Appendix H3

Assessment of Effects of the Cadiz Groundwater Conservation Recovery and Storage Project Operations on Springs

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Executive Summary

Cadiz is proposing to implement the Groundwater Conservation Recovery and Storage Project (Project) in the Fenner-Bristol-Cadiz watershed, which will include installation of extraction wells to lower groundwater levels and thereby facilitate the capture of groundwater that would otherwise flow to Bristol and Cadiz Dry Lakes, where it would evaporate. Cadiz plans to extract an average of 50,000 acre-feet per year (AFY) from an extraction wellfield in the vicinity of Fenner Gap (Figure 1). There are no springs within 11 miles of the Project. However, many springs exist in the Fenner Watershed that support habitat of the desert environment and it is Cadiz's intent to operate the Project in a manner that avoids impacts to any of these distant springs. This technical memorandum presents an assessment of the potential impact of the proposed operation of the extraction wellfield on springs in the Fenner Watershed.

There is no information demonstrating a physical connection of those identified springs in the local mountains to groundwater in the alluvial aquifer where Cadiz's pumping will take place. In addition, the alluvium west of Clipper Mountains is likely to be unsaturated as it thins over bedrock highs, which further limits hydraulic continuity between the alluvial aquifer and springs located in the mountains on the west side of the valley. There is no observed hydraulic continuity between groundwater in fractured granitic bedrock where the springs exist and the regional groundwater table of the alluvial aquifer. Consequently, because there is little or no hydraulic connection the Project will not likely have any impact on springs.

In order to address more completely assess concerns about potential impacts on springs, this memorandum also presents and analysis as to whether there could be a potential impact of the Project on the identified springs by assuming the existence of hydraulic continuity between the groundwater feeding springs and groundwater in the alluvial aquifer. The results of this assessment demonstrates that for many reasons, including distance between drawdown in the alluvial aquifer and springs, change in elevation, the required low transmissivity of fractured bedrock, and hydraulic connectivity, that any impact would be very minor and likely within the natural climatic variability.

Springs in the Fenner Watershed

Many springs have been identified in the Fenner Watershed and documented in United States Geological Survey (USGS) reports dating as far back as 1908 and 1929 (Mendenhall, 1909 and Thompson, 1929, respectively). Figure 2 shows the location of wells and springs largely documented in 1984 by the USGS based on a literature review and a field survey of groundwater resources of the Lanfair and Fenner Valleys (Freiwald, 1984).

Those springs closest to the proposed Cadiz extraction wellfield are located in the adjacent mountains and include: Bonanza Spring, Hummingbird Spring, and Chuckwalla Spring in the Clipper Mountains to the north; Willow Spring, Honeymoon Spring, Barrel Spring and Fenner Spring in the Old Woman and Piute Mountains on the east; and Van Winkle Spring, Dripping Spring, Unnamed-17BS1, Unnamed-17GS1, Granite Cove Spring, Cove Spring, BLM-1 and BLM-2 springs at the Southern End of the Providence Mountains. The Bonanza Spring in the Clipper Mountains, which is the closest spring to the proposed extraction wellfield, is over 11 miles from the center of the Fenner Gap. Mendenhall (1909) briefly describes the following springs in the USGS Water Supply Paper 224 on "Some Desert Water Places in Southeastern California and Southwestern Nevada:" Cove Springs and Bonanza Springs, as well as several other springs in the northern reaches of the watershed. Thompson (1929) describes the following springs: Van Winkle Spring, Cove Springs, Cottonwood Springs, Dripping Springs, Arrow Weed Spring (possibly the same as Cottonwood Spring) in the southern part of the Providence Mountains; Bonanza Spring (also called Danby Spring) and an unnamed spring in the Clipper Mountains; Fenner Spring (which originates as a tunnel dug 200 feet into the mountain side) and Barrel Spring in the Piute Mountains; and Honeymoon Spring (derived from a dug tunnel into granite) in the Old Woman Mountains.

Thompson (1929) did not physically locate those springs in the Southern Providence Mountains, but locations were based on the "best available information that could be obtained." The Bonanza Spring (or Danby Spring) is reported by Thompson (1929) to consists of a tunnel 360 feet long, dug in clay, "cement," and gravel and was reported to yield about 10 gallons per minute, approximately 16 acre-feet per year (AFY). The spring supplied water to Danby via pipeline for locomotive use. Thompson (1929) reported that the water from the Fenner Spring comes from a tunnel 200 feet long that served the railroad via pipeline at Fenner. The Honeymoon Spring also originates as a tunnel dug into the granite mountain, which was used to supply the Golden Fleece Mine.

Freiwald (1984) completed a study for the Bureau of Land Management to develop hydrogeologic information on the Lanfair and Fenner Valleys for water-resources planning and development. This study included a review of literature and a field canvass of wells, springs, and mine shafts. The field canvass included locating wells and springs, measurement of groundwater levels and collection of samples of groundwater for chemistry, and measurements of spring flow. Figure 2 is based largely on Freiwald's field canvass of wells and springs, which have been incorporated into the USGS online data base (http://waterdata.usgs.gov/ca/nwis/inventory and http://waterdata.usgs.gov/nwis/gwconstruction). Figure 3 shows the altitude of each of these springs and observed discharges, where there was flow observed during Freiwald's survey, as many of these springs were reported as dry. The largest flows were observed at the Bonanza Spring (3.5 gallons per minute [gpm], 5.6 AFY) and Van Winkle Springs (0.5 gpm, 0.8 AFY) during Freiwald's survey.

Physical Setting

The Fenner Watershed encompasses approximately 1,100 square miles (mi^2). It is bounded by the Granite, Providence and New York Mountains on the west and north and the Piute, Old Woman, Ship and Marble Mountains on the east and south. Fenner Gap occurs between the Marble and Ship Mountains, where the surface drainage exits Fenner Watershed and enters the Bristol and Cadiz watersheds. The Clipper Mountains rise from the southern portion of the watershed, just north of Fenner Gap.

Topography

Figure 4 shows a topographic map of the larger area of study based on the National Elevation Dataset (USGS, 2006a). The New York Mountains rise to elevations of approximately 7,532 feet above the National Geodetic Vertical Datum of 1988 (NGVD). The Granite and Providence Mountains range from 6,786 feet to 7,178 feet above NGVD, respectively. The Piute Mountains range up to 4,165 feet above NGVD. The Clipper Mountains rise to an elevation of over 4,600 feet above NVGD. Finally, the Marble and Ship Mountains range up to 3,842 and 3,239 feet above NGVD, respectively. Generally, the Fenner Valley slopes southward toward the Fenner Gap, at an elevation of about 900 feet above NGVD, which is the surface water outlet from the valley.

Precipitation

Davisson and Rose (2000) describe environmental factors that complicate the distribution of precipitation through southeastern California and western Nevada, which include, the rain shadow effect of the Sierra Nevada, San Gabriel, and San Bernardino Mountains, and storms moving up from the Gulf of California that create more precipitation in the eastern Mojave Desert than in the western Mojave Desert. The rain shadow effect of the Sierra Nevada has its greatest impact on precipitation just east of the Sierra Nevada and decreases eastward into Nevada. In general, Davisson and Rose (2000) show that precipitation versus elevation is higher east of the 116^o W longitude than west of it. The Fenner Watershed lies to the east of this demarcation, so this watershed is expected to have higher precipitation with increases in elevation as compared to watersheds in the western Mojave Desert.

