APPENDIX A: Entities who discussed this assessment with TNC staff

A list of entities who met with TNC staff regarding this assessment is included in Table A.1.

Table A-1. Name and organization of entities who met with TNC staff for the Nevada GDE stressor and threat assessment.

Name	Organization
Sarah Peterson	Bureau of Land Management
Boris Poff	Bureau of Land Management
Christine Albano	Desert Research Institute
Justin Huntington	Desert Research Institute
Dan McEvoy	Desert Research Institute
Ken McGwire	Desert Research Institute
Blake Minor	Desert Research Institute
Don Sada	Desert Research Institute (Retired)
Van Simhoft	Great Basin Institute
Chris Crookshanks	Nevada Department of Wildlife
Jinna Larkin	Nevada Department of Wildlife
Jennifer Newmark	Nevada Department of Wildlife
Jon Sjöberg	Nevada Department of Wildlife
Eric Miskow	Nevada Division of Natural Heritage
Kip Allander	Nevada Division of Water Resources
Jon Benedict	Nevada Division of Water Resources
Bunny Bishop	Nevada Division of Water Resources
Will Boyer	Nevada Division of Water Resources
Micheline Fairbank	Nevada Division of Water Resources
Nicole Goehring	Nevada Division of Water Resources
Levi Kryder	Nevada Division of Water Resources
Stephanie Snider	Nevada Division of Water Resources
Adam Sullivan	Nevada Division of Water Resources
Tim Wilson	Nevada Division of Water Resources
Emily Hagler	Pyramid Lake Paiute Tribe
Robyn Mercer	Pyramid Lake Paiute Tribe
Zach Freed	The Nature Conservancy, Oregon Chapter
Holly Richter	The Nature Conservancy, Arizona Chapter
Susan Abele	US Fish and Wildlife Service
Laurie Averill-Murray	US Fish and Wildlife Service
Sue Braumiller	US Fish and Wildlife Service
Lee Ann Carranza	US Fish and Wildlife Service
Jessica Czara	US Fish and Wildlife Service
James Harder	US Fish and Wildlife Service
Michelle Hunt	US Fish and Wildlife Service
Corey Kallstrom	US Fish and Wildlife Service
Glen Knowles	US Fish and Wildlife Service
William Kutosky	US Fish and Wildlife Service
Chad Mellison	US Fish and Wildlife Service
Michael Schwemm	US Fish and Wildlife Service
Andy Starotska	US Fish and Wildlife Service

John Tull	US Fish and Wildlife Service
Sean Vogt	US Fish and Wildlife Service
Cathy Williamson	US Fish and Wildlife Service
Jeanne Chambers	US Forest Service, Rocky Mountain Research Station
Kip Allander	US Geological Survey (now with NV Div of Water Resources)
Mike Dettinger	US Geological Survey (retired)
Jill Frankforter	US Geological Survey
Rebecca Frus	US Geological Survey
Phil Gardner	US Geological Survey
Geoff Moret	US Geological Survey
Greg Paulson	US Geological Survey
David Prudic	US Geological Survey (Retired)
Jon Wilson	US Geological Survey

APPENDIX B: Examples illustrating the complexity of the relationship between groundwater withdrawal distance and impact to GDEs

Withdrawing groundwater near a GDE is likely to lower the water table and capture groundwater that had been supplying that GDE (Patten et al. 2008), but water withdrawals at greater distance from a GDE do not necessarily have a lessened impact to the GDE. Heterogenous characteristics of the geology and soils can provide barriers or conduits for flow or affect how easy or difficult it is to transmit flow (Somers and McKenzie 2020). Thus, aside from GDEs in areas of shallow groundwater within 800 m (0.5 mile) of groundwater withdrawal, we did not rate GDEs for distance to groundwater withdrawals. We stress that it is important to do site-specific regional and localized studies of potential impacts of groundwater withdrawals to GDEs, which may also require development, calibration, and use of numerical groundwater models. Here we provide two examples to illustrate how distance to groundwater withdrawals can have non-linear relationships to impacts to GDEs.

