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To: Geoff Poole, General Manager, Borrego Water District; and
Chris Martinez, Engineering Geologist, California Department of Water Resources, Proposition 68 Sustainable Groundwater Management Grant Program

From: Travis Huxman, Chair, Department of Ecology and Evolutionary Biology, University of California, Irvine

Subject: Technical Memorandum reviewing technical assumptions and assertions regarding groundwater dependent ecosystems underlying aspects of the Borrego Subbasin Groundwater Management Plan.

We are pleased to provide the attached Technical Memorandum, "Review of Technical Work That Supported Groundwater Dependent Ecosystems (GDE) Conclusions in the Borrego Subbasin Groundwater Management Plan." This is in satisfaction of Task 1(a) in our proposal and Work Plan and provides a foundation for our projects goal of determining potential GDE presence, activity, and extend within the Borrego Subbasin.

We have passed drafts of this document through three iterations of scientific and editorial review. We have provided drafts to stakeholders in the Borrego Springs area for feedback on our analysis, conclusions, and implications. We are confident in the inference provided on the issue, the conclusions concerning data gaps and needs, along with the methods we employed in our analysis. However, our effort focused on knowledge gaps, and we expect further information to come to light, from our project, from you, and from other vested sources within the basin, that will shape the planning and progress of the rest of our work on the project.

We look forward to your comments, questions, and posting of this document on your website.

Review of Technical Work That Supported Groundwater Dependent Ecosystems (GDE) Conclusions in the Borrego Subbasin Groundwater Management Plan

Technical Memorandum of 2023/03/02

Product of the *Groundwater Dependent Ecosystems (GDE) Identification, Assessment, and Monitoring Program* (hereafter 'the GDE Project')

This Technical Memorandum is provided to the Borrego Water District and California Department of Water Resources as the deliverable for Task 1a of the GDE Project Workplan, to "Review the technical work that supported the opinions/assertions regarding Subbasin GDEs in the GMP (Groundwater Management Plan) and delineate the data gaps in the GMP."

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Notes to Readers

1. Work reported in this document was supported by the Budget Act of 2021 Sustainable Groundwater Management (SGM) Grant Program SGM Act (SGMA) Implementation – Round 1, managed by the California Department of Water Resources (DWR), administered by the Borrego Water District (BWD), in response to the proposal by Robert Staehle, David Garmon, Travis Huxman, Jon Rebman, and Mark Jorgensen, "Groundwater Dependent Ecosystems (GDE) Identification, Assessment and Monitoring Program," Project Information Submittal Form, submitted to Borrego Water District for the California Department of Water Resources, 2022 February 13. This work was led and performed by researchers at the University of California Irvine (UCI).

2. Most length and depth measurements in the scientific literature are reported in metric units, usually meters. In this report, where appropriate, we have made the conversions into feet (3.28 ft = 1 m) for reader. Significant figures in these converted quantities is not intended to imply a precision or accuracy beyond than reported in original measurements.

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TECHNICAL MEMORANDUM

Executive Summary

We have performed a review of the technical work supporting conclusions in the Borrego Springs Subbasin Groundwater Management Plan (GMP) (Borrego Water District and County of San Diego, 2020) to illuminate knowledge gaps and data needs. We have found three important discrepancies with information contained or cited within the GMP, or in its supporting Appendix D4 (Appendix D4, 2020). These findings call into question the confidence of the GMP's assertion that there is no longer significant nexus between groundwater and the mesquite bosque, referred to as GDE Unit 3. Specifically:

