Species Status Assessment for

Dixie Valley Toad (*Anaxyrus williamsi*)

Churchill County, Nevada

Dixie Meadows, Churchill County, Nevada

Version 1.0
U.S. Fish and Wildlife Service
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Interior Region 10 California-Great Basin

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EXECUTIVE SUMMARY

This report summarizes the results of a species status assessment (SSA) for Dixie Valley toad (*Anaxyrus williamsi*). This report is intended to provide a summary of the current understanding of the biological status of Dixie Valley toads. This SSA report does not represent a decision by us, the U.S. Fish and Wildlife Service (Service), whether or not to list the species under the Endangered Species Act (Act). Instead, this SSA report provides a review of the best scientific and commercial information available on Dixie Valley toads.

Dixie Valley toads are a recently described species and is a narrow-ranging endemic known only from one population in the Dixie Meadows area of Churchill County, Nevada (Gordon et al. 2017, entire). Dixie Valley toads are the smallest species in the western toad (*Anaxyrus boreas*) species complex, is highly aquatic throughout its lifecycle, and relies on the thermal water found in the spring province at Dixie Meadows. Dixie Meadows is a ground water dependent ecosystem consisting of at least 122 springs and seeps located on the east side of the Stillwater Range. Approximately 90 percent of all occupied habitat is located on Department of Defense (DoD) lands and the remaining is on public lands managed by the Bureau of Land Management (BLM). No military training occurs in Dixie Meadows (DoD 2014, p. 3–15).

To evaluate the biological status of Dixie Valley toads, 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). Together, the 3Rs comprise the key characteristics that contribute to a species' viability, its ability to sustain populations in the wild over time. When combined across populations, they measure the health of the species as a whole.

Historically and through the present, Dixie Valley toads and their habitat have been negatively impacted to varying degrees by multiple threats, including newly approved geothermal power plant, predation and competition, vegetation and soil disturbance, spring modification, and groundwater pumping. Sources of these threats include invasive, nonnative species; roads; wildfire; grazing and browsing by ungulates; recreation; and human development. In many cases, these impacts affect individuals or result in short-term declines to the Dixie Valley toad population. While these threats may continue to affect the Dixie Valley toad to some extent in the future despite a variety of ongoing conservation measures, this analysis reveals that threats most likely to impact future conditions are habitat modification from geothermal development, groundwater pumping, and changing climate conditions that result in altered precipitation, and ultimately spring discharge.

Based on our understanding of historical, current, and probable future conditions, we developed four scenarios to assess the 3Rs over the next 50 years. This timeframe is based on our balancing a reasonably long-term future for the species—incorporating the biology of Dixie Valley toads, with balancing our confidence in estimating future habitat changes relating to such factors as hydrology, climate change, and species recovery efforts. However, if geothermal energy development begins at Dixie Meadows, we expect the most severe changes to occur within 10 years. While we expect water temperature and adequate spring discharge to be the main biological and physical needs potentially affected, such reductions may also impact the amount of suitable vegetation and wetland habitat available for the toad. The four scenarios we

considered are:

1) Springflow or discharge is completely eliminated;
2) Springs experience extreme reduction in temperature and springflow or discharge;
3) Springs experience slight to moderate reductions in temperature and springflow or discharge; and
4) Springs maintain temperature and springflow or discharge similar to current conditions.

To evaluate these scenarios, we considered how each would affect the resiliency, redundancy, and representation of Dixie Valley toads. We assessed resiliency by taking into consideration the toad's ability to withstand past disturbances, the current conditions of springs and spring provinces, and the extent of occupied habitat. To assess redundancy, we factored in whether the species is sufficiently distributed across its range. Representation is measured through ecological diversity (environmental variation) and genetic diversity within the population.

Under all scenarios that include the geothermal plant operating as permitted (Scenarios 1-3), projections show a significant impact to the wetland system that the Dixie Valley toad relies upon. The expert elicitation panelists that helped inform this SSA determined that the spring system will respond quickly once geothermal energy production begins, with a median response time of roughly 4 years and a 90 percent chance that the largest magnitude changes will occur within 10 years (Figure 4.2; Appendix A). The largest magnitude of changes range from complete drying of the wetlands due to reduced springflow, to reduction of springflow of 31% (we assume 1:1 reduction in springflow to reduction in available wetland habitat) and temperature reduction of 10 °C (18 °F; Table 6.1; Appendix A).

Projections of springflow and temperature reductions were input into a multi-state, dynamic occupancy model for the Dixie Valley toad. The occupancy model projects both scenarios two and three having a high risk of reproductive failure in addition to the clear reproductive failure that would occur under scenario one due to complete drying of the wetlands. Under all scenarios that include the geothermal plant operating as permitted (Scenarios 1-3), we anticipate there would be a significant reduction in resiliency, redundancy, and representation, which would put the species at an increased risk for stochastic and catastrophic events. Additionally, Scenario 1 projects a plausible extinction of the species resulting from a complete loss of habitat.

Under Scenario 4 the geothermal plant is not constructed change or the Monitoring and Mitigation Plan is improved; climate is the primary threat to the species. In this scenario we anticipate the species would persist into the future because we project minimal changes in temperature and springflow.

Based on projections of altered precipitation and air temperature, and our current understanding of ongoing geothermal energy development and groundwater withdrawal that might be expected with human population growth, Dixie Valley toads will be discussed below as they pertain to probable impacts extending into the next 50 years. The following information summarizes the historical, current, and probable future conditions for Dixie Valley toads and their habitat.

ABBREVIATIONS AND ACRONYMS

Acronym or Abbreviation	**Full Name**
°C	Degrees Celsius
°F	Degrees Fahrenheit
µS/cm	microSiemens per centimeter
3Rs	Resiliency, Redundancy, and Representation
BLM	Bureau of Land Management
cfs	Cubic feet per second
cm/sec	Centimeters per second
DCNR	Nevada Department of Conservation and Natural Resources
DO	Dissolved oxygen
ESA	Endangered Species Act
FLPMA	Federal Land Policy and Management Act
ft	Foot or feet
gpm	Gallons per Minute
GCM	General circulation model
GDE	Groundwater Dependent Ecosystem
GIS	Geographic Information Systems
HA	Hydrographic Area
in	Inch(es)
In/sec	Inches per second
IPCC	Intergovernmental Panel on Climate Change
km	kilometers
L/min	Liters per minute
m	Meter(s)
mi	Miles
mm	Millimeter(s)
mg/L	Milligrams per liter
NDOW	Nevada Department of Wildlife
NDWP	Nevada Division of Water Planning
NEPA	National Environmental Policy Act of 1970
NSE	Nevada State Engineer
NV	Nevada
ppm	Parts per million
RMP	Resource Management Plan
Service	U.S. Fish and Wildlife Service
sp. *or* spp.	Species
SSA	Species Status Assessment
TDS	Total Dissolved Solids
USGS	United States Geological Survey
WAP	Wildlife Action Plan

WSA	Wilderness Study Area

GLOSSARY OF TERMS

Term	Definition
aquifer	Rock or sediment layer that contains and transmits groundwater
Climate change	Change in the mean or variability of one or more measures of climate (e.g., temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both.
Cold springs	Springs with temperatures below 70 °F (21.1 °C).
exposure	Extent to which a target resource and threat actually overlap in space or time.
Groundwater dependent ecosystem (GDE)	Ecological communities of species that depend on groundwater for survival.
Invasive species	Species that is nonnative to an ecosystem and causes, or is likely to cause, economic or environmental harm, or harm to human health.
Local aquifer	Aquifer fed by precipitation from a large area with supported springs located between valley floors and mountain bases.
macroinvertebrate	Organism without backbones that is visible to the eye without the aid of a microscope. Aquatic macroinvertebrates live on, under, and around rocks and sediment on the bottoms of lakes, rivers, and streams.
mountain block aquifer	Aquifer that is usually perched, relatively small, and fed by precipitation from a small area.
nonnative	Originating in a different geographic region and acclimated to a new environment.
perched aquifer	Aquifer that occurs above the regional water table and is generally a relatively small body of water.
phreatophyte	Plants that rely on shallow groundwater for some of their water requirements.
population	Group of individuals of the same species that have the potential to interbreed.
redundancy	Ability of a species to withstand catastrophic events.
Regional aquifer	Large aquifer characterized by water that is warmer and moves slower through the aquifer, in comparison to perched and local aquifers; supported springs are supplied from recharge extending over vast areas.
response	Extent to which a target resource responds to specific threat.
Representation	Ability of a species to adapt to changing environmental conditions.
springbrook	Water outflow from a spring source.
Spring province	A series of springs clustered in a single area connected by a common groundwater source.
Thermal spring	Springs with temperatures above 70 °F (21.1 °C).

1.0 INTRODUCTION

The Species Status Assessment (SSA) framework (Service 2016, entire) is an in-depth review of a species' biology and risks, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The SSA report is intended to support all functions of the Endangered Species Program, including the development of listing rules, recovery plans, and 5-year reviews, should the species warrant listing as an endangered or threatened species under the Act. The SSA report is a living document and we may update it periodically as new information becomes available.

The format for this SSA report includes:

- Description of the analysis framework and methodology (Chapter 2).
- Background information on the range and distribution of Dixie Valley toads; general biological information; and general information on spring characteristics, function, and hydrology important for understanding the physical and biological needs of Dixie Valley toads (Chapter 3).
- Descriptions of the resources needed by Dixie Valley toads at the individual, population, and species levels (Chapter 3).
- Descriptions of potential factors that may impact the needs and current conditions of Dixie Valley toads (Chapter 4).
- Evaluation of the current condition of Dixie Valley toads, including quantity and quality of habitat that is present at Dixie Meadows, information on needs that may be unique to Dixie Valley toads, the historical and current distribution of the species, the relative abundance (Chapter 2) of the Dixie Valley toad population, and the current conditions of the Dixie Valley toad population (Chapter 5).
- An evaluation of the probable future condition of Dixie Valley toads, including a description of the species' viability in terms of resiliency, redundancy, and representation based on potential future condition scenarios (Chapter 6).

1.1 State Listing Status

The Nevada Department of Wildlife received approval by the Legislative Council Bureau to add Dixie Valley toads as a protected amphibian by the State of Nevada under Nevada Administrative Code (NAC) 503.075(2)(b). The revised list of protected amphibians is expected to be finalized in 2022. Per NAC 503.090(1), there is no open season on those species of amphibian classified as protected. Per NAC 503.094, the State issues permits for the take and possession of any species of wildlife for strictly scientific or educational purposes. The State's Department of Conservation and Natural Resources maintains the Nevada Division of Natural Heritage (NDNH), which tracks the species status of plants and animals in Nevada. The NDNH recognizes Dixie Valley toads as critically imperiled, rank *S1*. Ranks of *S1* are defined as species with very high risks of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors.

2.0 ANALYSIS FRAMEWORK

2.1 Analysis Area

Dixie Valley toads are distributed throughout springs, spring provinces (a series of springs clustered in a single area connected by a common groundwater source), and associated wetlands in Dixie Meadows, Churchill County, Nevada (Figures 2.1 and 2.2). Dixie Meadows is a 3.1 square kilometer (km^2) (760 acres (ac)) wetland complex fed by both cold and hot springs which emanate from a piedmont fault that runs along the eastern edge of the Stillwater Range. Species-specific location and hydrographic information is presented in Figures 2.1–2.2 and Chapter 4.

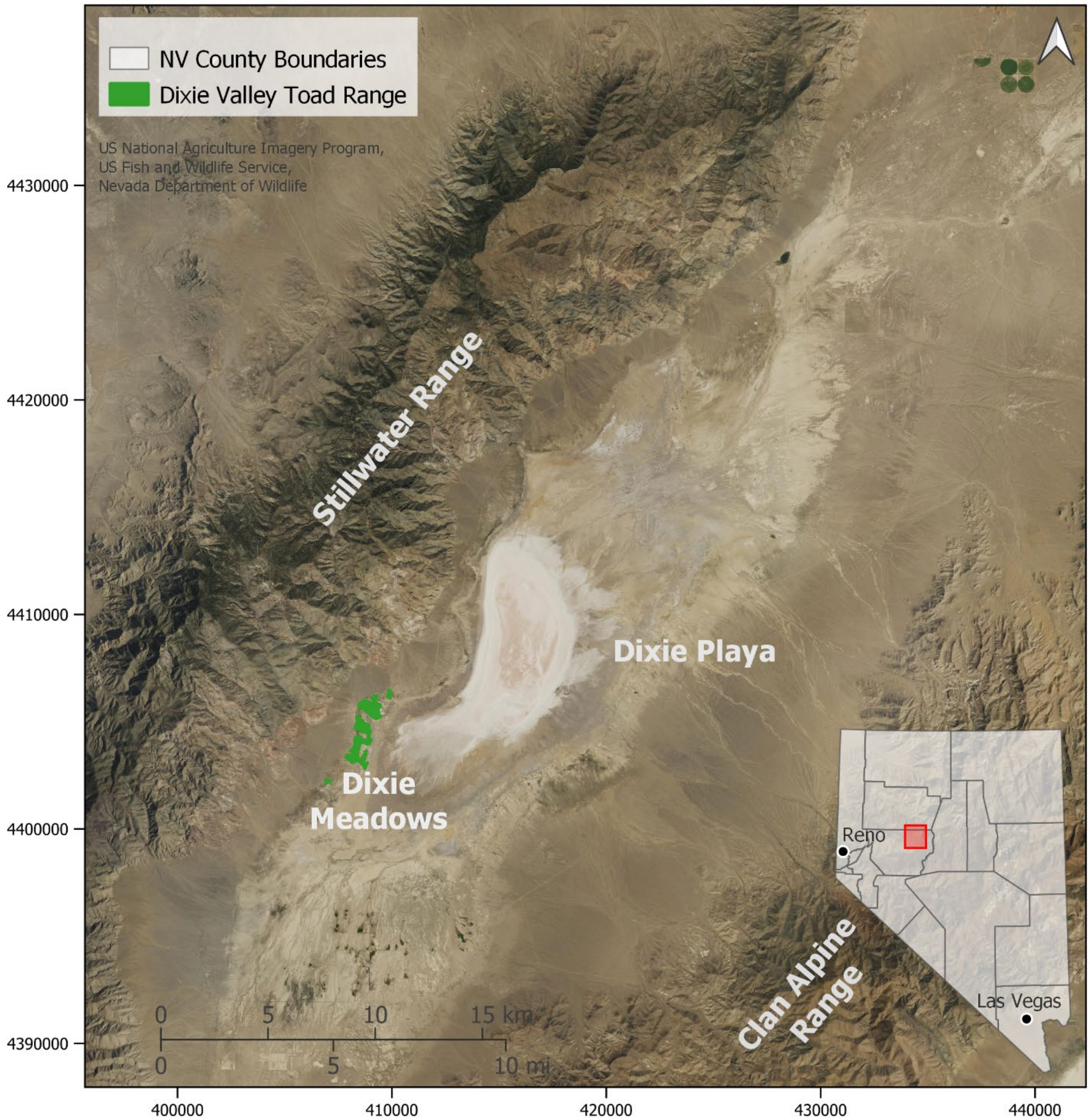

Figure 2.1. An overview of Dixie Valley including the Stillwater Range, Clan Alpine Range, Dixie Playa, and Dixie Meadows, Churchill County, Nevada.

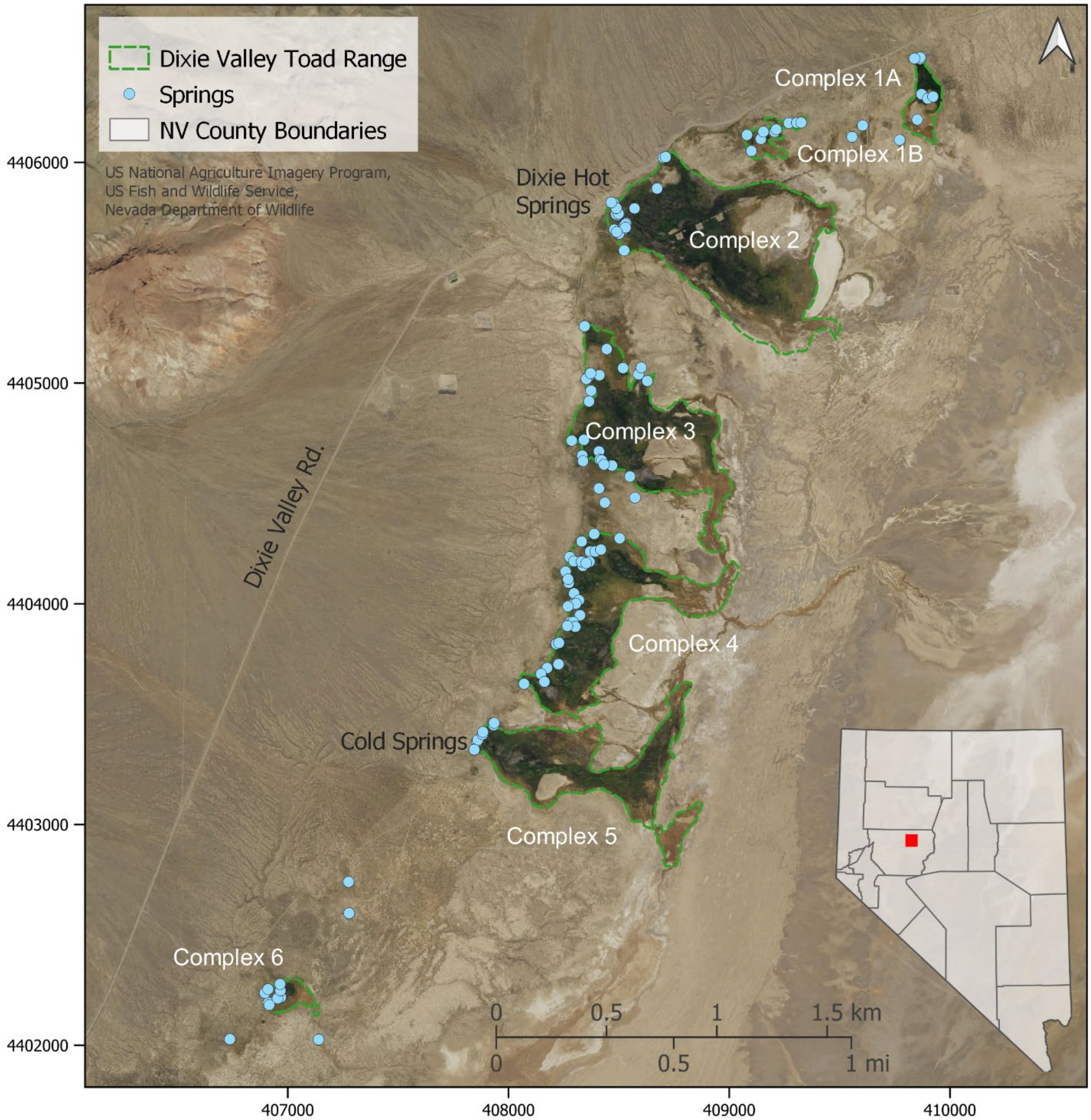

Figure 2.2. The entire range of the Dixie Valley toad, Dixie Meadows, Churchill County, Nevada. Known spring locations in each of the six wetland complexes are depicted.

2.2 SSA Framework

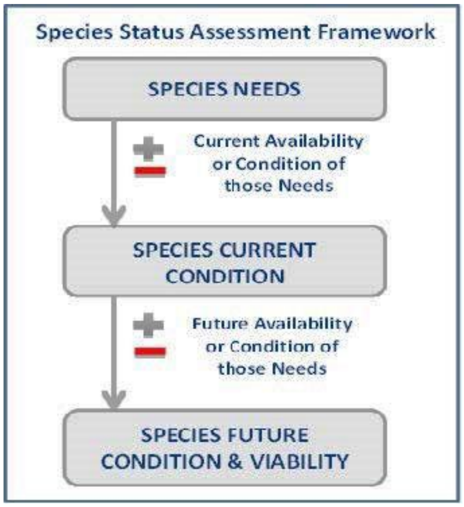

Figure 2.3. Species status assessment framework.

To evaluate the biological status of Dixie Valley toads both currently and into the future, we assessed a range of conditions to allow us to consider the species' needs and ultimately its resiliency, redundancy, and representation (3Rs). This SSA report provides a thorough assessment of Dixie Valley toad's biology and natural history, and assesses demographic risks, threats, and limiting factors in the context of determining the viability and risks of extinction for the species.

Definitions of the 3Rs

The following are working definitions of the 3Rs that are used throughout this document. They are derived from the SSA framework (Figure 2.3; Service 2016, entire):

- **Resiliency** is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford et al. 2011, p. 40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. We can best gauge resiliency by evaluating population level characteristics such as: demography (abundance and the components of population growth rate -- survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity. Also, for species prone to spatial synchrony (regionally correlated fluctuations among populations), distance between populations and degree of spatial heterogeneity (diversity of habitat types or microclimates) are also important considerations.

- **Redundancy** is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely (Mangal and Tier 1993, p. 1,083). We can best gauge redundancy by analyzing the number and distribution of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale, or for narrow-ranged species, at the species level.

- **Representation** is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments—referred to as adaptive capacity—is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al. 2015, p. 1,269). Species adapt to novel changes in their environment by either (1) moving to new, suitable environments; or (2) by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Beever et al. 2016, p. 132; Nicotra et al. 2015, p. 1,270). The latter (evolution) occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift (Crandall et al. 2000, pp. 290–291; Sgro et al. 2011, p. 327; Zackay 2007, p. 1). We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In assessing the breadth of variation, it is important to consider both larger-scale variation (such as morphological, behavioral, or life history differences that might exist across the range and environmental or ecological variation across the range), and smaller-scale variation (which might include measures of interpopulation genetic diversity). In assessing the dispersal ability, it is important to evaluate the ability and likelihood of the species to track suitable habitat and climate over time. Lastly, to evaluate the evolutionary processes that contribute to and maintain adaptive capacity, it is important to assess (1) Natural levels and patterns of gene flow, (2) degree of ecological diversity occupied, and (3) effective population size. In our species status assessment, we assess (or estimate via proxy) all three facets to the best of our ability based on available data.

2.3 Methodology

In preparing this SSA report, we reviewed available reports and peer-reviewed literature, unpublished surveys, consulted with species experts, planned site visits, and reviewed aerial imagery and Geographic Information Systems (GIS) data. We considered uncertainties in our assessment of the species' life history, current conditions, and future conditions. We also reviewed the relevant literature for similar species.

The general approach involved a conceptual model to identify the species needs of Dixie Valley toads and the subsequent evaluation of threats. The basic species needs included sufficient wetted area, adequate water temperature, wetland vegetation, and water quality. We carried forward wetted area and adequate water temperature into our analysis as the driving forces of viability, as wetland vegetation is directly tied to wetted area and we do not have sufficient information to evaluate water quality. The qualitative evaluation of the extent to which these needs were satisfied is presented later in Chapter 3 and the evaluation of threats to the species are described in Chapter 4. A multi-state occupancy model was used to provide estimates for the percentage of the range occupied for current condition (Chapter 5) and future condition (Chapter 6) of the species. For the species' future conditions (Chapter 6), this model was combined with expert judgments on potential impacts to water temperature and wetted area due to installation of a geothermal plant in the Dixie Meadows spring province, extractive water use in the basin, and ongoing climate change.

For the purpose of this assessment, we generally defined viability as the ability of Dixe Valley toads to sustain its population in Dixie Meadows over time. We chose 50 years for the timeframe of our future condition analysis because it is within the range of available hydrological and climate change model forecasts (see Intergovernmental Panel on Climate Change (IPCC) 2014, pp. 10–15); however, the timeframe for the most severe impacts are expected within the first 10 years from the start of geothermal energy production (see Chapter 4 for more details).

3.0 SPECIES ECOLOGY AND RESOURCE NEEDS

This chapter presents general information on the range and distribution of Dixie Valley toads, followed by basic biological information on taxonomy and genetics, morphological features, life history traits, and feeding habits. Habitat characteristics and function are also described because springs, spring provinces, and associated wetlands constitute habitat and the physical and biological needs of Dixie Valley toads. Additional species- and area-specific descriptions and information are in Chapter 5.

3.1 Dixie Valley Toad Biogeography, Biology, and Habitat

3.1.1 Range, Distribution, and Population Estimates

Dixie Valley toads are endemic to Dixie Meadows, Churchill County, Nevada. Dixie Meadows is a ground water dependent ecosystem consisting of at least 122 springs and seeps located on the east side of the Stillwater Range (Figure 2.1). Approximately 90 percent of all occupied habitat is located on Department of Defense (DoD) lands and the remaining is on public lands managed by the Bureau of Land Management (BLM). The wetlands located in Dixie Meadows cover 3.1 km^2 (760 ac); Figures 2.1 and 2.2).

Dixie Valley toads are a narrow endemic with a single meta-population. The extent of occurrence, or the minimum convex hull around known localities, is 5.76 km^2 (1,423 ac). The potential area of occupancy was estimated as 1.46 km^2 (360 ac) based on the extent of wetland-associated vegetation. Extent of occurrence measures the degree of risk spreading across a species' range and area of occupancy measures the amount of the range that is potentially habitable (Gaston and Fuller 2009, pp. 4–6). Both values suggest Dixie Valley toads currently have low redundancy to withstand catastrophic events to the single population and low representation due to the limited range and lack of dispersal opportunities. Because toads are rarely encountered more than 14 m (46 ft) from aquatic habitat (Halstead et al. 2021, p. 7), we have high confidence in its estimated range size. The closest wetlands supporting populations of western toads (*Anaxyrus boreas*) occur approximately 50 km (31 mi) to the northeast and 30 km (18.6 mi) to the southwest of Dixie Meadows and are separated by large expanses of arid playa or the Stillwater Range (Forrest et al. 2017, pp. 164–165).

Population estimates are not available for Dixie Valley toads. Time-series data of toad abundance are available from various surveys conducted by the Service and NDOW from 2009–2012; however, differences in sample methodology between years and low recapture rates of marked toads make it difficult to infer temporal trends or population size. In addition to adult toads, surveys recorded eggs, tadpoles, and juveniles in all survey years, suggesting consistent reproduction is occurring.

3.1.2 Biology and Life History

3.1.2.1 Taxonomy

Goebel et al. (2009, entire) described the *Anaxyrus* (*Bufo*) *boreas* species complex found in western North America as consisting of four different species: (1) The widely distributed western toad (*A. boreas*) and three localized species, (2) Yosemite toad (*A. canorus*), (3) Amargosa toad (*A. nelsoni*), and (4) Black toad (*A. exsul*); however, the authors reported that this species complex is poorly understood and may contain other isolated cryptic species. Dixie Valley toads (*A. williamsi*) were recently described as a new species by Gordon et al. (2017, entire) as part of the *A. boreas* species complex. In short, Gordon et al. (2017, entire) concluded that Dixie Valley toads are a unique species within the *A. boreas* species complex due to morphological differences, genetic information, and its isolated distribution.

In addition to Dixie Valley toads, Gordon et al. (2020, entire) described two other endemic cryptic species of toads that belong to this species complex: (1) Hot Creek toad (*A. monfontanus*), and (2) Railroad Valley toad (*A. nevadensis*). The three newly described toad species have been accepted as valid by the two leading authorative websites: (1) AmphibiaWeb (http://amphibiaweb.org), and (2) Amphibian Species of the World (Frost 2021, entire; http://research.amnh.org/vz/herpetology/amphibia/). All North American toads were removed from the genus *Bufo* and given the genus *Anaxyrus* by Frost et al. (2006, pp. 66–70, 222, 363) because they do not form a monophyletic group and this change in genus has been accepted by the Society for the Study of Amphibians and Reptiles, the accepted authority on amphibian and reptile taxonomy (Table 3.1; Crother et al. 2017, pp. 6–10).

Table 3.1. Hierarchy of main taxonomic ranks, scientific name, and common names of the ranks reviewed in this SSA report.

Taxonomic Rank	Scientific Name and Author	Common Name(s)
Kingdom	Animalia	animal
Phylum	Chordata	vertebrate
Class	Amphibia	amphibians
Order	Anura	frogs and toads
Family	Bufonidae	true toads
Genus	*Anaxyrus*	North American toads
Species	*Anaxyrus williamsi* (Gordon et al. 2017)[1]	Dixie Valley toad

[1]Forrest et al. (2017, entire) also published a paper describing Dixie Valley toads and had similar results but stopped short of concluding it is a unique species. The Service has evaluated both papers and concluded the Gordon et al. (2017, entire) paper provided a better sampling design to answer species level genetic questions and conducted a more thorough morphological analysis. The Service defers to the larger scientific community which has accepted the findings in Gordon et al. (2017, entire).

3.1.2.2 Morphological Description

Gordon et al. (2017, pp. 124–126) measured 14 different morphological characteristics of Dixie Valley toads and compared these to several other species within the *A. boreas* species complex. While all 14 morphological characteristics measured for Dixie Valley toads were significantly different from the other species within *A. boreas* complex, the most striking differences found were the average size of adults (mean snout to vent length (SVL) 54.6 millimeters (2.2 inches), which is the smallest species within the *A. boreas* species complex), the close-set eyes and perceptively large tympanum, and its unique coloration (Figure 3.1, Gordon et al. 2017, pp. 125–131). There is no sexual dimorphism; however, males have nuptial pads on the dorsal side of their thumbs, which is a characteristic of most North American toads (Gordon et al. 2017, pp. 129, 134).

Figure 3.1. Adult Dixie Valley toad. Photo credit: M. Maples, used with permission.

3.1.2.3 Reproduction, Growth, Survival, and Longevity

Limited information is available specific to the life history of Dixie Valley toads; therefore, closely associated species are used as surrogates where appropriate. Breeding (denoted by observing a male and female in amplexus, egg masses, or tadpoles) occurs annually between March and May (Forrest et al. 2013, p. 76). Breeding appears protracted due to the thermal nature of the habitat and can last months with toads breeding early in the year in habitats closer to the thermal spring sources and then moving downstream into habitats as they warm throughout the spring and early summer, which is not typical of other toad species that have a much more contracted breeding season of 3–4 weeks (e.g., Sherman 1980, pp. 18–19, 72–73).

Eggs are laid in double strands, similar to other bufonids (e.g., Muths and Nanjappa 2005, p. 394; Figure 3.2). Mean number of eggs per clutch for Dixie Valley toads is unknown, although female Black toad's mean clutch size was documented to be 1,320 ± 447 eggs (Sherman 1980, p. 107). Dixie Valley toad tadpoles hatch shortly after being deposited; however, time to hatching is not known but is likely dependent on water temperature (e.g., Black toad tadpoles hatch in 7 to 9 days; Sherman 1980, p. 97). Fully metamorphosed Dixie Valley toadlets were observed 70 days after egg laying with a mean SVL of 15.25 mm (0.60 in) and a mean weight of 0.375 grams (0.013 ounce) (Forrest et al. 2013, pp. 76–77), which is comparable to Black toad (Sherman 1980, p. 98).

Dixie Valley toad growth rates, age at maturity, and annual survival estimates and longevity are unknown, and therefore we rely on the related Black toad and Amargosa toad for the best available information for these attributes. Black toad juveniles approximately doubled in size their first summer (15 mm to 30 mm (0.6 to 1.2 in) SVL) and were between 40–45 mm (1.6–1.7 in) by the end of the following year (Sherman 1980, pp. 102–105). Male Black toads mature at age 2 or 3 and most females matured at age 3 (Sherman 1980, pp. 105–107). Annual survival estimates for adult Amargosa toads between 1998–2013 averaged 48 percent and a few toads survived past 10 years during this same timeframe (Kegerries et al. 2019, pp. 5–6, 15).

Figure 3.2. A pair of adult Dixie Valley toads in amplexus with egg stands visible. Photo credit: K. Urquhart, used with permission.

3.1.2.4 Feeding Habits

There is no published information on the feeding habits of Dixie Valley toads. It is assumed that terrestrial Dixie Valley toads are opportunistic feeders, similar to other toad species (e.g., Muths and Nanjappa 2005, p. 395), and most likely consists of the available aquatic and terrestrial invertebrates found in Dixie Meadows. Aquatic larvae are assumed to feed on algae and detritus (e.g., Fellers 2005, p. 407).

3.2 Spring Characteristics and Function

The following section is a general description of spring systems found throughout the Great Basin and surrounding areas. We will explicitly state when a topic is applicable to the springs found in Dixie Meadows. Desert springs support relatively small aquatic and riparian systems as surface flow is maintained by groundwater. They range widely in size, temperature, water chemistry, morphology, landscape setting, and persistence. They occur from mountain tops to valley floors, some of which occur in clusters (defined in this SSA report as spring provinces; see Glossary), and are predominantly isolated from other aquatic and riparian systems. Springs occur where subterranean water under pressure reaches the earth's surface through fault zones, rock cracks, or orifices that occur when water creates a passage toward the surface. In general, most springs are unique based on the province influences of aquifer geology, morphology, discharge rates, and regional precipitation.

Spring hydrology depends on subterranean water flow through aquifers and precipitation that enters the soil and accumulates in aquifers where it is stored; this is influenced by characteristics of regional and local geology, and how water moves through an aquifer. Geologically, the Great Basin in Nevada is broken into valleys by intervening mountain ranges. Most of the valleys contain alluvial sediments that are often permeable aquifers. These valley aquifers are recharged by springtime runoff during snowmelt from adjacent mountain ranges. There are also regional aquifers that facilitate groundwater transport between valleys. Regional aquifer waters are often ancient and are not as affected by annual precipitation as compared to valley aquifers. The regional aquifer below Dixie Valley encompasses multiple valleys including from Jersey and Pleasant Valleys to the North and Fairview and Stingaree Valleys to the south (Huntington et al. 2014, p. 1).

Three aquifer types occur in arid parts of the United States (Sada and Mihevc 2011, pp. 1–2). These aquifers differ primarily in their water transit time or residence time (see Glossary) and water depth, which in turn affects water temperature, water chemistry, and spring discharge. Water emanating from the springs in Dixie Meadows are a combination of these aquifers. Sada and Mihevc (2011, p. 2) describe these aquifers as follows:

- Mountain block aquifer springs have short residence times, so they are cooler and contain fewer dissolved chemical constituents than water in aquifers with longer residence time. These springs are generally small, often ephemeral, and occur in the mountains.
- Local aquifer springs are generally warmer than mountain block aquifer springs and contain higher concentrations of dissolved chemical constituents. Also, springs fed by local aquifers are usually located on alluvial fans near the base of mountains, although

they can occur in the central parts of some valleys, primarily in valleys without springs fed by regional aquifers. Cold springs discharging at Dixie Meadows are primarily this type.

- Regional aquifer springs have long residence times (generally hundreds to thousands of years) as well as high and constant discharge rates, warm temperatures, and elevated concentrations of dissolved chemical constituents. They generally occur on valley floors near the center of a valley. Thermal springs discharging at Dixie Meadows are primarily this type.

A spring's size is generally a function of discharge, which can be affected by precipitation and evapotranspiration. Also, springs can be characterized as an endpoint in a continuous spectrum of groundwater discharge processes (van der Kamp 1995, pp. 5–6), or points of focused groundwater discharge from groundwater flow systems. These flow systems transport groundwater from recharge areas to discharge areas under the influence of gravity. The rate of springflow averaged over several years equals the average rate of recharge to the flow systems that feed the spring. The annual rate of groundwater recharge is always less than the annual precipitation, and can be estimated on the basis of precipitation and evapotranspiration. Overall, any evapotranspiration loss results in reduced flow from springs, which is the principal reason why many small springs dry up entirely during hot, dry weather. There are approximately 122 springs and seeps within Dixie Meadows with varying amounts of discharge from 0.5280 cubic feet per second (cfs) (237 gallons per minute (gpm)) to tiny seeps which are unmeasurable. See Section 3.3.1 (Sufficient Wetted Area) below for more details.

Within a spring's flow system, environmental characteristics (i.e., temperature and dissolved oxygen (DO)) vary depending on proximity to the spring's main source of water, also called the springhead. Environmental variation is typically lowest near the springhead. Variation increases downstream from the springhead with higher variability in temperature, DO concentration, and other factors (Deacon and Minckley 1974, pp. 396–397). As a result, the composition of springhead and downstream communities is usually different, and many species of invertebrates become absent from downstream habitats (Hayford et al. 1995, p. 83; Hershler 1998, p. 11; O'Brien and Blinn 1999, p. 225). In general, water temperature at many springs varies little throughout the year while other factors vary considerably; however, at Dixie Meadows, temperatures and water chemistry can vary depending on where the water is originating from and potentially mixing. Springs found in Dixie Meadows can be characterized as a mix of cold, warm, and hot temperatures due to the water source and variable mixing of the aquifers. Once the water emerges from the ground, the average water temperature and the variability of temperature are controlled by the geometry of the flow system, solar radiation, air temperature, season, and other factors. Groundwater temperatures about 10 m (33 ft) below the surface are typically constant, where the annual fluctuation of surface temperature does not penetrate.

Another environmental characteristic that can vary across springs is water chemistry, which is strongly influenced by aquifer geology (Sada and Pohlmann 2002, p. 2). Unmack and Minckley (2008, pp. 28–29) describe the role that carbon dioxide, bicarbonate, and calcium carbonate provide in spring function. Groundwater often carries carbon dioxide from decomposing organics in strata through which it moves. Carbon dioxide combines with water to form weak carbonic acid, which dissolves calcium carbonate rocks to form bicarbonate. Groundwater gas concentrations vary with pressure and temperature, which are often released when a spring emerges. A result of these processes is deposition of insoluble calcium carbonate as travertine, which produces the hard substrate that armors springbrooks, thus reducing bank erosion and prevents water from either entering or leaving the springbrook (Sada and Cooper 2012, p. 18). Water chemistry within the springs found in Dixie Meadows is variable depending on the source of water and the variable strata in which the water travels before coming to the surface (Huntington et al. 2014, pp. 27–49).