<u>Surface water capture models – Paradise Valley (HA 069) example</u>

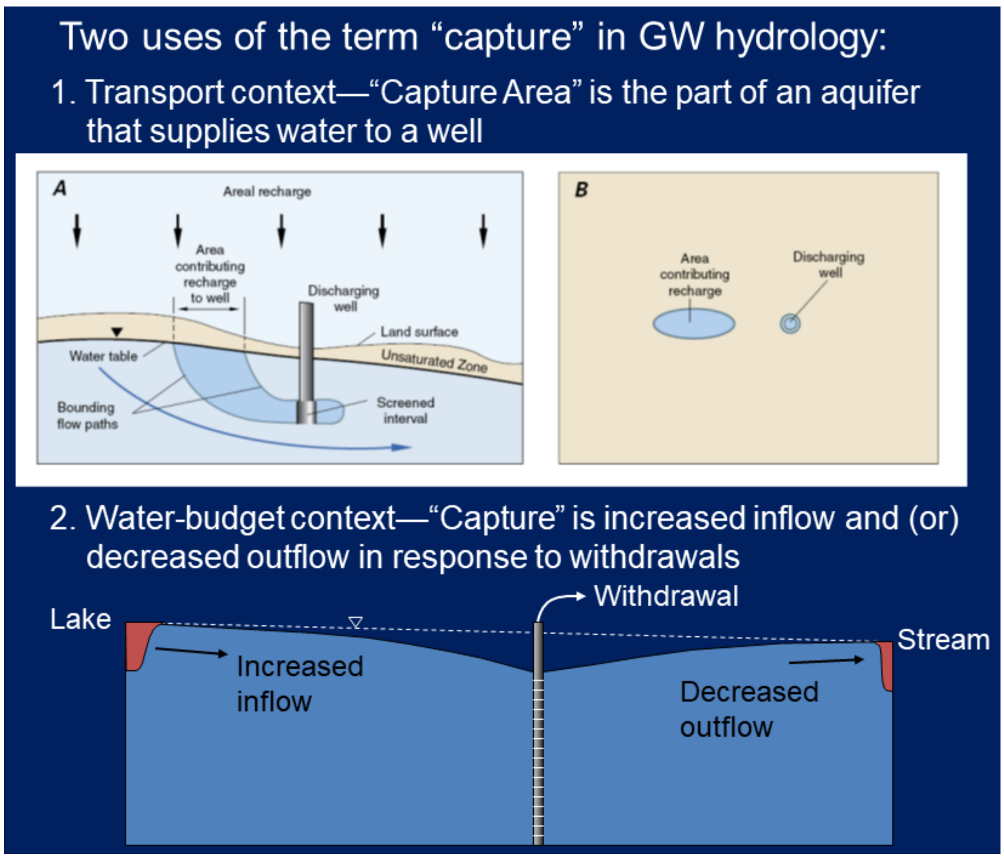

Figure B-1. Illustration of groundwater capture from Leake (2007)

Surface water capture by groundwater pumping occurs when drawdown from pumping alters hydraulic gradients, thereby changing groundwater fluxes with a surface water body (Figure 1c in main report; Figure B-1; Leake 2007; 2011). As mentioned in the main body of the report, groundwater pumped from an aquifer must be balanced by a reduction of groundwater storage, capture of natural discharge, or induced recharge (Theis 1940). When water is coming from natural discharges of surface water or inducing recharge from surface water, it is considered capture (Box 2; Konikow and Leake 2014). While distance is a factor in determining capture, it is also dependent on the hydraulic diffusivity of the aquifer (Leake 2011). Hydraulic diffusivity is the ratio of transmissivity (describes the capacity of a rock or aquifer to transmit water under pressure) to the aquifer storage coefficient (describes the volume of water that can be taken into storage per unit surface area per unit change in head). Konikow and Leake (2014) noted that groundwater storage and capture problems must take into account local and regional scales and recommend using well-calibrated numerical models to analyze the sources of water derived from wells.

Leake et al. (2008) used a MODFLOW model of the Upper San Pedro River basin in Arizona to estimate the amounts of river water that would be captured by pumping in different locations of the watershed under scenarios of alternative pumping rates over 100 years using 1-year time steps. The general approach is as follows (Leake et al. 2008):

1. Run the calibrated steady-state model without added withdrawal (i.e., a base case)
2. For a location in the region to be mapped for groundwater capture, run a transient model with the added withdrawal
3. For time *t*, calculate the change in flow from each feature (i.e., spring, river reach, etc.) and the change in groundwater storage between the runs for Steps 1 and 2
4. For time *t*, compute the capture value as the fraction of change in flow divided by the pumping rate, and the storage change value as the fraction of change in storage divided by the pumping rate.
5. Repeat Steps 2 through 4 for all locations to be mapped.
6. Use a geographic information system (GIS) or another contouring program to make a contour map of the capture fractions for all locations saved.

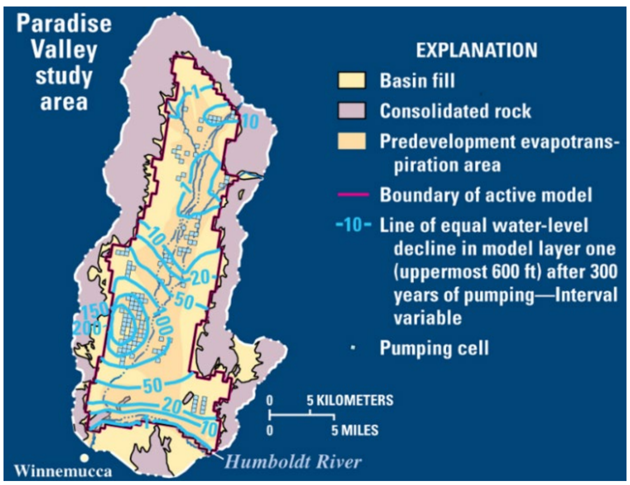

Figure B-2. Paradise Valley study area for preliminary capture modeling from Leake (2007).