Figure 5 shows precipitation and temperature stations in the study area. Those stations with relatively long and complete records in the immediate area of study include Mitchell Caverns and Amboy stations. Stations with short and less complete records in the area and vicinity include San Bernardino County stations of Goffs, Essex, and Kelso. The long-term annual average precipitation at Mitchell Caverns, located at an altitude of 4,350 feet, is 10.47 inches. Amboy is represented by two stations, Amboy – Saltus #1, with an elevation of 624 feet and a long-term annual average precipitation of 3.28 inches (from 1967 to 1988) and Amboy – Saltus #2, with an elevation of 595 feet and long-term annual average precipitation of 2.71 inches (1972-1992)

Figure 6 shows isohyets of average annual precipitation for the larger area of study based on the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) map for the period 1971 through 2000. PRISM was developed by Dr. Christopher Daly of Oregon State University starting in 1991. PRISM uses point estimates of climate data and a digital elevation model (DEM) to generate estimates of climate elements, such as average annual, monthly and event-based precipitation among other elements (www.prism.oregonstate.edu). This isohyet map shows average annual precipitation that varies from about four inches in Bristol Valley to over 12 inches in the New York Mountains.

Figure 7 shows the cumulative departure from mean precipitation for Mitchell Caverns and Amboy stations. The trend of relatively dry conditions prior to the mid-1970's (overall declining trend in the cumulative departure curve) and relatively wet conditions (overall rising trend in the cumulative departure curve) since the mid-1970's is typical of much of Southern California.

Regional Geology

The Fenner Watershed is located within the Basin and Range province of North America. Figure 8 is a simplified geologic map of the larger area of study showing the distribution of "bedrock" and "alluvial/dune/lacustrine" deposits. Bedrock includes igneous, metamorphic and consolidated sedimentary rocks (including carbonates) and alluvial/dune/lacustrine deposits are unconsolidated sediments deposited by streams, wind, or in playa lakes for the purposes of this map. In general, bedrock forms the perimeter of the major watersheds. Large bedrock masses occur within watersheds such as Clipper Mountains, which are located in the Fenner Watershed.

The Bristol and Cadiz watersheds form a broad depression that is referred to as the Bristol Trough (Thompson, 1929; Bassett et al., 1964; Jachens et al., 1992). This depression is thought to be six to ten million years old (Rosen, 1989), having formed as a result of regional movement along faults.

The crystalline basement rocks exposed in the mountain ranges of the project area consist primarily of Precambrian granitic and metamorphic rocks, which are locally overlain by a sequence of Paleozoic sedimentary rocks. The Paleozoic rocks consist of sandstones, shales, slates, limestones and dolomites. These Paleozoic sediments and the underlying basement rocks have been faulted and folded by numerous periods of regional tectonism. The crystalline basement rocks are generally much less permeable than alluvium and typically yield only small quantities of water to wells (Freiwald, 1984 and results of investigations for this Project). Some of the Paleozoic sedimentary sections, particularly those limestone and dolomites sections that are fractured or contain solution cavities, can and do yield large quantities of water to wells (as found as a part of this Project). Mitchell Caverns, located on the eastern side of the Providence Mountains, occur in karstic limestone of this section. These carbonate units are expected to be significant aquifers where dissolution features are present in the subsurface.

The basement complex and the overlying Paleozoic section were locally metamorphosed and intruded by granitic plutons during Mesozoic time. In the Old Woman Mountains, the Precambrian and Paleozoic section was also intensely deformed by ductile thrusting which accompanied the Mesozoic plutonism (Karlstrom et. al., 1993). Throughout the project area, mostly fractured crystalline basement rocks form the boundaries of the groundwater aquifer system.

In the Fenner Valley, the Paleozoic section is unconformably overlain by clastic sediments and interbedded volcanic rocks of mid- to late-Tertiary age. The Tertiary volcanic rocks consist of lava flows of basaltic to andesitic composition, and pyroclastic tuffs of rhyolitic to dacitic composition. The USGS (2006b) reports that a shallow trap-door caldera roughly 10 km in diameter is centered in the eastern Woods Mountains, based on gravity and aeromagnetic anomalies, that was formed from a major eruption 15.8 million years ago, with resurgent eruptions filling the caldera with rhyolitic flows and tuffs. Dikes of similar composition are exposed in the Marble and Ship Mountains. The Tertiary sediments consist of conglomerate, fanglomerate, sandstone, siltstone, water-laid tuff, and lake sediments, which form a composite section more than 7,000 feet thick (Dibblee 1980a and 1980b). The Tertiary sediments and interlayered volcanic rocks are gently dipping, due to extensional normal faulting of late-Tertiary age.

The Quaternary and late-Tertiary alluvial fill in the basins is largely derived from the Precambrian basement rocks, Paleozoic sediments and Tertiary volcanic rocks. The USGS (2006b) mapped alluvial deposits exceeding 300 m in thickness in the northern Fenner Valley. Geophysical evidence indicates that this alluvial fill locally exceeds 3,500 feet in thickness beneath a portion of the southern Fenner Valley (Maas 1994) and is even thicker under Bristol Valley. These alluvial sediments form one of the principal aquifers in the study area.

The playa sediments underlying Bristol, Cadiz and Danby dry lakes consist of brine-saturated clay, silt, fine-grained sand and evaporite deposits. The clastic sediments were deposited when stream flow and sheet flow from the surrounding alluvial fans spread onto the playas during major storm events (Gale 1951). The evaporite deposits formed from evaporation of both surface water and groundwater, which seeps into the playa sediments from the adjacent alluvial fans (Rosen 1989).

Bristol, Cadiz and Danby dry lakes have static groundwater levels at or near the playa surfaces (Moyle 1967; Rosen 1989). Sodium chloride and/or calcium chloride are currently being recovered from trenches and brine wells on all three of these playas. Thompson (1929), Gale (1951), Bassett et. al., (1959), Handford (1982) and Rosen (1989) concur that the principal recharge to the playas occurs as diffuse seepage of groundwater onto the playas from the adjacent alluvial fans.

Cadiz and Bristol dry lakes are locally bordered by active dunes formed by fine to medium-grained windblown sand. These Holocene deposits overlie older playa deposits of differentiated Quaternary age (Moyle 1967).

Amboy Crater, located near the western margin of Bristol Dry Lake, is a basaltic cinder cone and lave field believed to be as young as 6,000 years (Parker 1963; Hazlett 1992).

Structural Geology

The larger area of study is located at the eastern margin of the “eastern California shear zone” a broad seismically active region dominated by northwest trending right-lateral strike-slip faulting (Dokka and Travis 1990). Roughly a dozen fault zones showing evidence of Quaternary movement (during the last 1.6 million years) have been identified in and adjacent to Bristol, Cadiz and Fenner valleys (Howard & Miller 1992).

Cadiz Valley is underlain by two major northwest trending faults, inferred on the basis of gravity and magnetic data (Simpson et. al., 1984). These fault zones have strike lengths of at least 25 miles, and may merge to the north and northwest with extensions of the Bristol-Granite Mountains and South Bristol Mountains fault zones (Howard & Miller 1992; Metropolitan 2001).

Right-lateral slip along the Cadiz Valley fault zone of as much as 16 miles has been postulated on the basis of correlation of a distinctive Precambrian gneiss unit across the zone (Howard & Miller 1992). Slickenside surfaces, produced by fault movement, and steeply dipping sediments recovered from cored frill holes beneath Cadiz Dry Lake, suggest that the fault zone displaces sediments of Pleistocene age (Bassett et. al., 1959).