Riparian vegetation within and adjacent to arid springs exhibit unique characteristics due to their distinctive environments as well as colonization and extirpation dynamics that characterize these small, isolated habitats. Riparian vegetation associated with springs may be restricted to the immediate boundaries of a spring's aquatic habitat, or it may follow water that extends outward for substantial distances. Typical vegetation at large and minimally disturbed springs includes sedges (e.g., *Carex* sp.), rushes (e.g., *Juncus* sp.), grasses (e.g., *Distichlis* sp.), and woody phreatophytes (e.g., *Salix* sp. (willows)). The continually waterlogged condition of some springs creates anaerobic conditions that slow decomposition of plant material, which facilitates soil development (Coles-Ritchie et al. 2014, p. 2). See section 3.3.3 (Wetland Vegetation) below for more details on the wetland vegetation communities found in Dixie Meadows.

Freshwater springsnails (e.g., *Pyrgulopsis* sp.) are indicators of spring inhabitants or conditions of spring ecosystems, most of which are characterized by permanent water with variable discharge and flow rates. The most important implication for Dixie Valley toads is the permanent water which both taxa require. Springs that harbor springsnails may have a high mineral content but must be relatively unpolluted (Mehlhop and Vaughn 1994, p. 69). Springsnails have been documented in five of 122 springs and seeps within the Dixie Meadow wetland complex (McGinley and Associates 2020, pp. 3–4).

3.3 Physical and Biological Needs of Dixie Valley Toads

The current condition and potential future condition of Dixie Valley toads is most influenced by those species needs that are critical for survival and reproduction. Based on our review of the best available scientific and commercial information, and the knowledge and expertise of Service staff and other technical experts, we determined the following spring conditions are most critical in influencing the physical and biological needs of Dixie Valley toads: (1) Sufficient wetted area, (2) adequate water temperature, (3) wetland vegetation, and (4) adequate water quality (Figure 3.3 and Table 3.2). When each of these physical and biological needs is satisfied and functioning within Dixie Meadows, a stable population of Dixie Valley toads is expected.

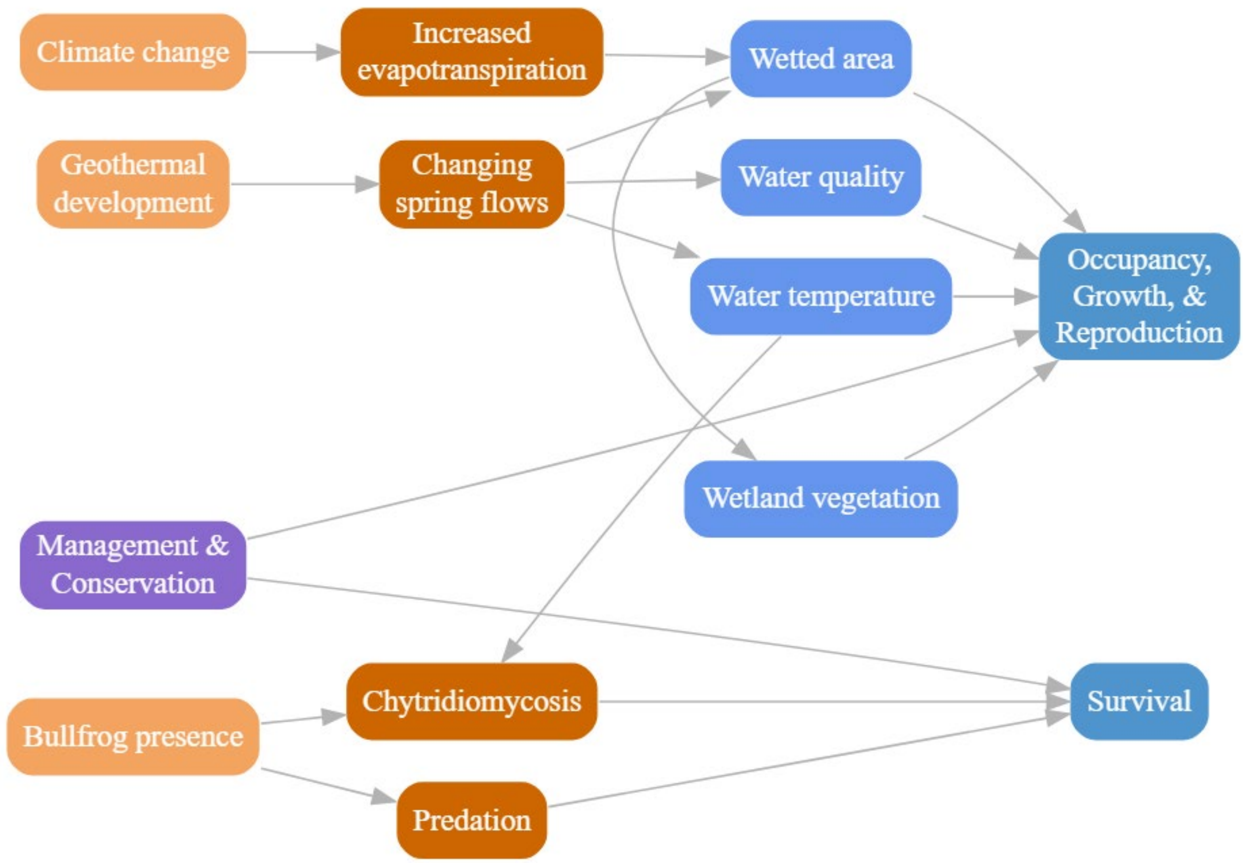

Figure 3.3. Conceptual model of major threats to Dixie Valley toads demographic rates, showing ecological needs in light blue and threats and sources in dark orange and light orange, respectively.

Table 3.2. Physical and biological needs of Dixie Valley toads.

Life Stage	Resource Needs	References
Egg (March-June)	• wetted area within the range of historical data • water temperature within the range of historical data • water quality within the range of historical data • shallow, warm water to breed in, farther away from the spring	Forrest 2013, p. 76 Muths and Nanjappa p. 394
Tadpole (April-July)	• wetted area within the range of historical data • water temperature within the range of historical data	Forrest 2013, p. 74 Muths and Nanjappa p. 394

	• water quality within the range of historical data • algae and detritus	
Juvenile & Non-Breeding Adult	• wetted area within the range of historical data • water temperature within the range of historical data • water quality within the range of historical data • existing, thick vegetation • invertebrates • warm temperatures for brumation	Forrest 2013, pp. 76–77 Halstead et al. 2021, pp. 27–35
Breeding Adult	• wetted area within the range of historical data • water temperature within the range of historical data • water quality within the range of historical data • existing, thick vegetation • invertebrates • warm temperatures for brumation • shallow, warm water to breed in, farther away from the spring	Forrest 2013, pp. 75–76 Halstead et al. 2021, pp. 27–35

3.3.1 Sufficient Wetted Area

Dixie Meadows contains 122 known spring and seep sources (see Figure 2.2) and discharges approximately 1,109,396 cubic meters per year (m^3/yr) (900 acre feet per year (afy)) (McGinley and Associates 2021, pp. 1–2), which distributes water across the wetland complex then flows out to the playa or is collected in a large ephemeral pond in the northeast portion of the wetland complex. Some of the larger springs have springbrooks that form channels while in other areas the water spreads out over the ground or through wetland vegetation creating a thin layer of water or wet soil that helps maintain the wetland. Dixie Valley toads are a highly aquatic species and is rarely found more than 14 m (46 feet (ft)) away from water (Halstead et al. 2021, pp. 28, 30). Any change in the amount of wetted area will directly influence the amount of habitat available to Dixie Valley toads. Due to the already restricted range of the habitat, the species needs to maintain the 1.46 km^2 (360 ac) potential area of occupancy, based on the extent of the wetland-associated vegetation.

Adequate spring discharge is inherently linked to the amount of wetted area within the wetland complex. Adequate spring discharge is important for the viability of Dixie Valley toads and changes to discharge rates may impact the ability of the toad to survive in a particular spring complex. In the assessment of the current condition of this factor, we assume that spring discharge is adequate if the species is observed in a spring complex. Decreases in spring discharge will reduce habitat in the wetland complex and render certain areas uninhabitable if water becomes absent.

Groundwater discharge through evapotranspiration from wetland vegetation and the playa has been estimated at 8,628,640–34,514,560 m^3/yr (7,000–28,000 afy) (Harrill and Hines 1995) and 28,351,246 m^3/yr (23,000 afy) (Garcia et al. 2015, p. 75). Total spring discharge in Dixie Meadows is estimated at 1,220,336 m^3/yr (990 afy) (McGinley and Associates 2021, pp. 1–2). Discharge can vary seasonally and annually depending on precipitation and evapotranspiration among other factors. Limited information exists on the seasonal/annual variability of discharge at any given spring found within the Dixie Meadows wetland (Table 3.3).

Table 3.3. Existing discharge data for select springs based on Table 9 in (McGinley and Associates 2021, p. 65).

Site ID	Date	Discharge (gpm)	Discharge (cfs)
USGS-101	29-May-2019	15.3	0.0341
NDOWSS-1	23-Oct-2009	191	0.4256
	08-Mar-2011	177	0.3944
	24-Jun-2011	107	0.2384
	29-May-2019	146	0.3253
Spring 4	29-May-2019	40.7	0.0907
Spring 6	29-May-2019	26.2	0.0584
Dixie Spring complex confluence	26-Oct-2011	162	0.3609
	04-May-2012	237	0.5280
	29-May-2019	144	0.3208
Western Playa	29-May-2019	132	0.2941

3.3.2 Adequate Water Temperature

In addition to Dixie Valley toads being highly aquatic, the temperature of the water is also important to its life history. Dixie Valley toads select areas that are warmer than other surrounding habitat available to them, particularly in spring, fall, and winter months (Halstead et al. 2021, pp. 30, 33–34). In the spring, Dixie Valley toads select areas with warmer water for breeding (oviposition sites), which allows for faster egg hatching and time to metamorphosis. In the fall, Dixie Valley toads select different areas (closer to thermal springs with dense vegetation), which satisfies their thermal preferences as nighttime temperatures decrease. As they enter into winter months, toads find areas with consistent warm temperatures during brumation so they do not freeze (Halstead et al. 2021, pp. 30, 33–34). This affinity for warm water temperature during brumation is unique to Dixie Valley toads as compared to other species within the *A. boreas* species complex, the latter of which selects burrows, rocks, logs, or other structures to survive through winter (Browne and Paszkowski 2010, pp. 53–56; Halstead et al.

2021, p. 34). Therefore, Dixie Valley toads need water temperatures warm enough to successfully breed and survive colder months during the year.

Spring water temperatures recorded mostly in May 2012 are provided in Table 3.4 (Schwering 2013, p. 25; McGinley and Associates 2021, pp. 57–62). The maximum temperature recorded at Dixie Hot Springs (located in Complex 2) in monitoring data from 2015–2020 was 74 °C (165 °F) (McGinley and Associates 2021, pp. 59, 207–208). Five different springs have monthly data that show some have stable temperatures while others indicate variable temperatures (Figure 3.4; McGinley and Associates 2021, pp. 57–62). Water temperatures measured in 2019 at toad survey sites throughout Dixie Meadows (i.e., not at springheads) ranged from 10–41 °C (50–106 °F), with a mean and standard deviation of 16.9 ± 6.1 °C (62.4 ± 22.0 °F) (Halstead and Kleeman 2020, entire).

Table 3.4. Summary statistics for spring water temperatures collected in summer 2012, 2018, and 2019 by wetland complex (Schwering 2013, p. 25; McGinley and Associates 2021, pp. 57–62, 207–208).

Spring Complex	No. springs	Median °C (°F)	Range °C (°F)	No. measurements
1A	6	22 (72)	19–28 (66–82)	5
1B	9	17 (63)	16–17 (61–63)	2
2	21	60 (140)	39–74 (102–165)	22
3	22	48 (118)	16–61 (61–142)	18
4	33	45 (113)	32–56 (90–133)	10
5	7	25 (77)	17–34 (63–93)	9
6	8	14 (57)	13–15 (55–59)	2

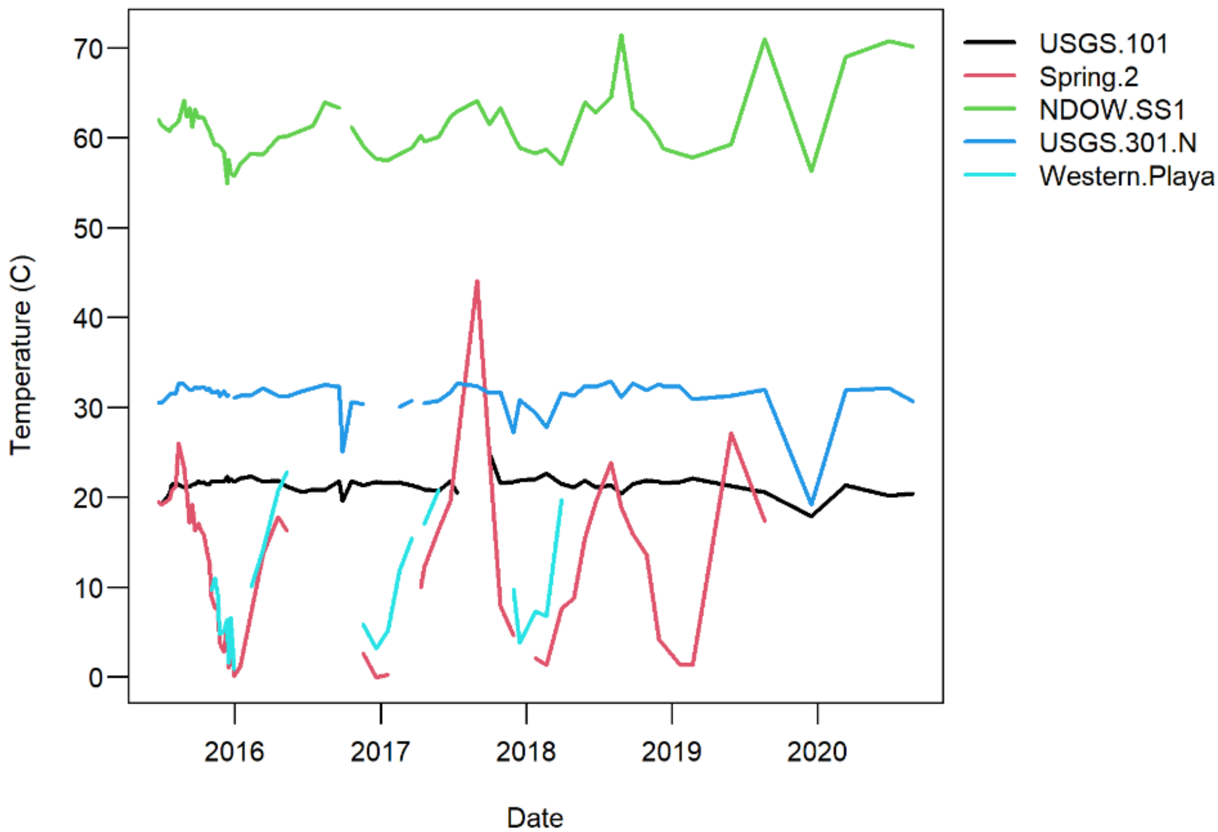

Figure 3.4. Continuous water temperature measurements at five different springs within Dixie Meadows based on Table 7 in McGinley and Associates (2021, pp. 57–62).

3.3.3 Wetland Vegetation

Dixie Meadows is an oasis surrounded by an extremely dry, desolate landscape. Looking at Dixie Valley as a whole, which comprises 45,439 hectares (112,282 acres) of phreatophyte area (i.e., area containing deep-rooted plants that absorb water from a constant source of surface or groundwater and where the water table is near the surface), remote sensing reveals 86 percent of the valley is composed of drylands (big sagebrush and shrubland and steppe, greasewood shrubland, desert scrub, salt desert scrub and sparse vegetation), 6.2 percent as wetland/riparian vegetation (depressional wetland, freshwater marsh, western riparian woodland and shrubland and open water), and 7.8 percent disturbed/developed areas (various agriculture and introduced vegetation) (Albano et al. 2021, p. 68). The most common wetland vegetation found within Dixie Meadows comprises 308 hectares (760 acres) and includes *Juncus balticus* (Baltic rush), *Schoenoplectus* spp. (bulrushes), *Phragmites australis* (common reed), *Eleocharis* spp. (spikerushes), *Typha* spp. (cattails), *Carex* spp. (sedges), and *Distichilis spicata* (saltgrass) (AMEC Environment and Infrastructure 2014, p. I-1; Tierra Data 2015, pp. 2-25–2-29; McGinley and Associates 2021, pp. 50–52, 93–99). Several species of invasive and nonnative plants also occur in Dixie Meadows including *Cicuta maculate* (water hemlock), *Cardaria draba* (hoary cress), *Lepidium latifolium* (perennial pepperweed), *Eleagnus angustifolius* (Russian olive) and *Tamarix ramosissima* (saltcedar) (AMEC Environment and Infrastructure 2014, p. 3-59). Dixie Valley toads need sufficient wetland vegetation to use as shelter. Toads are not choosing vegetation disproportionately from the available vegetation; however, they are avoiding bareground. At a minimum, maintaining the current heterogeneity of the wetland vegetation found in Dixie Meadows is an important consideration for conserving Dixie Valley toads (Halstead et al. 2021, p. 34).

3.3.4 Adequate Water Quality

Amphibian species spend all or part of their life cycle in water; therefore, water quality characteristics can directly affect amphibians. Temperature (discussed in section 3.3.2), DO, pH, salinity and water conductivity, and excessive nutrient concentrations (among others) have all been shown to have direct and indirect impacts to amphibian species when found to be outside of naturally occurring levels for any particular location (Sparling 2010, pp. 105–117).

Various water quality data have been collected from a few springs within Dixie Meadows including and from wells drilled during geothermal exploration activities (McGinley and Associates 2021, pp. 57–64). The exact water quality parameters preferred by Dixie Valley toads is unknown; however, this species has evolved only in Dixie Meadows and is presumed to thrive in the current existing complex mix of water emanating from both the basin-fill aquifer and the deep geothermal reservoir. Within the unique habitat in Dixie Meadows, and given the life history and physiological strategies employed by Dixie Valley toads, a good baseline of existing environmental water quality factors that are most important for all life stages should be studied (Rowe et al. 2003, pp. 957). Maintaining the natural variation of the current water quality parameters found in Dixie Meadows is an important consideration for conserving Dixie Valley toads.

Table 3.5. Range of values for various water quality measurements from several springs within Dixie Meadows. Modified from McGinley and Associates 2021 (pp. 57–64).

Site ID	TDS (mg/L)	DO (%)	DO (mg/L)	pH
USGS 101	358–688	53.5	4.81	7.83–8.36
Spring 2	461–1313	17.2	1.54	6.34–8.02
NDOW-SS1	487–1688	4.7	0.18	7.52–8.52
Spring 4	469–727	1.4	0.05	7.97–9.17
Spring 5A	425–465	17.9	0.78	7.9–9.18
Spring 5B	433–787	107	6	8–9
Spring 6	917–1936	50	2	7–8
Spring 7	568–1291	22	1	8
Spring 8	677–1085	11	1	7–8
USGS-301 North	500–996	–	–	7.78–8.74
USGS-301 Salt Cedar	530–1029	74.2	6.14	7–8.15
MW-1	1520–4588	51	4	8
Western Playa	1,900	–	–	9.56
Eastern Playa	3,100	–	–	9.2
Dixie Spring Complex Confluence	590	–	–	8.52

3.4 Unknowns

Dixie Valley toads have received relatively little attention regarding their ecology and conservation relative to other amphibians. Much of the early investigations involved understanding taxonomic relationships and species description. Outside of taxonomy, few ecological studies have directly addressed Dixie Valley toads, but major life-history traits and threats are presumed to be similar across the *A. borea*s species complex. Unknown life history traits and resource needs identified above that may influence the current or future conditions of the species include longevity, annual survival, and recruitment success.

4.0 FACTORS THAT MAY INFLUENCE SPECIES NEEDS

In order to analyze the current condition of Dixie Valley toads and their habitat, an understanding of potential factors impacting the physical and biological needs is necessary. These potential factors include how groundwater and surface water reach the Dixie Meadows springs, and what threats influence the availability of groundwater. This includes how water is managed in Nevada, and how existing regulatory and voluntary conservation measures may reduce impacts from these threats.

4.1 Hydrology and Water Management Considerations

4.1.1 Hydrology

The numerous springs and spring provinces in the Dixie Meadows discharge area represent a unique feature in Dixie Valley. Outside of the Dixie Meadows wetland, the surrounding landscape is characterized by expansive xeric habitats nearly devoid of surface water. Surface water flowing from Dixie Meadows springs are formed from a combination of shallow basin-fill aquifer, mainly recharged from atmospheric contributions which fall on the Stillwater Range, and a deep geothermal reservoir (Huntington et al. 2014, p. 2). Springs with temperatures less than 20 °C (68 °F) generally have no geothermal influence and are considered to come from basin-fill, springs with temperatures greater than 20 °C (68 °F) and less than 50 °C (122 °F) have a mixture of basin-fill and geothermal water, and springs with temperatures greater than 50 °C (122 °F) are considered to be from a geothermal reservoir only, with little influence from basin-fill water (Huntington et al. 2014, p. 39). Researchers also use known chemical indicators to determine where spring water is originating (basin-fill versus geothermal) as another line of evidence. Springs found within Dixie Meadows have all three temperature ranges described above and chemical indicators which suggest a complex interaction between the basin-fill aquifer and the geothermal reservoir (Huntington et al. 2014, pp. 39–43; McGinley and Associates 2021, p. 6). The hottest springs are located within spring complex 2 and 3 (Figure 2.2; McGinley and Associates 2021, pp. 57-62, 207–208).

4.1.2 Water Management

Water management in Nevada is administered by the State Engineer from the Nevada Division of Water Resources (NDWR). Groundwater management is divided into and administered by groundwater basin (Nevada Department of Conservation and Natural Resources (DCNR) 2017, entire). To ensure the amount of groundwater withdrawn from a basin over a period of time does not exceed the long-term recharge of the basin, the State Engineer designates basins to reflect water resources based on the extent of water development and water use, and the appropriation of water rights (DCNR 2017, entire). Any use of water requires a state permit with two exceptions. The first exception is that domestic wells do not require permits if the well uses less than 6,814 liters (1,800 gallons) of water per day (Nevada Division of Water Planning 1999, p. 8-3). Although domestic wells do not require a permit, some oversight is provided by the requirement of a permit to drill a new well (Welden 2003, p. 8). The second exception is permits are not required for those uses that pre-date water law requirements (DCNR 2017, entire).

In Nevada, the Nevada State Engineer identifies basins as designated or not designated based on the concept of perennial yield. Perennial yield is defined as the maximum amount of groundwater that can be salvaged each year over the long-term without depleting the groundwater reservoir (DCNR 2017, entire) and is measured in acre feet per year (afy). Perennial yield cannot be more than the natural recharge of the groundwater reservoir and is usually limited to the maximum amount of natural discharge. In some areas, natural discharge in the form of spring discharge may be appropriated already as surface water, although the perennial yield estimate may still include this water (DCNR 2017, entire). Groundwater seepage or discharge may help sustain ecosystems in other areas (DCNR 2017, entire).

The Nevada State Engineer identifies a basin as designated if a determination is made that further administration of the basin is needed (Welden 2003, p. 8). This typically occurs when water use is approaching or exceeding water recharge (Welden 2003, p. 8). By identifying a basin as designated, the Nevada State Engineer is granted additional authority in the administration of the groundwater resources within the designated basin. In basins where groundwater is being depleted, the Nevada State Engineer may issue orders, regulations, or rules to ensure that water use and recharge are balanced (Welden 2003, p. 8). Orders, regulations, and rules may include identifying preferred water uses, prohibiting the drilling of new domestic wells, monitoring pumping inventories, declaring critical management areas, and using other management tools (Welden 2003, p. 8; DCNR 2017, entire).

The springs at Dixie Meadows are included in Hydrographic Area (HA) 128, Dixie Valley, and are located within a designated basin (O-715). The estimated perennial yield for this basin is 18,489,943 m^3/yr (15,000 afy) and currently, there are 18,758,663 m^3/yr (15,218 afy) of appropriated consumptive groundwater rights in HA 128 (NDWR 2021, entire). Geothermal groundwater appropriations are not considered consumptive by NDWR since geothermal water must be reinjected into the aquifer. Total geothermal water rights appropriated in Dixie Valley is 15,659,749 m^3/yr (12,704 afy) (NDWR 2021, entire).

4.2 Threats Affecting Dixie Valley Toads and Their Habitat

We determined the following threats (Figure 4.1) may impact specific Dixie Valley toad needs (Chapter 4) and ultimately the resiliency of the Dixie Valley toad population (Chapters 5 and 6). We also describe the general potential effects of these threats on the needs of Dixie Valley toads.

4.2.1 Geothermal Development

Geothermal resources are reservoirs of hot water or steam that are found at different temperatures and depths below the ground. These geothermal reservoirs can be used to produce energy by drilling a well and bringing the heated water or steam to the surface. Geothermal energy plants use the steam or heat created by the hot water to drive turbines that produce electricity. There are three main technologies being used today that convert the geothermal water into electricity: dry steam, flash steam, and binary cycle. Binary technology is the focus for this analysis since that is the type of geothermal power technology that has been approved for development at Dixie Meadows.

Binary cycle power plants use the heat from the geothermal reservoir, which heats a secondary fluid (e.g., butane) that generally has a much lower boiling point than water. This process is accomplished through a heat exchanger, and the secondary fluid is flashed into vapor by the heat from the geothermal fluid; the vapor drives the turbines to generate electricity. The geothermal fluid is then reinjected back into the ground to maintain pressure and be reheated.

General impacts from geothermal production facilities are presented below. Because every geothermal field is unique, it is difficult to predict what influence from geothermal production may occur.

Prior to geothermal development, the flow path of water underneath the land surface is usually not known with sufficient detail to understand and prevent surface impacts (Sorey 2000, p. 705). Changes associated with surface expression of thermal waters from geothermal production are common and are expected. Typical changes seen in geothermal fields across the globe include, but are not limited to, changes in water temperature, flow, and water quality, which are all needs of Dixie Valley toads (Sorey 2000, entire; Bonte et al. 2011, pp. 4–8; Kaya et al. 2011, pp. 55–64; Chen et al. 2020, pp. 2–6).

Changes in temperature and flow from geothermal production areas are documented throughout the western United States (Sorey 2000, entire). For example:

(1) Long Valley Caldera near Mammoth, California. Geothermal pumping between 1985-1998 resulted in several springs ceasing to flow and declines in pressure of the geothermal reservoir, which has caused reductions of 10-15 °Celsius (C (50-59 °Fahrenheit (°F)) in the reservoir temperature and a localized decrease of approximately 80 °C (176 °F) near the reinjection zone (Sorey 2000, p. 706).

(2) Steamboat Springs near Reno, Nevada. Geothermal development of this area resulted in the loss of surface discharge (geysers and springs) on the main terrace and a reduction of thermal water discharge to Steamboat Creek by 40 percent (Sorey 2000, p. 707).

(3) Northern Dixie Valley near Reno, Nevada. Other common changes that accompany the loss of surficial water sources, such as geysers and thermal springs, from geothermal production include an increase in steam discharge and land subsidence (Sorey 2000, p. 705). Both steam discharge and land subsidence were detected at an existing 56 megawatt (MW) geothermal plant in northern Dixie Valley, Nevada, which has been in production since 1985 (Sorey 2000, p. 708; Huntington et al. 2014, p. 5). The northern Dixie Valley geothermal plant

began pumping water from the cold basin fill aquifer (local aquifer) and reinjecting it above the hot geothermal reservoir (regional aquifer) to try and alleviate land subsidence issues (Huntington et al. 2014, p. 5). This approach may have led to an increase in depth to groundwater from 1.8 m (6 ft) in 1985 to 4.3–4.6 m (14–15 ft) in 2009–2011 (Albano et al. 2021, p. 78). (Albano et al. 2021, p. 78).

(4) Jersey Valley near Reno, Nevada. In 2011, a 23.5 MW geothermal power plant started production in Jersey Valley, just north of Dixie Valley. Measured springflow of 0.08–0.17 cubic feet per second (cfs) (35–75 gallons per minute (gpm)) at a perennial thermal spring began to decline almost immediately after the power plant began operation (BLM 2022, p. 1; Nevada Department of Water Resources (NDWR) 2022, unpublished data). By 2014, the Jersey Valley Hot Spring ceased flowing (BLM 2022, p. 1; NDWR 2022, unpublished data). The loss of aquatic insects from the springbrook has diminished the foraging ability of 8 different bat species which occur in the area (BLM 2022, p. 28). To mitigate for the spring going dry, the BLM proposed to pipe geothermal fluid 1.1 km (3,600 ft) to the spring source (BLM 2022, p. 8); however, mitigation has not yet occurred. If a similar outcome were to occur in Dixie Meadows, resulting in the complete drying of the springs, the Dixie Valley toad would likely be extirpated if mitigation to prevent the drying of the springs is not satisfactorily or timely achieved.

In an effort to minimize changes in water temperature, water quantity and quality, and to maintain pressure of the geothermal reservoir, geothermal fluids are reinjected into the ground. This practice entails much trial and error in an attempt to equilibrate subsurface reservoir pressure. It can take several years to understand how a new geothermal field will react to production and reinjection wells; however, reinjection does not always have the desired effect (Kaya et al. 2011, pp. 55–64).

Geothermal environments often harbor unique flora and fauna that have evolved in these rare habitats (Boothroyd 2009, entire; Service 2019, entire). Changes to these rare habitats often cause declines in these endemic organisms or even result in the destruction of their habitat (Yurchenko 2005, p. 496; Bayer et al. 2013, pp. 455–456; Service 2019, pp. 2–3). Because Dixie Valley toads rely heavily on wetted area and water temperature to remain viable, reduction of these two resource needs could cause significant declines in the population and changes to its habitat that are not likely to benefit the species. Geothermal energy production has been cited as the greatest threat to the persistence of Dixie Valley toads (Forrest et al. 2017, pp. 172–173; Gordon et al. 2017, p. 136; Halstead et al. 2021, p. 35).

4.2.2 Background on the Dixie Meadows Geothermal Project

In addition to 50 active geothermal leases within Dixie Valley in Churchill County (Figure 4.1), two geothermal exploration projects were approved in Dixie Meadows in 2010 and 2011 (BLM 2010, entire; BLM 2011, entire). Most recently, on November 23, 2021, the BLM approved the Dixie Meadows Geothermal Utilization Project (BLM 2021, entire). The following is a timeline of the NEPA coordination:

- 5/9/2017 Dixie Meadows Geothermal Utilization Project EA Issued
- 6/23/2017 Meeting with BLM

- 6/30/2017 Service Comment Letter and Comment Matrix on Draft EA submitted to BLM
- 7/19/2018 Service, DoD, BLM, Ormat meet on Dixie Meadows to start development of Aquatic Resources Monitoring and Mitigation Plan (Monitoring and Mitigation Plan)
- From 2019 -2021 BLM, Ormat and Service met to discuss technical details relating to the EA and Monitoring and Mitigation Plan. Ormat provided drafts, and Service provided comments on each draft.
- 1/13/2021 Dixie Meadows Geothermal Utilization Project Revised EA published including Monitoring and Mitigation Plan
- 2/12/2021 Service submits comments to BLM on EA, including Monitoring and Mitigation Plan during 30 day comment period
- 11/5/2021 BLM sends Service "August 2021 Final EA" including Monitoring and Mitigation Plan
- 11/16/2021 Service submits recommendations for the proposed project
- 11/23/2021 BLM issues Decision Record approving project subject mitigation and monitoring requirements

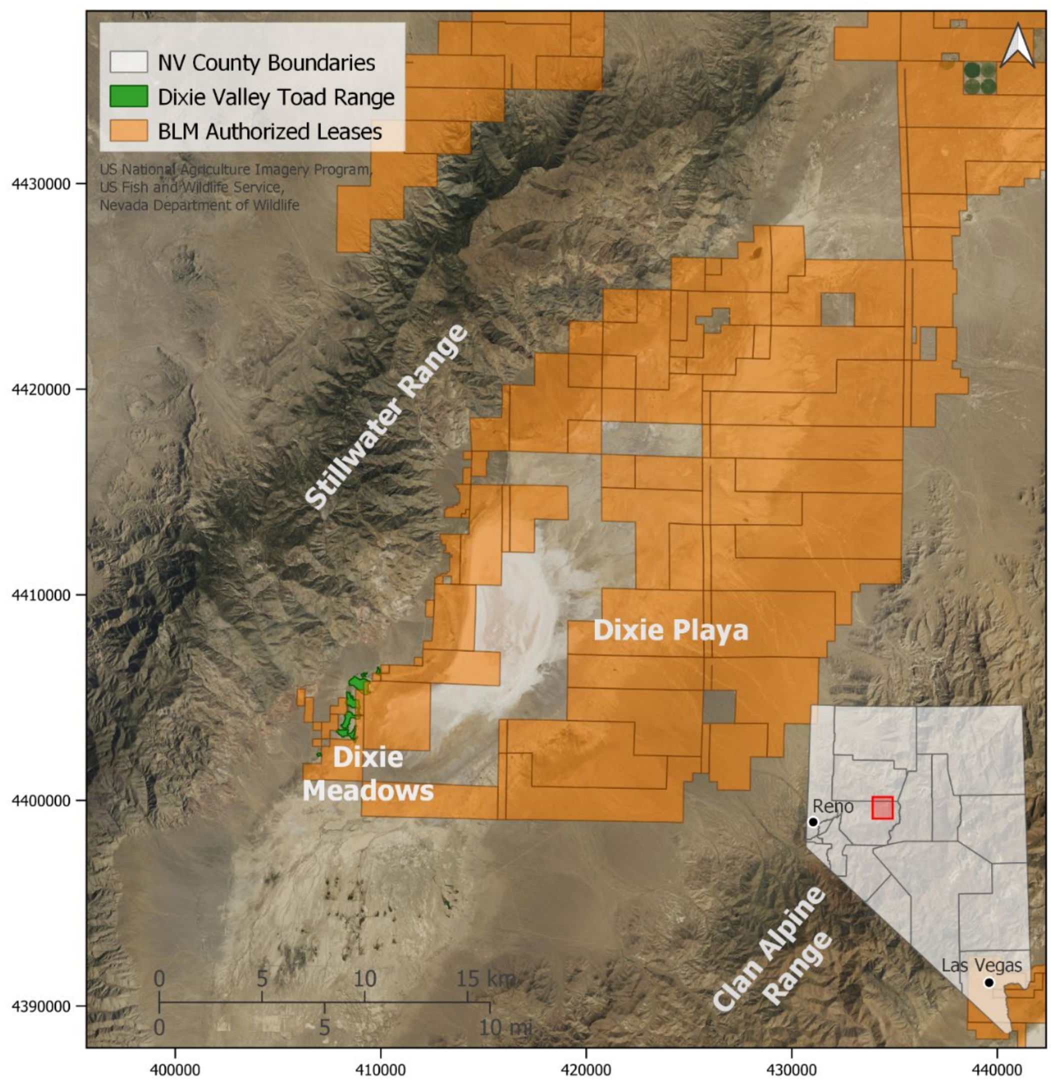

Figure 4.1. Currently authorized geothermal leases in Dixie Valley, Churchill County, Nevada.

Data available from the Bureau of Land Management at <https://data.doi.gov/dataset/blm-nv-geothermal-authorized-leases>. Accessed November 24, 2021.

The following is a brief summary of the approved geothermal project: "ORNI 32 LLC (ORNI 32), a subsidiary of Ormat, proposes to construct up to two 30 MW geothermal power plants 6.5 hectares (16 acres) each; construct up to 18 well pads (107 x 114 m (350 x 375 ft)), upon which up to three wells per pad may be drilled for exploration, production, or injection; construct and operate pipelines to carry geothermal fluid between well fields and the power plant(s); and construct either a 120 kilovolt (kV) or a 230 kV transmission gen-tie and associated access roads and structures" (BLM 2021, p. 1-1). "Based upon data from other Ormat facilities, the total geothermal fluid production rate for each Dixie Meadows facility would be up to about 2.9 million kg per hour (6.4 million pounds per hour) per plant at a rate of 53,000 liters per minute (14,000 gpm) per plant at an average temperature of 149 °C (300 °F). Production well flow rates are expected to range from approximately 7,570–11,356 liters per minute (2,000–3,000 gpm) per well, based on five or six production wells (BLM 2021, p. 2-17). All the geothermal fluid brought to the power plant would be injected back into the geothermal reservoir. The injection location, pressure, and the volume injected per well, would depend on the permeability of each well's injection zone. The total estimated injection rate into the injection wells would be similar to the production rate, but slightly lower volume due to fluid contraction due to cooler temperatures (typical minimum temperature of 65.5–76.6 °C (150–170 °F). Injection rates would depend on the final number of injection wells installed, as well as the permeability of each well's injection zone" (BLM 2021, p. 2-17).

