currently recognized subspecies *(K. s. sonoriense)*, although it is not strongly differentiated (see Section 2.2 below). The other subspecies, *K. s. sonoriense*, is commonly referred to as Sonora mud turtle.

The currently accepted classification is:

Kingdom: Animalia
Phylum:Chordata
Class:Reptilia
Order: Testudines
Family: Kinosternidae
Subfamily: Kinonsterninae
Tribe: Kinosternini
Species: *Kinosternon sonoriense*
Subspecies: *Kinosternon sonoriense longifemorale*

The Kinosterninae subfamily contains the largest, most wide-ranging, and ecologically diverse genus of turtles, *Kinosternon,* in the New World comprising fully aquatic to semiaquatic to almost completely terrestrial forms that range from eastern North America in southern Canada south through Mexico to South America (Ernst and Barbour 1989, p. 69). The genus Kinsternon is diverse in the Southwest with six species in the U.S. and Mexico, reflecting there hardiness to arid and semi-arid conditions (Crother 2012, pp. 77–78, Rorabaugh and Lemos-Espinal 2016, p. 230–232). Recent phylogenetic analysis suggests that the Sonora mud turtle (*Kinosternon sonoriense*) is part of a clade of largely tropical species of mud turtles (Spinks *et al.* 2014, p. 257–258). The Sonoyta mud turtle has been differentiated from the nominate subspecies Sonora mud turtle based on morphometric analysis of shell measurements and mitochondrial DNA

analysis (Iverson 1981, p. 62; Rosen 2003, entire; Rosen *et al*. 2006, entire). The Sonoyta mud turtle is an endemic subspecies found in the Rio Sonoyta basin of southwestern Arizona and northwestern Sonora, which is the most arid part of the Sonora mud turtle subspecies' range (Rosen *et al.* 2006, p. 14). It is hydrologically isolated from populations of the Sonora mud turtle which is found in Arizona, New Mexico, Sonora, and western Chihuahua and possibly California (Figure 2.1.1) (Ernst and Lovich 2009, p. 494; Lovich and Beaman 2008, p. 132; Iverson, 1992, p. 235; and Rosen *et al.* 2006, pp. 7–10).

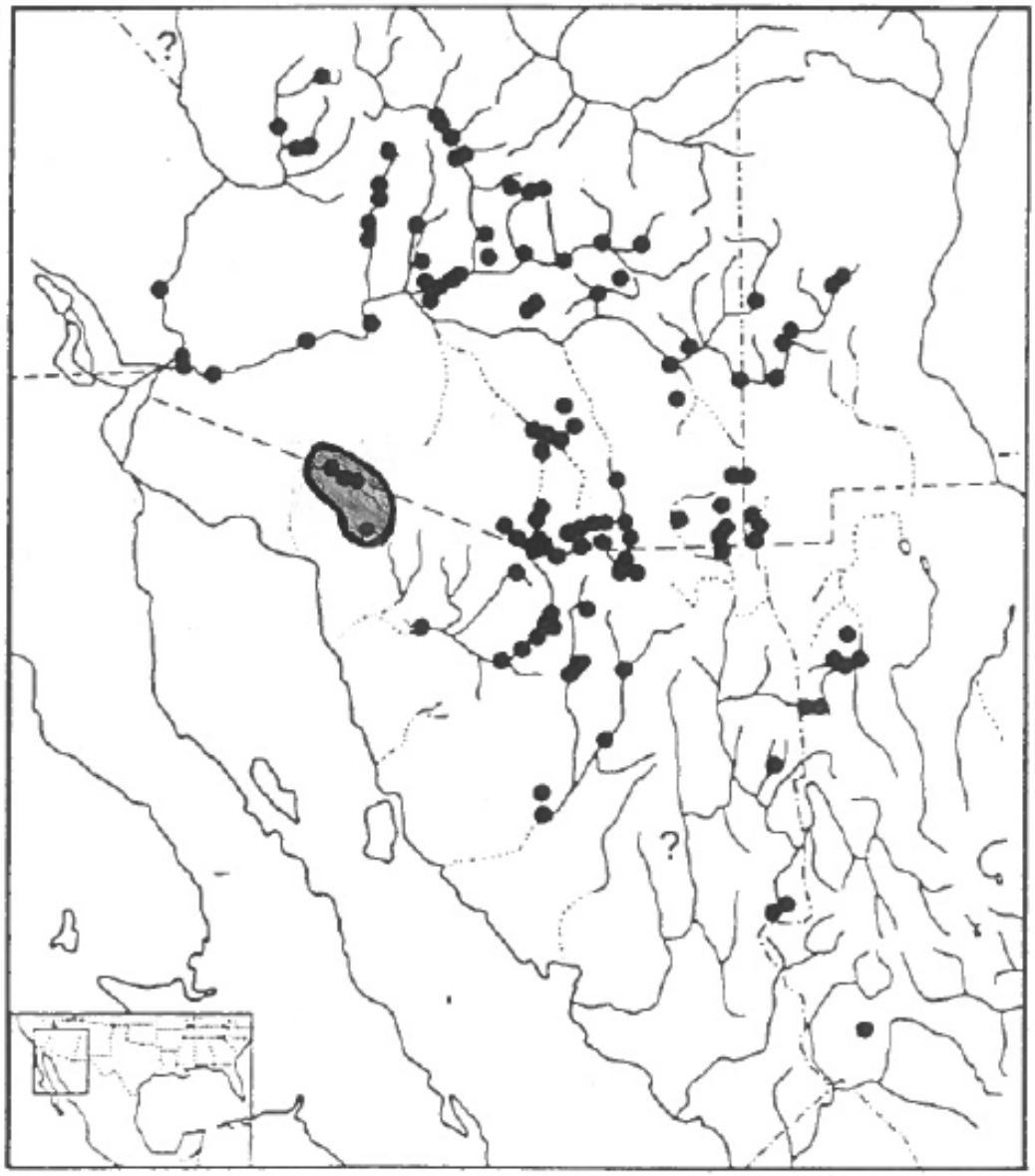


Figure 2.1.1. General distribution of Sonoyta mud turtle subspecies (depicted in gray area) in relation to the nominate subspecies, Sonora mud turtle (modified from Iverson 1992, p. 235).

2.2. Genetics

Genetic investigations (Rosen 2003, pp. 8–13; Rosen *et al.* 2006, p. 10) indicate *K. s. longifemorale* exhibits some level of genetic diversity among populations at Quitobaquito Springs, the Rio Sonoyta (Papalote and Xochimilco reaches), and Quitovac. However, the localities were all genetically close, with suggestion of isolation by distance and dry land with the two isolated spring sites (Quitobaquito Springs and Quitovac) being the most disparate and furthest apart, and the two Rio Sonoyta mainstem sites (Papalote and Xochimilco) falling into place between them (Rosen *et al.* 2006, p. 10). The populations in the Sonoyta sewage lagoon were not sampled. These two studies are explained in more detail below.

Rosen (2003, p. 7) examined mtDNA from tissues of specimens collected at three sites in the Rio Sonoyta region (Quitobaquito Springs, Arizona; Presa Xochimilco on the Rio Sonoyta, Sonora, Mexico; and Quitovac, Sonora, Mexico) and 11 sites representing the rest of the range of *K. sonoriense* in Arizona and the portion of the range in New Mexico. He found that *K. sonoriense* from the Rio Sonoyta region in Arizona and Mexico differed genetically from samples taken from southwestern New Mexico and throughout Arizona, confirming the existence of two subspecies of *K. sonoriense—K. s. sonoriense* and *K. s. longifemorale*. This was based on 6 base-pair substitutions in the 961 base-pair section of the d-loop on the mitochondrial genome (Rosen 2003, p. 10). Figure 2.2.1 below depicts a simplified cladogram (a stylized tree, showing inferred historical branching patterns among taxa) of the base-pair substitution results. Three of the base-pair substitutions were shared by all samples from New Mexico and Arizona outside of the Rio Sonoyta region considered to be the nominate (denoting the subspecies that is given the same epithet as the species to which it belongs) subspecies *K. s. sonoriense.* Two of these base-pair substitutions distinguished all of the animals considered to be the nominate subspecies from all samples of animals from the Rio Sonoyta region considered to be the second subspecies *K. s. longifemorale*.

Seven of 10 individuals from the Presa Xochimilco in the Rio Sonoyta region site shared a derived character with *K. s. sonoriense*, suggesting a paraphyletic relationship (group's last common ancestor and all descendants of that ancestor excluding a few) between the two subspecies, which may indicate re-contact between the "evolving nominate subspecies *(K. s. sonoriense)*" and Rio Sonoyta mainstem population (*K. s. longifemorale),* the timing of which is discussed below (Rosen 2003, p. 10–11).

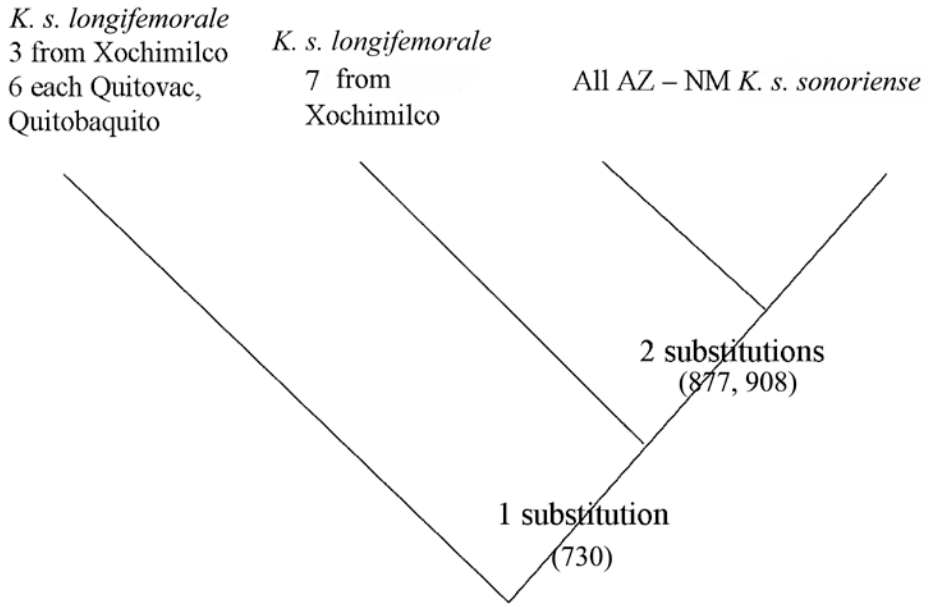


Figure 2.2.1. Simplified cladogram for *Kinosternon sonoriense* from Arizona, New Mexico, and the region of Rio Sonoyta (Rosen 2003, p. 12).

Subsequent phylogenetic (evolutionary history and relationships among individuals or groups of organisms) analysis of the entire species by Rosen *et al*. (2006, p. 5) included additional *K. s. sonoriense* sites in Mexico, and an additional site for *K.s. longifemorale* along the Papalote reach on the Rio Sonoyta, as well as sites for the rough-footed mud turtle, *K. hirtipes*, in Mexico as an outgroup. They analyzed a different mtDNA gene (ND4) for 89 *K. sonoriense* including the samples from the 2003 study described above (Rosen *et al.* 2006, p.1), and an additional 12 samples representing *K. s. longifemorale* and 38 more samples representing *K.s. sonoriense* in Sonora and Chihuahua, Mexico. Rosen *et al.* (2006, p. 7) concluded that there are three well-supported clades (a grouping that includes a common ancestor and all the descendants of that ancestor) found within *K. sonoriense*: a north Sierra Madrean clade, a south Sierra Madrean clade, and a widespread poorly resolved derived "lowland clade" encompassing all localities from Arizona, New Mexico, and non-Madrean localities in Sonora, Mexico including those in the Rio Sonoyta basin (Figure 2.2.2). Analyses of the mitochondrial protein-coding gene ND4 data suggested that *K. s. longifemorale* is the basal, and possibly paraphyletic portion of the derived lowland clade. However, 2 of 6 individuals from an outlying population of lowland *K. s. sonoriense* share a haplotype (group of genes within an organism that was inherited together from a single parent) with *K. s. longifemorale* (Rosen *et al.* 2006, pp. 4, 8, 9). The proportion of the total genetic variance contained in the three clades and *K. s. longifemorale* relative to the total genetic variance trends indicates low genetic distances within each of the clades and much larger distances between them (Rosen *et al.* 2006, p.10).

This analysis added uncertainty to the validity of the subspecies based on much deeper subdivisions found within the species in the Sierra Madre populations that were not included in the Rosen (2003) (Rosen *et al.* 2006, p. 14). However, the authors concluded that "our evidence indicates that *K s. longifemorale* is a recognizable entity with an apparently unique history, although it is not strongly differentiated". Iverson (1981, 1999, entire) clearly demonstrated a morphological basis for *K. s. longifemorale*: together, this and our genetic results argue persuasively against relegating it to the synonymy of *K. sonoriense* at the present time" (Rosen *et al.* 2006, p. 14). For the remainder of this SSA Report we will refer to *K. s. longifemorale as* Sonoyta mud turtle.

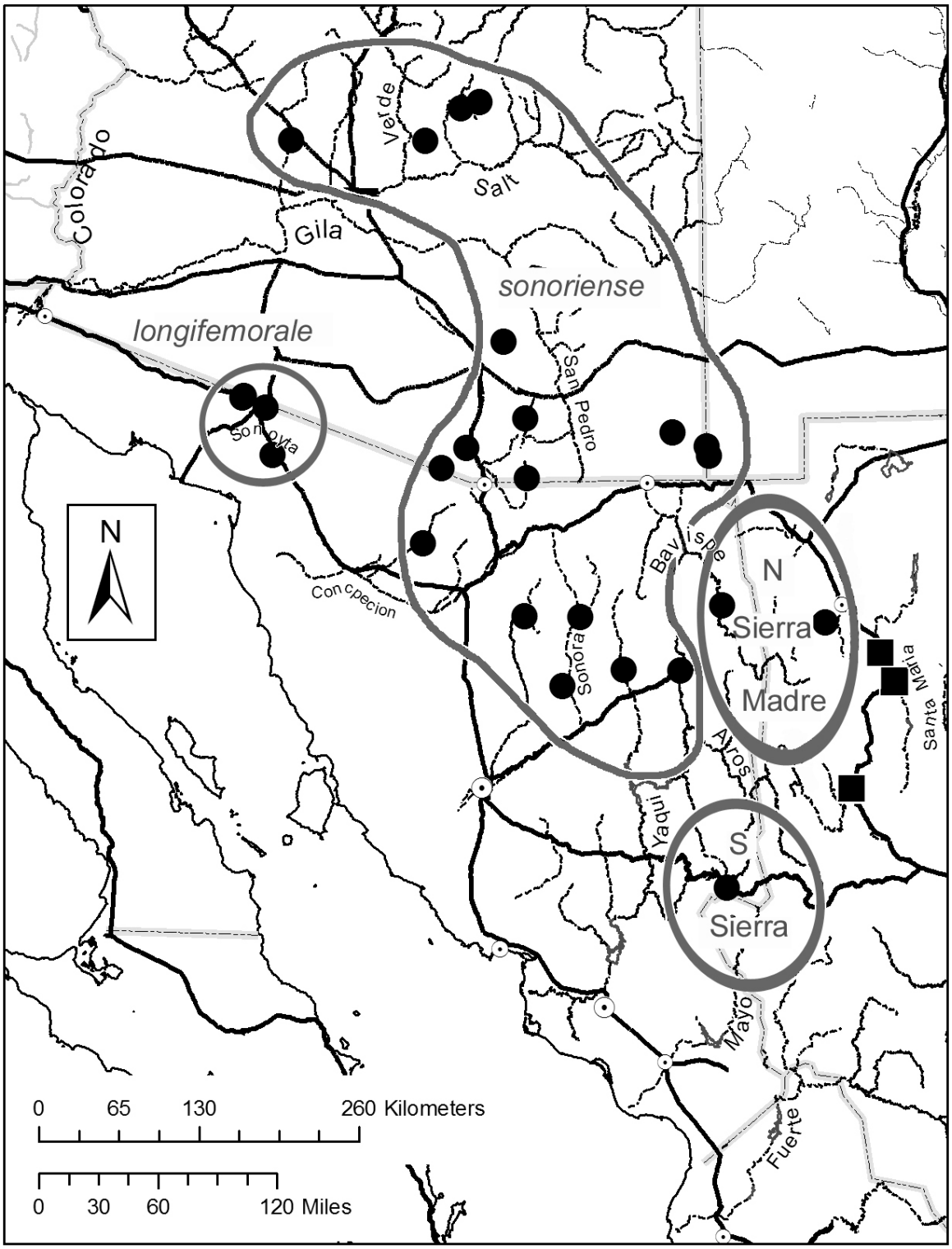


Figure 2.2.2. Rosen *et al*. (2006) sampling locations for *K. sonoriense* (solid circles) and *K. hirtipes* (solid squares). *K.s. longifemorale* subspecies and clades within *K. sonoriense* are labeled and enclosed in heavy gray lines.

2.3. Morphological Description

The Sonoyta mud turtle is a dark, relatively small-sized, freshwater turtle with a mottled pattern on the head, neck, and limbs (Ernst and Lovich 2009, p. 494). The upper shell (carapace) is olive brown to dark brown with dark seams; the lower shell (plastron) is hinged, front and rear, and yellow to brown. Long barbels are typically present on the chin, and all four feet are webbed. Maximum carapace length measured was for an adult male Sonoyta mud turtle was 133 millimeters (mm) (5.2 inches (in)) and for an adult female was 135 mm (5.3 in) (P. Holm, pers. comm. 2017). Carapace length is the length of the fused dorsal plates of a turtle. Adult females have a short tail and flat plastron, and adult males have a concave plastron, a long thick spine-tipped tail, and two patches of raised, horny scales on the inner surface of each leg (Iverson 1981, p. 42). The Sonoyta mud turtle appears to be distinctive from the nominate subspecies based on a long femoral scute (thickened horny or bony plate on a turtle's shell), short anal scute, wide first vertebral scute, and narrow gular scutes (Iverson 1981, pp. 43–44).

(a)

(b)

(c)

Figure 2.3.1. (a) carapace, (b) plastron, and (c) long chin barbells of adult Sonoyta mud turtle in the Rio Sonoyta, Sonora, Mexico. Photos by Jim Rorabaugh.

2.4. Life History

All turtle life histories are thought to be characterized, to varying degrees, by delayed maturity (age at first reproduction), great longevity, and repeated cycles of reproduction (Wilbur and Morin 1988, entire; Congdon and Gibbons 1990, entire), although life-history strategies vary depending on demography of each species (Riedle *et al.* 2012, p. 187). The Sonoyta mud turtle follows this general paradigm. Life history traits of the Sonoyta mud turtle are based on studies at sites along the Rio Sonoyta in Sonora, Mexico by Paredes-Aguilar and Rosen (2003, entire) and at Quitobaquito Springs in Arizona by Rosen (1986, 1987, both entire), and Rosen *et al.* (1996, entire), as well as demographic monitoring of the subspecies at Quitobaquito Springs conducted by the National Park Service (NPS) and its partners since 2001, some of which has been analyzed by Riedle *et al*. (2012, entire). Other information on life history of the subspecies is inferred from work on the nominate subspecies in Arizona and New Mexico (Emslie 1982, Hall and Steidl 2007, Hulse 1976 and 1982, Iverson 1981, Ligon and Peterson 2002, Ligon and Stone 2003a, Ligon and Stone 2003b, Peterson and Stone 2000, Rosen 1987, Stanila *et al*. 2008, Stone 2001, Stone *et al*. 2005, Stone *et al*. 2015, van Loben Sels *et al*. 1997, all entire).

2.4.1 Reproduction

There is limited information on the reproductive ecology of Sonoyta mud turtles. A single event of potential nesting behavior of the Sonoyta mud turtle observed was a gravid female, "apparently preparing to lay eggs", digging 15 centimeters (cm) (6 in) into the soil (Rosen and Lowe 1996, p. 23). Although no mating or other nesting behavior has been documented in Sonoyta mud turtles in the wild, it is likely broadly similar to the nominate subspecies. In the Sonora mud turtle, mating occurs in water from April to late June (Rosen 1986, p. 7; Stone *et al.* 2015, p. 735), and is characterized by a male following a female, biting and nipping at her head causing her to withdraw into her shell, and then mounting the female after which copulation occurs (D. Hall, pers. comm. 2017). Ovulation and shelling of eggs begins in June, and eggs remain in the oviducts until the monsoon rains occur from mid to late July through September (van Loben Sels *et al*. 1997, p. 343). In mid to late July through September, females leave the water briefly to lay eggs in terrestrial nests. Eggs may undergo embryonic diapause (delayed embryo development) in the nest for up to 11 months after being laid, development commences as eggs warm during the following spring and takes about 80 days, and hatchlings emerge and disperse from the nest the following year to coincide with the onset of summer rains (van Lobel Sels *et al*. 1997, p. 343; Ernst and Lovich 2009, p. 497; Stone *et al*. 2015, p. 735).

Minimum age of sexual maturity of female Sonoyta mud turtles at Quitobaquito Springs was just under 6 years, and males around 4 years (Rosen and Lowe 1996, pp. 14–16). Minimum age of sexual maturity is similar to that of nominate subspecies populations (Rosen 1987, p. 15; van Loben Sels *et al.*1997, p. 341). Observed egg carrying season for female Sonoyta mud turtles at Quitobaquito Springs was mid-July to mid-September (Rosen and Lowe 1996, p. 21). The nominate subspecies produces the largest number of eggs per clutch (complete set of eggs produced at one time) (up to 8) of any kinosternine (Iverson 1981, p. 43), but observed clutch size of Sonoyta mud turtles at Quitobaquito Springs was smaller with an average of 4 eggs per clutch based on three gravid females (Rosen 1986, p. 7), with the difference reflecting relationships between body size and clutch size. Clutch frequency was estimated at 1.4–1.6 clutches/year/female based on proportion of gravid female Sonoyta mud turtles, which is considered low for this subspecies (Rosen and Lowe 1996, pp. 7, 21).

2.4.2 Survival, Growth, and Longevity

The Sonoyta mud turtle is considered a relatively long-lived organism, but may not exhibit the long life-spans seen in other chelonians (Riedle and Kazmaier 2009, p .6), which can be over 100 years. To maintain population stability, populations of long-lived organisms require both high average annual juvenile survivorship and high adult survivorship (Congdon *et al.* 1993, pp. 83–832; Congdon *et al.* 1994, pp. 405–406). This requires a fairly even age distribution in a population. A male-biased sex ratio has been observed at Quitobaquito Springs since the early 1980s, ranging from 2:1 by Rosen and Lowe (1996, pp. 9, 19) to 1.4:1 by Riedle *et al.* (2012, p. 185), and 1.02:1 to 1.5:1 over the past 4 years by NPS (2012a, 2013, 2014a, 2015). Effects of this skewed sex ratio on the population are unknown. Survivorship of Sonoyta mud turtles is known only from the Quitobaquito Springs population. Male survivorship ranged from 0.83–0.95, female survivorship ranged from 0.85–0.95, and juvenile survivorship was lower than adult survivorship with a gradual transition to higher survivorship as turtles moved towards adulthood (Riedle *et al.* 2012, p. 187; Rosen and Lowe 1996, p. 23). Annual survivorship of Sonoyta mud turtle adults (7–12 years old) and juveniles (<7 years old) in this population revealed that variation in juvenile survivorship had the strongest negative effect on female replacement rate and in turn population growth rate (Rosen and Lowe 1996, p. 23; Riedle *et al.* 2012, p. 187). Riedle and Kazmaier (2009, p. 6) concluded that maintaining reproduction and juvenile survivorship is important the persistence of this population.

Sonoyta mud turtles from Quitobaquito Springs were generally smaller than those in some Sonora mud turtle populations (Hensley *et al.* 2010, p. 183; Rosen 1987, p. 41; Stanila 2009, p. 31; Stone 2001, p. 45). Stanila (2009, p. 31) found that variation in body size among populations of Sonora mud turtles appears to be related to water permanence and that size was significantly larger in permanent habitats compared to intermittent and ephemeral habitats. In permanent water sites, Rosen and Lowe (1996, pp. 33 and 35) showed that growth and body size positively correlated with aquatic invertebrate abundance at a site. At Quitobaquito Springs, aquatic invertebrate abundance and Sonoyta mud turtle size were lower than at Sonora mud turtle sites, which they attributed to competition from fish. Growth rates from hatching to maturity were roughly linear and then abruptly slowed (see Table 2.4.1. below; Rosen 1986, p.35; Rosen and Lowe 1996, p.14).

The oldest Sonoyta mud turtle on record is a 39 year old female found at Quitobaquito Springs in 2015 (P. Holm, pers. comm. 2016a). Rosen (1986, p. 29) initially calculated a mean cohort generation time (average length of time between when an individual is born and the birth of its offspring for a group of same-aged individuals from birth throughout their lives) for turtles at Quitobaquito Springs to be 10.25 years based on 3 years of data in the early 1980s and assuming a stable age distribution and equal survival rates for males and female. Using actual age-structure data for females collected during this time period (1982–1985), he estimated a mean cohort generation time of 12.09 years for females (Rosen 1986, p. 30). With an additional 13 years of data available, Rosen and Lowe (1996, p. 39) calculated a mean cohort generation time for female turtles at Quitobaquito Springs to be 11.94 years. Based on Rosen and Lowe's (1996, p. 30) life table model for females, we calculated average expected longevity for female Sonoyta mud turtles to be around 19 years. This average expected longevity does not include the 2016 recapture of an individual that was 39 years old.

Table 2.4.1. Life history of Sonoyta mud turtle

Life Stage	Life History Biology[1]	References
Egg	Ovulation and shelling of eggs begins in June for nominate subspecies Eggs remain in the oviducts until the monsoon rains occur from mid to late July through September for nominate subspecies	van Loben Sels *et al*. 1997, p. 343
	Eggs laid from mid-July to mid-September Eggs of nominate subspecies at least sometimes undergo embryonic diapause and hatch about 11 months after laying	Rosen and Lowe 1996, p.21 van Loben Sels *et al*. 1997, p. 342
	Survivorship of eggs unknown	
	Estimated clutch frequency at Quitobaquito Springs was 1.4–1.6 clutches/year/female Overall estimated clutch frequency for both subspecies in Arizona 2–4 clutches/year/female Successive clutches in nominate subspecies are produced approximately 28–30 days apart (successive reproduction is not known in Sonoyta mud turtles)	Rosen 1987, p. 44 Rosen 1986, p. 7; van Loben Sels *et al*. 1997, p 340; Rosen and Lowe 1996, p. 21
	Clutch size averaged 4 eggs per clutch at Quitobaquito Springs (n=3) Clutch size, and mass (weight of all eggs) low at Quitobaquito Springs & half of other studied populations of nominate subspecies Individual egg mass (weight of individual egg) compared to female size was high at Quitobaquito Springs	Rosen and Lowe 1996, p. 21 Rosen 1987, p. 52 Rosen and Lowe 1996, pp. 21–22
	Embryo development takes about 80 days after diapause in nominate subspecies Nominate subspecies exhibits temperature dependent sex determination (higher = more females)	Ernst and Lovich 2009, p. 497 Ewert 1991, Ernst and Lovich 2009 Rosen and Lowe 1996, p. 23
	Nest dug 15 cm (6 in) into the soil in a mesquite bosque 9 m (30 ft) from the edge of the pond at Quitobaquito Springs	Rosen and Lowe 1996, p. 23
Hatchling	< 30 millimeter (mm (1.6 in)) carapace length (CL) in nominate subspecies ≈ 1 year old in nominate subspecies Emerge from June-August (11 or more months after laying) in nominate subspecies	Hensley *et al* 2010, p. 182, Stone 2001, pp. 45–46, Rosen pers. comm. 2016 Ernst and Lovich (2009, p. 497)
	Appear at Quitobaquito Springs by September 1st or earlier	Rosen 1986, p.7
Juvenile/ subadult	19–84 mm (1.6–3.3 in) CL in nominate subspecies Up to 7 years old in nominate subspecies	Hensley *et al*. 2010, p. 182, Stone 2001, p. 46, Rosen pers. comm. 2016 van Loben Sels *et al*. 1997, p.341
Adult	>85 mm (3.3 in) CL in females, smaller in males for both subspecies ≥ 4–7 years old (minimum mature age in males); ≥ 6 years (minimum mature age females) in both subspecies (there is overlap in size and age of subadults and adults and it varies among populations)	Rosen 1986, pp. 34–35 Rosen 1987, p. 61 Rosen and Lowe 1996, p. 14 Stone 2001, p. 45 Riedle *et al*. 2012, p. 185
	Earliest age of sexual maturity: males ~3–4 years old, females just under 6 years old Males mature at a smaller size than females in nominate subspecies	Rosen and Lowe 1996,p p. 14–16 Stone 2001, p. 50

Life Stage	Life History Biology[1]	References
	Size at sexual maturity of females nominate subspecies ranges from 86–106 mm (3.4–4.2 in) CL in both subspecies	Riedle *et al.* 2012, p. 185–186, Rosen 1987 pp. 61–62, van Loben Sels *et al.*1997 p. 340, Hulse 1976, p. 344
	Male-biased sex ratio observed in populations of both subspecies (may be explained by males maturing at smaller size and younger age than females)	Rosen 1986 p. 5, Riedle and Kazmaier 2009 p. 5, NPS annual reports, 2007–2015 Stone 2001 p. 50
	In females, size increase greatest up to age 6 year, reduced from age 7 years to age 10–12 years, and slower thereafter In males, size increase with age slowed markedly at age 4 years, continue at reduced rate to age 10 years, and very slow thereafter	Rosen and Lowe 1996, p. 14
	One turtle observed at Quitobaquito Springs reached up to 39 years of age in 2015 Cohort generation time for females 11.94 years Average expected longevity 18.99 years	P. Holm, pers. comm. 2016a, Rosen and Lowe 1996 , p. 39, Calculated from Rosen and Lowe 1996 life table, p. 39
	Male survivorship rate ranged from 0.83–0.95 Female survivorship rate ranged from 0.85–0.95 Juvenile survivorship was lower than adult survivorship with a gradual transition to higher survivorship as turtles moved towards adulthood	Riedle *et al.* 2012, p. 187; Rosen and Lowe 1996, p. 23

[1]Some of the life history information is not known for the Sonoyta mud turtle, in these instances we refer to the nominate subspecies

2.5. Resource Needs (Habitat) of Individuals

The Sonoyta mud turtle is a freshwater turtle encountered in or near water in an otherwise arid environment that commonly experiences drought and extreme heat (ambient temperatures can exceed 45 degrees Celsius (°C) (113 degrees Fahrenheit (°F)). Sonoyta mud turtles depend on both aquatic and terrestrial habitats, as they need aquatic habitat for foraging, shelter, and mating, and terrestrial habitat for nesting and estivating. Natural aquatic habitats of Sonoyta mud turtles are sustained by groundwater discharged from springs or other geographic features in a stream-bed acting like springs and augmented by seasonal rainfall. However, natural aquatic habitats are highly limited. Sonoyta mud turtles can also be sustained by modified natural habitats or completely human created habitats that provide similar permanent or almost permanent surface water. The Sonoyta mud turtle historically occupied habitat in two ecological settings supported by groundwater-fed springs, including cienegas and streams. Currently, there are still populations within stream habitat but all the cienegas have been modified from their natural state. Currently, aquatic habitat is found in streams and natural and manmade ponds with perennial or near-perennial (water present more than 10–11 months of the year for multiple years) sources of water. Terrestrial habitat consists of riparian areas along water courses or around ponds that maintain a cooler environment with higher soil moisture than adjacent uplands. Much of the information on resource needs of the Sonoyta mud turtle subspecies is inferred from work on the nominate subspecies, and noted accordingly in this section.

Aquatic habitat in ponds and streams is usually shallow water (to 2 m (7 ft)) deep, with a rocky, muddy, or sandy substrate, and emergent or submergent vegetation, or both (NPS 2015, p. 2; Paredes-Aguilar and Rosen 2003, p. 5–7; Rosen 2003, p. 5; Rosen *et al*. 2010, p. 14). Sonoyta mud turtles need perennial or near-perennial surface water for feeding, for protection from predators, to prevent desiccation, and for mating. We define near-perennial as water present more than 10–11 months of the year for multiple years. Hatchling, juvenile, and subadult turtles prefer aquatic habitat with shallow water and dense emergent vegetation and overhanging vegetation along the stream channel or pond margin that provides foraging opportunities as well as protection from predators (Rosen 1986, pp. 14 and 36; Rosen and Lowe 1996, p. 11). Emergent aquatic vegetation includes plants such as American bulrush (*Schoenoplectus americanus*), cattail (*Typha domingensis*), spikerush (*Eleocharis geniculate*), and travelling spikerush (*Eleocharis rostellata*) (Felger *et al*. 1992, p. 33 and 36). Adults will also use shallow water habitat, but prefer aquatic habitat with accessible, deeper, open water (up to 2 m (7 ft)) when available, and submerged vegetation for feeding on benthic and plant-crawling invertebrates along the substrate (Rosen 1986, p. 14 and 16; Rosen and Lowe 1996, p. 11). In the Sonora mud turtle, large adult turtles have exhibited site fidelity to specific pools in a stream channel (Hall and Steidl, 2007, p. 410), and although not studied could also be true for the Sonoyta mud turtle. Submerged aquatic vegetation includes plants such as holly-leaved water nymph (*Najas marina*), slender pondweed (*Potamogeton pectinatus*), ditch-grass (*Ruppia maratima*), and horned pondweed (*Zannichellia palustris*) (Felger *et al*. 1992, p. 36). Adults, juveniles, and subadults also use aquatic habitat with structure that provides protection from predators such as root masses, complex rock features, and undercut banks. Sonoyta mud turtles have been observed basking under root masses a few inches below water surface, on the water surface, and along the channel at Quitobaquito (USFWS 2016, p. 1).Sonoyta mud turtles have

rarely been seen basking outside of shallow water, but this may be a function of lack of basking sites or high ambient air temperatures of its environment (USFWS 2016).

Aquatic habitat supports prey for Sonoyta mud turtles, as they are opportunistic carnivores feeding primarily on aquatic invertebrates that live on emergent and submerged vegetation or the substrate of ponds and streams (Rosen 1986, pp. 14 and 31; Rosen and Lowe 1996, pp. 32–35) and require a variety of prey such as algae, diatoms, other microorganisms. Like the Sonora mud turtle, hatchling and juveniles likely feed on littoral invertebrate fauna found at the edge of a stream or pond, while subadults and adults prefer benthic and plant-crawling invertebrates (Hulse 1974 pp. 197–198, Lovich *et al*. 2010 pp. 135–136, Rosen 1986 pp. 14 and 31; Rosen and Lowe 1996 pp. 32–35, Stanila *et al*. 2008 p. 345). In habitats with poor aquatic invertebrate faunas, Sonoyta mud turtles will shift to omnivorous feeding including plants and vertebrates such as fish (Rosen and Lowe 1996, pp. 32–35). However, where fish are abundant, Sonoyta mud turtles catch few of them (Hulse 1974, pp. 197–198; P. Rosen, pers. comm. 2016a). Sonora mud turtles are also known to consume other vertebrates including toads, and even reptiles and birds when available for capture (Ligon and Stone 2003a, entire; Lovich *et al*. 2010, p. 136; Stone *et al*. 2005, entire). Analysis of stomach contents of the Sonora mud turtle revealed animal material represented 69.0–93.6 percent total volume with plant material making up the remaining volume (Hulse 1974, p. 197). Aquatic invertebrates found in the stomach contents included members of 11 invertebrate orders such as dragonflies (Anisoptera), caddisflies (Trichoperta), files (Diptera), beetles (Coleoptera), and aquatic snail species (Basommatophora). A carnivorous diet primarily consisting of aquatic invertebrates supports rapid growth and high lipid content (Hulse 1974, pp. 195–199; Ligon and Stone 2003a, pp. 241–242; Stone *et al* 2005, entire). When invertebrates are abundant, and competition is low, turtles grow rapidly and have sufficient lipid content to support reproduction. Turtle recruitment is likely driven in significant part by invertebrate prey available. Rosen and Lowe (1996, p. 41) concluded that nutritional stress on females may result in a reduction in annual survivorship.

Sonoyta mud turtles need aquatic habitat free of nonnative predators and competitors. The presence of nonnative predators, including crayfish (*Orconectes* spp. and *Cherax* spp.), American bullfrogs (*Lithobates catesbeianus)*, and sunfish (centrarchids), could decrease population stability or potentially decimate populations of the Sonoyta mud turtle (Drost *et al.* 2010 p. 33–34, Hensley *et al.* 2010 pp. 186–187, Fernandez and Rosen 1996 pp. 39–41). These species, along with black bullheads (*Ameiurus melas*), African cichlid fishes (tilapia), western mosquitofish (*Gambusia affinis*), and exotic turtles compete with mud turtles for food or disrupt the food chain, which could alter the invertebrate community (Taylor *et al.* 1984, pp. 330–331; Fernandez and Rosen 1996, pp. 39–40; Duncan 2013, p. 1). Such competition, in turn, could decrease the type and amount of aquatic invertebrate prey available to Sonoyta mud turtles (Fernandez and Rosen 1996, pp. 39–40) and lead to lower fitness of turtles. American bullfrogs and crayfish are also known predators of hatchling and juvenile turtles of the Sonora mud turtle (Fernandez and Rosen 1996, pp. 33–43, Akins and Jones 2010, p. 343, Hensley *et al*. 2010, p. 186–187; Schwendiman 2001, p. 39), and if introduced would likely eat younger Sonoyta mud turtles and reduce recruitment. Because high average annual juvenile survivorship is required for populations of long-lived organism to maintain population stability (Congdon *et al.* 1993, pp. 83–832; Congdon *et al.* 1994, pp. 405–406), nonnative predators that reduce recruitment in Sonoyta mud turtle populations could cause population declines. Populations of the Sonora mud

turtle have coexisted with moderate and high densities of bullfrogs (Rosen and Schwalbe 2002, p. 230). However, a high density of bullfrogs may reduce population density of mud turtles (van Lobel Sells 1997, p. 343). Crayfish are detrimental to populations of the Sonora mud turtle and not only prey on small mud turtles, but likely compete with native aquatic invertebrate food source of mud turtles (Fernandez and Rosen 1996, pp. 39–40). Fernandez and Rosen (1996, pp. 40–41) documented cessation of mud turtle recruitment 2 years after crayfish introduction to an area that had supported a population of approximately 1,000 Sonora mud turtles. Large Centrarchidae (sunfish family), such as largemouth bass (*Micropterus salmoides*), also have the potential to reduce recruitment in populations of Sonoyta mud turtles because their large gape (mouth opening) makes it possible for them to prey on hatchling and juvenile Sonoyta mud turtles (Stanila 2009, p. 50). Largemouth bass are known to eat other aquatic turtle species and Rosen (1987, p. 6) reported the lowest population densities of Sonora mud turtles in habitats with largemouth bass.