Bristol Dry Lake is bordered by probable extensions of the Cadiz Valley and South Bristol Mountains fault zones to the east, and by probable extensions of the Broadwell Lake and Dry Lake fault zones to the west (Howard & Miller 1992). Geophysical data indicate this structural depression may exceed 6,000 feet in depth (Simpson et. al., 1984; Maas 1994). Drill cores recovered from depths of over 1,000 feet beneath Bristol Dry Lake suggest that subsidence of this basin began by Pliocene time and continues to the present (Rosen 1989), and therefore may be tectonically active.

Fenner Gap appears to be a structural half-graben, formed by a system of northeast trending, northwest dipping normal faults, some of which are exposed in outcrops of the bedrock that flank the gap. The presence of these northeast trending faults beneath the alluvial deposits that underlay the gap can be inferred from surface geology mapping, gravity surveys, a seismic reflection survey conducted across the gap by NORCAL Geophysical Consultants, Inc. (1997), and recent test wells drilled as a part of the this current study.

Kinney (2011) conducted an extensive geologic investigation of the Fenner Gap. The structure of the Gap is dominated by Jurassic intrusions and Miocene extension. Jurassic intrusives caused major folding of Paleozoic sediments, with uplifting resulting in substantial erosion of these older rocks. Miocene extension resulted in a series of north-south striking upper plate listric normal faults through the Gap, which are believed to be associated with a deeper detachment fault. Those upper plate rocks along these normal faults and the detachment fault are highly fractured and are expected to be very transmissive.

Hydrogeology

The primary sources of replenishment to the groundwater system in the project area include direct infiltration of precipitation (both rainfall and snowfall) in fractured bedrock exposed in mountainous terrain and infiltration of ephemeral stream flow in sand-bottomed washes, particularly in the higher elevations of the watershed. The source of much of the groundwater recharge within the regional watershed occurs in the higher elevations (Metropolitan 2001; USGS 2000, Davisson and Rose, 2000).

Precipitation infiltrates and moves downward to the water table. In some cases, the infiltrating water may be diverted to the land surface or groundwater may intersect land surface creating a spring prior to seeping downward through the unsaturated soil and rock, where it ultimately reaches the regional groundwater system and continues to flow downgradient through principal aquifer systems.

Groundwater occurrence in fractured bedrock of the watershed-perimeter mountains has been known since before the turn of the twentieth century (Mendenhall, 1909). The USGS documented the occurrence of wells and springs (see discussion above) throughout Southeastern California and Southwestern Nevada for the benefit of travelers and prospectors (Mendenhall, 1909). The USGS documented at least ten wells and springs in the mountains and hills around the Fenner Watershed and a number of wells drilled into the alluvium by the Santa Fe Railroad. Another USGS study by Thompson (1929) provided additional information on more wells and springs in the study area in order to survey, mark and provide protection of watering places. Additional wells and springs were identified in the area of study and described by Thompson (1929). A more recent USGS survey of wells and springs in the area of study was conducted by Freiwald (1984). These studies provide evidence of the fractured nature of the surrounding bedrock and the continuous infiltration of precipitation and movement of water through these perimeter rocks.

Although some precipitation is tapped by vegetation near the range fronts, the remainder joins the regional groundwater table and moves slowly downgradient through Fenner Valley and Orange Blossom Wash into the Bristol and Cadiz depressions, where it eventually discharges to Bristol and Cadiz dry lakes. Evaporation of groundwater and surface water from the dry lakes over the past several million years has resulted in thick deposits of salt (primarily calcium chloride and sodium chloride) and brine-saturated sediments (Rosen 1989).

Bristol, Cadiz, and Danby dry lakes have static groundwater levels at or near the playa surfaces (Moyle 1967; Rosen 1989). Sodium chloride and/or calcium chloride are currently being recovered from trenches and brine wells on all three of these playas. Thompson (1929), Gale (1951), Bassett et. al., (1959), Handford (1982), and Rosen (1989) concur that the principal source of groundwater recharge to the playas occurs as diffuse seepage of groundwater into the playa sediments from the adjacent alluvial fans.

The mountain ranges that define the boundaries of the regional watersheds are comprised predominantly of granitic and metamorphic basement rock, as described above. This less permeable basement complex forms the margins and bottoms of the aquifer systems (Freiwald 1984). More permeable carbonate bedrock of Paleozoic age occurs locally within the boundaries of these watersheds (see above discussion for general distribution).

Hydrogeologic Units

Based on available geologic, hydrologic, and geophysical data, the principal formations in the study area that can readily store and transmit groundwater ("aquifers") have been divided into three general units: an upper (younger) alluvial aquifer; a lower (older) alluvial aquifer; and a carbonate rock unit aquifer (principally carbonate units are aquifers, but the unit contains interbedded quartzite and shale). In addition, fractured bedrock units, especially along fault zones, are capable of readily transmitting water (as determined as a part of this Project).

The younger alluvial aquifer consists of Quaternary and late-Tertiary alluvial sediments, including stream-deposited sand and gravel with lesser amounts of silt (Moyle 1967; GSSI

1999). The thickness of the upper alluvial sediments ranges to approximately 1,000 feet (GSSI, 1999, and field investigations as a part of recent investigations for the Cadiz Project). The lower alluvial aquifer consists of older sediments, including interbedded sand, gravel, silt, and clay of mid- to late-Tertiary age. Where these materials extend below the water table, they yield water freely to wells but generally may be less permeable than the upper aquifer sediments (Moyle 1967; GSSI 1999, and field investigations as a part of recent investigations for the Cadiz Project). Production well PW-1, located in Fenner Gap, draws water primarily from the upper and lower aquifers and yields 3,000 gallons per minute with less than 20 feet of drawdown (GSSI 1999). The Cadiz Inc. agricultural wells draw water from the alluvial aquifers and typically yield 1,000 to more than 2,000 gallons per minute.

Based on findings from recent drilling in Fenner Gap, carbonate bedrock of Paleozoic age, located beneath the alluvial aquifers, contains groundwater and is considered a significant aquifer (GSSI 1999 and field investigations as a part of recent investigations for the Cadiz Project). Groundwater movement and storage in this carbonate bedrock aquifer primarily occurs in secondary porosity features (i.e. joints, faults, and dissolution cavities that have developed over time). The full extent, potential yield, and storage capacity of this carbonate aquifer have not been quantified at this time.

As noted above, granite and metamorphic basement rock form the subsurface margins of the aquifer system. This basement rock is generally less permeable and typically yields smaller quantities of water to wells (Freiwald, 1984) but is more permeable where fractured, especially along fault zones (as determined as a part of this Project).

Groundwater Movement

In general, groundwater within the watersheds flows in the same direction as the slope of the land surface. In the Fenner Valley, groundwater generally flows southward and discharges through Fenner Gap toward Bristol and Cadiz dry lakes.

Figure 9 presents a generalized contour map of groundwater elevations and horizontal flow directions in the alluvial aquifer in the area of study. The contours in this figure are based on water levels from the alluvial aquifers and calibration of a three-dimensional groundwater flow model to those water levels (as a part of this Project). There is no available information that indicates that the alluvial aquifer west of Clipper Mountains is saturated and it is reasonably expected to be unsaturated as the alluvium is projected to thin over bedrock highs.