In addition to the proposed action, an Aquatic Resources Monitoring and Mitigation Plan (ARRMP; McGinley and Associates 2021, entire) has been developed and is provided as an appendix in BLM's Environmental Assessment (BLM 2021, entire). A general overview of the Monitoring and Mitigation Plan is provided below. "The goal of the Monitoring and Mitigation Plan is to identify hydrologic and biologic resources, spring-dependent ecosystems, aquatic habitat, and special status species, and describe the plan that Ormat would implement to monitor and mitigate potential impacts to those resources and ecosystems associated with its future geothermal exploration and production/injection in the Dixie Meadows area" (McGinley and Associates 2021, p. 1). "This ARMMP identifies a framework of proposed adaptive management actions and mitigation measures based on monitoring results, baseline conditions and triggers, as well as thresholds based on the current understanding of the natural variability of hydrological and biological conditions, and the potential importance to special status species in Dixie Meadows. Adaptive management and mitigation are tied to the parameter range identified for hydrologic conditions, special status species, and aquatic habitat sustainability. If potential changes are detected in baseline conditions and threshold values are exceeded, a proactive set of adaptive management actions and mitigation would be implemented with the goal of preventing any potential impacts to hydrologic resources, special status species, or aquatic habitat. Management actions would initially concentrate on early detection of changes in baseline conditions. In the event that changes to baseline conditions are occurring or thresholds are being exceeded, adaptive management and mitigation measures would be implemented to avoid and minimize risk of potential impacts to hydrologic resources, aquatic habitat, and special status species. Management actions may include geothermal reservoir pumping and injection adjustments, such as redistribution of injection between shallow and deep aquifers. If more aggressive actions are necessary, mitigation measures have been identified and may include augmenting impacted springs with geothermal fluids or fresh water at a quality and quantity sufficient to restore pre-production temperature, flow, stage, and water chemistry. The ARMMP establishes an adaptive management approach. It would require continuous monitoring and data collection to support thresholds and mitigation measure implementation and modifications for the life of the Dixie Meadows project. In the event mitigation actions are not sufficient for protection of species and habitat, pumping and injection would be suspended until appropriate mitigation through adaptive management is identified, implemented, and shown effective to maintain appropriate conditions" (McGinley and Associates 2021, pp 3–4).

4.2.3 Baseline Information

As mentioned above, two geothermal exploration projects were approved by the BLM in 2010 and 2011 (BLM 2010, entire; BLM 2011, entire); however, required monitoring and baseline environmental surveys for those exploration projects did not occur (BLM 2021, pp. 3-17–3-18). Limited monitoring and baseline environmental information (e.g., water quality metrics data such as flow, water temperature, and water pressure) was collected between 2016–2021 and little continuous data was obtained. Most of the information collected during this timeframe were singular measurements taken quarterly or annually which does not characterize the variability in environmental conditions observed in Dixie Meadows.

The Service and other agencies have provided comments to the BLM regarding the Monitoring and Mitigation Plan which was first provided to agencies in January 2021. We continue to offer suggestions to improve the Monitoring and Mitigation Plan; however, given the approval of the project by BLM, onsite construction beginning on or about February 14, 2022, and inadequate time to collect relevant baseline information prior to beginning operation of the plant, we, and experts, believe the Monitoring and Mitigation Plan needs further refinement to adequately detect and respond to changes in the wetlands and the Dixie Valley toad population. The ability of the Monitoring and Mitigation Plan to detect changes in baseline conditions and the proposed minimizing measures are further discussed below and in Appendix A.

One expert in the expert elicitation panel, described below in Section 4.2.4 and Appendix A, commented that there was "Limited baseline data and high natural variability and monitoring plan does not seem to take variability into account sufficiently." Another expert agreed, stating that "the bulk of their uncertainty was below 50 because to make accurate assessments of a noisy system you need long term baseline data, which seems lacking here. Also, no statistical approach was outlined for how to detect these changes and test whether they deviate from baseline conditions." A third expert says the "mitigation plan is short, doesn't give the information needed to evaluate it's impacts." And a fourth expert says that there was "insufficient baseline monitoring and poorly conceived."

4.2.4 Expert Knowledge Elicitation

This analysis used a modified version of the Sheffield Elicitation Framework (SHELF), which follows established best practices for eliciting expert knowledge (Gosling 2018, entire; O'Hagan 2019, pp. 73–81; Oakley and O'Hagan 2019, entire). A critical step in an expert knowledge elicitation is identifying and recruiting the appropriate expert panel, which typically contains between 4–8 participants in the SHELF protocol (O'Hagan 2019, p. 74). The use of multiple experts provides decision makers with a diversity of perspectives and helps reduce the risk of overconfidence in judgments by any single expert. Potential experts were identified and invited following best practices for expert knowledge elicitation (Burgman 2016, entire; Dias et al. 2018, pp. 393–443).

The relevant areas of expertise we sought to include were hydrology (surface and groundwater), geology, geothermal development, climate effects, and experience in the Dixie Valley system. To ensure that the expert knowledge represented unbiased and diverse judgments related to potential habitat changes in Dixie Meadows, the selection process prioritized experts not affiliated with the Service (decision maker), Bureau of Land Management (permitting authority), or developers for the proposed geothermal project. Potential participants were identified by searching the peer-reviewed literature using combinations of the terms Dixie Valley, geothermal, development, hydrology, hydrogeologic, and groundwater, or through recommendations by previously identified experts. Out of 19 identified experts, nine were contacted and six agreed to participate. The workshop panelists are shown in Table 4.1. All participants met the following criteria to ensure relevant scientific expertise:

1. Hold a graduate degree in hydrology, geology, geophysics, geothermal energy, or related disciplines.
2. Hold a research position in government, academia, or the non-profit sector, or a position in a management agency with responsibility for groundwater-dependent resources.
3. Have a record of peer-reviewed publications, technical reports, or scientific presentations on hydrology, geology, geophysics, or geothermal energy development within the Great Basin.

Table 4.1. The names, professional titles, affiliations, and areas of expertise of the six panelists used in the expert knowledge elicitation.

Name	Title	Affiliation	Areas of Expertise
James Faulds, PhD	Director, State Geologist, and Professor	Nevada Bureau of Mines and Geology and the Department of Geological Sciences and Engineering, University of Nevada, Reno	Structural geology, fault controls on fluid dynamics, and geothermal activity in the Great Basin
Drew L. Siler, PhD	Research Geologist	US Geological Survey, Minerals, Energy, and Geophysics Science Center	Structural geology, fluid flow in geothermal systems
Jerry Fairley. PhD	Professor, Department Head, and Professional Geologist	University of Idaho, Department of Geography and Geological Sciences	Characterization and modeling of geothermal systems, with emphasis on fault-controlled hydrothermal systems

Jenna Huntington, MS	Hydrologist	US Geological Survey, Nevada Water Science Center	Hydrogeology, basin water budgets, geothermal and shallow aquifer connectivity
Christine Albano, PhD	Assistant Research Professor	Desert Research Institute	Ecohydrology, response of meadow and riparian vegetation to climate variability
Mark Hausner, PhD	Associate Research Professor	Desert Research Institute	Near-surface environmental heat transfer processes, groundwater-surface water interactions

This expert panel consisted of a multidisciplinary group with backgrounds in the geologic structure of basin and range systems, various components of deep and shallow groundwater flow, as well as geothermal exploration and development. All panelists have direct experience in the Great Basin, and most in Dixie Valley and Dixie Meadows, specifically. Due to the complexity of the hydrologic system at Dixie Meadows, this range of expertise and backgrounds was needed to capture all factors that may affect the hydrology of the meadows. Experts were provided training in quantifying personal beliefs using materials provided with the SHELF protocol (Oakley and O'Hagan 2019, entire). The workshop began with a practice quantity of interest (the depth of fluid circulation at Dixie Meadows in meters below ground) before experts provided judgments in support of this SSA. The elicitation workshop was carried out remotely using a series of three-hour video conferencing calls (14 hours total) between August 17–20, 2021.

The expert panelists requested that quantities 1–4 be discussed first to provide a common understanding of the natural response time of the system and the expected efficacy of the monitoring and mitigation plan. Quantities 5–6 were then defined based on the results of the previous quantities. Changes in water temperature and springflows were specified for the core wetland complexes (2–5) because of the expectation that the timing and magnitude of change will vary spatially throughout the meadows (Figure 2.2). A facilitated discussion was then used to understand how projected changes may differ in the peripheral wetland complexes (1 and 6) or under a future scenario with no geothermal development.

4.2.5 Recording Expert Judgments

For each quantity of interest, experts were first provided a summary of the existing data to reduce the availability bias (see Chapters 3 and 4). Experts received an evidence dossier synthesizing relevant literature and the proposed Dixie Meadows Geothermal Utilization Project and had the opportunity to add additional data or references prior to the workshop. During the individual judgment round, experts provided private judgments for each of the quantities of interest. This approach begins by specifying an upper and lower plausible limit to counter overconfidence and anchoring effects (O'Hagan 2019, p. 75). The median value is then estimated by dividing the plausible limits into two equally probable parts following the bisection method

(Raiffa 1968, pp. 161–168). This bisection procedure is then repeated to specify an upper quartile and lower quartile using the previously specified median value and plausible limits. Judgments were submitted via an online form and probability distributions were fit by minimizing the sum of squared differences between elicited and fitted probabilities along the cumulative distribution function using the SHELF package in R (Oakley 2019, entire).

Experts were then led through a facilitated group discussion where they provided the reasoning for their judgments, including which factors were of greatest concern or generated the most uncertainty. During the group judgment round, experts were asked to provide new quartiles from the perspective of a Rational Impartial Observer (RIO) who had listened to the group discussion and understood their arguments (O'Hagan 2019, pp. 77–78). Each expert privately provided a RIO judgment using the same procedure described above, and a linear pool of the fitted distributions was used to select the final RIO quartiles. This slight modification to the original SHELF protocol was necessary to avoid a single group judgment to ensure compliance with the Federal Advisory Committee Act. Finally, an appropriate family of probability distribution was fit to these quartiles to represent the collective uncertainty surrounding the quantity.

4.2.6 Results of Expert Knowledge Elicitation

A complete record of the expert knowledge elicitation workshop, along with notes from the discussions is provided in Appendix A. The following is a brief summary highlighting the key points relevant to assessing the future risk to Dixie Valley toads. The expert panelists believe that the Dixie Meadows spring province will respond quickly once geothermal energy production begins, with a median response time of roughly 4 years and a 90 percent chance that the largest magnitude changes will occur within 10 years (Figure 4.2; Appendix A). Uncertainty within individual judgments on response time was related to the efficacy of mitigation measures and interactions between short-term impacts from geothermal development and longer-term impacts from climate change and consumptive water use.

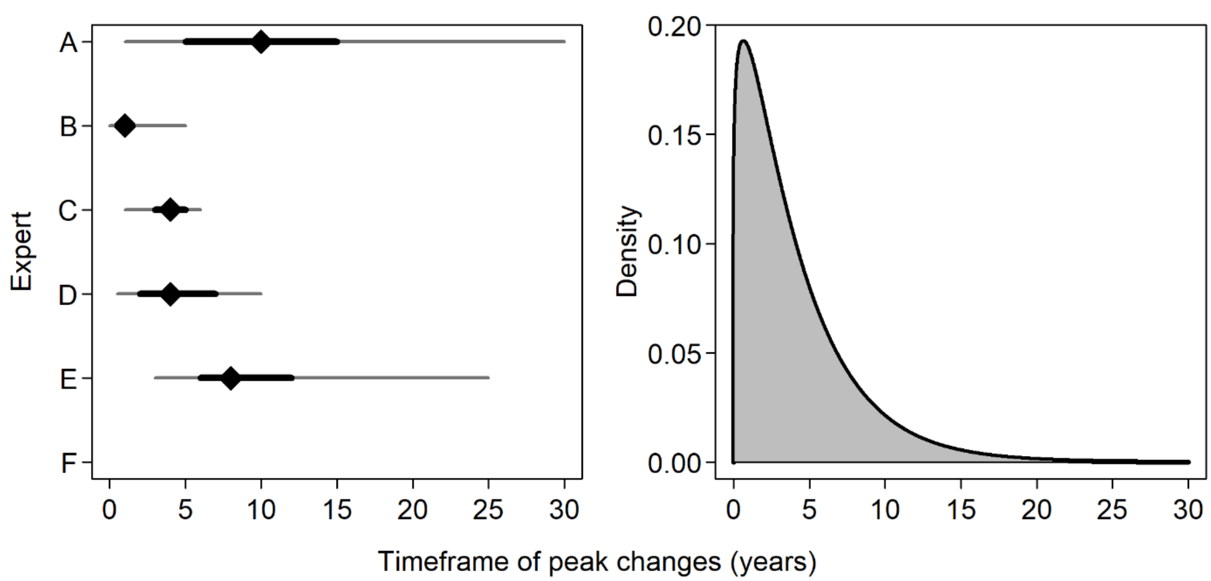

Figure 4.2. Expert judgments on the timeframe for peak changes in Dixie Meadows following initiation of energy production. The left panel shows initial expert judgments for the median (symbol), 50 percent CI (thick black line), and plausible limits (thin grey line). The right panel shows a probability distribution fitted to the experts' RIO judgments, where the height of the curve represents relative likelihood. Note that expert F did not provide a judgment for this quantity due to scheduling conflicts, but commented afterwards that the RIO distribution and discussion points seemed reasonable.

Experts had low confidence in the ability of the proposed monitoring and mitigation plan's to both detect and mitigate changes to the temperature and flow of surface springs in Dixie Meadows. Although the aggregated distribution for the ability to detect changes ranged from 0–100 percent, the median expectation was a roughly 38 percent chance of detecting (Figure 4.3; Appendix A). These judgments reflect a belief that it is less likely than not the proposed plan could detect changes in the system due to the complexity and natural variability of the system, limited baseline data, and perceived inadequacies of the monitoring and mitigation plan. The monitoring and mitigation plan was perceived as inadequate due in part to limited monitoring locations, low frequency of monitoring and reporting, and lack of a statistical approach for addressing variability and uncertainty. The degree of belief in the ability to mitigate changes was even lower (median of roughly 29 percent, Appendix A) based on previously stated concerns about the plan, lack of information on how water quality would be addressed, interacting effects of climate change and extractive water use, and questions about the motivation to mitigate if measures ran counter to other operating goals of the plant. The experts judged that it could take multiple years to mitigate perturbations once detected, with a median expectation of 4 years (Figure 4.4; Appendix A).

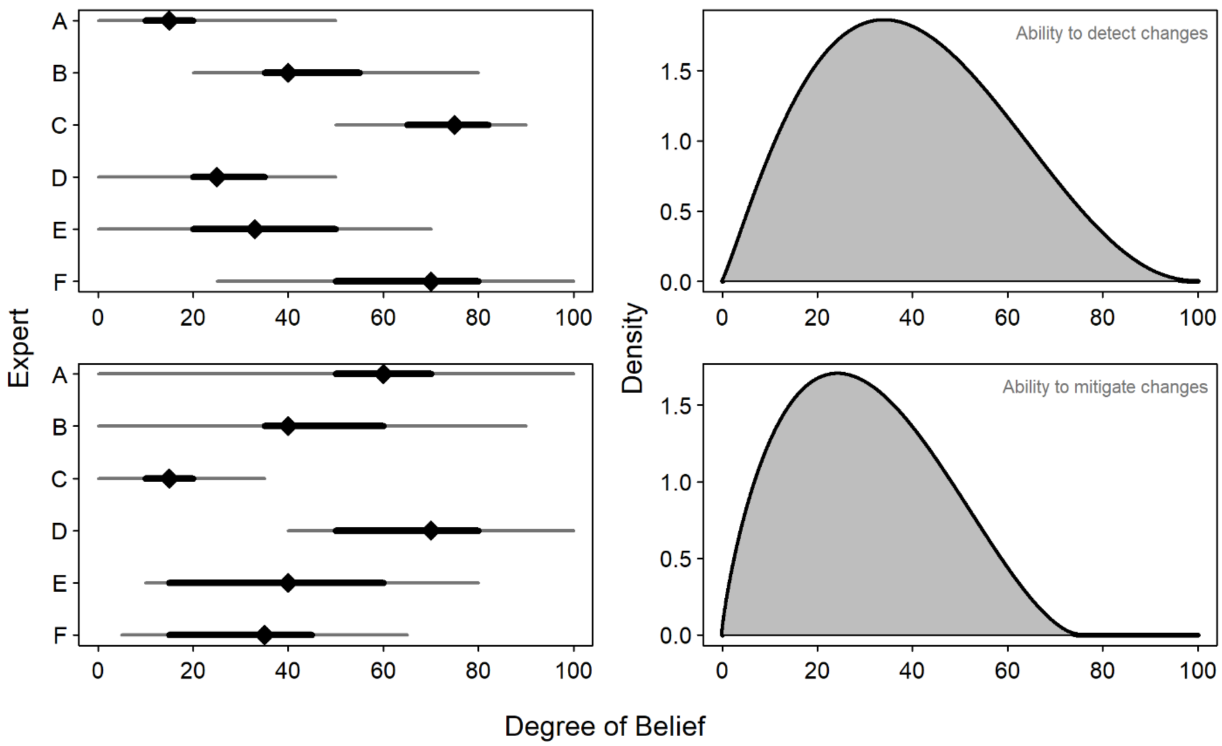

Figure 4.3. Expert judgments on the ability of the proposed monitoring and mitigation plan to detect (top row) and mitigate (bottom row) changes in spring temperatures and discharge within Dixie Meadows. The left panels show initial expert judgments for the median (symbol), 50 percent CI (thick black line), and plausible limits (thin grey line). The right panels show probability distributions fitted to the experts' RIO judgments.

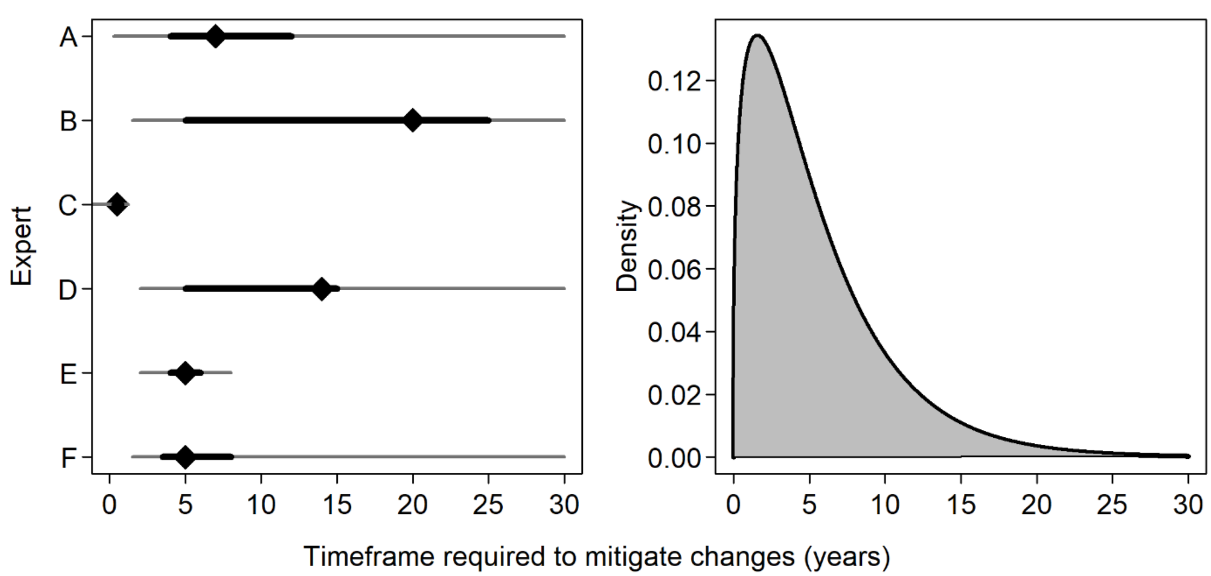

Figure 4.4. Expert judgments on the timeframe required to mitigate changes in temperature and flow once detected and assuming that mitigation is technically feasible. The left panel shows initial expert judgments for the median (symbol), 50 percent CI (thick black line), and plausible limits (thin grey line). The right panel shows a probability distribution fitted to the experts' RIO judgments, where the height of the curve represents relative likelihood.

Although there is large uncertainty in the magnitude of expected changes, all experts had high confidence the system will change in response to geothermal energy development. Experts' judgments on the plausible changes to spring temperatures ranged from a lower limit of a 55 °C (99 °F) decrease to an upper limit of a 10 °C (18 °F) increase, with a median expectation of a 10 °C (18 °F) decrease (Figure 4.5; Appendix A). This uncertainty is due to the wide spatial variation in spring temperatures across the meadows, but reflects the expectation that the spring temperatures could plausibly drop to ambient levels (i.e., a complete loss of geothermal contributions). Similarly, the lower limit of the aggregated judgments considered it plausible that springs in Dixie Meadows could dry up as the geothermal contribution was reduced, with a median expectation of a 29 percent decrease in surface discharge (Figure 4.6). These judgements reflect the high pumping rates of the proposed plants, perceived inadequacies with the monitoring and mitigation plan, and that fact that drying of surface springs have been documented at other nearby geothermal development projects (Nevada State Engineer Ruling 6305, p. 2–3).

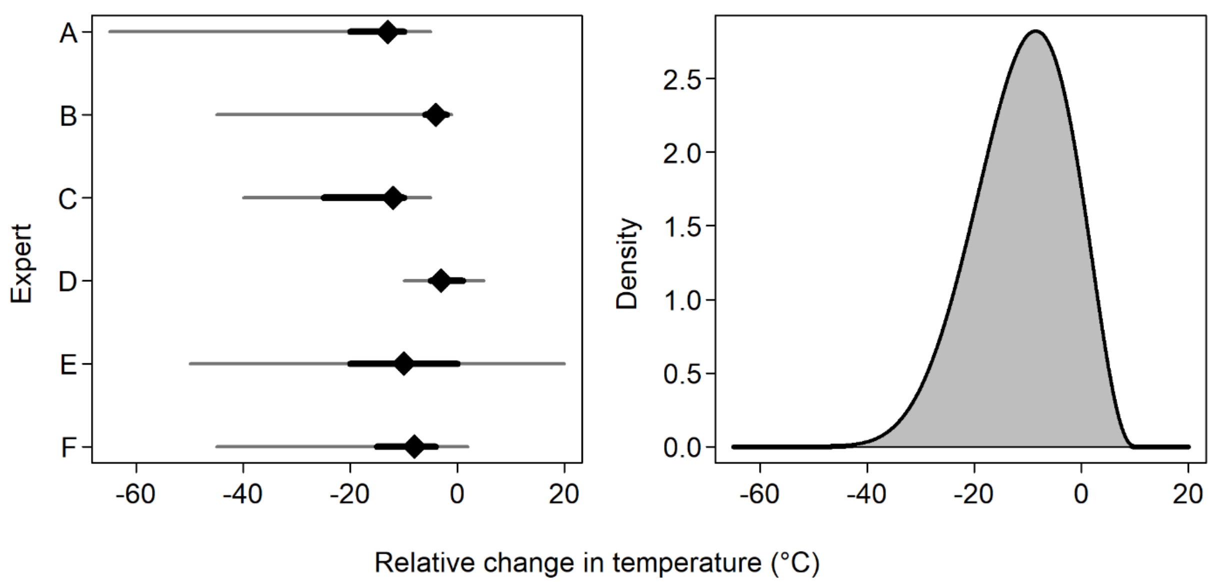

Figure 4.5. Expert judgments on the expected relative changes in spring temperatures following geothermal energy production. The left panel shows initial expert judgments for the median (symbol), 50 percent CI (thick black line), and plausible limits (thin grey line). The right panel shows a probability distribution fitted to the experts' RIO judgments, where the height of the curve represents the relative likelihood of the given amount of change.

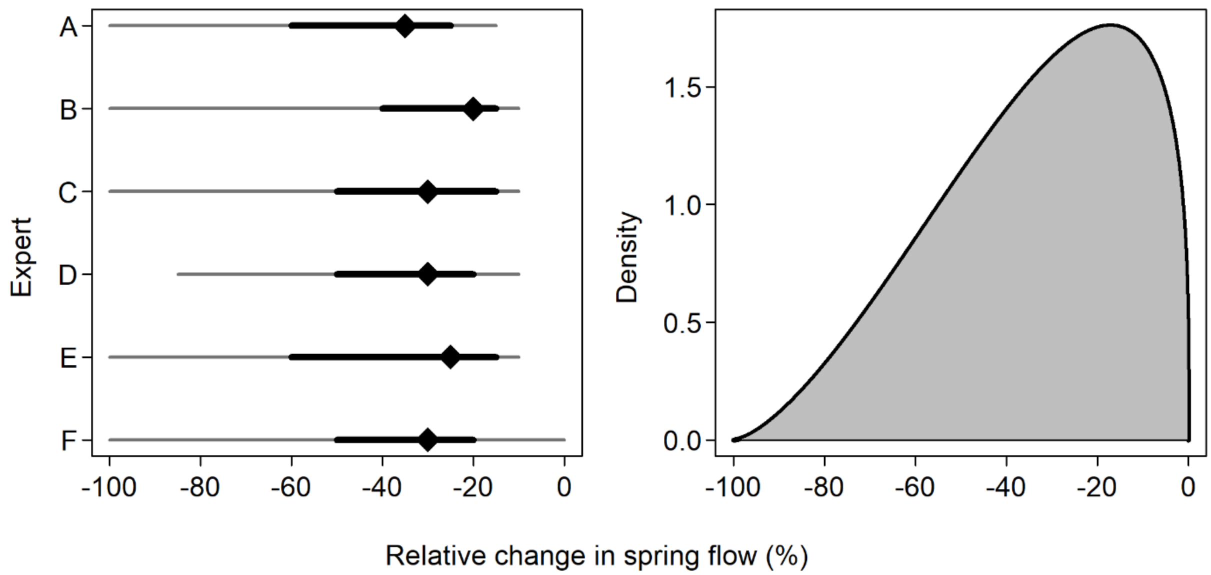

Figure 4.6. Expert judgments on the expected relative changes in springflows following geothermal energy production. The left panel shows individual expert RIO judgments for the median (symbol), 50 percent CI (thick black line), and plausible limits (thin grey line). The right panel shows a probability distribution fitted to the experts' RIO judgments, where the height of the curve represents the relative likelihood of the given amount of change. Note that the left panel shows the RIO round judgments rather than initial judgments due to some confusion on whether judgments should reflect geothermal contribution or surface expression.

Geothermal energy production is considered a renewable energy resource as it is non-consumptive and most geothermal technology does not release harmful by-products into the atmosphere. However, this does not mean geothermal energy development is without environmental impacts as explained above. Environmental impacts are to be expected; however, difficult to predict as every geothermal resource is unique. Negative impacts to springflow and water temperature are expected to occur (see Appendix A) which will ultimately impact Dixie Valley toad persistence.

4.2.7 Predation

Predation has been reported in species similar to Dixie Valley toads and likely occurs in Dixie Meadows; however, predation has not been documented. Likely predators on the egg and aquatic larval forms of Dixie Valley toads include predacious diving beetles (*Dytiscus* sp.) and dragonfly larvae (Odonata). Garter snakes (*Thamnophis* sp.) are typical predators for many amphibian species; however, snakes have not been documented in Dixie Meadows (Rose et al. 2015, p. 529, 532). Common ravens (*Corvus corax*) and other corvids are known to feed on juvenile and adult Black toads and Yosemite toads (Sherman 1980, pp. 90–92; Sherman and Morton 1993, p. 194–195). Raven populations are increasing across the western United States and are clearly associated with anthropogenic developments such as roads and power lines (Coates and Delehanty 2010, p. 244–245; Howe et al. 2014, pp. 44–46). Ravens are known to nest within Dixie Valley (Environmental Management and Planning Solutions 2016, p. 3-4).

The American bullfrog (*Lithobates catesbeianus*), a ranid species native to much of central and eastern North America, now occurs within Dixie Meadows (Casper and Hendricks 2005, pp. 540–541, Gordon et al. 2017, p. 136). Bullfrogs are recognized as one of the 100 worst invasive species in the world (Global Invasive Species Database 2021, pp. 1–17). Bullfrogs are known to compete with and prey on other amphibian species (Moyle 1973, pp. 19–21; Kiesecker et al. 2001, pp. 1,966–1,969; Pearl et al. 2004, pp. 16–18; Casper and Hendricks 2005, pp. 543–544; Monello et al. 2006, p. 406; Falaschi et al. 2020, pp. 216–218).

Bullfrogs are a gape-limited predator which means they can eat anything they can swallow (Casper and Hendricks 2005, pp. 543–544). Dixie Valley toads are the smallest toad species in the *A. boreas* species complex and can easily be preyed upon by bullfrogs. Smaller bullfrogs eat mostly invertebrates (Casper and Hendricks 2005, p. 544) indicating they may compete with Dixie Valley toads for food resources. Within Dixie Valley, bullfrogs are known to occur at Turley Pond and in one area of Dixie Meadows adjacent to occupied Dixie Valley toad habitat (Forrest et al. 2013, pp. 74, 87; Rose et al. 2015, p. 529; Halstead et al. 2021, p. 24).

4.2.8 Disease

Over roughly the last 4 decades, pathogens have been associated with amphibian population declines, mass die-offs, and even extinctions worldwide (Bradford 1991, pp. 174–176; Muths et al. 2003, pp. 359–364; Weldon et al. 2004, pp. 2,101–2,104; Rachowicz et al. 2005, pp. 1,442–1,446; Fisher et al. 2009, pp. 292–302; Knapp et al. 2011, pp. 8–19). One pathogen strongly associated with dramatic declines on all continents that harbor amphibians is chytridiomycosis caused by the chytrid fungus *Batrachochytrium dendrobatidis* (chytrid fungus) (Rachowicz et al. 2005, pp. 1,442–1,446). Chytrid fungus has now been reported in amphibian species worldwide (Fellers et al. 2001, pp. 947–952; Rachowicz et al. 2005, pp. 1,442–1,446). Early doubt that this particular pathogen was responsible for worldwide die-offs has largely been overcome by the weight of evidence documenting the appearance, spread, and detrimental effects to affected populations (Vredenburg et al. 2010, pp. 9,690–9,692).

Clinical signs of chytridiomycosis and diagnosis are described by Daszak et al. (1999, p. 737) and include abnormal posture, lethargy, and loss of righting reflex. Gross lesions, which are usually not apparent, consist of abnormal epidermal sloughing and ulceration; hemorrhages in the skin, muscle, or eye. Chytridiomycosis can be identified in some species of amphibians by examining the oral discs of tadpoles that may be abnormally formed or lacking pigment (Fellers et al. 2001, pp. 946–947).

Despite the acknowledged impacts of chytridiomycosis to amphibians, little is known about this disease outside of mass die-off events. There is high variability between species of amphibians in response to being infected including within the *A. boreas* species complex. Two long-term study sites have been documented with differences in apparent survival of western toads between sites in Montana and Wyoming (Russell et al. 2019, pp 300–301). Various diseases are confirmed to be lethal to Yosemite toads (Green and Sherman 2001, p. 94), and research has elucidated the potential role of chytrid fungus infection as a threat to Yosemite toad populations (Dodge 2013, pp. 6–10, 15–20; Lindauer and Voyles 2019, pp. 189–193). These various diseases and infections, in concert with other factors, have likely contributed to the decline of the Yosemite toad (Sherman and Morton 1993, pp. 189–197) and may continue to pose a risk to the species

(Dodge 2013, pp. 10–11; Lindauer and Voyles 2019, pp. 189–193). Amargosa toads are known to have high infection rates and high chytrid fungus loads; however, they do not seem to show adverse impacts from the disease (Forrest et al. 2015, pp. 920–922). Not all individual amphibians that test positive for chytrid fungus develop chytridiomycosis.

Dixie Valley toads have been sampled for chytrid fungus in 2011–2012 and 2019–2021 (Forrest et al. 2013, p. 77; Kleeman et al. 2021, entire) and both times chytrid fungus was not found. However, chytrid fungus has been documented in bullfrogs in Dixie Valley (Forrest et al. 2013, p. 77). Bullfrogs are a known vector for chytrid fungus and they can spread diseases to other amphibians (Daszak et al. 2004, pp. 203–206; Urbina et al. 2018, pp. 271–274; Yap et al. 2018, pp. 4–8).

The best available information indicates that the thermal nature of Dixie Valley toads habitat may keep chytrid fungus from becoming established; therefore, it is imperative that the water maintains its natural thermal characteristics (Forrest et al. 2013, pp. 75-85; Halstead et al. 2021, pp. 33-35). Boreal toads that were exposed to chytrid fungus survive longer when exposed to warmer environments (mean 18 °C (64 °F)) as compared to boreal toads in cooler environments (mean 15 °C (59 °F)) (Murphy et al. 2011, pp. 35-38). Additionally, chytrid fungus zoosporangia grown at 27.5 °C (81.5 °F) remain metabolically active; however, no zoospores are produced, indicating no reproduction at this high temperature (Lindauer et al. 2020, pp. 2-5). Generally, chytrid fungus does not seem to become established in water greater than 30 °C (86 °F). (Forrest and Schlaepfer 2011, pp. 3-7). Any reduction in temperature would not only affect the ability of Dixie Valley toads to persist during cold months, but could also make the species vulnerable to chytrid fungus.

4.2.9 Livestock Grazing

Dixie Meadows is located within an active grazing allotment (Boyer Ranch Allotment) administered by the BLM. The allotment is approximately 580 km^2 (143,413 ac) and is split into two pastures (Low Pasture and High Pasture) with Dixie Meadows located in the Low Pasture. Grazing in the Low Pasture is currently authorized for 179 cattle from May 1 to June 30 and October 1 to February 28 annually. The High Pasture is grazed from July 1 to September 30 annually (BLM 2018, entire). Direct mortality of amphibians from livestock trampling is usually described anectdotally in the literature while biologists are doing other monitoring (Bartelt 1998, p. 96; Ross et al. 1999, p. 163) including at Dixie Meadows where a radio-marked Dixie Valley toad was found stepped on by a cow (USGS pers. comm). Trampling by livestock can be assumed to induce mortality on all lifestages of Dixie Valley toads since grazing is allowed in the Dixie Meadows area while all lifestages are present (Ross et al. 1999, p. 163; Peterson et al. 2010, pp. 958–966). Most livestock grazing studies focus on impacts to riparian/wetland habitat (e.g., Green and Kauffman 1995, pp. 308–313; Belsky et al. 1999, entire) or water quality related impacts (e.g., Agouridis et al. 2005, entire), and their associated impacts to aquatic organisms such as amphibians (e.g., Arkle and Pilliod 2015, pp. 12, 16, 30, 33).

Bull and Hayes (2000, pp. 292–294) found no impacts of cattle grazing on the reproductive success of Columbia spotted frogs (*Rana luteiventris*) in ponds in northeastern Oregon; however, there was high variability in their results. Grazing intensity and timing was not evaluated in this study. In addition, Adams et al. (2009, pp. 135–137) found no significant short-term effects of cattle exclosures on the number of Columbia spotted frog egg masses, larval survival, size of metamorphs, or water quality measurements. Moreover, nutrient levels often associated with negative impacts to amphibians, were very low to non-detectable (Adams et al. 2009, pp. 136–137).

In contrast, Gray et al. (2007, pp. 99–100) found higher levels of *Ranavirus* (an emerging pathogen implicated in many amphibian declines) in green frogs (*Lithobates* (formerly *Rana*) *clamitans*) sampled from ponds accessed by cattle. Howard and Munger (2003, p. 10) found lower survival of Columbia spotted frog larvae in their high livestock waste treatment; however, the high waste treatment larvae that survived had higher growth rates. Schmutzer et al. (2008, pp. 2,617–2,619) found significantly larger green frog, bullfrog (*L. catesbeianus*), and pickerel frog (*L. palustris*) larvae in ponds with cattle grazing; however, larval abundance for all three species was significantly higher in ponds with no cattle grazing. Additionally, water quality measurements including turbidity and specific conductivity were significantly higher while dissolved oxygen was significantly lower in ponds with grazing (Schmutzer et al. 2008, pp. 2,618–2,619). Capture probabilities of post-metamorphic green frogs were significantly higher in ungrazed ponds versus grazed ponds; however, the opposite was found for American toads (*Anaxyrus* (formerly *Bufo*) *americanus*) indicating species-specific impacts to amphibians from cattle grazing (Burton et al. 2009, pp. 272–273). Recently, Arkle and Pilliod (2015, pp. 12, 16, 30, 33) concluded that livestock grazing impacts were negatively related to Columbia spotted frog occupancy within the Great Basin DPS. They found that heavy livestock utilization of emergent vegetation, which was found to be very important in Columbia spotted frog occupancy, is the mechanism in which livestock impact Columbia spotted frogs (Arkle and Pilliod 2015, pp. 12, 16, 30, 33).

In summary, heavy livestock grazing has been shown to negativly influence amphibian populations and their habitat. Dixie Meadows is grazed by livestock; however, there is no indication of habitat loss due to the effects of heavy grazing. No information is available at this time on water quality impacts due to defecation/urination in the water. Direct mortality of individuals is known to occur from being stepped on but the degree of this threat is unknown at this time.

4.2.10 Spring Modifications

Spring modifications include channel modification, surface water diversions, and impoundment at springs. Such modifications may occur for development, management, or restoration purposes and have been documented in the Dixie Meadows wetland, and therefore, Dixie Valley toads have been potentially impacted from this threat historically (Stantec 2019, pp. 13, 50–51, 104–105, 132–133; Albano et al. 2021, pp. 72–75).

Human alterations of springheads, to concentrate or divert discharge, negatively impact spring systems and invariably result in loss of biota (Unmack and Minckley 2008, p. 20). Documented examples of springs in Death Valley National Park that were developed for municipal water use have changed aquatic and riparian habitats and eliminated several populations of endemic macroinvertebrates (Sada and Herbst 2006, p. 1). For springs assessed in this report, several springs in Dixie Meadows have been altered to some degree by development (Stantec 2019, pp. 13, 50–51, 104–105, 132–133; Albano et al. 2021, pp. 72–75) prior to NAS Fallon acquiring the land in 1986, but are no longer in use.