Terrestrial habitat that maintains soil moisture needed for Sonoyta mud turtles occurs in riparian areas along the banks of ponds and streams, including intermittently dry sections of a stream channel. The vegetation in riparian areas creates an area shadier, cooler, and moister environment than the vegetation in adjacent upland areas. Sonoyta mud turtles likely need moist soil for nesting to prevent desiccation of eggs and estivation sites to prevent desiccation of juveniles and adults. Riparian vegetation includes plants such as Fremont cottonwood (*Populus fremontii*), Gooding willow (*Salix goodingii*), honey mesquite (*Prosopis glandulosa*), screwbean mesquite (*P. glandulosa*), seepwillow (*Baccharis salicifolia*), greythorn (*Ziziphus obtusifolia*), wolfberry (*Lycium* spp.), salt grass (*Distichlis spicata*), arrowweed (*Pluchea sericea*) (Felger *et al*. 1992, p. 4).

Sonoyta mud turtles need accessible shoreline without insurmountable rock or artificial vertical barriers to movement between wetted sites, between aquatic habitat and terrestrial nest sites, and between water and estivation sites. Sonora mud turtles in dry or low surface water conditions may either travel along dry intermittent sections of a stream channel to find water or they will estivate (Hall and Steidl 2007, pp. 406; Hensley *et al*. 2010, p 181–182; Ligon and Stone 2003, pp. 752–753; Stone 2001, pp. 46–49). Sonora mud turtles that live in permanent bodies of water have shown highly aquatic behavior with little terrestrial behavior or movement between water sources, while Sonora mud turtles in more ephemeral habits have been documented moving through or out of dry stream beds to reach wetted pools, for winter hibernation, or for estivation during drought as a drought-survival strategy (Hall and Steidl, 2007, pp. 406–408; Hensley *et al.* 2010, pp. 181–182; Ligon and Stone 2003b, pp. 752–753; Stone 2001, pp. 46–51).

Sonora mud turtles can endure lack of surface water for a short time and have been documented estivating in the wild for 11 to 34 days (Ligon and Stone 2003b, p. 752), and up to 68 days in a laboratory setting (Peterson and Stone 2000, entire; Ligon and Stone 2003b, p. 753). Adult Sonoyta mud turtles have the ability to close their shells nearly completely and likely can survive short periods without surface water as seen in the nominate subspecies (<80 days) by estivating in terrestrial habitat or burying themselves in mud remaining in a stream or pond bed (Ligon and Stone 2003b, p.753; Peterson and Stone 2000, p. 688). However, the ability of Sonoyta mud turtles to estivate may depend on behavioral cues provided by the level of permanence of water they reside in (Ligon and Stone 200b3, p.753; Stanila 2009, p. 45). Turtle recruitment can be

affected by the amount of surface water available, how long it is available, as well as its fluctuation. Prolonged and recurrent estivation is expected to reduce fitness and increase mortality (Peterson and Stone 2000, pp. 692–698). Terrestrial estivation sites consist of depressions under vegetation, soil, or organic matter; in rock crevices; or in soil burrows under overhanging banks of streams or ponds. One study found Sonora mud turtles estivating up to 79 m (259 ft) from a streambed during summer even when water was available, with mud turtles using clumps of vegetation or spaces under large rocks in the terrestrial environment (Ligon and Stone 2003b, pp. 752–753).

Estivation has not been verified in the Sonoyta mud turtle, and physiological tolerances for estivation are unknown. However, Sonoyta mud turtles have been found in burrows up to 1 m (3.3 ft) deep in stream banks, presumably using these burrows to escape from predators (Paredes-Aguilar and Rosen 2003, p. 8) or for refuge from drought. Overhanging riparian vegetation along the stream channel or pond margin provides some protection from predators for turtles in the water near the shoreline. Riparian vegetation may also provide some level of protection from terrestrial predators while turtles are out of the water. Further, based on the physiological requirements of the Sonora mud turtle and the arid environment in which the Sonoyta mud turtle lives, we think that they estivate during times of little or no surface water.

Long-distance movements of Sonora mud turtles exceeding 7 kilometers (5 miles) in straight-line distances occurred between aquatic habitats, and may reduce reproductive isolation and lower the probability of extirpation of populations (Hall and Steidl 2007 p. 408; Hensley *et al.* 2010, pp. 181–182; Stone *et al*. 2015, p. 736). Although not well-studied, no movement of Sonoyta mud turtles of these magnitudes has been documented, and their extreme arid environment may reduce such movements (Paredes-Aguilar and Rosen 2003 p. 9;USFWS 2016, p.6). Dispersal habitat along drainages between populations of the Sonoyta mud turtle is likely needed to maintain connectivity between aquatic habitats on a range-wide scale.

Sonora mud turtle females are known to lays eggs in terrestrial nests that maintain some level of moisture in sites such as vegetation litter, soil burrows, and rock crevices away from water up to 52 m (171 ft) (Rosen and Lowe 1996, p. 21 and 23; Stone *et al.* 2015, p. 735; D. Hall, pers. comm. 2016, Rosen 1986, p. 7; A. Owens2007, p. 1; P. Holm, pers. comm. 2016b). Three presumed nest sites have been observed for the Sonoyta mud turtle that indicate this subspecies uses similar nest sites as the Sonora mud turtle. The first observation was of a gravid female, “apparently preparing to lay eggs”, digging 15 cm (6 in) into the soil in a mesquite bosque (cluster of trees along a stream) 9 m (30 ft) from the edge of the pond at Quitobaquito Springs (Rosen and Lowe 1996, p. 23). A second turtle nest site was found in a small cavity (5 x 5 cm (2 x 2 in)) within a 3 m (10 ft) high soil bank that runs next to the spring-fed channel leading to Quitobaquito pond (A. Owens 2007, p. 1). The third nest site was found in a small depression in soil beneath a piece of tree bark on top of an undercut bank at the edge of Quitobaquito pond (P. Holm, pers. comm. 2016b).

Habitat needs for various life history functions of the Sonoyta mud turtle are summarized in Table 2.5.1. below.

Table 2.5.1. Resource (habitat) needs for life history functions

Life Stage	Life History Resource Needs (Habitat)	References
Eggs	Laid in vegetation litter, soil burrows, or possibly in rock crevices with some level of moisture maintained	Rosen 1986 p. 7, Rosen and Lowe 1996 p. 23 A. Owens, 2007 p. 1 P. Holm, pers. comm. 2016b
Hatchling & Juvenile/ Subadult	Prefer shallow water with dense emergent vegetation and overhanging vegetation along the stream channel or pond margin that provides foraging opportunities [likely feed on littoral (situated along shoreline) invertebrate fauna] as well as protection from predators	Rosen 1986 pp. 14 & 36; Rosen and Lowe 1996 p. 11
Adult	Prefer water with complex structure including root masses, complex rock features, and undercut banks with aquatic submerged vegetation, as well as overhanging vegetation along the stream channel or pond margin for protective shelter but also deeper sections of ponds (up to 2 m (7 ft)) where they likely forage (prefer benthic and plant-crawling invertebrates) in vegetation and along bottom. .	Rosen 1986 pp. 14 & 36; Rosen and Lowe 1996 p. 11
	In nominate subspecies, adult turtles have exhibited site fidelity to specific pools, especially males and large females	Hall and Steidl 2007 p.410
	Mating	
All life stages except eggs	Aquatic habitat in streams and natural and manmade ponds with perennial or near-perennial water with little water level fluctuation to prevent desiccation, protection from predators, provide forage and prey, 2 m (7 ft) deep rocky, muddy, or sandy substrate, and emergent or submergent vegetation, or both.	Paredes-Aguilar and Rosen 2003 p. 8, Hensley *et al.* 2010 p. 182, Ligon and Stone 2003b p. 752, Rosen *et al.* 2010 pp. 144–145 USFWS 2016, pp. 2-3
	Accessible shoreline without insurmountable rock or artificial vertical barriers to movement between terrestrial nest site and water, and between water and estivation sites	Rosen and Lowe 1996 p. 11
	Feed primarily on aquatic invertebrates that live on emergent and submerged vegetation, but will shift to omnivorous feeding (plants and fish) in habitats with poor aquatic invertebrate faunas. Benthic and plant-crawling invertebrates preferred by subadults and adults;	Hulse 1974 pp. 197–198, Lovich *et al*. 2010 pp. 135–136, Rosen 1986 pp. 14 & 31, Rosen and Lowe 1996 pp. 32–35, Stanila *et al*. 2008

Life Stage	Life History Resource Needs (Habitat)	References
	hatchling and juveniles feed on littoral invertebrate fauna Small vertebrates including fish areeaten opportunistically.	p. 345
	Basking sites or shallow water to maintain body temperature likely not a strong factor in nominate subspecies. Refuges from extreme heat in shallow water sites are likely required in Sonoyta mud turtle populations. Sonoyta mud turtles have been seen basking under root masses a few inches below water surface, on the water surface, and along the channel at Quitobaquito and Xochimilco.	USFWS 2016, p. 1
	Aquatic habitat free of nonnative predators, specifically crayfish, bullfrogs, and sunfish; and competitors, specifically catfish such as black bullhead, African cichlid fishes, western mosquitofish, and exotic turtles	Drost *et al.* 2010 p. 33–34, Hensley *et al.* 2010 pp. 186–187, Fernandez and Rosen 1996 pp. 39–41, Schwendiman 2001 p. 39; Taylor *et al*. 1984 pp. 330–331, Duncan 2013 p. 1
All life stages	Terrestrial habitat consisting of riparian areas along water courses or around ponds that maintain a cooler environment with higher soil moisture than adjacent uplands. Terrestrial habitat includes terrestrial nesting and estivation sites consist of burrows under overhanging banks or streams or ponds, and also in roots, depressions under vegetation, soil, or organic matter; and in rock crevices. Riparian vegetation may also provide some level of protection from terrestrial predators while turtles are out of the water.	Hall and Steidl 2007 pp. 406–408, Hensley *et al.* 2010 pp. 181–182, Ligon and Stone 2003b, pp. 752–753, Stone 2001, pp. 46–51 Rosen and Lowe 1996 p. 21 and 23, Stone *et al.* 2015 p. 735, D. Hall pers. comm. 2016, Rosen 1986 p. 7, A. Owens 2007 p. 1, P. Holm pers. comm. 2016b

CHAPTER 3. HISTORICAL RANGE, POPULATION NEEDS, AND CURRENT CONDITION

In this chapter, we consider the Sonoyta mud turtle's historical distribution, current distribution, and the subspecies' needs for viability. We first review the historical and current information on the range and distribution of the subspecies. We next review the conceptual needs of the subspecies, including population resiliency, and subspecies redundancy and representation to support viability. Finally, we consider the current conditions of the Sonoyta mud turtle populations.

3.1. Historical Range and Distribution

The Sonoyta mud turtle was historically found only in the Rio Sonoyta basin in Arizona and Sonora, Mexico (Figure 3.1.1.a). The Rio Sonoyta drainage covers 3,160 square kilometers (km^2) (1,220 square miles (mi^2)). The Rio Sonoyta originates near the Sierra del Pozo Verde in Mexico, running northwest in Sonora, it turns west as Vamori Wash and joins San Simon Wash, draining into the western Tohono Oodham Nation, and then continues west in Mexico 48 km (30 mi) east of Sonoyta, Sonora. The Rio Sonoyta continues west approximately 23 km (14 mi) through Sonoyta, paralleling the U.S. and Mexico border. Quitobaquito Springs in Arizona is north of this section of the river. The Rio Sonoyta then turns south along the east side of the Pinacate volcanic shield, passing through the eastern fringe of a sand field (the Gran Desierto) before reaching the Sea of Cortez east of Puerto Peñasco, Sonora, Mexico.

The Quitobaquito-Rio Sonoyta region of southwestern Arizona and northwestern Sonora, Mexico, is characterized by an extremely arid climate and hydrological isolation from other river systems (i.e., Colorado and Gila rivers and Río Concepción). Isolation of the Rio Sonoyta drainage probably occurred sometime in the last 100,000 to 1,000,000 years when eruptions from the Pinacate Volcanic Field diverted flow of the Rio Sonoyta southward to the Gulf of California. Prior to isolation of the Rio Sonoyta drainage, many aquatic species including gartersnakes, leopard frogs, fishes, and turtles likely inhabited the Rio Sonoyta. Species richness probably dwindled over a very long time period, so that there are now endemic animal taxa from this aquatic system that are relicts of a time long past when the Rio Sonoyta was connected to the other river systems. These remaining species include the Sonoyta mud turtle along with the Quitobaquito pupfish and the Longfin Dace (Ives 1936, pp. 349–350; Turner 1983, p. 691). The Sonoyta mud turtle was likely historically distributed throughout the Rio Sonoyta basin in Arizona and Sonora when there was more surface water to provide connectivity between populations allowing for immigration and emigration (Figure 3.1.1b) (Rosen 2003, p. 11).

The hydrology of Rio Sonoyta basin is not fully understood, but it appears that historical and existing perennial surface waters are closely associated with shallow rock which forces groundwater in the underlying aquifer to the surface (Rosen *et al*. 2010, p. 145). There were at least three historical perennial sections of the Rio Sonoyta, including the Sonoyta, Santo Domingo, and Papalote (also referred to as Agua Dulce) reaches (Rosen *et al.* 2010, p. 152). Before 19th and 20th century, degradation of water quantity by groundwater pumping, livestock grazing and subsequent down cutting of the river had not yet occurred. Consequently, perennial waters likely flowed through these three sections of the Rio Sonoyta separated by seasonally

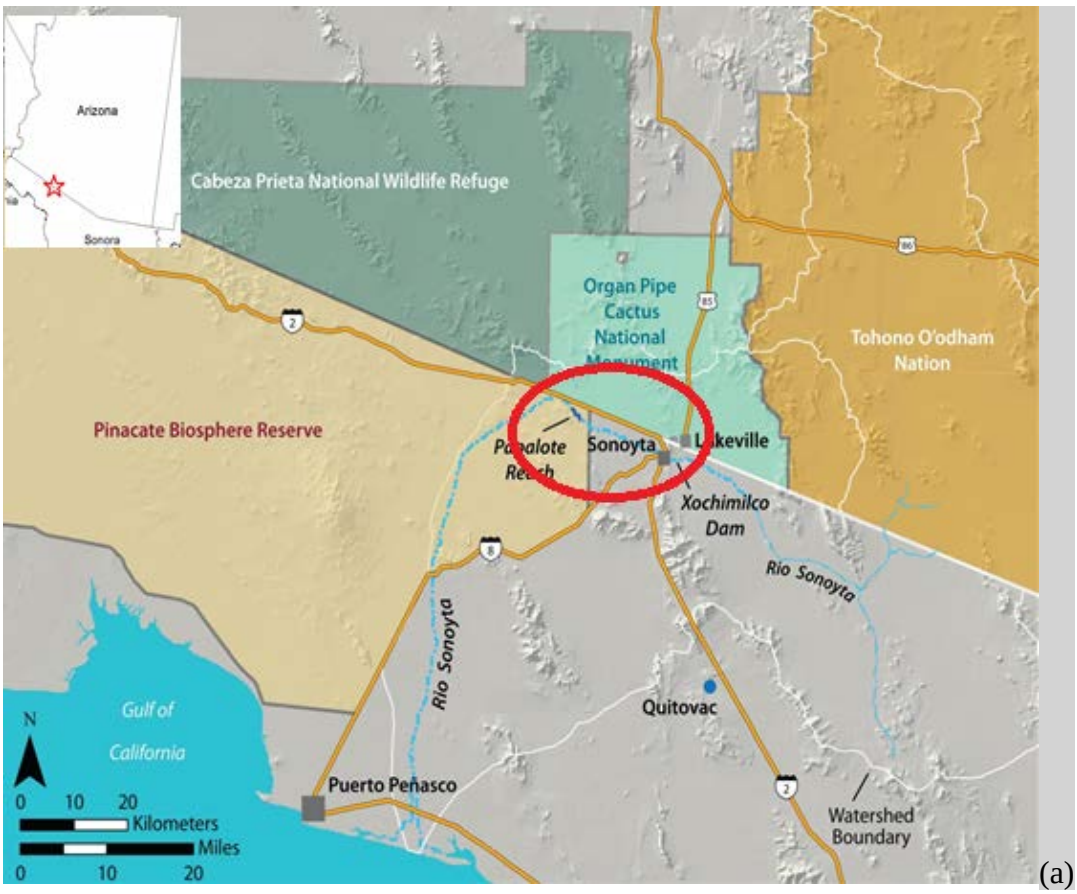
ephemeral sections (Figure 3.1.1.b), and groundwater also supported springs and cienegas (wet, marshy areas) in the area (Miller and Fuiman 1987, p. 602; Schoenherr 1988, p. 110; Hendrickson and Varela-Romero 1989, p. 481). Historically, perennial water in the Sonoyta reach probably originated at the south tip of the Sonoyta Hills where bedrock is exposed in the river channel and included multiple springs that produced an extensive marshy meadow with stream flow, as well as scour pools associated with the main path of storm runoff (Rosen *et al* 2010. p. 145 and 152). The Sonoyta reach continued beyond another spring site known today as Presa Xochimilco (Rosen *et al*. 2010 p. 145). The main source of water for the Santo Domingo reach was a non-perennial spring in the riverbed that occurs at the river's narrow point between two rhyolitic hills (Rosen *et al*. 2010 p. 147). The Papalote reach occurs at the next major rocky choke-point after the Santo Domingo reach, consisting of identical-looking decomposing granite to the north (Quitobaquito Hills) and south (Cerro de Tres Verredos, an outlier of the Sierra los Tanques). Rosen *et al.* (2010 p. 148) postulated that the river course is pushed to the south against the flank of Sierra los Tanques by the large bajada of the Puerto Blanco Mountains and water is forced to the surface by subterranean granitic rock. The source and fate of the Papalote reach are unknown, but the reach is likely the product of the aquifer between Sonoyta and Santo Domingo and its attenuating continuation over the subsurface Aguajita Springs granite (Rosen *et al.* 2010 p. 149).

These three distinct perennial reaches of the Rio Sonoyta together likely provided 19 to 27 km (12 to 17 mi) of stream habitat for the Sonoyta mud turtle, from the upstream Sonoyta reach beginning about 4 km (2.4 mi) above the town of Sonoyta to the downstream Papalote reach ending due west or southwest of Quitobaquito Springs (Figure 3.1.1, Table 3.1.1). The Rio Sonoyta probably flowed for short periods during wet seasons providing connectivity for mud turtles, and with the stream rapidly retracting during the dry season, as it still does today. During decadal periods of above-average precipitation, the river may have been continuous for longer periods, making turtle population connectivity more likely along Rio Sonoyta.

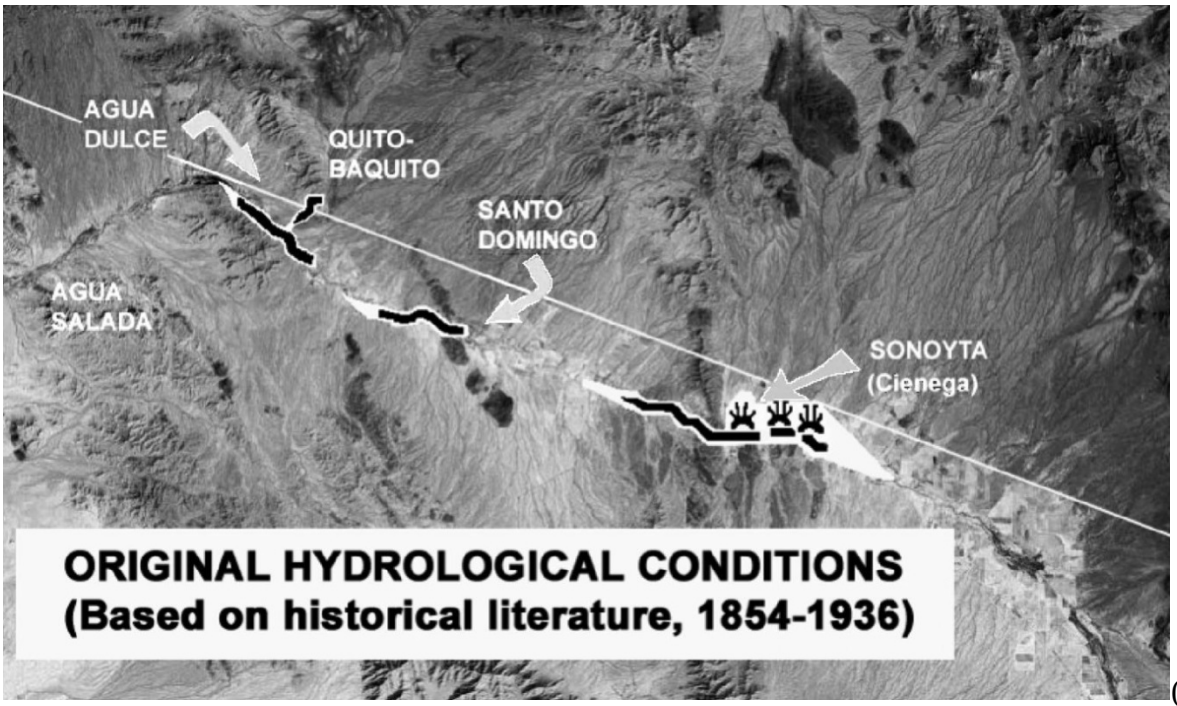
Sonoyta mud turtles have been found in each of the three historical reaches of the Rio Sonoyta and other sites in the Rio Sonoyta basin (see Table 3.1.1. below; Paredes-Aguilar and Rosen 2003, entire; Rosen *et al*. 2010, pp. 152–153). The Sonoyta mud turtle was historically known from five sites in the Rio Sonoyta basin: one site in the U.S. and at least four sites in Mexico. We state "at least four" because of the uncertainty of some of the location information. Some of the historical location information is vague and we used our best professional judgment to determine the locations. The first verified museum record in Mexico was collected from an artificial pond fed by springs adjacent to the Rio Sonoyta east of the town of Sonoyta in 1894 by E.A. Mearns (Iverson 1981, p. 43 and 62; Iverson 1992, p. 235). The next three records were three adult mud turtles collected from the "Sonoyta River, 3 mi [4.8 km] from Sonoyta" by B.A. Wood (Iverson 1981, p. 43 and 62; Iverson 1992, p. 235). Both of these localities are likely within the historical Sonoyta reach of the Rio Sonoyta. The fourth historical museum record was collected "29.0 km [18 mi] west of Sonoyta on Highway 2" (Iverson 1981, p. 43 and 62; Iverson 1992, p. 235). This location is within the Rio Sonoyta basin, and Iverson (1992, p. 235) maps it within the historical Papalote reach of the Rio Sonoyta before the river turns southwest towards the Sea of Cortez (Figure 2.2.1). While precise locations of these five historical records are unclear, Sonoyta mud turtles were documented in the three historical reaches along the Rio Sonoyta in the early 2000s as discussed below under Section 3.2 (Paredes-Aguilar and Rosen

2003, pp. 2–5; Knowles *et al* .2002, p. 1, Rosen *et al* .2010, p. 152). We assume that the historical locations of the Sonoyta mud turtles were in areas of the Rio Sonoyta basin that maintained perennial surface water at all times except, possibly, during rare, protracted drought periods. These locations may no longer have reliable surface water to support mud turtles or sufficient surface water to support as large a population as they used to (Paredes-Aguilar and Rosen 2003, p. 2; Rosen *et al.* 2010, p. 155).

Perennial water also existed outside of the Rio Sonoyta in cienegas such as the cienega fed by Quitobaquito Springs on Organ Pipe Cactus National Monument. Quitobaquito Springs is predominately supplied by groundwater along Aguajita Wash and in the La Abra Plain that was originally shed by the Puerto Blanco Mountains (Carruth 1996, pp.14, 18). Sonoyta mud turtles have only been recorded at this single location in the U.S. While R.D. Krizman and T.J. Cox (Iverson 1981, p. 43) collected the first museum record of the subspecies at Quitobaquito Springs in 1965, there are written records of a population of turtles at Quitobaquito Springs in the 1950s. The headwaters of the Rio Sonoyta include drainages that flow through Tohono O'odham Nation lands, although there are no perennial reaches of streams that could support turtles. There are livestock tanks and other impoundments on Nation lands that could support turtles and Paredes-Aguilar and Rosen (2003, p. 5) stated that the subspecies could possibly occur in the southwestern corner of the Tohono O'odham Nation at Gu Vo. However, it is currently unknown if Sonoyta mud turtles occur anywhere on the Tohono O'odham Nation.



(a)



(b)

Figure 3.1.1. (a) Map of Sonoyta mud turtle historical range (in red oval). (b) Extent of historical reaches occupied by the Sonoyta mud turtle based on inferred original conditions with uncertainty suggested by narrowing white outlining (Rosen *et al.* 2010, p. 146).

Table 3.1.1. Estimated Abundance and Extent of Historical Populations

Location	**Abundance**	**Perennial Stream km (mi)**	**Citations**
AZ			
Quitobaquito Springs	Several hundred in 1950s	unknown	Rosen 1986 p.16
Mexico			
Rio Sonoyta[1]		19–27 (11.8–16.8)	
Papalote Reach (or the Agua Dulce)	unknown	5–6 (3.1–3.7)	Rosen *et al* 2010, p. 152; Iverson 1981, p. 43 & 62; Iverson 1992, p. 235
Santo Domingo[4]	unknown	4–6 (2.5–3.7)	Rosen *et al* 2010, p. 152; Iverson 1981, p. 43 & 62; Iverson 1992, p. 235
Sonoyta Reach[2,3,4]	unknown	10–15 (6.2–9.3)	Rosen *et al* 2010, p. 152; E.A. Mearns 1894 record; Iverson 1981, p. 43 & 62; Iverson 1992, p. 235

Total of 4 locations

[1] We assume that the 3 unspecified historical occurrences of the Sonoyta mud turtles in the Sonoyta basin would have occurred in the areas of the Rio Sonoyta that retained the maximum amount of water given their reliance on water.
[2]. Mearn's 1894 record was likely adjacent to the Sonoyta reach
[3]. The historical Sonoyta reach includes the area referred to today as the Xochimilco reach. It included the Sonoyta Cienega which is no longer a functioning cienega.
[4]. There is a historical site described as 4.8 km (3 mi) from Sonoyta. However, the record does not indicate if this is west or east. Consequently, this record could be from the Sonoyta Cienega reach or the Santo Domingo reach.

3.2. Current Range and Distribution

Currently there are five extant populations of Sonoyta mud turtles. In this assessment, we define a population of Sonoyta mud turtle as a group of interbreeding individuals living in an ecological community and is separated from other populations by barriers including desert upland (overland, not connected by riparian or xeroriparian habitat) or in-channel distances that lack water most of the time. Periodic movement between populations may occur during periods of high rainfall, but extent of immigration and emigration is unknown but thought to be unlikely (P. Rosen, pers. comm. 2016b and 2016c, USFWS 2016, p. 6). No overland immigration has been discovered between two populations studied by mark-recapture and separated by one mile of upland habitat (Rosen *et al*. 2010, p. 145). Consequently, we assume that movement among populations is rare to limited due to limited hydrological connection. Of the five extant populations, one is in the U.S. in the pond and channel associated with Quitobaquito Springs in Organ Pipe Cactus National Monument, Arizona. The other four populations are in Sonora, Mexico (Rosen *et al.* 2010, p.152). Two populations in the Rio Sonoyta in the Papalote reach and Sonoyta reach (now restricted to the Xochimilco reach) are extant but perennial water flow in these reaches is reduced from historic levels. The other two populations, the Sonoyta sewage lagoon and Quitovac in Mexico, were historically unknown and recently found by Knowles *et al*. 2002 (p. 74) investigating potential new turtle habitats in and around the Rio Sonoyta basin. Table 3.2.1 lists these populations and Figure 3.2.1 depicts the locations of these populations. Exchange of genetic material between Quitobaquito Springs and populations along the Rio Sonoyta is unlikely due to complete lack of hydrological connection and has not been observed despite some mark-recapture effort at these sites (Rosen *et al*. 2010, p. 145). Exchange of genetic material among populations of the Rio Sonoyta is likely a rare event limited to prolonged periods of precipitation or high flow events along the Rio Sonoyta that connects these populations by providing stepping stones of wetted habitat through which mud turtles could move or disperses. This may not occur under existing hydrology, even during periods of wet years, if the absence of movement between Quitobaquito and Papalote also applies to crossing of normally dry river reaches.

The population at Quitobaquito Springs has been extensively monitored since the early 1980s. Surveys in the Rio Sonoyta basin in Sonora, Mexico from 2001 through 2006 provide most of our knowledge of the current populations in Mexico (Table 3.2.2; Paredes-Aguilar and Rosen 2003, entire; Knowles *et al.* 2002, entire; Rosen *et al.* 2010, pp. 152–153). However, we have low confidence that the population information for the Sonora populations remains the same today as many changes since the early 2000s have reduced or degraded habitat at most of the

sites that still support Sonoyta mud turtles. In October 2001, a single turtle was found in a soup-bowl-sized remnant of water at the semi-perennial spring at Ejido Josefa Ortiz in the Santo Domingo reach (Rosen *et al.* 2010, pp. 152–153), and we now think this historical population is likely extirpated due to loss of perennial surface water in this reach (P. Rosen, pers. comm. 2016b). Each extant population is described below.

Table 3.2.1. Current and Extirpated Populations of Sonoyta Mud Turtle

Population Name	**Historical Reach**	**Land Owner**	**Location Name**	**Extant or Extirpated**
Arizona, U.S.				
Quitobaquito Springs	None	NPS (U.S.)	Organ Pipe Cactus National Monument	Extant
Sonora, MX				
Papalote Reach (Agua Dulce)	Papalote Reach	NPS (MX)	Rio Sonoyta, Pinacate Biosphere Reserve	Extant
Santo Domingo	Santo Domingo	Ejido Josefa Ortiz de Dominguez	Rio Sonoyta, Historical site of Santo Domingo	Presumed Extirpated
Sonoyta Sewage Lagoon	None	Town of Sonoyta	Rio Sonoyta, Town of Sonoyta	Extant
Xochimilco Reach[1,2]	Sonoyta Reach	Town of Sonoyta	Rio Sonoyta, Town of Sonoyta	Extant
Quitovac	None	Quitovac y su anexo el Chujubabi	Quitovac	Extant

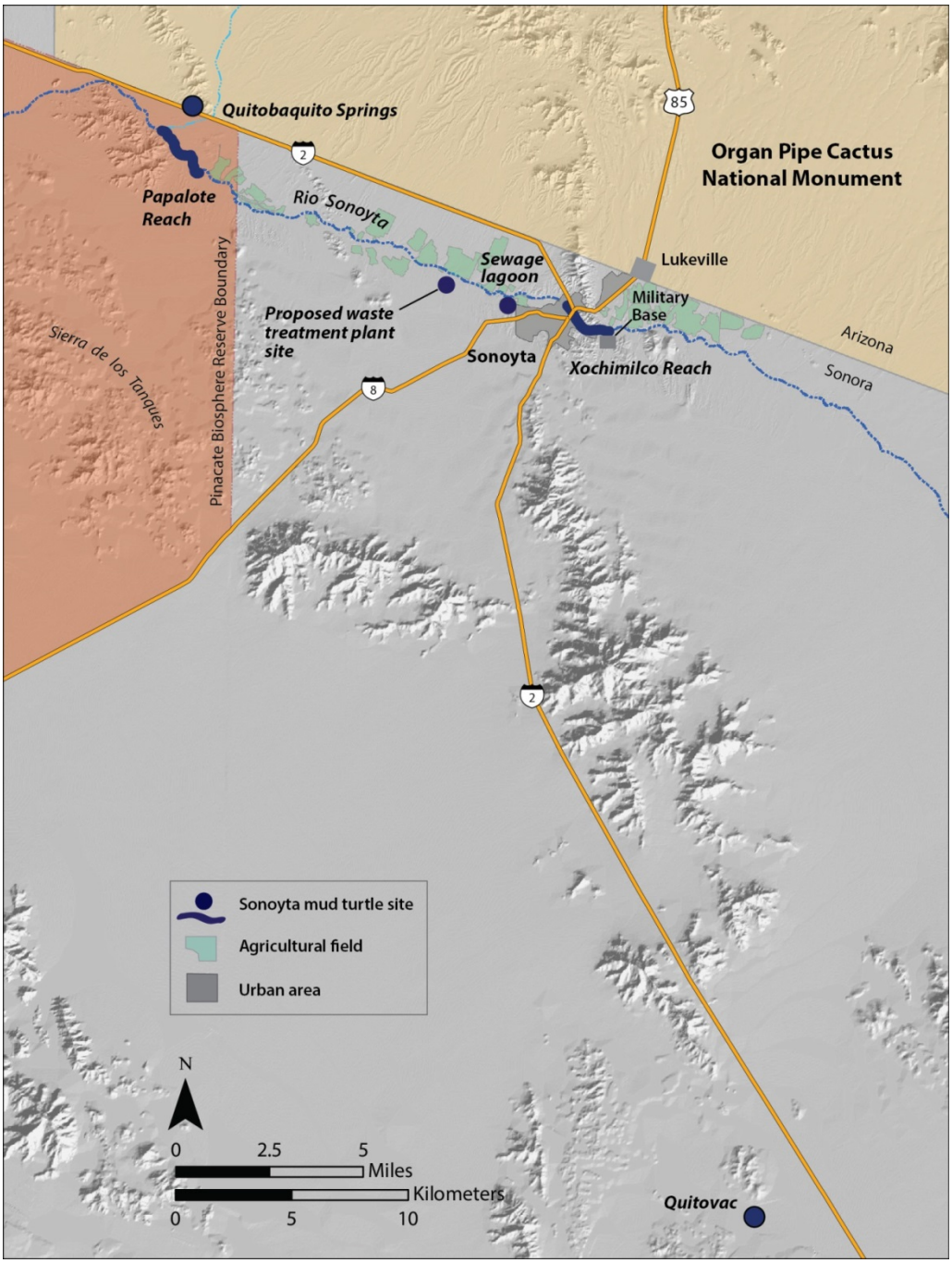


Figure 3.2.1. Current range and distribution of Sonoyta mud turtle in U.S. and Mexico

Table 3.2.2. Most recent Estimated Abundance and Extent of Extant Populations

Location	Abundance	Stream km(mi)	Area	Depth cm (in)	Citations
AZ					
Quitobaquito Springs	2015=141±25 Avg=110[1]	0.244 (0.15)	<0.27 ha (0.67 ac)	81–94 (32–37)	NPS 2001 – 2015
Mexico					
Rio Sonoyta					
Papalote Reach (or Agua Dulce Reach)	2003=>100, low density Now= 50 turtles have been captured and marked in 2017.	1.5–3 (0.9–1.9)	pool size 2–4.5 m^2 (22–48 ft^2)	See description below	Paredes-Aguilar and Rosen 2003, p. 8; Rosen 2003 p. 5; Knowles 2002, p. 72; C. Minkley 2017 p. 2
Xochimilco Reach	2002=~345 Now=unknown	0–2.5 (0–1.6)	pool size 10–48 m^2 (107–516 ft^2)	See description below	Rosen 2003, p. 3 & 4; Paredes-Aguilar and Rosen 2003, p. 9
Sonoyta Sewage Lagoon	2003=~300 Now = unknown	n/a	>5 ha (>12.3 ac)	See description below	Rosen 2003, p. 4
Quitovac	2002=~200 2015=unknown	n/a	>1 ha (>2.5 ac)	See description below	Paredes-Aguilar and Rosen 2003, p. 9–11
Total of 5 unconnected populations					

[1]Estimates from Quitobaquito Springs include adults only, no young-of-the-year are included. This average is from 2001 to 2015.

3.2.1. Quitobaquito Springs, Arizona, U.S.

Quitobaquito Springs lies on the international border of Arizona and Mexico in the southwestern corner of Organ Pipe Cactus National Monument. Aquatic habitat originates from a pair of natural springs that seep up through a fault in fractured granite and gneiss rock that runs along the base of the Quitobaquito Hills (Figure 3.2.2). This aquatic habitat supports a number of sensitive native aquatic species at Quitobaquito Springs including the Sonoyta mud turtle, endangered desert pupfish (*Cyprinodon macularius*) [=Sonoyta pupfish (*C. eremus*)], longfin dace (*Agosia chryogaster*), and Quitobaquito tryonia (*Tryonia quitobaquitae*). Historically, the aquatic habitat at Quitobaquito Springs was presumably a cienega-like (wet marshy area usually fed by springs) formation (Rosen 1986, p.16). Fossil spring deposits to the west of Quitobaquito Springs indicate that, during floods or in times of greater natural flow, water filled an adjacent wash and established a connection to the Rio Sonoyta (Miller and Fuiman 1987, p. 603). Permanent contact between the two probably occurred at some time in the Holocene and certainly during Pleistocene and earlier times.

Figure 3.2.4. Conducting turtle surveys at the pond at Quitobaquito Springs, AZ.

Large-scale water management at Quitobaquito Springs began in 1863 when the first European American settler dug a pond (current location of pond), built a dam to hold water diverted from the two main spring sources, and dug irrigation ditches to fields south and west of the pond to grow corn, cereals, melons, and fruit trees (Bennett and Kunzmann 1989, p. 15; Pearson and Conner 2000, p. 392). The Quitobaquito Springs area was inhabited by Papago (Tohono O'odham and Hia C-ed O'odham) farmers for centuries, perhaps longer, and the Papago excavated basins to capture water from the springs for irrigation prior to the 1860s (Bennett and Kuzmann 1989, pp. 1–22; Nabhan *et al.* 1982, pp. 124–126). Quitobaquito Springs was also used as a waypoint for European travelers from the late 1600s to early 1900s, and as a U.S. government station in the late 1800s to the 1950s. The pond at Quitobaquito Springs was already created when the NPS acquired the site in 1937 as part of Organ Pipe Cactus National Monument. In the early 1950s, the U.S. government built a low concrete dam across the spring channel and water was supplied to the station for human use through 305 m (1,000 ft) of pipe (Bennett and Kunzmann 1989, p. 22). An underground pipeline was installed to direct flows from the northeast spring to the southwest spring and then a human-made stream channel was constructed to direct flows from the southwest spring south into the pond constructed by European Americans (Figure 3.2.2). Water also continued to be used by the O’odham Oresco family for livestock and irrigation of crops through 1957, after which the NPS halted all grazing and irrigation in the Quitobaquito Springs area.

To maintain the small pond, which is the desire of the NPS, requires active management to remove sediment that builds up and to stop native vegetation such as American bulrush

(*Schoenoplectus americana*) from completely filling in the pond. Photos taken of Quitobaquito Springs in 1953 revealed a shallow cienega-like pond, with low amounts of bulrush growing in and around the pond due to existing livestock grazing (Bennett and Kunzmann 1989, p. 30). By 1961, conditions had deteriorated due to lack of ditch maintenance that reduced water flow from the springs to the pond, and the pond had reduced capacity due to sedimentation from the surrounding desert and encroaching bulrush resulting from grazing cessation (Bennett and Kunzmann 1989, p. 33). In 1961, the pond was drained and deepened to a depth of 1.5 m (5 ft), after which Sonoyta mud turtles became increasingly rare in the area (Bennett and Kunzmann 1989, p. 34). These alterations eliminated shallow water habitat in the pond and ditch habitat that had existed between the two springheads and was likely used by Sonoyta mud turtles. When the pond was subsequently drained in 1970 to eliminate nonnative fish and enhance habitat for the endangered desert pupfish, "about 100 turtles were found" (Bennett and Kunzmann 1989, p. 34), and many of them were collected and given away to individuals (Rosen 1986, p. 17).