Projected Impacts to Springs Due to Proposed Cadiz Project Operations

The Cadiz Groundwater Conservation Recovery and Storage Project includes extraction of an average of 50,000 acre-feet per year of groundwater over 50 years from a proposed wellfield in the Fenner Gap area. GSSI (2011) developed a three-dimensional groundwater flow and solute transport model of the Fenner, Bristol and Cadiz watershed areas to simulate the operation of the proposed wellfield and its effects on groundwater levels and the freshwater/saltwater interface near the dry lakes. GSSI simulated three recharge scenarios, including 5,000 AFY, 16,000 AFY, and 32,000 AFY to assess effects on groundwater levels and the freshwater/saltwater interface near the dry lakes. The 32,000 AFY recharge scenario is based on INFIL3.0 modeling of the soil-moisture water budget for the Fenner and Orange Blossom Wash watershed areas. GSSI (2011) simulated this large range in long-term average annual recharge by reducing the projected recharge by 50 percent (16,000 AFY) and then to an amount that is generally equivalent to Cadiz historical agricultural pumping (5,000 AFY) in order increase the conservatism of the analysis (identify potential worst-case impacts).

GSSI (2011) simulated two wellfield configurations as shown in Figures 4 and 5 of Attachment A. These wellfield configurations allow for, 1) installation of two large-capacity wells in the karstic carbonate units encountered in the Fenner Gap area, which results in a more tightly clustered wellfield in the Fenner Gap area and, 2) a more dispersed wellfield with pumping more evenly distributed among the wells.

Figures 10 through 15 of Attachment A show groundwater-level drawdown for those various recharge scenarios simulated, both at the end of 50 years of pumping and then for 50 years since cessation of pumping (for a total of simulated period of 100 years). The following observations are made from these simulations:

- Drawdown in regional groundwater levels does not extend to the uppermost reaches of the watershed – in general, the drawdown is negligible at Interstate 40 under all scenarios.
- The extent of drawdown is greater for the higher recharge scenarios, which is expected as the average hydraulic conductivity of hydrogeologic units needs to be higher in order to transmit higher rates of recharge through the groundwater flow system. A higher hydraulic conductivity results in a “spreading out” of the cone of depression from the wellfield. For decreases in recharge, the average hydraulic conductivity of hydrogeologic units needs to be lower in order to transmit lower rates of recharge and maintain the observed regional hydraulic gradients. A lower hydraulic conductivity results in a more “focused” cone of depression centered around the wellfield, with greater drawdown locally and less drawdown further from the center of pumping compared to the higher hydraulic conductivity case.

GSSI extended the groundwater flow simulations for 450 years beyond the operation of the wellfield (for a total simulation period of 500 years) in order to assess the equilibration of the groundwater system after pumping ceases. Figures 10 and 11 show hydrographs for two locations in the alluvial aquifer in Fenner Valley: at Interstate 40 (I-40) and approximately at Danby. In general, the drawdown effects from pumping in the higher recharge scenarios reach their maximum drawdown earlier and tend to recover quicker than in the lower recharge scenarios. Figure 10 shows that groundwater levels at I-40 never drop more than 8 feet for the recharge scenario of 32,000 AFY per year and even less for lower recharge-rate scenarios. These effects are even more attenuated with distance upgradient toward the mountain ridges and at transitions in geologic media, such as from alluvium to lower permeability bedrock units (as further shown below). Figure 11 shows similar responses as Figure 10, except drawdown is greater and recovery begins sooner after cessation of pumping compared to alluvial groundwater levels up gradient. Based on these simulations, the potential for impacts of the Cadiz Project pumping on any springs north of Interstate 40 are extremely remote.

The potential for impacts on springs south of Interstate 40 is also very remote because either, 1) there is no observed and likely direct physical hydraulic connection of these spring to the regional groundwater levels in the alluvium and/or, 2) even if there were a hydraulic connection, any changes in gradients between groundwater in the alluvial aquifer and springs due to the Project is unlikely to create fluctuations in groundwater levels at the springs that exceed natural fluctuations due to natural climatic variations as described below.

The closest spring to proposed extraction wellfield in Fenner Gap is the Bonanza Spring in Clipper Mountains. This spring is located at an altitude of 2100 feet above NGVD. Groundwater modeling by GSSI (2011) shows that groundwater-level declines in the alluvial aquifer, although not significant, would be greatest near this spring of all the identified springs south of Interstate 40. Accordingly, to address any remaining doubts, we also analyzed whether the Project would have an impact even assuming for purposes of this analysis that there is hydraulic continuity. If any impacts were to occur as a result of the project, then the Bonanza Spring would be impacted first given it is the closest. Therefore, the remainder of this assessment is focused on the Bonanza Spring and whether any impact would be material under an assumed hydraulic continuity scenario.

Conceptual Models

There are two conceptual models of the Bonanza Spring, which are expected to apply to all the springs in the Fenner Watershed. Each is summarized below. In both cases, the source of water to the springs is precipitation in the mountains that infiltrates into the ground and travels to the springs. There is no information that suggests that these springs are a result of any other source of water, such as deeply circulating groundwater, confined groundwater, or other similar mechanisms attributable to spring formation.

Concept 1: Disconnected from A Deep Regional Water Table

Concept 1 is based on observations of available data on groundwater levels in wells, geology, and observations of characteristics of identified springs. Figure 12 is a surficial geologic map of the Clipper Mountains and surrounding area based on the Preliminary Surficial Geologic Map Database of the Amboy 30x60 Minute Quadrangle, California (Bedford et. al., 2006). Many of those springs that have been observed in the lower Fenner Watershed area and reported by the Freiwald (1984) are shown on this map. Attachment B includes the Bedford et. al., (2006) Amboy 30x60 Minute Quadrangle map, which provides the explanation of geologic symbols used in Figure 12. The Bonanza Spring is located in granitic rocks, near the contact with partially consolidated sediments. Cross sections E-E′ (northwest to southeast) and F-F′ (southwest to northeast) are taken through the Clipper Mountains and shown in Figures 13 and 14, respectively. The water table in the alluvial aquifer adjacent to Clipper Mountains is shown as a solid line, based on groundwater level measurements and steady-state groundwater flow model calibrations. Concept-1, as shown in Figures 13a and 14a assumes that the water table is connected through the Clipper Mountains, with little influence (i.e., limited mounding) from recharge that occurs over these mountains and that groundwater flow through fractures in the rock feed these springs, and that this fracture flow occurs entirely above the regional water table. In other words, the fractures are poorly connected with one another, and the flow to the springs represents an isolated flow path that is independent of subsurface flow at elevations lower than the spring.

Concept 2: Connected to A Regional Water Table

Although there is no available information that demonstrates hydraulic continuity of groundwater at the springs with the regional groundwater table, Concept-2 assumes that fractures in the bedrock are sufficiently interconnected to form an "equivalent porous medium." In this case, there would be a relatively uniformly sloping water table below the Clipper Mountains, from the peak to the contact with the alluvial aquifer as shown in Figures 13b and 14b and Plate 1. Subsurface flow would be driven by the hydraulic gradient based on the water table, and the equivalent "bulk" hydraulic conductivity of the bedrock fractures. In this concept, the low elevation area of Bonanza Spring (and other springs in the area) intersects the water table, and the flow to the springs is driven by the water table. Accordingly, under Concept-2, if one assumes hydraulic continuity between the springs and the regional groundwater table through fractured porous medium, a decline in the water table could affect flow to the springs if the regional water table was lowered at the elevation of these springs. Concept 2 considers whether a potential impact is material even where it is assumed that there is hydraulic continuity.