Aquatic habitat and productivity are affected by diversion in a number of ways. As discharge is reduced, springbrook length and wetted width and depth decrease. Decreasing the volume of water also alters thermal characteristics of the springbrook, as well as aspects of water chemistry such as pH and DO concentration. Consequences of these incremental changes include reduced productivity, habitat heterogeneity, and benthic macroinvertebrate microhabitat availability (Sada 2015, pp. 45–46).

Riparian vegetation has an early and evident response to a reduction in springflow. Plants occurring in springbrooks are adapted for life in waterlogged soil; however, as water levels decline, soil dries and becomes aerated, which facilitates invasion of forbs, shrubs, and trees. New water depths and soil conditions may also allow stands of cattails (*Typha* spp.) and reeds (*Phragmites* spp.) to expand, sometimes reducing or eliminating open water (Unmack and Minckley 2008, p. 24).

In summary, spring modifications may include surface water diversion, impoundment, or channel modification, including dredging. These spring modifications affect Dixie Valley toad needs by changing how water is distributed throughout the wetland, and open water needed for plant productivity, which provides food and shelter. Because the thermal and chemical properties of water are influenced by water depth and flow, alteration of these properties may affect water quality. The level and effect of spring modifications across all the locations analyzed in this report range from an absence of spring modifications to potentially significant impacts.

Sufficient riparian vegetation are species needs that may influence all life stages of Dixie Valley toads and its population's condition (Halstead et al. 2021, p. 34). A groundwater dependent ecosystem (GDE) study occurred in Dixie Meadows and throughout various valleys in Nevada to establish a baseline for monitoring and assessing the potential impacts of groundwater developments (e.g., geothermal energy, agriculture) on GDEs. Baseline information was collected by quantifying the current status and historical trends in the condition of groundwater dependent vegetation relative to trends in both climate and groundwater levels based on field observations, groundwater level data, gridded meteorological data, and 35 years (1985–2019) of Landsat satellite imagery (Albano et al. 2021, p. 111).Within Dixie Meadows, a more in depth analysis was completed in five different areas of influence (AOI). Three of the AOIs were located in the southern portion of Dixie Meadows and the remaining two AOIs were located in the northern portion of Dixie Meadows. Two of the three AOIs in the southern portion of Dixie Meadows showed statistically significant declines in Normalized Difference Vegetation Index (NDVI; an indicator of vegetation vigor) starting in the late 1980s then stabilizing in the early 1990s to 2019 indicating a drying trend in these AOIs (Albano et al. 2021, pp. 72–73). The third AOI in the south, which is located in between the two declining AOIs, showed a statistically significant increase in NDVI over the 35 year timeframe (Albano et al. 2021, pp. 72–73) indicating wetter conditions. The two AOIs located in the northern portion of Dixie Meadows were tracking each other until 2001 when they started to diverge with one AOI increasing and decreasing, indicating changing water flow paths and a corresponding change in vegetation

(Albano et al. 2021, pp. 72–73). This report identifies other areas outside of the AOIs throughout Dixie Meadows, which are either drying or getting wetter; however, statistical analyses were not performed outside of the AOIs (Albano et al. 2021, p. 72). Figure 4.7 shows locations of Dixie Valley toads between 2009–2014 in relation to NDVI trends indicating clear selection by Dixie Valley toads for wetter areas. In summary, NDVI clearly shows the vegetation within Dixie Meadows is changing and is associated with climate variability and/or changing water flow paths from the spring sources through the wetlands. Historical water management of Dixie Meadows has likely had dramatic impacts on how water flows through the wetlands as evidence of dikes, channelization, and deteriorating pipes can be found throughout the area (Stantec 2019, pp. 13, 50–51, 104–105, 132–133; Albano et al. 2021, pp. 72–75).

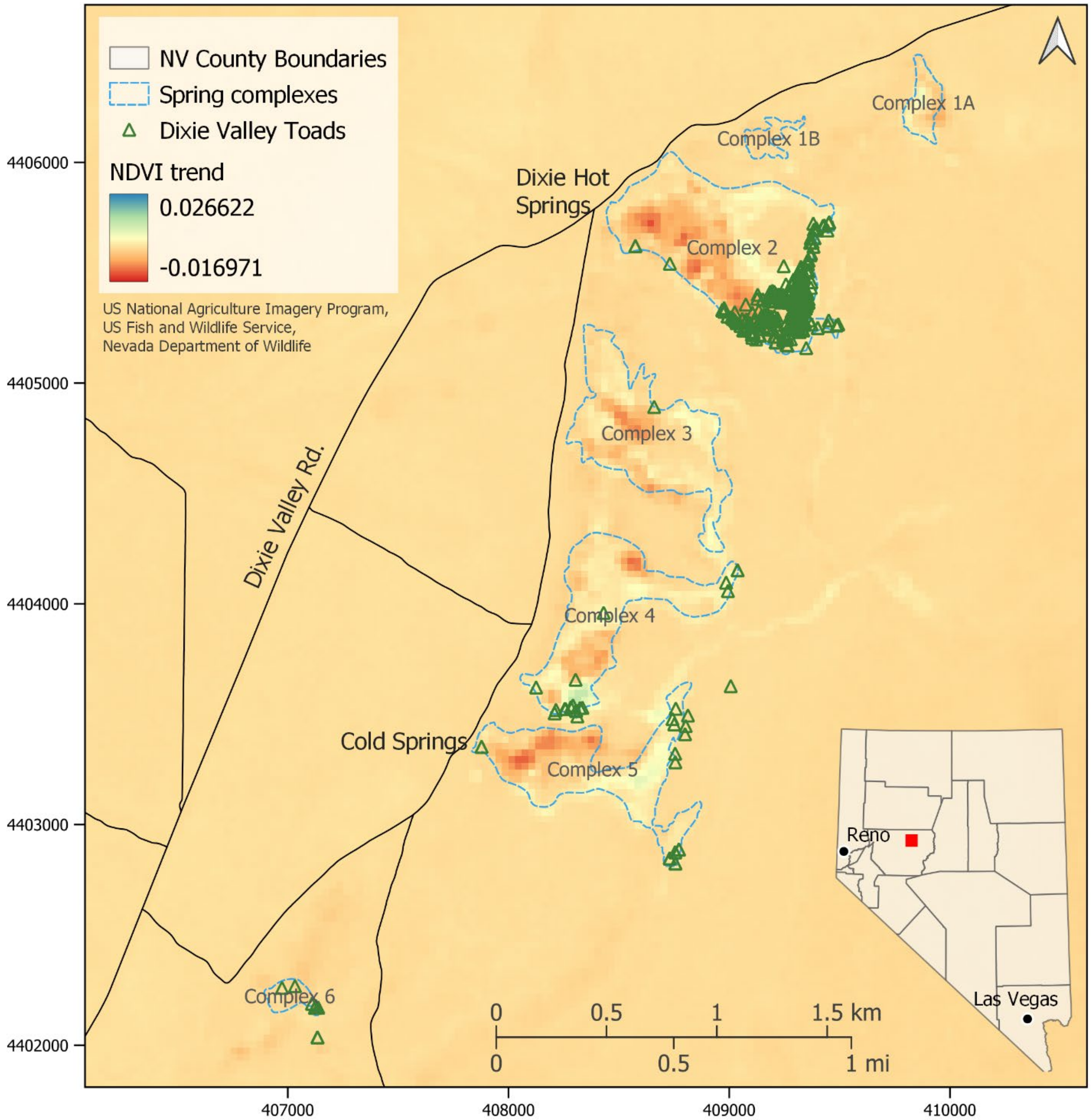

Figure 4.7. Normalized Difference Vegetation Index (NDVI) of Dixie Meadows (Albano et al. 2021, p. 72) with known locations of Dixie Valley toads using data from the Nevada Department of Wildlife (NDOW, unpublished data). Cool NDVI colors (blue) indicate areas getting wetter while warm NDVI colors (red) indicate areas getting drier.

4.2.11 General Impacts from Groundwater Pumping

The basin is fully appropriated for consumptive groundwater uses (18,758,663 m^3/yr (15,218 afy) of an estimated 18,489,943 m^3/yr (15,000 afy) perennial yield) and the proposed Dixie Valley groundwater export project by Churchill County is seeking an additional 12,326,628–18,489,943 m^3/yr (10,000–15,000 afy) (Huntington et al. 2014, p. 2). Total geothermal water rights appropriated in Dixie Valley as of 2020 are 15,659,749 m^3/yr (12,704 afy) (Ormat 2020, p.

15).

Increased groundwater pumping in Nevada is primarily driven by human water demand for municipal purposes, irrigation, and development for oil, gas, geothermal resources, and minerals. Many factors associated with groundwater pumping can affect whether or not an activity will impact a spring. These factors include the amount of groundwater to be pumped, period of pumping, the proximity of pumping to a spring, depth of pumping, and characteristics of the aquifer being impacted. Depending on the level of these factors, groundwater withdrawal may result in no measureable impact to springs or may reduce spring discharge, change the temperature of the water, reduce free-flowing water, dry springs, alter Dixie Valley toad habitat size and heterogeneity, or create habitat that is more suited to nonnative species than to native species (Sada and Deacon 1994, p. 6). Pumping rates that exceed perennial yield can lower the water table, which in turn will likely affect riparian vegetation (Patten 2008, p. 399).

Groundwater withdrawal that exceeds perennial yield can be difficult to monitor and reverse due to inherent delays in detection of pumping impacts and the subsequent lag time required for recovery of discharge at a spring (Bredehoeft 2011, p. 808). Groundwater pumping initially captures stored groundwater near the pumping area until water levels decline and a cone of depression expands, potentially impacting water sources to springs or streams (Dudley and Larson 1976, p. 38). Spring aquifer source and other aquifer characteristics influence the ability and rate at which a spring fills and may recover from groundwater pumping (Heath 1983, pp. 6 and 14). Depending on aquifer characteristics and rates of pumping, recovery of the aquifer is variable and may take several years or even centuries to recover (Halford and Jackson 2020, p.70; Heath 1983, p. 32). Yet where reliable records exist, most springs fed by even the most extensive aquifers are affected by exploitation, and springflow reductions relate directly to quantities of groundwater removed (Dudley and Larson 1976, p. 51).

The most extreme effects of groundwater withdrawal on Dixie Valley toads are desiccation and extirpation or extinction. If groundwater withdrawal occurs but does not cause a spring to dry, there can still be adverse effects to Dixie Valley toads or their habitat. Reduction in springflow both reduces the amount of water and amount of occupied habitat. If the withdrawals also coincide with altered precipitation and temperature from climate change, even less water will be available. Cumulatively, these conditions could result in a delay in groundwater recharge at springs, which may then result in a greater effect to Dixie Valley toads than the effects of the individual threats acting alone. Across the Dixie Meadows spring province, discharge varies greatly, with some springs with low discharge at present likely due to a combination of influences, both natural and anthropogenic. Therefore, any future effects of groundwater withdrawal are of significant importance.

4.2.12 Altered Precipitation and Temperature from Climate Change

The southwest region where Dixie Valley toads occur is one of the hottest and driest areas of the United States, and climate change is likely to exacerbate these conditions. Changes in climate have already been observed in this region and are expected to continue. Average annual temperatures have increased almost 1.1 °C (2 °F) over the last century (Garfin 2014, p. 464), and an additional increase of 1.9 to 5.3 °C (3.5 to 9.5 °F) is predicted to occur by the year 2100 (Walsh 2014, p. 23). In recent decades, reductions in precipitation and winter snowpack have been observed, and this pattern is expected to continue (Garfin 2014, p. 465; Figure 4.8). The frequency and intensity of these reductions have increased on a global scale (IPCC 2014, p. 51), and climate change is projected to reduce surface and groundwater resources in most subtropical deserts (IPCC 2014, p. 69). The majority of model simulations based upon future climatic conditions predict a drying trend throughout the Southwest during the 21st century (Seager 2007, pp. 1,181–1,184). Overall anticipated climate change impacts for the region include: warmer temperatures, decreased precipitation, fewer frost days, longer dry seasons, reduced snowpack, and increased frequency and intensity of extreme weather and disturbance events (heat waves, droughts, storms, flooding, wildfires, insect outbreaks; Archer and Predick 2008, pp. 23–25; Seager 2007, p. 1,183; USGCRP 2009, p. 131; Garfin 2014, p. 463; Walsh 2014, p. 36). General circulation model (GCM) projections indicate a marked reduction in spring snow accumulation in mountain watersheds across the southwestern United States (Figure 4.8, top panel) (Garfin 2013, pp. 117–118). More rain and less snow, earlier snowmelt, and to some extent, drying tendencies, cause a reduction in late-spring and summer runoff (Figure 4.8, middle panel). These effects, along with increases in evaporation, result in lower soil moisture by early summer (Figure 4.8, bottom panel).

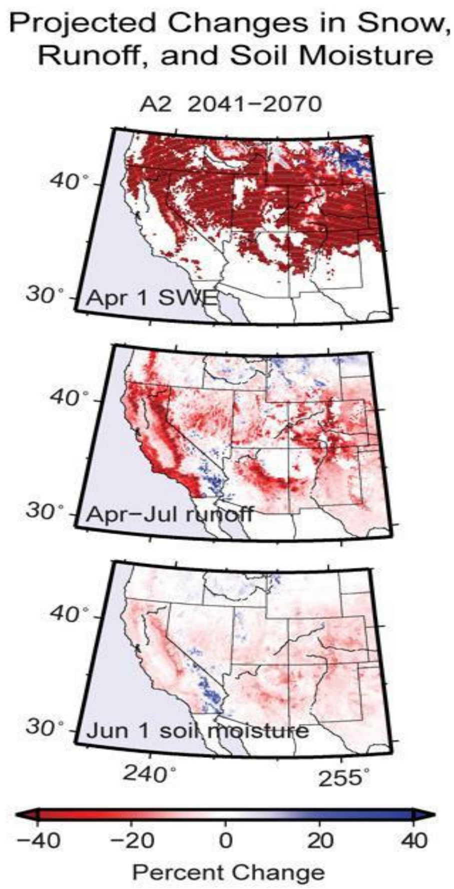

Figure 4.8. Mid-century (2041–2070) percent changes from the simulated historical median values from 1971–2000 for: (1) April 1 snow water equivalent (SWE, or snowpack, top), (2) April-July runoff (middle), and (3) June 1 soil moisture content (bottom), as obtained from the median of 16 Variable Infiltration Capacity (VIC) simulations under the high-emissions (A2) scenario (Garfin 2013, p. 118).

Both human settlements and natural ecosystems in the southwestern U.S. are largely dependent on groundwater resources, and decreased groundwater recharge may occur as a result of climate change (USGCRP 2009, p. 133). Furthermore, the human population in the southwest is expected to increase 70 percent by mid-century (Garfin 2014, p. 470). Resulting increases in urban development, agriculture, and energy production facilities will likely place additional demands on already limited water resources. Climate change will likely increase water demand while at the same time shrink water supply, since water loss may increase evapotranspiration rates and run-off during storm events (Archer and Predick 2008, p. 25).

In order to identify changing climatic conditions more specific to Dixie Meadows, we conducted a climate analysis using the Climate Mapper web tool (Hegewisch et al. 2020, online) The Climate Mapper is a web tool for visualizing past and projected climate and hydrology of the contiguous United States of America. This tool maps real-time conditions, current forecasts, and future projections of climate information across the United States to assist with decisions related to agriculture, climate, fire conditions, and water.

Historical climate data comes from gridMET (AKA METDATA). The University of Idaho gridMET gridded surface meteorological dataset covers the continental United States from 1979-present mapping surface weather variables at a approximate 4-km spatial grain. This dataset is updated by 12 pm daily with data for the previous day (i.e., 1-day lag) (Abatzoglou 2013, p. entire).

For projected climate data, projections from 20 climate models and 2 scenarios (RCP 4.5 and RCP 8.5) were downscaled to an approximate 4-km resolution across the U.S. for compatibility with the gridMET data (Abatzoglou and Brown 2012, entire).

For our analysis, we used the mapping tool to download geoTIFFs for the Mean Annual Temperature and percent precipitation using the historical period of 1971–2000 and the projected future time period 2040–2069; models beyond this timeframe are less reliable. We then examined emission scenarios RCP 4.5 and RCP 8.5 using ArcGIS Pro.

Our analysis predicts increased air temperatures Dixie Meadows occurs (Figure 4.9), along with a slight increase in precipitation (Figure 4.10). Annual mean air temperature is projected to increase between 2.5 and 3.4 °C (4.5 and 6.1 °F); average 3.0 °C (5.3 °F) throughout Dixie Meadows between 2040 and 2069 (Figure 4.9; Hegewisch et al. 2020, GIS data). Projections related to annual precipitation range from percent increases of 4.5 to 7.7 percent among the two emission scenarios (Figure 4.10; Hegewisch et al. 2020, GIS data).

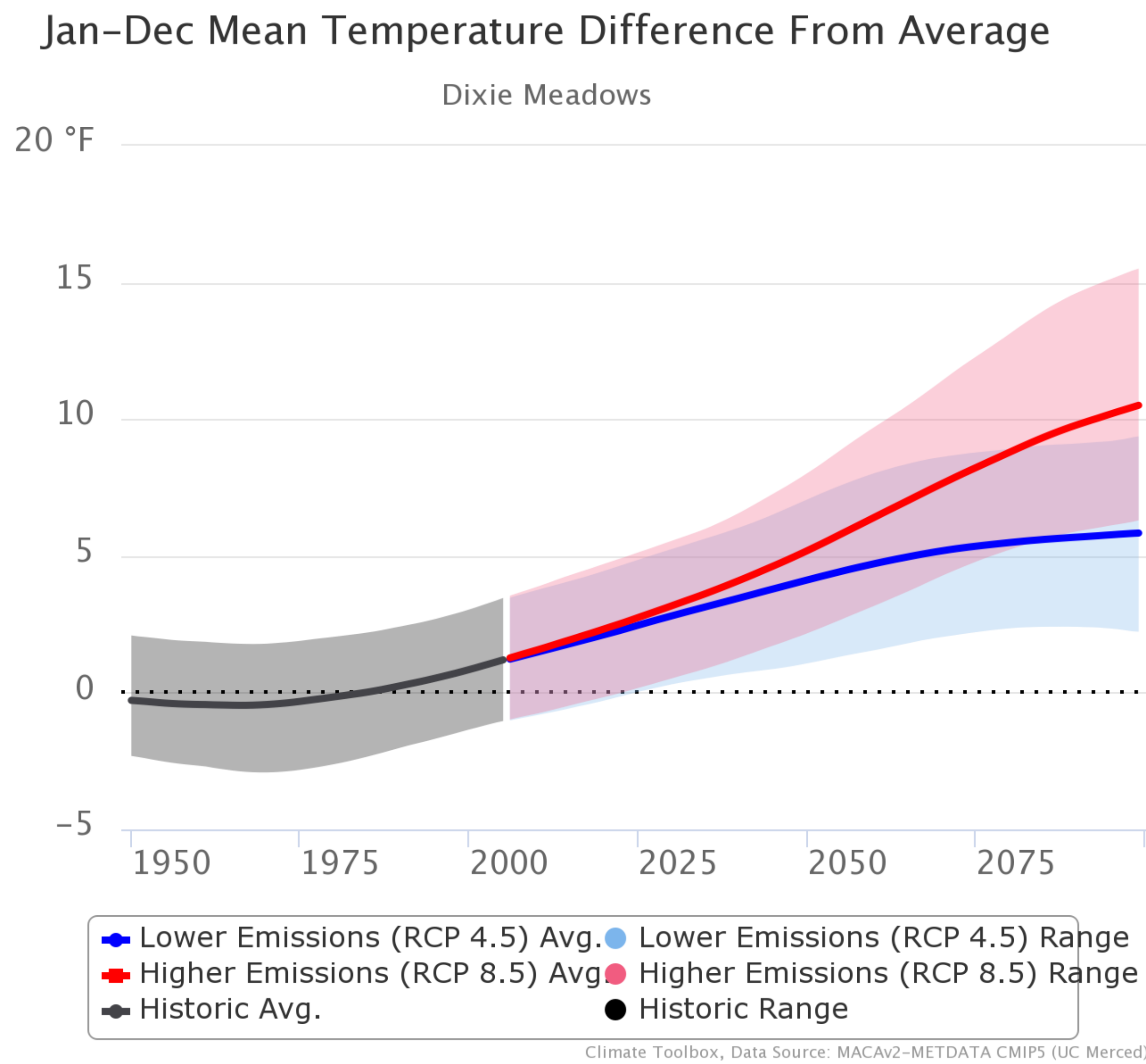

Figure 4.9. Graph showing changes in average annual temperature at Dixie Meadows predicted for the time period 2040–2069 as compared to the 1971–2000 baseline average using emission scenarios RCP 4.5 and RCP 8.5 (Hegewisch et al. 2020, online).

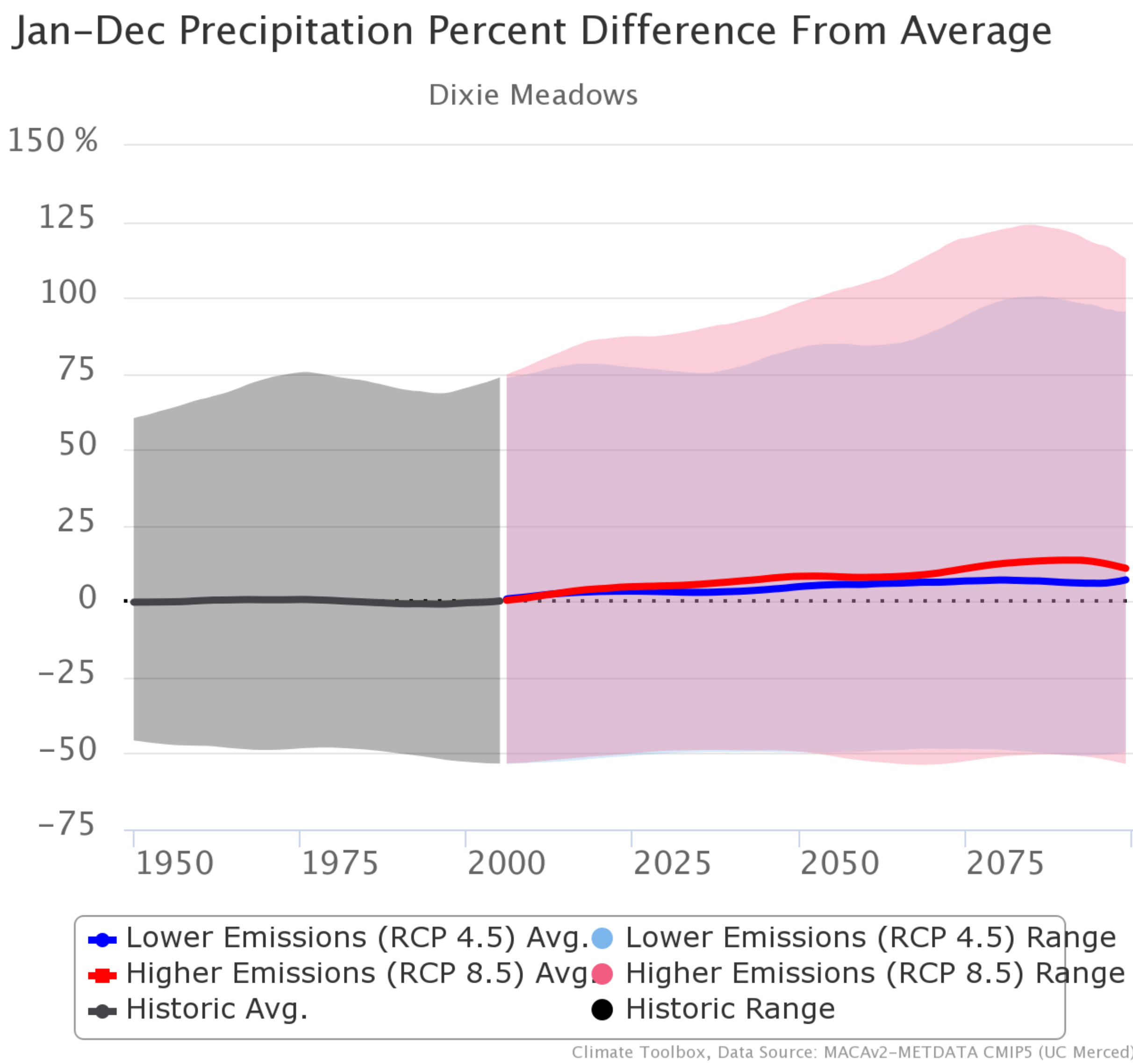

Figure 4.10. Graph showing changes in average annual precipitation at Dixie Meadows predicted for the time period 2040–2069 as compared to the 1971–2000 baseline average using emission scenarios RCP 4.5 and RCP 8.5 (Hegewisch et al. 2020, online).

Although it seems certain that climate change in conjunction with increased demands on water resources from a growing human population will result in lowered groundwater levels (Jaeger 2014, p. 13,895), little is known about how and when springflows may be affected by changes in climate. Direct hydrological connections have not been established in most cases, and for many areas, these connections remain difficult to make. The presence of an amphibian species endemic to Dixie Meadows speaks to the consistency and reliability of these aquatic habitats over thousands of years. Naturally occurring climatic variation resulted in changes to connectivity between the Lahontan Basin and Dixie Valley approximately 650,000 years before present which was the last known time these basins were connected (Reheis et al 2002, p. 103). The last highstand of Pleistocene lakes was approximately 12,000–13,000 years before present when Lake Dixie covered much of the valley including the currently known location of Dixie

Meadows (Caskey 2004, p. 132). Since that time a gradual drying of the region has resulted in the complete drying of Lake Dixie leaving behind the springs in Dixie Meadows as the most consistent water source in the area which has allowed Dixie Valley toads to persist.

Ultimately, the degree to which springflows are affected by climate change largely depends on influences on surface water processes and precipitation, since aquifers are recharged through exchanges with surface water (Green 2011, p. 541). Components of surface water systems that may be altered by climate change include atmospheric water vapor, precipitation patterns, rates of evapotranspiration, snow cover and melting of glaciers, soil temperature, and surface runoff and stream flows (Green 2011, p. 538). Changes to these components will likely result in changes to groundwater systems, but climate change impacts on groundwater resources are poorly understood (Green 2011, p. 533). Relationships between climate and groundwater are considered more complicated than those between climate and surface water (Holman 2006, p. 638). Interpretation of potential impacts is further complicated by a lack of data and background studies necessary to determine the magnitude and direction of possible groundwater changes (Kundzewicz 2008, p. 7). Furthermore, groundwater level responses are highly variable across a landscape due to spatial differences in sediment permeability and recharge characteristics. For example, increased precipitation often leads to higher groundwater levels at some testing locations but not at others nearby (Chen 2002, p. 106). Accordingly, some studies have shown a decrease in groundwater recharge rate, while others have predicted positive effects or concluded that it is not known whether overall groundwater recharge will increase, decrease, or stay the same throughout the western United States as a result of climate change (Jyrkama and Sykes 2007, p. 248; Herrera-Pantoja and Hiscock 2008, p. 12; Gurdak and Roe 2010, pp. 1,762–1,763).

Climate change may impact Dixie Valley toads and their habitat in two main ways: (1) Reductions in springflow as a result of changes in the amount, type, and timing of precipitation, increased evapotranspiration rates, and reduced aquifer recharge; and (2) reductions in springflow as a result of changes in human behavior in response to climate change (e.g., increased groundwater pumping as surface water resources disappear). Impacts vary geographically, but identifying which springs may be more or less vulnerable is challenging. For example, a study examining different springs over a 14-year period at Arches National Park in Utah found that each spring responded to local precipitation and recharge differently (Weissinger 2016, p. 9).

Regional springs (Section 3.2) are typically fed by older and larger aquifers compared to mountain block aquifers, and have relatively longer residence times (sometimes hundreds to thousands of years for regional aquifers) (Sada 2017, p. 4). Local and regional springs also tend to occur in low elevation alluvial fans and valley floors where production wells are typically located. In this case, effects to these aquifers may be more driven by increased groundwater extraction rather than climate-driven decreases in recharge.

Predicting individual spring response to climate change is further complicated by the minimal information available about the large hydrological connections for most sites and the high degree of uncertainty inherent in future precipitation models. Regardless, the best available data indicate that Dixie Valley toads may be vulnerable to climate change to an unknown degree, but we cannot say with any certainty where impacts may be manifested or the greatest.

4.3 Summary

Dixie Valley toads are endemic to the 3.1 km^2 (760 ac) wetland complex at Dixie Meadows. Dixie Valley toads are highly aquatic and prefer warm water for much of its life history needs. Geothermal energy production targets the same resources that Dixie Valley toads rely on which is why it has been described as the greatest threat to the persistence of Dixie Valley toads (Forrest et al. 2017, pp. 172–173; Gordon et al. 2017, p. 136; Halstead et al. 2021, p. 35). The BLM authorized the Dixie Meadows geothermal plant in November 2021. Other threats include nonnative bullfrogs, which are found in Dixie Meadows. Bullfrogs are known predators and also have been found with chytridiomycosis, one of the most devastating amphibian diseases ever studied. Current water rights allocated for Dixie Valley indicate the basin is over allocated. Export of groundwater from Dixie Valley has been proposed which would result in detrimental impacts to aquatic resources. Past spring modification and irrigation occurred in Dixie Meadows; however, large scale effects from these activities are not apparent. Future climate change is predicted to be warmer and while the amount of precipitation is not expected to change, the form of precipitation is expected to shift to more rain in the winter. Warmer temperatures are also expected to increase evapotranspiration which will decrease the amount of water available to Dixie Valley toads. Livestock grazing occurs in Dixe Meadows and direct mortality due to trampling has been documented. Impacts to wetland habitat, water quality, and vegetation from grazing has not been documented.

5.0 CURRENT CONDITIONS—DIXIE VALLEY TOAD HABITAT AND SPECIES VIABILITY

In this chapter, we provide current information on the Dixie Valley toad population in Dixie Meadows considered in this report. This information is organized by habitat, and includes the historical and current distribution of Dixie Valley toads, the relative abundance of Dixie Valley toads where information is available, and the current condition of the habitat in Dixie Meadows.

Dixie Valley toads are a narrow endemic with a single meta-population occurring in Dixie Meadows (Figure 2.2). The extent of occurrence, or the minimum convex hull around known localities, is 5.76 km^2 (2.2 mi^2). The potential area of occupancy was estimated as 1.46 km^2 (0.57 mi^2) based on the extent of wetland-associated vegetation. Extent of occurrence measures the degree of risk spreading across a species' range and area of occupancy measures the amount of the range that is potentially habitable (Gaston and Fuller 2009, pp. 4–6). Both values suggest Dixie Valley toads currently have low redundancy to withstand catastrophic events to the single population and low representation due to the limited range and lack of dispersal opportunities. Because toads are rarely encountered more than 14 m from aquatic habitat (Halstead et al. 2021, p. 7), we have high confidence in these range estimates. The closest wetlands supporting populations of western toads (*Anaxyrus boreas*) occur approximately 50 km (31.1 mi) northeast and 30 km (18.6 mi) southwest of Dixie Meadows and are separated by large expanses of arid playa or the Stillwater Range (Forrest et al. 2017, pp. 164–165).

Population estimates are not available for Dixie Valley toads, although the restricted range likely limits population size. Time-series data of toad abundance are available from the Service and NDOW surveys conducted from 2009–2012; however, differences in sample methodology between years and low recapture rates of marked toads make it difficult to infer temporal trends or population size. In addition to adult toads, surveys recorded eggs, tadpoles, and juveniles in all survey years, suggesting consistent reproduction is occurring.

5.1. Occupancy modeling framework

A recently developed, multi-state occupancy model (Halstead et al. 2019, entire) represents the highest resolution data available on current conditions despite a shorter historical timeframe. Due to the limited success of previous capture-mark-recapture (CMR) methods, it was agreed in partnership with the U.S. Geological Survey (USGS) that the proportion of area used for reproduction (as evidenced by pre-metamorphic life stages) and occupied by the species in general (in other words, one or more adults) was a reasonable metric of population health (Halstead et al. 2019, p. 3). This information could be collected by detection-nondetection surveys on a random selection of plots and, if repeated annually, would provide information on changes in the proportion of area occupied by adults and pre-metamorphic life stages over time. In addition to trends over time, this framework would explain the distribution of population states as a function of water temperature, water availability, water depth, water quality, and vegetation characteristics (Halstead et al. 2019, p. 3).

To obtain a probabilistic sample of the available habitat in Dixie Meadows, USGS divided the meadows into five strata defined by the different spring complexes and overlaid a 20 meter (m) × 20 m (65.5 ft × 65.5 ft) grid over each stratum (Figure 5.1). Sixty cells were then randomly selected from the grid so that each spring complex had at least three plots and the number of plots was proportional to the area of each wetland. Detection-nondetection surveys were performed in each plot. For a complete description of the methods used see Halstead et al. (2019, pp. 3–5). Monitoring Dixie Valley toads using these methods was originally started in April 2018, and has continued annually since.

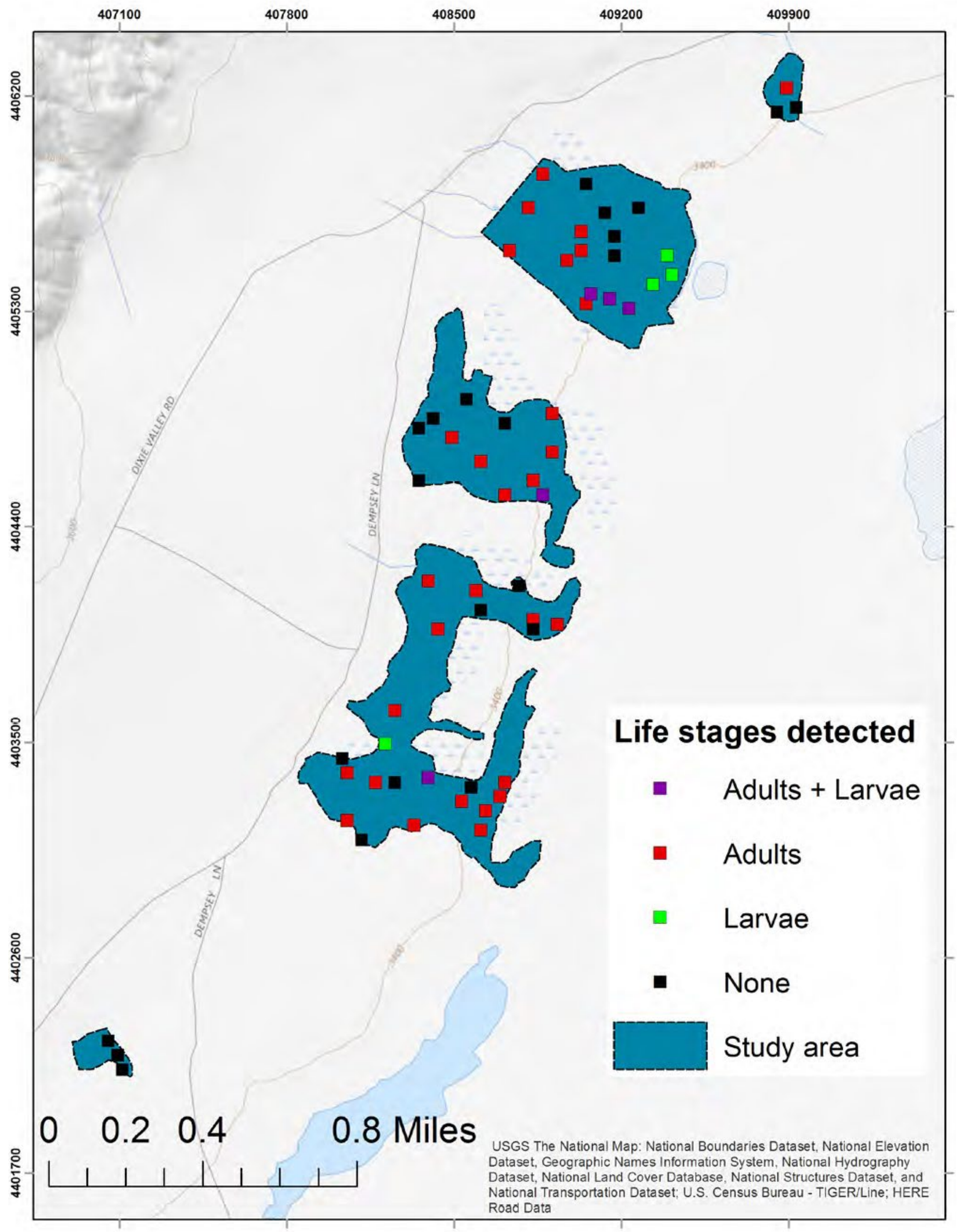

Figure 5.1. Location of the sampling plots used to determine occupancy of Dixie Valley toads (Halstead et al. 2019, p. 4). Depicted detections are from 2018.

These data were then incorporated into a multi-state, dynamic occupancy model that extends the model described in Halstead et al. (2019, entire) to estimate occupancy rates for Dixie Valley toads from 2018–2021 (Rose et al. 2022, entire). Following the approach described in Halstead et al. (2019, pp. 8–9), each plot may exist in one of three states: occupied by adults, occupied and used for reproduction, or unoccupied. The model relates the site occupancy at time *t* to the occupancy in the previous time step (*t*-1) through colonization and local extirpation events. The probability of colonization was modeled as a logit-linear function of percent wetted area and emergent vegetation. The probability that a site remains occupied (i.e., site survival probability) was modeled as a logit-linear function of percent wetted area, water depth, and water temperature. The probability of reproduction was modeled as a logit-linear function of percent wetted area, emergent vegetation cover, water temperature, and the distance to the nearest spring. The model also included random effects of each primary period to account for stochastic annual variation. Detection probability of adults and larvae were modeled separately as functions of time of day, day of year, survey time, air temperature, and emergent vegetation to account for imperfect detection. Details of the model are further described in Halstead et al. (2019, pp. 8–9), and the extended model specification to account for additional sampling periods follows Duarte et al. (2020, pp. 1,466–1,468).