In 1989–1990, NPS began implementing conservation measures for Sonoyta mud turtles including construction of a small shallow area and nesting island in the pond, and creation of a 244–m (800–ft) stream channel to connect the southwest springhead to the pond (Figure 3.2.2) (Bennett and Kunzmann 1989, p. 36; Rosen and Lowe 1996, p.6). These modifications improved habitat for all age classes of Sonoyta mud turtles in the pond and created additional shallow perennial habitat along the new stream channel that is primarily used by juvenile mud turtles. However, both the channel and pond require maintenance by NPS to remove encroaching vegetation, as well as preserve stream flow and pond levels. For example, the spring collection system was again renovated in 2007, the pond was renovated in 2008, and bulrush was thinned annually from 2006 through 2012 (Pearson and Conner 2000, pp. 393–394; NPS 2007, entire, NPS 2008a, entire, NPS 2012b, entire). Today, pond habitat for the Sonoyta mud turtle population at Quitobaquito Springs continues to be dependent on manipulation and maintenance by NPS, which is further discussed in Chapter 4. Flow from the springs has experienced an average annual reduction in discharge of 1.2 percent, which equals a 42 percent reduction in discharge over the past 35 years (P. Holm, pers. comm. 2016c and 2016d) and pond levels have fluctuated dramatically due to infrastructure failure including leaks in the berm and pond liner, drought conditions, and water consumption by vegetation in the pond (Figure 3.2.3) (NPS 2015, p. 2). In the early 1990s, the pond was usually at maximum capacity. The outflow pipe level is 107 cm (42 in) deep on the south shore (full pond depth), creating a maximum 0.27 ha (29,000 ft^2) in surface area when the pond is full. The pond has averaged 81 to 94 cm (32 to 37 in) in depth in recent years (Figure 3.2.3), and surface area has not been measured, but is less than the maximum 0.27 ha (29,000 ft^2). From 2006 through 2009, surface elevation of the springs lowered to levels unprecedented since the 1962 dredging and related modifications, and the pond reached progressively lower levels, resulting in large temporary reductions in total water volume and pond surface area. In recent years, there has been a pronounced seasonal pattern with the pond level declining during spring and fall dry seasons, and increasing during summer and winter rainy seasons. Aside from the seasonal pattern, there has been a trend of declining pond level since the early 1990s (further discussed in Chapter 4). The total loss of pond depth is about -70 cm (-27.5 in).

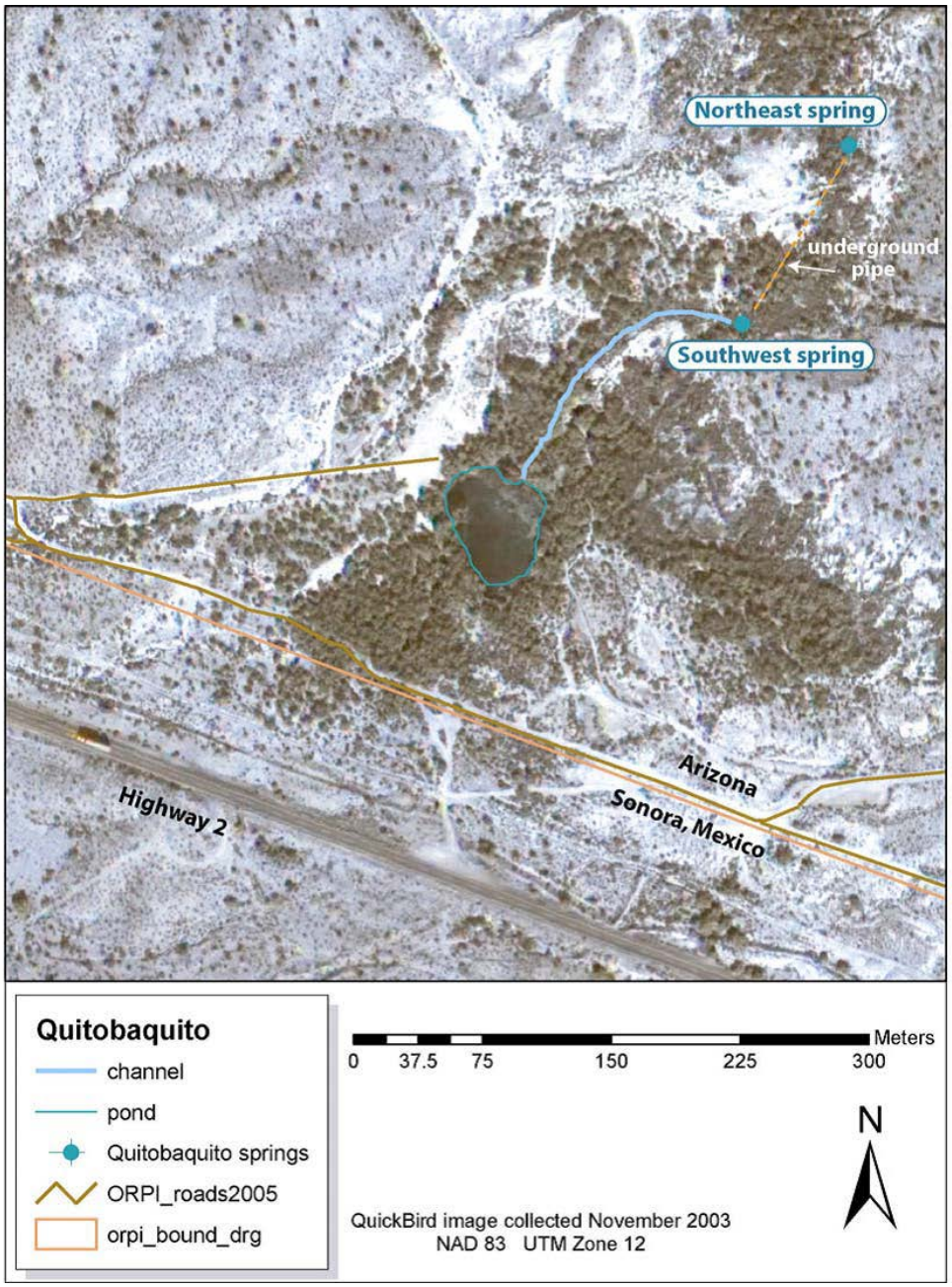


Figure 3.2.2. Aerial view of Quitobaquito Springs and Pond, Arizona with Highway 2 in Sonora Mexico to the south. (ORPI=Organ Pipe National Monument)

As another conservation measure, 81 turtles were removed from Quitobaquito Springs between October 2007 and August 2009 and placed in captivity while resource managers addressed declining water levels in the pond resulting from evapotranspiration loss from bulrush and leakage at the retaining berm likely caused by structural damage from tree roots (NPS 2011a, p. 17). In the summer of 2011, 24 captive turtles were repatriated and another 12 were due to be released in 2012. However, low water levels in June 2012 prompted a decision to delay the release of additional turtles until the pond could be stabilized and no additional turtles have been repatriated. Since 2011, 14 of the 24 repatriated turtles have been captured alive and two others have been found dead. Two of the 24 turtles released from captivity in 2011 were recaptured in the latest 2015 sampling effort. A total of 30 animals have died in captivity, and there are 27 turtles remaining in the captive population. This is discussed further in Chapter 4. Population numbers discussed below include repatriated animals that were previously salvaged from Quitobaquito Springs.

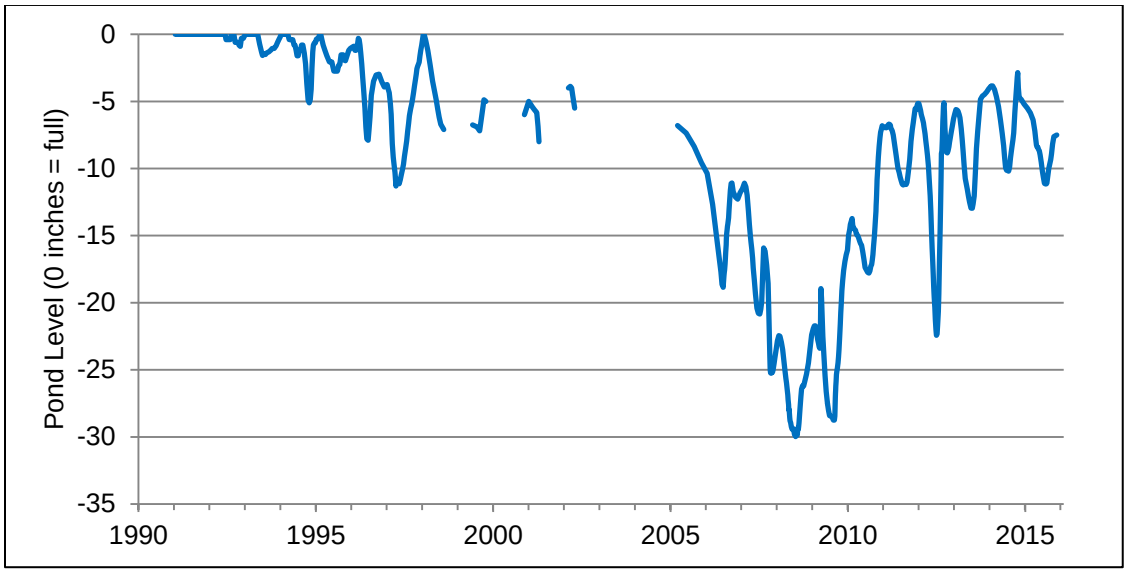


Figure 3.2.3. Variation in water level at the pond at Quitobaquito Springs since 1991, Organ Pipe Cactus National Monument. Gaps are due to missing data. Total loss of pond depth is -70 cm (-27.5 in).

Rosen and Lowe (1996, p. 3) surmised that Sonoyta mud turtles at Quitobaquito Springs probably numbered in the hundreds in the late 1950s. Gehlbach (1981, p. 263) estimated the population at between 76 and 162 in the 1970s and Rosen and Lowe (1996, p. 3) estimated about 108–114 individuals in the early 1980s with a continued decline into the late 1980s to a low of less than 70 animals in 1989 (Figure 3.2.5) (Rosen and Lowe 1996, p. 20). They hypothesized that the decline was due to low survivorship of juvenile turtles and nutritional stress (Rosen and Lowe 1996, pp.40–41) based on recovery of numerous dead adults with extremely low total body fat. Low survivorship among juveniles turtles was attributed to predation and degradation of shallow-water, well-vegetated habitat for juveniles due to earlier management actions (Rosen and Lowe 1996, p.40). Following NPS restoration of shallow, well-vegetated habitat for juvenile mud turtles along the spring runs and in the pond in 1989 and 1990, Rosen and Lowe (1996, p. 20) detected an increase in juvenile survivorship along with rising population abundance (Figure

3.2.5).

Since 2001, Organ Pipe Cactus National Monument and partners have conducted annual mark-recapture surveys of Sonoyta mud turtles (Figure 3.2.4) following a standard trapping methodology at Quitobaquito Springs. Census methods and previous results are described in annual reports (NPS 2001–2015). Excluding young-of-the-year (< 40 mm (1.6 in) carapace length), population estimates since 1984 ranged from a low of 39 turtles in 2005 to a high of 189 in 2013 with an average annual population estimate of 110 turtles for turtles with carapace length >40 mm(1.6 in)(Figure 3.2.5)(NPS 2015, p. 1). Surveys were not conducted and subsequent population estimates were not generated in 2008 and 2009 due to low water levels (NPS 2011a, p. 1). The population estimate of 189 +/- 78 turtles for 2013 was the largest estimate since mark-recapture surveys began in 1984. The population estimate for 2015 was 141±25 turtles. Trapping returns for young-of-the-year, not included in the population estimates, has fluctuated since 2001 (Figure 3.2.6).

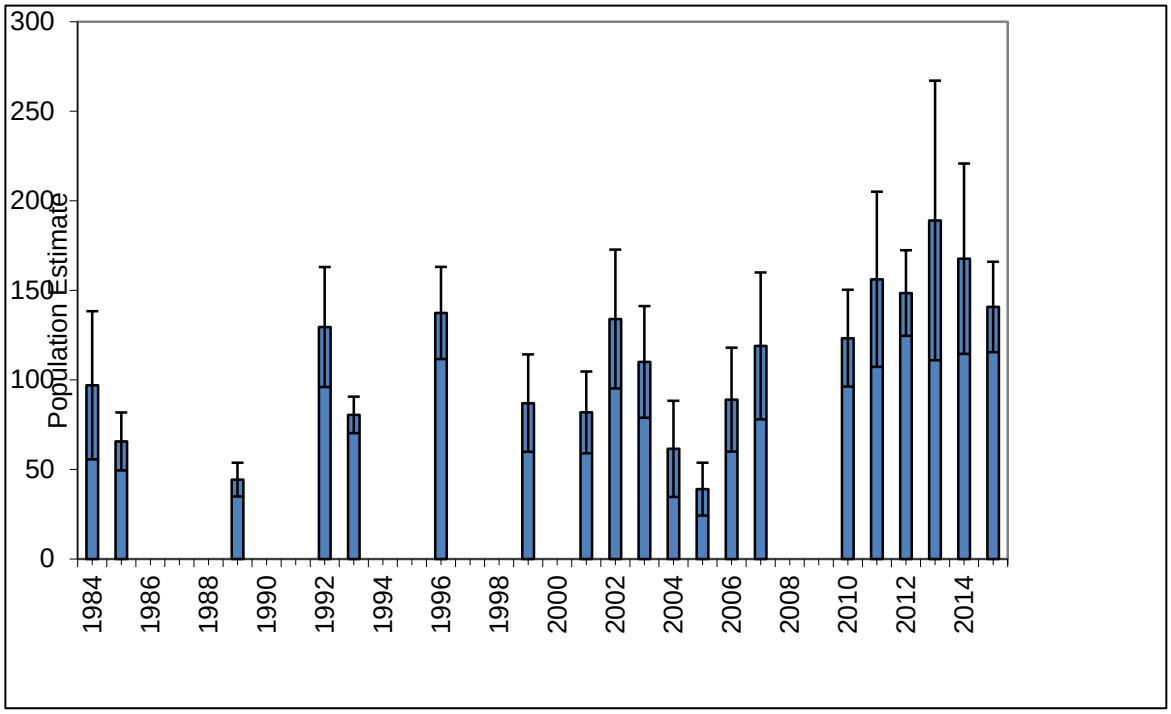


Figure 3.2.5. Population estimates and standard error for Sonoyta mud turtle at Quitobaquito Springs, Organ Pipe Cactus National Monument, Arizona. (Beginning in 2001, population estimates are standardized to include yearling and older turtles (carapace length ≥40 mm (1.6 in)). No data was collected or estimated for 2008 and 2009 due to low water levels.

From 1982 to the present, age-frequency distribution of Sonoyta mud turtles at Quitobaquito Springs has shifted from the majority of mud turtles being less than 7 years old to an almost equal split between turtles < 7 and turtles ≥ 7 years old. The 7–year mark was used because males and females are both easy to sex by this age, and are of reproductive age by 7 years. Turtles captured at Quitobaquito Springs based on 1982 to 1995 sampling periods revealed 59 percent of turtles captured were < 7 years old, 30 percent age 7 to 12, and 11 percent > 12 years

old, (Figure 3.2.7)(Rosen and Lowe 1996, pp. 14–17; Riedle *et al.* 2012, p.185). From 2001 to 2006, proportion of turtles <7 years old decreased to 46 percent of captured individuals (Riedle *et al.* 2012, p.185). During the latest sampling effort 48 percent of turtles were < 7 years old, 33 percent age 7 to 12, and 19 percent > 12 years old, so that recruitment appears to be remaining fairly stable and aging adults are shifting to the higher age classes.

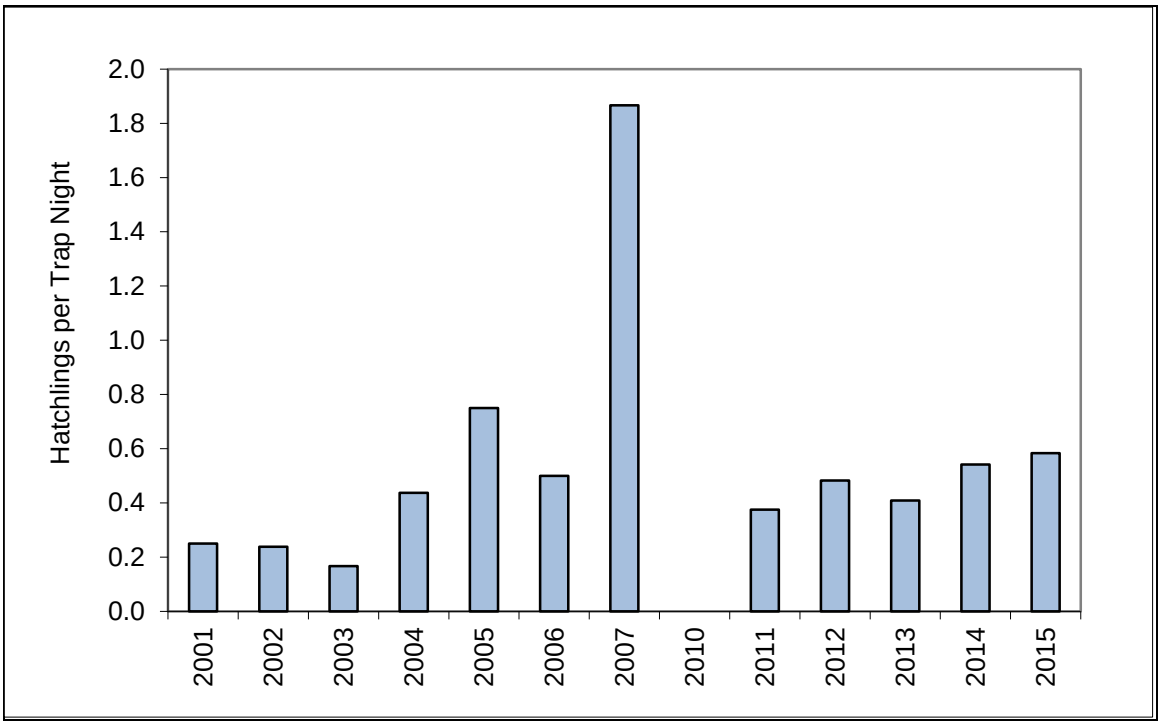


Figure 3.2.6. Young-of-the-year (carapace length <40 mm (1.6 in)) caught per trap night at Quitobaquito, Organ Pipe Cactus National Monument, Arizona. (Trapping effort in 2003 and 2010 probably not sufficient for comparison because of too few trap nights during these two years of sampling.)

Riparian vegetation at Quitobaquito Springs is well established. Although a diverse aquatic invertebrate community is present, stomach analysis of turtles revealed animals were also heavily consuming young shoots of bulrush, and this may have been due to competition with native desert pupfish for aquatic invertebrates (Rosen and Lowe 1996, pp. 32, 41*)*. This is further discussed in Chapter 4.

Organ Pipe Cactus National Monument biologists continually monitor Quitobaquito Springs for nonnative aquatic species, and none are currently established there. Black bullheads (*Ameiurus melas*) were removed from the pond at Quitobaquito Springs in 1993 (Rosen and Lowe 1996, p. 6). Golden shiners (*Notemigonus crysoleucas*) were illegally introduced and established in the 1960s, and removed in 1969–70 (Minckley 1973, p. 92). In addition, several other turtle species have been documented in the pond, including Arizona mud turtles (*Kinosternon arizonense*); currently native upstream in the Rio Sonoyta; (Smith and Hensley 1957, p. 201), southern painted turtle (*Chrysemys picta dorsalis*) (Rosen *et al.* 2010, p. 14), and red-eared slider

(*Trachemys scripta elegans*) (Rosen and Lowe 1996, p. 6). "Pet turtles" were said to be left by visitors in the 1970s (Bennett and Kunzmann 1989, p. 34). However, nonnative aquatic species are not currently established at Quitobaquito Springs.

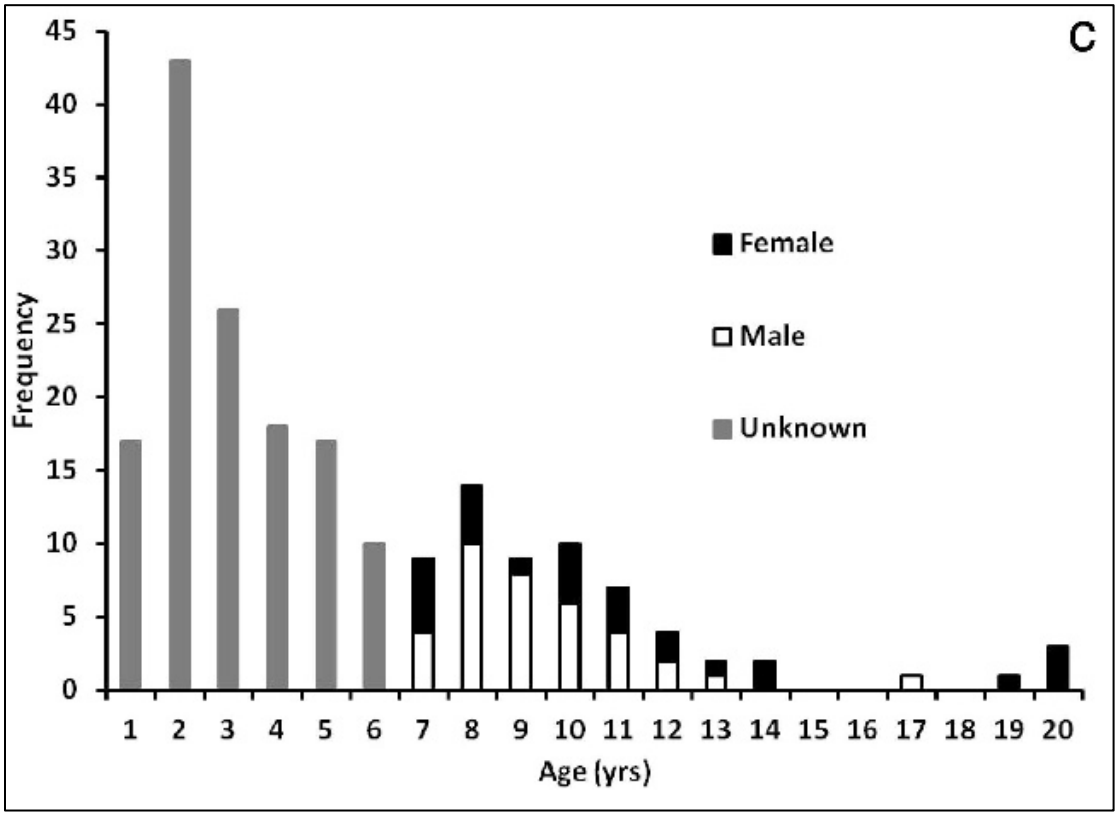


Figure 3.2.7. Age frequency distributions from adjusted sex frequency classifying turtles <7 years as juveniles for Sonoyta mud turtles at Quiotobaquito, Arizona based on 1982–1995 sampling periods (Riedle *et al.* 2012, p. 186).

In summary, this population has experienced fluctuations in numbers since at least 1984, and currently is slightly larger than the 1984 estimate range, but is likely lower than historical levels. The amount of water from the source springs has decreased by 42 percent over recent decades, and pond level has remained below maximum since the early 1990s. The site supports an invertebrate prey population that is apparently of low availability to Sonoyta mud turtles, possibly due to competition with native desert pupfish (Rosen and Lowe 1996, p. 41). Riparian habitat is well established. This site requires continued maintenance by the NPS to maintain water levels in the man-made pond and to control encroachment of vegetation in the spring run and pond. The site is accessible by road in the United States and nearby Mexican Highway 2, and thus vulnerable to exotic species introduction.

3.2.2 Papalote Reach of Rio Sonoyta, Sonora, MX

The Papalote reach of the Rio Sonoyta, also known as the Agua Dulce reach, is in the northeastern corner of the Reserva de la Biosfera el Pinacate y Gran Desierto de Altar (the Pinacate Biosphere Reserve) in Sonora, Mexico, centered almost due south of Quitobaquito Springs (Rosen 2003, pp. 2–5). Water in the river is from groundwater forced up where the river channel passes between the U.S Quitobaquito Hills and the Mexico Sierra Los Tanques creating a reach of nearly perennially flowing surface water in the river. The Papalote reach is the only remaining nearly perennial reach supported completely by a natural water source in the Rio Sonoyta (Rosen 2003, p. 5; Rosen *et al.* 2010, p. 149). At the driest times of the year, there are only isolated pools within this reach with no flow between them (Rosen *et al.* 2010:149, USFWS files). Currently, this stream section is largely shallow, with sandy runs and riffles that generally vary from 1–2 m (3.3–6.6 ft) wide and 15–30 cm (6–12 in) deep. The reach includes widely spaced pools that measured 1–1.4 m by 2–3 m (3.3–4.6 ft by 6.6–9.8 ft) in area and 0.4–0.9 m (1.3–3 ft) in the deepest spots from 2001 through 2006 (Figure 3.2.8)(Rosen 2003, p. 5; Rosen *et al.* 2010, p. 149). Groundwater pumping in excess of recharge, when combined with the present drought, is readily apparent in the length of streamflow at Papalote reach of the Rio Sonoyta.

Paredes-Aguilar and Rosen (2003, p. 8), found 11 turtles during survey efforts in 2002 but had no recaptures to estimate population size in the Papalote reach. However, Paredes-Aguilar and Rosen (2003, p. 8) used best professional judgement to estimate a low density population of over 100 animals based on available habitat. Paredes-Aguilar and Rosen (2003, p. 9) stated that "the turtle population at Papalote appears to be healthy, though small, with consistent recruitment" Although dated, combined demographic information for the Papalote reach, Xochimilco reach, and Quitovac is shown (Figure 3.2.9). Site specific demographic data cannot be pulled from the combined data from the early 2000s. In 2017, biologists at Pinacate Biosphere Reserve began monitoring turtles in the Papalote Reach and have marked 57 turtles to date, including 25 males and 32 females (Grageda-García and García-Miranda 2017, p. 2). All animals were caught within a 2–km (1.24 mi) portion of the Papalote reach, and five of these animals have radio transmitters. Over the past 4 months, 8 turtles have been recaptured and a single animal found dead. Maximum total linear movement of a single turtle was 473 m (1,552 ft) (Grageda-García and García-Miranda 2017, p. 2).

Figure3.2.8 Rio Sonoyta Papalote, Sonora reach, April 2008, with above average flow

Although the recent study has just begun, records of mud turtles appear to be widespread throughout the 2–km (1.24 mi) study area but mainly close to the spring at the upstream end (Grageda-García and García-Miranda 2017, p. 2). Turtles were found burrowing in the stream bank up to at least 1 m (3 ft, Paredes-Aguilar and Rosen 2003, p. 8). We have no information on nest sites or invertebrate prey availability for the Sonoyta mud turtle population in the Papalote

reach, although we expect to get this information from the current study being conducted by Pinacate Biosphere Reserve. However, we assumed prey availability is moderate based solely on water availability. In addition to Sonoyta mud turtles, the Papalote reach supported populations of two native fish, the desert pupfish and longfin dace, but now only desert pupfish are extant (C. Minckley, pers. comm., 2017).

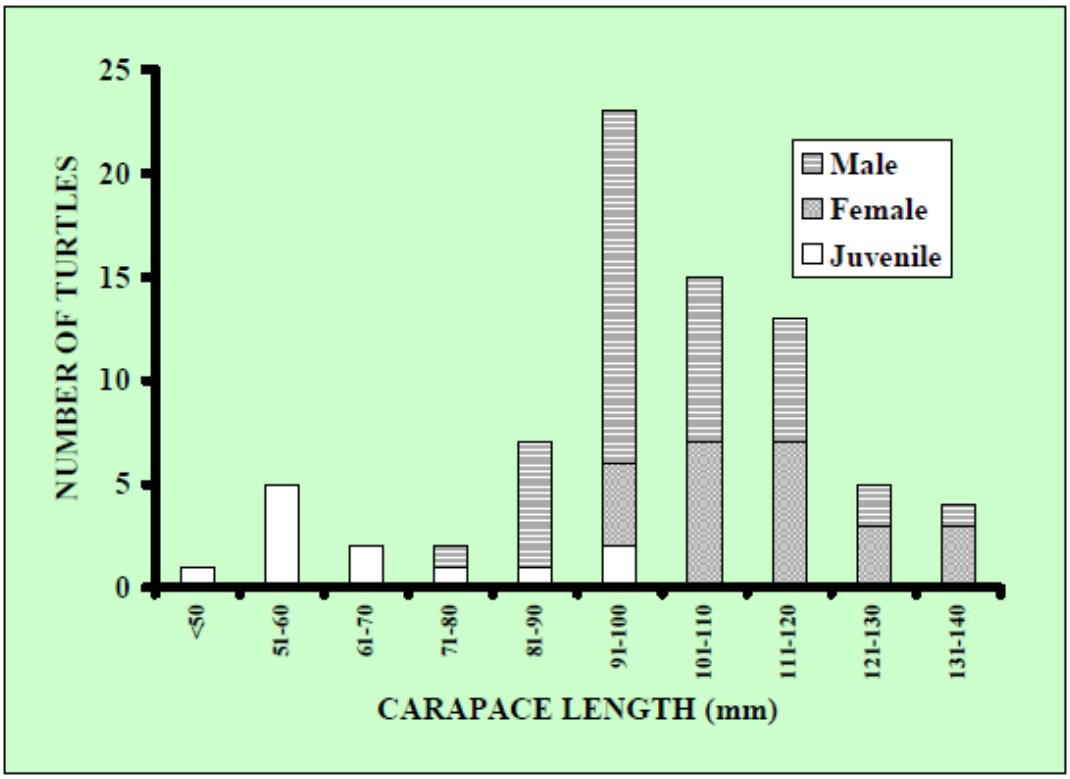


Figure 3.2.9. Histogram of size class of Sonoyta mud turtles in Papalote, Xochimilco, and Quitovac based on carapace length (mm) of turtles captured during the 2002 sampling season (Paredes-Aguilar and Rosen 2003, p. 10).

There is little vegetation cover in the stream channel of the Papalote reach although pools have good cover in deeply undercut banks stabilized by seep-willow (*Baccharis salicifolia*) and saltcedar (*Tamarix ramosissima*) roots (Figure 3.2.8)(Rosen 2003, p. 5). Adjacent riparian is strongly dominated by dense saltcedar and some willows (*Salix* spp.) with a fringe of open mesquite bosque on the first terrace above the shallowly incised stream bottoms (Paredes-Aguilar and Rosen 2003, p. 8). There is a second higher terrace dominated by mesquite (*Prosopis velutina*), smoketree (*Psorothamnus spinosus*), and alkali scrub plants including saltbush species (*Atriplex spp.*). Vegetation on both of these terraces supports a microclimate that provides soil moisture needed for Sonoyta mud turtles. In the past, saltcedar has been thought to reduce groundwater availability, but this has not been proven. There has been a constant loss of riparian vegetation of the Papalote reach of the Rio Sonoyta that may have resulted from a decrease in water flow in the river (Fisher de León 2007, p. 63).

The reduction in water flow is likely primarily due to groundwater pumping in excess of

recharge for agricultural and residential use, which likely began in the late 1970s. When combined with the present drought, groundwater pumping continues to reduce the length of current streamflow in the Papalote reach. Table 3.2.3 lists the surface water extent measurements for this reach over time. Some data are from Google Earth Pro imagery, which because of the quality of resolution, are not highly accurate but this is the best available data. When other sources of data were available, we used this information rather than Google Earth Pro. We were not able to correlate this data with rainfall or groundwater withdrawal. The Papalote reach naturally fluctuates markedly in extent throughout the year due to the natural hydrograph. However, the reduction in flow extent during the normal dry period (May and June) has recently continued beyond June during drought years with little precipitation during the monsoon season. This indicates a major loss of flow, and illustrates why conservationists are pessimistic about the Papalote reach continuing as perennial water (Paredes-Aguilar and Rosen 2003, p. 8; Duncan and Tibbitts 2008, entire; Rosen *et al.* 2010, p. 155; Izaguirre Pompa 2011, entire). Severe drought during the 21st century caused extinction of longfin dace in the Rio Sonoyta and threatens the population of desert pupfish.

Table 3.2.3. Recent history for extent of surface water at Papalote reach, Rio Sonoyta, Sonora, Mexico.

Date	Extent of surface water		Source
1977–1984	5–6 km	3.1–3.7 mi	Miller and Fuiman 1987, p. 606
April 1983	5 km	3.1 mi	McMahon and Miller 1985, p. 243
September 1987	13 km	8 mi	Hendrickson and Varela Romero 1989
September 1992	3.8 km	2.4 mi	Google Earth Pro
June 1996	2.5 km	1.5 mi	Google Earth Pro
2001–2006	1.6–2.7 km	1–1.7 mi	Rosen *et al.* 2010, p. 149
"Drought" of 2002	1 km	0.6 mi	Paredes–Aguilar and Rosen 2003, p. 8
October 2002	2–3 km	1.2–1.9 mi	Knowles *et al.* 2002
September 2003	4.0 km	2.5 mi	Google Earth Pro
April 2005	2.8 km	1.7 mi	Google Earth Pro
December 2005	2.8 km	1.7 mi	Google Earth Pro
May 2006	2.7 km	1.7 mi	Google Earth Pro
June 2007	300 m	984 ft	Google Earth Pro
September 2010	250 m	820 ft	Google Earth Pro
March 2011	3.1 km	1.9 mi	Google Earth Pro

Grazing has also occurred in the Papalote reach in the past although the area was fenced off from grazing at one time. However, there is no longer a secure fence that excludes cattle from the stream. Cattle are known to water in the few remaining pools in the reach during times of drought, further exacerbating water loss, which is discussed further in Section 4.2. Nonnative western mosquitofish (*Gambusia affinis*) and black bullhead are also found in the Papalote reach and may impact Sonoyta mud turtle through competition for invertebrates and predation on young turtles (Taylor *et al.* 1984, pp. 330–331; Fernandez and Rosen 1996, pp. 39–40; Duncan 2013, p. 1). Conservation measures including saltcedar removal and eradication of bullhead were not successful.

In summary, the amount of water at this site has decreased over the years and groundwater pumping exacerbated by drought is an ongoing threat. This is a highly fluctuating system with one year experiencing a flood and the next only a few isolated pools. Twelve turtles were found at this site in 2002, and historical occupancy is unknown. While no surveys have been conducted since 2002, mud turtle numbers have likely declined due to the reduced aquatic habitat available.

3.2.3. Xochimilco Reach of Rio Sonoyta, Sonora, MX

The Xochimilco reach (a reduced reach of the formerly known Sonoyta reach) of the Rio Sonoyta within and adjoining the town of Sonoyta, supports Sonoyta mud turtles. We consider the present day reach to extend from approximately 5 km (3 mi) upstream of the Mexican Highway 2 bridge near San Rafael to 0.5 km (.3 mi) below the bridge in Sonoyta. The Xochimilco reach likely always had perennial water, though historically, surface water was also contained in adjacent cienegas. A dam built in the early 1900s created an impoundment of water, referred to as Presa Xochimilco. Currently, flow and pooled water in the Xochimilco reach is intermittent except for surface water below the dam appears to remain year-round in small pools on bedrock. The dam may occur at the site where springs were historically found, and may explain the apparently permanent water that is at the base of the dam. Water below the dam could also come from water trapped in the sediment impounded by the dam, and leaking through the dam or bedrock to create these pools. In addition, Presa Xochimilco captures urban runoff, untreated residential sewage runoff, and stormwater flows in the Rio Sonoyta (Figure 3.2.10). In the past, untreated sewage effluent from an army base was discharged directly into the Xochimilco reach upstream of the dam. In 2008, the effluent was piped to the Sonoyta sewage lagoon, bypassing the Xochimilco reach so that the army base no longer contributes water to support Sonoyta mud turtles in this reach. Water no longer flows year-round upstream of the dam near San Rafael or downstream of the dam near the Highway 2 bridge in Sonoyta. There is no agricultural return water in this reach.

Figure 3.2.10. Presa Xochimilco on the Rio Sonoyta Xochimilco reach, Sonora, April 2008

Recent extent of water extent in the Xochimilco reach is summarized below in Table 3.2.4. Water levels supporting turtles naturally fluctuate greatly between the wet and dry seasons (Table 3.2.4. below); however, fluctuations are likely more extreme than what occurred historically. In October 2001, near the end of the wet season when water levels are usually highest, perennial water that could support Sonoyta mud turtles in the Xochimilco reach extended from 2 km (1.2 mi) above the Highway 2 bridge to 0.5 km (0.3 mi) below the bridge, including a large ponded area over 0.5 km (0.3 mi) long upstream of the dam and continuous spring flow for several hundred meters below the dam (Figure 3.2.8)(Knowles *et al.* 2002, p. 72;

Rosen *et al* 2010, p. 147). Five months later in March 2002 after a dry winter, the large pond upstream of the dam was reduced to a few pools, flow below the dam was reduced, and some of the previously dense vegetation had been removed (Knowles *et al.* 2002, p. 73). Surface water was reduced to approximately 10 pools ranging from 0.3 to >1.5 m (1 to > 5 ft) deep in 2005 and 2006 (Figure 3.2.1) (Rosen *et al.* 2010, p. 147). Currently, the water level is not clearly known but an overall decline has occurred since sewage effluent was rerouted to the Sonoyta sewage lagoon. There was also a 100 m (328 ft) long stretch of pools in the vicinity of San Rafael at the upstream end of the Xochimilco reach about 5 km (3 mi) above the Highway 2 bridge that supported Sonoyta mud turtles in 2001 (Knowles *et al*. 2002, p. 72) but is now probably dry (P. Rosen, pers. comm. 2016c).

Table 3.2.4. Recent extent of surface water at Xochimilco reach, Sonora, Mexico.

Date	Extent of water		Source
October 2001	full (~2.5 km plus 100 m of pools near San Rafeal)	~1.6 mi	Paredes-Aguilar & Rosen 2003
March 2002	few large puddles	—	Paredes-Aguilar & Rosen 2003
March 2002	dry	—	Paredes-Aguilar & Rosen 2003
September 2002	full	—	Paredes-Aguilar & Rosen 2003
October 2002	1 pool at dam	—	Paredes-Aguilar & Rosen 2003
November 2003	200 m[1]	656 ft	Google Earth Pro
January 2005	650 m	2,132 ft	Google Earth Pro
April 2005	470 m	1,542 ft	Google Earth Pro
December 2005	dry	—	Google Earth Pro
May 2006	20 m	66 ft	Google Earth Pro
August 2011	flood	—	Google Earth Pro

[1] Water in the Xochimilco reach extended 200 m (656 ft) upstream of the dam

Figure 3.2.11. Xochimilco reach above dam: October 2001 on left and March 2002 on right.

Rosen *et al.* (2010, p. 153) stated that the principal turtle population was likely historically in the Cienega de Sonoyta, originating 3 km (1.9 mi) upstream of the current dam at Xochimilco, in an area that no longer has flowing water. This is the approximate location where turtles were found in a 100 m (328 ft) stretch of pools in 2001. Paredes-Aguilar and Rosen (2003, p. 9) used best professional judgement to estimate a Sonoyta mud turtle population of 400 animals in the Xochimilco reach in 2001,with essentially no evidence of successful recruitment of hatchlings after 1997 (Rosen *et al.* 2010, p. 153). Rosen *et al.* (2010, p. 152) concluded that Sonoyta mud turtles were common in the Xochimilco reach from 2001 to 2006, no trapping has been conducted since then. We have no site-specific demographic data for the Xochimilco reach, but combined demographic information for the Papalote reach, Xochimilco reach, and Quitovac is shown (Figure 3.2.9).