A similar approach is currently being used for in Nevada in which groundwater flow models are being developed by the USGS and DRI to enable estimation of Humboldt River flow captured by groundwater pumping at different locations in the Humboldt River Basin (NDWR 2018). Final results of the capture modeling have not yet been released, but Leake (2007) prepared a preliminary capture map of hydrographic area 069 (Paradise Valley) to illustrate how capture maps could work in the Humboldt River Basin (Figure B-2). The preliminary results were displayed in maps that showed how the percentage of pumped water that is captured after 10 years or 50 years of continued pumping depends on where a well is located in the basin (Figure B-3) and are not solely dependent on distance from the groundwater-dependent Humboldt River. For example, the yellow region in Figure B-3 indicates that wells located in this area are modeled to obtain 40

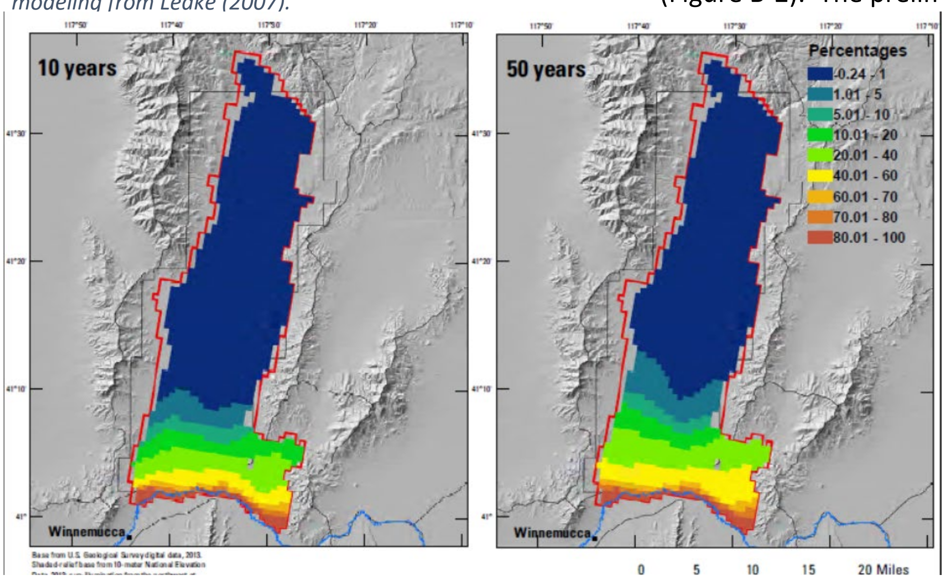

Figure B-3. Preliminary results of capture modeling for Paradise Valley showing percentage of pumped water from the Humboldt River after 10 years (left) and 50 years (right) from Leake (2007) to 60% of their water from the Humboldt River after 10 or 50 years of continued pumping, but the distance of this band is not uniformly distant from the Humboldt River (blue line at the bottom of the panels).

Importance of regional hydrogeology – Megachannel to Devils Hole

Devils Hole is a small pool in a limestone collapse depression in the southeastern Amargosa Desert that has a rare fish species called the Devils Hole pupfish (*Cyprinodon diabolis*; Dudley and Larson 1976). The endangered pupfish requires access to a rock shelf for food and spawning, but pumping of several wells within 5 km of the pool led to water levels declines in Devils Hole that threatened the pupfish access to the rock shelf (Glazer and Likens 2012). Litigation of this case resulted in a court decision (*Cappaert v. United States* [426 U.S. 128 (1976)]) that limits groundwater withdrawals to maintain a minimum pool elevation at Devils Hole (Halford and Jackson 2020). In 2008, the Nevada State Engineer issued Order 1197 for the Amargosa Desert hydrographic area (HA 230) where Devils Hole is located that was later superseded by Order 1197A in 2018 to curtail new appropriations of groundwater in HA 230 within a 25-mile radius from Devils Hole. The orders also denied changes in the point of diversion of an existing groundwater right to a point of diversion closer to Devils Hole within the 25-mile radius from Devils Hole.

Using isotopic and major-ion chemistry, Winograd and Pearson (1976) suggested that there is a highly transmissive confined feature between northern Yucca Flat and the Ash Meadows discharge area that includes Devils Hole. They called this feature a "megachannel" in which drawdowns in the shallow-carbonate could propagate quickly and recover slowly (Halford and Jackson 2020; Winograd and Pearson 1976).