Modeling was conducted in the program Just Another Gibbs Sampler (JAGS) version 4.3.0 using the package rjags (Plummer 2019, entire). Markov Chain Monte Carlo samplers adapted over 1,000 iterations and posterior parameter estimates were based on four chains of length 2,500 with a burn-in of 10,000. Convergence was assessed using the Gelman-Rubin diagnostic and visual inspection of trace plots. Predictor variables were standardized to mean zero and unit variance to improve convergence and all priors were diffuse on the scale of the data.

5.1.1 Current occupancy results

In 2018, Dixie Valley toads were detected in 38 of 60 randomized plots in the Dixie Meadows wetlands, with a 95 percent credible interval (Bayesian equivalent of a confidence interval) for probability of toad occurrence of 0.55–0.98 in plots of average water temperature (18.8 °C (65.8 °F)) (Halstead et al. 2019, p. 9). In other words, adult toads currently have high occupancy rates and are generally more likely than not to occur across the Dixie Meadows wetlands. The 95 percent credible interval for the probability of reproduction in an average plot (18.8 °C, 65.8 °F and 45 percent wetted area) was 0.01–0.26 and increased as a function of wetted surface area in plots with adults present (Halstead et al. 2019, p. 10). Although larvae were found to have a lower probability of occurring within an average plot, warmer water temperatures were found to strongly influence the probability of reproduction (Halstead et al. 2019, pp. 10–11). This suggests that adult toads are seeking out a specific subset of habitat for reproduction based in part on water temperature. The percentage of the range currently occupied by adults remained similarly high throughout 2018–2021 and across seasons (Figure 5.2; Rose et al. 2022, entire). The apparent dip in area occupied by larvae in late 2019 is due to a fall sampling event when we would not expect reproduction to be occurring.

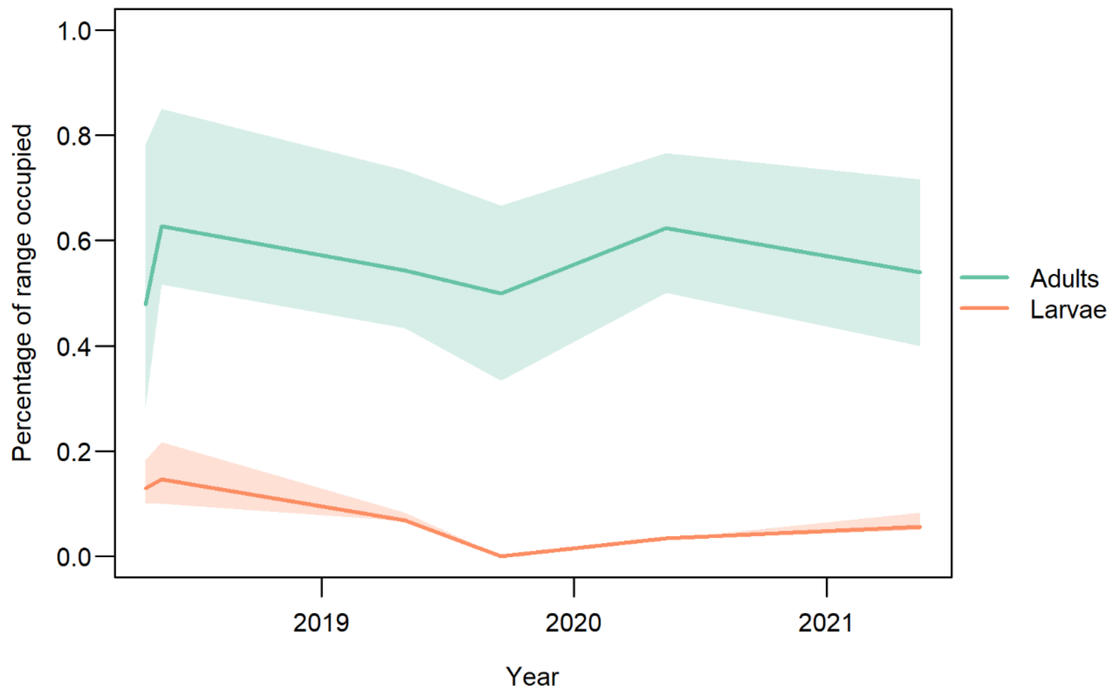

Figure 5.2. Percentage of the range occupied from 2018–2021 based on multistate occupancy models described in Halstead et al. (2019, entire).

5.2 Summary of Current Conditions

The high occupancy rate observed from 2018–2021 and evidence of reproduction observed between 2009–2021 suggest that Dixie Valley toads currently maintaining resilience to the historical and current environmental stochasticity present at Dixie Meadows; however, the limited period of occupancy estimates make it difficult to compare these with historical rates. The narrowly distributed, isolated nature of the single population of the species suggests that Dixie Valley toads will have no ability to withstand stochastic or catastrophic events through dispersal, and the species' adaptive capacity will depend entirely on its ability to persist within Dixie Meadows. Due to limited information on genetic diversity and population size, the species' ability to adapt to environmental changes is uncertain. However, because the species evolved in a unique spring province with little historical variation, we believe it has low potential to adapt to a fast-changing environment. As a single-site endemic with no dispersal opportunities outside the current range, the species has inherently low redundancy and representation, and depends critically on the continued availability of habitat in Dixie Meadows.

Because the risks posed by geothermal development are immediate, the species' current risk profile also depends heavily on projected occupancy rates in the short-term. We discuss the near-term projections of species response in the future conditions chapter, recognizing that a full evaluation of the species current viability will involve consideration of these future occupancy rates and how the habitat is expected to change given impending threats.

5.3 Unknowns/Uncertainties

The lack of data on abundance is notable because of its link to resiliency of this single population. All demographic rates are currently unknown, but would be informative and allow a better link between reproduction and persistence than we are able to model below. Related to the above items, it is worth emphasizing that occupancy, even in multi-state models, is a crude index of species' health because the binary nature of the data makes it insensitive to declines until extirpation occurs. However, once occupied, this insensitivity extends in the other direction as well, so it can't tell you if increases in abundance are occurring.

6.0 POTENTIAL FUTURE CONDITIONS – SPECIES VIABILITY

The occupancy models described in the previous chapter provide estimates of the effects of water temperature, water depth, and wetted area on the probabilities of occurrence and reproduction for Dixie Valley toads (Halstead et al. 2019, entire), but the potential for changes to these habitat characteristics due to geothermal activity, climate change, and extractive water uses represent a major source of uncertainty. The future viability of Dixie Valley toads will directly depend on how these habitat characteristics may change. Because limited empirical data are available to project changes, and the environmental impacts from geothermal development are expected to be site- and project-specific (Sorey 2000, entire; Kaya et al. 2011, entire), expert knowledge elicitation was used to obtain a scientific assessment of how the toads' habitat may change in the future. Judgments from the experts were used to inform the plausible future scenarios considered in the SSA, and the outputs from the occupancy model were projected based on the future scenarios of habitat change.

6.1 Future Scenarios

The probability distributions for the potential changes in habitat characteristics (Figures 4.5 and 4.6, right panels) were then used as input to the occupancy model to capture the range of potential species response. Due to computational demands of the Dixie Valley toad dynamic occupancy model, several discrete scenarios were modeled based on standard summary statistics of these probability distributions(Table 6.1). It is important to note that although the scenarios described below are framed in terms of habitat changes, those changes are based directly on projections of the various threats and how they may interact. For example, the variation in projected changes in flow rate was due in part to experts' uncertainty in how effective the geothermal plant's mitigation strategy would be, where production/injection wells would be located, and whether or not the effects from geothermal would coincide with a multi-year drought due to ongoing changes in climate.

For all scenarios, we project that the basin will remain over-allocated. For scenarios 1–3 we assume development and the monitoring and mitigation plan will continue as proposed. The monitoring and mitigation plan is less likely than not to be able to detect changes in the system (median expectation of 38 percent chance of detection [Figure 4.3; Appendix A) and less likely to be able to mitigate changes (median expectation of 29 percent [Figure 4.3; Appendix A). The expert panel had a median expectation that, if able to detect and mitigate changes, it would take four years to mitigate any perturbations to the system once detected (Figure 4.4; Appendix A).

Scenario 1:

Scenario one projects increases in temperature, evapotranspiration, and extreme precipitation events (Figure 4.9 and 4.10) seen under RCP 8.5. In this scenario the monitoring and mitigation plan fails to detect and mitigate changes to the surficial spring province and geothermal production has catastrophic impacts to the surficial spring province.

Scenario 2:

Scenario two also projects increases in temperature, evapotranspiration, and extreme precipitation events (Figure 4.9 and 4.10) seen under RCP 8.5. In this scenario the monitoring and mitigation plan fails to detect and mitigate changes to the surficial spring province and geothermal production has severe impacts to the surficial spring province.

Scenario 3:

Scenario three projects increases in temperature, evapotranspiration, and moderate changes in precipitation (Figure 4.9 and 4.10) seen under RCP 4.5. In this scenario the monitoring and mitigation plan mitigates some impacts to the surficial spring province and geothermal production has moderate impacts on the surficial spring province.

Scenario 4:

Scenario four also projects increases in temperature, evapotranspiration, and moderate changes in precipitation (Figure 4.9 and 4.10) seen under RCP 4.5. In this scenario the geothermal plant is not constructed. Instead, the effects of climate change and the over-allocated basin are the main threats to the species.

Scenario Results:

The results from each scenario are displayed in Table 6.1. These results were then used as inputs into the multi-state, dynamic occupancy model described in Chapter 5. Scenario 1 results in a catastrophic loss of habitat and likely extinction of the species. Scenario 2 results in a significant decline in temperature, which may affect the ability of Dixie Valley toads to overwinter in the springs, and also a significant decline in flow rate, reducing available habitat by 74 percent assuming a linear 1:1 reduction in wetted area for decreased flow rate. Scenario 3 would see a moderate decrease in temperature and a 31 percent reduction in available habitat. Scenario 4 would see an increase in temperature because of increasing temperatures due to climate change and a small decrease in flow rate because of increased evapotransporation due to climate change and the continued over allocation of the basin.

Table 6.1. Future scenarios of habitat change based on standard summary statistics of expert elicited judgments.

	Future Scenarios			
Projected Changes*	**Scenario 1 Springs dry (lower limit)**	**Scenario 2 Large magnitude change (lower 90% CI)**	**Scenario 3 Median change (50% quantile)**	**Scenario 4 Small magnitude change (upper 90% CI)**
Temperature (C)	NA	-27	-10	2
Flow rate (%)	-100	-74	-31	-5

* Temperatures will be reduced by the amount specified, but will be constrained to remain above freezing. We assume a linear (1:1) reduction in wetted area for decreased flow rate.

6.1.1 Modelling framework

The projected changes in habitat were incorporated into the multi-state, dynamic occupancy models described in Chapter 5 to estimate how occupancy rates may change in the future. Specifically, projected habitat changes were applied to the mean habitat variables in each year as a linear change over a five-year period, and the variation around mean projections was based on the variance observed between 2018–2021. The mean changes were then held constant for an additional 5 years. This approach allowed for random spatial variation around mean projections of habitat conditions across specific plots. Ten years was selected as the future timeframe for projections based on expert judgments of the response time of the system (Figure 4.2) and the widely used practice of considering at least 10 years or 3 generations in extinction risk assessments. Because scenario one would lead to catastrophic effects for an amphibian, we do not explicitly project this outcome using the occupancy model.

Projected habitat changes assumed a 1:1 relationship between decreases in spring discharge and both mean wetted area and water depth. This assumption represents a key piece of uncertainty in the modeled habitat changes, as the local topography will likely result in different areas in the meadows drying at different rates. Additionally, experts anticipate that a certain percentage reduction in springflow will result in a greater percentage reduction of wetted area and water depth (not a 1:1 ratio between spring discharge and wetted area and water depth). The projected decreases in mean water temperature were constrained to remain above freezing because we were primarily interested in projecting the probability of reproduction occurring during the Spring breeding season. Potential reductions in the geothermal contributions to the springs will be particularly important during the winter brumation period, and these additional risks are addressed below. How changes in mean temperature at the springs interacts with air temperature, solar irradiance, and other factors that impact water temperature at the plot level represents another source of uncertainty. For the purposes of the future conditions analysis, mean changes at the plot level were assumed to directly follow changes at the springheads with stochastic spatial variation between plots. All other habitat variables (e.g., air temperature, percent emergent vegetation, and variables affecting detection rates) were projected based on the mean and variance observed between 2018–2021.

6.1.2 Projections of future occupancy

The projected future occupancy of adult Dixie Valley toads is highly uncertain under the three modeled scenarios, with the 95 percent CI for the percentage of range occupied between 0–88 percent in scenario two, 8–92 percent in scenario three, and 28–88 percent in scenario four. Although the effects of wetted area and water temperature were less certain for adult toads, it is revealing that scenarios two and three suggest the percentage of range occupied could credibly drop as low as 0 and 8 percent, respectively. In addition, the complete drying of springs in scenario one would clearly lead to catastrophic impacts by removing all available aquatic habitat from Dixie Meadows. Compared to the 28 percent lower credible interval estimated between 2018–2021, this suggests that the risk to Dixie Valley toads will increase in the immediate future under all scenarios that include geothermal development.

It is important to emphasize that the projected occupancy rates do not explicitly model demographic processes such as recruitment or local abundance. For example, it is possible for the distribution to remain relatively static even while abundance is steadily decreasing (Royle and Kery 2007, p. 1,819). Therefore, it is helpful to focus on how these projected habitat changes will impact the potential for reproduction to better understand the demographic risks.

The patterns for larval occupancy and the probability of reproduction were much clearer, with both scenarios two and three suggesting a high risk of reproductive failure in addition to the clear reproductive failure that would occur under scenario one. Under scenario two, the mean percentage of the range occupied drops to 0 percent by 2024 with an upper credible interval of 2 percent (Figure 6.1). Scenario three projects a mean of 1 percent of the range occupied with an upper credible interval of 5 percent by 2026. The certainty is higher in projections of larval occupancy compared to adults because water temperature was found to strongly influence the probability of reproduction (Halstead et al. 2019, pp. 10–11). The projected decreases in water temperature therefore result in a decreased percentage of the range being used for reproduction on top of the decreases in wetted area. Scenario four revealed less certainty in future projections, with mean projections centered around the historical mean and 95 percent credible intervals ranging from 0–23 percent of the range occupied by larvae. These results suggest that Dixie Valley toads have a high risk of reproductive failure in the near-term, with three scenarios projecting clear declines in the probability of reproduction and all four scenarios including 95 percent credible intervals that include a chance of no reproduction occurring.

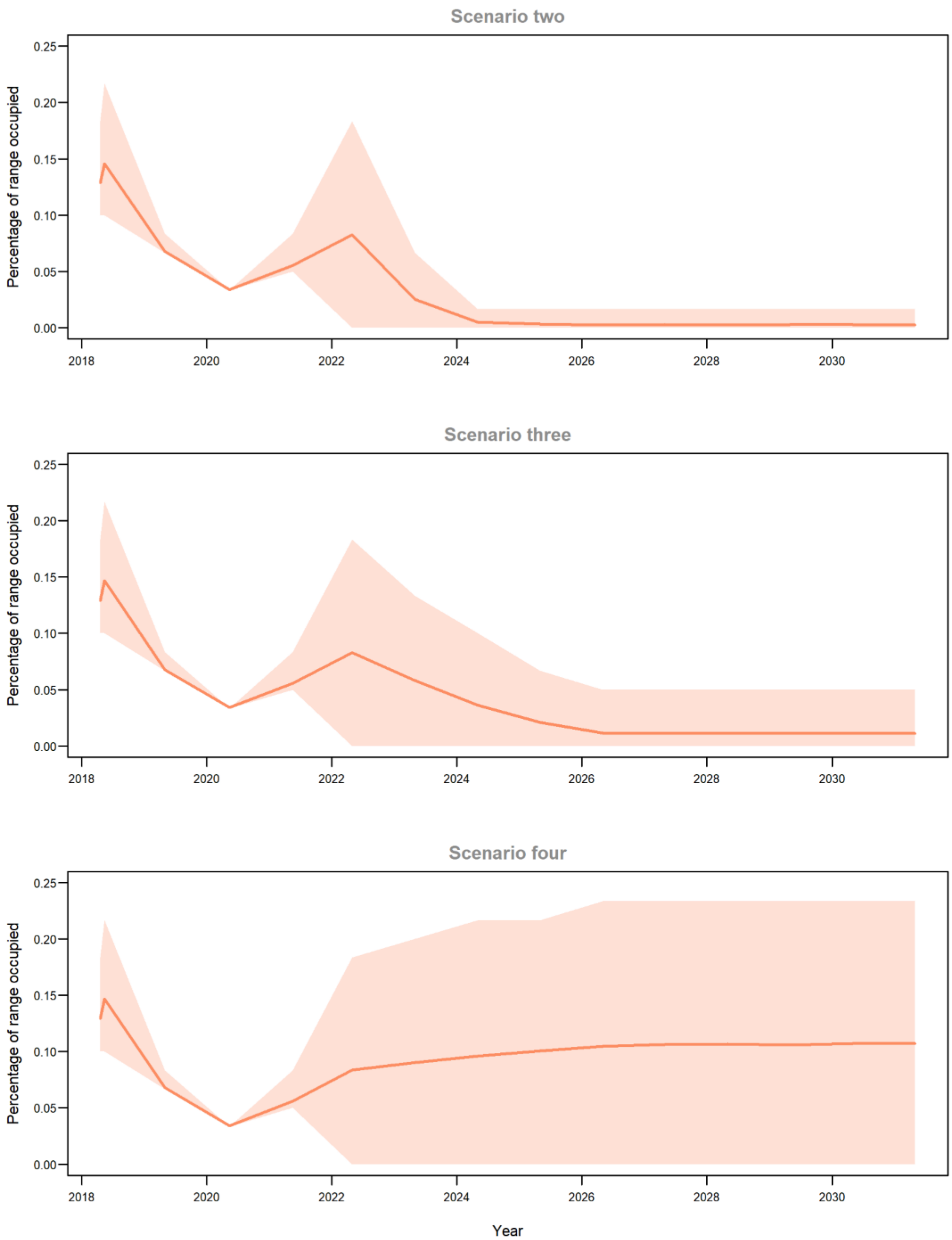

Figure 6.1. Projected changes in larval occupancy during the breeding season under the three modeled scenarios of habitat change. Scenarios were based on the lower 95 percent credible interval (CI), median, and upper 95 percent CI from expert judgments on the changes in springflow and water temperature.

*6.*1.3 Additional factors not accounted for in occupancy model

Although the occupancy model described above represents the best available projection framework for Dixie Valley toads, not all demographic and risk factors relevant to understanding species viability are included. One major threat not accounted for is the synergistic effect of changes in temperature with the risk posed by exposure to chytrid fungus that causes the disease chytridiomycosis. Chytrid fungus growth and survival are sensitive to both cold and hot temperatures, with optimal growth conditions in culture occurring between 15–25 °C (59–77 °F). There is equivocal evidence on whether colder temperatures limit the effects of chytrid fungus (Voyles et al. 2017, pp. 367–369); however, hot geothermal waters above 25°C (77 °F) appear to provide protection against chytrid fungus by allowing individuals to raise body temperatures through behavioral fever (Murphy et al. 2011, p. 39; Forrest and Schlaepfer 2011, entire). This suggests that future decreases in water temperature associated with scenarios two and three are likely to increase the risk that chytrid fungus could become established within Dixie Valley toads. If chytrid fungus becomes established within the Dixie Valley toad population, there would be negative, and plausibly, catastrophic effects to the species.

The effects of chytrid fungus have been shown to vary widely across species, but declines in annual survival and reproductive output have been observed in Western toad populations in Colorado, Wyoming, and Montana (Muths et al. 2003, entire; Pilliod et al. 2009, entire; Russell et al. 2019, pp. 300-301). Estimates for the mean reduction in individual survival probabilities range from 31–42 percent (Pilliod et al. 2009, p. 1265) to 19–55 percent (Russell et al. 2019, pp. 300-301). Although these rates do not suggest rapid declines in Western toads, they do indicate that the presence of chytrid fungus leads to negative effects on the populations over time. Importantly, these negative impacts on individual survival rates would be in addition to estimated declines in occupancy due to projected habitat changes, further reducing resiliency within remaining patches. These risks are heightened by the fact that chytrid fungus positive American bullfrogs already occur in the southern part of the range associated with the cold springs in wetland complex 5 (Gordon 2017, p. 136; Forrest 2013, p. 82; Halstead et al. 2021, p. 24), providing a clear path for introduction of chytrid fungus into Dixie Valley toads.

The seasonal timing of changes in water temperature are also particularly important. Dixie Valley toads strongly rely on aquatic environments throughout their life cycle (Halstead et al. 2021, entire). Unlike Western toads which may be found hundreds to thousands of meters from aquatic breeding sites, Dixie Valley toads were almost always found in water (Halstead et al. 2021, pp. 30–31). When not detected in water, Dixie Valley toads were found 4.2 m (13.8 ft) from water on average and brumate both in and above water (Halstead et al. 2021, p. 30). Autumn brumation sites were found to be warmer than random locations available, and toads are 1.3 times more likely to select sites for each 1° C increase in water temperature (Halstead et al. 2021, p. 30). Because toads are found closer to springheads in autumn compared to sites selected during other times of year, it is likely that they are selecting areas where water temperatures will remain stable throughout the winter (Halstead et al. 2021, p. 34). The selection of areas with stable, warm water temperatures suggests that reductions in geothermal contributions during winter could lead to thermal stress, reductions in available habitat as waters cool, or even mortality if geothermal contributions are removed completely or reduced to a level that toads are unable to adapt their brumation strategies. These seasonal and individual level effects are not explicitly captured in the modeled projections and the additional risks posed by unmitigated changes to winter habitat should be considered in addition to the quantitative results presented above.

*6.*1.4 Key Unknowns and Assumptions

One major assumption in the future projection model is the linear relationship between expected changes in water temperature and availability at the springheads and the conditions within plots throughout the meadows. This analysis used a linear relationship for the decrease in wetted area due to a lack of high resolution-topographic data for Dixie Meadows. The model uses random variation around mean changes to account for this uncertainty, but the habitat will likely dry unevenly due to spatial variability across springs, topographic relief collecting remaining water in springbrooks, and evapotranspiration accelerating drying in shallower areas. Similarly, we have assumed that temperature changes throughout the meadows are the same as temperature changes at the springheads. This model does not account for complex interactions between spring temperatures, solar irradiance, and air temperature as water moves throughout the meadows. These unknowns would likely have the greatest influence on future scenarios projecting small changes in the habitat, but are unlikely to affect projected trends in the larger magnitude changes expected under scenarios 1 and 2, for example.

Geothermal development may also have impacts on water chemistry (see chapter 4 for further discussion), but how these changes in water chemistry may impact Dixie Valley toads is unknown and not reflected in the occupancy model approach.

6.2 Summary of Future Conditions

Dixie Valley toads have low redundancy because they are a narrow endemic with a projected occupancy of only 1.46 km^2 (360 ac), have limited dispersal opportunities due to the harsh, arid nature of the surrounding landscape, and consist of one population. Subsequently, the species' future viability depends critically on maintaining resilience within Dixie Meadows. Multiple future scenarios lead to reduced resiliency in the near-term (i.e., likely within 10 years). The combination of projected reductions in available habitat for breeding and increased risk of declining survival rates from chytrid fungus exposure suggest that reductions in population size are likely to occur under multiple future scenarios. In addition, it is plausible that desiccation of springs (as seen in the nearby Jersey Valley system) could lead to a catastrophic event. With no redundant populations, this loss of resiliency could have major consequences for the species' viability.

Available evidence suggests that Dixie Valley toads have maintained resilience to the historical threats and variation present in Dixie Meadows; however, the changes anticipated under a future of geothermal energy production and increased risk of exposure to chytrid fungus represent novel threats and rates of change the species likely has not experienced previously. Whether Dixie Valley toads have sufficient representation to adapt to these novel changes is unknown. Our discussion of viability has focused primarily on geothermal energy development and exposure to chytrid fungus due to the immediacy of these risks, but it is important to emphasize that these will be overlaid on top of gradual, longer-term risks to the habitat posed by an over allocated water basin and projected increases in air temperature and evapotranspiration in Dixie Valley. To have a chance at adapting to these longer-term impacts, the single population will need to maintain high levels of resilience and genetic diversity in the short-term.

6.3 Cumulative Effects

Threats both current and in the future may act together to affect Dixie Valley toads in Dixie Meadows. Geothermal development, groundwater pumping, predation and competition from nonnative bullfrogs, chytrid fungus, and altered precipitation and temperature may adversely affect the entire population of Dixie Valley toads if one, some, or all threats occur concurrently (both now and in the future). Potential future conditions from geothermal development, groundwater pumping, or altered precipitation and temperature could also produce population-level impacts at Dixie Meadows depending on the severity of effects to wetted area, water temperature, wetland vegetation and water quality.

7.0 Status Assessment Summary

We used the best available scientific and commercial information to project the likely future conditions for Dixie Valley toads. Our results described a range of possible and probable conditions in terms of resiliency, redundancy, and representation, both currently and into the future. The small occupied area, isolated single population, unknown demographic information, and uncertainty regarding impacts from current and future threats, all contribute to uncertainty in assessing conservation of Dixie Valley toads. We reason that protecting the thermal springs that provide for the species needs at present confer high likelihood of supporting the Dixie Valley toad population into the future with reasonable certainty.

The best available information suggests that the threats discussed in this SSA report are already occurring or may occur with similar or increased intensity in the future. Despite limited species-specific information on how habitat change influences the species, Dixie Valley toads require thermal waters found only in Dixie Meadows. As such, the most significant threat for Dixie Valley toads into the future is the further reduction in springflow and change in water temperature. Reduction in flow directly influences species needs of adequate wetted area, adequate water temperature, wetland vegetation, and water quality. In consideration of geothermal energy production and climate change, it is reasonable that springflow and water temperature will change, but we are uncertain of the magnitude of risk. Thus, four scenarios of future springflows (i.e., maintenance, some reduction, and extreme reduction) provide a range of potential outcomes.

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APPENDIX A: Overview of Dixie Valley Toad Expert Knowledge Elicitation

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The US Fish and Wildlife Service is developing a Species Status Assessment for the Dixie Valley Toad (*Anaxyrus williamsi*) to support Endangered Species Act decision making. Occupancy models are available to provide estimates of the effects of water temperature, water depth, and wetted area on the probabilities of occurrence and reproduction for Dixie Valley Toads (Halsteadt et al. 2019, entire), but the expected changes in water temperature and spring discharge due to geothermal activity, climate change, and extractive water uses represent a major source of uncertainty. The future viability of Dixie Valley Toads will directly depend on how these habitat features change. Because limited empirical data are available to project changes, and the environmental impacts from geothermal development are expected to be site- and project-specific (Sorey 2000, entire; Kaya et al. 2011, entire), expert knowledge elicitation was used to obtain a scientific assessment of how the toads' habitat may change in the future. Judgments from the experts will be used to inform the plausible future scenarios considered in the Species Status Assessment and will be combined with the empirical occupancy models to project plausible changes in the species future response.

Expert Knowledge Elicitation

This analysis uses the Sheffield Elicitation Framework (SHELF), which follows established best practices for eliciting expert knowledge (Gosling 2018, entire; O'Hagan 2019, pp. 73-81; Oakley and O'Hagan 2019, entire). A critical step in an EKE is identifying and recruiting the appropriate expert panel, which typically contains between 4–8 participants in the SHELF protocol (O'Hagan 2019, p. 74). The use of multiple experts provides decision makers with a diversity of perspectives and helps reduce the risk of overconfidence in judgments by any single expert. Potential experts were identified and invited following best practices for expert knowledge elicitation (Burgman 2016, entire; Dias et al. 2018, pp. 393-443).

The relevant areas of expertise we sought to include were hydrology (surface and groundwater), geology, geothermal development, climate effects, and experience in the Dixie Valley system. To ensure that the expert knowledge represented unbiased and diverse judgments related to potential habitat changes in Dixie Meadows, the selection process prioritized experts not affiliated with the US Fish and Wildlife Service (decision maker), Bureau of Land Management (permitting authority), or developers for the proposed geothermal project. Potential participants were identified by searching the peer-reviewed literature using combinations of the terms Dixie Valley, geothermal, development, hydrology, hydrogeologic, and groundwater, or through recommendations by previously identified experts. Out of 19 identified experts, nine were contacted and six agreed to participate. The workshop panelists are shown in Table 1.
All participants met the following criteria to ensure relevant scientific expertise:

1. Hold a graduate degree in hydrology, geology, geophysics, geothermal energy, or related

disciplines.
2. Hold a research position in government, academia, or the non-profit sector, or a position in a management agency with responsibility for groundwater-dependent resources.
3. Have a record of peer-reviewed publications, technical reports, or scientific presentations on hydrology, geology, geophysics, or geothermal energy development within the Great Basin

This expert panel represents a multidisciplinary group with backgrounds in the geologic structure of basin and range systems, various components of deep and shallow groundwater flow, as well as geothermal exploration and development. All panelists have direct experience in the Great Basin, and most in Dixie Valley and Dixie Meadows, specifically. Due to the complexity of the hydrologic system at Dixie Meadows, this range of expertise and backgrounds was needed to capture all factors that may affect the hydrology of the meadows. Experts were provided training in quantifying personal beliefs using materials provided with the SHELF protocol (Oakley and O'Hagan 2019, entire). The workshop began with a practice quantity of interest (the depth of fluid circulation at Dixie Meadows in meters below ground) before experts provided judgments in support of this SSA. The elicitation workshop was carried out remotely using a series of three-hour video conferencing calls (14 hours total) between August 17–20, 2021.

Table 1. Panelists for expert knowledge elicitation workshop

Name	Title	Affiliation	Areas of Expertise
James Faulds, PhD	Director, State Geologist, and Professor	Nevada Bureau of Mines and Geology and the Department of Geological Sciences and Engineering, University of Nevada, Reno	Structural geology, fault controls on fluid dynamics, and geothermal activity in the Great Basin
Drew L. Siler, PhD	Research Geologist	US Geological Survey, Minerals, Energy, and Geophysics Science Center	Structural geology, fluid flow in geothermal systems
Jerry Fairley. PhD	Professor, Department Head, and Professional Geologist	University of Idaho, Department of Geography and Geological Sciences	Characterization and modeling of geothermal systems, with emphasis on fault-controlled hydrothermal systems
Jenna Huntington, MS	Hydrologist	US Geological Survey, Nevada Water Science Center	Hydrogeology, basin water budgets, geothermal and shallow aquifer connectivity
Christine Albano, PhD	Assistant Research Professor	Desert Research Institute	Ecohydrology, response of meadow and riparian vegetation to climate variability
Mark Hausner, PhD	Associate Research Professor	Desert Research Institute	Near-surface environmental heat transfer processes, groundwater-surface water interactions

Structuring the Quantities of Interest (QoI)

The primary quantities of interest (QoI) are the expected relative change in water temperature and discharge of the springs in Dixie Meadows; however, the experts felt that several additional quantities needed to be considered first to understand those expected changes. The workshop began by developing a conceptual model of the factors impacting water temperature and availability in Dixie Meadows (Figure 1). Expert panelists then considered six quantities:

1. Over what timeframe (years in the future) do you expect peak changes in Dixie Meadows in response to the threats outlined in the conceptual model?
2. What is your likelihood on a scale of 0-100 that the proposed monitoring plan could detect changes before a certain perturbation in temperature and spring flow occurs (e.g., 15°C or 40% reduction in flow)?
3. What is your likelihood on a scale of 0-100 that the proposed mitigation plan could mitigate changes in temperature and spring flow?
4. What timeframe (in months) would be required to fully mitigate the perturbations in temperature and flow once detected?
5. What is your expected change in water temperature in °C for the core wetland complexes at the time of peak change based on the threats outlined in the conceptual model?
6. What is your expected change in spring flows as a percentage increase or decrease for the core wetland complexes at the time of peak change based on the threats outlined in the conceptual model?

Figure 1. Conceptual model developed by expert panelists for factors influencing water temperature and availability in Dixie Meadows.

Quantities 1–4 were required to provide panelists with a common understanding of the natural response time of the system and the expected efficacy of the monitoring and mitigation plan. Quantities 5–6 were then defined based on the results of the previous quantities. A distinction was made between core wetland complexes (2–5) and peripheral wetland complexes (1 and 6) because of the expectation that the timing and magnitude of change will differ spatially. A facilitated discussion was used to understand how the judgments provided for the core wetlands would change for the peripheral wetland complexes or under a future scenario with no geothermal development, as panelists felt the expected responses were captured within uncertainty provided for the previous quantities of interest.

A complete record of the expert knowledge elicitation workshop is in Appendix I.

Recording Expert Judgments

For each quantity of interest, experts were first provided a summary of the existing data to reduce the availability bias. Experts received an evidence dossier (Appendix II) synthesizing relevant literature and the proposed Dixie Meadows Geothermal Utilization Project and had the opportunity to add additional data or references prior to the workshop. During the individual judgment round, experts provided private judgments for each of the quantities of interest. This approach begins by specifying an upper and lower plausible limit to counter overconfidence and anchoring effects (O'Hagan 2019, p. 75). The median value is then estimated by dividing the plausible limits into two equally probable parts following the bisection method (Raiffa 1968, pp. 161-168). This bisection procedure is then repeated to specify an upper quartile and lower quartile using the previously specified median value and plausible limits. Judgments were submitted via an online form and probability distributions were fit by minimizing the sum of squared differences between elicited and fitted probabilities along the cumulative distribution function using the SHELF package in R (Oakley 2019, entire).

Experts were then led through a facilitated group discussion where they provided the reasoning for their judgments, including which factors were of greatest concern or generated the most uncertainty. During the group judgment round, experts were asked to provide new quartiles from the perspective of a Rational Impartial Observer (RIO) who had listened to the group discussion and understood their arguments (O'Hagan 2019, pp. 77-78). Each expert privately provided a RIO judgment using the same procedure described above, and a linear pool of the fitted distributions was used to select the final RIO quartiles. Finally, an appropriate family of probability distribution was fit to the final RIO judgments to represent the collective uncertainty surrounding the quantity.

Results of Expert Knowledge Elicitation

The following is a summary highlighting the key points relevant to assessing the risk to the Dixie Valley Toad.

The expert panelists believe that the system will respond quickly once geothermal development begins, with a median response time of roughly 4 years and a 90% chance that the largest magnitude changes will occur within 10 years (p. 13 in elicitation report). Uncertainty within individual judgments on response time related largely to the efficacy of mitigation measures and interactions between short-term impacts from geothermal development and longer-term impacts from climate change and consumptive water use.

Expert judgments expressed concern over the proposed monitoring and mitigation plan's ability to both detect and mitigate changes to the temperature and flow of surface springs in Dixie Meadows. Although the aggregated distribution for the ability to detect changes ranged from 0-100%, the median expectation was a roughly 38% chance of detecting (p. 18 in elicitation report). These judgments reflect a belief that it is less likely than not the proposed plan could detect changes in the system due to the high natural variability of the system, limited baseline data, and perceived inadequacies of the monitoring and mitigation plan. The degree of belief in the ability to mitigate changes was even lower (median of roughly 29%, p. 22 in elicitation report), and experts thought that it would take multiple years to mitigate perturbations once detected (median of 4 years, pp. 24-27 in elicitation record).

Experts' judgments on the plausible changes to spring temperatures ranged from a lower limit of a 55°C decrease to an upper limit of a 10°C increase, with a median expectation of a 10°C decrease (pp. 28-31 of elicitation record). This uncertainty is due to the wide spatial variation in spring temperatures across the meadows but reflects the expectation that the spring temperatures could plausibly drop to ambient levels (i.e., a complete loss of geothermal contributions). Similarly, the lower limit of the aggregated judgments considered it plausible that springs in Dixie Meadows could dry up as the geothermal contribution was reduced, with a median expectation of a 29% decrease in surface discharge. These judgements reflect the high pumping rates of the proposed plants, perceived inadequacies with the monitoring and mitigation plan, and that fact that drying of surface springs have been documented at other nearby geothermal development projects.

APPENDIX B: Current Management and Conservation Measures

The Dixie Valley toad occurs only on Federal lands. Various laws, regulations, policies, and management plans may provide conservation or protections for Dixie Valley toads. Particularly relevant ones include the following:

Federal Laws, Regulations, Policies, and Management Plans

Department of Defense

Integrated Natural Resources Management Plan, Naval Air Station, Fallon

The Integrated Natural Resources Management Plan (INRMP) provides Naval Air Station Fallon, Nevada (NAS Fallon) with a viable framework for future management of natural resources on lands it owns or controls (AMEC Environmental and Infrastructure, Incorporated. 2014, entire). Required by the Sikes Act (16 U.S. Code [USC] § 670 et seq., as amended) for the U.S. Department of Defense (DoD), the INRMP is a long term planning document to guide the installation commander in the management of natural resources to support the installation mission, while protecting and enhancing installation resources for multiple use, sustainable yield, and biological integrity.

For NAS Fallon, the overall goal is to provide good stewardship to protect, manage, and enhance the land, water, and wildlife resources of NAS Fallon while fulfilling the military mission. This is to be accomplished such that natural resource conservation, restoration, and enhancement can proceed consistent with and unhindered toward internal and regional ecosystem management goals for these lands and waters, without loss to the military mission.