Dominant vegetation in the area includes mesquite, saltcedar (*Tamarix* spp.), and Gooding's willow (*Salix gooddingii*). The presence of willow indicates shallow ground water. We have no information on aquatic invertebrates or related emergent vegetation to support them in the Xochimilco reach. However, we assume that prey availability is low solely based on water availability. There are agricultural fields near the Rio Sonoyta, for 25 km (16 mi) upstream of Presa Xochimilco. It is highly likely that all agriculture is supported by groundwater pumping. There might be water from the fields that returns to the river, but this has not been observed, and on balance, water is being removed from the ground at a greater rate than what is returned. The Xochimilco reach is used for recreation and grazing. There is anecdotal information turtles periodically have been collected and sold by townspeople from this reach (Paredes-Aguilar and Rosen 2003, p. 7). Mosquitofish and black bullhead have been found at Presa Xochimilco, though their current status is unknown. No one has looked for fish in this reach.

Figure 3.2.13. Sonoyta Sewage Lagoon, Sonora, aerial view showing proximity to Rio Sonoyta

In summary, this site has undergone a reduction in the amount of aquatic habitat. There is no longer a large area of perennial water at this site. More recently, both rerouting of sewage effluent and decadal drought has further greatly reduced the amount of perennial and near-perennial surface water. The estimated population size was about 400 in 2001with no recruitment recorded. Currently, the status is unknown, but abundance is almost certainly far less, considering the reduced spatial and temporal extent of surface water.

3.2.4. Sonoyta Sewage Lagoon, Sonora, MX

The Sonoyta sewage lagoon consists of two facultative lagoons (type of settling ponds used for

biological treatment of wastewater) comprising 4.8 ha (11.9 ac; Figure 3.2.12), and is at the western and downstream-most end of the town of Sonoyta associated with the Rio Sonoyta floodplain. These lagoons were constructed in 1994 (R. Kohn, pers. comm. 2016). No chemical treatment of sewage occurs at this location. Instead, raw sewage comes from the town of Sonoyta, is biologically treated via two facultative lagoons (type of ponds used for biological treatment of wastewater), and then is discharged to an agricultural drain. Some of the discharged effluent is used for agricultural purposes, and the remaining effluent flows into the channel of the Rio Sonoyta (U.S. Environmental Protection Agency [EPA] 2008, pp. 2–5). Most of the overflow into the channel seeps into the ground and does not provide surface water habitat for Sonoyta mud turtles.

Figure 3.2.12. Sonoyta Sewage Lagoon, Sonora, view of large oxidation pond looking northwest.

The two facultative lagoons (Figure 3.2.13) have a design capacity of 16 liters/second (l/s) (0.37 million gallons per day (MGD)). However, the inflow is greater than the design capacity by 7 l/s (0.16 MGD). Because inflow is greater than capacity, the time that wastewater spends in the lagoons is decreased and less biological treatment occurs which contributes to the poor water quality in the lagoons and in the outfall to the river. The lagoon system is currently overloaded and unable to treat the wastewater to satisfy water quality regulations in Mexico (EPA 2008, pp. 1–2). The maximum daily average total nitrogen and biochemical oxygen demand levels in Mexico for aquatic life protection are 15 mg/L milligrams/liter (15 parts per million (ppm)) and 30 mg/L (30 ppm), respectively (Secretariat of the Environment and Natural Resources (SEMARNAT) 1996, p. 14). Daily average total nitrogen at the lagoons was 26.0 mg/L (26 ppm) at the inflow and 2.6 mg/L (2.6 ppm) at the outflow (Servicios de Ingeniería e Informática 2008, p. 10). Daily average biochemical oxygen demand was 260 mg/L (260 ppm) at the inflow and 72 mg/L (72 ppm) at the outfall (Servicios de Ingeniería e Informática 2008, p. 10). Fecal coliform counts are extremely high throughout the system (Servicios de Ingeniería e Informática 2008, p. 10).

Sonoyta mud turtles were first discovered at this site by U.S. biologists in 2002, although they have likely been present since soon after the Sonoyta wastewater treatment plant came into operation in 1994. Trapping efforts of Sonoyta mud turtles have never been implemented at the Sonoyta sewage lagoon due to complications with sampling in a highly polluted environment, but numerous turtles have been observed there. Rosen *et al*. (2010, p. 152) states that the subspecies remained common during visual surveys conducted from 2001–2006. Turtles are most likely recruiting, since they have been here since 1994 and appeared to be common in 2006. Demographic data are lacking for this site. No known conservation measures have been implemented at this site to date, although they are proposed to take place once the new wastewater treatment plant is online as described in the Resolutivo. This is discussed below under “Land Management Actions”.

Riparian vegetation surrounding the Sonoyta sewage lagoon includes mesquite and desert broom. Turtles have been observed basking at the shoreline of the lagoon on branches of trees (USFWS 2016, p. 1). We have no information on aquatic invertebrates or related emergent vegetation to support them at this site. However, we assume aquatic invertebrate numbers are low based on poor water quality. It is unlikely that there are any nonnative fish species in the Sonoyta sewage lagoon as fish can generally not survive in an environment with total nitrogen greater than 1.0 mg/L (1.0 ppm).

Officials in the town of Sonoyta determined that infrastructure improvements were needed to address the town's wastewater system deficiencies. As a result, a new wastewater treatment plant was designed to receive wastewater from more areas of Sonoyta, including the army base near the Xochimilco reach. The new wastewater treatment plant is located 2.4 km (1.5 mi) northwest of the current facility. Construction of the new wastewater treatment plant to replace the sewage lagoons began in 2010 and is still incomplete. Although construction of the new wastewater treatment plant began in 2010, the berms around the new lagoons failed so that the new plant is yet to be online. As of May 2017, work on the new wastewater treatment plant is on hold with no estimated completion date (R. Kohn, pers. comm. 2017). In the meantime, wastewater from additional residences and the military base has already been piped to the existing sewage lagoons that are already beyond capacity. Consequently, the Sonoyta sewage lagoon has the maximum amount of surface water possible to support mud turtles and excess surface water is being discharged to agricultural fields or the river. Because the EPA authorized the use of Border Environmental Infrastructure Funds for the City to help construct a new facility to expand the Sonoyta wastewater collection system, USFWS was able to work with EPA, National Commission of Natural Protected Areas Pinacate Biosphere Preserve, the wastewater treatment collection utility, and Mexico's SEMARNAT to develop conservation measures to benefit Sonoyta mud turtles at the new facility. These measures are captured as conditions of approval in SEMARNAT's 2008 official finding on the project sent to the wastewater treatment collection utility, and is referred to as the "Resolutivo" in the remainder of this SSA report (SEMARNAT 2008, p. 6). However, EPA is not providing any further funding for the project and the National Water Commission in Mexico, CONAGUA, is looking for funding to complete construction of the wastewater treatment plant (R. Kohn, pers. comm. 2017).

The Sonoyta Sewage Lagoon will be closed and dried if the new wastewater treatment plant becomes fully operational. Based on the conditions of approval in the Resolutivo, as many Sonoyta mud turtles as possible should be removed from the sewage lagoons and relocated to the new wastewater treatment plant (SEMARNAT 2008, p. 6). At this time we do not have a clear understanding of the number of turtles that should be moved or what "as many as possible" means. The wastewater treatment plant has an initial design capacity of 27 l/s (0.62 MGD), with further expansion planned. The water quality of processed wastewater is supposed to be suitable for fish. Surface water will remain at a steady level due to the constant influx of surface water effluent. The amount of water flowing through the new habitat will increase from that in the existing facility, as the new treatment plant is designed to serve the current human population base and the projected 20–year human population growth, not to exceed 30 percent growth. There are multiple lagoons planned for the new wastewater treatment plant. However, some of the lagoons will be lined, and will provide limited habitat for Sonoyta mud turtle because

adjacent riparian vegetation will be extremely limited. Requirements from the Resolutivo require the new site to provide specific unlined habitat for turtles, which will be a reduction of 75 percent in size of the current Sonoyta sewage lagoon. Effluent flowing through the turtle habitat will be discharged into the Rio Sonoyta channel and provide additional turtle habitat in the channel itself, but the amount of this habitat is unknown.

Because the new wastewater treatment plant site is downstream from the existing sewage lagoon, it may contribute to groundwater recharge in areas closer to current and historic Sonoyta mud turtle habitat. The outflow water from the new plant will likely have lower nitrogen, higher oxygen, and less human fecal coliforms than the existing sewage lagoon. We do not know what effect this would have on mud turtles, but it is likely that this higher water quality could support fish that could then predate on or compete with turtles for food.

In summary, the water in the Sonoyta Sewage lagoons is currently stable although polluted. However, turtles appear to survive and recruitment is likely happening, although not quantifiable because no one will survey turtles at this site due to pollutant levels that may be hazardous to humans. At some point in the future if the new wastewater treatment plant is completed, the existing lagoons will be drained and probably only a portion of the turtles will be relocated to the new wastewater treatment plant that will support a smaller number of turtles.

3.2.5 Quitovac Spring and Pond, Sonora, MX

Quitovac is a 2 ha (5 ac) spring system located about 40 km (25 mi) southwest of the town of Sonoyta. Based on the fossil record, the springs of Quitovac have flowed for millennia, and there have been five springs clustered closely at Quitovac since at least 1774 (Nabhan et al. 1982, p. 125). Similar to Quitobaquito Springs, spring flow is currently impounded in a body of still water (the pond) by a dike. Quitovac is not in the Rio Sonoyta basin, but is in the Rio Guadalupe basin. The Sonoyta mud turtle population at Quitovac might represent an introduced population, as there are no present day aquatic pathways between Rio Sonoyta and Quitovac, or it could be an isolated relict population (Paredes-Aguilar and Rosen 2003, p. 10). The possibility of humans moving mud turtles in the area would not be surprising because the Camino del Diablo (a.k.a. “The Devil’s Road”) went north from Caborca, with Quitovac and Quitobaquito Springs serving as important stops for water along this historic human travel route.

Figure 3.2.14. Pond at Quitovac, Sonora

The spring system has been used and managed by the O’odham peoples for centuries. O’odham use continues to include hunting, swimming, agricultural cultivation, and use by livestock, gathering of medicinal and edible plants, and water consumption (Nabhan *et al*. 1982, p. 130).

Management activities related to these uses include water diversion, burning emergent vegetation, and at least twice, bulldozing the pond (Nabhan et al. 1982, p. 130; Nabhan 2008, p. 252; USFWS files). During a visit to the site on June 3, 2015, we discovered that the pond and spring heads had been completely excavated by the O'odham (D. Duncan, pers. comm. 2015). The five spring heads and part of the spring runs were enlarged and deepened, and the pond was dredged between late 2014 and 2015. The spring with the lowest flow has not flowed into the pond in the past and did not flow during this visit. The four remaining springs flow into the pond and have likely refilled the pond to full depth, enabling this site to continue to support Sonoyta mud turtles.

Sonoyta mud turtles were discovered at Quitovac in March 2002 while investigating potential new turtle habitats in and around the Rio Sonoyta basin (Paredes-Aguilar and Rosen 2003, p. 5). Over one night, a total of 13 turtles were captured in five traps. A hatchling and one juvenile turtle were captured, providing evidence of successful reproduction (Paredes-Aguilar and Rosen 2003, pp. 9–11). The population was estimated at around 200 turtles and Paredes-Aguilar and Rosen (2003, p. 11) stated that the population appears to be stable. Combined demographic information for the Papalote reach, Xochimilco reach, and Quitovac is shown (see Figure 3.2.9). The USFWS has made periodic visits to Quitovac since 2002, but turtles have only been opportunistically monitored. A hatchling turtle was seen in 2011 (J. Rorabaugh, pers. comm. 2016) and a single turtle with a damaged shell was found at the spring head in 2015 (Quitobaquito Rio Sonoyta Work Group 2015, p. 1). We have no data on current status of this population of Sonoyta mud turtles.

Figure 3.2.15. Spring run at Quitovac

The pond is used for watering small numbers of livestock and irrigating fruit trees (Paredes-Aguilar and Rosen 2003, p. 11; USFWS files). Before the recent complete excavation, the pond and springs contained nonnative tilapia and mosquitofish, as well as introduced native fish. With help from US biologists, Pinacate Biosphere Reserve biologists released native desert pupfish and longfin dace to Quitovac in 2007 (Minckley *et al*. 2013, pp. 289–290). All of these fish species likely compete with Sonoyta mud turtles for aquatic invertebrates or alter the invertebrate community so that aquatic invertebrates are reduced. The pupfish established a small population there, but longfin dace were not seen after the stocking event. There has also been gold mining in the area surrounding Quitovac, and mine exploration and development continue. The mines are open pits, which reduce surface water by intersecting the groundwater source for springs or future mining could directly divert the spring outflow and pond waters. There is an abandoned open pit gold mine about 12 km (7.5 mi) southeast of Quitovac (referred to as La Mina). Though the mine is down-gradient from Quitovac Springs, the use of water during mining, and the continuing loss of water from the pit lake via evaporation has removed, and is continuing to remove, groundwater in the area. However, the surface water in the pit lake

is of sufficient quality that black bullhead survive there. It has been discussed as a potential release site for the mud turtle and native fishes, but no plans have been made to date to release any native aquatic species.

Riparian vegetation available to Sonoyta mud turtles at Quitovac is limited to orchards and a riparian analog consisting of mesquite, saltcedar, bullrush, and a few cottonwoods (Nabhan *et al*. 1982, p. 130). We have no information on aquatic invertebrates or related emergent vegetation to support them at this site. However, we assume prey availability is moderate based solely on water availability.

In summary, water is supplied to the 2 ha (5 ac) system by four adjacent springs and this water supply considered stable. Turtles may have been introduced in recent times, and there were a roughly estimated 200 turtles at this site in 2002. Recruitment at this site is also unknown. Turtles appeared to survive partial dredging activities in the past, but we do not know how many turtles survived the recent dredging of the entire site. Riparian vegetation is limited and invertebrate prey species are unknown.

Summary

We think that the historical locations of the Sonoyta mud turtle occurred in the areas of the Rio Sonoyta basin that maintained perennial surface water via springs fed by ground water (Paredes-Aguilar and Rosen 2003, p. 2; Rosen *et al.* 2010, p. 155). The perennial water supporting four of the five turtle populations has been reduced, and all five populations are isolated from one another. For the sole population in the U.S., discharge from Quitobaquito Springs has diminished by 42 percent over the past 35 years with 5,500 cubic feet (cf)/day average discharge measured in the period 1981–1992 down to 3,157 cf/day measured from 2005–present (Carruth 1996, pp. 13, 21; P. Holm, pers. comm. 2016c and 2016d). Thus far, declining spring flow has been associated with < 30 cm (12 in) of surface water level decline at the pond, the depth of which ranges from 81 to 94 cm (32 to 37 in). In Mexico, the two populations in the Xochimilco and Papalote reaches are isolated from one another even more than they used to be historically because the lengths of the perennial reaches in the Rio Sonoyta have contracted. Added to this, a previously extant population in the Santa Domingo reach that was located between the remaining extant populations is no longer extant due to complete lack of perennial water (P. Rosen, pers. comm. 2016b). The perennial waters in these three reaches have decreased by 80 to 92 percent from 19–27 km (11.8–16.8 mi) historically to approximately 1.5–5.5 km (0.9–3.4 mi) currently (Table 1. Historical and Current Population Data, and Figure 3.1.1 of the SSA Report) due to groundwater pumping and persistent drought. Periodic movement between populations in the Rio Sonoyta basin may occur during prolonged periods of high rainfall, but the extent of immigration and emigration of turtles is unknown. We assume that movement among populations is rare to limited due to distances between populations coupled with limited hydrological connection. The current status of the population at Xochimilco is unknown. A total of 57 turtles have been marked in the Papalote reach in 2017 for a mark-recapture study that will provide better information on the status of the Sonoyta mud turtle in this reach in the next few years. The population at the Sonoyta sewage lagoon adjacent to the Rio Sonoyta has the most reliable source of water at this time and may be the largest of the five populations based on water availability, but we have no current data on numbers of turtles at this site. If a new

wastewater treatment plant is completed for the town of Sonoyta, the existing Sonoyta sewage lagoons will be drained and the new wastewater treatment plant will have 75 percent less habitat available for Sonoyta mud turtles. The fourth population in Mexico at Quitovac is outside of the Rio Sonoyta watershed, in the Rio Guadalupe basin, and has no present-day hydrological connection to the Rio Sonoyta. Table 1 lists the status and condition of each population.

3.3. Needs of Sonoyta Mud Turtle Populations and Subspecies

As described in Chapter 1, for the purpose of this assessment, we define **viability** as the ability of the species or subspecies to sustain populations in the wild over time. In Chapter 2, we assessed the needs of individuals. Using the SSA framework, we now examine the factors driving the population by describing the species' viability by characterizing the status of the species in terms of its **resiliency**, **redundancy**, and **representation** (the 3Rs) (see Introduction for definition of the 3Rs).

Note: This section contains **summaries** of the population needs. These summaries are based on the information in Chapter 2 and the preceding sections of this chapter (Chapter 3).

3.3.1. Population Resiliency

For the Sonoyta mud turtle to maintain viability, its populations, or some portion of its populations, must be resilient enough to withstand stochastic events such as fluctuations in water levels, habitat modification, and introduction of nonnative predators. In a highly resilient Sonoyta mud turtle population, turtles are able to complete their life functions and breeding is successful enough to maintain a population that is able to withstand stochastic events, and has an influx of turtles from neighboring populations. The most important factor that influences the resiliency of populations is survivorship across all age classes, especially juveniles, and connectivity to other populations. Influencing those factors are elements of Sonoyta mud turtle habitat that determine whether survivorship among age classes is achieved in Sonoyta mud turtle populations, thereby increasing the resiliency of populations. Population resiliency levels for the Sonoyta mud turtle are described in Table 3.3.1. below. The factors used to develop these resiliency levels are discussed below and outlined in Table 3.3.2. We did not include population size as a measure of population resiliency because of the high uncertainty of existing population estimates.

Table 3.3.1. Population resiliency categories for Sonoyta mud turtle

High (Good)	Moderate	Low	None

A population with high resilience is where all or the majority of turtles are able to complete their life functions and breeding is successful to maintain a population, and able to withstand stochastic events or recover from stochastic events from connected populations.	A population with moderate resilience is where some turtles can complete life functions and have some successful breeding but population is not increasing, could be stable or decreasing, and could withstand some stochastic events or a portion of the population could withstand stochastic events but not able to recover through the immigration of connected populations.	A population with low resilience is one where only some or few can complete life functions and some or few have successful breeding but population is decreasing and the population is not able to withstand stochastic events but not able to recover through the immigration of connected populations.	A population with no resiliency is one that might be extirpated completely.

Habitat Elements

Surface Water –Sonoyta mud turtles require perennial or mostly perennial water to complete their life history functions (See Section 2.4 Life History). Again, we define near-perennial as water present more than 10–11 months of the year for multiple years. Aquatic habitat in ponds and streams with water 2 m (7 ft) deep, with a rocky, muddy, or sandy substrate, and emergent or submergent vegetation, or both is needed (NPS 2015, p. 2; Paredes-Aguilar and Rosen 2003, p. 5–7; Rosen 2003, p. 5; Rosen *et al*. 2010, p. 14). Turtle recruitment can be affected by the amount of surface water available, how long it is available, as well as its fluctuation. In addition, hydrologic connectivity is needed for a population to recover from a stochastic event. See Resource Needs section for further detail.

Terrestrial Habitat – Sonoyta mud turtles need terrestrial habitat that maintains soil moisture for Sonoyta mud turtles in riparian areas along the banks of ponds and streams, including intermittently dry sections of stream channels. Riparian habitat provides shadier, cooler, and moister conditions than the adjacent upland areas. Sonoyta mud turtles further need accessible shoreline without insurmountable rock or artificial vertical barriers to allow for movement between wetted sites, between aquatic habitat and terrestrial nest sites, and between water and estivation sites. See Resource Needs section for further detail.

Invertebrate Prey – Sonoyta mud turtle hatchlings and juveniles need littoral invertebrate fauna, while subadults and adults need benthic and plant-crawling invertebrates. In habitats with poor aquatic invertebrate faunas, Sonoyta mud turtles will shift to omnivorous feeding, including plants and vertebrates See Resource Needs section for further detail.

Nonnative predators and competitors – Sonoyta mud turtles need aquatic habitat free of problematic nonnative predators and competitors, primarily crayfish, American bullfrogs, sunfish, black bullheads, African cichlid fishes (tilapia), western mosquitofish, and exotic turtles.

See Resource Needs section for further detail.

Table 3.3.2. Habitat characteristics used to create condition categories.

	Habitat Elements			
Condition Category	**Surface water**	**Riparian habitat**	**Invertebrate prey**	**Nonnative predators**
High	Based on seasonal averages, there is a high amount of perennial lotic or lentic water (volume or extent) that remains stable all year so that all or most turtles are able to complete all life functions, and hydrologically connected to another population at least once every few years.	A high amount of riparian or riparian analog adjacent to the water feature that maintains: moisture in soil, organic matter, rock piles/crevices, burrows that provide ample nesting sites, estivation sites for drought refuge, and shelter during large flooding events.	High invertebrate abundance and supporting vegetation present; turtle health is good, turtles growing rapidly and do not show detrimental health signs, no unexplained mortality, sufficient body lipid content.	No nonnative predators including crayfish, bullfrogs, centrarchids, and possibly ictalurids.
Moderate	Based on seasonal averages, there is a moderate amount of perennial lotic or lentic water (volume or extent) that may disappear from May to June in any one year, but not in consecutive years so that a moderate number of turtles are able to complete all life functions in at least some years and not hydrologically connected to another population.	A moderate amount of riparian or riparian analog adjacent to the water feature that maintains moderate or limited: moisture in soil, organic matter, rock piles/crevices, burrows that provide some nesting sites, estivation sites for drought refuge, and shelter during large flooding events.	Moderate amount of invertebrate abundance and supporting vegetation present, so that moderate number of turtles are growing rapidly and do not show detrimental health signs, with some unexplained mortality, some with insufficient body lipid content.	Low to moderate impacting nonnatives such as small centrarchids and ictalurids are occasionally present, but discovered and removed (or site dries out during year which can remove nonnatives), or turtles may not be affected strongly or negatively by some nonnatives or under some circumstances.
Low	Based on seasonal averages, there is a low amount of perennial lotic or lentic water (volume or extent) and fluctuates somewhat throughout the year. All water supporting a population may disappear for a period beyond May to June in consecutive years or multiple years but there is water in some of the	Little or no riparian or riparian analog (i.e. few scattered trees or shrubs), with little moisture in soil, organic matter, rock piles/crevices, burrows, adjacent to the water feature that provide few nesting sites, estivation sites for drought refuge, and shelter during large flooding events.	Low to poor invertebrate population and low supporting vegetation present, slow growth in most turtles, detrimental health signs such as low lipid levels (i.e., skinny legged turtles or observed mortality of turtles with very low body lipid levels).	Nonnatives are abundant in the system.

	wet season and not hydrologically connected to another population.

3.2. Species Representation and Redundancy

The Sonoyta mud turtle 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 historical 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, p. 5; Redford *et al.* 2011, entire).

Representation

Sonoyta mud turtles need genetic or ecological diversity to adapt to changing environmental conditions. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. Currently, the Sonoyta mud turtle exhibits genetic and ecological diversity. To maintain gene flow among populations and counteract genetic drift and deleterious effects of inbreeding connectivity among populations is needed. A minimum of 1 and maximum of 10 migrants per generation is needed to successfully breed in populations of a species (Mills and Allendorf 1996, p. 1517; Nathan *et al*. 2017, p. 270; Wang 2004, p. 341). This is a large range of migrants per generation, and we do not know where within this range the Sonoyta mud turtle falls to maintain genetic diversity among the fragmented populations of the subspecies. As described in Chapter 2, genetic analysis conducted in the mid-2000s reveals that successful migration has likely occurred in the past (Rosen 2006, p. 10). Maintaining representation in the form of genetic or ecological diversity is important to maintain the Sonoyta mud turtle's capacity to adapt to future environmental changes.

Redundancy

Sonoyta mud turtle needs multiple resilient populations spread over their historical range distributed in such a way that a catastrophic event will not result in the loss of all populations. In addition, hydrologic connectivity is needed for a population to recover from a catastrophic event. We do not have any estimate for how many populations are needed to withstand localized loss of habitat and maintain redundancy. However, the loss of Quitobaquito Springs, Quitovac, and either Rio Sonoyta Papalote or Rio Sonoyta Xochimilco would reduce the representation for the subspecies.

3.4. Current Conditions

We have examined the historical and current distribution and determined from the available information that the current distribution of the Sonoyta mud turtle is one site in Arizona, U.S. and four sites in Sonora, Mexico. The subspecies has been extirpated from one site in Mexico

and connectivity between populations has been reduced or lost. We then examined what populations need for the three defined levels of resiliency and what the subspecies needs in terms of representation and redundancy. This section assesses the current condition in terms of the resiliency of each population, and the representation and redundancy for the subspecies (see section 3.3 Population Resiliency).

3.4.1. Current Population Resiliency

To summarize the overall current conditions of Sonoyta mud turtle populations, we assessed them under three resiliency categories (high, moderate, and low; see Section 3.3 Table 3.3.1). The resiliency categories are based on the population factors and habitat elements discussed in Tables 3.3.2. Table 3.4.1 below summarizes the current condition of each population factor and habitat elements, as well as the overall condition of the population. Also included in Table 3.4.1 is a population that is (or is presumed to be) extirpated to show the entire current condition of the subspecies. The summary category is a qualitative estimate based on the analysis of one population factor and three habitat elements. In determining the summary categories, we gave more consideration to the habitat elements because we have more information on the habitat elements than we do for the population factor. Since water is the primary limiting factor, this drives the condition of the population. Consequently, the surface water habitat element limited the overall current condition. For example, if surface water ranked moderate but everything else ranked high, the overall condition of the population would be ranked as moderate.

Table 3.4.1. Summary of Current Condition of Sonoyta mud turtle populations expressed in terms of resiliency. See Table 3.3.1 for description of population resiliency levels.

Country	Population Name	Current Condition
U.S.	Quitobaquito Springs	**Moderate**
Mexico	Papalote Reach (Agua Dulce)	**Moderate**
	Sonoyta Sewage Lagoon	**Moderate**
	Xochimilco Reach (Sonoyta Reach)	**Low**
	Quitovac	**Low**
	Santo Domingo[1]	**Ø**

[1] This population is extirpated.

Table 3.4.2. Population and habitat elements rankings to determine current condition of Sonoyta mud turtle populations expressed in terms of resiliency. See Table 3.3.2 for description of condition categories.

	Population Factor	**Habitat Elements**				
Population	**Juvenile Survivorship**	**Surface water**	**Riparian habitat**	**Prey**	**Nonnative predators**	**Current Condition**
			U.S.			
Quitobaquito Springs	**High**	**Moderate**	**High**	**Low**	**Moderate**	**Moderate**

Mexico						
Papalote Reach	Low	Moderate	High	Moderate	Moderate	Moderate
Sonoyta Sewage Lagoon	Moderate	Moderate	Moderate	Low	High	Moderate
Xochimilco Reach	Low	Low	Moderate	Low	Moderate	Low
Quitovac	Low	Moderate	Low	Moderate	Moderate	Low
Santo Domingo	Ø	Ø	Moderate	Low	Moderate	Ø

None of the populations are considered highly resilient primarily because of the lack hydrologic connectivity, which would prohibit natural recolonization after a stochastic event that eliminated a population. All of the habitat in the U.S. is on Organ Pipe Cactus National Monument managed by the NPS and is currently protected. The management plan for Organ Pipe Cactus National Monument includes provisions to protect the Sonoyta mud turtle and its habitat to maintain water levels and habitat in the pond and spring run at Quitobaquito Springs. Although habitat is protected, spring flow discharge that provides water to Quitobaquito Springs has decreased by an annual average of 1.2 percent for a total 42 percent reduction in discharge over the past 35 years (P. Holm, pers. comm. 2016d). Overall, the extant population in the U.S. occurs in an area of good habitat and exhibits high survivorship among all age classes with increasing recruitment of juveniles.

Resiliency of the four populations in Mexico is less certain as habitat is very limited in the Papalote and Xochimilco reaches, survivorship among age classes is unknown at the Sonoyta sewage lagoon due to lack of surveys, and demographic status at Quitovac is entirely unknown due to limited sampling and recent dredging of all of the aquatic habitat available for mud turtles. Current abundance of mud turtle populations in Mexico is unknown and we have low confidence that numbers have been increasing, although populations in the Papalote reach and Sonoyta sewage lagoon may remain stable. A new mark-recapture study of the population in the Papalote reach that began in 2017 has resulted in marking of 57 turtles to date which is more turtles than have ever been found in this reach. The population at the Sonoyta sewage lagoon has never been sampled, but habitat conditions there remain stable, consequently we assume abundance and recruitment has remained stable. The most recent data we have for the other two populations in Mexico is over a decade old and dredging at Quitovac and decreased perennial water in the Xochimilco reach since then has likely decreased the number of turtles supported at these two sites. Overall, habitat is moderate and survivorship and abundance is unknown at Quitovac.

3.4.2. Current Subspecies Representation

Genetic investigations (Rosen 2003, pp. 8–13; Rosen *et al.* 2006, p. 10) indicate the subspecies exhibits some level of genetic diversity among populations at Quitobaquito Springs, the Rio Sonoyta (Papalote and Xochimilco), and Quitovac. Populations in the Sonoyta sewage lagoon were not sampled. Exchange of genetic material between Quitobaquito Springs and populations along the Rio Sonoyta is unlikely due to complete lack of hydrological connection and has not been observed despite some mark-recapture effort at these sites (Paredes-Aguilar and Rosen 2003, p. 9). Exchange of genetic material among populations of the Rio Sonoyta is likely a rare event limited to instances when a mud turtle may move during the wet season if there are

prolonged periods of precipitation or high flow events along the Rio Sonoyta that connects these populations by providing stepping stones of wetted habitat through which mud turtles could move or disperse. Rosen *et al.* (2006, p. 10) determined that these four localities were all genetically close, yet indicated a suggestion of isolation by distance and dry land with the two isolated sites (Quitobaquito Springs and Quitovac) being the most disparate and furthest apart, and the two Rio Sonoyta mainstem reaches (Papalote and Xochimilco) falling into place between them. Genetic diversity is unknown for the Sonoyta sewage lagoon population. However, this also means that due to lack of connectivity there would be little chance of natural rescue if one were to be extirpated, and that one or more population extirpations would likely reduce genetic and environmental diversity. The loss of Quitobaquito Springs, Quitovac, and either Rio Sonoyta Papalote or Rio Sonoyta Xochimilco would reduce the representation for the subspecies.

3.4.3. Current Subspecies Redundancy

Currently redundancy is limited to five populations, four populations spread throughout the Rio Sonoyta basin and one population in the northern part of the Rio Guadalupe basin (Figure 3.2.1). The four populations in the Rio Sonoyta basin are separated by 2 to 19 km (1 to 12 mi) indicating that a catastrophic even in one site might not affect another site. However, it is possible that a catastrophic event, such as severe drought or fire, could impact three of the five populations-Papalote reach, Xochimilco reach, and Quitobaquito Springs. A severe drought could impact the sewage lagoon via desiccation of nesting habitat, although sewage effluent is expected to maintain water levels regardless of drought. Conversely, catastrophic events such as disease would not likely impact multiple populations since the hydrological connection among populations is limited or nonexistent. Today, the five remaining populations are significantly isolated from one another such that recolonization of previously extirpated populations or those that may become extirpated is extremely unlikely. The one population in a different drainage basin and a sewage lagoon population would potentially be protected from hydrological degradation in the Rio Sonoyta basin.

CHAPTER 4. FACTORS INFLUENCING VIABILITY

In this chapter, we evaluate the past, current, and future factors that are affecting what the Sonoyta mud turtle needs for long term viability. We analyzed these factors in detail using the tables in Appendix B in terms of causes and effects on the species. These tables analyze the pathways, by which each factor affects the species, and each of the causes is examined for its past, current, and potential future effects on the species' status. Current and potential future effects, along with current assumed distribution, determine present and future viability. For more information about each of these influences, see Appendix B. Those risks that are not known or currently suspected to have effects on Sonoyta mud turtle populations, such as overutilization for commercial and scientific purposes and disease, are not discussed in this SSA Report.

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

Climate change itself is not one of the influencing factors we analyzed. However, climate

change and its effects will impact the influencing factors to some degree. The greatest impact, by far, that climate change, is on the amount of water; and most of the other influencing factors are largely impacted by the amount of water.

The primary negative factors affecting the future viability of the Sonoyta mud turtle is continued loss of water that supports aquatic and riparian habitat, and the primary positive factor is implementation of management actions that promote conservation of the subspecies. The Rio Sonoyta basin has experienced extensive recent anthropogenic changes, resulting in a reduction in and less suitable aquatic habitat for Sonoyta mud turtles. Ongoing management of the spring, channel and pond at Quitobaquito Springs on Organ Pipe Cactus National Monument by NPS and the Quitobaquito Rio Sonoyta Work Group has allowed the only population of Sonoyta mud turtles in the U.S. to persist. The Quitobaquito Rio Sonoyta Work Group has also implemented management actions to benefit the populations in Sonora, Mexico. Table 4.1 provides a summary of those factors influencing viability

Table 4.1. Summary of factors influencing viability of Sonoyta mud turtle.

Influencing Factors	Past	Current	Future	Population Level Effects?
Amount of Water	Yes	Yes	Yes	Yes
Amount of Riparian Area	Yes	Yes	Yes	Yes
Amount of Invertebrate	Yes	unknown	unknown	unknown
Amount of Nonnative species	No	No	Yes	unknown
Management Actions	Yes	Yes	Yes	Yes

4.1. Loss of Water

Sonoyta mud turtle populations rely on aquatic habitat in ponds and streams with perennial or near-perennial water with riparian habitat to support resilient populations. Reduction in water reduces the amount and quality of the aquatic and riparian habitat available to the species and thereby impacts population resiliency. The sources of water loss affecting Sonoyta mud turtles include groundwater pumping, drought, changes to wastewater infrastructure, consumption by livestock, surface water diversion, and habitat manipulation. In addition, impacts from climate change (discussed below) are expected to exacerbate water loss. Of these sources, water loss caused by drought and groundwater pumping, both of which are exacerbated by climate change, and changes to wastewater infrastructure are the primary activities causing population level impacts to the Sonoyta mud turtle. The other sources of water loss are not likely to have population level impacts unless mining near Quitovac is intensified and unregulated. However, all of the factors are additive in terms of impacts to populations that are already stressed by the primary activities causing population level impacts.

Diminished water reduces the amount of space, prey, and cover (from predators and for estivation) available to mud turtles. Reduction in aquatic habitat (i.e. space) leads to crowding and increased competition for limited resources (Stanila 2009, p. 45). Mud turtles can tolerate spatially intermittent water that is present most of the year but absent during the dry season in less arid parts of the species' range and, presumably, to some extent in the arid region inhabited by the Sonoyta mud turtle. Lack of surface water for a short time may be endured periodically,

but over the long term will reduce fitness and increase mortality. If water is not reliably present all year and absent beyond the dry season, turtles are not able to forage, may not reproduce, and as drought periods lengthen may eventually desiccate (Stanila 2009, p. 45). Sonoyta mud turtles in dry or low surface water reaches will burrow in channels to escape desiccation for a short period of time. After time, burrows themselves may become too dry, turtles will lose fat reserves due to lack of foraging opportunity, females may not have viable eggs due to lack of nutrition and fat reserves, thereby reducing reproduction, and eventually turtles will die from either starvation or desiccation.

Ground water pumping impacts the amount of surface water in areas used by Sonoyta mud turtles because the perennial sections of the Rio Sonoyta as well as the pond at Quitobaquito Springs and Quitovac are supplied by ground water. The Rio Sonoyta exists in an area where runoff has concentrated into a definable channel. In most of the Rio Sonoyta, the channel cuts into dry soils, so that flow is ephemeral. In the Papalote and Xochimilco reaches of the Rio Sonoyta where Sonoyta mud turtles live, the defined channel intersects regional ground water held in storage, the ground water saturates streamside channel bottom soils, and water is discharged to the stream. While flow in the Papalote reach is still perennial, flow in the Xochimilco reach ceases in dry years, with water only remaining in year-round small pools on bedrock below the dam. In an unaltered system, equilibrium exists so that recharge and discharge volumes of water are equal. When pumping occurs in such a ground water system, it alters this equilibrium so that less water is available for discharge to the stream and springs and reduces the amount of surface water available to the Sonoyta mud turtle.

The Sonoyta mud turtle was likely historically distributed throughout the Rio Sonoyta basin in Arizona and Sonora when there was more surface water providing connectivity between populations to allow for immigration and emigration (Rosen 2003, p. 11). Rio Sonoyta once had cienegas feeding it (Gehlbach 1981, p. 262). In 1891, the combination of heavy grazing, agriculture, and heavy flooding caused the river to erode and entrench itself, which caused mesquite bosques (forests) to replace cienegas, and riparian bottomlands, and perhaps associated semi-arid grasslands to disappear (Gehlbach 1981, p. 262).

Today, four of the five remaining populations of Sonoyta mud turtles are physically isolated from one another by 2 to 12 km (1 to19 mi) along the Rio Sonoyta and Quitobaquito Springs, and the fifth population at Quitovac is 52 km (32 mi) from the closest Rio Sonoyta population. The Quitobaquito Springs population in Organ Pipe Cactus National Monument has not had an aquatic connection with the Rio Sonoyta in recent times and nearby Mexico Highway 2 provides an additional impediment to movement of turtles between these two sites. The Quitobaquito Springs population is just over a mile from perennial water in the Papalote reach of the Rio Sonoyta, so it is possible that turtles could move overland between these two sites, although this has never been observed. For the purposes of this SSA, we assume that movement between these two sites is rare, although rapid degradation at one of the sites could catalyze emigration. However, if emigration occurred, turtles may or may not find the other occupied site. The three Sonoyta mud turtle populations within the Rio Sonoyta are disjunct from one another, and only connected by water during brief periods of high rainfall (Ives 1936, p. 351; Rosen *et al.* 2010, p. 152). The Rio Sonoyta flows continuously from the town of Sonoyta through the Pinacate Biosphere Reserve but rarely flows all the way to the Sea of Cortez during very wet years

(Brusca 2017, p. 42 and R. Brusca, pers. comm. 2017). Sonoyta mud turtles were marked at Quitobaquito Springs and the Papalote and Xochimilco reaches of the Rio Sonoyta in the early 2000s (Paredes-Aguilar and Rosen 2003, p. 8). However, none have been recaptured at a different location. These early mark-recapture efforts in the Rio Sonoyta occurred almost exclusively during the current drought episode (Rosen *et al*. 2010, pp. 143–144), reducing the likelihood that turtles would move among these three population sites. When Pinacate Reserve Biologists began marking Sonoyta mud turtles in the Papalote reach in 2017, several high water flows occurred in the first few months of this effort and none of the five radio-telemetered turtles moved during the high flow events (USFWS 2017, p. 1). This study has just begun, and we have no other information regarding whether or how often Sonoyta mud turtles move during prolonged high flow events. In populations of the nominate subspecies in semi-desert grassland and oak woodland, turtles commonly move up to 7 km (4.3 mi) across land within and between drainages to take advantage of extended flow and pools that provide habitat during the wet season (Ligon and Stone 2003b; pp. 752–753; Hall and Steidl 2007, pp. 406–408; Hensley *et al*, pp. 181–182; Stone 2001, pp. 46–51), but this may not be applicable to movement during droughts. Finally, the Quitovac population has not been naturally connected to the Rio Sonoyta population in historical times, if ever, and remains disconnected. Given the observed and expected increase in ambient temperatures and evaporation rates, as well as continued groundwater pumping (both discussed below), it is less likely that these sites will be hydrologically connected for long periods. Rather it is likely that what little connectivity there is will decrease. Therefore, recolonization of areas previously extirpated or areas that may be extirpated is extremely unlikely.