Halford and Jackson (2020) used the Death Valley version 3 model (DV3 model) to examine the effects of pumping on water levels at Devils Hole to confirm the extent of the megachannel (Figure B-4). The extent of the modeled megachannel is outlined by the blue line in Figure B-4, and blue and red dots indicate wells likely to impact water levels at Devils Hole because they are capturing water at Devils Hole. If distance had a predictable effect of pumping on Devils Hole water levels, such dots should fall within a radius of Devils Hole, but Figure B-4 shows how wells to the southeast of Devils Hole that are just as far from Devils Hole as wells to the northwest have no effect on water levels at Devils Hole. In January 2022, the Nevada State Engineer issued Order 1330 which vacated Order 1197A, stating that any applications for additional groundwater rights will be denied in HA 230, and applications to change points of diversion will be evaluated with the DV3 model for potential impacts to Devils Hole. Thus, the order eliminates the 25-mile radius criteria that was present in Order 1197A for evaluating impacts to Devils Hole.

This example illustrates how a method that assumes a propagation of pumping impacts with distance that might apply for an alluvial valley with fairly homogenous aquifer characteristics is not appropriate for assessing pumping impacts in a high hydraulic diffusivity carbonate region. It is conceivable that conditions similar to the "megachannel" exist elsewhere in the Great Basin carbonate and alluvial aquifers.

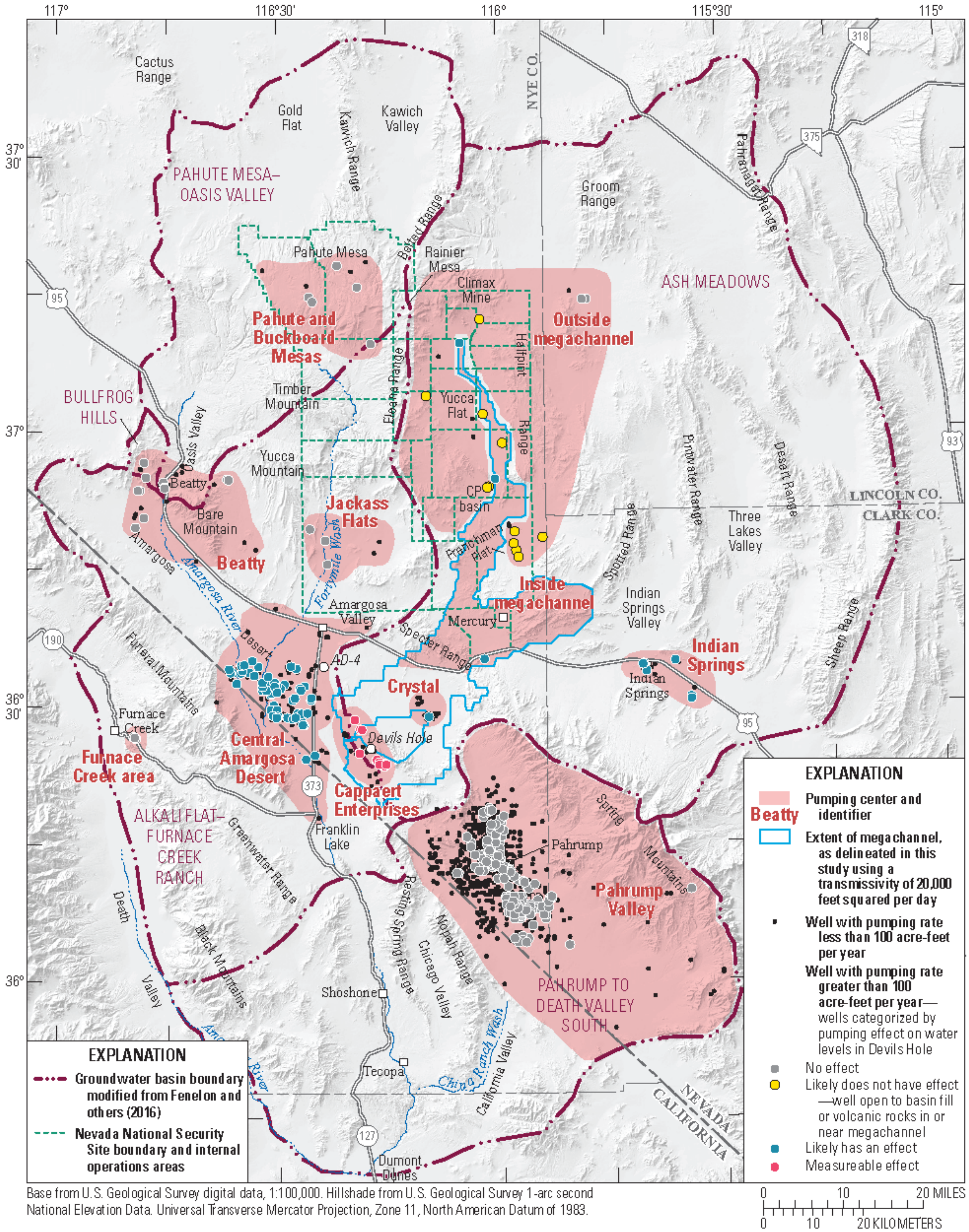

Figure B-4. Modeled megachannel and pumping centers analyzed for likelihood of affecting water levels in Devils Hole. Results are from Death Valley version 3 groundwater model (Figure 91 from Halford and Jackson 2020).