1. We identified data indicating deeper mesquite roots and shallower groundwater than suggested in the GMP. While the GMP cites a mesquite rooting depth of 15.3 feet (Appendix D4, 2020), we found evidence of roots down to 39.4 feet (Jenkins et al. 1988). Additionally, while the GMP states a groundwater depth of 55 feet below ground surface (bgs) near the Borrego Sink, we found evidence of possible groundwater depths ranging from 13 to 94 feet bgs across the Borrego Sink (West Yost, 2023). Hence, it is probable that there are mesquite still capable of accessing groundwater based on these rooting and groundwater depths.
2. The map used in Appendix D4 mistakenly excludes much of the area in the Subbasin covered by the mesquite bosque. The spatial extent of the mesquite bosque evaluated in Appendix D4 is based on a 1998 map of the vegetation of Anza-Borrego Desert State Park which excluded large swaths of mesquite bosque located on parcels of private and other non-State Park land in the Borrego Springs Community Planning Area[1] (Keeler-Wolf et al., 1998). Mapping from SanGIS (San Diego Geographic Information Source, 2022) estimates extant mesquite bosque as 2,800 acres, rather than the 13.2 acres reported by the GMP (Appendix D4, 2020).
3. Appendix D4's evaluation of mesquite health using remotely-sensed normalized difference vegetation index (NDVI) data was restricted to a small portion of the mesquite bosque in the Subbasin and used a coarse temporal analysis of trends in greenness that does not capture periods of likely groundwater use. Interpretation of NDVI data is frequently confounded by the multitude of responses of desert vegetation to changes in environmental conditions and requires higher resolution data and field validation to best interpret trends.

Together, these initial findings compel revisiting if the mesquite bosque is a beneficial user of groundwater in the Borrego Springs Subbasin through the collection of on-site data and more refined remote sensing analyses.

[1] Also known as the "Subregional Group Area of Borrego Springs" described in: Mark Wardlaw, Director, Planning & Development Services/County of San Diego, "Borrego Springs Community Plan," County of San Diego General Plan, Amendment GPA 12-007, June 18, 2014, see Document page 1, Figure 1 (.pdf page 5 of 108) as downloaded 9 December 2022 from: https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/CP/Borrego_Springs_CP.pdf

Introduction

The 2014 Sustainable Groundwater Management Act (SGMA) stipulates that all beneficial users of groundwater, including environmental users such as groundwater dependent ecosystems (GDE), be considered in Groundwater Sustainability Plans (GSP) (California Water Code, Part 274, Chapter 4, Section 10723.2). Under SGMA, GDEs are defined as "ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface" (California Code Regulations, Title 23, Section 351(m)). To assess the inclusion of GDEs in the Borrego Springs Subbasin GSP, Dudek, an environmental planning and engineering firm headquartered in Encinitas, California, USA, prepared a technical memorandum. This document, entitled "Draft Final Technical Memorandum," was finalized on 21 August 2019 and became Appendix D4: Borrego Springs Subbasin Groundwater Dependent Ecosystems of the Borrego Springs Subbasin GSP and later the Borrego Springs Subbasin Groundwater Management Plan (GMP; Borrego Water District and County of San Diego, 2020).

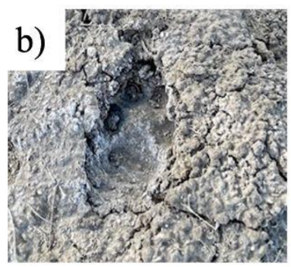
In this technical memorandum we review the findings of Appendix D4 and the methods and limitations of several data sources on which key conclusions of Appendix D4 rely. We also discuss data gaps that limit the conclusions that can be drawn from Appendix D4. It should be noted that Appendix D4 was completed with limited time and budget (T. Driscoll, personal communication, 12 December 2022) and this review of its conclusions aims to primarily to illuminate areas requiring further research to enhance decision making surrounding a collective environmental challenge for stakeholders of the region. We focus specifically on what the GMP refers to as "GDE Unit 3," the ecological complex surrounding the Borrego Sink, consisting in part of an extensive, natural mesquite bosque – a stand of mesquite trees (Box 1).

Box 1. Importance of the mesquite bosque.

Mesquite bosque near the end of Yaqui Pass Rd, Borrego Springs, California. June 10, 2019. Photo credit: Sicco Rood. https://www.calflora.org/entry/occdetail.html?seq_num=mg87728

Groves of mesquite trees, also referred to by the Spanish term "mesquite bosques," construct a biodiversity hotspot that sustains a unique collection of insect, reptile, bird, and mammal species in the drylands of the southwestern U.S. Mesquite bosques are an important element of the overall Anza-Borrego Desert ecosystem as their relatively small areal footprint supports a large fraction of the plant and animal species represented in the larger region.

Evidence of a diverse habitat



a) Lucy's Warbler found on 30 March 2014 in the mesquite bosque near the Borrego Sink. Credit: Justyn Stahl. https://www.calflora.org/entry/occdetail.html?seq_num=mg87728
b) Coyote track found in the mesquite bosque on 4 March 2022. Credit: Lori Paul.
c) A variety of owl pellets were found in the mesquite bosque on 4 March 2022. The contents and size of the various pellets suggest the following species: Great Horned Owl, Barn Owl, Long-eared Owl, and/or Western Burrowing Owl (a species classified by the California Depart of Fish and Wildlife as a Bird Species of Special Concern). Credit: Lori Paul.