Water demands on the aquifer that provides water to the Sonoyta mud turtle in the Rio Sonoyta basin include agriculture and a growing human population that are almost wholly dependent on groundwater. The Sonoyta Valley from where the Sonoyta river leaves Arizona heading south and turns west around the Sierra de la Nariz, west and downstream almost to the Papalote reach has been subjected to groundwater pumping far in excess of natural recharge (Pearson and Connor 2000, p. 388), which has decreased surface water available for the Sonoyta mud turtle in the Rio Sonoyta (Rosen *et al*. 2010, pp. 153, 158). Although livestock and agricultural practices in the Sonoyta Valley began in the late 1600s, direct groundwater withdrawal did not occur until the introduction of wells that provided water via centrifugal pumps in the Sonoyta Valley in 1952 (Pearson and Conner 2000, p. 382). Development of agriculture stimulated economic growth in the town of Sonoyta and by the late 1980s total annual water withdrawal was more than 2.5 times the annual groundwater recharge rate (Brown 1991, p. 28). Agricultural markets slumped in the early 1990s and water withdrawal dropped (Pearson and Conner 2000, p. 391), but by 1997 agriculture in the Sonoyta Valley seemed to be on the rebound with water usage nearly equal to 1991 levels (NPS 2006, p. 15–16). Rosen *et al.* (2010, p. 155) observed that many of the agriculture fields seemed to be currently out of production based on Google Earth imagery. We do not have any recent observations and do not know if groundwater pumping still exceeds recharge, although that is highly likely based on trends of depth to groundwater measured at Organ Pipe Cactus National Monument in wells that are close to the agricultural zone of Sonoyta, Sonora (Figure 4.1.1)(NPS 2011b, p. 8). Based on total number of wells installed by the year 2000, existing capacity for wells to withdraw water is six times groundwater recharge (Pearson and Connor 2000, p. 388).

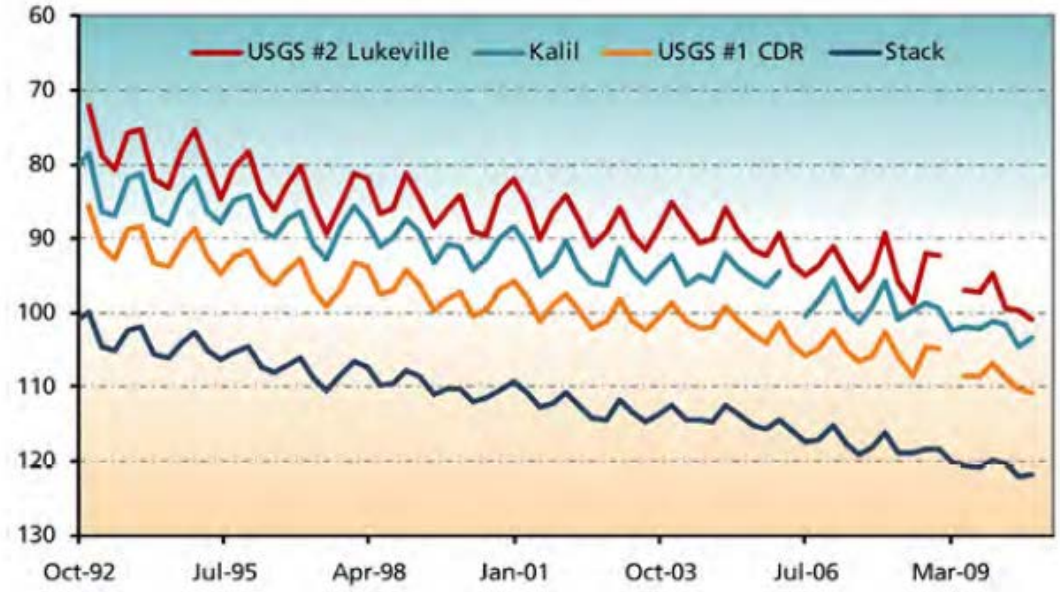


Figure 4.1.1. Depth to groundwater at the four wells on Organ Pipe Cactus National Monument nearest the populated agricultural zone of Sonoyta, Sonora, from 1992 to May 2010 (from NPS 2011b, p. 8).

Quitobaquito Springs is predominantly supplied by groundwater under Aguajita Wash and the La Abra Plain (Carruth 1996, pp. 14, 18). This is indicated by the age of the water being discharged, which is between 500 and several thousand years old. Although the groundwater basin of the La Abra Plain is considered somewhat isolated from the regional aquifer in the Sonoyta Valley, it is likely that there is a connection between the two systems, but the impact of groundwater pumping on Quitobaquito Springs is unknown. Thus, Quitobaquito Springs could experience a delayed or reduced affect by an increase in groundwater drawdown occurring in Mexico (Carruth 1996, p. 21). Historical information demonstrates that the output of the two springs that supply the pond at Quitobaquito Springs has been variable and is lower than it used to be. Discharge from springs has diminished by 1.2 percent annually for a total 42 percent decrease over the past 35 years with 156 cubic meters/day (cm/day, 5,500 cubic feet/day (cf/day)) average discharge measured from 1981 to 1992 down to 89 cm/day (3,157 cf/day) measured from 2005 to present (Carruth 1996, pp. 13, 21; P. Holm, pers. comm. 2016d). Thus far, declining spring flow has been associated with less than 1 foot of surface water level decline at the pond, which could indicate that current lower water levels are also caused by leakage or evapotranspiration, and not just reduced spring flow (NPS 2012b, p. 1). Although the average annual decrease in discharge at the springs has been 1.2 percent over the past 35 years, the rate of decline has been decreasing over time, so that we do not expect flow to completely disappear in the near future (P. Holm, pers. comm. 2016d). However, at some point, flow may not be able to maintain enough water in the pond to support a viable population of Sonoyta mud turtles.

Although Quitovac is not within the Rio Sonoyta watershed, the five springs that provide water to the impounded pond could be impacted by groundwater withdrawal in the future. One of the five springs was not flowing into the pond during a visit to the site in 2015 (Quitobaquito Rio Sonoyta Work Group 2015, p. 1). There has been gold mining in the area surrounding

Quitovac, and mine exploration and development continue. The mines are open pits, which reduce surface water by removing groundwater if the pit intersects ground water. Water for mine operation is wholly supplied by groundwater. There is an abandoned open pit gold mine about 12 km (7.5 mi) southeast of Quitovac (referred to as La Mina). Though the mine is likely down-gradient from Quitovac Springs, the use of water during mining, the likely pumping of water from the pit during mining, and the continuing loss of water from the pit lake via evaporation has removed and is continuing to remove groundwater in the area. Any new mines closer to Quitovac would be highly likely to impact groundwater, though impacts from groundwater withdrawal to Quitovac Springs could take decades, or even centuries.

Groundwater storage in the Rio Sonoyta and Quitovac areas may also decline due to reduction in natural channel recharge resulting from changing climatic patterns in the Southwest. Seager *et al.* (2007, pp. 1181–1184) analyzed 19 different computer models to estimate the future climatology of the southwestern United States and northern Mexico. 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 three 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 of climate change impacts on the Sonoran Desert 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) (Weiss and Overpeck 2005, p. 2074; Archer and Predick 2008, p. 24). For the Southwestern U.S., Garfin *et al.* (2013, pp. 5–6) predict the following influences of climate change:

1. Warming is expected to continue, with longer and hotter heat waves in summer.
2. Average precipitation will decrease in the southern Southwest and perhaps increase in northern Southwest.
3. Precipitation extremes in winter will become more frequent and more intense. Precipitation extremes in summer have not been adequately studied.
4. Late-season snowpack will continue to decrease.
5. Declines in river flow and soil moisture will continue.
6. Flooding will become more frequent and intense in some seasons and some parts of the Southwest, and less frequent and intense in other seasons and locations.
7. Droughts in parts of the Southwest will become hotter, more severe, and more frequent

In addition, Strittholt *et al.* (2012, pp. 104–152) analyzed projected average annual temperature, seasonal summer temperature (July-September), and winter temperature (January-March) in models for the Sonoran Desert Ecoregion. Results show that the ecoregion is expected to undergo general warming over the entire region with a > 2° C increase by 2060 in some locations, particularly in the southwestern portion of the ecoregion (Strittholt *et al.* 2012, p. 126). Average summer temperatures are expected to increase, but greater increases are projected to occur during the winter months.

Any reductions in annual rainfall associated with climate change, coupled with hotter temperatures that are projected with very high confidence and will alone bring reductions in

aquifer inputs due to higher evaporation rates, would likely have negative effects on aquifers across the Southwest. Virtually any plausible future climate scenario projects longer dry spells between rains, which can have more severe impacts on the landscape, especially in spring and summer (Lenart 2008, entire). It is therefore likely that some existing Sonoyta mud turtle habitat along the Rio Sonoyta will completely go dry in spring and summer during the current century.

Because warmer air holds more water vapor than cooler air, climate models project an increase in the capacity for the atmosphere to hold water vapor (Trenberth *et al.* 2003 pp. 1212–1213; Garfin *et al*. 2013, pp. 134–135). This creates conditions that potentially could lead to bigger and more frequent floods by causing more intense, heavy rainfall events (Overpeck *et al.* 2013, p. 6). Such floods may be even more destructive as riparian vegetation declines. Intense rainfall events are more likely to carry rainwater quickly away from the area in intense floods, with less water reaching the aquifers or remaining as semi-permanent water. Models for the Sonoran Desert Ecoregion predict surface runoff will slightly increase over the near term, and slightly decrease over the 2045–2060 time-frame (Strittholt 2012, p. 138). Although predictions about the impacts of climate change are based on modeling, many predictions have already occurred and are currently being felt across the region (Fleishman *et al*. 2013, p. 149; Gershunov *et al*. 2013, p.132; Hoerling *et al*. 2013, entire; Pincetl *et al*. 2013, p.270). Thus, the models appear relatively reliable, and. Climate change trends are highly likely to continue (Overpeck *et al.* 2013, entire). Climatic impacts on the Sonoyta mud turtle will likely be further complicated by interactions with other factors (e.g., interactions with nonnative species and other habitat-disturbing activities).

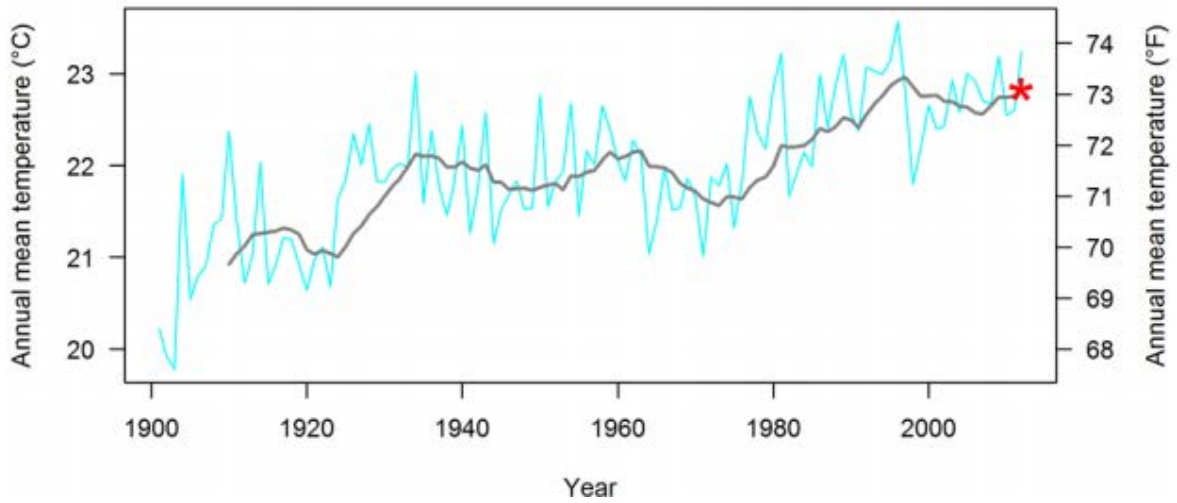


Figure 4.1.2. Annual average temperature (blue line), 10–year moving average (grey line), and average temperature of most recent available 10–year moving window (2003–2012) (red asterisk) measured at Organ Pipe Cactus National Monument, 1901–2012 (from NPS 2014b, p. 1).

Rainfall in the southwest deserts typically follows a cyclic pattern (Figure 4.1.3). Recent climatic history in the Rio Sonoyta basin area included two extremely wet periods from 1977 to 1984 and 1991 to 1995, followed by drought conditions from the latter-1990s to today that have (Figure 4.1.3)(Rosen *et al.* 2010, pp. 149, 185; NPS 2011b, p. 7). The Sonoyta mud turtle

populations we see today may not yet fully reflect the consequences of the long-term drought that began in the latter-1990s (Rosen *et al.* 2010, p. 153)), particularly in Rio Sonoyta, where rigorous sampling has not occurred since 2006. On top of global warming and cyclical fluctuations associated with El Nino-Southern Occilation, there are longer-term cycles that may reach a new nadir of regional aridity some time close to the mid-century, at which time a severe global warming-type drought (Breshears *et al*. 2005, pp. 15144, 15148) could produce ecological impacts that far exceed those seen to date.

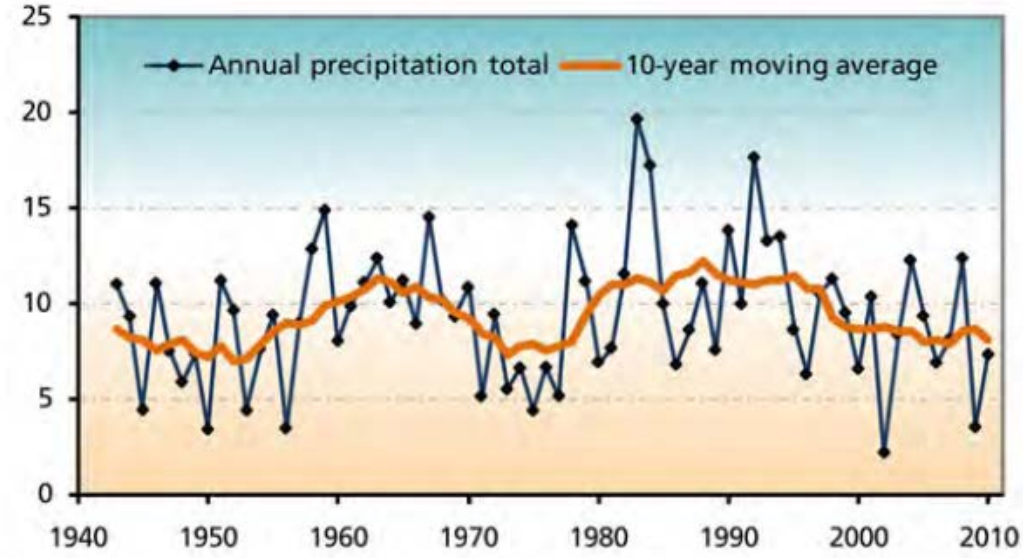


Figure 4.1.3. Annual average precipitation (blue line) and 10–year moving average (orange line) measured at Organ Pipe Cactus National Monument headquarters, 1943–2010 (from NPS 2011b, p. 7).

Current models suggest a continued decrease in precipitation in the Southwest (Kundzewicz *et al.* 2007, entire; Seager *et al.* 2007, pp. 1181–1182, Cayan *et al*. 2013, entire), which would lead to reduced streamflow and a reduced amount of habitat for Sonoyta mud turtle. Streamflow is predicted to decrease in the Southwest even if precipitation were to increase moderately (Nash and Gleick 1993, entire; State of New Mexico 2005, entire; Hoerling and Eischeid 2007, p. 35). Warmer air temperatures lead to increased evaporation, increased transpiration, and decreased soil moisture. These three factors would lead to decreased streamflow even if precipitation increased moderately (Garfin 2005, p. 43; Seager *et al.* 2007, p. 1182). The effect of decreased streamflow is that streams become smaller, intermittent or dry, and thereby reduce the amount of habitat available for Sonoyta mud turtles. Streams like the Rio Sonoyta that have low depth relative to surface area of flow are affected more by air temperature than a larger one, exacerbating the effects of warm and cold air temperatures and accelerating decreased streamflow (Smith and Lavis 1975, p. 236). Although Sonoyta mud turtles evolved in the Southwest and have survived drought in the past, it is anticipated that a prolonged, intense drought would affect all populations, in particular those occupying the Rio Sonoyta which is likely to go dry. In addition, turtles isolated in pools may be subject to increased predation from nonnative aquatic predators and native terrestrial mesopredators such as skunks, raccoons, and canids.

Management actions exacerbated by drought at Quitobaquito Springs caused highly fluctuating surface water levels in the pond in the past, although these fluctuations have been attenuated since 2010. Pond leakage resulting from various causes, the senescent cottonwood tree in the pond berm, and evapotranspiration from native emergent vegetation in the pond has contributed to short-term water loss at Quitobaquito Pond, although this loss is monitored and addressed as needed as explained below in Section 4.5.

Wastewater effluent has provided surface water to support two of the five populations of the Sonoyta mud turtle: Sonoyta sewage lagoon and Xochimilco reach (i.e., excluding the minor water source further upstream at San Raphael). Wastewater discharge from a military complex located above Presa Xochimilco created sizeable perennial pools within the Rio Sonoyta streambed at the upper end of the Xochimilco reach. Despite the potential detrimental effects of chemical pollutants and nutrient loading, effluent provided surface water for Sonoyta mud turtles during frequent periods when the stream reach was otherwise dry. Xochimilco was the largest known population of the Sonoyta mud turtle in Mexico (Paredes-Aguilar and Rosen 2003, p. 9). In 2008, the effluent was piped to the wastewater lagoon in the town of Sonoyta, bypassing the Xochimilco reach. As a result, this reach has variable and little flowing water much of the year relying only on minimal spring-like flow just downstream of the dam, stormwater runoff, and sewage effluent from adjacent residential homes so that remaining pools are presumed to be no longer perennial except for one or more small pools below the dam.

The second site supported by wastewater effluent, the Sonoyta sewage lagoon, will be decommissioned once a new wastewater treatment facility is completed. This will result in elimination of wastewater flow into the existing sewage lagoon and Rio Sonoyta, and cause the lagoon to dry so that it no longer supports the population of Sonoyta mud turtles there. Although the wastewater treatment facility may be completed in 2017, it will be approximately 75 percent smaller than the current habitat at the Sonoyta sewage lagoon, the ponds will be lined with plastic pond liner, thus may support a smaller turtle population. However, inflow to the new wastewater treatment facility will include wastewater from most currently unserved residents in the town of Sonoyta so that more outflow will be released into the Rio Sonoyta (EPA 2008, p. 2–1). This increased outflow could improve recharge of the shallow aquifer and create perennial flow in the river downstream of the wastewater treatment facility as well as contribute to recharge of the Rio Sonoyta, which may raise the water table. This in turn, might provide increased surface water downstream sites so that it might support Sonoyta mud turtles populations west of Sonoyta proper, although perhaps not likely as far as Santo Domingo reach (that is no longer extant), or the Papalote reach.

In addition to groundwater extraction, decreased precipitation and increased evapotranspiration related to increased severity and duration of drought conditions, and changes to wastewater treatment infrastructure have already led to reduced surface water and drying of habitat supporting the subspecies. These activities and associated impacts are expected to continue at all sites that support populations of the Sonoyta mud turtle. Further, recent climatic conditions in the Rio Sonoyta watershed have already shifted beyond the historically recorded range of variability as depicted in analysis of annual mean temperature of the area within 30 km (18.6 mi) of Organ Pipe Cactus National Monument (Figure 4.1.2).

4.2. Loss of Riparian Habitat

Loss of surface water will also cause a loss of riparian habitat used by Sonoyta mud turtles. Riparian vegetation surrounding water features provides essential habitat for some and possibly all life stages of turtles. Reduced surface water and ground water reduce the survival and growth of vegetation in the riparian areas. Reductions in riparian habitat will decrease subsurface moisture needed for nesting sites, drought refuge for hatchlings, juvenile and adult turtles, and shelter from large flooding events for hatchlings, juveniles and adults. It is likely that only adults will be the most resistant to severe droughts. Decreased riparian vegetation will lead to deterioration of the microclimate that provides soil moisture for nest sites and burrows. Loss of riparian habitat will affect the entire range of the species over the long-term, except for the Sonoyta sewage lagoon and wastewater treatment plant, as it is connected to loss of water. There will be a lag time between surface water loss and degradation of riparian habitat, and therefore it is likely that the two populations in the Rio Sonoyta will decline first in response to loss of surface water permanence but simultaneously face increasingly severe threat from severe drought as riparian refuges degrade.

Results from a study by Fisher de León (2006, p. 63) showed that on the Pinacate Biosphere Reserve, there has been an ongoing loss of riparian vegetation of the Papalote reach of the Rio Sonoyta. The recent losses in vegetation may have resulted from a decrease in water flow in the river. Fisher de Leon attributed the loss of riparian vegetation to a drop in the water table. Comparison of satellite imagery taken over time by looking at the difference in absorption, transmittance, and reflectance of solar energy by vegetation in the red and near-infrared portions of the electromagnetic spectrum showed there are also perceivable changes in the condition of the riparian vegetation of the Rio Sonoyta (Fisher de León 2006, pp. 38–39, 86, 106–107). Future changes in riparian vegetation along the river would be expected if groundwater and subsequent surface water depletion continues. We have no site specific information on how riparian vegetation changes affect Sonoyta mud turtle nesting and estivation habitat. However, it is likely that loss of riparian vegetation will cause reduced soil moisture that will in turn increase desiccation of eggs at nest sites and of individual turtles in estivation sites.

4.3. Decrease in Invertebrate Prey Availability

Sonoyta mud turtles prefer aquatic invertebrates for food. Adequate invertebrate prey allows juvenile turtles to grow rapidly with enhanced survivorship, and for adults to survive resource droughts and to have sufficient lipid content to support reproduction. Poor body condition may be associated with lower clutch frequency and size, probably translating strongly to slower population growth (Wilkinson and Gibbons 2005, p. 875). Rosen and Lowe (1996, p. 20) hypothesized the decline into the late 1980s at Quitobaquito Springs was due to low survivorship of juvenile turtles and nutritional stress. Limited analysis of stomach contents of turtles at Quitobaquito Springs revealed animals were consuming significant amounts of bulrush shoots and trap monitoring revealed low abundance of aquatic invertebrates. An unusual number of adult turtles were found dead for non-obvious reasons, but detailed carcass analysis revealed depleted body lipid reserves similar to those of musk turtles that had been experimentally subjected to starvation (King *et al.* 1996, p. 5 in Rosen and Lowe 1996). Dissection and carcass analysis did not yield diagnoses of contaminant or infectious disease

effects thus, indicating a possible dietary deficiency. Rosen and Lowe (1996, p. 32, 41) thought that turtles dietary restrictions associated with low invertebrate abundance may reflect competition with native desert pupfish that occur as a population estimated in the range of 5,000–15,000 individuals. Desert pupfish are well known to feed on many of the same invertebrates that Sonora mud turtles consume (Rosen and Lowe 1996, p. 41). Pupfish densities at Quitobaquito Springs are similar or greater than the density used in an experimental pond study that demonstrated strong effects of desert pupfish on aquatic invertebrate abundance, so that competition between Sonoyta mud turtles and desert pupfish is plausible (Rosen and Lowe 1996, p. 41). Water permanence may also affect the diversity of aquatic invertebrate prey available for mud turtles, with ephemeral habitats having lower diversity than intermittent or perennial habitats (Stanila 2009, p. 38). However, temporally intermittent waters and other fish-free waters can have extremely high aquatic invertebrate abundance for short periods of time (Stanila 2009, p. 38-42), so the initial loss of water permanence may have beneficial effects on Sonoyta mud turtle food availability. Presence of nonnative aquatic species could also decrease the availability of invertebrate prey as described below in Section 4.4, but currently not the case at Quitobaquito and this is unclear in the Papalote Reach and Quitovac where nonnative aquatic fish are known to be present.

4.4. Introduction of Nonnative Species

Establishment of some nonnative aquatic vertebrate species may affect future persistence of the Sonoyta mud turtle. Low survivorship among juvenile turtles at Quitobaquito Springs was attributed to predation and degradation of shallow-water, well-vegetated habitat for juveniles due to earlier management actions (Rosen and Lowe 1996, p.40). Currently at least two, Papalote and Quitovac, of the five populations of Sonoyta mud turtles exist with some nonnative species present. Black bullheads and western mosquitofish were introduced (for unknown reasons) and currently persist in the Rio Sonoyta Papalote reach (and may persist in the Xochimilco reach, where they were previously present), and blue tilapia (for local food source) at Quitovac are very abundant (Rosen *et al.* 2010, pp. 153–154; Minkley *et al*. 2013, p. 289). Golden shiners were once established at Quitobaquito Springs and both black bullhead and exotic turtles have also been found there and removed by NPS. Red-eared sliders have also previously been found in a school pond near the Rio Sonoyta Xochimilco reach. Other nonnative aquatic species including bullfrogs, crayfish, and centrarchids are not currently present in areas occupied by the Sonoyta mud turtle, but could be released and become established, as they have been in many of the nominate Sonora mud turtle populations in the U.S. (Fernandez and Rosen 1996, pp. 39–41; Hensley *et al.* 2010, pp. 175–176; Drost *et al.* 2011, p. 33).

Bullfrogs, crayfish, and large centrarchids are known to prey upon hatchling and juvenile turtles, and crayfish, in particular, could decimate a population if introduced (Fernandez and Rosen 1996, pp. 41–43; Stanila 2009, pp. 49–51; Hensley *et al.* 2010, pp. 186–187). In addition, black bullhead, tilapia, western mosquitofish, and exotic turtles may also disrupt the food chain which could alter the invertebrate community (Taylor *et al.* 1984, pp. 330–331; Fernandez and Rosen 1996, pp. 39–40; Duncan 2013, p. 1). This, in turn, could decrease type and amount of aquatic invertebrate prey available to Sonoyta mud turtles (Fernandez and Rosen 1996, pp. 39–40). Numbers and effects of nonnative aquatic species that are currently present at sites that support two of the five Sonoyta mud turtle populations are unknown, although the turtle population in the

Papalote reach is persisting in the presence of the nonnative black bullhead and native desert pupfish (Minckley 2017, p. 2)

4.5. Land Management Actions

There are a number of conservation actions that have been implemented or are planned to improve our understanding of the species, minimize threats, and maintain or improve the status of the Sonoyta mud turtle in both the U.S. and Mexico. There are also land management actions that have been implemented that have not benefited the species. Both are discussed here.

In 2001, the Quitobaquito Rio Sonoyta Work Group was formed to address threats to the Sonoyta mud turtle. This group consists of biologists and managers from the NPS, Arizona Game and Fish Department, USFWS, University of Arizona, Arizona-Sonora Desert Museum, Commission on Ecology and Sustainable Development of the State of Sonora, Pinacate Biosphere Reserve, and private citizens interested in conservation of aquatic native species in the Rio Sonoyta basin of Arizona and Sonora. Management actions in the U.S. include monitoring of the one wild population, creating a refuge population, habitat management, and manipulating habitat to maintain pond water levels at Quitobaquito Springs. Management actions in Mexico have included defining the ecological status and distribution of the Sonoyta mud turtle in Sonora, planning to create new habitat to replace future lost habitat at the Sonoyta sewage lagoon, removing nonnative aquatic species, advocating for integration of biodiversity conservation into urban infrastructure design, and outreach.

The Sonoyta mud turtle population at Quitobaquito Springs is now dependent on habitat manipulation and maintenance by humans. The NPS recognizes the unique nature of the Sonoyta mud turtle population and manages for its conservation. The NPS identified habitat features that are becoming less available to the subspecies, such as basking sites, banks free of vegetation, access to terrestrial habitats, and pools in the inlet channel. The NPS is working to maintain these habitat features and improve habitat heterogeneity. The NPS is committed to continued conservation of the Sonoyta mud turtle on Organ Pipe Cactus National Monument under a multi-species management approach. If left alone with no management, the site would likely revert to a cienega that would still support a population of Sonoyta mud turtles.

In the early to mid–1990s, low survivorship among juvenile turtles at Quitobaquito Springs was attributed to circumstantial evidence of predation by wading birds and degradation of shallow-water, well-vegetated habitat for juveniles from earlier management actions (Rosen and Lowe 1996, p.40). Following NPS restoration of shallow, well-vegetated habitat for juvenile mud turtles along the spring runs and in the pond in 1989 and 1990, Rosen and Lowe (1996, p. 20) detected an increase in juvenile survivorship along with rising population abundance (Figure 3.2.5).

In late 2005 and early 2006, the pond water level began dropping for unknown reasons. The water level eventually reached historical lows in 2008, at 71 cm (28 in) below the outflow pipe (Figure 3.6). Water flowed from the outflow pipe as late as 1998. Efforts by Organ Pipe Cactus National Monument included trucking water, spring renovation, strengthening the dike, re-lining parts of the pond, and removing bulrush, eventually resulted in pond water levels stabilizing near

historical norms. Despite these efforts, water levels in the pond dropped 46 cm (18 in) between December 2011 and July 2012. This was the largest single loss of water in recorded history of the pond. The cause of the loss was likely a combination of pressure-induced activation of one or more leaks in the pond bottom, failure of the seal around a senescent cottonwood tree on the berm, ongoing reductions of spring flow, and large-scale evapotranspiration loss via increasing stands of bulrush. Organ Pipe Cactus National Monument staff measured water level in the pond on April 3, 2014 at -8 cm (-3.15 in), which is the highest level recorded in April since April 19, 2002. Pond levels were in sharp decline by the spring of 2016 as water level in the pond dropped 9 inches from -20.3 cm (-8 in) on March 22 to -43.2 cm (-17 in). A comparable time period in 2015 indicated that the water dropped only 8.25 cm (3.25 in). The lack of rains in summer 2015 and winter 2016, extreme heat, and large scale evaporation exacerbated the problem. These issues were compounding with the continued loss of water through the senescent cottonwood tree. In May and June 2016 NPS staff at Organ Pipe Cactus National Monument removed woody brush off the berm, removed the cottonwood tree, resorted the berm, and repaired of the pond liner. These actions appear to have stopped the excessive flow of water out of the pond (NPS 2016). It should be noted that these and future management actions and monitoring at Quitobaquito are and may continue to be costly and thus dependent on significant federal funding for biodiversity management and conservation.

Beginning in 2007, after the drop in water levels in late 2005 and early 2006, the Quitobaquito Rio Sonoyta Work Group decided to salvage turtles and place them in captivity while resource managers addressed declining water levels in the pond (NPS 2008b, p. 6). Initially 13 animals were salvaged and taken to the Arizona-Sonora Desert Museum in Tucson, Arizona. Unfortunately, all but one of these turtle was eaten by raccoons. Salvages continued through 2009 with a total of 81 animals removed from the wild. In 2011, 24 animals were released back to the wild population at Quitobaquito Springs, and no other releases have occurred. If water levels in the pond ever drop significantly again, turtles will be salvaged and housed temporarily at Organ Pipe Cactus National Monument and then taken to the Arizona-Sonora Desert Museum. There are currently 17 individuals remaining in the refuge population at the Arizona-Sonora Desert Museum including 6 males, 5females, 3 juveniles, and 3 hatchlings (S. Poulin, pers. comm. 2017). A total of 40 animals have died in captivity for various reasons. The long-term plan is for 12 turtles to remain at the Arizona-Sonora Desert Museum as an assurance population. There are also two mud turtles currently in a high school pond in the town of Sonoyta. The University of Arizona has one pair of Sonoyta mud turtles from Quitovac, which were collected in 2002 for genetic study, and 10 of their offspring.

Removal of saltcedar, fencing off areas from cattle, and removal of black bullhead have all been attempted in the Papalote reach of the Rio Sonoyta (Rosen *et al.* 2010, entire; Izaguirre-Pompa 2011, entire). Introduced saltcedar growing in Sonoyta mud turtle habitat might cause a lack of water at critical times (Bolster 1990, R. Bransfield, pers. comm. 1999); however, recent scientific information contradicts the long-held belief that saltcedar consumes more water than native trees (Glenn and Nagler 2005). Regardless, effects of the saltcedar removal in the Papalote reach were never monitored so potential effects on Sonoyta mud turtle populations remains unknown. Saltceder growing along the stream banks at Papalote stabilize the banks. Turtle burrows, which are apparently used by all turtles in the reach on a likely daily basis, are primarily in these root-stabilized banks. Thus, eliminating the saltcedar without

compensatory increase in other streamside trees could be catastrophic for the turtles. Fencing was installed to exclude cattle from the Papalote reach, but it was removed by the area rancher within a year. Absence of black bullhead was also short-lived.

Once the current Sonoyta sewage lagoon is decommission it will presumably no longer support its Sonoyta mud turtle population. Consequently, the EPA, USFWS, La Comisión Nacional de Áreas Naturales Protegidas (specifically, the El Pinacate y Gran Desierto de Altar Biosphere Reserve), the Sonoyta municipal government and wastewater treatment collection utility, and SEMARNAT worked together to come up with measures to benefit Sonoyta mud turtles at the new wastewater treatment facility. Mexico's Resolutivo captures these "conditions of approval" to create habitat for mud turtles at the new wastewater treatment facility, translocate turtles from the old sewage lagoon to the new habitat, plant riparian vegetation around the new habitat that supports the Sonoyta mud turtle, and require all effluent from the wastewater treatment facility to be directed to Rio Sonoyta for recharge. There will inevitably be some loss of turtles and reduction in the population size of the lagoon population as it is transferred to the wastewater treatment facility. While habitat at the new wastewater treatment facility is smaller, and thus might not support as many turtles as the current habitat at the Sonoyta sewage lagoon (depending on habitat quality), potential benefits from recharging an increasing amount of water into the Rio Sonoyta could bring the water table up in downstream portions of the Rio Sonoyta that historically supported Sonoyta mud turtles but currently do not. If a persistent effluent-dependent aquatic habitat is created in the streambed, as seen in some other desert urban areas, native turtles, fishes, and natural riparian environments may be sustained. Depending on currently unknown subsurface permeability and aquifer conditions, the effluent might flow some distance. Given the magnitude and extent of agricultural pumping, effluent recharge sufficient to benefit the Papalote reach probably would require reduction or elimination of water extraction from the aquifer.

There are also some management actions that have been implemented that do not benefit conservation of the Sonoyta mud turtle. These include rerouting of wastewater effluent that used to provide surface water for turtles in the Xochimilco reach (see Section 4.1), release of nonnative fish into the Papalote reach discussed in section 4.4 Introduction of Nonnative Species; draining and removal of turtles at Quitobaquito Springs, and dredging of turtle habitat at Quitovac. The pond at Quitobaquito Springs was drained twice to eliminate nonnative fish and enhance habitat for the endangered desert pupfish without concerns about the Sonoyta mud turtle population. During these drying episodes, many Sonoyta mud turtles were collected and apparently distributed to individuals (Rosen 1986, p. 17). Complete dredging of the pond and spring run at Quitovac occurred sometime during 2014 and 2015. Before the recent complete dredging event at Quitovac, periodic dredging of smaller portions of Quitovac had taken place to remove bulrush, which likely had some short term negative effects to the population, but likely were not as harmful as the complete dredging that took place recently. We do not know the effects of the latest dredging event on the population of turtles at Quitovac, although a single turtle with a cracked shell discovered at the site after dredging took place likely resulted from trauma associated with dredging activities (Quitobaquito Rio Sonoyta Work Group 2015, p. 1). Introduction and establishment of nonnatives is discussed in section 4.4 Introduction of Nonnatives.

The only turtle population that is currently secure due to management actions is Quitobaquito

Springs in Arizona. Sonoyta mud turtle recruitment at Quitobaquito Springs has increased and numbers are currently high (Figure 3.5). If the new wastewater treatment facility becomes operational and the actions agreed to by Mexico are implemented, a portion of the Sonoyta sewage lagoon population at the new wastewater treatment facility will be secured. Management actions for the Papalote reach and Quitovac populations have not proven successful and may not be effective at maintaining these populations.

4.6. Summary

Our analysis of past, current, and future influences on Sonoyta mud turtle needs for long term viability identified influences posing the largest predicted risk to future viability of the species. The most significant past, current, and future stressor to the Sonoyta mud turtle is loss of aquatic and riparian habitat needed to support resilient populations. The primary causes of past, current, and future habitat loss within the range of the Sonoyta mud turtle is related to drought and anthropogenic groundwater pumping both of which have reduced surface water available to the species. These stressors are exacerbated by lack of connectivity, and climate change now and in the future. Groundwater withdrawal will continue to affect base flow in the Rio Sonoyta basin, although we cannot quantify when and how it will affect the sites that support the species. The implementation of the conservation measures by the NPS and Quitobaquito Rio Sonoyta Work Group has resulted in maintaining the only Sonoyta mud turtle population in the U.S. and should secure one population in Mexico at the new wastewater treatment facility, although perhaps smaller than the population it is replacing. The primary source of potential future habitat loss is groundwater depletion exacerbated by climate change that could result in reduced or eliminated surface water for four of the five remaining populations of the Sonoyta mud turtle in the US and Mexico, leaving only the new wastewater treatment facility.

CHAPTER 5. SPECIES VIABILITY

We have considered what the Sonoyta mud turtle needs for viability and the current state of those requirements (Chapters 2 and 3), and we reviewed the factors that drive the historical, current, and future conditions of the species (Chapter 4). We now consider the species' likely future conditions, and apply future forecasts to the concepts of resiliency, redundancy, and representation to describe the future viability of the Sonoyta mud turtle. Here we assume that the Quitobaquito Rio Sonoyta Work Group can implement conservation measures in Mexico for the Best Case and Moderate Case scenarios. Political change in either country could impact the implementation of conservation actions.

5.1. Introduction

The Sonoyta mud turtle was historically known from five sites in the Rio Sonoyta basin: one site in the U.S. and at least four sites in Mexico. We state "at least four" because of the uncertainty of some of the location information. Some of the historical location information is vague and we used our best professional judgment to determine the locations. Currently the species occurs at five small, isolated sites: one in the U.S., two historical sites in Mexico within the Rio Sonoyta, and two sites in Mexico where it was not found historically based on museum records or published reports. Due to more extensive and consistent availability of water inferred from conditions during the mid-1800s to 1930s, Sonoyta mud turtle habitat was most likely less fragmented and isolated than it is today (Rosen *et al*. 2010, p. X)(Figure 3.1.1).