APPENDIX C: Examples of calculations for different GDE types for stressor risk factors due to falling groundwater level trends; stressor and threat risk factors for non-native species, and stressor and threat risk factors due to additional impacts of human development

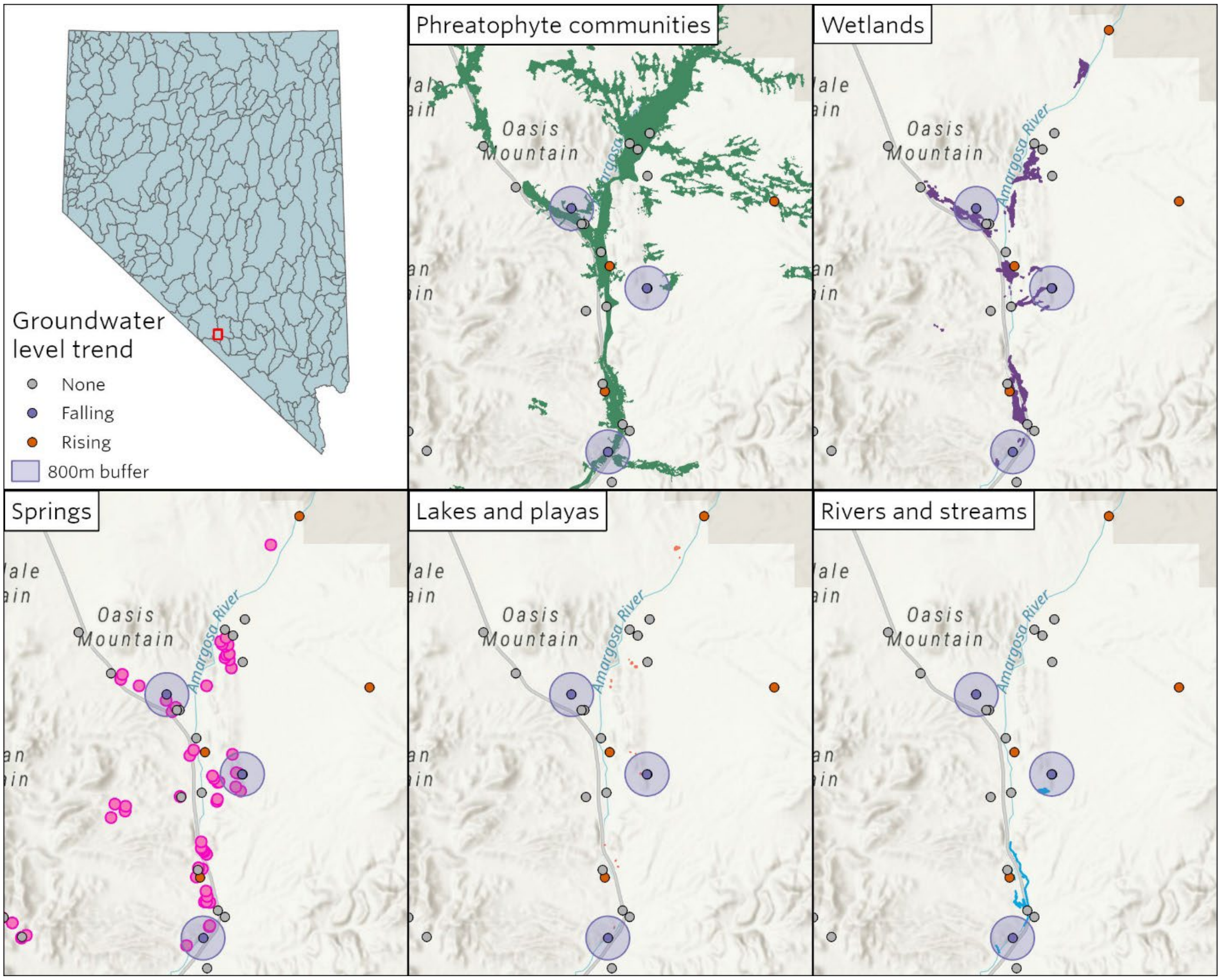

Figure C-1. Example of calculations for stressor risk factor of falling groundwater level trends for different GDE types. Purple dots are wells with significantly falling groundwater level trends and the circles around these dots show the 800-m (0.5 mile) radius around these wells. Indicators of phreatophyte communities (shown in green in middle top panel), groundwater-dependent wetlands (shown in purple in top right panel), springs (shown in pink in lower left panel), groundwater-dependent lakes and playas (middle lower panel; none are located in this image), and groundwater-dependent rivers and streams (shown in blue lines in lower right panel) within 800 m (0.5 mile) of the three sites with falling trends were given a stressor risk factor value of 1.0 for falling groundwater levels. All other iGDEs in the panels were given a stressor risk factor value of 0.1.