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The GMP and Appendix D4

The cumulative assertion in Appendix D4 is that there is no longer a significant nexus between the mesquite bosque and Borrego Springs Subbasin groundwater, and therefore the mesquite bosque is not a GDE. Appendix D4's argument has three primary pillars: (1) a mismatch between the rooting depth of mesquite and the depth to groundwater; (2) the diminished spatial extent of the mesquite bosque through time; and, (3) remote sensing analyses of mesquite health to suggest a lack of relationship between groundwater elevation changes and mesquite. Understanding the data supporting such inference is important for identifying knowledge gaps and confidence in using such conclusions for decision-making.

1. Rooting depth of the mesquite and the depth to groundwater

Rooting depth

Appendix D4 asserts a mesquite rooting depth of 15.3 feet, a number which comes from a 2015 United States Geological Survey (USGS) report (USGS, 2015, p. 93). This rooting depth was a calibrated model parameter from a hydrologic model rather than coming from the literature or site-specific knowledge. Additionally, in communications with the lead author of this USGS report, it appears that the number 15.27 feet in Table 13 was an error and that the rooting depth calibrated by the model was actually 23 feet, found in Table 18 (p. 100) (C. Faunt, personal communication, 17 January 2023). Using a rooting depth calibrated from a model is an inexact estimation of possible rooting depths because of the inherent uncertainty associated with modeling efforts. It would be more appropriate to use rooting depths from the literature.

While Appendix D4 asserts that there is a "...lack of site-specific information on the root depth of the honey mesquite community…" (Appendix D4, 2020, p. 16), there is a 1988 study on the mesquite bosque surrounding the Borrego Sink which cites a rooting depth of 39.4 feet (Jenkins et al., 1988). The authors used a split steel, continuous sampling tube to sample the vertical soil profile at the edge of three mesquite canopies in the Borrego Sink playa and three other locations, including a similar playa in New Mexico. The drilling depth "was determined by either the absence of roots in two consecutive 1.56-m [5.1 feet] sampling tube lengths, or the presence of coarse, dry loose soil that could not be retained in the tube" (Jenkins et al., 1988, p. 1645). The maximum drilling depth in the Borrego Springs playa location was 39.4 feet (Jenkins et al. 1988). The study indicates that the final soil cores in Borrego Springs playa still contained root mass at 36.1 - 39.4 feet (30.4 mg root biomass/kg soil; Jenkins et al., 1988, p. 1646). It is unclear if sampling was stopped due to a lack of roots or an inability to continue to collect soil samples. Hence it is possible that further root material may have been found deeper than 39.4 ft at the playa site in Borrego Springs. It should also be noted that mesquites have some of the deepest recorded rooting depths. For example, roots of *Prosopis juliflora* were found at a depth of 175 feet 20 miles southwest of Tucson (Phillips, 1963).

Documenting maximum rooting depth in plants is notoriously difficult (Canadell et al., 1996) and so there are likely mesquite roots in the Borrego Basin deeper than 39.4 feet. Directly sampling roots is laborious, with the probability of recovering active root material being quite rare with soil volumes extracted from deeper and deeper substrate layers (Maeght et al., 2013). In water-limited regions, rooting depths can also be determined by the environment rather than the traits of species, such as the frequency of water infiltrating to different soil depths following rainfall events or impervious soil features that restrict root expansion (Rundel & Nobel, 1991). Each of these issues bias estimates of rooting depth to much shallower values than most species' maximum rooting depth potential. Additionally, substantial water extraction from the soil can be made by a very small number of roots so that the distribution of root number or biomass in the soil with depth does not predict specific water extraction rates (Ogle et al., 2004).

Given the evidence above, we assert the rooting depth of 15.3 feet stated in Appendix D4 is a considerable underestimate of the maximum mesquite rooting depth near the Borrego Sink.