Evaluation of Potential Impacts and Timing

This section evaluates potential impacts to springs as a result of the Project. Potential impacts are summarized for each of the two conceptual models.

Potential Impacts, Concept 1

Under this concept, the spring is fed by upstream fracture flows that are not hydraulically connected to the water table. Accordingly, the flow rates at the spring are independent of groundwater levels in the alluvium, and no impacts would occur to the spring as a result of project operations. In this concept, the springs get their water supply first and any remaining water continues to the underlying regional groundwater system (note that water supplied to the spring may re-infiltrate downstream and continue to percolate to the regional groundwater system as well).

Potential Impacts, Concept 2

A simple numerical model was developed to evaluate potential impacts under Concept-2, where hydraulic continuity is assumed, in which the regional water table forms the source of water to the springs. The model is a simple representation of a generic mountain system with similar characteristics to the Clipper Mountains, intended to evaluate the general response of a water table in fractured bedrock of mountains under various assumptions that are specific to the Bonanza Spring hydrogeologic conditions.

Model Setup

The groundwater flow model consists of one layer, two rows, and 100 columns. It is designed to simulate groundwater flow through continuous fractured bedrock from a mountain ridge to alluvium at the base of a mountain, as may be the case for Clipper Mountains. Column width was set to 250 feet for all columns, for a total of 25,000 feet from the simulated mountain ridge to the alluvium at the base. This is roughly the distance from the ridge of the Clipper Mountains southeast to the extent of the alluvium simulated in the groundwater model. Rows were specified to be 5,000 feet wide each.

Recharge was applied to the first 40 cells (a distance of 10,000 feet), which approximately represents the area between the mountain ridge and the surficial contact between bedrock outcrops and (unsaturated) alluvium in the area of Bonanza Spring in the Clipper Mountains. Recharge was applied at a rate of 0.00033 feet per day, or a total of 280 acre-feet per year (AFY), which would be the equivalent of 1,400 AFY across the length of the Clipper Mountains. This recharge rate is about half of the total recharge estimated from the INFIL3.0 model of 2,800 AFY in the Clipper Mountains, with the assumption that half of this recharge would flow northwest and half would flow southeast. The "sides" of the model, as well as the upgradient boundary, were specified as no-flow, which effectively represent flow lines. The downgradient boundary condition was a constant head set at 1,100 feet elevation, which is approximately the water table elevation in the alluvium in the Fenner Watershed (see Figure 12).

The model layer was simulated as unconfined, allowing for a water table surface to be simulated. The bottom elevation was set at 500 feet at the upgradient end of the model and -900 feet at the downgradient end of the model, with a uniform linear slope between the two ends. Bottom elevations were specified such that the saturated thickness is about 2,000 feet.

Simulated hydraulic conductivity values were adjusted until a reasonable representation of a potential water table was achieved; that is, produced the same hydraulic gradient as between the Bonanza Spring and water table in the adjacent alluvium. The hydraulic conductivity value used was 0.025 ft/day, which yielded a water table elevation at the upgradient end of the model of about 2,375 feet. This gradient is consistent with one that would result in the Bonanza Spring being in contact with the water table, at an elevation of 2,100 feet.

For transient simulations described below, a specific yield value was assumed to be two percent.

Model Results

Water Table Response to Drawdown In The Alluvial Aquifer

The model was used to simulate response of a bedrock water table to a 10-foot head decline in the downgradient alluvium (as simulated by GSSI (2011)[1]). This was accomplished by using a transient model with a constant head value in the alluvium set at 1,090 feet, and comparing change in groundwater levels to the simulated groundwater levels equilibrated to a constant head value in the alluvial aquifer of 1,100 feet. This simulation assumed that recharge to the water table is steady and does not change year to year.

Simulated water table elevations in the bedrock at select times are presented in Figure 15. It can be seen that there is little change in the water table elevation relative to the overall slope of the water table from the mountain ridge to the alluvial aquifer. However, a plot of

[1] GSSI presented groundwater modeling results in a draft technical memorandum dated June 16, 2011. The groundwater flow model simulations continue to be refined; however, the results of these refinements are not expected to differ materially from the initial results presented in the draft memorandum. Should the final groundwater flow model results differ from those used in this assessment of impacts to springs, then this memorandum will be updated to reflect those updated results.

simulated drawdown (Figure 16) suggests that bedrock groundwater levels could decline by about 5 to 10 feet in response to a 10-foot decline in alluvium groundwater levels. The timing of the response, however, is relatively slow. At the location of the spring (about 10,000 to 15,000 feet from the ridge), the model suggests there would be a fraction of a foot of water level decline after 10 years (note that this is 10 years after the groundwater in the alluvial aquifer declined to 10 feet), about three feet of decline after 50 years, and sometime after 500 years it would reach a new equilibrium state about six to seven feet lower than the current equilibrium state. As shown in Figure 11, groundwater levels in the alluvial aquifer are expected to recover over this long period, so impacts upgradient toward the spring will be significantly less than shown in Figure 16, which assumes that a 10-foot decline is maintained indefinitely.

A second model run was performed assuming an indefinite 30-foot decline in groundwater levels in the alluvial aquifer in response to pumping. The intent of this run was to evaluate how the magnitude of drawdown in the alluvial aquifer may affect the magnitude of water-table decline in the bedrock. Model simulation results suggest that the magnitude of water-table decline is about three times that of the 10-foot drawdown scenario, and the spatial distribution and timing of the decline is about the same. Accordingly, these simulation results can be scaled to any other amount of potential drawdown in the alluvial aquifer.

Figure 15: Change in water table elevation in response to a ten foot decline in water levels in adjacent alluvium