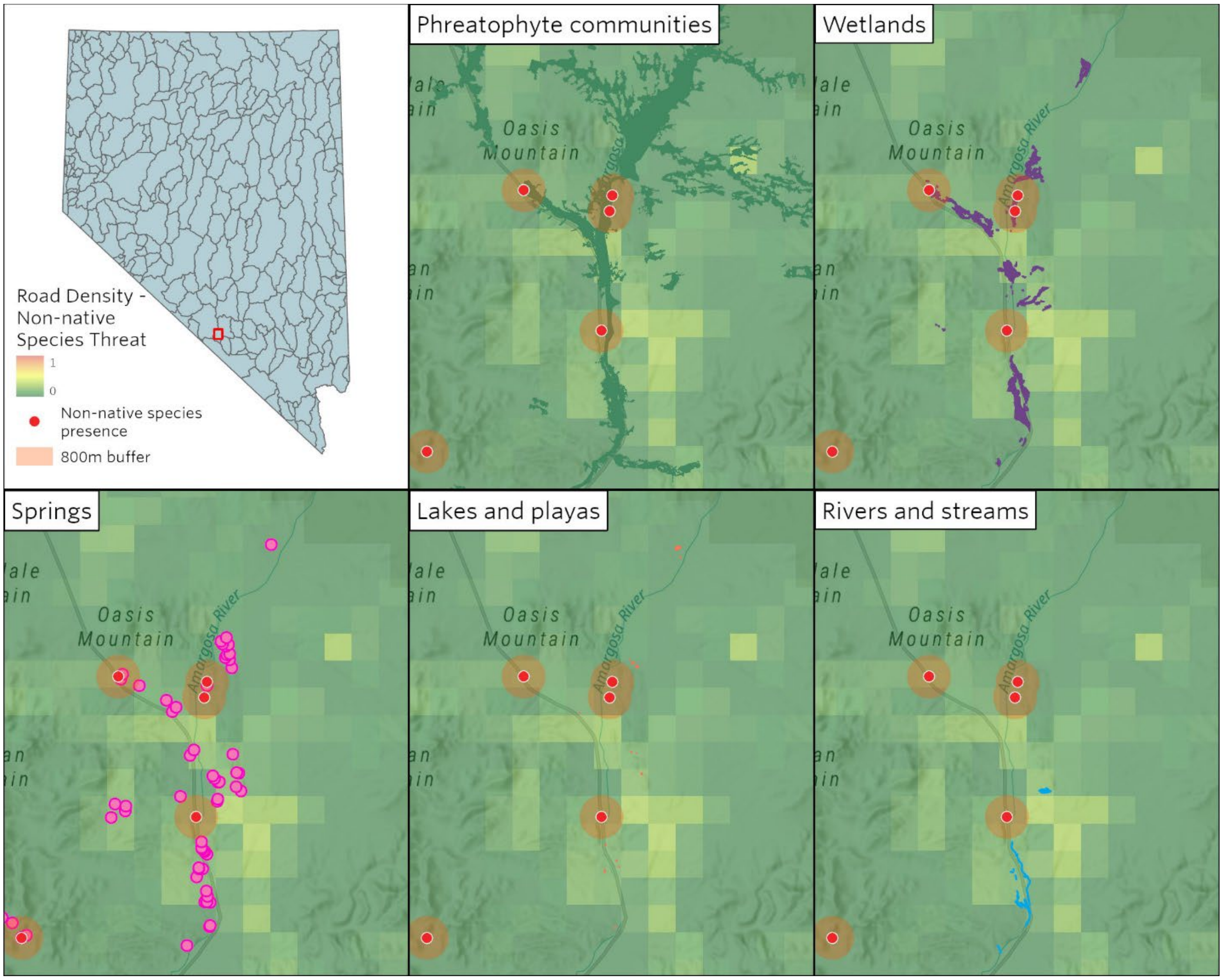

Figure C-2. Example of calculations for stressor and threat risk factors for non-native species for different GDE types. Red dots are locations with non-native species presence and the circles around these dots show the 800-m (0.5 mile) radius around these wells. Indicators of phreatophyte communities (shown in green in middle top panel), groundwater-dependent wetlands (shown in purple in top right panel), springs (shown in pink in lower left panel), groundwater-dependent lakes and playas (middle lower panel; none are located in this image), and groundwater-dependent rivers and streams (shown in blue lines in lower right panel) within 800 m (0.5 mile) of the three sites with known presence of non-native species were given a stressor risk factor value of 1.0 for presence of non-native species. All other iGDEs in the panels were given a stressor risk factor value of 0.1 for presence of non-native species. Also shown is the normalized road density raster for non-native species threat. Indicators of GDEs were assigned the non-native species threat risk factor value of the associated normalized road density raster on which they overlap.