Table 5.1. Change in population abundance and water availability over time.

Population Name	Abundance	Water
Quitobaquito Springs[1]	Historical=hundreds Now=110 to 141 (+/-25)	Reduced spring flow by 42 percent Reduced pond level by 70 cm (27.5 in)
Papalote Reach	Historical=unknown 2003=>100, moderate density[2] Now=unknown	Decrease in length of perennial reach of 3–3.5km (1.9–2.2 mi)
Santo Domingo	Unknown	No perennial reaches
Sonoyta Reach[3] **(Xochimilco Reach)**	Historical=unknown 2002=~345[2] Now=unknown	Decrease in perennial stream length of 10–12.5 km (6.2–7.7 mi)
Sonoyta Sewage Lagoon	This site was not known historically	This site was not known historically
Quitovac	This site was not known historically	This site was not known historically

[1] Estimates from Quitobaquito Springs include adults and juveniles >41 mm carapace length, no young-of-the-year are included
[2] Estimates for Papalote and Sonoyta reaches were best professional judgement and not based on mark-recapture data
[3]The historical Sonoyta reach includes the area referred to today as the Xochimilco reach.

Past human actions affecting water quantity were the primary drivers of habitat and population loss, and these actions continue today (see Chapter 4). Additionally, a drought that began in the

1990s continues to affect surface water availability in the Rio Sonoyta basin (Fisher de León 2006, p. 76; Rosen *et al*. 2010, p.p. 149, 185; NPS 2011b, p. 7). The five small extant populations occur at sites with low to moderate habitat element condition categories (See Table 3.3.2) and all populations are currently at some risk from water loss, and ongoing changes in climate. The four sites in Mexico are also currently and in the future at risk from surface water loss from groundwater pumping activities around the Rio Sonoyta, wastewater treatment changes in the town of Sonoyta, and dredging activities and potential mining at Quitovac. We are relatively certain that climate change and increased human population levels in the Rio Sonoyta basin will continue into the future and will result in lowered groundwater levels, but we are less certain about how and when the amount of water needed to support mud turtle populations would be affected.

Because the remaining populations are isolated and the four in Mexico are smaller than in the past, they are presumably less resilient. A single stochastic event such as pond or stream drying, pond dredging, or long-term drought could eliminate an entire population of Sonoyta mud turtles, further reducing the current overall redundancy and representation of the species. These effects are heightened at the range-wide level because the isolation of the populations prohibits natural recolonization through movements from other populations, which likely occurred in the past and allowed for the species to ebb and flow from suitable areas. This connectivity would have made the species more resistant to the effects of local stochastic events. However, under current conditions, restoring any habitat connectivity on a large scale is not feasible. As a consequence of current conditions, the viability of the Sonoyta mud turtle now primarily depends on maintaining the remaining isolated populations and potentially restoring any extirpated population or creating new ones where feasible.

5.2. Scenarios

Resiliency of Sonoyta mud turtle populations depends on future water quantity, available riparian habitat, available invertebrate prey, and absence of certain nonnative aquatic species. Because we have uncertainty regarding how and when surface water loss and associated riparian habitat impairment may occur, as well as if and when various nonnative species may occur, we have forecast what the effects to the Sonoyta mud turtle may be in terms of population resiliency, and species redundancy and representation under three plausible future scenarios over three meaningful time frames: 7 years, 35 years, and 70 years. We chose 7 years based on the area's drought cycle, 35 years because it incorporates both the maximum life span of the species and the mid-century climate projections for the southwestern U.S., and 70 years because it is within the range of the available drought and climate change model forecasts and is about twice the maximum life span of the species (Lenart 2008, entire; Strittholt *et al.* 2012, entire; Garfin *et al.* 2013, entire). We did not include an assessment of juvenile survivorship for the future scenarios. In the future, the age class structure of the population will reflect whether or not reproduction and recruitment are occurring. For these projections, high, moderate, and low population resiliency conditions follow those described in Table 3.3.1 in Chapter 3. Since surface water availability limits the other elements and the carrying capacity of the site, the ranking of the surface water was weighted higher than the other metrics. This means that if surface water was ranked moderate and all other elements were ranked high, the overall ranking would be moderate. The following three general scenarios are included in our analysis:

(1) Best Case – All habitats occupied by Sonoyta mud turtle experience **no measurable drop** in surface water and nonnatives are absent;
(2) Moderate Case – Surface water in habitats occupied by Sonoyta mud turtle is **somewhat reduced but not eliminated,** and nonnatives remain at status quo; and
(3) Worst Case – All surface water at sites occupied by Sonoyta mud turtle is **extremely reduced or eliminated**, and nonnatives are present in all populations.

For each scenario, we used the scale in Table 5.2 below to estimate likelihood of scenario occurrence.

Table 5.2.1. Explanation of confidence terminologies used to estimate the likelihood of scenario occurrence.

Highly likely	**We are more than 90% sure that this scenario will occur.**
Moderately likely	We are **70 to 90% sure** that this scenario will occur.
Somewhat likely	We are **50 to 70% sure** that this scenario will occur.
Unlikely	We are less than **50% sure** that this scenario will occur.

5.3. Scenario 1 – Best Case

Under the best case scenario, the current long-term drought ends in the 7 and 35–year time step but resumes by the 70–year time step due to the cyclical nature of drought in the area. The new Sonoyta wastewater treatment plant in the town of Sonoyta does not come online and the Sonoyta Sewage Lagoon remains in place. Groundwater pumping in Mexico for agriculture and human consumption does not increase from current levels because the human population in the area stabilizes. Because groundwater withdrawal continues at current rate, no groundwater recharge occurs. Nonnative aquatic species do not increase or are removed completely. Finally, the Quitobaquito Rio Sonoyta Work Group continues to implement conservation measures that improve habitat quality throughout the range of the subspecies. We also assume that climate change impacts will be minimal in the 7– and 35–year time steps, but would increase at the 70–year time step. These scenarios are applied to the projected future time periods of 7, 35, and 70 years and depicted in the Tables below. In our description of resiliency below, we are describing the change over time from the current to the 70–year time step.

5.3.1. Resiliency

Table 5.3.1. Summary of Sonoyta mud turtle population resiliency under current condition, and scenario 1 – best case at 7, 35 and 70 years.

Best Case Scenario Time Step	**Population Factor**	**Habitat Elements**				**Overall Condition**
	Juvenile Survivorship	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators**	

QUITOBAQUITO SPRINGS						
Current Condition	High	Moderate	High	Low	Moderate	Moderate
7 years	Moderate	Moderate	High	High	High	Moderate
35 years	High	Moderate	High	High	High	Moderate
70 years	High	Moderate	High	High	Moderate	Moderate
PAPALOTE REACH						
Current Condition	Low	Moderate	High	Moderate	Moderate	Moderate
7 years	Moderate	Moderate	High	Moderate	High	Moderate
35 years	Moderate	Moderate	High	Moderate	High	Moderate
70 years	Low	Moderate	Moderate	Moderate	High	Moderate
SONOYTA SEWAGE LAGOON						
Current Condition	Moderate	Moderate	Moderate	Low	High	Moderate
7 years	Moderate	Moderate	Moderate	Low	High	Moderate
35 years	Moderate	Moderate	Moderate	Low	High	Moderate
70 years	Moderate	Moderate	Moderate	Low	High	Moderate
XOCHIMILCO REACH						
Current Condition	Low	Low	Moderate	Low	Moderate	Low
7 years	Low	Low	Moderate	Low	Moderate	Low
35 years	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
70 years	Low	Low	Moderate	Low	Moderate	Low
QUITOVAC						
Current Condition	Low	Moderate	Low	Moderate	Moderate	Low
7 years	Low	Moderate	Low	High	High	Low
35 years	Moderate	Moderate	Moderate	High	High	Moderate
70 years	Moderate	Moderate	Moderate	High	High	Moderate
SANTO DOMINGO						
Current Condition	Ø	Ø	Low	Low	High	Ø

Quitobaquito Springs – Under this scenario, the Quitobaquito Springs population would experience little to no surface water loss in the pond, as surface water would be maintained by spring flow through each of the three time frames because groundwater pumping stabilizes and the long-term drought ends. Spring flow would continue to drop, but at a much lower rate than the current annual 1.2 percent reduction. Loss of water due to climate change (i.e. drought or evapotranspiration) would be minimal at the 7–year and 35–year time steps as the long-term drought would end and drought would not be an issue until later at the 70–year time step. In the meantime, management actions would be implemented to completely halt and prevent pond leakage and to continue to minimize evapotranspiration from emergent plants in the pond (through vegetation control). As a result of minimizing water loss from the pond, there would be minimal loss of riparian habitat. Although abundance of invertebrates is fairly low at this site, management actions would also increase invertebrate prey populations so that they provide a significant portion of the turtle population's diet, and no nonnative aquatic species would be introduced to the system. By the 70–year time step, another long-term drought would occur so that the surface water in the pond would be reduced back to its current state or decrease even

more. When drought becomes an issue again, the NPS would implement additional management actions to maintain surface water levels in the pond. We would expect juvenile survivorship to increase somewhat in the best case scenario due to higher invertebrate prey availability and consistent water levels in the pond at the 7 and 35–year time steps. The refuge population of Sonoyta mud turtles from Quitobaquito Springs would continue to be maintained at the Arizona-Sonora Desert Museum, and might be used to establish at least one new population in the U.S. However, our confidence level rating for this scenario occurring is "unlikely" because climate change will increase the likelihood of drought occurring in the future at the 70–year time step so we expect spring-flow to decrease gradually so that it eventually cannot maintain consistent water depth in the pond. Further, although the NPS will implement additional management actions to maintain surface water, at some point it would become untenable.

Rio Sonoyta Papalote Reach – Under this scenario, the Papalote reach population would experience little to no surface water loss by the end of each of the 7– and 35–year time frames because groundwater pumping would not increase and the long term drought would end and implementation of management actions by the Quitobaquito Rio Sonoyta Work Group including water management and fencing out cattle. Loss of water due to climate change (i.e. drought or evapotranspiration) would be minimal at the 7–year and 35–year time steps but drought would be an issue later at the 70–year time step. Management actions would also remove aquatic nonnatives from the river and maintain this reach nonnative free, while maintaining invertebrate prey through all three time steps. By the 70–year time step, another long-term drought would occur, so that the surface water in the reach would be reduced back to its current state or decrease even more. We would expect juvenile survivorship to increase somewhat during the 7 and 35–year time steps of the best case scenario due to an initial increase in surface water and removal of nonnatives from the system, and then decrease by the 70–year time step. However, our confidence rating for this scenario occurring is "unlikely" because groundwater withdrawal is likely to continue, climate change will increase the likelihood of drought continuing into the immediate future or occurring later, and it is unlikely that conservation actions described will be implemented.

Sonoyta Sewage Lagoon – Under the best case scenario, the Sonoyta sewage lagoon population would experience no surface water or riparian habitat loss, as the lagoon would remain in operation and continue to receive sewage from the town of Sonoyta by the end of each of the three time frames. Loss of water due to climate change would not occur since this site does not rely on groundwater and wastewater would continue to flow consistently into the system. Invertebrates would remain available to Sonoyta mud turtles and no nonnatives would be problematic in the system. We would expect juvenile survivorship to be maintained in the best case scenario; however, data is lacking to inform juvenile survivorship. For this SSA Report we assume that the juvenile survivorship is currently moderate since the subspecies has persisted here since its establishment. The Sonoyta sewage lagoon population's condition would be expected to maintain resiliency. Our confidence rating for this scenario occurring is "somewhat unlikely" because the new Sonoyta wastewater treatment is currently delayed and it is unknown when it will become operational and therefore, the current Sonoyta sewage lagoon may continue to exist.

Rio Sonoyta Xochimilco Reach – Under this scenario, the Xochimilco reach population would

experience little to no surface water loss by the 7–year time step that would be maintained through the 35–year time step due to no increase in groundwater pumping combined with consistent flows resulting from the end of the current long-term drought. The reach would also continue to receive the current small amount of water flow below the dam. The reach will continue to receive raw sewage from the nearby residences since a new Sonoyta wastewater treatment plant will not be in operation, but the amount of sewage will remain steady due to no population increase in the town of Sonoyta. Loss of water due to climate change (i.e. drought or evapotranspiration) would be minimal at the 7–year and 35–year time steps, but would occur by the 70–year time step. Invertebrates would remain available to Sonoyta mud turtles and no nonnatives would be problematic in the reach. We would expect juvenile survivorship to increase by the 35-year time step but then decrease back to current condition in the best case scenario due to stabilization of surface water during the first two time steps. Overall, the Xochimilco reach population remains the same at its current low condition, and would continue to have low resiliency through the 70–year time step. Our confidence rating for this scenario occurring is "unlikely" because climate change will increase the likelihood of drought continuing into the immediate future and it is likely that residences will be connected to the wastewater distribution system and no longer contribute surface water to the reach in the form of raw sewage.

Quitovac – Under this scenario, the Quitovac population would experience little to no surface water loss due to lack of mining development in the nearby area and the assumption that any future drought conditions would not affect spring flow to the point that surface water levels in the pond would diminish by the end of each of the three time frames. Management actions would increase riparian habitat surrounding the pond by the 35–year time step and periodic dredging of portions of the system would be preceded by short-term salvage of turtles that would be returned to the system. The invertebrate population would increase due to permanent removal of the nonnative tilapia and mosquitofish from the pond by the 7–year time step. Data is lacking to inform juvenile survivorship, but we assume it is negatively impacted by the periodic dredging of the site. Juvenile survivorship would increase by the 7–year time step because there would be no competition with nonnative aquatic species and dredging would not occur before this time. Partial dredging of the site would occur once every 10 years between the 7–year and 70–year time steps. Management actions would include salvaging turtles before dredging an area, although it is likely that all sized turtles would not be detected and could be killed by the dredging. Because only small areas will be dredged at one time and the period between dredging will be longer, we assume that juvenile survivorship would remain low at the 7–year time step but increase to moderate by the 35 and 70–year time step despite loss of some hatchling and smaller turtles during dredging activities because dredging is reduced and at least some turtles are salvaged. The Quitovac population's overall condition would be expected to increase by the 35–year time step and remain stable at the 70–year time step. Our confidence rating for this scenario occurring is "somewhat unlikely" because climate change will increase the likelihood of drought occurring in the future and it is unlikely that conservation actions described will be implemented.

Summary

The best case scenario provides an impression of the Sonoyta mud turtle's best plausible

condition over the three time frames (Table 5.3.2). This scenario is very optimistic as it depends on the current long-term drought ending, groundwater pumping not increasing, and successful implementation of a myriad of management actions throughout the range of the subspecies. Although habitat conditions would improve by the 7–year point under this scenario, population resiliency would remain in its current condition at this time, with the exception of Xochimilco reach (Table 5.3.3). At the 7–year time step there would be three moderately resilient populations, and two populations with low resilience. At 35 years, we would then expect population resiliency to increase somewhat with two populations to have high resiliency and three to have moderate resiliency (Table 5.3.4). At 70 years, population resiliency would return to current levels at three sites, remain consistent at one site, and increase to moderate at one site (Table 5.3.5). Therefore, overall the population at Quitovac would increase in resiliency due to human intervention, the population at the Sonoyta sewage lagoon would remain the same due to consistent water levels not subject to drought or climate change, and the other three populations would end up with their current resiliency due to return to current surface water levels and associated riparian habitat, and control of nonnatives followed by reoccurrence of drought conditions by the 70–year time step. This scenario is very optimistic and we think it is unlikely to occur due to human population demands for water and projected climate change.

Table 5.3.2. Summary of Sonoyta mud turtle population resiliency under scenario 1 – best case at each time step compared to current condition.

			Best Case Scenario		
Country	**Population Name**	**Current Condition**	**7–year time step**	**35–year time step**	**70–year time step**
U.S.	Quitobaquito Springs	Moderate	Moderate	Moderate	Moderate
Mexico	Papalote Reach (Agua Dulce)	Moderate	Moderate	Moderate	Moderate
	Sonoyta Sewage Lagoon	Moderate	Moderate	Moderate	Moderate
	Xochimilco Reach (Sonoyta Reach)	Low	Low	Low	Low
	Quitovac	Low	Low	Moderate	Moderate
	Santo Domingo	Ø	Ø	Ø	Ø

Table 5.3.3. Sonoyta mud turtle population resiliency under scenario 1 – best case at 7–years.

	Population Factor	**Habitat Elements**				
Population	**Juvenile Survivorship**	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators**	**Overall Condition**
			U.S.			
Quitobaquito Springs	Moderate	Moderate	High	High	High	Moderate
			Mexico			
Papalote Reach	Moderate	Moderate	High	Moderate	High	Moderate
Sonoyta Sewage Lagoon	Moderate	Moderate	Moderate	Low	High	Moderate
Xochimilco Reach	Low	Low	Moderate	Low	High	Low
Quitovac	Low	Moderate	Low	High	High	Low

Table 5.3.4. Sonoyta mud turtle population resiliency under scenario 1 – best case at 35 years.

	Population Factor	Habitat Elements				
Population	**Juvenile Survivorship**	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators s**	**Overall Condition**
			U.S.			
Quitobaquito Springs	High	**Moderate**	High	High	High	**Moderate**
			Mexico			
Papalote Reach	**Moderate**	**Moderate**	High	**Moderate**	High	**Moderate**
Sonoyta Sewage Lagoon	**Moderate**	**Moderate**	**Moderate**	**Low**	**High**	**Moderate**
Xochimilco Reach	**Moderate**	**Low**	**Moderate**	**Moderate**	**High**	**Low**
Quitovac	**Moderate**	**Moderate**	**Moderate**	**High**	**High**	**Moderate**

Table 5.3.5. Sonoyta mud turtle population resiliency under scenario 1 – best case at 70 years.

	Population Factor	Habitat Elements				
Population	**Juvenile Survivorship**	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators**	**Overall Condition**
			U.S.			
Quitobaquito Springs	**High**	**Moderate**	**High**	**High**	**Moderate**	**Moderate**
			Mexico			
Papalote Reach	**Low**	**Moderate**	**Moderate**	**Moderate**	**High**	**Moderate**
Sonoyta Sewage Lagoon	**Moderate**	**Moderate**	**Moderate**	**Low**	**High**	**Moderate**
Xochimilco Reach	**Low**	**Low**	**Moderate**	**Low**	**High**	**Low**
Quitovac	**Moderate**	**Moderate**	**Moderate**	**High**	**High**	**Moderate**

5.3.2. Representation

As stated in Chapter 3, we consider the Sonoyta mud turtle to currently have representation in the form of genetic diversity at Quitobaquito Springs, Quitovac, and Papalote and Xochimilco reaches of the Rio Sonoyta. Under this scenario these sites will not be lost by the 70–year time step. Under the best case scenario, it is possible that at least one Sonoyta mud turtle per generation will move between the three sites in or adjacent to the Rio Sonoyta, and maintain genetic representation in these three populations. It is less likely that genetic exchange will occur between Quitobaquito and the Papalote reach of the Rio Sonoyta, and highly unlikely that it will occur between Quitovac and the Rio Sonoyta. The known genetic diversity among the five populations would therefore decrease over the 70–year time step, and the subspecies would lose some of its existing adaptive capacity. Environmental representation is also maintained through the 70–year time step as populations would remain in both lotic and lentic sites and within two drainage basins, the Rio Sonoyta and the Guadalupe.

5.3.3. Redundancy

Resiliency of all but the Quitovac population would remain the same and resiliency of the population at Quitovac would increase. Consequently, under the best case scenario, Sonoyta mud turtle would maintain current redundancy through the 70–year time step as all five extant populations of Sonoyta mud turtle would be maintained.

5.4. Scenario 2 – Moderate Case

In the moderate case scenario, which we assessed as the most likely scenario to occur, we projected the current level of stressors associated with the current conditions continuing. Under the moderate case scenario long-term drought continues or recurs, a new Sonoyta wastewater treatment plan in the town of Sonoyta comes on line, groundwater pumping in Mexico for agriculture and human consumption increases from current levels due to population growth, nonnatives are a problem in some areas, and the Quitobaquito Rio Sonoyta Work Group continues to implement some conservation measures to maintain viability of Sonoyta mud turtle populations at Quitobaquito Springs and the Sonoyta Sewage lagoon. We also assume that climate change impacts will be minimal in the 7–year time step but increase over the 35 and 70–year time steps in terms of more frequent and longer droughts, reduced precipitation, alteration in the timing and frequency of precipitation, and increased evapotranspiration. These scenarios are applied to the projected future time steps at 7, 35, and 70 years and depicted in the Tables below. In our description of resiliency below, we are describing the change over time from the current to the 70–year time step.

5.4.1. Resiliency

Table 5.4.1. Summary of Sonoyta mud turtle population resiliency under current condition, and scenario 2 – moderate case at 7, 35 and 70 years.

Moderate Case Scenario Time Step	**Population Factor**	**Habitat Elements**				**Overall Condition**
	Juvenile Survivorship	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators**	
QUITOBAQUITO SPRINGS						
Current Condition	High	Moderate	High	Low	Moderate	Moderate
7 years	High	Moderate	High	Low	High	Moderate
35 years	High	Moderate	High	Low	High	Moderate
70 years	Moderate	Low	Moderate	Low	High	Low
PAPALOTE REACH						
Current Condition	Low	Moderate	High	Moderate	Moderate	Moderate
7 years	Low	Moderate	High	Moderate	Moderate	Moderate
35 years	Ø	Ø	Moderate	Ø	Ø	Ø
70 years	Ø	Ø	Low	Ø	Ø	Ø
SONOYTA SEWAGE LAGOON						
Current Condition	Moderate	Moderate	Moderate	Low	High	Moderate

7 years	Low	Low	Moderate	Low	High	Low
35 years	Ø	Ø	Low	Ø	Ø	Ø
70 years	Ø	Ø	Ø	Ø	Ø	Ø
NEW SONOYTA WASTEWATER TREATMENT PLANT						
Current Condition	Not established					
7 years	Moderate	Moderate	Low	High	High	Moderate
35 years	High	Moderate	Moderate	Moderate	Moderate	Moderate
70 years	Moderate	Moderate	High	Moderate	Moderate	Moderate
XOCHIMILCO REACH						
Current Condition	Low	Low	Moderate	Low	High	Low
7 years	Low	Low	Moderate	Low	High	Low
35 years	Ø	Ø	Moderate	Ø	Ø	Ø
70 years	Ø	Ø	Low	Ø	Ø	Ø
QUITOVAC						
Current Condition	Low	Moderate	Low	Moderate	Moderate	Low
7 years	Low	Moderate	Low	Moderate	Moderate	Low
35 years	Low	Moderate	Low	Low	Moderate	Low
70 years	Low	Moderate	Low	Low	Moderate	Low
SANTO DOMINGO						
Current Condition	Ø	Ø	Low	Low	High	Ø

Quitobaquito – In the moderate scenario in time steps 35 and 70, the Quitobaquito Springs site would experience moderate surface water loss in the pond resulting from an increase in the current downward trend of spring discharge due to periods of long-term drought exacerbated by climate change. Spring discharge would continue to drop, but would level out eventually. However, we expect that decreased spring discharge would reduce surface water in the pond by the end of the 35–year time frame and even more at the 70–year time frame. Management actions would be implemented by Organ Pipe Cactus National Monument to completely halt and prevent pond leakage by the 7–year time step, continue to control vegetation to minimize evapotranspiration from emergent plants in the pond, and supplement water in the pond as needed. As a result of minimizing water loss from the pond, there would be limited loss of riparian habitat, leaving enough for turtle needs to maintain population stability. Invertebrate prey populations available to Sonoyta mud turtles would remain at current presumed low levels, and no nonnatives would be problematic to the system. The refuge population of Sonoyta mud turtles from Quitobaquito Springs would continue to be maintained at the Arizona-Sonora Desert Museum. We would expect juvenile survivorship to maintain its current level at the 7–year time step, a slight decrease at the 35–year time step, and a moderate or more decrease at the 70–year time step when surface water levels have dropped enough so that little shallow water aquatic habitat important for hatchlings and juveniles remains in the pond. Our confidence in this scenario occurring is “moderately likely” based on the climate change models that predict an increase in the frequency and duration of droughts, an increase in ambient temperatures, reduced precipitation, and an increase in evapotranspiration. Further, we assume that the stress from low lipid levels of the turtles here (likely due to the low invertebrate numbers) will be exacerbated by the reduction in water.

Rio Sonoyta Papalote Reach – Under the moderate scenario, the Papalote reach site would experience moderate to high surface water loss and moderate riparian habitat loss due to continued long-term drought and consistent groundwater pumping. This surface water loss would result in this reach becoming ephemeral with no standing pools by the 35–year time step and possibly even at the 7–year time step. Once the channel becomes ephemeral, invertebrates would become significantly reduced or the community would change over time after the reach becomes ephemeral. All of this would have negative impacts to the subspecies. A number of Sonoyta mud turtles would be salvaged and moved to the new Sonoyta wastewater treatment plant. We would expect juvenile survivorship to remain low and eventually cease when the reach becomes ephemeral. Aquatic nonnatives would not survive in ephemeral water so that this reach would become nonnative free. Overall Sonoyta mud turtle population condition would decrease from moderate and eventually the population would disappear. Our confidence in this scenario occurring is "moderately likely" based on probably increase in anthropogenic use of groundwater combined with climate change models that predict an increase in the frequency and duration of droughts, an increase in ambient temperatures, reduced precipitation, and an increase in evapotranspiration.

Sonoyta Sewage Lagoon – Under the moderate scenario, the Sonoyta sewage lagoon population would experience 100 percent surface water loss by the 35–year time step because the lagoon would be removed from service and would dry once the new waste water treatment plant became functional. Depending on when the new wastewater treatment plant comes online, surface water may or may not remain at the Sonoyta sewage lagoon at the 7–year time step. Once the sewage lagoon is decommissioned water is like to evaporate quickly. Aquatic invertebrates would disappear by the 35–year time step, and possibly by the 7–year time step if the sewage lagoon is decommissioned in the next couple of years. The site would remain free of nonnative aquatic species during all three time steps. Management actions would include moving as many turtles as possible to the new waste water treatment plant to establish a new population site (see description below), but the Sonoyta mud turtle would no longer be extant in the currently existing Sonoyta sewage lagoon by the 35–year time step. Even though a replacement population will be established, we presume it will to be of a smaller size as less overall habitat will be available than in the current Sonoyta sewage lagoon. Our confidence rating for this scenario occurring is "somewhat likely" because it is unclear if and when the new Sonoyta wastewater treatment plant will open resulting in closure of the existing Sonoyta sewage lagoon, and if the Mexican governmental entities will implement conservation measures for the Sonoyta mud turtle as outlined in the Resultivo.

Waste Water Treatment Plant – Under the moderate scenario, a population of Sonoyta mud turtles salvaged from the Sonoyta sewage lagoon would be translocated to a new Sonoyta wastewater treatment plant by the 7–year time step. There are multiple lagoons planned for the new wastewater treatment plant. However, all but one lagoon will be lined, and will provide limited habitat for Sonoyta mud turtle because adjacent riparian vegetation will be extremely limited. The Resolutivo requires the new site to provide an unlined pond for turtles. The pond at the new Sonoyta wastewater treatment plant will have less than 25 percent (a 75 percent reduction) of the surface area of the existing Sonoyta sewage lagoon and therefore will support a smaller population of mud turtles. Surface water will be at maximum capacity in the new habitat and remain at a steady level due to the constant influx of surface water effluent. The volume of

water flowing through the new habitat will increase from that in the existing sewage lagoon, as the new treatment plant will serve an additional 35 percent of the town of Sonoyta's residences. Effluent flowing through the treatment ponds will be discharged into the Rio Sonoyta and provide additional turtle habitat in the channel itself, but the amount of habitat that will develop as a result of the effluent is unknown. Discharge into the stream-bed could raise the water table enough so that previously perennial sections of the river downstream of the plant may flow again, but we think this is unlikely to happen because they are far from the treatment plant site and there are groundwater deficits which will likely worsen. Riparian habitat will essentially be nonexistent at the new habitat created for turtles at the wastewater treatment plant at first, but management actions will include planting native riparian vegetation which will be supported by the consistent flow of surface water effluent. However, the establishment of riparian habitat will not likely be fully developed until the 35–year time step. Invertebrate prey will establish quickly at the new site and remain high at the 7–year time step but decrease by the 35–year time step due to competition with nonnative aquatic species that are introduced to the system. It is possible that nonnative aquatic species would be released to the new site due to its proximity to the town of Sonoyta regardless if fencing is in place or not, and could become established here since the water will be of higher quality than the existing sewage lagoon. We would expect juvenile survivorship to be moderate at the 7–year time step due to lack developed riparian habitat and predation by nonnative aquatic species. We assume juvenile survivorship would increase to high by the 35–year time step, but then decrease back to moderate by the 70–year time step due to competition with and predation by well-established nonnative aquatic species. Our confidence in this scenario occurring is "somewhat likely" because it is unclear if and when the new Sonoyta wastewater treatment plant will open resulting in closure of the existing Sonoyta sewage lagoon, and if the Mexican governmental entities will implement conservation measures for the Sonoyta mud turtle as outlined in the Resultivo.

Rio Sonoyta Xochimilco Reach – Under this scenario, the population in the Rio Sonoyta Xochimilco reach would experience high surface water loss since it would no longer receive raw sewage from nearby residences. It would also experience highly reduced flow from the spring at the dam, continued groundwater pumping, increase in the frequency and duration of drought, increase in evapotranspiration. The site already is essentially ephemeral except for a handful of pools that may remain year-round. Raw sewage would be redirected to the new Sonoyta wastewater treatment plant at least by the 35–year time step, and possibly by the 7–year time step. There would be moderate loss of terrestrial habitat by the70–year time step. Invertebrates would become significantly reduced or the community would change after the perennial pools disappear by the 35–year time step and possibly the 7–year time step. We would expect juvenile survivorship to remain low and eventually cease. Aquatic nonnatives would not survive so that this reach would remain largely nonnative free. Overall population condition would eventually be extirpated. Our confidence in this scenario occurring is "highly likely" because water levels in this reach area already so low, and climate change will increase the likelihood of drought occurring in the future and groundwater pumping will continue.

Quitovac – Under this scenario, the Quitovac population would experience some surface water loss by the 35–year time step due to surface water diversion for small-scale agriculture, and increased evaporation from drought conditions. Periodic dredging of portions of the site will likely continue through all three time steps without salvaging mud turtles. Riparian vegetation

condition will remain low at this site. Invertebrate prey populations will be low at the 35 and 70–year time steps due to continued competition with nonnative aquatic species already present in the system. We would expect juvenile survivorship to remain low through all three time steps due to periodic dredging and competition with nonnative aquatic species. Our confidence in this scenario occurring is "moderately likely" because climate change will increase the likelihood of drought occurring in the future and periodic dredging and minor surface water diversion will continue to exist.

Summary

The moderate case scenario provides a reasonably likely snapshot of the Sonoyta mud turtle's condition over the three time frames (Table 5.4.2). This scenario is the most plausible as it depends on the current long-term drought continuing or recurring, the new Sonoyta wastewater treatment plant coming online, and some problematic nonnatives, continued water loss to due groundwater pumping or water diversions, successful implementation of some management actions throughout the range of the subspecies. Habitat conditions would remain at current levels by the 7–year point except for the Sonoyta sewage lagoon, which may not have any habitat at this time step. Population resiliency would remain in its current condition at the 7–year time step due habitat conditions and juvenile survivorship remaining stable, with the exception of the Sonoyta sewage lagoon (Table 5.4.3). The projected removal of surface water at Sonoyta sewage lagoon and outflow and creation of surface water and outflow at the new Sonoyta wastewater treatment plant would result in a net decrease in condition of habitat. This along with only a portion of turtles successfully salvaged and moved to the new habitat would decrease the resiliency of the "replaced" population. There would be one highly resilient population, two moderately resilient populations, and three populations with low resiliency at the 7–year time step. At 35 years, we assume the resiliency of the new Sonoyta wastewater treatment population would increase somewhat with improving juvenile survivorship as turtles become more established in the new habitat. We also assume the Sonoyta sewage lagoon, Xochimilco reach and Papalote reach populations would disappear due to absence perennial surface water, resulting in a new population created with moderate resiliency, two with low resiliency, and two populations extirpated (Table 5.4.4). At 70 years, we expect problematic nonnatives to be established at the new Sonoyta wastewater treatment site, so that its resiliency would be reduced to moderate. Less surface water at Quitobaquito Springs would result in a decreased population resiliency for this population as well. Overall under the moderate case scenario at the 70–year time step, three populations will remain that contribute to resiliency of the Sonoyta mud turtle (Table 5.4.5).

Table 5.4.2. Summary of Sonoyta mud turtle population resiliency under scenario 2 – moderate case at each time step compared to current condition.

			Moderate Case Scenario		
Country	**Population Name**	**Current Condition**	**7–year time step**	**35–year time step**	**70–year time step**
U.S.	Quitobaquito Springs	**Moderate**	**Moderate**	**Moderate**	**Low**
Mexico	Papalote Reach (Agua Dulce)	**Moderate**	**Moderate**	**Ø**	**Ø**
	Sonoyta Sewage Lagoon	**Moderate**	**Low**	**Ø**	**Ø**

	New Sonoyta wastewater treatment plant	Ø	Moderate	Moderate	Moderate
	Xochimilco Reach (Sonoyta Reach)	Low	Low	Ø	Ø
	Quitovac	Low	Low	Low	Low
	Santo Domingo	Ø	Ø	Ø	Ø

Table 5.4.3. Sonoyta mud turtle population resiliency under scenario 2 – moderate case at 7 years.

	Population Factor	**Habitat Elements**				
Population	**Juvenile Survivorship**	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators**	**Overall Condition**
			U.S.			
Quitobaquito Springs	High	Moderate	High	Low	High	Moderate
			Mexico			
Papalote Reach	Low	Moderate	High	Moderate	Moderate	Moderate
Sonoyta Sewage Lagoon	Low	Low	Moderate	Low	High	Low
WWTP[1]	Moderate	Moderate	Low	High	High	Moderate
Xochimilco Reach	Low	Low	Moderate	Low	High	Low
Quitovac	Low	Moderate	Low	Moderate	Moderate	Low

[1]New Sonoyta wastewater treatment plant

Table 5.4.4. Sonoyta mud turtle population resiliency under scenario 2 – moderate case at 35 years.

	Population Factor	**Habitat Elements**				
Population	**Juvenile Survivorship**	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators**	**Overall Condition**
			U.S.			
Quitobaquito Springs	High	Moderate	High	Low	High	Moderate
			Mexico			
Papalote Reach	Ø	Ø	Moderate	Ø	Ø	Ø
Sonoyta Sewage Lagoon	Ø	Ø	Low	Ø	Ø	Ø
WWTP[1]	High	Moderate	Moderate	Moderate	Moderate	Moderate
Xochimilco Reach	Ø	Ø	Moderate	Ø	Ø	Ø
Quitovac	Low	Moderate	Low	Moderate	Moderate	Low

[1] New Sonoyta wastewater treatment plant

Table 5.4.5. Sonoyta mud turtle population resiliency under scenario 2 – moderate case at 70 years.

	Population Factor	Habitat Elements				
Population	**Juvenile Survivorship**	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators**	**Overall Condition**
			U.S.			
Quitobaquito Springs	**Moderate**	**Low**	**Moderate**	**Low**	**High**	**Low**
			Mexico			
Papalote Reach	**Ø**	**Ø**	**Low**	**Ø**	**Ø**	**Ø**
Sonoyta Sewage Lagoon	**Ø**	**Ø**	**Ø**	**Ø**	**Ø**	**Ø**
WWTP[1]	**Moderate**	**Moderate**	**High**	**Moderate**	**Moderate**	**Moderate**
Xochimilco Reach	**Ø**	**Ø**	**Low**	**Ø**	**Ø**	**Ø**
Quitovac	**Low**	**Moderate**	**Low**	**Low**	**Moderate**	**Low**

[1] New Sonoyta wastewater treatment plant

5.4.2. Representation

Under the moderate case scenario, Sonoyta mud turtle representation will be substantially reduced due to the extirpation of the subspecies in the Xochimilco and Papalote reaches of the Rio Sonoyta. Loss of both populations in the Rio Sonoyta will decrease genetic diversity. Additional representation may be lost due to extirpation of the subspecies at the Sonoyta sewage lagoon; however, we do not know how this population contributes to genetic diversity. Further, the loss of these populations would decrease environmental representation, it is likely that new lotic habitat in the Rio Sonoyta will develop downstream of the new wastewater treatment plant due to increased effluent and turtles are expected to inhabit this area. The three remaining populations will occur in highly managed habitats with two that are spring-fed and one that is maintained by wastewater effluent; however, only one of these populations is in the U.S.

5.4.3. Redundancy

Under the moderate case scenario, we expect to lose three of the five Sonoyta mud turtle populations and create a new population with animals from one of the lost populations, for a net of three remaining populations. The loss of three of the five populations will reduce redundancy across the range.

5.5. Scenario 3 – Worst Case

Under the worst case scenario, groundwater pumping increases, long-term drought worsens and is continuous, a new Sonoyta wastewater treatment plant comes on line in the town of Sonoyta, nonnatives are problematic, and the Quitobaquito Rio Sonoyta Work Group is only able to implement conservation measures for two of five populations of Sonoyta mud turtles. These scenarios are applied to the projected future time periods of 7, 35, and 70 years and depicted in

the Tables below. In our description of resiliency below, we are describing the change over time from the current to the 70–year time step.

5.5.1. Resiliency

Table 5.5.1. Summary of Sonoyta mud turtle population resiliency under current condition, and scenario 3 – worst case at 7, 35, and 70 current condition years.