Key objectives for natural resources management on NAS Fallon include the following:

- Ensure no net loss in the capability of the land and natural resources at NAS Fallon to support its current and future military mission;
- Ensure compliance with applicable laws and regulations as they pertain to natural and cultural resources;
- Maintain and enhance the level of biodiversity within the constraints of the military mission;
- Outlease lands that are suitable and available for agricultural production and grazing;
- Implement adaptive management techniques to provide flexible and responsive management strategies based on scientific data gathered from monitoring programs, literature, and resource experts;
- Maintain public access for wildlife viewing and other recreational activities on lands not closed to the public for security or public safety;
- Protect the quality of wildlife habitat, where feasible; and
- Maintain sufficient professionally trained natural resources personnel to implement, manage, and monitor the management strategies of the INRMP.

This INRMP is currently being revised.

Department of Defense Natural Resources Program, Strategic Plan for Amphibian and Reptile Conservation and Management on Department of Defense Lands

The purpose of this document is to summarize current reptile and amphibian related challenges and concerns on Department of Defense (DoD) lands, and to highlight reptile and amphibian strategies and priorities that can inform and enhance DoD's natural resource conservation and management activities. Success will be achieved by implementing proactive, habitat-based management strategies that maintain healthy landscapes and training lands in ways that sustain and enable DoD's testing, training, operations, and safety mission (Lovich et al. 2015, entire).

National Environmental Policy Act of 1969

All Federal agencies are required to adhere to comply with the National Environmental Policy Act of 1970 (as amended; 42 USC §§ 4321 et seq.), which is a procedural statute, for projects they fund, authorize, or carry out. Prior to implementation of projects with a Federal nexus, NEPA requires the agency to analyze the project for potential impacts to the human environment, including natural resources. If an Environmental Impact Statement is prepared for an agency action, the agency must provide a full and fair discussion of significant environmental impacts and inform decision makers and the public of reasonable alternatives that would avoid or minimize adverse impacts or enhance the quality of the human environment (40 CFR § 1502.1). The Council on Environmental Quality's regulations for implementing NEPA states that agencies shall include a discussion of the environmental impacts of the various project alternatives (including the proposed action), any adverse environmental effects that cannot be avoided, and any irreversible or irretrievable commitments of resources involved (40 CFR part 1502). The public notice provisions of NEPA provide an opportunity for the Service and other interested parties to review proposed actions and provide recommendations to the implementing agency. NEPA does not impose substantive environmental obligations on Federal agencies—it merely requires informed agency action.

Bureau of Land Management

Land management by the BLM is directed by the following laws, policies, manuals, and management plans. These directives provide conservation assurance to Dixie Valley toads as stated in the following:

Federal Land Policy and Management Act of 1976

The Federal Land Policy and Management Act of 1976 (FLPMA; 43 U.S.C. 1701 *et seq.*) is the primary Federal law governing most land uses on BLM lands, and directs development and implementation of Resource Management Plans (RMPs) that direct management at a local level. Resource Management Plans are the basis for all actions and authorizations involving BLM-administered lands and resources. They authorize and establish allowable resource uses, resource condition goals and objectives to be attained, program constraints, general management practices needed to attain the goals and objectives, general implementation sequences, intervals and standards for monitoring and evaluating RMPs to determine effectiveness, and the need for amendment or revision (43 CFR 1601.0-5(k)). The RMPs also provide a framework and programmatic direction for implementation plans, which are site-specific plans written to regulate decisions made in a RMP. Examples include fluid mineral development, travel management, and wildlife habitat management plans. Implementing plan decisions normally require additional planning and NEPA analysis, as described above.

The BLM portion of Dixie Meadows and the fluid mineral rights are managed under the Carson

City Field Office Consolidated Resource Management Plan (RMP; BLM 2001, entire). The Carson City Field Office Consolidated RMP provides management guidance for approximately 5.3 million acres of public land administered by the BLM in 11 counties in western Nevada and eastern California. It identifies and analyzes alternatives for long-term management of public lands and resources administered by BLM in the Carson City Field Office. The RMP is a comprehensive document that addresses all resources and programs administered by BLM, including livestock and rangeland management, riparian management, wildlife, special status species, minerals and energy, among other programs. Management direction for each resource and program is further divided into into National Policy, RMP Level Decisions, Implementation Level Decisions, Administrative Actions, and Standard Operating Procedures.

The resources and programs objectives and management directions that may apply to Dixie Valley toads and their habitat include:

- Dixie Valley toads are a designated sensitive species. BLM Manual 6840 – Special Status Species Management (BLM 2008) states that "Bureau sensitive species will be managed consistent with species and habitat management objectives in land use and implementation plans to promote their conservation and to minimize the likelihood and need for listing under the Endangered Species Act" (BLM 2008, p. .05V). BLM Manual 6840 further requires that RMPs should address sensitive species, and that implementation "should consider all site-specific methods and procedures needed to bring species and their habitats to the condition under which management under the Bureau sensitive species policies would no longer be necessary" (BLM 2008, p. 2A1). State Directors, usually in cooperation with state wildlife agencies, may designate sensitive species. By definition the sensitive species designation includes species that could easily become endangered or extinct in a state. Therefore, if sensitive species are designated by a State Director, the protection provided by the policy for candidate species shall be used as a minimum level of protection.

- Special Status Species Objective SS-2: Manage habitat to further sustain the populations of Federally listed species so they would no longer need protection of the Endangered Species Act. Manage habitats for non-listed special status species to support viable populations so that future listing would not be necessary.

- Management Direction SS-2-a: Enter into conservation agreements with the U.S. Fish and Wildlife Service and the State of Nevada that, if implemented, could reduce the necessity of future listings of the species in question.

- Water Resource Management Objective WT-1: Maintain the quality of waters presently in compliance with State and/or Federal water quality standards. Improve the quality of waters found to be in noncompliance.

- Water Resource Management Objective WT-3: Ensure availability of adequate water to meet management objectives including the recovery and/or re-establishment of Special Status Species.

- Maintain and improve wildlife habitat, including riparian/stream habitats, and reduce habitat conflicts while providing for other appropriate resource uses.

- Maintain or improve the habitat condition of meadow and aquatic areas. Habitat condition for any wildlife species can be defined as the ability of a specific area to supply the forage, cover, water and space requirements of an animal. Habitat condition, therefore, is a measure of habitat quality, and is determined by assessments, surveys and studies.

- State Listed Species. The BLM shall carry out management for the conservation of state listed plants and animals. State laws protecting these species, apply to all BLM programs and actions to the extent that they are consistently with FLPMA and other federal laws. In states where the state government has designated species in categories that imply local rarity, endangerment, extirpation, or extinction, the State Director will develop policies that will assist the state in achieving their management objectives for those species. See below for the status of Dixie Valley toads protection with the State of Nevada.

State Plans

STATE OF NEVADA

The Nevada Department of Wildlife received approval by the Legislative Council Bureau to add Dixie Valley toad as a protected amphibian by the State of Nevada under Nevada Administrative Code (NAC) 503.075(2)(b). The revised list of protected amphibians is expected to be finalized in 2022. Per NAC 503.090(1), there is no open season on those species of amphibian classified as protected. Per NAC 503.094, the State issues permits for the take and possession of any species of wildlife for strictly scientific or educational purposes. The State's Department of Conservation and Natural Resources maintains the Nevada Division of Natural Heritage (NDNH), which does track the species status of plants and animals in Nevada. The NDNH recognizes Dixie Valley toads as critically imperiled, rank *S1*. Ranks of *S1* are defined as species with very high risks of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors.

Nevada Department of Wildlife, Nevada State Wildlife Action Plan, 2012

The Nevada Department of Wildlife developed its State Wildlife Action Plan as a requirement to apply for State Wildlife Grant funds through the U.S. Fish and Wildlife Service (Wildlife Action Plan Team 2012, entire). These funds are used by Nevada Department of Wildlife for the conservation of Nevada's wildlife. One of the State Wildlife Action Plan's goals is to establish "springs and springbrook habitats functioning naturally within the natural fluctuation inherent to the spring type". Objectives that would need to be met to achieve this goal include the following: (1) a measurable increase in the number of springs and springbrooks functioning naturally and supporting the natural ecological community expected for each spring by 2022; and (2) no net loss of spring/springbrook-dependent Species of Conservation Priority. To assist in meeting these objectives, the Nevada Department of Wildlife and Utah Division of Wildlife Resources initiated a multi-partner planning process to develop a regional Conservation Agreement and

Strategy for springsnails throughout the states of Nevada and Utah, discussed further below.

Voluntary and Stipulated Agreements

Conservation Agreement and Strategy for Springsnails in Nevada and Utah (CAS), 2017

The Conservation Agreement for springsnails in Nevada and Utah was developed to assist in the implementation of conservation measures for springsnail species in Nevada, Utah, and adjacent areas as a collaborative and cooperative effort among resource agencies, governments, and landowners. The desired outcome is to ensure the long-term conservation and persistence of springsnails and their associated habitats throughout Nevada and Utah and to contribute to development of range-wide conservation efforts for these species. By conserving the springsnails and their habitat in Dixie Meadows, this will also help conserve Dixie Valley toads and their habitat since they occupy the same area.

The conservation agreement outlines goals and objectives to protect species and their habitats and will be linked to a conservation strategy that includes the actions intended to address the conservation agreement goals and objectives. The Conservation Agreement (Agreement) between multiple agencies, stakeholders, and other interested parties was completed in 2017 and executed in 2018. The corresponding Strategy is being drafted and should be completed by the end of 2019. The CAS has a ten-year duration and covers 98 species including the genera *Pyrgulopsis* (including all six species evaluated in this document)*, Assiminea, Eremopyrgus, Juga, Fluminicola,* and *Tryonia* with the realization that accommodations for taxonomic changes are likely.

The primary goal of this Agreement is to ensure the continued persistence of springsnails and their habitats in Nevada and Utah to preclude ESA listing. The goal will be achieved through implementation of specific objectives listed below and conservation measures identified in the Strategy. The conservation actions described in the Strategy should lead to the protection and enhancement of these unique species and their associated habitats. The status of springsnail species will be evaluated annually by the Springsnail Conservation Team (SCT) through an adaptive management framework to assess program progress.

The following conservation objectives will be implemented to reach the goal of the Agreement. Included with each objective is a statement on how the objective will benefit springsnail species in Nevada and Utah and a standard to determine if the objective was successful at achieving the goal. The conservation actions and commitments by the signatories will be implemented as proposed in the Strategy. To date, Objective 4 is complete and the SCT is actively working on the other objectives.

- Objective 1. Compile known springsnail distribution, status, and habitat data into a single comprehensive and accessible database and incorporate new information as it becomes available to manage extant and future spatial and biological information for springsnail conservation.
- Objective 2. Identify, assess, and reduce known and potential threats to springsnail populations and their associated habitats at occupied sites.

- Objective 3. Maintain, enhance, and restore springsnail habitats in Nevada and Utah to ensure the continued persistence of the species.
- Objective 4. Develop a Springsnail Conservation Team, which will be tasked with development and implementation of the Strategy and coordinating on-the-ground conservation actions for identified springsnail species and habitats.
- Objective 5. Create education and outreach tools that generate broad awareness and strong support for the conservation of springsnails and their habitats among landowners, agencies, and the general public.

ELICITATION RECORD – Part 1

The Workshop Context

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Dixie Valley Toad Species Status Assessment
Date	17-August-2021 to 20-August-2021 This elicitation workshop was held remotely using a series of three-hour video conferencing calls. An initial two-hour video call was held on 21 July 2021 to introduce participants, begin structuring the QoIs, and review the available evidence.
Part 1 start time	17-August-2020, 9:00 PDT (12:00 EDT)

Attendance and roles	Dr. James Faulds, expert panellist Dr. Drew Siler, expert panellist Jena Huntington, expert panellist Dr. Jerry Fairley, expert panellist Dr. Mark Hausner, expert panellist Dr. Christine Albano, expert panellist Dr. Daniel Fitzgerald, facilitator Dr. David Smith, facilitator Chad Mellison, SSA lead biologist Dr. Brian Halstead, lead for toad occupancy model
Purpose of elicitation	The US Fish and Wildlife Service is developing a Species Status Assessment (SSA) for the Dixie Valley Toad (*Anaxyrus williamsi*) to support Endangered Species Act decision making. Occupancy models are available to estimate the effects of water temperature, water depth, and wetted area on the probabilities of occurrence and reproduction for Dixie Valley Toads, but the expected changes in water temperature and surface flows from geothermal activity and climate change represent a major source of uncertainty.
This record	Participants are aware that this elicitation will be conducted using the Sheffield Elicitation Framework, and that this document, including attachments, will form a record of the session.
Orientation and training	Experts were sent the SHELF Expert Briefing document (attached) and provided an overview of how elicitation results would be used in the SSA. Training on the process of making

	probability judgments was completed using the attached presentation.
Participants' expertise	**Dr. James Faulds, Director and State Geologist** – Ph.D. University of New Mexico (1989), M.S. University of Arizona, (1986), B.S. University of Montana, highest honors (1981). Has worked with the Nevada Bureau of Mines and Geology and the Department of Geological Sciences and Engineering, University of Nevada at Reno since 1997. Areas of expertise include geologic mapping, structural geology and fault controls on fluid dynamics, and geothermal activity in the Great Basin. Has co-authored over 100 peer-reviewed articles and was cited in the draft Aquatic Resources Monitoring and Mitigation Plan. **Dr. Drew Siler, Research Geologist** – Ph.D. in Geology from Syracuse University (2011), B.S. in Earth and Space Science from University of Washington (2005) Has worked at the US Geological Survey's Geology, Minerals, Energy, and Geophysics Science Center in Menlo Park since 2016. Previously worked for the Lawrence Berkeley National Laboratory and the Nevada Bureau of Mines and Geology. Current research focuses on characterizing geologic systems in 3-dimensions. This includes geologic mapping and working with a wide variety of data sets including drill cuttings and core, subsurface temperature data, seismic reflection data, potential-field geophysical data, and structural analyses, among others. Applies these tools and techniques to evaluate permeability distribution in fault systems in 3D and characterizing the geologic controls of fluid flow in geothermal systems. **Jena Huntington, Hydrologist** - M.S. in Hydrogeology from the University of Nevada, Reno (2005), B.S. in Geoscience from Northland College, in Ashland, WI (2003). Career with the U.S. Geological Survey-Nevada Water Science Center has involved a variety of projects, including constructing and calibrating groundwater models in the Lake Tahoe Basin, basin water budgets, evapotranspiration, geothermal and basin-fill aquifer connectivity, and groundwater quality studies, among others. From 2009-2014, co-managed a broad-scale USGS hydrogeologic framework project in Dixie Valley to describe groundwater flow, groundwater change, the chemical composition of the basin-fill aquifer, and the connection between the basin-fill and geothermal aquifers. Cited throughout the draft Aquatic Resources Monitoring and Mitigation Plan. **Dr. Jerry P. Fairley, Professor of Geology (Hydrogeology)** – Chair of the Department of Geography and Geological Sciences, Professional Geologist (Idaho, License PGL-1707), received PhD in Earth Resources Engineering in 2000 from the University of California, Berkeley (advisor: P.A. Witherspoon).

	Has been employed as teaching and research faculty by the University of Idaho since 2000; promoted to full professor in 2013, and department chair in 2020. Was a visiting researcher at Kyoto University's Aso Volcanological Laboratory, Japan (2009--2010), and an Erskine Fellow at the University of Canterbury, New Zealand (2013). Has ~10 years of industry experience, including serving for two years (1993–1995) as the Chief Hydrologist for Site Characterization on the USDOE's Yucca Mountain Project. Primary area of research is the characterization and modeling of geothermal systems, with special emphasis on fault-controlled hydrothermal systems, heat and mass transfer in the near-surface, and shallow subsurface/environment interactions. Authored more than 20 peer-reviewed manuscripts in this area. **Dr. Mark Hausner, Associate Research Professor (Hydrology)** – PhD in Hydrogeology from University of Nevada, Reno (2013), M.S. in Hydrologic Science from University of Nevada Reno (2010), B.S. in Civil and Environmental Engineering from Cornell University (1997). Expertise in near-surface environmental heat transfer processes, especially in the use of heat as a tracer. Research applications of heat as a tracer include groundwater-surface water interactions, groundwater flow characterization, thermal modelling of the unsaturated zone, and modelling surface flows using computational fluid dynamic software. Focuses specifically on the interactions between physical hydrologic systems and the communities that occupy those systems. Teaching at the university level includes groundwater hydrology, field methods in hydrology, vadose zone hydrology, and scientific computing. **Dr. Christine Albano, Assistant Research Professor (Ecohydrology)**– PhD in Hydrologic Sciences from University of Nevada, Reno, an MS in Ecology from Colorado State University, and a BS in Biology (Minors: Chemistry and Environmental Studies) from Westminster College Work is focused on the relative roles of climate and natural resource management on water availability and ecological conditions in the southwestern US. Expertise includes the influence of atmospheric rivers as drivers of hydrologic and ecological variability in the western US, quantifying sensitivities of meadow and riparian vegetation to climate variability in the Sierra Nevada and Great Basin, characterizing the effects of flow alterations in aquatic and terrestrial ecosystems, and landscape-scale conservation and climate adaptation planning.
Declarations of interests	**Dr. James Faulds** – none declared.

	Dr. Drew Siler – none declared. **Jena Huntington** – I do not have a personal interest in the outcome of this elicitation, however, since I spent considerable time working in Dixie Valley during the previously mentioned USGS study, I am professionally interested to learn how the proposed groundwater development will progress in Dixie Valley and what affect it will have on the local aquifers and surface expressions. **Dr. Jerry Fairley** – I do not have an interest in the outcome of this elicitation as I understand this question. However, I have a professional interest (as a researcher) in characterizing and studying the hydrothermal outflow areas of the Dixie Valley Meadows that are the focus of this elicitation, and I have considered applying for funding to conduct basic research at the site. I have previously conducted fieldwork at the Dixie Meadows site (Summer, 2006), and would like to do more work there before development of the geothermal system, should it take place, closes the site to future investigations and potentially impacts the natural system. **Dr. Mark Hausner** – Aside from being a Nevada electric rate payer, I have no conflicts to declare. **Dr. Christine Albano** – none declared.
Strengths and weaknesses	This expert panel represents a multidisciplinary group with backgrounds in the geologic structure of basin and range systems, various components of deep and shallow groundwater flow, as well as geothermal exploration and development. All panellists have direct experience in the Great Basin, and most in Dixie Valley and Dixie Meadows, specifically. Due to the complexity of the hydrologic system at Dixie Meadows, this range of expertise and backgrounds was needed to capture all factors that may affect the hydrology of the meadows.
Evidence	The experts received an evidence dossier (attached) summarizing information on the hydrogeologic framework in Dixie Meadows, previous studies, and available baseline monitoring data. Experts received a draft one month prior the workshop to discuss available evidence and were given an opportunity to provide additional data or confirm they were not aware of missing items.
Structuring	Experts discussed potential QoIs and approaches during a 2-hour preliminary call. The group was most comfortable first assessing the expected response time of the system and conditioning subsequent QoIs on that response time.
Definitions	

Part 1 end time	20 August 2021, 11:00 PDT (14:00 EDT)
Attachments	Evidence dossier; SHELF expert briefing; Training presentation

ELICITATION RECORD – Part 2

Eliciting a Continuous Distribution

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 1
Date	17 August 2021
Quantity	Training QoI – The depth of fluid circulation at Dixie Meadows in meters below ground
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	12:00 EDT

Definition	The depth of fluid circulation at Dixie Meadows in meters below ground.
Evidence	Y reviewed the following evidence, then opened the discussion for other pieces of evidence that might be relevant to this training quantity. a. Helium isotopic studies reveal that 7.5% of the He in the Dixie Valley system is derived from mantle sources, requiring fluid input from below the brittle–ductile transition, where the upper, more brittle crust transitions to the lower, more ductile crust (Kennedy and van Soest 2006). b. For a temperature gradient of 115 °C/km, Weis *et al.* (2012) showed that this transition to reduced permeability occurs at depths of 3–5 km. The average temperature gradient for Dixie Valley is 63 °C/km, although some isolated locations reach a gradient greater than 100 °C/km (Wanner *et al.* 2014, p. 131). c. McKenna and Blackwell (2004) used numerical modeling based on the Dixie Valley system to

	postulate a large-scale fluid convection cell where water reaches a depth up to 8 km before finally ascending to the surface. d. Moulding and Brikowski (2012) argued that such deep fluid infiltration seems unrealistic considering that the lithostatic stress at this depth (and below the brittle-ductile transition) reduces the permeability needed to establish significant advective fluid flow. e. In modelling simulations based on a 2D reactive transport model for the Dixie Valley, increasing the permeability of a small-scale fracture system feeding the model's geothermal spring resulted in a shallow convection cell < 1 km deep (Wanner *et al.* 2014, p. 140). The authors suggested this may be a general feature of Basin and Range geothermal systems. f. Northeast of Dixie Meadows, temperatures reach over 200°C at 1.9–2.9 km below land surface (Iovenitti 2014, p. 3). C – clarified that this quantity refers to a broad-scale circulation model and does not account for smaller convective cells. Reality of system is more complex, includes conduits and fractures. B – this is one of the top five processes we are trying to understand in the field, so it is a tough training question. In a project northeast of Dixie Meadows, they are producing geothermal fluid at 2.5 km below ground, so the water circulates at least 2.5 km deep there. C – One thing to note about the modeling studies referenced is that they are a simplification. The actual fault structure in the center could be very complex, and have poor understanding of downwelling.
Plausible range	See judgments spreadsheet for complete record.
Individual elicitation	**Method:** Quartile **Judgements:** See judgments spreadsheet for complete record.

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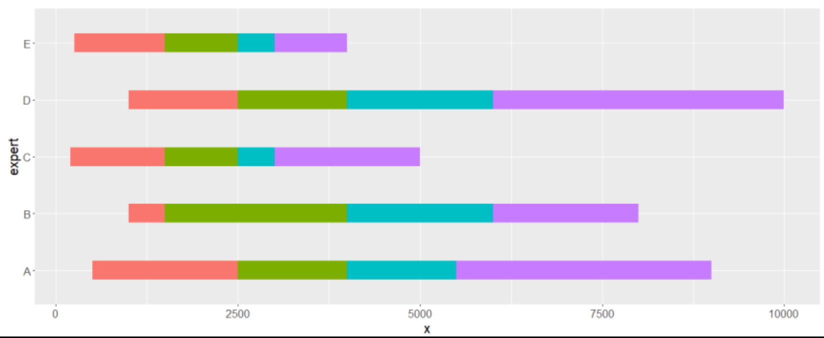
<tr><td></td><td>
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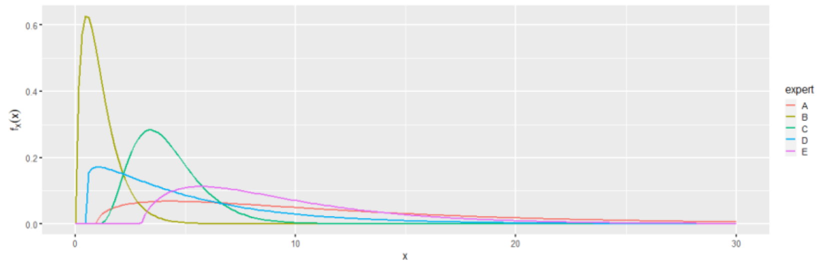
<tr><td>Fitting</td><td>
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<tr><td>Group discussion</td><td>Y – began discussion by asking for justifications for highest upper limits

D – 8 km was noted by one study as an upper limit, extended that a little further to capture additional uncertainty they may not have accounted for

A – similar reasoning

B – thought of 8km as an upper physical limit

C – thought about the maximum temperatures observed in the surrounding geothermal fields (not greater than 220 degrees C) and used an average geothermal gradient of 30-50 degrees C/km. This was all conditional on it being a non-magmatic system.

E – discounted the modelling results almost completely. Helium can come from lots of sources, so that data is not very informative. Lower limit was based on water movement, which wants to move away from a heat source, so there has to be something forcing it down that far.

E – asked if the RIO judgments could be interpreted as how much they are willing to accept the arguments of the other panel members. Also asked if personal judgments would be shown.

Y – clarified the concept of RIO and that the experts should try to consider what a rational impartial observer would think, not themselves. But, if that line of thinking was helpful, it is consistent with the intent of the second round of judgments.</td></tr>
<tr><td>Group plausible</td><td>See judgments spreadsheet for complete record.</td></tr>
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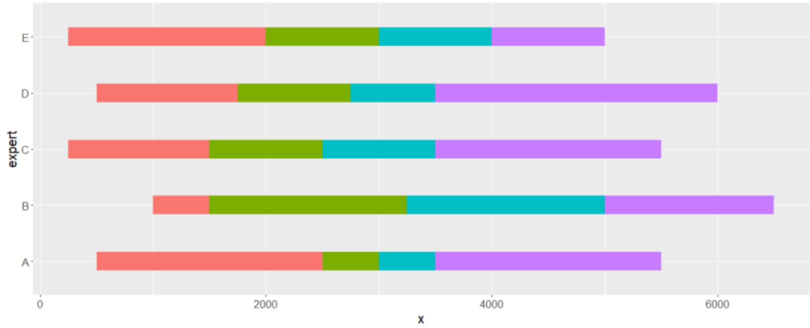
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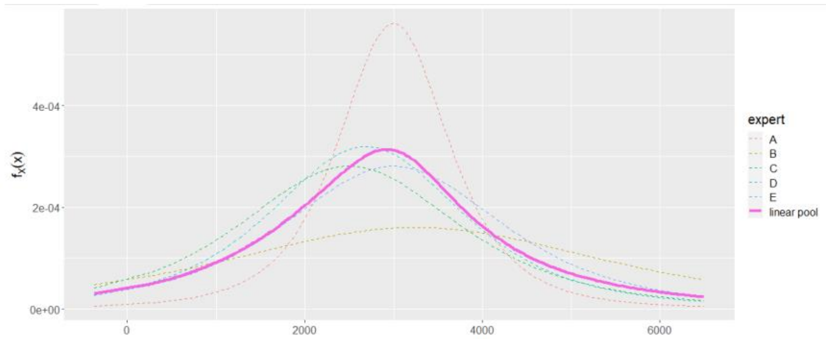
<tr><td>Fitting and feedback</td><td>

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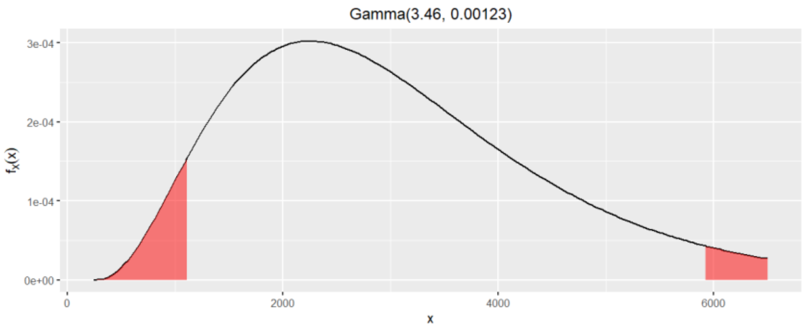
M: 2876
Q3: 3808
U: 6500 (highest RIO U)</td></tr>
<tr><td>Chosen distribution</td><td>

Fitted quantiles and cumulative probabilities
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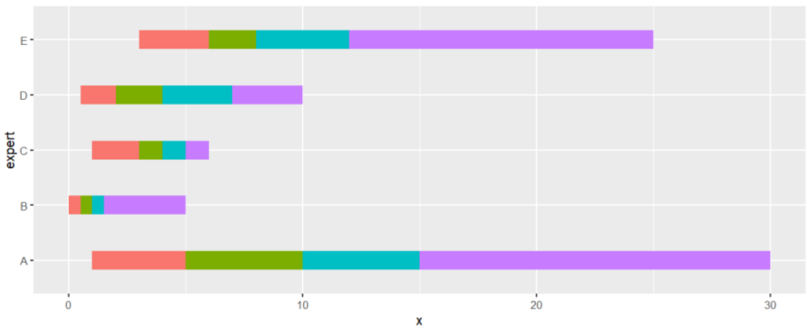
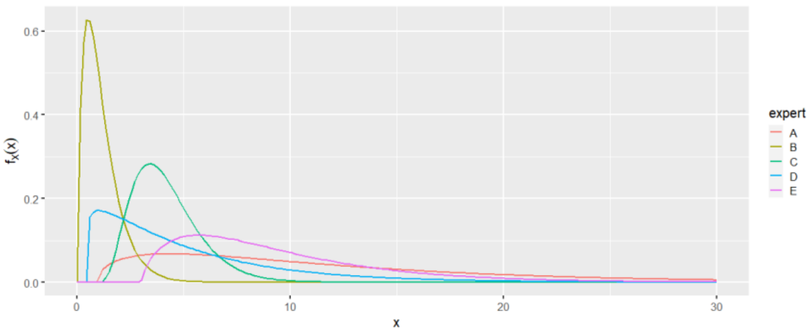
<tr><th>quantiles</th><th>values</th><th>values</th><th>probabilities</th></tr>
<tr><td>0.05</td><td>1110.00</td><td>250.00</td><td>0.00</td></tr>
<tr><td>0.95</td><td>5930.00</td><td>6500.00</td><td>0.97</td></tr>
</table></td></tr>
<tr><td>Discussion</td><td>The group discussed the process and any remaining questions from the training. Expert D stated that they see how this process can account for uncertainty and allow</td></tr>
</table>

	you to reason your way towards a statement about the unknown quantity, but wondered if such a wide distribution was useful. Concerns about groupthink. *Y – reiterated that we want an accurate accounting of the uncertainty, and what we've done is take multiple sources of conflicting data, combined with your personal experience and offered a single distribution that reflects the state of that knowledge, which is useful for incorporating this into models, or for non-subject matter experts.*

End time	13:30 EDT
Attachments	Judgments spreadsheet

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 1
Date	17 August 2021
Quantity	QoI 1: timeframe of peak changes in Dixie Meadows
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	13:40 EDT

Definition	Over what timeframe (years in the future) do you expect peak changes in Dixie Meadows in response to the threats outlined in the conceptual model?
Evidence	Y – asked the experts which pieces of the evidence dossier were most relevant to the QoI. For example, one part that stands out is the timeframe for changes seen in other geothermal projects (section 3.7). D – referenced the variability of temperature measurements over time displayed in figure 3 (and the limited scope of those data). E – thinks of the response time as being asymptotic, and asked to clarify if by peak change we mean highest rate of change or greatest magnitude. Y and Z clarified that they were thinking of the greatest magnitude, the point in time when the system is pushed farthest from baseline variation. Need to keep in mind that this is all from the perspective of the toad. The group discussed the distinctions between the greatest rate and magnitude of changes, and that those points may not coincide. Agreed to move forward with quantity as defined and discuss the response curves they were considering in making their judgments. B – asked if the time frame starts from today, when the plant is fully built, permitted, etc. The group discussed the options and decided to base judgments from the point at which the plant begins operating, combined with all other ongoing factors. B – asked about the status of Churchill county water allocation. The likelihood of the permit is unknown. The USGS studies referenced in dossier were initiated partially

	in response to that proposal. It was found that the ground water would need additional treatment to be potable. The basin is currently fully allocated. E - the rate of pumping is very high compared with the rate for the basin. About twice annual budget. Water will not be returned to exact location. D – the mitigation plan is also highly relevant to the response time, and whether or not the frequency of sampling is able to detect changes. Few sites with continuous monitoring. C – the timeframes from other studies in the Sorrey paper are only from a few systems. Asked if any panel members were aware of response times from other projects they have studied. No one proposed any other studies. Y – reminded the experts that they should weigh the limited number of studies in their judgments and adjust their uncertainty accordingly.
Plausible range	See judgments spreadsheet for complete record.
Individual elicitation	**Method:** Quartile **Judgements:** See judgments spreadsheet for complete record. 
Fitting	

Group discussion	Y – asked for expert B to start with reasoning behind early impacts B – wanted to stress that the data are limited and they are making their best guess, but the lower limit was a physical limit of the system and felt that change will be most extreme in the beginning, effects will start as soon as pumping starts, and then will move towards some new equilibrium or steady state by around 5 years. A – The role of mitigation and uncertainty in how quickly or when it will occur played heavily into their upper limit. If pumping continued unmitigated they could imagine getting to a large change. If the system was managed adaptively, this might delay the changes for a while and the peak changes would come later. C – data are slim, but Jersey Valley hot springs ceased flowing in 4 years. The structural setting of Jersey Valley is similar to Dixie Meadows, so assumed similar rates of change could occur. Did not take mitigation into account at all. Their judgments represent natural response of the system. E – on upper end, pushed out to 25 years to be fair (based on challenging an initial limit of 20), but doesn’t expect changes to take that long. Put 3 for lower limit because the hydrology might have some lag time, especially for a deeper system, may need time to respond. The large pumping rates mean the effects will be felt soon. D – Did not consider mitigation due to concerns that the monitoring regime is not sufficient enough to capture changes. Because of the mixing of the basin fill and geothermal fluid expects quick impacts in either area. B – also was thinking about the toad, in that the species may feel impacts before peak changes occur, which led them to expect earlier impacts. Y – summarizing, broad agreement on low end and that the bulk of probability is for peak changes to occur within a decade, uncertainty and differences in the upper limit reflect differing opinions on how mitigation may play out or whether it was considered in their responses, in addition to a longer term lower magnitude change from climate and consumptive water use. B – monitoring seems sparse, and may not be effective, which led them to not include it in their judgments. The group discussed whether monitoring/mitigation should be considered. Decided that individuals can incorporate that uncertainty as they see fit, as long as their rationale is clear on how they considered that in their judgments.