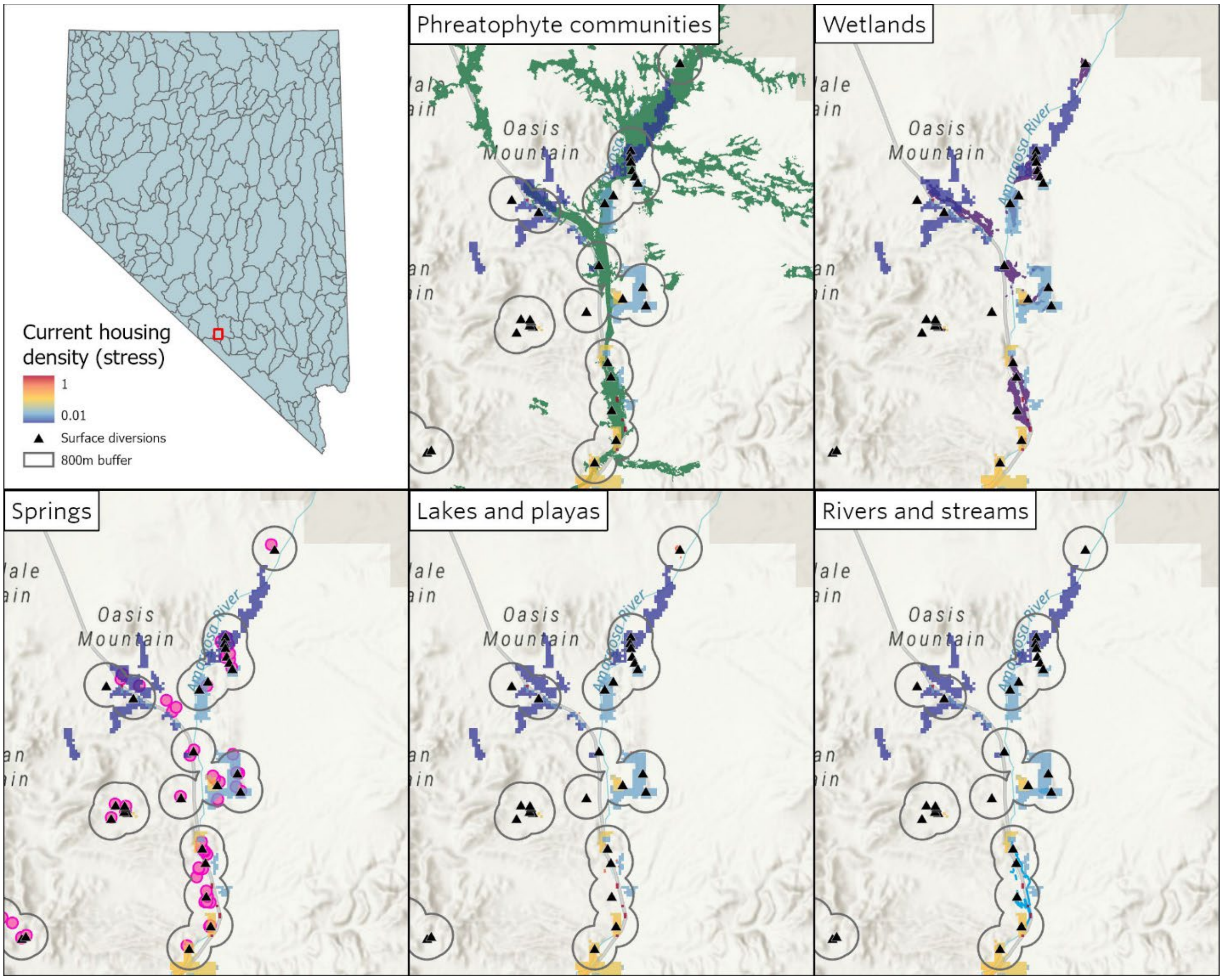

Figure C-3. Example of calculations for stressor risk factors for additional human development for different GDE types. Black triangles indicate points of diversion (PODs) for surface water and the circles around these dots show the 800-m (0.5 mile) radius around these PODs. Indicators of phreatophyte communities (shown in green in middle top panel), groundwater-dependent wetlands (shown in purple in top right panel), springs (shown in pink in lower left panel), groundwater-dependent lakes and playas (middle lower panel; none are located in this image), and groundwater-dependent rivers and streams (shown in blue lines in lower right panel) within 800 m (0.5 mile) of the PODs a stressor risk factor value of 1.0 for falling groundwater levels. All other iGDEs in the panels were given a POD stressor risk factor value of 0.1. Also shown are the locations of current normalized current house density stressor risk factor values. Areas of current housing density normalized stressor risk factor values are shown with the color ramp from blue (negligible risk) to red (high risk). Only areas with current housing density data are shown; it is assumed there is no current housing density risk if the color ramped areas are not shown. Indicators of GDEs were assigned the current housing density stressor risk factor value on which they overlap.