Groundwater depth

Appendix D4 asserts groundwater levels have declined by 44 feet between 1955 and 2018 (Appendix D4, 2020, p. 17). This estimate is derived by subtracting a groundwater table depth of 11 feet bgs (below ground surface) from well "Sink-7N1'' (hereafter 7N1; state ID: 11S07E07N001S) measured in 1955 from a different well's groundwater table depth of 55 feet bgs (well MW-5B; state ID: 11S007EQ7R002S) measured in fall 2018 (Figure 1); the two wells are 0.9 miles apart with well 7N1 at 481 feet above mean sea level (amsl) and well MW-5B at 468 feet amsl.

It is challenging to compare depth to groundwater across different wells without a clear conceptual or computational model providing a reliable groundwater surface. This is particularly an issue in the vicinity of the Borrego Sink, where it appears that the depth to groundwater can be variable—Appendix D4 states that the depth to groundwater in the Borrego Sink ranged from 55 feet bgs to 134 feet bgs in fall 2018 (the source for 134 feet bgs is not clear).

It may be more straightforward instead to assess the change in depth to groundwater using a singular well, such as well 12G (Figure 1, state ID: 11S06E12G001S, 481 feet amsl), which has data collected at 10 timepoints between 1965 and 2009 and is located within the perimeter of the mesquite bosque as defined by the San Diego Geographic Information Source (SanGIS) vegetation map (see **Mesquite bosque extent and mapping** section for discussion). For this well, groundwater declined from 29.66 feet bgs to 62.50 feet bgs (a decline of 32.84 feet) between 1965 and 2009. Appendix D4 states that this well is now dry, which may mean that is cannot represent groundwater depth, or may not provide sufficient flow to act as a production well. Hence, Appendix D4 is correct in asserting that water levels have generally declined in the vicinity of the mesquite bosque, but the magnitude of decline is less clear.

Even with declines in groundwater, it is likely that mesquites are still able to access groundwater. Firstly, the mesquite may exhibit compensatory growth in response to increased depth to groundwater and extend their roots to greater depths; mesquite exhibit high variability in root depths based on water availability (Ansley et al., 2014; Gibbens & Lenz, 2001; Gile et al., 1997). Secondly, mesquite do not typically extend their roots below the water table due to the anoxic conditions and instead take up water from the zone directly above the water table called the capillary fringe where groundwater seeps upwards via capillary action (Jarrell & Virginia, 1990). The capillary fringe may extend above the groundwater table by at least 6.5 feet (Todd and Mays, 2005, p. 48) and has been estimated to a thickness of 11.3 feet for silt loam (Shen et al., 2013), a common soil type in the mesquite bosque (Soil Survey Staff, 2022).

To better understand the possible depths to groundwater across the mesquite bosque we used the depth to groundwater contours provided by the Borrego Springs Watermaster draft Water Year 2022 Annual Report for the Borrego Springs Subbasin (West Yost, 2023). First, we overlaid the contours onto the SanGIS mapped extent of the mesquite bosque. Then, we then calculated the surface elevation every 5 feet along segments of the contour which overlapped the mesquite bosque using a 5-foot horizontal resolution digital elevation model derived from light detection and ranging data. Finally, we subtracted the groundwater contour elevation from the surface elevation. We found a range in depths to groundwater of 74 to 94 feet bgs in the mesquite bosque along cline A at 420 feet amsl, 13 to 45 feet bgs along cline B at 440 feet amsl, and 17 to 22 feet bgs along cline C at 460 feet amsl (Figure 2). These findings suggest a range of groundwater depths across the mesquite bosque, including depths that are well within the rooting depth of 39.4 feet found at this site (Jenkins et al., 1988).

Appendix D4 refrains from directly stating that the rooting depth taken in context with the groundwater levels indicate the mesquite are no longer able to access groundwater: “simple comparisons between known groundwater levels and maximum root depths likely oversimplifies the evaluation of impacts to GDEs” (Appendix D4, 2020, p. 17). The report, however, implies a disconnect of 39.7 feet between the depth to groundwater (55 feet bgs in fall 2018 [well MW-5B]) and their reported mesquite rooting depth (15.3 feet). We find that based on the available data there is a potential overlap of 26.4 feet between the depth to groundwater (13 feet bgs minimum from the cline B groundwater elevation contour, West Yost, 2023) and a reported rooting depth at the Sink (39.4 feet) (Figure 3). That being said, these are merely the bounding depths for which data are currently available. The depth to groundwater in the vicinity of the Sink is variable and it is reasonable that mesquite rooting depths vary accordingly, with some roots likely surpassing 39.4 feet in depth. Hence, the potential overlap of 26.4 feet is provided only as a rebuttal to the implied gap in Appendix D4 rather than as a description of a literal overlap between mesquite roots and groundwater.