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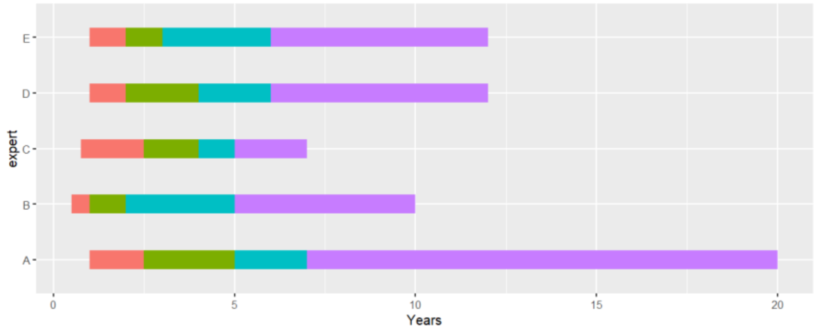
<tr><td></td><td></td></tr>
<tr><td>Group plausible range</td><td>See judgments spreadsheet for complete record.</td></tr>
<tr><td>Group elicitation</td><td>Method: quartile

Judgements: see judgment spreadsheet for complete record.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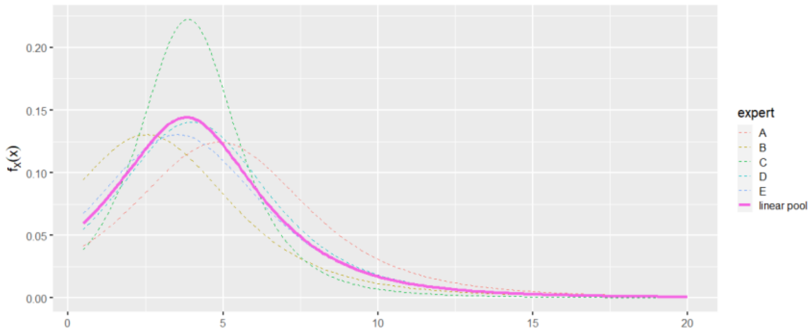
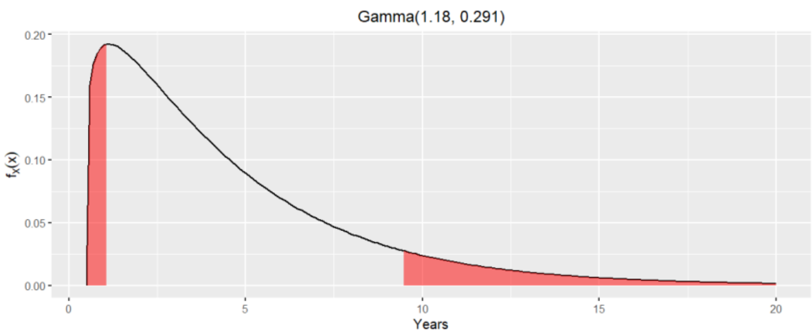
<tr><td>Fitting and feedback</td><td>

Quartiles of linear pool:
L: 0.5 (lowest RIO L)
Q1: 1.77
M: 3.78
Q3: 5.75
U: 20 (highest RIO U)</td></tr>
<tr><td>Chosen distribution</td><td>

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<tr><td>0.90</td><td>9.47</td><td>20.00</td><td>0.99</td></tr>
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Discussion	*Y asked if it is reasonable that the RIO judgments have lost the upper limit of 30 expressed by expert A in the personal round.* *Group discussed that some upper limits have been extended, some have been reduced, but the bulk of the distribution remains in the 0-10 years range.* *A – wanted to express a longer tail to capture uncertainty, but agrees that peak change is likely to occur on the shorter end. Might be thinking more about magnitude of change and not rate of change. Feels this distribution is reasonable and reflects the discussion.* *B – mentioned that 30 years is typically viewed as the lifetime of a geothermal plant, so original upper limit might be a natural one.*

End time	15:00 EDT
Attachments	Judgments spreadsheet

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 2
Date	18 August 2021
Quantity	Likelihood that the proposed monitoring plan could detect changes
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	13:35

Definition	What is your likelihood on a scale of 0-100 that the proposed monitoring plan could detect changes before a certain perturbation in temperature and spring flow occurs (e.g., 15°C or 40% reduction in flow)?
Evidence	The group began discussing evidence related to the change in water temperature for core wetlands, but decided that to appropriately tackle this quantity they first needed to address the mitigation questions. The first part of the following notes refer to that discussion, which focused on the types of mitigation actions outlined, including moving water around the landscape, changing where fluid is pumped or reinjected, etc. E – thinks that for these questions we have to consider monitoring. They are linked. Some monitoring and mitigation efforts will mesh with expertise of the panel, some may not. A - referenced Jersey Valley geothermal project, initial EA had monitoring occurring once a year, and the mitigation measures were also piping water around the landscape. Questioned how nimble they could be if Jersey Valley hot spring ceased flowing and required another EA for the mitigation measures. F – asked about water quality issues and whether the toad could adapt. W, X, and Y clarified that we know very little about how those changes would impact the toad, which is in part why that question is not being asked of the panel. The occupancy models do not include a parameter related to water quality changes. D – asked about the motivation to mitigate and any legal requirements. There are currently no state or federal protections for the toad C – the core problem is that there are clearly going to be impacts, but there is also a mitigation plan, so to what extent are we confident that water could be diverted or

	moved around to keep the system within natural variation. The group reviewed the toad occupancy modelling results to provide context on the magnitude of changes that would be concerning. Moving 15 Celsius above or below the optimum likely pushes the toad towards physiological limits. The water the toad is occurring in is also warm because it is shallow and heated by the sun, but this provides an idea of the approximate size of changes we would be interested in detecting at the spring heads. F - mentioned the 10% thresholds in the monitoring and mitigation plan and how percentages mean different changes depending on the temperature scale. These thresholds, however, were not selected with the toad's ecology in mind, and experts were asked to consider changes on the order referenced above. *Following suggestion by expert A, the group now began focusing specifically on the likelihood that changes could be detected.* D – the monitoring plan suggests even continuously monitored data will be downloaded or checked monthly. F – reporting requirement mentions quarterly reports, continuous data might not be acted upon on a continuous basis E – concerned about sampling bias, how sites were selected, maybe they were convenient sites or largest springs, which will be affected differently than smaller springs F – seems to be only one continuous monitoring site in most wetland complexes A – asked about past monitoring. Referenced figure 3 and table 2 in dossier, wondered if any other data X – referenced soil sampling, spring mapping, and other data collection efforts, but all time series data we are aware of has been provided
Plausible range	See judgments spreadsheet for complete record.
Individual elicitation	**Method:** Quartile **Judgements:**

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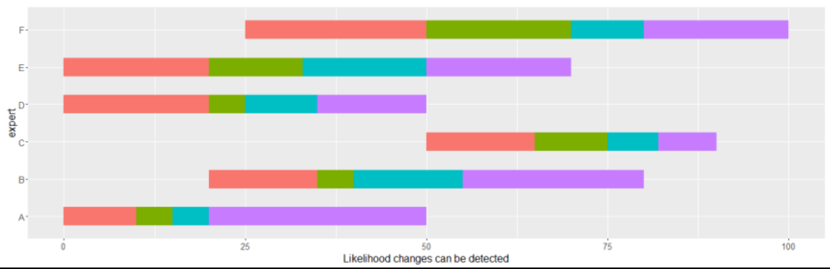
<tr><td></td><td>
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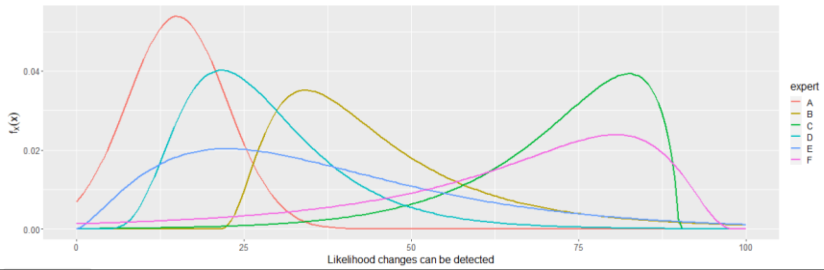
<tr><td>Fitting</td><td>
</td></tr>
<tr><td>Group discussion</td><td>
C – thinks they will be able to detect the changes. The monitoring plan could be more robust and needs more careful thought, but ultimately thinks detection of those changes will be possible. Different than ability to mitigate.
D – lower likelihood mainly reflected limited number of locations for monitoring, and low frequency of monitoring. Even continuous data may only be looked at monthly and reported/summarized quarterly.
A – the lower range of judgments reflected the variability in flow discharge historically, which may mean detecting subtle changes in the system will be difficult. Limited baseline data and high natural variability. Monitoring plan does not seem to take variability into account sufficiently.
E – Agreed, the bulk of their uncertainty was below 50 because to make accurate assessments of a noisy system you need long term baseline data, which seems lacking here. Also, no statistical approach was outlined for how to detect these changes and test whether they deviate from baseline conditions.
F – was more optimistic about detecting changes because the 5 springs monitored appear to account for around 2/3 of the estimated annual discharge. The 10% thresholds referenced in the plan seem to be below the example thresholds relevant to the toads, and would be triggered first.
E – questioned how trigger points would be applied (means, maximum?). Assumes average annual values, which then suggests it would take longer than a year to detect and respond.
B – there is one wetland complex without a continuous monitor of any kind (complex 4).
</td></tr>
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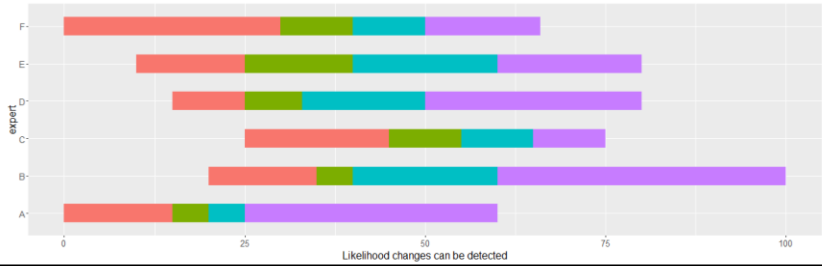
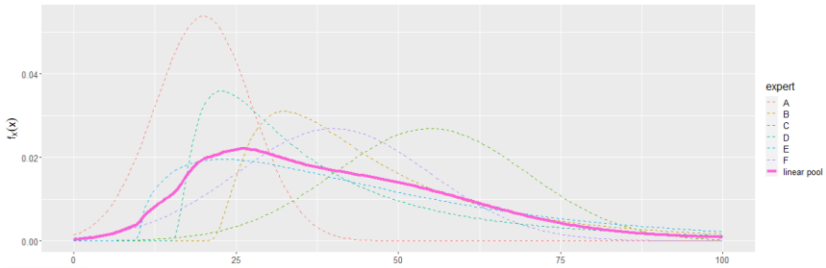
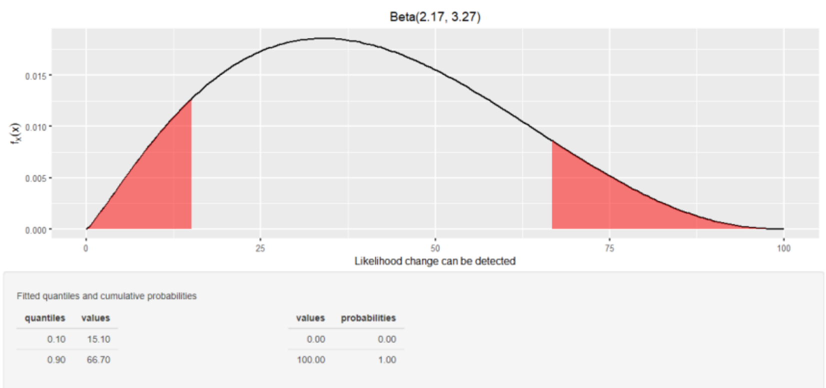
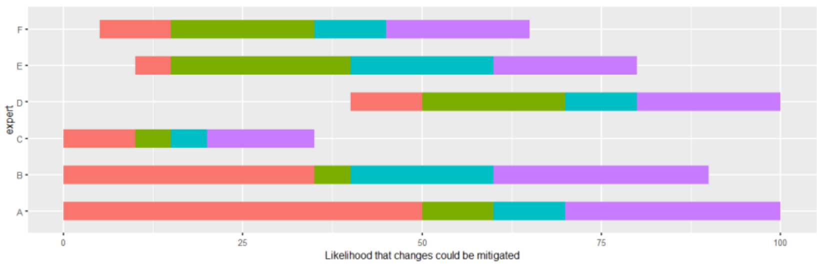
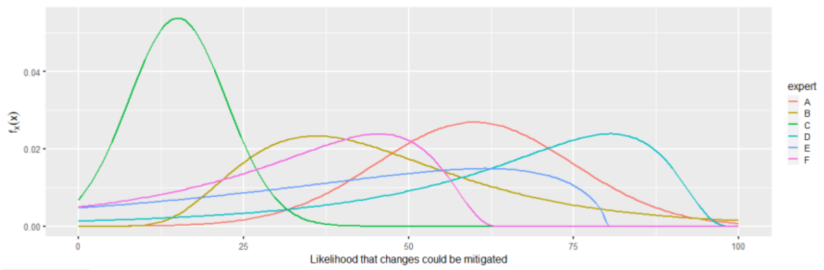
	F – larger springs being monitored will respond more slowly than other smaller springs, so admits some changes there may go undetected.
Group plausible range	See judgments spreadsheet for complete record.
Group elicitation	**Method:** Quartile **Judgements:** 
Fitting and feedback	 Quartiles of linear pool: L: 0 (lowest RIO L) Q1: 25.4 M: 37.8 Q3: 54.2 U: 100 (highest RIO U)
Chosen distribution	
Discussion	*70% of the distribution is below 50 representing an expectation that it is less likely than not that the proposed monitoring plan could detect changes due to limitations of the plan and noise in the system both spatially and temporally. It would require a more thoughtful monitoring plan to increase likelihood.*

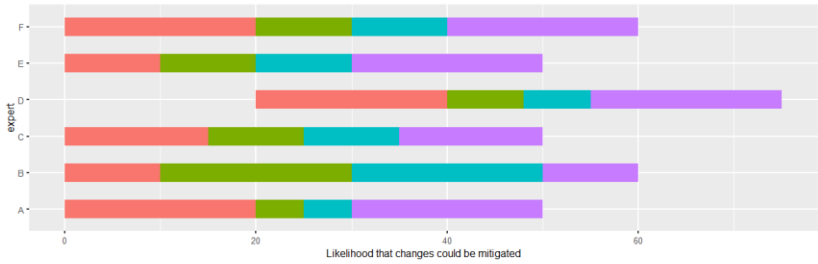
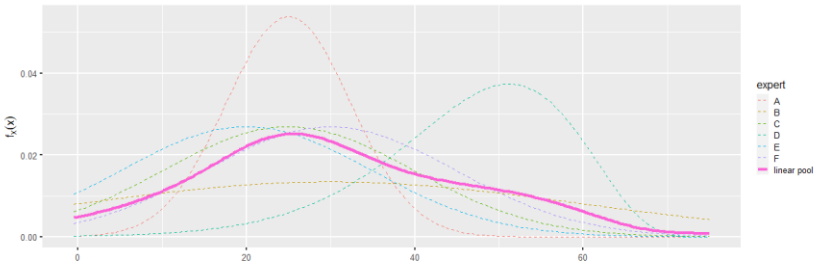
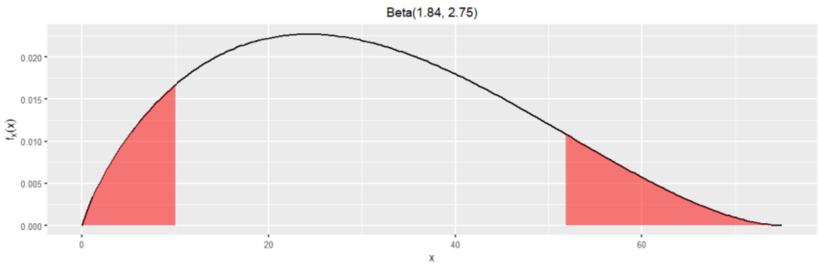
	F – potential sampling bias discussion and reminder that one wetland complex does not have a continuous monitor changed judgments relative to personal round. *E – Lowered likelihood relative to personal round due to variability in baseline data and how noisy these systems can be.*

End time	14:15
Attachments	Judgments spreadsheet

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 2
Date	18 August 2021
Quantity	Likelihood proposed plan could mitigate changes
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	14:15

Definition	What is your likelihood on a scale of 0-100 that the proposed mitigation plan could mitigate changes in temperature and spring flow? Mitigation is defined as restoring conditions to within baseline variability over any amount of time and we are assuming the changes have been adequately detected.
Evidence	The group reviewed many of the same discussion points and pieces of evidence reviewed for the previous quantity of interest. C – There will be a reduction in temperature due to the nature of the processes, the question is how much or little. For example, we've seen subtle changes at McGinness Hills but more extreme changes elsewhere. This complicates the idea of returning to a baseline.
Plausible range	See judgments spreadsheet for complete record.
Individual elicitation	**Method:** Quartile **Judgements:** 
Fitting	
Group discussion	Y – began discussion by asking for reasoning behind large uncertainty intervals

	A – large plausible range is because they don't feel they have a good understanding of the type of mitigation measures used in these facilities or their effectiveness. D – upper plausible limit reflects that if given enough time, they could potentially mitigate the changes. A – scale of the variability also affects the likelihood of mitigating. Site or spring specific mitigation seems more difficult, but range-wide conditions might be easier to achieve. F – the basin is already overallocated, so any mitigation efforts will also be facing synergistic impacts from other sources. Even outside of the plant, expects discharge will decline. D – Toad is in a wetland that is a mixture of temperatures from multiple springs, this might be easier to mitigate. This is why they switched from a low likelihood of detecting to a higher likelihood of mitigating. C – had opposite pattern; high confidence in detection, low confidence in ability to mitigate based on the current plan, which is cavalier. This is a complex system, the plan needs to be well thought out to handle the mixture of cold and hot springs, and needs to explain how they will engineer mitigation solutions. Chemistry is fundamental to this system, but that is not talked about at all in the plan. A more well thought out plan could work, but based on the proposed plan I have low confidence changes can be mitigated effectively. B – broad plausible range reflects that you could theoretically move water around (engineering problem), but this is a complex engineering problem. No idea how seasonal variation affects the toad, and assumes any mitigation would dampen natural variability. F – questioned the motivation to mitigate. It could theoretically be done, but would require a lot of effort E – injecting water is inherently uncertain, requires trial and error, and you can't assume injected water will go where intended. Is the company willing to move wells around over and over to find the right balance. There are two different objectives to reinjecting water 1) to maintain system pressure and 2) to stabilize the ecological system. These two goals might be in conflict. C – the mitigation plan was not well thought out and seems like an afterthought. Given the complexity and stakes you need to do due diligence.
Group plausible	See judgments spreadsheet for complete record.

range	
Group elicitation	**Method:** Quartile **Judgements:** 
Fitting and feedback	 Quartiles of linear pool: L: 0 (lowest RIO L) Q1: 17.9 M: 28.5 Q3: 41.5 U: 75 (highest RIO U)
Chosen distribution	 Fitted quantiles and cumulative probabilities quantiles / values: 0.10 – 10.00; 0.90 – 51.80 values / probabilities: 0.00 – 0.00; 75.00 – 1.00
Discussion	*Y asked if it is reasonable that the upper plausible limit decreased for the RIO judgments.* *E – dropped the L for their RIO judgment because they felt even though they wanted to express uncertainty, they were stretching what was probable.* *Y - summarizing implications of the linear pool: this reflects an overall opinion that changes to the system are unlikely to be mitigated (88% of the distribution is below 50) based on limitations and lack of rigor of the current*

	mitigation plan, logistics involved in mitigating, complexity of the system, interconnectedness of the wetlands, and competing interests with the goal of energy production. *Experts agreed that reflects the discussion and judgments.*

End time	15:05
Attachments	Judgments spreadsheet

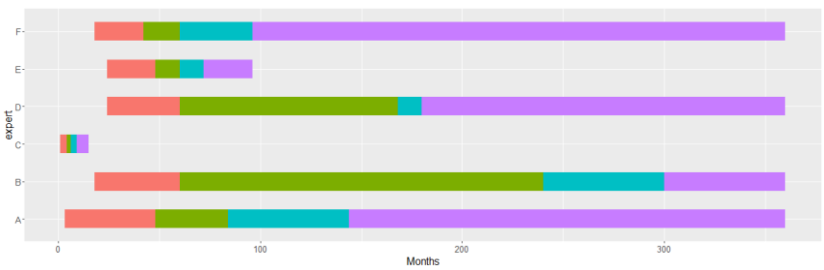
Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 3
Date	19 August 2021
Quantity	Timeframe required to fully mitigate
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	12:00

<table>
<tr><td>Definition</td><td>What timeframe (in months) would be required to fully mitigate the perturbations in temperature and flow once detected? For this quantity, assume changes have been detected, assume it is technically feasible to mitigate the problem, and assume there is a willingness to participate from all parties. Note: 1 day ~ 0.033 months.</td></tr>
<tr><td>Evidence</td><td>Y – summarized discussion points from previous day.

A – referenced table 18 in ARMMP. Wanted to emphasize that moving water around, adding new pipelines, or adding rapid infiltration basins all may require additional Environmental Assessments

B – wanted to clarify how to think about this if perturbations are continuous over life of the plant (~30 years). Group agreed the question is about the time needed to move the system back into baseline conditions.

E – wanted to clarify if time should include experimentation needed to dial in mitigation efforts. Group agreed that it should.</td></tr>
<tr><td>Plausible range</td><td>See judgments spreadsheet for complete record.</td></tr>
<tr><td>Individual elicitation</td><td>Method: Quartile

Judgements:


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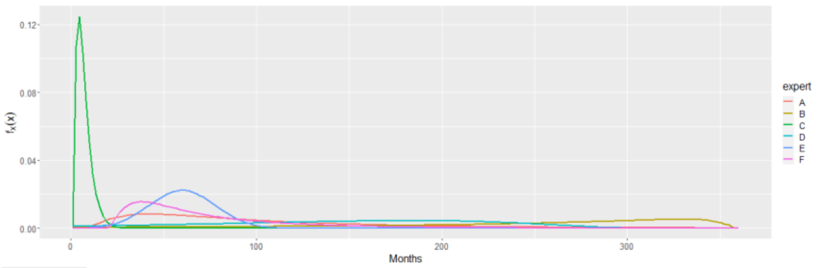
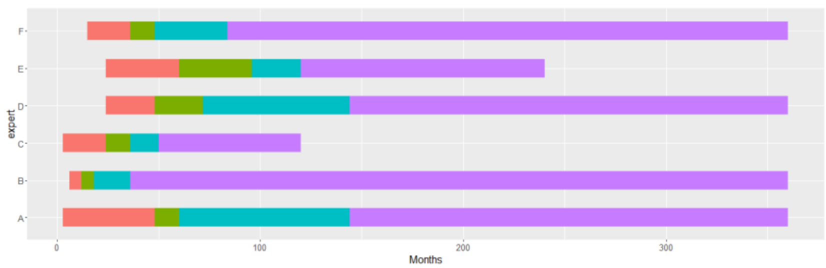
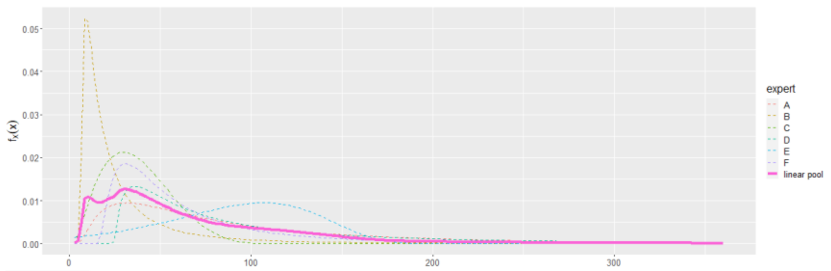
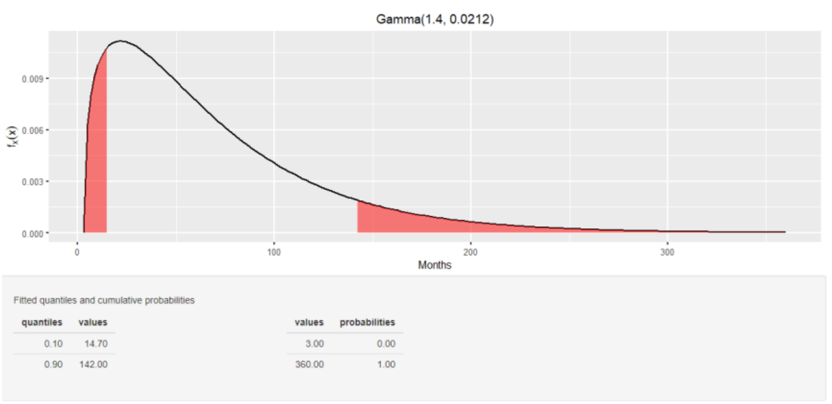
Fitting	
Group discussion	C – for lower limit thought 1 month could be the quickest response in best case scenario for small impacts, and for more significant impacts thought 1 – 1.5 years (15 months) would be required for permitting, logistics, etc. Assumed perturbations detected early. B – this is the question they feel the least confident in addressing. High upper limit reflects that they might be seeing impacts from first plant as the second plant is being finished, and that second plant would be starting from scratch in terms of trial and errors process to mitigate. May not be able to ever get back to previous natural system dynamics. Lower limit based on a guess as to when second plant might come online. It seems plausible the system could never return to normal. Not confident in placement of Q1 or Q2. E – took seriously the assumption that it could be mitigated, which is why upper limit is low compared to others. If plant stopped pumping, it would take 3-4 years to return to original conditions, maybe longer. Also need to add time for failed experimentation, permitting time, failed strategies, water rights allocation if that becomes necessary (need water for pressure support). F – similar to logic of B. Thinking of multiple, continual perturbations over time. D – median is farther out in time due to permitting, infrastructure, and trial and error process. Was thinking of this similar to the whack-a-mole game. It will be a constant process of responding to numerous impacts that pop up across the landscape C – wants to clarify that this is not mining. We are not removing heat from the system. There is a decrease in heat over time, but we are getting better at recharging the system and returning heat. The total decrease in Desert Peak plant for example, is on the order of 20 degrees C. What we don't know is if we turn the system off, how long does it take to return to baseline conditions. This is partly due to bad historical monitoring. E asked C about operation of plants. C – this type of plant would likely be reinjecting deeper (aside from mitigation

	efforts). Can't reinject near withdrawal. The technology has improved a lot. B – Jersey Valley plant is newer technology, and they still saw a complete drying of the hot springs, so not 100% effective C – doesn't think they were ever required to monitor springs. If unchecked, springs will absolutely dry up because we are moving water and temperatures around in ways it doesn't move naturally. When asked if Dixie Valley plant is operationally different from Dixie Meadows plant, stated that they think so. B – Dixie Valley is a (flash plant?), they are losing steam
Group plausible range	See judgments spreadsheet for complete record.
Group elicitation	**Method:** Quartile **Judgements:** 
Fitting and feedback	 Quartiles of linear pool: L: 3 (lowest RIO L) Q1: 29.3 M: 51.8 Q3: 95.4 U: 360 (highest RIO U)

Chosen distribution



Discussion

X asked if flow or temperature would be easier to mitigate.

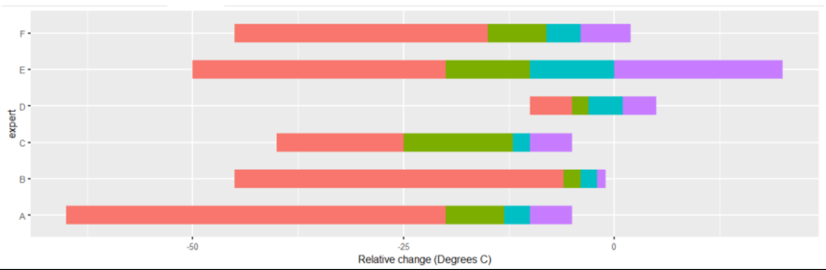
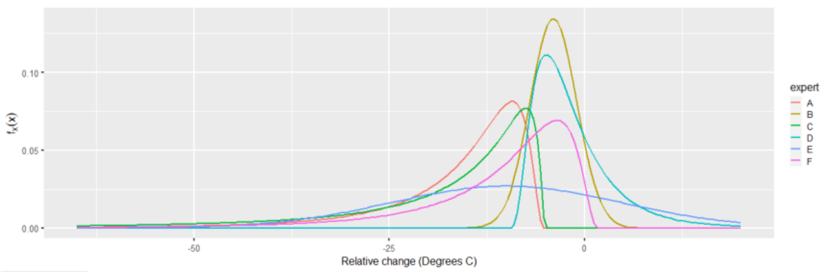
F – thinks they are the same because the two are linked

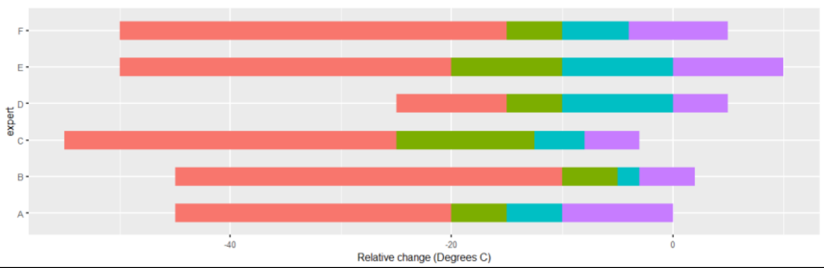
E – disagrees, flow would be easier to mitigate because you can always move water around if you do not need to pay attention to temperatures.

End time	12:50 EDT
Attachments	Judgments spreadsheet

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 3
Date	19 August 2021
Quantity	Change in water temperature for the core wetlands
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	12:55 EDT

Definition	What is your expected change in water temperature in °C for the core wetland complexes at the time of peak change based on the threats outlined in the conceptual model?
Evidence	Reviewed previously discussed evidence. C – most springs at Brady Hot Springs are still boiling, but they have dried up because injection occurs several km away, so upwelling is not returning to original springs. F – wanted to clarify that the changes mentioned in the last section of the evidence dossier are changes to the geothermal resource, not the springs, so can't necessarily compare the two. C – in that last section, most of those sites are older technology. The examples are well taken, and worth considering, but technology has changed since then. B – the mixing of the geothermal fluid and basin fill (based on water chemistry) is how we will need to translate those changes in the resources to expected changes at the springs. The power plants are located in the areas of greater mixing. The group reviewed USGS study and estimates for geothermal mixing. 20-30% geothermal fluid. D – If pumping at depth changes the gradient, how would we expect the geothermal mixing to change? E – raised concerns that this distribution might be bimodal and difficult to represent. Temperature could decline if reinjected deep, or increase if reinjected shallow. Without mitigation, they will reinject at depth, with mitigation they will reinject shallow. Based on results of previous QoIs on mitigation, the group decided to focus on impacts without effective mitigation, but wanted to covey that additional areas could flash steam, new hot springs could arise, or temperatures could even increase in some spots. There is additional

	uncertainty that may be lost in this framing. C – mitigation plan is short, doesn’t give the information needed to evaluate it’s impacts. It is feasible to stop steam flashes, but you need that plan in place ahead of time. A – insufficient baseline monitoring and poorly conceived. F – the other major uncertainty not captured in this framing is how changes at the springs translate to changes throughout the meadows. D asked about Jersey Valley flow rate and capacity. B - ~ 22 MW, so twice the flow rate at proposed Dixie Meadows plants. E – these pumping rates are high, almost twice the basin water budget. D – those are the allocations for the basin fill aquifer, but agrees that the two budgets are linked on some level. E – asked whether they should apply temps on average or think through differences between cold springs and hot springs. Personally, was thinking about coldest and hottest springs for plausible limits, and an average change for median, etc. B – Asked about ambient spring temps at non-geothermal springs. Should they assume 19-20 degrees C? Estimates from others were 10-15 and 12-17 degrees C.
Plausible range	See judgments spreadsheet for complete record.
Individual elicitation	**Method:** Quartile **Judgements:** 
Fitting	
Group discussion	A – wide range because doesn’t feel this is personal area of expertise, and used a worst case scenario of strong impacts with 40% Geothermal flow being reduced to zero for lower limit.

	D – at peak change couldn't see there being more than a 10 degree decrease. Much more likely to decrease than increase, but allowed for some increase due to climate change. B – thought about change in geothermal reservoir, then converted that to springs based on 20-30% mixing. Assumed 1 degree C per year decrease is about what a geothermal company would tolerate in reservoir before wanting to change things, leads to 10 degrees in 10 years, and 30% of that for upper. Lower limit reflects if springs went to ambient temperature. F – Lower limit similar to B, upper limit assumes plant doesn't affect springs, and considers how climate might impact. Assumed a decreased contribution from geothermal. E - Lower limit reflects if hottest spring drops to ambient. Upper limit is that the coolest springs could warm up a little. Median of -10 is an expected average across all of those. C – not much to add to discussion. Felt like they were guessing. We really need some more data to evaluate this. Lower limit is if we totally lose geothermal component. There is absolutely going to be an impact, but is indifferent to whether that is -5 or -10 for example. Upper end harder to predict. A – didn't include climate effects on upper end, but will adjust to include that in next round.
Group plausible range	See judgments spreadsheet for complete record.
Group elicitation	**Method:** Quartile **Judgements:** 

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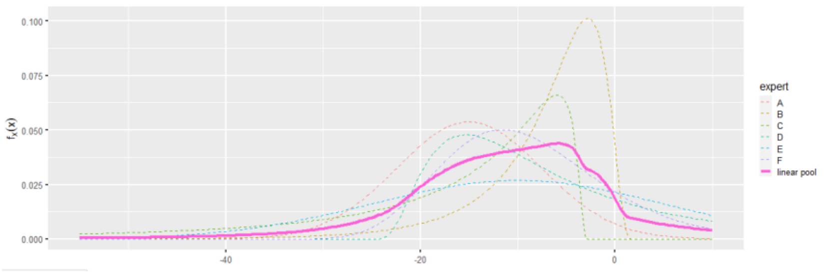
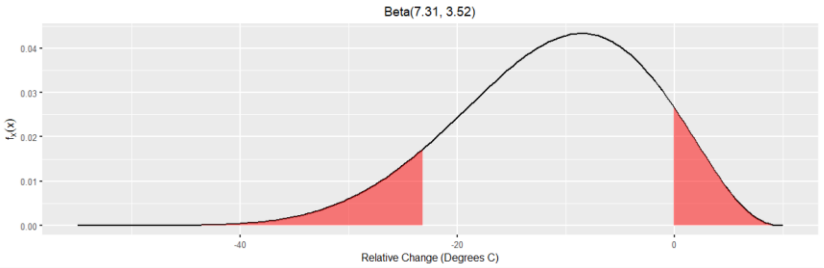
<tr><td>Fitting and feedback</td><td>

Quartiles of linear pool:
L: -55 (lowest RIO L)
Q1: -17
M: -10.4
Q3: -4.5
U: 10 (highest RIO U)</td></tr>
<tr><td>Chosen distribution</td><td>

Fitted quantiles and cumulative probabilities
<table><tr><th>quantiles</th><th>values</th><th>values</th><th>probabilities</th></tr><tr><td>0.10</td><td>-23.20</td><td>-55.00</td><td>0.00</td></tr><tr><td>0.90</td><td>-0.06</td><td>10.00</td><td>1.00</td></tr></table></td></tr>
<tr><td>Discussion</td><td>C – this distribution is reflective of the conversation and judgments, but wanted to emphasize how limited the data are that are feeding into these judgments.</td></tr>
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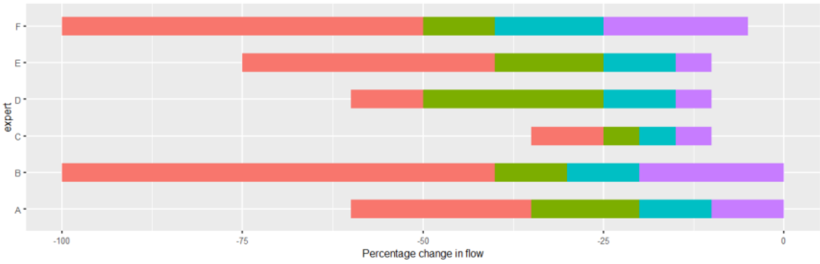
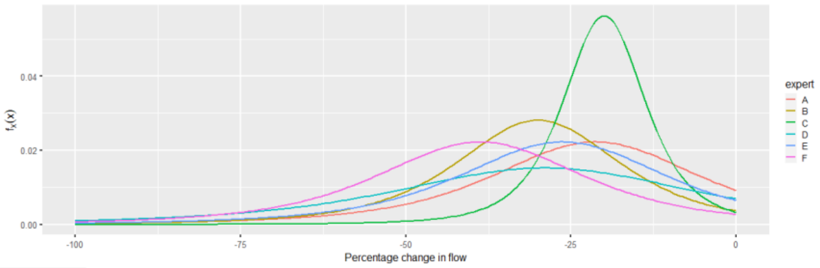
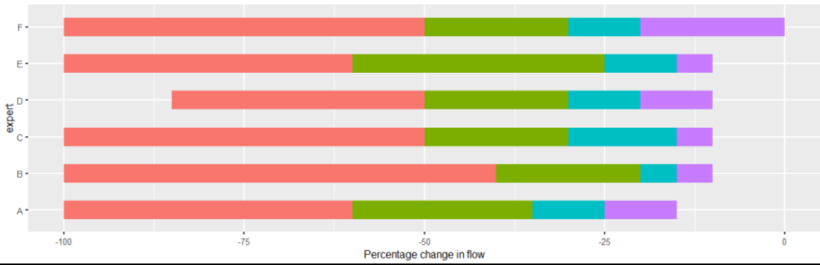
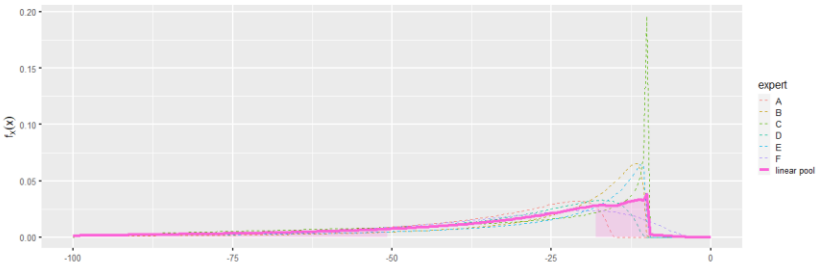
End time	14:00 EDT
Attachments	Judgments spreadsheet

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 3
Date	19 August 2021
Quantity	Change in spring flows for the core wetlands
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	14:00 EDT

Definition	What is your expected change in spring flows as a percentage increase or decrease for the core wetland complexes at the time of peak change based on the threats outlined in the conceptual model?
Evidence	All previous evidence discussed is also relevant. C – asked about chemistry of the spring water, if meteoric or brine. D – Sampling from the playa produced brines (based on Lithium and …), but springs appeared to be mostly meteoric and geothermal. (20-30% geothermal). Group reviewed climate projections for temperature, ET, and precipitation. A – wanted to note that some of the most current models show a much dryer future so there is likely some uncertainty on the lower end of projections that is not captured here. Expected increase in ET is ~ 33% (200 acre ft/year) C – for surface discharge, is there a threshold for decrease in geothermal contribution where surface discharge ceases? E.g., if we decrease input by 50%, would springs dry up? A – this is a large concern. There is high variability in springs flows in table 2 of dossier. Is this due to precipitation? Can geothermal contribution vary like that? If decreases in geothermal contribution happen at the end of 5-year drought for example, this could be a large change. C – geothermal fluid shouldn't vary seasonally, variations likely due to ET, precipitation, and shallow aquifer contributions. E – table 2 might not be useful, such limited sampling, different times of year, lack of replication, no way to compare. F – how these translate to wetted area is going to be a large source of uncertainty.

Plausible range	See judgments spreadsheet for complete record.
Individual elicitation	**Method:** Quartile **Judgements:** 
Fitting	
Group discussion	D – mixing is 30%, so lower limit was if all geothermal contribution goes away, plus added impacts from climate C – feels they could benefit from more hydrogeothermal experience. Selected 35% as lower limit and thinks that could result in the springs drying up [*note: judgments were focused on changes in geothermal contribution, not surface expression, which is why lower limit is higher than others*]. Didn't bring climate impacts into consideration. F – pessimism is due to reality that the effects of the plant will be superimposed on top of ongoing processes like increasing ET, increasing temperatures, etc. Even if a plant is not built, significant reductions in spring discharges are likely. E – lower limit reflects if all of geothermal contribution goes away along with losing other contributions due to climate change and basin over allocation, leading to 75%. This would probably mean some springs dry on the surface. In fact, springs would likely dry on the surface even at much lower values than this. B – Upper limit at zero because this geothermal system is at low point in the basin, so may get some benefit there from larger drainage area. A – because low end included consideration of geothermal impacts coinciding with end of a 5 year drought, I felt I also had to give some credibility to 0 change on upper end. But, I don't think this is likely.