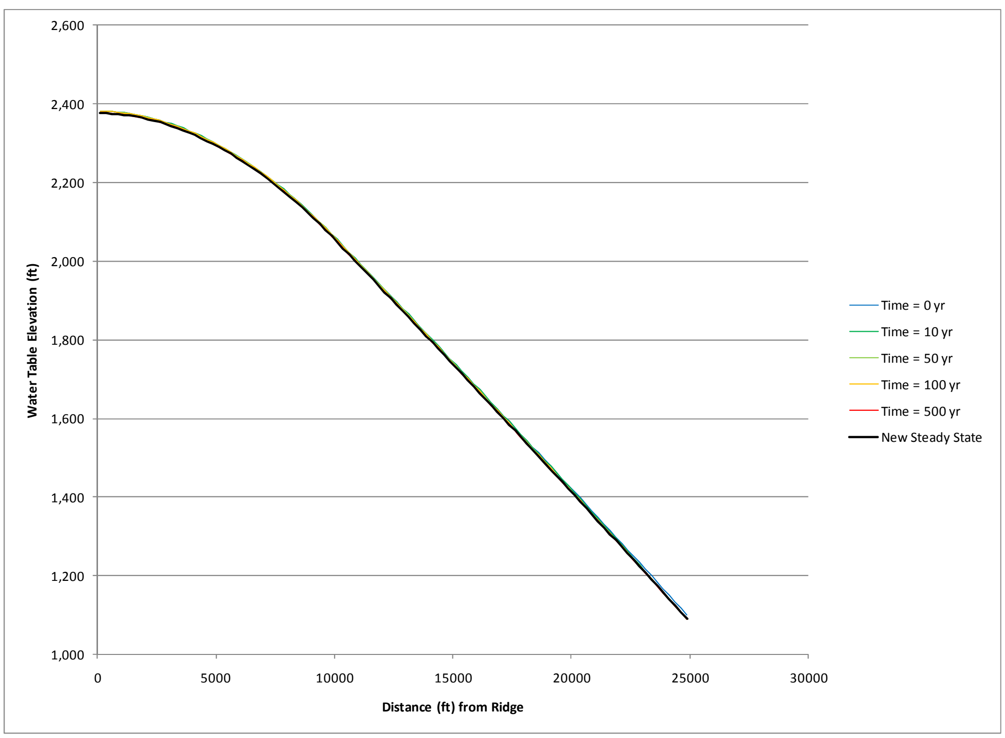
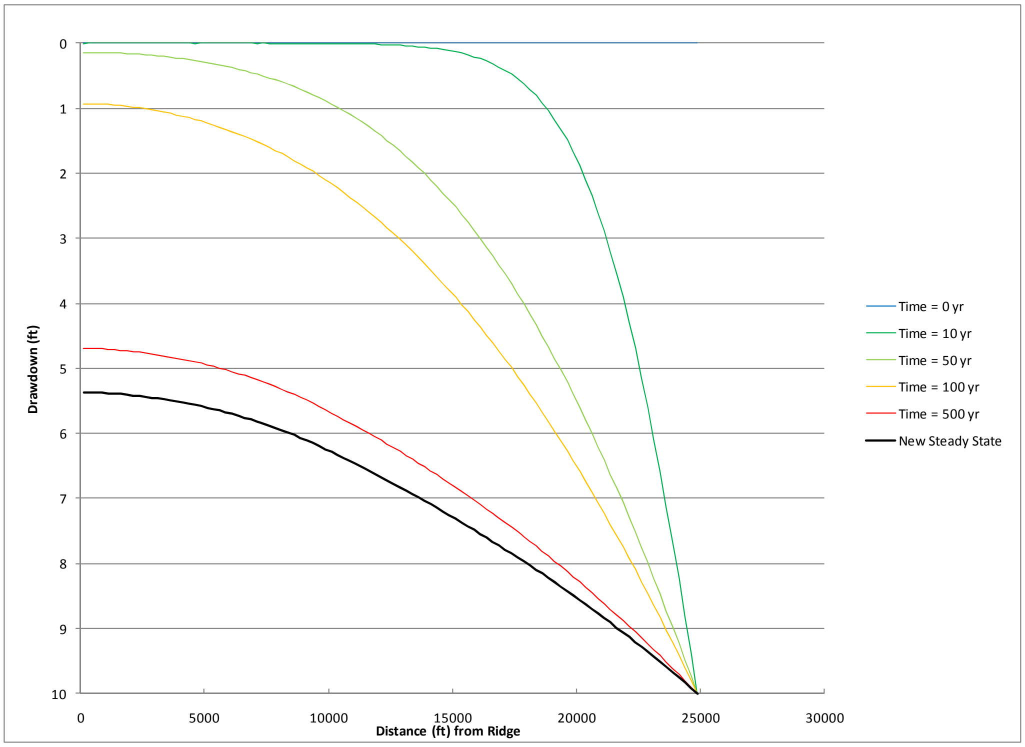


Figure 16: Drawdown in response to a ten foot decline in water levels in the alluvium

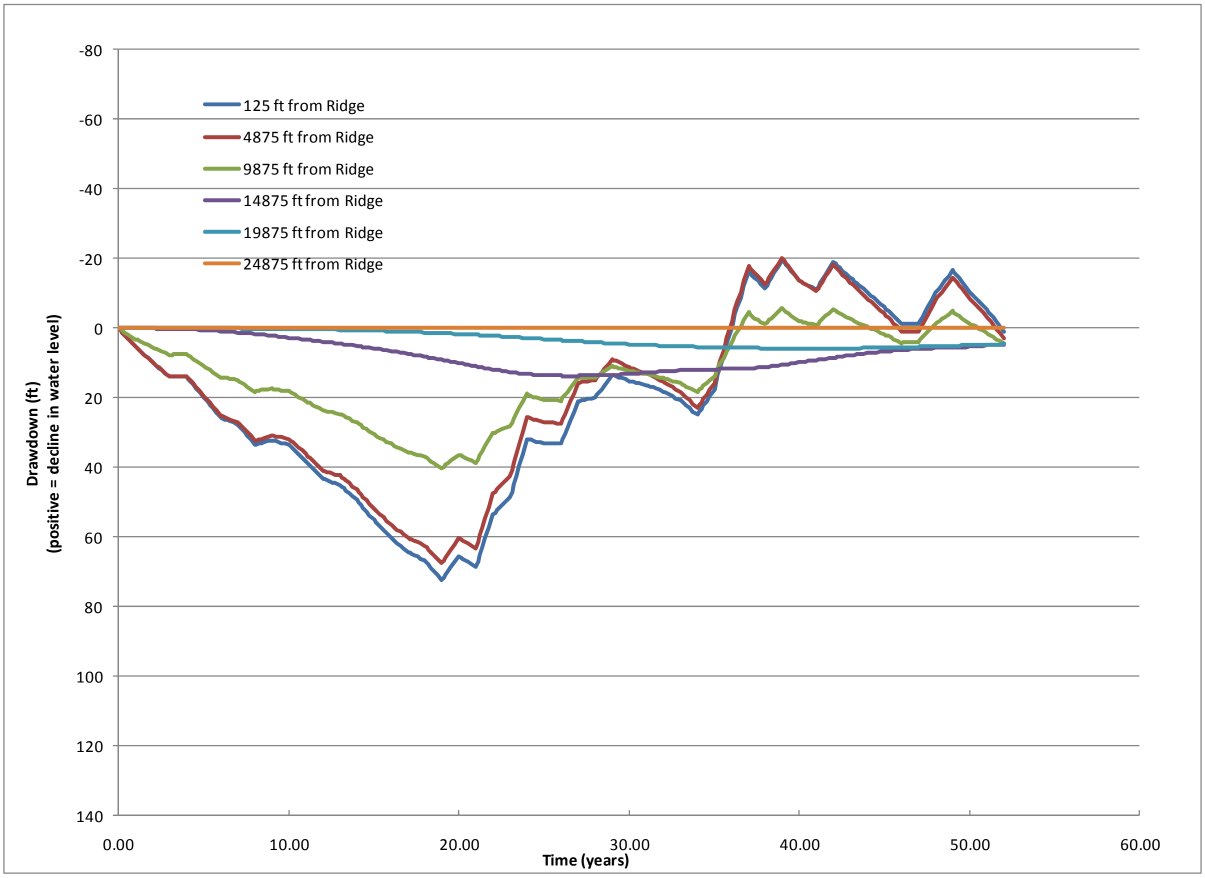


Response to Transient Recharge

A separate simulation was performed to evaluate changes in groundwater levels in the bedrock in response to transient recharge. In this case, a 50-year simulation was run in which recharge varied in proportion to the total estimated recharge based on the INFIL3.0 model for the Fenner Watershed. The minimum annual recharge rate was about one percent of the long-term average, and the maximum was nearly 400 percent of the long-term average (so from one percent to 400 percent of 250 AFY, varying annually based on INFIL3.0 percentages relatively to the long-term average in this watershed).