Worst Case Scenario Time Step	Population Factor	Habitat Elements				Overall Condition
	Juvenile Survivorship	Surface water	Riparian habitat	Prey	Absence of Nonnative predators	
QUITOBAQUITO SPRINGS						
Current Condition	High	Moderate	High	Low	Moderate	Moderate
7 years	High	Moderate	High	Low	Moderate	Moderate
35 years	Moderate	Low	High	Low	Low	Moderate
70 years	Low	Low	Moderate	Low	Low	Low
PAPALOTE REACH						
Current Condition	Low	Moderate	High	Moderate	Moderate	Moderate
7 years	Ø	Ø	High	Ø	Ø	Ø
35 years	Ø	Ø	Moderate	Ø	Ø	Ø
70 years	Ø	Ø	Ø	Ø	Ø	Ø
SONOYTA SEWAGE LAGOON						
Current Condition	Moderate	Moderate	Moderate	Low	High	Moderate
7 years	Ø	Ø	Moderate	Ø	Ø	Ø
35 years	Ø	Ø	Low	Ø	Ø	Ø
70 years	Ø	Ø	Ø	Ø	Ø	Ø
NEW SONOYTA WASTEWATER TREATMENT PLANT						
Current Condition	Not established					
7 years	Ø	Moderate	Ø	High	High	Ø
35 years	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
70 years	Low	Moderate	Moderate	Low	Low	Low
XOCHIMILCO REACH						
Current Condition	Low	Low	Moderate	Low	High	Low
7 years	Low	Low	Moderate	Low	High	Low
35 years	Ø	Ø	Low	Ø	Ø	Ø
70 years	Ø	Ø	Ø	Ø	Ø	Ø
QUITOVAC						
Current Condition	Low	Moderate	Low	Moderate	Moderate	Low
7 years	Low	Moderate	Low	Moderate	Moderate	Low
35 years	Low	Moderate	Low	Moderate	Moderate	Low
70 years	Ø	Low	Ø	Low	Moderate	Ø
SANTO DOMINGO						
Current Condition	Ø	Ø	Low	Low	High	Ø

Quitobaquito Springs – Under this scenario, we assume the Quitobaquito Springs population would experience high surface water loss in the pond resulting from high rate of spring flow loss and a continuation of long-term drought punctuated by a few above normal years of precipitation. By the 7–year time step, the rate of decline in spring discharge would accelerate due to increased groundwater withdrawal in Sonora, Mexico and cause further reduction of spring flow at the site. At the end of the 70–year time step, there would be very little spring flow. We expect that accelerated rate of decline of spring discharge would begin to reduce surface water in the pond by the 35–year time step. NPS staff at Organ Pipe Cactus National Monument would implement management actions to minimize evapotranspiration from emergent plants in the pond, prevent ongoing leakage from the pond, and supplement water to the pond. However by the 70–year time step when spring flow ceased to provide water to the pond, NPS would no longer be able to add enough water to the pond to maintain surface water at a level to support a viable population of Sonoyta mud turtles. As a result of continuous drought conditions and groundwater withdrawal, water loss from the pond, and related spring flow loss, riparian habitat would begin to diminish at the 35–year time step. Invertebrate prey populations available to Sonoyta mud turtles would remain low through all three time steps. By the 35–year time step, NPS would no longer be able to remove problematic nonnatives periodically introduced to the system, so that they would become well established by the 70–year time step. Juvenile survivorship would begin to decrease at the 35–year time step when water levels in the pond began dropping and nonnatives were no longer removed. The refuge population of Sonoyta mud turtles from Quitobaquito Springs would fail at the Arizona-Sonora Desert Museum by the 70–year time step. Even if the refuge population persists, there would not be suitable habitat to release them into. Overall population condition would decrease from moderate to low over the three time frames. Our confidence in this scenario occurring is “unlikely” because we assume that NPS will be able to prevent continuing pond leakage and implement other management actions to maintain some water in the spring runs and pond at Quitobaquito Springs, and that groundwater withdrawal in Sonora will not reach the point that it affects spring discharge at this site.

Rio Sonoyta Papalote Reach – Under the worst case scenario, the Papalote reach population would experience high surface water loss and moderate riparian habitat loss due to continuous long-term drought and increased groundwater pumping. This surface water loss would result in this reach becoming ephemeral with no perennial standing pools by the 7–year time step. Riparian habitat would diminish with only saltcedar and mesquite remaining. Invertebrates would become significantly reduced and change composition after the reach becomes ephemeral. Once the channel became ephemeral, aquatic nonnatives would not survive so that this reach would become nonnative free. No Sonoyta mud turtles would be salvaged and moved to another site, and no other management actions would be implemented that would curtail loss of this population. We would expect juvenile survivorship to remain low and cease when the pools in the reach become ephemeral. Overall population condition would decrease from moderate to low in the next few years and disappear after 7–years. Our confidence in this scenario occurring is “somewhat likely” because we assume Sonoyta mud turtles will indeed be salvaged even though surface water is moderately likely to be lost due to continuation of groundwater pumping, and an increase in the frequency and duration of droughts projected by climate change models.

Sonoyta Sewage Lagoon – Under this scenario, the Sonoyta sewage lagoon population would experience 100 percent surface water loss before the 7–year time step because the lagoon would be removed from service once the new waste water treatment plant became functional. Riparian habitat would eventually disappear, aquatic invertebrates would disappear, and there would be no nonnative aquatic species. The Sonoyta mud turtle would no longer be extant in the existing Sonoyta sewage lagoon and no management actions would be implemented to curtail loss of this population of Sonoyta mud turtles. Our confidence in this scenario occurring is "somewhat unlikely" because we do not know if the Mexican government is committed to opening the new wastewater treatment plant (construction has ceased and it is unknown when it will resume) and closing the sewage lagoon site, although we assume it will occur before the 7–year time step.

Waste Water Treatment Plant – Under the worst case scenario, we assume that all ponds will be lined creating unsuitable habitat for d for the Sonoyta mud turtle at the new wastewater treatment plant. We further assume that no Sonoyta mud turtles were able to be salvaged from any of the four Mexico populations; turtles would be translocated from Quitobaquito Springs to establish a new population at the outflow of the waste water treatment plant by the 35–year time step. Effluent flowing through the facility would be discharged into the Rio Sonoyta channel and provide some turtle habitat immediately downstream of the facility. Discharge into the stream-bed would not raise the water table enough so that new or previously perennial sections of the river flow. Riparian vegetation will initially be minimal downstream of the treatment plant outflow, but will increase over time as it will be supported by consistent subsurface flow of surface water effluent. Invertebrate prey will establish quickly at the new site so that it is high at the 7–year time step. It is highly likely that nonnative aquatic species would be released to the new site due to its proximity to the town of Sonoyta, and they could become well established by the 35–year time step at the outflow since the water will be of higher quality. Competition with nonnative aquatic species would decrease invertebrate populations in the ponds and outflow to moderate by the 35–year time step and then to low at the 70–year time step. We would expect juvenile survivorship to be low at 35 and 70–year time steps due to predation by nonnative aquatic species and decrease invertebrate populations. Population condition would be moderate at the 35–year time step and low by the 70–year time step due to competition and predation, resulting in decrease invertebrate populations and low juvenile recruitment. Our confidence in this scenario occurring is "unlikely" because we assume the Mexican government is committed to implementing conservation measures for the Sonoyta mud turtle at the new wastewater treatment facility and nonnative aquatic species may not be problematic for the mud turtle.

Rio Sonoyta Xochimilco Reach – Under the worst case scenario, the population in the Rio Sonoyta Xochimilco reach would experience high surface water loss since it would no longer receive raw sewage from nearby residences, and pools that now support turtles would dry completely. All raw sewage would be redirected to the new Sonoyta wastewater treatment plant by the 7–year time step. Spring flow from the dam would cease by the 35–year time step due to drought and continued groundwater loss. There would be moderate loss of terrestrial habitat by the 70–year time step. Aquatic problematic nonnative species would not survive, and this reach would remain nonnative free. Invertebrates would become significantly reduced or the community would change to one that survives in ephemeral flows. No Sonoyta mud turtles would be salvaged and moved to another site, and no other management actions would be implemented that would curtail loss of this population. We would expect juvenile survivorship

to remain low at the 7–year time step and cease by the 35–year time step. Overall population condition would deteriorate quickly once the springs dried up and the population would disappear by the 35–year time step, possibly by the 7–year time step. Our confidence in this scenario occurring is "somewhat likely" because surface water is moderately likely to be lost due to removal of sewage effluent input, continuation of groundwater pumping will continue, and an increase in the frequency and duration of droughts will occur as projected by climate change models.

Quitovac – Under this scenario, the Quitovac population would experience high surface water loss due to larger scale agriculture at the site, as well as groundwater reduction for mines and increased evapotranspiration due to continuous drought. Whole-scale dredging of the site will occur several times without salvage of turtles, so that the population will be extirpated by the 70–year time frame. Invertebrate prey populations will continue to be moderate or low through all three time steps due to competition with nonnative aquatic species that now occur or will be introduced periodically, but removed during whole-scale dredging operations. We would expect juvenile survivorship to be low and overall population condition to be low until it is extirpated by the 70–year time step due to high surface water loss, periodic dredging of the entire site, and presence of nonnative tilapia. Our confidence in this scenario occurring is "unlikely" because even though climate change will increase the likelihood of drought occurring in the future, we assume that larger scale agriculture will not occur and that mine diversion will not occur to the extent that it will reduce spring flow at Quitovac.

Summary

The worst case scenario provides an idea of the Sonoyta mud turtle's worst plausible condition over the three time frames (Table 5.5.2). This scenario displays what could occur if all of the projected risks were to occur. Under this scenario, two of the five populations would be lost by the 7–year time step, and no new population would be created at the new Sonoyta wastewater treatment plant. The three remaining populations would maintain their current condition, so that there would be one highly resilient population, one moderately resilient population, and one population with low resilience at the 7–year time step (Table 5.5.3). At 35 years, we would expect another population to be lost, another created, and the resiliency of the Quitovac population to decrease due to loss of surface water but that the Quitobaquito Springs population would maintain a high condition due to delayed loss of surface water (Table 5.5.4). At 70 years, we expect loss of surface water at Quitobaquito Springs to decrease resiliency of this population to low, and nonnatives to be established at the new Sonoyta wastewater treatment site, so that its resiliency would be reduced to low. One more population would be extirpated at this time step so that there would be two populations with low resilience at the 70–year time step under the worst case scenario (Table 5.5.5).

Table 5.5.2. Summary of Sonoyta mud turtle population resiliency under scenario 3 – worst case at each time step compared to current condition.

			Worst Case Scenario		
Country	**Population Name**	**Current Condition**	**7–year time step**	**35–year time step**	**70–year time step**
U.S.	Quitobaquito Springs	**Moderate**	**Moderate**	**Moderate**	**Low**

Mexico	Papalote Reach (Agua Dulce)	Moderate	Ø	Ø	Ø
	Sonoyta Sewage Lagoon	Moderate	Ø	Ø	Ø
	new Sonoyta wastewater treatment plant	Ø	Ø	Moderate	Low
	Xochimilco Reach (Sonoyta Cienega)	Low	Low	Ø	Ø
	Quitovac	Low	Low	Low	Ø
	Santo Domingo	Ø	Ø	Ø	Ø

Table 5.5.3. Sonoyta mud turtle population resiliency under scenario 3 – worst case at 7 years.

	Population Factor	**Habitat Elements**				
Population	**Juvenile Survivorship**	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators**	**Overall Condition**
			U.S.			
Quitobaquito Springs	High	Moderate	High	Low	Moderate	Moderate
			Mexico			
Papalote Reach	Ø	Ø	High	Ø	Ø	Ø
Sonoyta Sewage Lagoon	Ø	Ø	Moderate	Ø	Ø	Ø
WWTP[1]	Ø	Moderate	Ø	High	High	Ø
Xochimilco Reach	Low	Low	Moderate	Low	High	Low
Quitovac	Low	Moderate	Low	Moderate	Moderate	Low

[1] new Sonoyta wastewater treatment plant

Table 5.5.4. Sonoyta mud turtle population resiliency under scenario 3 – worst case at 35 years.

	Population Factor	**Habitat Elements**				
Population	**Juvenile Survivorship**	**Surface water**	**Riparian habitat**	**Prey**	**Absence of Nonnative predators**	**Overall Condition**
			U.S.			
Quitobaquito Springs	Moderate	Low	High	Low	Low	Moderate
			Mexico			
Papalote Reach	Ø	Ø	Moderate	Ø	Ø	Ø
Sonoyta Sewage Lagoon	Ø	Ø	Low	Ø	Ø	Ø
WWTP[1]	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Xochimilco Reach	Ø	Ø	Low	Ø	Ø	Ø
Quitovac	Low	Moderate	Low	Moderate	Moderate	Low

[1] new Sonoyta wastewater treatment plant

Table 5.5.5. Sonoyta mud turtle population resiliency under scenario 3 – worst case at 70 years.

	Population Factor	**Habitat Elements**				

Population	Juvenile Survivorship	Surface water	Riparian habitat	Prey	Absence of Nonnative predators	Overall Condition
			U.S.			
Quitobaquito Springs	Low	Low	Moderate	Low	Low	Low
			Mexico			
Papalote Reach	Ø	Ø	Ø	Ø	Ø	Ø
Sonoyta Sewage Lagoon	Ø	Ø	Ø	Ø	Ø	Ø
WWTP[1]	Low	Moderate	Moderate	Low	Low	Low
Xochimilco Reach	Ø	Ø	Ø	Ø	Ø	Ø
Quitovac	Ø	Low	Ø	Low	Moderate	Ø

[1] new Sonoyta wastewater treatment plant

5.5.2. Representation

Under the worst case scenario at the 70–year time step, Sonoyta mud turtle representation will be almost completely lost due to the extirpation of the subspecies in the Rio Sonoyta Xochimilco and Papalote reaches, and Quitovac. Additional representation may be lost due to extirpation of the subspecies at the Sonoyta sewage lagoon; however, we do not know how this population contributes to genetic diversity. Loss of both populations in the Rio Sonoyta will decrease environmental representation, as there will be one remaining Sonoyta mud turtle population in a stream habitat and one in a spring-fed pond habitat. The two remaining populations will occur in highly managed lentic habitats with one that is maintained by wastewater effluent.

5.5.3. Redundancy

Under the worst case scenario at the 70–year time step, we expect to lose all of the Sonoyta mud turtle populations in Mexico. Redundancy across the range will be significantly reduced.

5.6. Status Assessment Summary

We used the best available information to forecast the likely future of the Sonoyta mud turtle. Our goal was to describe the viability of the subspecies in a manner that addresses the needs of the species in terms of resiliency, redundancy, and representation. We considered the possible future condition of the species through a range of potential scenarios that we think are reflective of what the Sonoyta mud turtle may face in the future up to the next 70 years. In addition, we considered the reduction in the range of the species. Our results describe a range of possible conditions in terms of how many and where Sonoyta mud turtle populations are likely to persist in the future.

The perennial waters in the Rio Sonoyta within the historical range of the Sonoyta mud turtle ranged from 19–27 km (11.8–16.8 mi). The perennial reaches within the Rio Sonoyta have decreased to approximately 1.5–5.5 km (0.9–3.4 mi) within historical range. This is a potential decrease of about 17.5–21.5 (10.8–13.4 mi) (8–21 percent change) of perennial water available to the subspecies. The Santo Domino reach is no longer perennial, and the formerly large

Sonoyta reach has been reduced to the Xochimilco reach. Habitat at Quitobaquito Springs was historically a cienega of unknown size but is now a pond of <0.27 ha (<0.67 ac) and a modified stream channel of ~0.244 km (0.15 mi). Other changes from the historical range and distribution are one new site was established, the Sonoyta sewage lagoon, and one new site was discovered, Quitovac. However, the Sonoyta sewage lagoon will highly likely be replaced by a new wastewater treatment plant resulting in reduced available habitat. Table 5.6.1 below provides a summary of the historical and current range.

Table 5.6.1. Summary of historical and current range of the Sonoyta mud turtle.

Site	Stream km (mi)		Area ha (ac)	
	Historical	**Current**	**Historical**	**Current**
AZ				
Quitobaquito Springs	Unknown	0.244 (0.15)	Unknown	<0.27 (0.67)
Mexico				
Rio Sonoyta	19–27 (11.8–16.8)	1.5–5.5 (0.9–3.4)	Not applicable	Not applicable
Papalote Reach (or the Agua Dulce)	5–6 (3.1–3.7)	1.5 to 3 (0.9–1.9)	Not applicable	Not applicable
Santo Domingo	4–6 (2.5–3.7)	Ø	Not applicable	Not applicable
Xochimilco Reach (in the Sonoyta Reach)	10–15 (6.2–9.3)	0 – 2.5 (0–1.6)	Not applicable	Not applicable
Sonoyta Sewage Lagoon	Not a historical site	Not applicable	Not a historical site	>5 (>12.3)
Quitovac	Not a historical site	Unknown	Not a historical site	>1 (>2.5)

Management actions undertaken by the NPS and Quitobaquito-Rio Sonoyta Working Group have ameliorated the majority of the risks to the single Sonoyta mud turtle population in the U.S. at Organ Pipe Cactus National Monument and these actions are expected to continue. Management actions undertaken by the Quitobaquito Rio Sonoyta Work Group have not addressed most of the risks to the four populations of the Sonoyta mud turtle in Mexico. If populations in Mexico continue to lose resiliency due to decline of available surface water, their persistence will likely depend on any future management actions conducted by the Quitobaquito Rio Sonoyta Work Group. Surface water supported by groundwater is the largest factor affecting future persistence of the Sonoyta mud turtle.

Under scenario 1, we would expect the Sonoyta mud turtle's viability to be characterized by the same level of resiliency, redundancy, and representation that is exhibited under current conditions. We anticipate that all five of the current populations will persist and perhaps four of five would even experience expansion. However, our confidence that this scenario will occur is unlikely (<50 percent) to somewhat likely (50–70 percent). In essence, there is more of a chance

that this scenario will not occur as opposed to that it will occur.

Under scenario 2, it is projected that in 70 years, contributions to the Sonoyta mud turtle's viability will only come from populations in three sites—Quitobaquito Springs in the U.S., and the new Sonoyta wastewater treatment plant and Quitovac in Mexico. Two populations will exhibit moderate, one will exhibit low condition, and three will be extirpated. One of the populations exhibiting moderate condition replaces one of the one of the high condition populations that will be extirpated. It is expected that populations that exist in moderate condition will continue to exhibit adequate levels of resiliency and will persist because habitats will continue to be available. Representation will be lost because one of three sites known to contribute to both genetic and environmental diversity of the subspecies will be extirpated. Redundancy will also be lost as there will be only three remaining populations of the Sonoyta mud turtle. Our confidence that this scenario will occur is moderately likely (70–90 percent), indicating that we conclude that there is a good chance that this scenario it will happen.

Under scenario 3, we would expect the subspecies' viability to be characterized by losses of resiliency, redundancy, and representation. All sites are expected to lose surface water, resulting in extirpation of all current populations in Mexico (a new population would be established at the new wastewater treatment plant). Our confidence that this scenario will occur is dependent on the amount of management that is likely to occur at each site. For the highly managed site of Quitobaquito Springs, this scenario is unlikely. However, for the remaining sites, our confidence is somewhat likely (50–70 percent), meaning that there is a slightly higher chance that this scenario will occur than that it will not occur.

APPENDIX A
LITERATURE CITED

Akins, C.M., and T.R. Jones. 2010. *Kinosternon Sonoriense* (Sonoran Mud Turtle) Predation. Herpetological Review 41:485–486.

Archer, S.R. and K.I. Predick. 2008. Climate change and ecosystems of the southwestern United States. Rangelands 30:23–28.

Bennett, P.S., and M.R. Kunzmann. 1989. A history of the Quitobaquito Resource Management Area, Organ Pipe Cactus National Monument. Cooperative Park Studies Unit, University of Arizona, Technical Report 26. 77pp.

Bolster, B.C. 1990. Five year status report for desert pupfish, *Cyprinodon macularius macularius*. California Department of Fish and Game, Inland Fisheries Division, Endangered Species Project, Rancho Cordova, CA.

Breshears, D. D., N. S. Cobb, P. M. Rich, K. P. Price, C. D. Allen, R. G. Balice, W. H. Romme, J. H. Kastens, M. L. Floyd, J. Belnap, J. J. Anderson, O. B. Myers, and C. W. Meyers. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences, USA (PNAS) 102(42):15144–48.

Brown, B. 1991. Land use trends surrounding Organ Pipe Cactus National Monument. Technical Report 39, Cooperative National Park Resources Studies Unit, School of Renewable Natural Resources, The University of Arizona, Tucson. 65pp.

Brusca, R.C. 2017. A brief geologic history of northwestern Mexico. Version date 23 April 2017. Unpublished Report. 99pp.

Carroll, C., R. J. Fredrickson, , and R.C. Lacy. 2012. Developing metapopulation connectivity criteria from genetic and habitat data to recover the endangered Mexican wolf. Conservation Biology 28:76–86.

Carruth, R.L. 1996. Hydrogeology of the Quitobaquito Springs and La Abra Plain area, Organ Pipe Cactus National Monument, Arizona, and Sonora, Mexico. U.S. Geological Survey Water Resource Investigations Report 95-4295, Tucson. 23pp.

Congdon J.D., Dunham A.E., and R.C. van Loben Sels. 1993. Delayed sexual maturity and demographics of Blanding's turtles (*Emydoidea blandingii*): Implications for conservation and management of long-lived organisms. Conservation Biology 7:826–833.

Congdon J.D., Dunham A.E., and R.C. van Loben Sels. 1994 . Demographics of common snapping turtles (*Chelydraser pentina*): Implications for conservation and management of long-lived organisms. American Zoologist 34:397–408.

Congdon, J. D., and J. W. Gibbons. 1990. The evolution of turtle life histories. Pages 45–54 *in* J. W. Gibbons, ed., Life history and ecology of the slider turtle. Smithsonian Institution Press, Washington, D.C., USA.

Crother, B.I., ed. 2012. Scientific and common names for amphibians and reptiles of North America north of México. Society for the Study of Amphibians and Reptiles, Herpetological Circular No. 39:78.

Drost, C.A., J.E. Lovich, S.V. Madrak, and A.J. Monatesti. 2010. Removal of nonnative slider turtles (*Trachemys scripta*) and effects on native Sonora mud turtles (*Kinosternon sonoriense*) at Montezuma Well, Yavapai County, Arizona. U.S. Geological Survey Open-File Report 2010–1177, 48pp. https://pubs.usgs.gov/of/2010/1177/

Duncan, D. K. 2013. Gila topminnow interactions with western mosquitofish: an update. Pages 283–287 *in* Gottfried, G.J., P.F. Folliott, B.S. Gebow, L G. Eskew, and L.C. Collins, comps., Merging Science and Management in a Rapidly Changing World: Biodiversity and Management of the Madrean Archipelago III and 7th Conference on Research and Resource Management in the Southwestern Deserts; 2012 May 1–5; Tucson, AZ, Proceedings, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, RMRS–P–67, Fort Collins, CO. 593pp.

Duncan, D. K., and T. Tibbitts. 2008. Conservation and management of the Quitobaquito pupfish, *Cyprinodon eremus*, in Sonora and Arizona. Abstract of presentation at the 40th annual meeting of the Desert Fishes Council, Cuatro Cienegas, MX, 12–16 Nov 2008. P. 17.

Emslie, S.D. 1982. Movements and behavior of the Sonora Mud Turtle (*Kinosternon sonoriense* Le Conte) in central Arizona. M.S. Thesis, Northern Arizona University, Flagstaff, Arizona, USA. 54pp.

Environmental Protection Agency (EPA). 2008. Environmental Assessment of Improvements to the wastewater collection and treatment for the city of Sonoyta, Sonora, Mexico. 50pp.

Ernst, C.H. and R.W. Barbour. 1989. Turtles of the World. Smithsonian Institution Press, Washington, D.C./London: [i]-xii, 313pp.

Ernst, C.H. and Lovich, J.E. 2009. Turtles of the United States and Canada. Second edition. Johns Hopkins University Press, Baltimore.

Ewert, M.A. 1991. Cold torpor, diapause, delayed hatching and aestivation in reptiles and birds. Pages 173–191 i*n* D. C. Deeming and M. J. W. Ferguson, eds., Egg Incubation: Its Effects on Embryonic Development in Birds and Reptiles, Cambridge Univ. Press, Cambridge.

Felger, R., P.L. Warren, S. Anderson, and G.P. Nabhan. 1992. Vascular plants of a desert oasis: flora and ethnobotany of Quitobaquito, Organ Pipe Cactus National Monument, Arizona. Proceedings of the San Diego Society of Natural History, #8. 39pp.

Fernandez P.J., and P.C. Rosen. 1996. Effects of the introduced crayfish *Orconectes virilis* on native aquatic herpetofauna in Arizona. IIPAM Project I94054 Crayfish Impacts on Wetland Herpetofauna. Heritage Program. Arizona Game and Fish Department, Phoenix AZ. 51pp.

Fisher de León, A.D. 2007. Monitoring vegetation change in the El Pinacate Y Gran Desierto De Altar Biosphere Reserve, Sonora, Mexico (1994–2005). M.S. Thesis, University of Arizona, Tucson. 131pp.

Fleishman, E, J. Belnap, N. Cobb, C. A. F. Enquist, K. Ford, G. MacDonald, M. Pellant, T. Schoennagel, L. M. Scmit, M. Schwartz, S. van Drunick, A. L. Westerling, A. Keyser, and R. Lucas. 2013. Natural ecosystems. Pages 148–167 *in* Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds., Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment, a report by the Southwest Climate Alliance, Island Press, Washington DC. 506pp.

Garfin, G. 2005. Climate change in the Colorado River Basin. Pages 36-44 *In* Colorado River Basin Climate: Paleo, Present, Future, a Special Publication for Association of California Water Agencies and Colorado River Water Users Association Conferences, November 2005.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. 2013. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press. 506pp.

Gehlbach, F.H. 1981. Mountain islands and desert seas: A natural history of the US Mexican borderlands. Texas A & M University Press, College Station, Texas.

Gershunov, A., B. Rajagopalan, J. Overpeck, K. Guirguis, D. Cayan, M. Hughes, M. Dettinger, C. Castro, R. E. Schwartz, M. Anderson, A. J. Ray, J. Barsugli, T. Cavazos, and M. Alexander. 2013. Pages 126–147 *in* Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds., Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment, a report by the Southwest Climate Alliance, Island Press, Washington, DC. 506pp.

Glenn, E.P., and P.L. Nagler. 2005. Comparative ecophysiology of *Tamarix ramosissima* and native trees in western U.S. riparian zones. Journal of Arid Environments 61:419–446.

Grageda-García and García-Miranda. 2017. Monitoring and telemetry of Sonoyta mud turtle (Kinosternon sonoriense longifemorale) at Agua Dulce RAMSAR site. Reserva de la Biosfera El Pinacate y Gran Desierto de Altar, Sonora Mexico. 9pp.

Hall, D.H., and R.S. Steidl. 2007. Movements, activity, and spacing of Sonoran mud turtles (*Kinosternon sonoriense*) in interrupted mountain streams. Copeia 2007(2):403–412.

Hall, D. H. 2017. Phone interview with David Hall, Senior Wildlife Biologist, University of Arizona, in Tucson, Arizona (May 12, 2017).

Hendrickson, D.A., and A. Varela Romero. 1989. Conservation status of desert pupfish, *Cyprinodon macularius*, in Mexico and Arizona. Copeia 1989:478 483.

Hensley, F.R., T.R. Jones, M.S. Maxwell, L.J. Adams, and N.S. Nedella. 2010. Demography, terrestrial behavior, and growth of Sonora mud turtles (*Kinosternon sonoriense*) in an extreme habitat. Herpetological Monographs 24: 174–193.

Hoerling, M., and J. Eischeid. 2007. Past peak water in the southwest. Southwest Hydrology January/February 2007:18–35.

Hollett, K.J. 1985. Geohydrology and water resources of the Papago Farms Great Plain area, Papago Indian Reservation, Arizona, and the upper Rio Sonoyta area, Sonora, Mexico. U.S. Geological Survey Water-Supply Paper 2258. 44pp.

Holm, P. 2016a. Email from Peter Holm, Ecologist, Organ Pipe Cactus National Monument, Arizona (April 18, 2016).

Holm, P. 2016b. Email from Peter Holm, Ecologist, Organ Pipe Cactus National Monument, Arizona (Nov 21, 2016).

Holm, P. 2016c. Email from Peter Holm, Ecologist, Organ Pipe Cactus National Monument, Arizona (March 29, 2016).

Holm, P. 2016d. Email from Peter Holm, Ecologist, Organ Pipe Cactus National Monument, Arizona (April 20, 2016).

Holm, P. 2017. Email from Peter Holm, Ecologist, Organ Pipe Cactus National Monument, Arizona (May 4, 2017).

Hulse, A.C. 1974. An autecological study of Kinosternon sonoriense LeConte (Chelonia : kinosternidae). Ph.D. Dissertation. Arizona State University, Tempe.

Hulse, A. 1976. Carapacial and plastral flora and fauna of the Sonora mud turtle, *Kinosternon sonoriense* Le Conte (Reptilia, Testudines, Kinosternidae). Journal of Herpetology 10(1):45–48.

Hulse, A.C. 1982. Reproduction and population structure in the turtle, *Kinosternon sonoriense*. Southwest Naturalist 27:447– 456.

Iverson, J.B. 1981. Biosystematics of the *Kinosternon hirtipes* species group (Testudines: Kinosternidae). Tulane Studies in Zoology and Botany 23:1–74.

Iverson, J.B. 1992. A revised checklist with distribution maps of the turtles of the world. Privately Printed, Richmond Indiana. 363pp.

Iverson, J.B. 1999. Reproduction in the Mexican mud turtle *Kinosternon integrum*. Journal of Herpetology 33: 145–149.

Ives, R.L. 1936. Desert floods in the Sonoyta Valley. Amer. J. Sci (Ser. 5) 32:349-360.

Izaguirre Pompa, I. 2011. Conservation and management of the Rio Sonoyta pupfish (*Cyprinodon eremus*) in Sonora. Abstract of presentation at the 43rd annual meeting of the Desert Fishes Council, Hermosillo, MX, 9–12 Nov 2011. P. 7.

King, K.A., C.T. Martinez, and P.C. Rosen. 1996. Contaminants in Sonoran mud turtles from Quitobaquito Springs, Organ Pipe Cactus National Monument, Arizona. U.S. Fish and Wildlife Service, Phoenix, Arizona. 12pp.

Kohn, R. 2016. Email from Roger Kohn, U.S. Environmental Protection Agency, San Francisco, California (May 6, 2016). (Relaying year Sonoita sewage lagoons were built)

Kohn, R. 2017. Phone interview with Roger Kohn, U.S. Environmental Protection Agency, San Francisco, California (May 3, 2017). (Status of Sonoita WWTP)

Knowles, G.W., R.P. Aguilar, D.H. Hall, J.C. Rorabaugh and P.C. Rosen. 2002. Status, distribution, and recommendations concerning the Sonoyta mud turtle in Sonora and Arizona. Pages 72–73 *in* Halvorson, W.L. and B.S. Gebow, eds., Meeting Resource Management Information Needs: Fourth Conference on Research and Resource Management in the Southwestern Deserts, Extended Abstracts. USGS Sonoran Desert Field Station, University of Arizona, Tucson.

Kundzewicz, Z.W., L.J. Mata, N W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen, and I.A. Shiklomanov. 2007. Freshwater resources and their management. Pages173–210 *in* Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, eds., Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.

LeConte J. 1854. Description of four new species of *Kinosternum*. Proceedings of the Academy of natural Sciences of Philadelphia. 7:180–90.

Lenart, M. 2007. Regional climate modeling. Climate Assessment for the Southwest. University of Arizona, Institute for the Study of Planet Earth, Tucson, AZ. From, *http://www.southwestclimatechange.org/contributors/melanie–lenart.*

Ligon, D.B. and C.C. Peterson. 2002. Physiological and behavior variation in estivation among mud turtles (*Kinosternon* spp.). Physiological and Biochemical Zoology 75(3):283–293.

Ligon, D. B., and P. A. Stone. 2003a. *Kinosternon sonoriense* (Sonoran mud turtle). Predator-prey. Herpetological Review 34:241–242.

Ligon, D.B. and P.A. Stone. 2003b. Radiotelemetry reveals terrestrial estivation in Sonoran mud turtles. Journal of Herpetology 37:750-754.

Lovich, J.E., and K.R. Beaman. 2008. Distribution of native turtles in the arid southwestern United States with comments on *Kinosternon sonoriense*: a species presumed to be lost from California's herpetofauna. Pages 127–134 *in* Reynolds, R.E., ed., The 2008 Desert Symposium and Field Guide and Proceedings. California State University, Desert Studies Consortium and LSA Associates, Inc.

Lovich, J., C. Drost, A.J. Monatesti, D. Casper, D.A. Wood, and M. Girard. 2010. Reptilian prey of the Sonora Mud Turtle (*Kinosternon sonoriense*) with comments on saurophagy and ophiophagy in North American turtles. The Southwestern Naturalist 55:135-138.

McMahon, T.E., and R.R. Miller. 1985. Status of the fishes of the Rio Sonoyta basin, Arizona and Sonora, Mexico. Pages 237–245 *in* Proceedings of the Desert Fishes Council, Bishop, California, USA.

Mearns, E.A. 1907. Mammals of the Mexican Boundary of the United States. U.S. National Museum Bulletin No. 56.

Miller, R.R., and L.A. Fuiman. 1987. Description and conservation status of *Cyprinodon macularius eremus*, a new subspecies of pupfish from Organ Pipe Cactus National Monument, Arizona. Copeia 1987(3):593–609.

Mills, L.S. and F.W. Allendorf. 1996. The one-migrant-per-generation rule in conservation and management. Conservation Biology 10(6): 1509-1518.

Minckley, W.L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix, 293pp.

Minckley, C. 2017. Email from Chuck Minckley, Ecologist, Benson, Arizona (March 21, 2017).

Minckley, C., I. Izaguirre Pompa, D. Duncan, R. Timmons, D. Caldwell, J. Lopez Mendez, and P. Rosen. 2013. Native aquatic vertebrates-conservation and management in the Rio Sonoyta Basin, Sonora, Mexico. Pages 288–291 *in* Gottfried, G.J., P.F. Ffolliott, B.S. Gebow, L.G. Eskew, and L.C. Collins, comps., Merging Science & Manage. in a Rapidly Changing World: Biodiversity & Manage. of the Madrean Archipelago III and 7th Conf. on Research and Resource Manage. in the Southwestern Deserts; 2012 May 1–5; Tucson, AZ, Proc., USDA, Forest Service, Rocky Mountain Research Station, RMRS–P–67, Fort Collins, CO. 593pp. *http://www.fs.fed.us/rm/pubs/rmrs_p067/rmrs_p067_288_291.pdf*

Murguia-Ruiz, M.D.L. 2000. El agua en la Reserva de la Biosfera el Pinacate y Gran Desierto de Altar, Sonora, Mexico: comunidades, vida silvestre y la frontera con Estados Enidos. Natural Resources Journal 40:411–434.

Nabhan, G.P. 2008. Plant diversity influenced by indigenous management of freshwater springs: Flora of Quitovac, Sonora, Mexico. Pages 215–233 *in* Stevens, L.E., and V.J. Meretsky, eds., Aridland Springs in North America: Ecology and Conservation. University of Arizona Press, Tucson.

Nabhan, G.P., A.M. Rea, K.L. Reichhardt, E. Mellink, and C.F. Hutchinson. 1982. Papago influences on habitat and biotic diversity: Quitovac oasis ethnoecology. Ethnobiology 2(2):124-143

Nash, L.L., and P.H. Gleick. 1993. The Colorado River Basin and climatic change. EPA 230–R–93–009, U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, Climate Change Division. Oakland, California.

Nathan, L.R., Y. Kanno, and J.C. Vokoun. 2017. Population demographics influence genetic responses to fragmentation: A demogenetic assessment of the 'one migrant per generation' rule of thumb. Biological Conservation 210:261-272.

National Park Service (NPS). 2006. Ecological Monitoring Program Report 1995–2005. Organ Pipe Cactus National Monument, Ajo, Arizona.

National Park Service (NPS). 2007. 2006 monitoring results for the Sonoyta mud turtle at Quitobaquito Organ Pipe Cactus National Monument, Arizona. Organ Pipe Cactus National Monument. Ajo, Arizona. 8pp.

National Park Service (NPS). 2008a. Emergency Actions to Stabilize Quitobaquito Pond, and Related Activities Final Project Report and Revised Biological Assessment ESA Emergency Consultation #22410–2008–FE–0273. 33pp.

National Park Service (NPS). 2008b. Sonoyta Mud Turtle Monitoring Annual Report for 2007: Quitobaquito Pond and Springs. Organ Pipe Cactus National Monument, Ajo, Arizona. 13pp.

National Park Service (NPS). 2009a. Biological Assessment for emergency actions to stabilize Quitobaquito Pond Part II: Renovating the southeast corner. Organ Pipe Cactus National Monument, Ajo, Arizona. 48pp.

National Park Service (NPS). 2009b. Quitobaquito Pond status and recommendations. Organ Pipe Cactus National Monument, Ajo, Arizona. 6pp.

National Park Service (NPS). 2011a. Organ Pipe Cactus National Monument: Superintendent's 2010 Report on Natural Resource Vital Signs. National Park Service, Ajo, Arizona.

National Park Service (NPS). 2011b. Resource Brief–2011 Status of the Sonoyta Mud Turtle. Organ Pipe Cactus National Monument, Ajo, Arizona. 2pp.

National Park Service (NPS). 2012a. Resource Brief–2012 Status of the Sonoyta Mud Turtle. Organ Pipe Cactus National Monument, Ajo, Arizona. 2pp.

National Park Service (NPS). 2012b. Short-term management summary for Quitobaquito Pond Summer 2012. Organ Pipe Cactus National Monument, Ajo, Arizona. 3pp.

National Park Service (NPS). 2013. Resource Brief–2013 Status of the Sonoyta Mud Turtle. Organ Pipe Cactus National Monument, Ajo, Arizona. 2pp.

National Park Service (NPS). 2014a. Resource Brief–2014 Status of the Sonoyta Mud Turtle. Organ Pipe Cactus National Monument, Ajo, Arizona. 2pp.

National Park Service (NPS). 2014b. Resource Brief–Recent climate change exposure of Organ Pipe Cactus National Monumnet, Ajo, airzona, 2pp.

National Park Service (NPS). 2015. Resource Brief–2015 Status of the Sonoyta Mud Turtle. Organ Pipe Cactus National Monument, Ajo, Arizona. 2pp.

National Park Service (NPS). 2016. Resource Brief–2016 Status of the Sonoyta Mud Turtle. Organ Pipe Cactus National Monument, Ajo, Arizona. 2pp.

Overpeck, J., G. Garfin, A. Jardine, D. Busch, D. Cayan, M. Dettinger, E. Fleishman, A. Gershunov, G. MacDonald, K. Redmond, W. Travis, and B. Udall. 2013. Chapter 1: summary for decision makers. In Garfin, G., A. Jardine, R. Merideth, M. Black, and J. Overpeck, eds., Assessment of Climate Change in the Southwest United States: a Technical Report Prepared for the U.S. National Climate Assessment. A report by the Southwest Climate Alliance, Southwest Climate Summit Draft, Tucson, AZ.

Owens, A. 2007. *Kinosternon Sonoriense longifemorale* (Sonoyta mud turtle): nest location and evidence of embryonic diapause. Draft Note. Arizona Game and Fish Department, Phoenix, Arizona. 3pp.

Paredes Aguilar, R., and P.C. Rosen. 2003. Status of the Sonoyta Mud Turtle (*Kinosternon sonoriense longifemorale*) in Río Sonoyta, Mexico. Review Draft Final Report to Arizona Game and Fish Department and U.S. Fish & Wildlife Service, January 2003.

Pearson, G. and C.W. Conner. 2000. The Quitobaquito desert pupfish, an endangered species within Organ Pipe Cactus National Monument: historical significance and management challenges. Natural Resources Journal 40:379–410.

Peterson, C.C., and P.A. Stone. 2000. Physiological capacity for estivation of the Sonoran mud turtle, *Kinsternon sonoriense*. Copeia 3:684-700.

Pincetl, S., G. Franco, N. B. Grimm, T. S. Hogue, S. Hughes, E. Pardyjak, A. M. Kinoshita, and P. Jantz. 2013. "Urban Areas." In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 267–296. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Poulin, S. 2017. Email from Stephane Poulin, Arizona-Sonora Desert Museum, Tucson, Arizona (August 9, 2017).