	Y – asked if decreases at the surface will always be greater than decreases in geothermal contribution. i.e., not a one-to-one reduction. B – thinks it will always be the case. Geothermal heat in this area could be making the water table more buoyant, this could be why springs are occurring. If you reduce the heat, you lose that as well. E – spatial distribution of the loses could also be worse, with some areas drying up much faster as the geothermal contribution decreases.
Group plausible range	See judgments spreadsheet for complete record.
Group elicitation	**Method:** Quartile **Judgements:** 
Fitting and feedback	 Quartiles of linear pool: L: -100 (lowest RIO L) Q1: -50.7 M: -29 Q3: -18 U: 0(highest RIO U)

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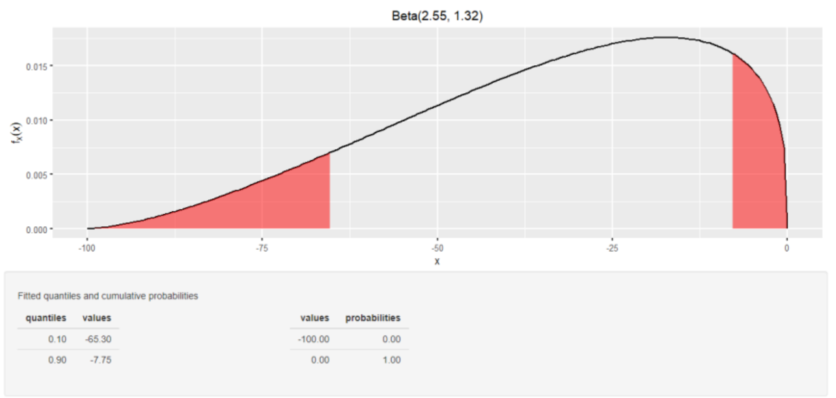
<tr><td>Chosen distribution</td><td>
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<tr><td>Discussion</td><td></td></tr>
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End time	15:00 EDT
Attachments	Judgments spreadsheet

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 4
Date	20 August 2021
Quantity	Expected changes in peripheral wetland complexes
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	12:00 EDT

Definition	The experts were asked to provide comments on how the shape and limits of the final RIO distributions for changes in water temperature would differ if focusing only on the peripheral wetland complexes. *Note: No formal judgments were elicited due to time constraints and results of previous quantities.*
Group discussion	F – peripheral wetlands are much cooler, in the lower limit, they don't have 40 degrees they could drop. The drop to ambient spring temperatures is the limit. -14 could be the low end. D – there is not as much geothermal mixing in the peripheral complexes, more from the basin fill E – in the upper limit, it doesn't seem credible that they would heat up B – complex 1 peripheral springs are right in the heart of the proposed wells, complex 6 springs are farther away from wells. Not sure what that means in terms of effect, but there is not much heat they can lose. C – do we have data on the chemistry for these peripheral springs, for relative geothermal/basin fill contributions? A – we would be cutting off that large lower tail, it is most likely a matter of a couple degrees change. Y summarized B – peripheral ponds are much smaller, so could temperature mitigation efforts impact those more W – most of overwintering occurs in north complex, there is consistent breeding in complex 6. Not sink meta-populations, but maybe just smaller parts of the range. F – increase in temperature in peripheral springs could occur, but this would be due to climate change pressures, not geothermal.

Definition	The experts were asked to provide comments on how the shape and limits of the final RIO distributions for changes in spring flows would differ if focusing only on the peripheral wetland complexes. *Note: No formal judgments were elicited due to time constraints and results of previous quantities.*
Group discussion	F – If springs are disconnected from geothermal, maybe we would see less change due to deep pressure changes D – even though less connected to geothermal, they are still connected (chemistry shows still some geothermal connections) larger influence from climate, but more susceptible to precipitation changes. More dynamic. E – might be more responsive to mitigation measures. Injection wells could change the near surface flow rates. Agrees with expert D, these outlying complexes are more sensitive. Not including a better focus on those in the monitoring program is missing a huge opportunity, we are likely to see changes there first. C – provided a structural perspective, trend in peripheral springs is much different. NNE direction is orthogonal to regional stress field, so more sensitive to changes in flow. Assume controlled by ENE structure, then more likely that you don't have a deeper connection. Temperature data back that up, and more likely that meteoric water is leaking upwards. The expectation is that peripheral springs have more shallow aquifer connection, so less sensitive to development, but even if a small connection changes in the geothermal component could still dry them up. F – no reason to expect an increase in spring flow because mitigation measures that increase flow would be stopped. C – might nudge judgments down a little bit (it is less likely there would be 100% decline). E asked C if it might not be a single fault controlling this, if there is a kink in the fault, or are there two faults. Is wondering how this will impact monitoring. C – this system is likely fault intersections combined with some steps in range west fault. NW intersecting NNE faults in steps and range front. Very active fault by the way. Holocene ruptures, 1954 ground breaks extend past dixie meadows. Fault intersection, secondary control fault step over. F – agrees, median and quartiles would shift towards zero

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 4
Date	20 August 2021
Quantity	Expected changes in absence of geothermal plant
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	12:30 EDT

Definition	The experts were asked to provide comments on how the shape and limits of the final RIO distributions for changes in water temperature would differ if the Dixie Meadows power plant was not built. *Note: No formal judgments were elicited due to time constraints and results of previous quantities.*
Group discussion	A – effects would primarily be increases of a couple degrees within the response time we identified earlier (out to 20 years). E – temps may become far more variable. As thermal mass shrinks, ponds become more susceptible to temperature swings. A – agrees, extremes might be more variable also F - asked about Dixie Valley plant and if that and other ongoing projects would impact Dixie Meadows B – the closest plant to the meadows is around 26 km A – the effects on groundwater to date are really uncertain. There are only a few years of measurements, scattered samples, some to the south of Dixie Meadows showed that the water levels have actually gone up. C – there is information on areal extent of groundwater depressions generated by geothermal production, data are INSAR data. In Brady hot springs, where injection is far removed, the cone of the depression is about 4-5 km along the fault zone. So, we wouldn't have the impact at the surface if we don't see the groundwater depression. A few km away is far enough removed, shouldn't be any local impact. Brady has been operating since around 1992. A – asked if Churchill county plans to move forward with water rights request and should we consider that D – the best place to put basins, according to the USGS study, was east or south in Dixie Valley. Following that study, the county shifted their request for water rights area

	to east side. It doesn't seem very plausible that it would move forward around the meadows. C – NV has been reluctant to approve groundwater transporting for big projects. The big project in eastern NV to move water to Vegas is not going to happen after much study. State engineer makes final decision. Reno has gotten approval for extraction just north, but big projects are generally declined. There is a good aquifer at Fallon, which is where the population center of the county sits.

Definition	The experts were asked to provide comments on how the shape and limits of the final RIO distributions for changes in spring flows would differ if the Dixie Meadows power plant was not built. *Note: No formal judgments were elicited due to time constraints and results of previous quantities.*
Group discussion	F – it comes into play at the upper end, if the plant has no effect that's where climate comes in. A decrease of 100% is a feasible bound over the next 20 years. The quartiles probably shift towards zero. But, it really wouldn't take much to dry up some of these springs. Y asked expert A to elaborate on their logic from previous session regarding synergistic effects of drought and geothermal production. A – discussed both the pulse and press of climate change effects, so both a prolonged drought (stochastic effect) and a slower increase over time (press effect) could plausibly dry up these springs over a 20-year time frame. In response to question about vegetation response to these kind of pressures – water block recharge, the uplands will be using more precipitation as climate warms up. Less recharge in upland. In the spring itself, increased evaporative demand, with essentially unlimited supply. Back-of-the-envelope calculations suggest by end of century, 200 acre ft increase in ET is reasonable expectation.

Elicitation title	Dixie Valley Toad Species Status Assessment
Workshop	Session 4
Date	20 August 2021
Quantity	Suggested changes to monitoring/mitigation plan
Anonymity	In this record experts will be referred to as A–F and facilitators/organizers will be referred to as W–Z.
Start time	13:00 EDT

Definition	The experts were asked to provide comments on changes to the monitoring and mitigation plan that would increase their confidence that effects could be limited to within historical variation. *Note: No quantitative judgments were elicited.*
Group discussion	Y began discussion by providing an example that we've heard previously about the lack of longer-term baseline data needed to account for variability of system. Asked for other similar suggestions. F – mentioned need for rigorous, statistically based sampling plan. Best indicator sites might not be the most convenient. D – sample frequency would need to increase, at least monthly compared to quarterly reports, this would better capture seasonal variability. E – sample bias is large concern. Would like to see a statistically informed sampling plan. There is a possibility that springs are controlled by different faults, so might need a stratified sampling plan. Need a higher percentage of the springs monitored. These data should be publicly available and the opportunity should be provided for impartial investigators to look at these data. Others need to be able to evaluate how well things are being managed or what is being missed. Access to data by investigators on a regular basis would do a lot to sway concerns. C – we could use more data from other projects. There is probably available data that could be mined from other areas, a more concerted attempt to look at available data from other similar sites could help better manage future sites F – the analysis and reporting frequency should be greater. A more frequent check or analysis is necessary. If a rapid temperature decrease occurs in winter, you need a rapid mitigation response. D – You need a dedicated person or team to do the

	monitoring well and to throw the red flag to begin mitigation when changes occur. E – worries that there are clauses in the plan that they can adjust the frequency or change the locations at will. There could be an adverse effect to decrease frequency in the future. An outside entity should be doing the monitoring. An independent agency would give more credibility to the plan. For example, the Great Basin geothermal center, or similar. Y asked if changing aspects of the plant (aside from ARMMP) would increase likelihoods from earlier QoIs. E – you have to design criteria for the plant (30MW, etc.), the rest is based on the fluids. It might be wishful thinking to say we could pump less. The entire investment is based on an expected output. D – that might just be flattening the response curve. But I think you would still have a similar impact, maybe just later in time. Doesn't think a slow ramp up, would change anything for the toad. C – if ramped up more slowly, that might allow for mitigation results to be more fruitful. Let the system get to an equilibrium where mitigation is working, then push farther, and do this in a stepped phase, allow the mitigation to catch up. E – more test pumping ahead of time could give a better clue. The data we are given on the pumping is useless. There are no rates, no time series, no way to evaluate those numbers. About operation of the plant, if we are injecting fluids, that will change the stress of the fault, so what's the chance for increased seismicity, springs could be reorganized, this should be considered or mentioned. C – from conventional systems we don't see much increased seismicity. But, if this was EGS, fracturing rock, that's where you would induce some seismicity. X – How about other mitigation measures? A – would find proposals much more plausible if the mitigation measures were already permitted. Maybe injection wells are easier to install quickly, but rapid infiltration basin would be much harder. The options to change thresholds or mitigation are worrying. Does not sound like DOI's definition of adaptive management. B – the infrastructure for mitigation needs to be built into the plant design, for example, existing pipe infrastructure

	in place that could move water around the wetlands. This seems like the problem at Jersey Valley, they had to request a permit for a new project ~ 4 years after the spring dried up. C – The plan is simply inadequate and some of these past projects have a poor track record. Where they weren't required to monitor or mitigate spring flows, springs dried up.

Final perspectives	*D – excited to see how much effort and thoughtfulness is going into this decision. These decisions were always a black box, but now has a better perspective on what is involved.* *F – liked the process, thinks it does what it was designed to do, gives a synthesis of the collective knowledge and forces you to grapple with the uncertainty.* *B – learned a lot in going through the process, found it relates to pedagogical approaches designed to get people to share information* *C – appreciates how much time is left for discussion. Was sceptical at first that we would simply be asked for a bunch of numbers, but was pleasantly surprised by the level of discussion* *E – was concerned that this process would lead to group think, but was surprised how well it worked. Thinks it was due to group dynamics (everyone open and willing to hear other perspectives) and facilitation.*

Appendix II

Evidence Dossier for Dixie Valley Toad Expert Elicitation

1. Context

The US Fish and Wildlife Service is developing a Species Status Assessment (SSA) for the Dixie Valley Toad (*Anaxyrus williamsi*) to support Endangered Species Act decision making. The primary threats affecting the toad's viability are potential habitat changes from geothermal energy development in Dixie Meadows and exposure to the fungal pathogen causing Chytridiomycosis. Both factors are linked to physical habitat features. Occupancy models are available to estimate the effects of water temperature, water depth, and wetted area on the probabilities of occurrence and reproduction for Dixie Valley Toads (Halsteadt et al. 2019), but the expected changes in water temperature and surface flows from geothermal activity and climate change represent a major source of uncertainty (Fig 1.). Because limited empirical data are available and environmental impacts may be site specific (Sorey 2000; Kaya *et al.* 2011), we have organized an elicitation workshop to obtain a scientific assessment of how key hydrologic features of the toads' habitat may change in the future.

Figure 1. Conceptual model of the factors that may influence how water temperature and availability may change within Dixie Meadows.

2. Quantities of Interest (QoI)

We are concerned with estimating expected changes to the surface hydrology of Dixie Meadows due to proposed geothermal activity, climate change, and water allocations in the basin. Specifically, this workshop seeks to elicit the following QoIs:

1. Over what timeframe (years in the future) do you expect peak changes in Dixie Meadows in response to the threats outlined in the conceptual model?
2. What is your expected change in water temperature in °C for the core wetland complexes at the time of peak change based on the threats outlined in the conceptual model?
3. What is your expected change in spring flows as a percentage increase or decrease for the core wetland complexes at the time of peak change based on the threats outlined in the conceptual model?
4. What is your expected change in water temperature in °C for the peripheral wetland complexes at the time of peak change based on the threats outlined in the conceptual model?
5. What is your expected change in spring flows as a percentage increase or decrease for the peripheral wetland complexes at the time of peak change based on the threats outlined in the conceptual model?
6. What is your likelihood on a scale of 0-100 that the proposed monitoring plan could detect changes before a certain perturbation in temperature or spring flow occurs (e.g., 15°C or 40% reduction in flow)?
7. How many days do you expect would be required to fully mitigate the perturbations in temperature and flow once detected?
8. What is your expected change in water temperature in °C for the core wetland complexes at the time of peak change based on the threats other than geothermal development outlined in the conceptual model (i.e., no power plant)?
9. What is your expected change in spring flows as a percentage increase or decrease for the core wetland complexes at the time of peak change based on the threats other than geothermal development outlined in the conceptual model (i.e., no power plant)?
10. What is your expected change in water temperature in °C for the peripheral wetland complexes at the time of peak change based on the threats other than geothermal development outlined in the conceptual model (i.e., no power plant)?
11. What is your expected change in spring flows as a percentage increase or decrease for the peripheral wetland complexes at the time of peak change based on the threats other than geothermal development outlined in the conceptual model (i.e., no power plant)?

3. Available Data

3.1 Anticipated geothermal activity

Based on the 2020 Aquatic Resources Monitoring and Mitigation Plan (ARMMP) and the 2021 revised EA, the Dixie Meadows Geothermal Utilization Project may construct up to two 30-MW geothermal power plants. This includes up to 18 production and injection well pads, 8 previously permitted core hole well pads, and a 120-kV gen-tie to the Jersey Valley power plant (Ormat 2020, p. 6). Additional well pads are also permitted within Dixie Meadows from previous authorizations (e.g., Dixie Hope 2010 lease). A map of the proposed and existing sites is shown in Figure 2; however, the exact production and injection sites are uncertain because the locations of well pads are tentative and there is potential for directional drilling. Based upon data from other Ormat facilities, the total geothermal fluid production rate for each Dixie Meadows facility is expected to be 14,000 gallons per minute per plant (EA p. 2-11).

3.2 Proposed monitoring plan

The proposed monitoring plan consists of 23 surface locations (20 seeps/springs, two channels, one pond) and nine groundwater wells (two geothermal bedrock wells, one freshwater bedrock well, and six alluvial wells). Continual discharge monitoring is proposed at five locations and monthly discharge measurements at an additional seven locations. Monthly site visits would be performed to collect/download all surface field parameters (Ormat 2020, p. 42). Groundwater wells will be monitored for temperature, pressure, and water chemistry monthly during the baseline monitoring period (minimum of one year) followed by quarterly samples (Ormat 2020, pp. 43-45). Table 19 in the draft ARMMP (Ormat 2020, p. 119) provides a complete list of proposed sites, parameters, monitoring frequencies, and known background conditions.

3.3 Conceptual models of groundwater flow

The Dixie Valley Fault Zone has been described as a series of step-down faults (1-2 km wide) composed of steeply dipping structures (75-85° to a depth of at least 3 km) with at least a range-front fault and piedmont fault (Iovenitti 2014, pp. 6-10, 27, 64, 78). The structural setting can be described as a dilatational fault intersection between oblique-slip normal faults (Iovenitti 2014, p. 80). A major piedmont fault at Dixie Meadows is coincident with the locations of thermal springs; the same piedmont fault has been identified as the main producing structure at both the Comstock and the Terra Gen geothermal production sites. Average geothermal mixing with basin-fill groundwater in Dixie Valley was 10–12% (Huntington *et al.* 2014, p. 49), but three sites within Dixie Meadows ranged from 22–31% (Huntington *et al.* 2014, p. 47). Spring water temperatures greater than 20°C suggest geothermal mixing, and three springs in Dixie Meadows (Cold Spring, Northern Meadows Spring, and Dixie Valley Hot Springs) had temperatures of 29°C, 26°C, and 58.5°C, respectively (Huntington *et al.* 2014, p. 19).

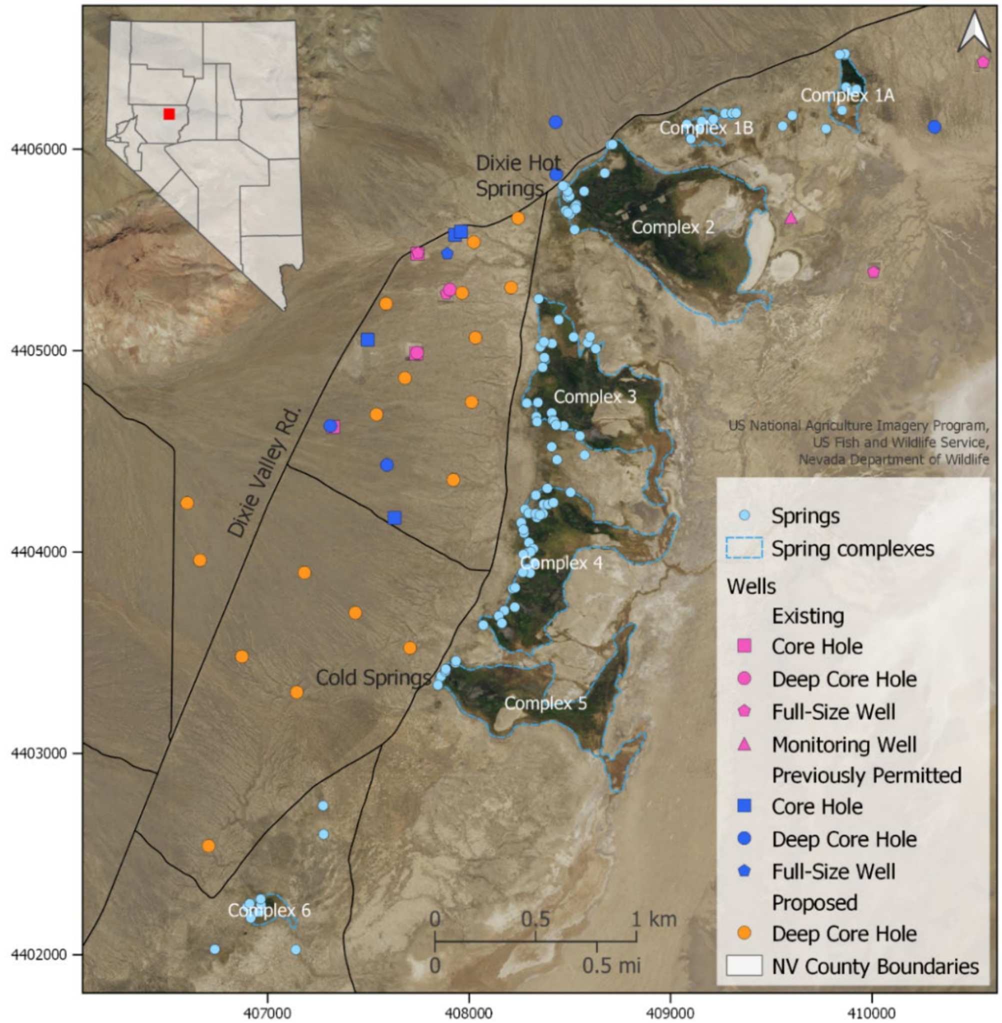

Figure 2. Proposed and existing well pad locations as provided in the 2020 ARMMP. Note that orange circles listed as proposed wells likely refer to well pads based on the number (18) provided in the ARMMP.

3.4 Current water temperature

Spring water temperatures recorded during previous monitoring are provided in Table 1 and Figure 3 (Schwering 2013; Ormat 2020, pp. 154-155, Table 7). The maximum temperature recorded at Dixie Hot Springs (Complex 2) in monitoring data from 2015–2020 was 71°C (Ormat 2020, p. 81) and 84°C based on previous studies (Iovenitti 2014, p. 54). Water temperatures measured in 2019 at toad survey sites throughout Dixie Meadows (*i.e.*, not at springheads) ranged from 10–41°C, with a mean and standard deviation of 16.9 ± 6.1°C (Halstead *et al.* 2019, associated data release). The expected average temperature of geothermal fluid is 149°C based on conditions at other Ormat facilities (EA, p. 2-11). Previously collected temperature-depth profiles for Dixie Meadows are provided in Figure 4. The average temperature gradient for Dixie Valley is 63 °C/km, although some locations reach a gradient greater than 100 °C/km (Wanner *et al.* 2014, p. 131). Temperatures in the Dixie Valley Geothermal Wellfield area (Northeast of Dixie Meadows) reach over 200°C at 1.9–2.9 km bls (Iovenitti 2014, p. 3).

Table 1. Summary statistics for spring water temperatures in summer 2012, 2018, and 2019 by wetland complex.

Spring Complex	No. springs	Median (°C)	Range (°C)	No. measurements
1A	6	22	19–28	5
1B	9	17	16–17	2
2	21	60	39–74	22
3	22	48	16–61	18
4	33	45	32–56	10
5	7	25	17–34	9
6	8	14	13–15	2

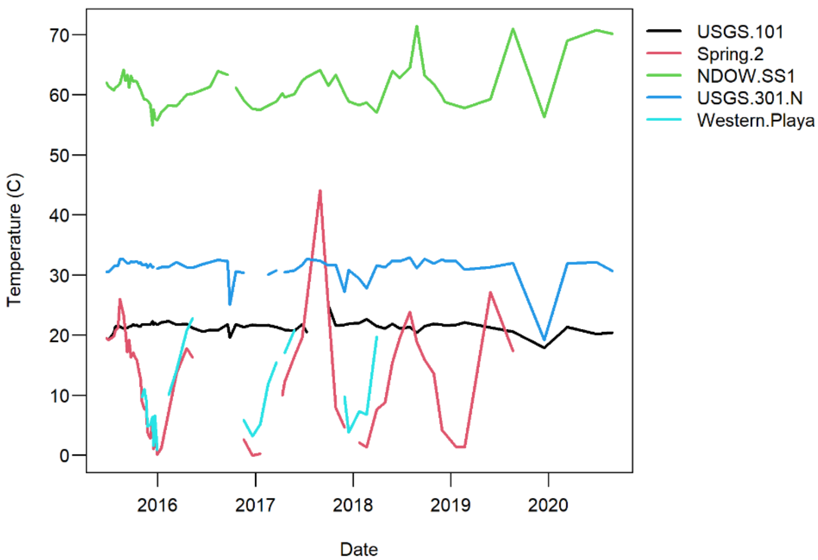

Figure 3. Water Temperature at current monitoring sites as provided in Ormat (2020, Table 7).

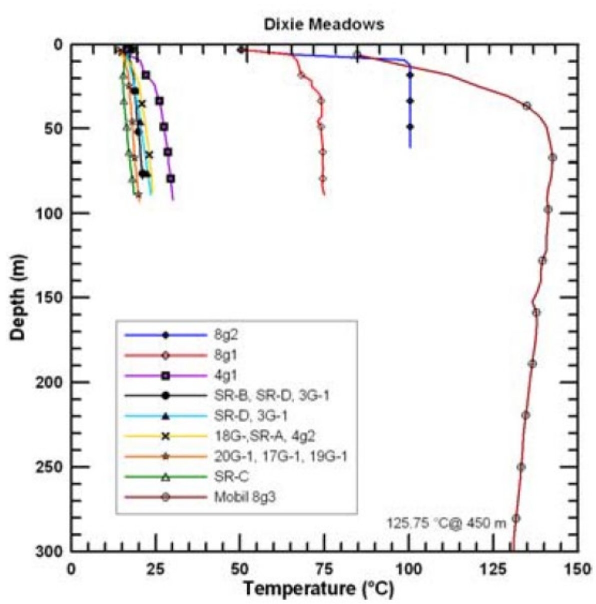

Figure 4. Temperature-depth profiles for Dixie Meadows as provided in Iovenitti (2014, p. 47)

3.5 Current water availability

Groundwater discharge through evapotranspiration from wetland vegetation and the playa has been estimated at 7,000–28,000 acre-feet per year (afy) (Harrill and Hines 1995) and 23,000 afy (Garcia *et al.* 2015, p. 75). Total spring discharge in Dixie Meadows is estimated at 990 afy, with 2,860 afy of total annual outflow (Ormat 2020, pp. 1-2). Discharge measurements from several Dixie Meadows springs are provided in Table 2.

Table 2. Discharge for select springs based on Table 11 in (Ormat 2020).

Site ID	Date	Discharge (gpm)	Discharge (cfs)
USGS-101	29-May-2019	15.3	0.0341
NDOWSS-1	23-Oct-2009	191	0.4256
	08-Mar-2011	177	0.3944
	24-Jun-2011	107	0.2384
	29-May-2019	146	0.3253
Spring 4	29-May-2019	40.7	0.0907
Spring 6	29-May-2019	26.2	0.0584
Dixie Spring complex confluence	26-Oct-2011	162	0.3609
	04-May-2012	237	0.5280
	29-May-2019	144	0.3208

The basin is fully appropriated for consumptive groundwater uses (15,218 afy of an estimated 15,000 afy perennial yield) and the proposed Dixie Valley groundwater export project by Churchill County is seeking an additional 10,000–15,000 afy. Total geothermal water rights appropriated in Dixie Valley as of 2020 are 12,704 afy (Ormat 2020, p. 15). Rates of groundwater movement across Dixie Valley are provided in Figure 5.

Large-scale pumping of the basin-fill aquifer to augment the pressure of the geothermal reservoir began in 1997 (Benoit *et al.* 2000). The Dixie Valley Geothermal Power Plant located 26 km northeast of Dixie Meadows pumps an average of 2,100 afy, which is reinjected above the deep geothermal aquifer (Huntington *et al.* 2014, p. 5). In 2010-2011, Dixie Valley Geothermal Plant withdrew 21,400 afy and reinjected 15,00 afy, leading to a net consumption of 6,600 afy (Huntington *et al.* 2014, p. 4). A summary of hydraulic responses during flow testing in Dixie Meadows are provided in Table 3.

Table 3. Hydraulic responses during flow testing based on Table 13 in (Ormat 2020).

	Pressure (psi)			
Well ID	Original	Minimum	Delta	Final
23-8	113.4	105	8.4	112.85
24A-8	61.8	59.65	2.15	61.1
42-9	118.49	104.95	13.54	116.2
86-7	75.35	67.15	8.2	68.5

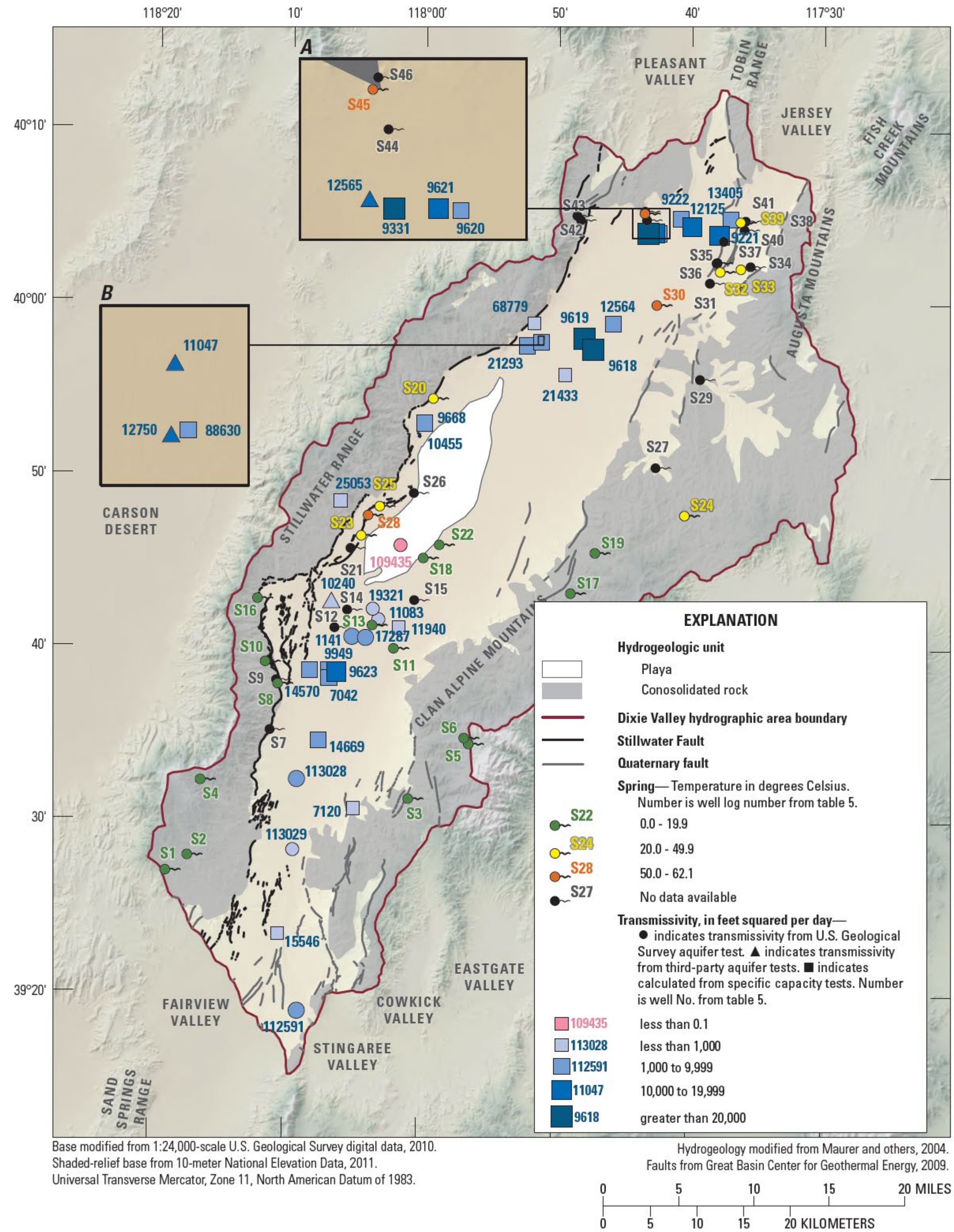

Figure 5. Estimates of spring temperatures and transmissivity across Dixie Valley from Huntington *et al.* 2014. Dixie Meadows is located near S23–S25, west of the Playa.

Sites occupied by Dixie Valley Toads were 43.4 ± 16.1% wetted on average, ranging from 9.4–67% (Halstead *et al.* 2019). Toads are rarely encountered more than 14 m from aquatic habitat (Halstead *et al.* 2021, p. 7).

3.6 Projected changes in climate

Because the Dixie Valley is hydrologically closed, most surface water and groundwater that enters remains until discharged by springs or evapotranspiration. Projected climate change in the region may therefore also affect surface water temperature and availability. Mean annual surface temperature and evapotranspiration are projected to increase in Dixie Meadows across 20 global climate models and two representative concentration pathways (Figure 6). Mean precipitation is projected to remain relatively constant, although large uncertainty exists around mean estimates.

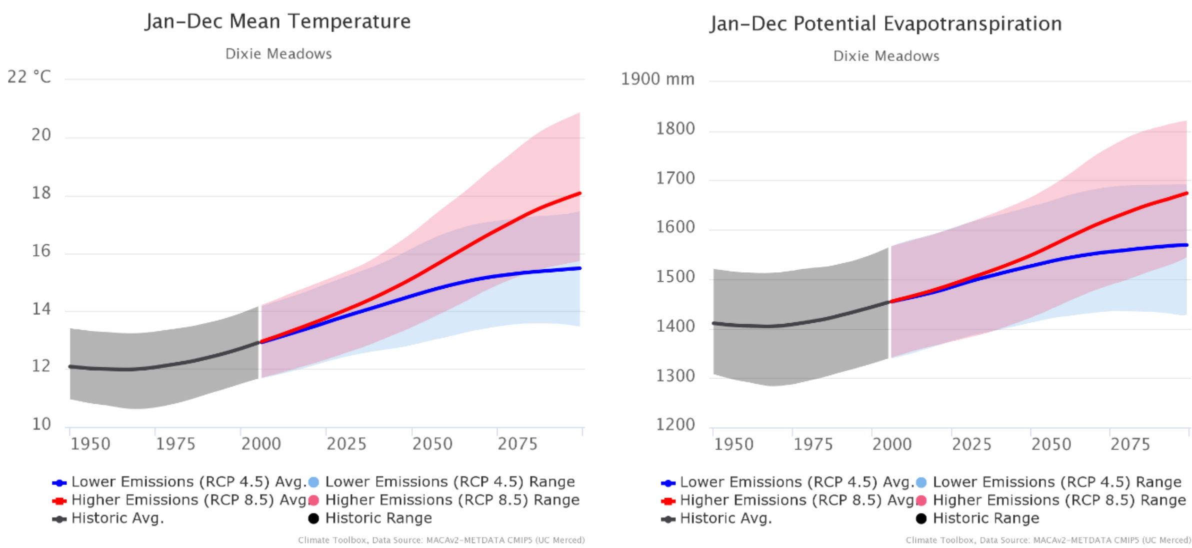

Figure 6. Projected mean surface temperature (left) and potential evapotranspiration (right) in Dixie Meadows. Global GCM data were statistically downscaled using the multivariate adaptive climate analogs method (Abatzoglou and Brown 2012). Data accessed from <https://climate.northwestknowledge.net/MACA/index.php>.

3.7 Impacts associated with nearby geothermal projects

Although effects of geothermal production on surface hydrology are site specific (Kaya *et al.* 2011, entire), experience from previous geothermal development projects can help characterize the range of plausible scenarios. For example, following development of the Jersey Valley Geothermal project located 65km NE of Dixie Meadows, the Jersey Hot Spring ceased flowing over a 4 year period between 2011–2015 from a 2009 baseline condition of 0.1114 cfs (Figure 7; Nevada State Engineer Ruling 6305, p 2-3). Development of Steamboat Springs, NV resulted in 40% declines in total discharge over a 2-year period (Sorey 2000, p. 707). Cessation of hot spring and geyser discharge has also occurred at Brady Hot Springs and Beowawe, NV and reductions in discharge have occurred downstream of well sites in Long Valley caldera, CA

(Sorey 2000, p. 708). Around the Dixie Valley Geothermal Power Plant (26 km NE of Dixie Meadows), land subsidence rates were documented as high as 10.4 cm/yr between 1992–1997 and 4.6 cm/yr from 2006–2008. This suggests total subsidence could be as high as 150 cm (Huntington *et al.* 2014, p. 5).

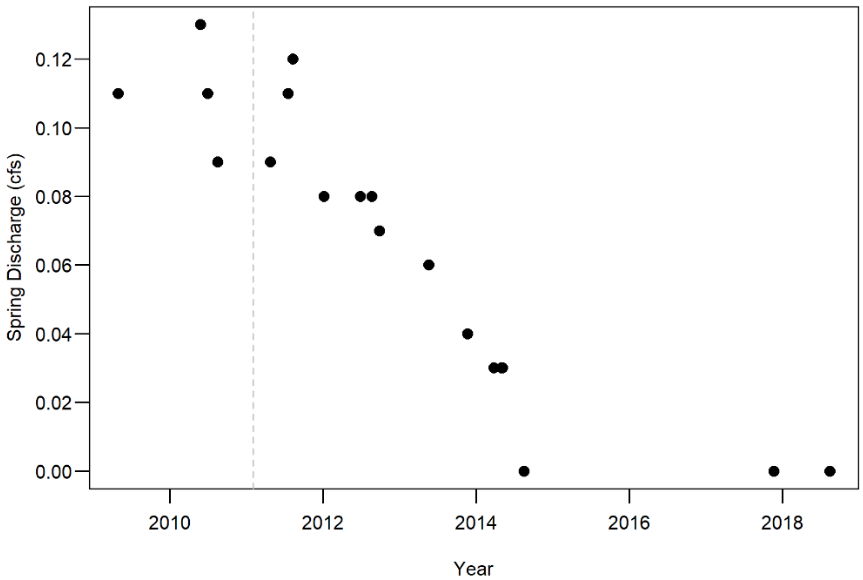

Figure 7. Spring discharge at Jersey Hot Springs after Jersey Valley Geothermal Plant brought online in 2011 (vertical dashed line). Data from NV Division of Water Resources site 132-N27-E40-29DDDB1. Accessed 2021-04-06 <http://water.nv.gov/SpringAndStreamFlow.aspx>.

Nearby geothermal projects have also coincided with changes in surface water temperatures. For example, temperatures at Brady Hot Springs (measured at the geothermal plant inlet) decreased 24°C (from 182°C to 158°C) between 1992–1995 (Krieger and Sponsler 2002, p. 735). Geothermal development in Long Valley caldera, CA coincided with decreases of 10–15°C in reservoir temperature and 30–40% declines in the thermal component of surface springs over an 8-year period (Sorey 2000, p. 706). At Steamboat Springs, NV an average temperature decline of 1°C per year has been recorded (Kaya *et al.* 2011, p. 56). Although not geographically close, some geothermal springs in New Zealand have experienced temperature decreases over 30°C following geothermal development (Hunt 2000, pp. 26, 34).

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