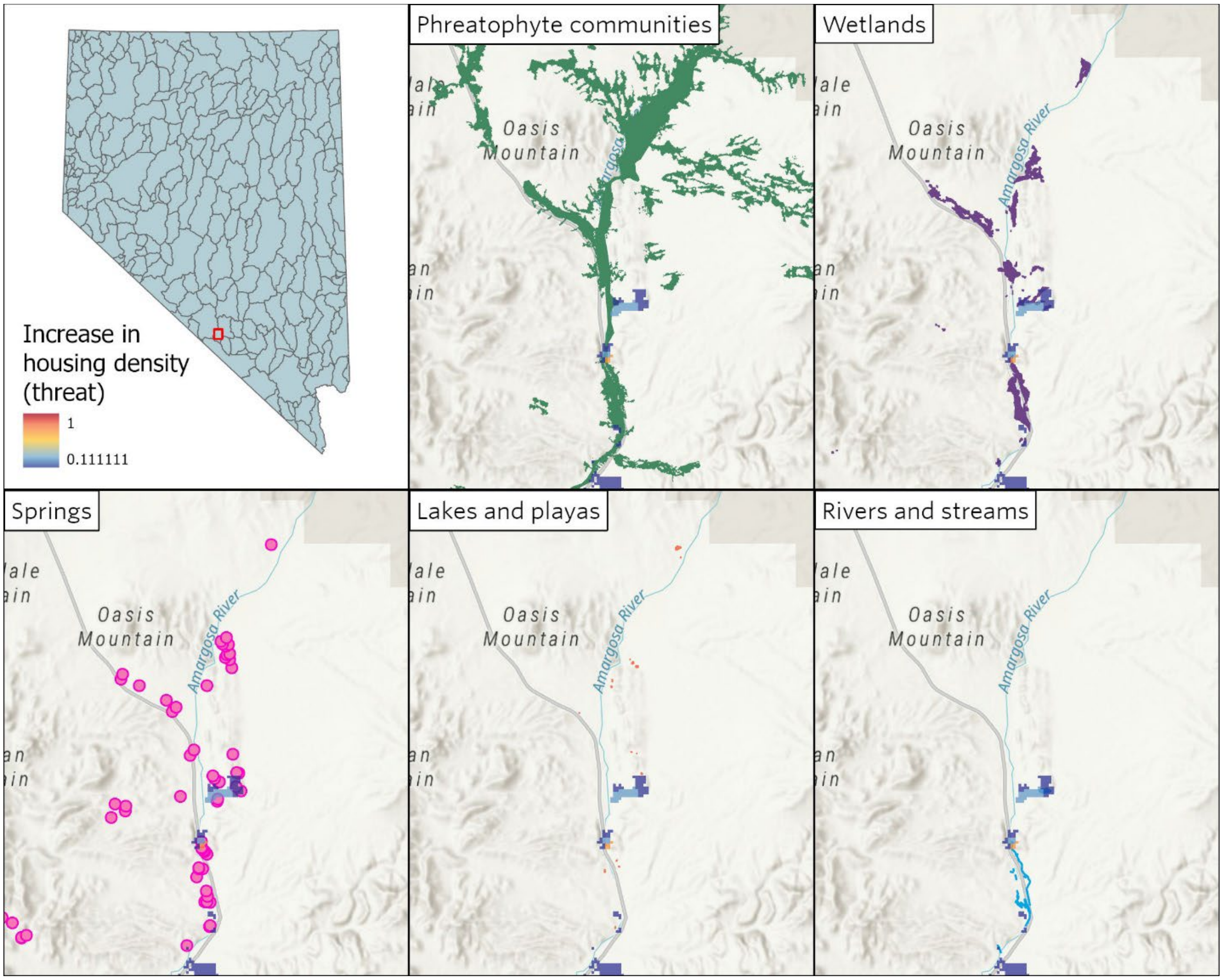

Figure C-4. Example of calculations for threat risk factor for additional human development for different GDE types. Areas of future increased housing density normalized threat risk factor values are shown with the color ramp from blue (negligible risk) to red (high risk). Only areas with future increased housing density data are shown; it is assumed there is no future housing density risk if the color ramped areas are not shown. Indicators of phreatophyte communities (shown in green in middle top panel), groundwater-dependent wetlands (shown in purple in top right panel), springs (shown in pink in lower left panel), groundwater-dependent lakes and playas (middle lower panel; none are located in this image), and groundwater-dependent rivers and streams (shown in blue lines in lower right panel) were assigned the future increased housing density threat risk factor value on which they overlap.