A plot of simulated drawdown (Figure 17) suggests that groundwater levels near the spring could fluctuate by as much as about 15 to 40 feet in response to climatic variations alone. It should be noted, however, that this is an "end-member" simulation, assuming the annual changes in recharge are applied to the water table in that same year. In reality, the percolating water would take some time to reach the water table, and the effect of year-to-year changes in percolation would likely be much more muted at the water table.

Figure 17: Drawdown in response to transient recharge



Sensitivity to Extent of Recharge

The above simulations assumed that recharge occurs at a uniform rate between the mountain ridge and a point 10,000 feet from the ridge. The effect of this assumption was evaluated by running the same simulations but changing the extent of recharge to the first 5,000 feet from the ridge. In this case, the recharge *rate* was doubled, but applied to half the area, so the resultant volume of recharge remains the same.

Results of the simulation of a 10-foot decline in alluvium water levels are presented in Figure 18. These results suggest that the recharge location has little effect on drawdown magnitude and timing in response to a decline in water levels in the alluvium.

Results of the transient simulation are presented in Figure 19. If recharge only occurred in the first 5,000 feet, model results suggest that groundwater level fluctuations at the upgradient end of the model would be nearly double the fluctuations if recharge occurred in the first 10,000 feet. However, near the spring, water table fluctuations would actually be less, on the order of 10 to 25 feet, so the impacts would vary depending on the location of the spring along the slope and actual recharge along the slope.

Figure 18: Drawdown in response to a ten foot decline in water levels in the alluvium, sensitivity case (recharge first 5,000 ft)

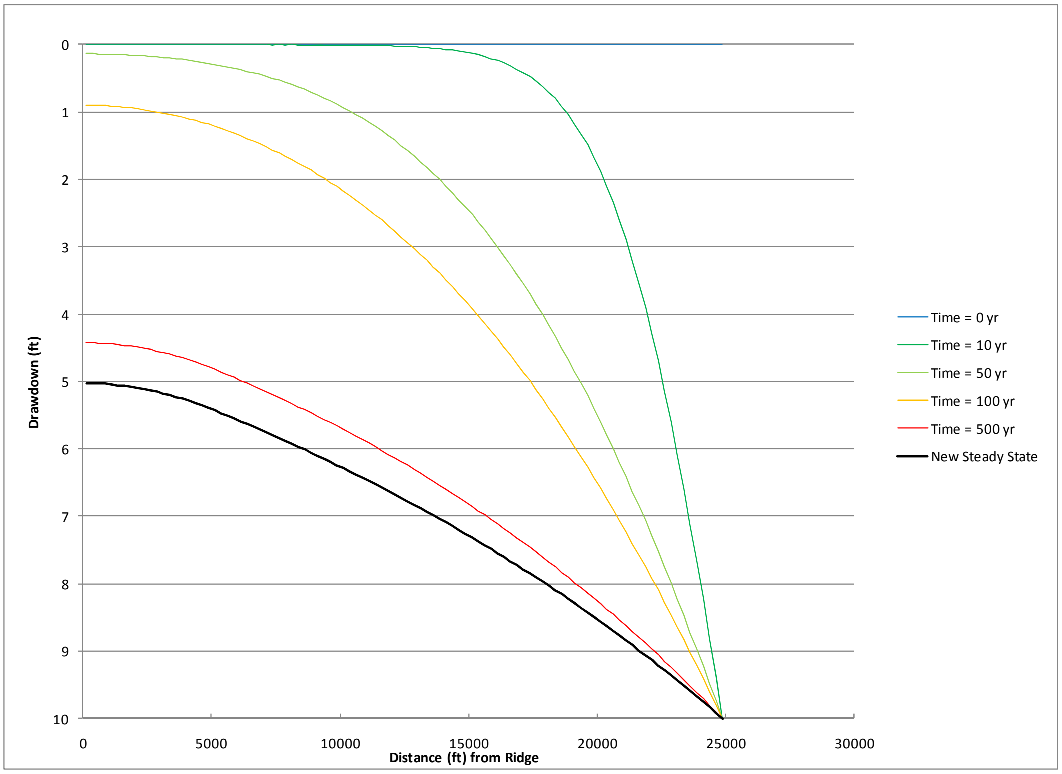
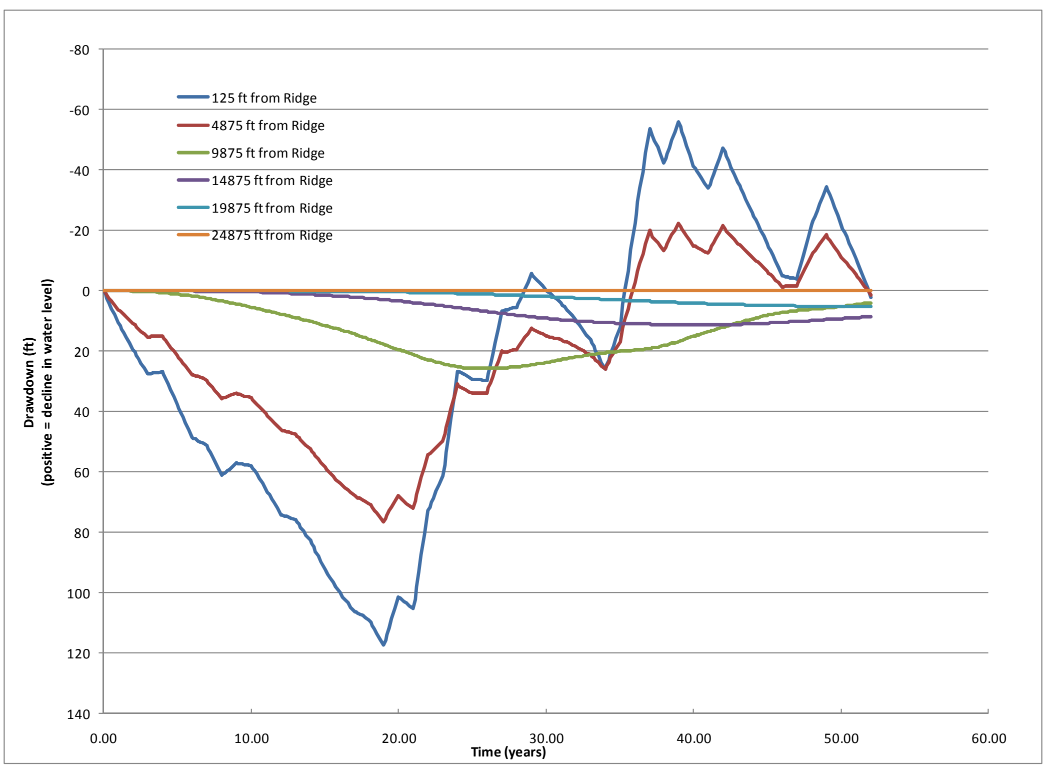