Quitobaquito Rio Sonoyta Work Group. 2015. Meeting Minutes of the Quitobaquito Rio Sonoyta Work Group annual meeting, Arizona-Sonora Desert Museum, Tucson, Arizona. 4pp.

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

Riedle, J.D., and R.T. Kazmaier. 2009. Population viability analysis of Sonoyta mud turtles at Quitobaquito Springs, Arizona, USA. A Final Report to Organ Pipe Cactus National Monument and Western National Parks Association, Department of Life, Earth, and Environmental Sciences, West Texas A&M University, Canyon, Texas. 10pp.

Riedle, J.D., P.C. Rosen, R.T. Kazmaier, P. Holm, and C.A. Jones. 2012. Conservation status of an endemic kinosternid, *Kinosternon sonoriense longifemorale*, in Arizona. Chelonian Conservation and Biology 11:182–189.

Rorabaugh, J. C. 2016. Information provided in peer review by Jim Rorabaugh, Biologist, U.S. Fish and Wildlife Service (retired), Arizona.

Rosen, P.C. 1986. Population decline of Sonoran Mud Turtles at Quitobaquito Springs. Report to U.S. National Park Service, Cooperative National Park Resources Studies Unit, University of Arizona, Tucson, Arizona.

Rosen, P.C. 1987. Female Reproductive variation among populations of Sonoran Mud Turtles (*Kinosternon sonoriense*). Masters Thesis, Arizona State University, Tempe, Arizona. 100pp.

Rosen, P.C. 2003. Taxonomic status of the Sonoyta mud turtle (*Kinosternon sonoriense longifemorale* Iverson) based on mitochondrial Dloop sequence, with a discussion of phylogeography. Unpublished report, School of Natural Resources, University of Arizona, Tucson. 33pp.

Rosen, P.C. 2016a. Email from Phil Rosen, Research Scientist, University of Arizona, Tucson, Arizona (December 6, 2016).

Rosen, P.C. 2016b. Email from Phil Rosen, Research Scientist, University of Arizona, Tucson, Arizona (July 29, 2016).

Rosen, P.C. 2016c. Email from Phil Rosen, Research Scientist, University of Arizona, Tucson, Arizona (August 12, 2016).

Rosen, P.C., and C.H. Lowe, Jr. 1996. Population ecology of the Sonoran Mud Turtle (*Kinosternon sonoriense*) at Quitobaquito Springs, Organ Pipe Cactus National Monument, Arizona. Final Report to Arizona Game & Fish Dept. Heritage Program, Phoenix. 52pp + appendices.

Rosen, P.C., and C.R. Schwalbe. 2002. Widespread effects of introduced species on reptiles and amphibians in the Sonoran Desert region. Pp. 220–240 *in* B. Tellman, Ed. Invasive exotic species the Sonoran Desert region. The University of Arizona Press and The Arizona-Sonora Desert Museum, Tucson, Arizona.

Rosen, P.C., H.W. Hermann, and C. Melendez. 2006. Phylogeography of the Southwestern mud turtle (*Kinosternon sonoriense* Leconte). Final report to Arizona Game and Fish Department and CONABIO (Mexico). 20pp.

Rosen, P.C., C. Melendez, J.D. Riedle, A.C. Pate, and E. Fernandez. 2010. Ecology and conservation in the Sonoyta Valley, Arizona and Sonora. Pages 143–160 *in* Halvorson, W., C. Schwalbe, and C. van Riper, ds. Southwestern Desert Resources, University of Arizona Press, Tucson, Arizona. 360pp.

Schoenherr, A.A. 1988. A review of the life history and status of the desert pupfish, *Cyprinodon macularius*. Bull. So. Calif. Acad. Sci. 87:104–134.

Schwendiman, A.L. 2001. *Kinosternon Sonoriense* (Sonoran Mud Turtle) Attempted predation. Herpetological Review 32:39.

Seager, R., T. Mingfang, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. Huang, N. Harnik, A. Leetmaa, N. Lau, C. Li, J. Velez, and N. Naik. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316:1181-1184.

Secretariat of the Environment and Natural Resources (SEMARNAT). 2008. Resolutivo de Ampliacion del Sistema de Alcantarillado a zonas sin servicio y la Construcción de una Planta de Tratamiento de Aguas Residuales en Sonoyta, Sonora. Hermosillo, Sonora. 16pp.

Servicios de Ingeniería e Informática. 2008. Manifestación de Impacto Ambiental “MIA” del Proyecto de Ampliación del Sistema de Alcantarillado a zonas sin Servicio y la Construcción de una Planta de Tratamiento de Aguas Residuales en Sonoyta, Sonora. 107pp.

Smith, P.W., and M.M. Hensley. 1957. The mud turtle *Kinosternon flavescens stejnegeri* Hartweg, in the United States. Proceedings of the Biological Society of Washington 70:201-204

Smith, K., and M.E. Lavis. 1975. Environmental influences on the temperature of a small upland stream. Oikos 26:228–236.

Spinks, P.Q., R.C. Thomson, M. Gidis, and H.B. Shaffer. 2014. Multilocus phylogency of the New-World mud turtles (Kinosternidae) supports the traditional classification of the group. Molecular Phylogenetics and Evolution 76:254–260.

Stanila, B.D. 2009. Morphology and demography of Sonoran Mud Turtles (*Kinosternon sonoriense*) along an aquatic habitat permanence gradient. M.S. Thesis, University of Central Oklahoma, Edmond, Oklahoma, USA. 68pp.

Stanila, B.D., K.J. Locey, and P.A. Stone. 2008. *Kinosternon sonoriense*: Diet. Herpetological Review 39:345.

State of New Mexico: New Mexico Office of the State Engineer. 2005. Potential effects of climate change on New Mexico. Agency Technical Workgroup, Santa Fe, New Mexico. http://www .nmenv.state.nm.us/aqb/cc/Potential_ Effects_ Climate_ Change_ NM.pdf. Accessed October 30, 2011.

Stone, P.A. 2001. Movements and demography of the Sonoran mud turtle, *Kinosternon sonoriense.* The Southwestern Naturalist 46(1):41-53.

Stone, P.A., M.E. Babb, B.D. Stanila, G.W. Kersey, and Z.S. Stone. 2005. *Kinosternon sonoriense* (Sonoran mud turtle). Diet. Herpetological Review 36:167–168.

Stone, P.A., K.J. Locey, S. Laverty, B.D. Stanila, and M.E.B. Stone. 2015. Implications of male-biased movements in Sonoran mud turtles (*Kinosternon sonoriense*) inhabiting intermittent aquatic habitats. Herpetological Conservation and Biology 10(2):728–739

Strittholt, J.R., S.A. Bryce, B.C. Ward, and D.M. Bachelet. 2012. Sonoran Desert Rapid Ecoregional Assessment Report. Prepared for the U.S. Department of the Interior, Bureau of Land Management, Denver, Colorado. Available online at: *http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html*

Taylor, J. N., W.R. Courtenay Jr, and J. A. McCann. 1984. Known impacts of exotic fishes in the continental United States. Pages 322–373 *in* Courtenay, W.R. and J.R. Stauffer. Distribution, biology, and management of exotic fishes. Johns Hopkins University Press, Baltimore, Maryland. 430pp.

Trenberth, K.E., A. Dai, R.M. Rasmussen, D.B. Parsons, 2003: The changing character of precipitation. Bull. American Meteorological Society 84:1205–1217.

Turner, B.J. 1983. Genetic variation and differentiation of remnant natural populations of the desert pupfish, *Cyprinodon macularius*. Evolution 37:690–700.

U.S. Fish and Wildlife Service (USFWS). 2007. Technical Assistance letter for Proposed Expansion of the Wastewater Collection System to Unserved Areas of the City and the Construction of a New Wastewater Treatment Facility in Sonoyta, Sonora, Mexico [AESO/SE 22410-2008-TA-0092]. Arizona Ecological Services Office, Phoenix, Arizona, 5pp.

U.S. Fish and Wildlife Service (USFWS). 2015. Endangered and Threatened Wildlife and Plants; Review of Native Species That Are Candidates for Listing as Endangered or Threatened; Annual Notice of Findings on Resubmitted Petitions; Annual Description of Progress on Listing Actions; Notice (80 FR 80584).U.S. Fish and Wildlife Service (USFWS). 2017. Summary notes from Species of Common Concern Meeting at Organ Pipe Cactus National Monument, Arizona, prepared by Doug Duncan, Fish Biologist, Arizona Ecological Services Office, Tucson, Arizona. 1p.

Valdez-Zamudio, D. 1994. Land cover and land use change detection in northwestern Sonora, Mexico using geographic information system and remote sensing techniques. M.S. Thesis, University of Arizona, Tucson. 83pp.

van Loben Sels, R.C., J.D. Congdon, and J.T. Austin. 1997. Life history and ecology of the Sonoran Mud Turtle (*Kinosternon sonoriense*) in southeastern Arizona: a preliminary report. Chelonian Conservation and Biology 2:338–344.

Wang, J. 2004. Application of the one-migrant-per-generation rule to conservation and management. Conservation Biology 18(2):332-343.

Weiss, J.L., and J.T. Overpeck. 2005. Is the Sonoran Desert losing its cool? Global Change Biology 11:2065–2077.

Wilbur, H.M., and P.J. Morin. 1988. Life history evolution in turtles. Pages 387–439 *in* Gans, C. and R.B. Huey, eds., Biology of the Reptilia. Vol. 16. Ecology B. Defense and Life History. Alan R. Liss, New York. 659pp.

Wikinson, L.R., and J.W. Gibbons. 2005. Patterns of reproductive allocation: cluth and egg size variation in three freshwater turtles. Copeia 4:868–879.

Wolf, S., B. Hartl, C. Carroll, M.C. Neel, and D.N. Greenwald. 2015. Beyond PVA: why recovery under the Endangered Species Act is more than population viability. BioScience Online Early. doi:10.1093/biosci/biu218.

APPENDIX B

Evaluating Causes and Effects for SONOYTA MUD TURTLE Species Status Assessment

Template for Cause and Effects Evaluation

THEME: ?			
[ESA Factor(s): A-F]	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	
– Activity(ies)	*What is actually happening on the ground as a result of the action?*		
STRESSOR(S)	*What are the changes in environmental 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 is 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 EEFFECTS			
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 affects 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?*		

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

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: Loss of water			
[ESA Factor(s): A, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Groundwater extraction, drought, changes to wastewater infrastructure, consumption by livestock, surface water diversion, and habitat manipulation have resulted in reduced surface water and drying of habitat. Climate change is expected to exacerbate current conditions.	High confidence	Archer and Predick 2008, p. 24 Bennett and Kunzmann 1989, p. 34 Brown 1991 p. 3 EPA 2008, pp. 1–2 Fisher de Leon 2006, pp. 63, 76 Garfin *et al*. 2013, entire Lenart 2008, entire Nabhan 2008, p. 252 Nabhan *et al*. 1982, p. 126 Overpeck and Weiss 2005, p. 2074 Paredes-guilar and Rosen 2003, pp. 8, 9 Pearson and Connor 2000, p. 388 SEMARNAT 2008, entire Strittholt *et al*. 2012, entire
– Activity(ies)	Unknown causes have reduced spring flow at Quitobaquito Springs.	High confidence that it is happening, low confidence for reason for spring flow loss	NPS 2007, p. 1 P. Holm, NPS, pers. comm. March 2016
	Irrigation and public-supply requirements in the Rio Sonoyta drainage are almost wholly dependent on groundwater. Irrigated agriculture is widespread in the Rio Sonoyta Valley, and continued development in the towns of Sonoyta is placing increased demands on limited water supplies and Lukeville may in the future.	High confidence	Brown 1991, pp. 48–49 Fisher de Leon 2006, p. 81 Hollett 1985, p.2 Pearson and Connor 2000, pp. 382, 387
	Groundwater is withdrawn for agriculture at Cerro Colorado Well Numero Dos (<1 mile upstream of the Papalote Reach), Santo Domingo Well, Cerro Colorado Well, and others along the Rio Sonoyta.	High confidence	Carruth 1996 pp. 8, 11 Murguia-Ruiz 2000, p. 414 Pearson and Connor 2000, p. 387 Valdez-Zamudio 1994, p. 72
	Livestock watering and grazing occurs in the Rio Sonoyta in the Papalote and Xochimilco reaches.	High confidence	Fisher de Leon 2006, p. 79 Murguia-Ruiz 2000, p. 422 Rosen 2003, p. 11
	Wastewater effluent from a military base was redirected in 2007 and will be redirected from residences in the near future so that it is no longer released directly into the Rio Sonoyta in the	High confidence	EPA 2008, pp. 3–10 USFWS 2007, p. 3 SEMARNAT 2008, entire

THEME: Loss of water			
[ESA Factor(s): A, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
	Xochimilco reach. This year round source of water, although polluted, used to provide water for turtles in the Xochimilco reach.		
	Surface water is diverted from the pond at Quitovac for agriculture.	High confidence	Nabhan *et al*. 1982, p.130 D. Duncan, USFWS, Pers. Obs., June 2015 J. Garcia, ASDM, Pers. Obs., June 2015
	Drought and habitat manipulation at Quitobaquito Springs has resulted in highly fluctuating surface water levels.	High confidence	NPS 2006, 2007, 2008a, 2008b, 2009a, 2009b, 2012a, 2012b, 2013, 2014b, 2015
STRESSOR(S)	Sonoyta mud turtles can tolerate spatially intermittent water that is present most of the year except during the dry season. Reduced water levels reduce overall habitat amount and quality causing crowding and increased competition for limited resources. If water is not reliably present all year and absent beyond the dry season, turtles are not able to forage, may not reproduce, and will eventually desiccate and die.	High confidence	Stanila 2009, p. 31, 45 Stone 2001, p. 45, 51 Hensley *et al*. 2010, p. 183
– Affected Resource(s)	Extent and volume of water	High confidence	
	Amount of prey (aquatic invertebrates-littoral and benthic)	High confidence	
	Amount and type of riparian habitat	High confidence	
– Exposure of Stressor(s)	Groundwater use in the Rio Sonoyta watershed is greater than the estimated recharge rate, and the Comisión Estatal de Agua del Estado de Sonora recommended no further well drilling in 2007.	High confidence	Brown 1991, p. 27–28 Carruth 1994, p. 17 Fisher de Leon 2006, p. 82 Murguia-Ruiz 2000, p. 412 Pearson and Connor 2000, p. 388
	Discharge from springs at Quitobaquito Springs diminished from 25–30 gpm in the early 1990s to 15–19 gallons/minute (gpm) ~2008. A long-term drought began in the early-mid 1990s, and continues today. With diminished rainfall, spring discharge has also gradually diminished. Increased groundwater withdrawal in Sonora.	High confidence that this is occurring, but low confidence as to why	P. Holm. pers. comm. 2016c Caruth 1996, pp. 13, 21 Pearson and Connor 2000, p. 396

THEME: Loss of water			
[ESA Factor(s): A, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
	Pond leakage resulting from various reasons and currently still including evapotranspiration from native emergent vegetation in pond at Quitobaquito Springs has occurred but is monitored and addressed as needed. Cottonwood tree that caused pond liner failure was removed in June 2016.	High confidence	Duncan and Tibbitts 2008, entire NPS 2006, 2007, 2008a, 2008b, 2009a, 2009b, 2012a, 2012b, 2014a, 2015, 2016
	The Papalote reach fluctuates markedly in extent throughout the year and extent of flow has been greatly reduced likely due to increased groundwater pumping and drought (Izaguirre-Pompa 2011). During the wet period of 1977–1984, the reach was "at least 5–6 km (3–3.7 mi)" (Miller and Fuiman (1987, p. 606), whose discussion implies that fish were found over at length of 10–13 km (6.2–8.1 mi) of river during 5–7 May 1986 (following a wet winter). From 2001–2006, it varied from 1.6–2.7 linear km (1–1.7mi) of surface water from a consistent source to a variable site of disappearance beneath the sandy riverbed (Rosen *et al*. 2010, p. 7).	Moderate confidence	Izaguirre-Pompa, 2011, entire Minckley *et al*. 2013, p. 289 Paredes-Aguilar and Rosen 2003, p. 8 Rosen *et al* 2010, p. 6–7 Miller and Fuiman 1987, p. 606
	Cattle are known to water in the Papalote reach which compounds loss of water during times of very low flows. Goats are known to graze in the Xochimilco reach.	High confidence	Murguia-Ruiz 2000, p. 422 Paredes-Aguilar and Rosen 2003, p. 7, 11 Rosen *et al*. 2010, p. 156
	The only apparently natural perennial water in the Xochimilco reach remaining may come from a "spring" at the dam in the town of Sonoyta. Sewage effluent from an army base at the site of old Sonoyta used to contribute flow to this reach until 2007. In 2001, a 0.5 km pool was maintained above the dam. The perennial spring below the dam was flowing for several hundred meters in 2001, but was reduced in 2005–6 to approximately 10 pools in the kilometer below the dam. The pools ranged from 0.3–>1.5 m (1–5 ft) deep, and some received small inputs of sewage effluent from individual	High confidence	EPA 2008, p. 3–5, 3–10 Paredes-Aguilar and Rosen 2003, p. 6 Rosen *et al*. 2010, p. 3, 5

THEME: Loss of water			
[ESA Factor(s): A, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
	homesteads atop the south arroyo wall. In 2008, the sewage effluent from an Army base was piped to the sewage lagoon in the town of Sonoyta, bypassing the Xochimilco reach.		
– Immediacy of Stressor(s)	Groundwater withdrawal will continue to increase due to human population growth, and drought is expected to increase in frequency and magnitude due to climate change.	High confidence	Seager *et al*. 2007, p. 1181–1184 IPCC 2014, p. 51
	Drought exacerbated by climate change may result in increased loss of discharge from the springs and loss of storage at the pond at Quitobaquito Springs.	High confidence	Seager *et al*. 2007, p. 1181–1184 IPCC 2014, p. 51 NPS 2007, p. 1
	Average rainfall contributing to Quitobaquito Springs inflow from 1981–1992 was 6.6 in/year, and average precipitation and discharge from Quitobaquito Springs was 5,500 cf/day (Carruth). Average rainfall in the upper Aguajita Wash basin (Acuna Basin) 1989 to present, is 7.66 in/year with no significant trend. Spring flow discharge (hand measured) from 2005 to present is 3,160 cf/day and the flow has declined by 444 cu/day in the past 10 years (Holm). Therefore spring flow discharge has decreased by 43% over the past 35 years.	High confidence	Carruth 1996, p.19–20 P. Holm, NPS, pers. comm. 2016c and 2016d
	Water loss in pond due to habitat manipulation is highly managed by NPS, and removal of the cottonwood tree in the pond in June 2016 may alleviate much of the current stressor.	High confidence	NPS 2006, 2007, 2008a, 2008b, 2009a, 2009b, 2012a, 2012b, 2014a, 2015, 2016
	Complete desiccation of the Papalote Reach is likely to occur in the next 5 years:	Low Confidence	Paredes-Aguilar and Rosen 2003, p. 8 Duncan and Tibbitts 2008, entire Rosen *et al* 2010, p. 155 Izaguirre-Pompa 2011, entire
	Groundwater extraction from the Rio Sonoyta for agriculture may have decreased in 2002–2003, but was likely temporary: downstream from Sonoyta, to	Somewhat confident	Paredes-Aguilar and Rosen 2003, p. 8 Rosen *et al* 2010, p. 155

THEME: Loss of water			
[ESA Factor(s): A, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
	Santo Domingo, there was decreasingly active use of irrigation systems; from Santo Domingo to downstream reaches associated with Agua Dulce and Agua Salada, most irrigation systems were in disuse; a number of those closest to the river lacked evidence of modern infrastructure.		
	Improvements to Mexican Highway 2 likely increased groundwater pumping temporarily that has contributed to greatly reduced water levels in the Papalote Reach since 2010.	Moderate confidence	Izaguirre Pompa 2011, entire
	The Papalote reach currently remains perennial but with only small pools remaining at the driest time of the year.	High confidence	Paredes-Aguilar and Rosen 2003, p. 8 Duncan and Tibbitts 2008, entire; Rosen *et al*. 2010, p. 148, 155 Izaguirre Pompa 2011, entire
	The Xochimilco reach likely has variable and little flowing water at any time of the year with a few remaining pools that hold water year-round; now relies only on stormwater runoff and sewage effluent from adjacent residential homes. Potential spring water at dam but unknown.	High confidence	EPA 2007, p. 3–5, 3–10 Paredes-Aguilar and Rosen 2003, p. 6 Rosen *et al*. 2010, p. 3, 5
	The existing sewage lagoon in the town of Sonoyta will be decommissioned once the new wastewater treatment plant (WWTP) is completed. This will result in elimination of wastewater flow into the existing sewage lagoon, and cause the lagoon to dry.	High confidence that this will happen, low confidence when this will happen	EPA 2008, p. 2–5 Minckley *et al*. 2010, p. 290 SEMARNAT 2008, p. 6 USFWS 2007, p. 3
	The future turtle habitat associated with the new WWTP will be constructed within the next five years and will have reduced water available for turtles compared to the old sewage lagoon. However, inflow to the new WWTP will include an additional 35% of residences in the town of Sonoyta and all outflow will be released into the Rio Sonoyta which could improve recharge of the shallow aquifer and create perennial flow in the river downstream of the WWTP as well as	High confidence that this will happen, low confidence when this will happen and how large future turtle pond will be	EPA 2008, p. 2–1 SEMARNAT 2008, p. 6 USFWS 2007, p. 3

THEME: Loss of water			
[ESA Factor(s): A, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
	contribute to recharge of the Rio Sonoyta.		
	In 2015, The Arizona-Sonora Desert Museum began working with the indigenous community living at Quitovac to grow fruit trees for their community. They are now diverting water from the pond to grow these trees.	High confidence that this is happening, low confidence in how much water will be used in the future.	D. Duncan, USFWS, Pers. Obs., June 2015 J. Garcia, ASDM, Pers. Obs., June 2015
Changes in Resource(s)	A complete lack of surface water eliminates habitat for Sonoyta mud turtle. Reduced flows cause a reduction in the amount of space, prey, and cover available to mud turtles. Lack of surface water for a short period of time may be endured periodically, but will reduce fitness and increase mortality over the long term.	High confidence	
Response to Stressors: – INDIVIDUALS	Sonora mud turtles will move between pools separated by dry stream reaches and also make long distance movement between drainages. However, long distance movements are much less frequent. Stone (2001) found a seasonal trend for Sonora mud turtles to move downstream from a stock tan to stream bed pools when the pools filled, and then to return to the stock tank when pools dried, with greatest movements exceeding 1 km. Hall and Steidl (2007) rarely documented long distance movements of the Sonora mud turtle with distances ranging from 500 to 7,200 meters along drainage bottoms. Hensley *et al* (2010) documented 9 movements of Sonoyta mud turtles > 700 m with longest movement of a female inferred to be over 4,500 m with a total accumulated movement distance of 7.96 km	High confidence	Stone 2001, pp. 47–48 Hall and Steidl 2007, p. 407 Hensley *et al*. 2010, p. 187

THEME: Loss of water			
[ESA Factor(s): A, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
	Sonoyta and Sonora mud turtles in dry or low surface water reaches will burrow in channels to escape desiccation for a short period of time. After time, burrows themselves may become too dry, turtles will lose fat reserves due to lack of foraging opportunity, if they mate females may not have viable eggs due to lack of nutrition and fat reserves, and eventually turtles will die from either starvation or desiccation.	High confidence	KISOSO: Rosen 1986, p. 15 Paredes-Aguilar and Rosen 2003, p. 8 KISOLO: Pearson and Conner 2000, pp. 607–698 Stanila 2009, p. 45 Hall and Steidl, 2007, pp. 406–408 Hensley *et al.* 2010, pp. 181–182 Ligon and Stone 2003b, pp. 752–753 Stone 2001, pp. 46–51
POPULATION & SPECIES EEFFECTS	Lower reproductive rates, reduced recruitment, reduced population growth rate, changes in distribution	High confidence	
Effects of Stressors: – POPULATIONS [RESILIENCY]	Partial loss of water would decrease size of a population. Complete loss of water at a site would likely result in extirpation of that population unless turtles are physically moved to another occupied site.	High confidence	
– SCOPE	Loss of water affects the entire range of the species. It is occurring and will continue to occur at sites supporting all five mud turtle populations.	High confidence	Brown 1991, p. iii Carruth 1994, p. 2 EPA 2007, pp. 3–5 Marguia-Ruiz 2000, p. 420 Izaguirre-Pompa 2011, p. 7 Minckley *et al*. 2010, entire NPS 2013, p. 17 Paredes Aguilar and Rosen 2003, p. 8 Pearson and Connor 2000, p. 398 Rosen 1986, p. 15 Rosen *et al*. 2006, p. 5–1 Rosen *et al*. 2010, p. 145 Valdez-Zamudio 1994, p. 18

THEME: Loss of water			
[ESA Factor(s): A, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: **– SPECIES (Rangwide) [REDUNDANCY]**	The number of populations and distribution across the subspecies range will decrease over the next 70 years. Because the five populations of mud turtles are fairly isolated from one another, and there is a lack of aquatic habitat "stepping stones" connecting these populations, turtles will likely not be able to disperse to other sites if a site loses all surface water for an extended period of time. In the short-term, we expect to lose all populations in the Rio Sonoyta, the only lotic stream that supports the sub-species. In the long-term, there may be a single population remaining in Mexico in the human-created WWTP system.	High confidence	Hensley *et al* 2010, p. 181–182 Hall and Steidl 2007, pp. 406–408 Ligon and Stone 2003b, pp. 752–753 Stone 2001, pp. 46–51
Effects of Stressors: **– SPECIES (Rangwide) [REPRESENTATION]**	In the next 70 years, loss of surface water could significantly reduce genetic and ecological diversity in the species since all five extant sites that each support a population of mud turtles could be extirpated due to complete loss of surface water, although one could be replaced by a new population at the new WWTP in Sonoyta. The two Rio Sonoyta populations (Papalote and Xochimilco reaches) are the most vulnerable to decreased flow due to loss of surface water in the short-term (7 years).	High confidence	

THEME: Loss of riparian habitat			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Groundwater extraction, drought, changes to wastewater infrastructure, livestock grazing, and habitat manipulation reduce the type and amount riparian habitat surrounding aquatic habitat for turtles.	High confidence	Archer and Predick 2008, p. 24 Bennett and Kunzmann 1989, p. 34 Brown 1988 p. 3 EPA 2007, pp. 1–2 Fisher de Leon 2006, p. 63 Nabhan 2008, p. 252 Nabhan *et al*. 1982, p. 126 Paredes-guilar and Rosen 2003, pp. 8, 9 Pearson and Connor 2000, p. 388
– Activity(ies)	– Refer to loss of water and management themes –		
	Livestock grazing	High confidence	Paredes-Aguilar and Rosen 2003, p. 7, 11 Rosen *et al* 2010, p. 149–150
STRESSOR(S)	Riparian vegetation surrounding water features provides essential habitat for all life stages of turtles. Reductions in riparian habitat will decrease subsurface moisture needed for nesting sites for eggs, drought refuge for juvenile and adult turtles, and shelter from large flooding events for juvenile and adult turtles.	High confidence	
– Affected Resource(s)	Soil moisture that supports nest sites and burrows		
– Exposure of Stressor(s)	– Refer to loss of water and management themes –		
	Livestock (cattle and horses) periodically graze riparian vegetation within the channel and on the banks of the Papalote reach. The Papalote reach was once fenced to exclude livestock, but rancher cut the fence.	High confidence	Rosen *et al* 2010, p. 149–150
	Goats have been seen grazing in the Xochimilco reach and are likely pruning riparian vegetation.	High confidence that is happening, low confidence that it is having an effect on turtles	Paredes-Aguilar and Rosen 2003, p. 7, 11

THEME: Loss of riparian habitat			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
– Immediacy of Stressor(s)	In general, riparian habitat at all five extant sites currently remains intact. There will be a lag time between surface water loss and degradation of riparian habitat.	High confidence that this will occur as water decreases, but low confidence for timeframe	
	Effects of livestock grazing in the Papalote reach on soil moisture for nests and burrows are currently unknown. If surface water eventually disappears, lush vegetation that livestock are after will disappear so grazing should decrease.	Low confidence	
Changes in Resource(s)	Decreased riparian vegetation will lead to deterioration of microclimate that provides soil moisture to nest sites and burrows.		Rosen *et al*. 2010, p. 156
Response to Stressors: – INDIVIDUALS	This stressor may decrease survival of all life stages of turtles.		
POPULATION & SPECIES EEFFECTS			
Effects of Stressors: – POPULATIONS [RESILIENCY]	Lower reproductive rate, higher mortality during stochastic events, reduced population growth rate		
– SCOPE	Loss of riparian will affect the entire range of the species over the long-term as it is tied to loss of water. Short term effects from grazing are unknown.		

THEME: Loss of riparian habitat			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: **– SPECIES (Rangwide)** **[REDUNDANCY]**	Because there will be a lag time between surface water loss and riparian vegetation degradation, it is likely that the two populations of the Rio Sonoyta will disappear before there are dramatic effects to soil moisture due to loss of riparian vegetation.		
Effects of Stressors: **– SPECIES (Rangwide)** **[REPRESENTATION]**	In the next 70 years, loss of riparian habitat could significantly reduce genetic and ecological diversity in the species since all five extant sites that each support a population of mud turtles could be extirpated due to complete loss of surface water, which would reduce needed soil moisture, although one could be replaced by a new population at the new WWTP in Sonoyta. The two Rio Sonoyta populations (Papalote and Xochimilco reaches) are the most vulnerable to decreased flow due to loss of surface water in the short-term (7 years).		

THEME: Amount of invertebrate prey			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Competition with native and nonnative fish species, interactions with contaminants	Somewhat confident for competition, low confidence for contaminants	Rosen and Lowe 1996, p. 41 King *et al*. 1996, p. 1,5
– Activity(ies)	Multi-species management at Quitobaquito Springs	Somewhat confident	NPS 2011b, pp. 16–17
STRESSOR(S)	Change in diet	High confidence	Rosen and Lowe 1996, p. 32
– Affected Resource(s)	Availability of prey to mud turtles Water permanence may also affect the diversity of benthic prey available for mud turtles, with ephemeral habitats having lower diversity than intermittent or perennial habitats.	Somewhat confident	Rosen and Lowe 1996, p. 41 Stanila *et al* 2009, p. 38
– Exposure of Stressor(s)	Only known at Quitobaquito Springs	Low confidence at other sites	Rosen and Lowe 1996, p. 32, 41
– Immediacy of Stressor(s)	This has occurred in the past and assumed to continue	High confidence that has occurred and somewhat confident still occurring	King *et al*. 1996, p. 1,5 Rosen and Lowe 1996, p. 32, 41
Changes in Resource(s)	Mud turtle dissections and feces at Quitobaquito Springs revealed turtles were consuming large amounts of plant matter, primarily young shoots of bullrush in their stomachs.	High confidence	King *et al*. 1996, p. 1,5
Response to Stressors: – INDIVIDUALS	Poor body condition (low fat reserves) may be a result of lack of invertebrates in diet, Lower clutch size	High confidence	King *et al*. 1996, p. 1,5 Rosen and Lowe 1996, p. 32, 41
POPULATION & SPECIES EEFFECTS			
Effects of Stressors: – POPULATIONS [RESILIENCY]	Lower reproductive rate, reduced population growth rage, decreased survival	High confidence	

THEME: Amount of invertebrate prey			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
– SCOPE	Only confirmed in one of the five extant mud turtle populations.	High confidence	
Effects of Stressors: – SPECIES (Rangwide) [REDUNDANCY]	May affect 1 of five extant populations. Level of effect unknown but likely will not cause extirpation of the population.	High confidence	
Effects of Stressors: – SPECIES (Rangwide) [REPRESENTATION]	None.	Somewhat confident	

THEME: Presence of nonnative species			
[ESA Factor(s): C]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Introduction by humans (some intentionally for management)	High confidence	
– Activity(ies)	Western mosquitofish (*Gambusia affinis*), black bullheads (*Ameiurus melas*), African cichlid fishes (tilapia) have been released to occupied Sonoyta mud turtle sites.	High confidence	Duncan *et al*. 2013 Duncan and Tibbitts 2008 Miller and Fuiman 1987 Izaguirre-Pompa 2011, p. 11 Minckley *et al*. 2010, p. 289 Paredes-Aguilar and Rosen 2003, entire Pearson and Connor 2000, p. 396 Rosen *et al*. 2010, entire
	Bullfrogs, crayfish, centrarchids, ictalurids, and exotic turtles such as red-eared sliders could be released and become established.	Moderate confidence	
STRESSOR(S)	Bullfrogs, crayfish, and large centrarchids and ictalurids prey upon mud turtles.	High confidence	Hensley *et al*. 2010 Fernandez and Rosen 1996
	Black bullheads, African cichlid fishes, western mosquitofish, and exotic turtles change ecosystem function: they may disrupt the food chain altering proportions of invertebrate community and therefore decreasing type and amount of benthic invertebrate prey available to mud turtles.	High confidence	Drost *et al*. 2011 Duncan 2013. P. 283 (Bence 1988; Hoy and others 1972; Hurlbert and others 1972; McDowall 1990; Ortega-Mayagoita and others 2002)
– Affected Resource(s)	Mud turtles, prey of mud turtles	High confidence	
– Exposure of Stressor(s)	Western Mosquitofish (*Gambusia affinis*) and the Black Bullhead catfish (*Ameiurus melas*) (an ictalurid) are present in the Papalote reach of Rio Sonoyta. A red-eared slider was found at Colegio de Bachilleres del Estado de Sonora in the town of Sonoyta close to the Xochimilco reach. African cichlid fishes (tilapia) have been released to and are present at Quitovac.	High confidence	Minckley *et al*. 2013, p. 289

THEME: Presence of nonnative species			
[ESA Factor(s): C]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
– Immediacy of Stressor(s)	Current effects of nonnative species presence on mud turtles in the Papalote reach and Quitovac are unknown. Bullfrogs, crayfish, centrarchids, and exotic turtles are currently not at any of the five occupied mud turtle sites, but could be released and become established in the future.	High confidence that this will occur in the next 70 years	
Changes in Resource(s)	Increased predation on juvenile and adult turtles, decreased prey available to juvenile and adult turtles	High confidence	
Response to Stressors: – INDIVIDUALS	Death, reduced fitness	High confidence	
POPULATION & SPECIES EEFFECTS			
Effects of Stressors: – POPULATIONS [RESILIENCY]	Reduced population numbers due to increased mortality, lower juvenile recruitment	High confidence	Stanila 2009, p. 49 Fernandez and Rosen 1996 Van Loben Sels *et al*. 1997
– SCOPE	Currently two of the five populations have nonnative species present. It is possible that all five populations will have nonnative species present in the next 70 years.	Moderate confidence	Duncan *et al*. 2014 Duncan and Tibbitts 2008 Miller and Fuiman 1987 Izaguirre-Pompa 2011, p. 11 Minckley *et al*. 2010, p. 289 Paredes-Aguilar and Rosen 2003, entire Pearson and Connor 2000, p. 396 Rosen *et al*. 2010, entire
Effects of Stressors: – SPECIES (Rangwide) [REDUNDANCY]	If a predator like crayfish were introduced to any of the populations, they would likely decimate the population.	High confidence	Fernandez and Rosen 1996 Van Loben Sels *et al*. 1997

THEME: Presence of nonnative species			
[ESA Factor(s): C]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: **– SPECIES (Rangwide) [REPRESENTATION]**	In the next 70 years genetic and ecological diversity in the species since all five extant sites that each support a population of mud turtles could be extirpated if nonnative predators become established at one or more of these sites.		

THEME: Management			
[ESA Factor(s): A,C,D,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Stakeholders are implementing management actions to conserve mud turtle populations	High confidence	Quitobaquito Rio Sonoyta Work Group 2015, entire Minckley *et al*. 2010, entire
– Activity(ies)	Active turtle management, habitat manipulation and management	High confidence	NPS
STRESSOR(S)	Management actions are intended to increase resiliency, redundancy, and representation of the Sonoyta mud turtle by maintaining or increasing populations. Actions may have short-term negative effects to the mud turtles.	High confidence	
– Affected Resource(s)	Turtles, habitat, prey	High confidence	
– Exposure of Stressor(s)	Quitobaquito Springs: creation of refuge population of mud turtles at ASDM, threshold water level established in pond for removal of mud turtles to refuge population at ASDM, various efforts to decrease water loss from both the springs and pond, habitat alteration to increase habitat available to mud turtles	High confidence	
	Papalote reach: Saltcedar removal ~15 years ago in Papalote reach, bullhead catfish removal	High confidence	Minckley *et al*.
	Sonoyta sewage lagoon: agreement between EPA, USFWS, and Mexican authorities to translocate turtles from this site to new WWTP.	Moderate confidence	SEMARNAT 2008, p. 6 USFWS 2007, p. 4
	WWTP: agreement between EPA, USFWS, and Mexican authorities to (1) create habitat for mud turtles at the new WWTP, (2) require all effluent from WWTP to be directed to Rio Sonoyta for recharge,	Moderate confidence	SEMARNAT 2008, p. 6 USFWS 2007, p. 4
	Quitovac: periodic dredging of portions of Quitovac has taken place to remove bulrush; education and outreach by Arizona-Sonora Desert Museum, Organ Pipe Cactus National Monument, Pinacate Biosphere Reserve, Quitobaquito Rio Sonoyta Work Group	High confidence	

THEME: Management			
[ESA Factor(s): A,C,D,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
– Immediacy of Stressor(s)	Quitobaquito Springs: The NPS is committed to continued conservation of the mud turtle into the future under a multi-species management approach.	High confidence	
	Papalote reach: Bullhead removal and instream habitat modification such as creation of one-rock to increase surface water retention have been discussed.	Somewhat confident	
	Sonoyta sewage lagoon: It is unknown when this facility will be closed, but it is likely to occur in the next 7 years.	Moderate confidence	
	WWTP: It is unknown when this facility will be operational, but it is likely to occur in the next 7 years.	Moderate confidence	
	Quitovac: Entire site (all springs and pond) was dredged in 2014 with unknown but likely detrimental effects to mud turtles and actions are underway to prevent it from occurring again in the future.	Low confidence	
Changes in Resource(s)	Turtle numbers have increased and habitat has improved.	High confidence	
Response to Stressors: – INDIVIDUALS	Increased survival of juvenile and adult turtles at Quitobaquito Springs.	High confidence	
POPULATION & SPECIES EEFFECTS			
Effects of Stressors: – POPULATIONS [RESILIENCY]	Mud turtle recruitment at Quitobaquito Springs has increased and numbers are at Quitobaquito Springs are currently at an all-time high. The Sonoyta sewage lagoon population will be replaced by the WWTP population. Management actions for the Papalote reach and Quitovac populations may not be effective at maintaining these populations.	High confidence	SEMARNAT 2008, p. 6
– SCOPE	Management actions are being implemented for four of the five extant mud turtle populations.	High confidence	

THEME: Management			
[ESA Factor(s): A,C,D,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: – SPECIES (Rangwide) [REDUNDANCY]	The only secure population due to management actions is Quitobaquito Springs and possibly the future WWTP population.	High confidence	
Effects of Stressors: – SPECIES (Rangwide) [REPRESENTATION]	The only secure population due to management actions is Quitobaquito Springs and possibly the future WWTP population.		