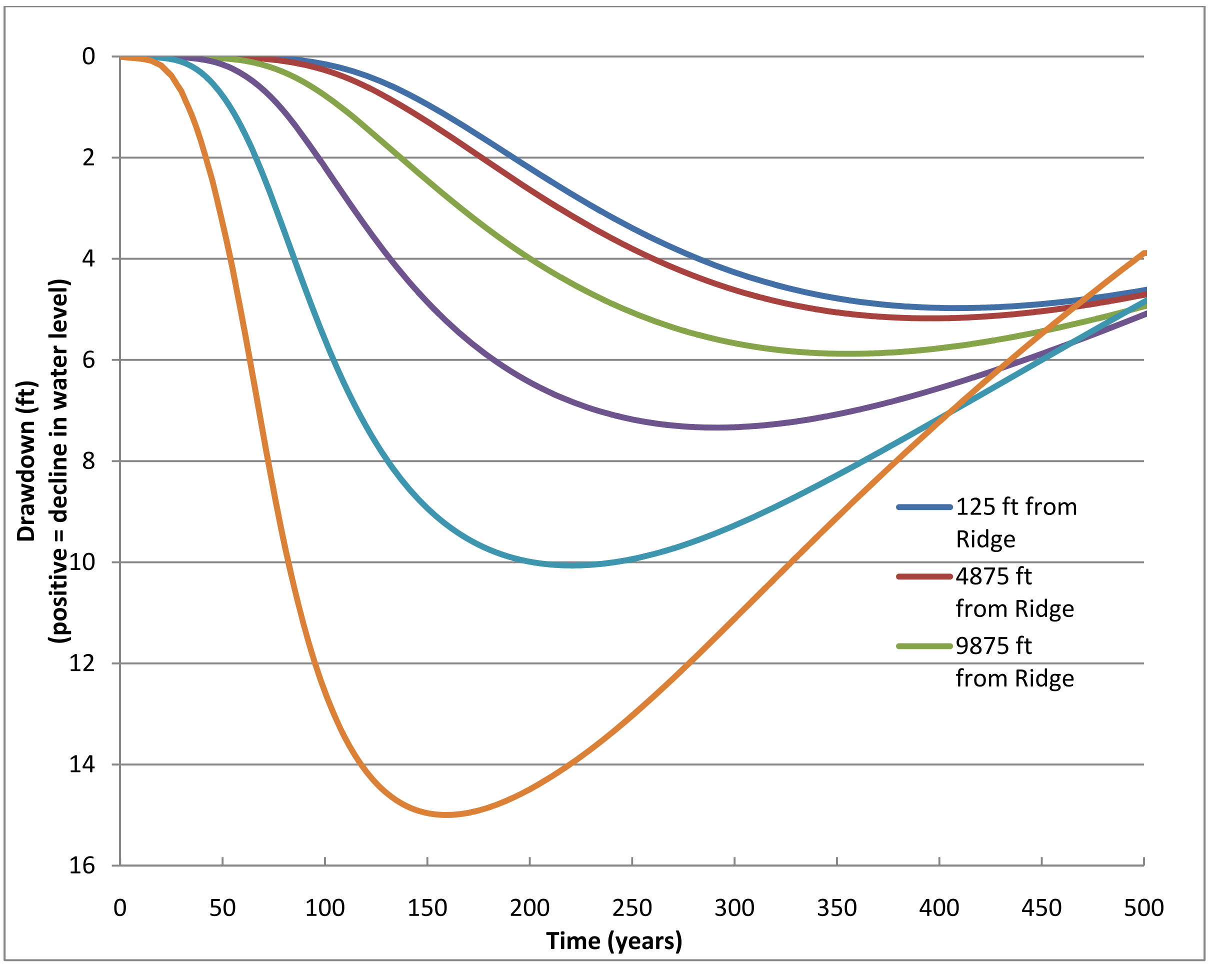
Figure 19: Drawdown in response to transient recharge, sensitivity case (recharge first 5,000 ft)



Sensitivity to Time-Varying Drawdown and Recovery in the Alluvial Aquifer

A separate model simulation was made to assess the effect of drawdown and recovery of groundwater levels in the alluvial aquifer on the water-table decline in the bedrock. As shown in Figures 10 and 11, groundwater levels in the alluvial aquifer equilibrate to changing conditions: first declining in response to pumping, then recovering followed by cessation of pumping. Figure 20 shows the response of groundwater levels in the bedrock as a result of declining then recovering groundwater levels in the alluvial aquifer for the 5,000 AFY recharge case, where the groundwater levels in the alluvial aquifer drawdown to 15 feet at the maximum and then recover after cessation of pumping. This simulation result demonstrates that the decline in the water table in the bedrock is arrested and never reaches the full extent of decline that would develop under a steady state condition, where groundwater levels in the alluvial aquifer are not assumed to recover. So, this simulation suggests that any potential impacts on the spring will be less than presented in the above simulation as a result of the recovery of groundwater levels in the alluvial aquifer.

Figure 20: Groundwater level responses in the bedrock due to drawdown and recovery in the alluvial aquifer (using the 5K AFY recharge scenario)



Summary and Discussion

There is no information demonstrating a physical connection of the springs to a regional groundwater table. If the springs are not connected to the regional water table, as illustrated in Concept-1, then no impacts to the springs are expected in response to the proposed project pumping operations.

Although there is no information that demonstrates a direct hydraulic connection between the springs and a regional groundwater table, Concept 2 assumes such as connection exists. Groundwater model results suggest that a bulk hydraulic conductivity of about 0.025 feet per day over a saturated thickness of 2,000 feet would be required to support a “mound” of groundwater below the Clipper Mountains such that the Bonanza Spring would be in contact with the regional water table (Concept-2).

Model results suggest that a ten foot decline in groundwater levels could result in about six to seven feet of drawdown at the springs after hundreds of years and assuming that the decline in the adjacent alluvial aquifer was maintained at ten feet of drawdown. For example, in the above simulations, after about 100 years, the drawdown would only be about 25 percent of the potential maximum drawdown in the alluvial aquifer. In addition, it is possible that, depending on how muted the water table response is to annual changes in precipitation, natural fluctuations of groundwater levels at the spring due to climate variability could be of a similar order of magnitude to potential project-induced drawdown at the springs. Such an impact is not considered to be material.

Under Concept 2, potential impacts to other springs in the southern part of Fenner Watershed are expected to be de minimus and even more remote than those potential impacts on the Bonanza Spring. Figures 21 through 23 show cross sections extending from the alluvial aquifer to Fenner, Barrel, and Honeymoon Springs, respectively. Plate 1 shows 1:1 (vertical to horizontal scales) cross sections for Barrel and Honeymoon Springs. These springs are at higher elevations and greater distances from the adjacent alluvial aquifer compared to Bonanza Spring. Groundwater-level drawdown in the alluvial aquifer is expected to be less in those areas adjacent to these springs compared to Bonanza Springs. Therefore, the impact to these springs is expected to be insignificant based on the assessment of the Bonanza Spring.

Potential Mitigation

The above analysis suggests that if there is no hydraulic connection between the springs and the regional groundwater table, there will be no impact on springs from the Project. If there is a hydraulic connection, the Project is not likely to have an impact, and if it does any impact would not be significant. It is anticipated that any effect on the water table would be small and it would take a long time for the spring to be affected such that recovery of groundwater levels may not have any effect whatsoever on the water table at the springs, and the effect may be subsumed with natural climatic background fluctuations in water table elevations in the bedrock. However, should the flow to the spring be affected, a mitigation measure could be to replace the flow to the spring by drilling a free-flowing well in the bedrock, which appears to be the origin of some springs in the area as described by the USGS’ earlier studies in the area. Based on the estimated bedrock water table gradient of about 0.07 (ft/ft), a horizontal well would only need to be drilled laterally into the bedrock a distance of about 150 feet to reach a point where the water table is 10 feet higher than it is at the spring. A well of about this "depth" should yield flow to the spring that would be similar to current pre-project flows. It would not be difficult to initiate such a measure, although it would be decades, if not centuries, before this would ever be required under the most conservative analysis.

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