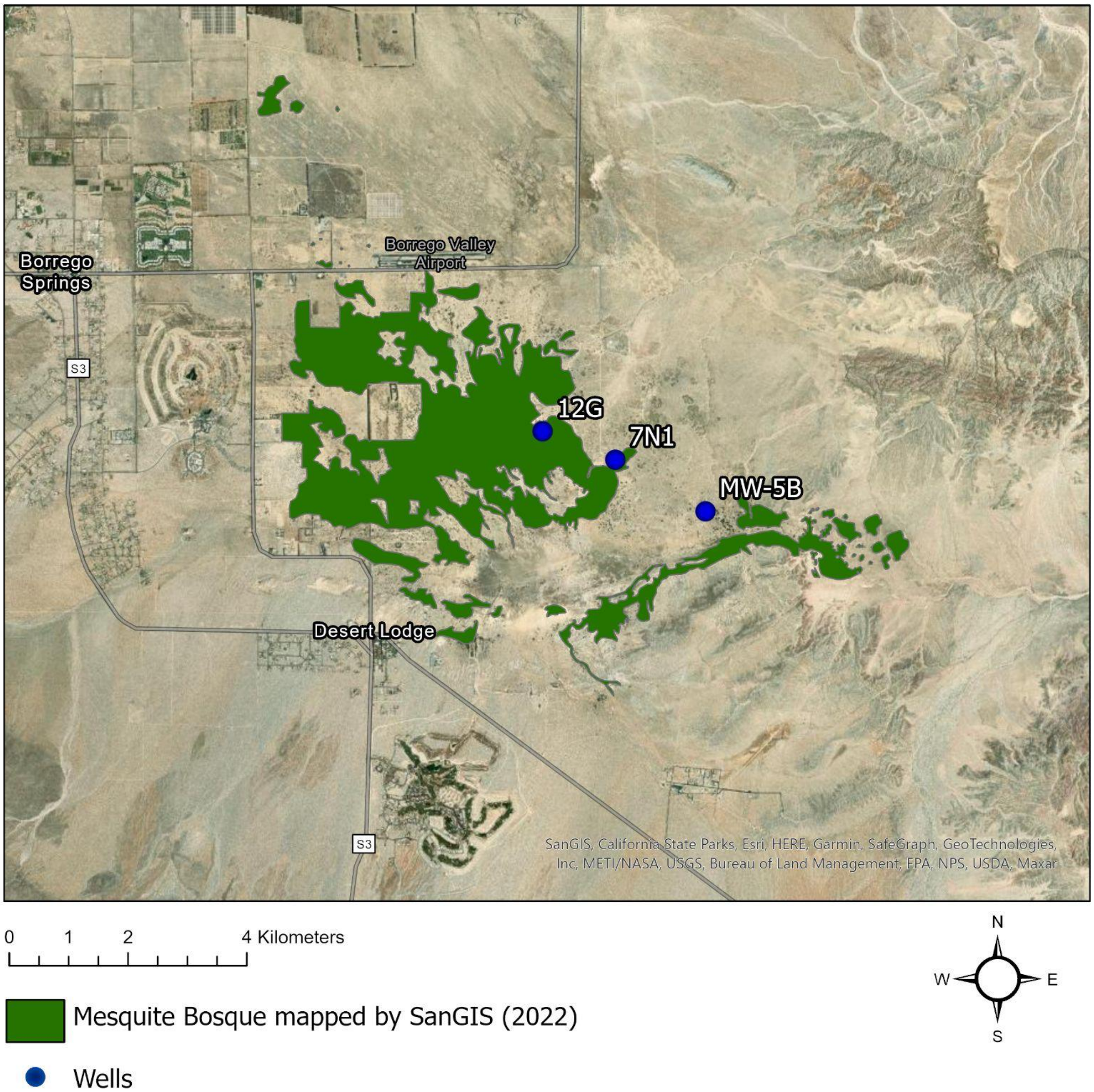

Figure 1. The location of wells discussed in this technical memorandum.

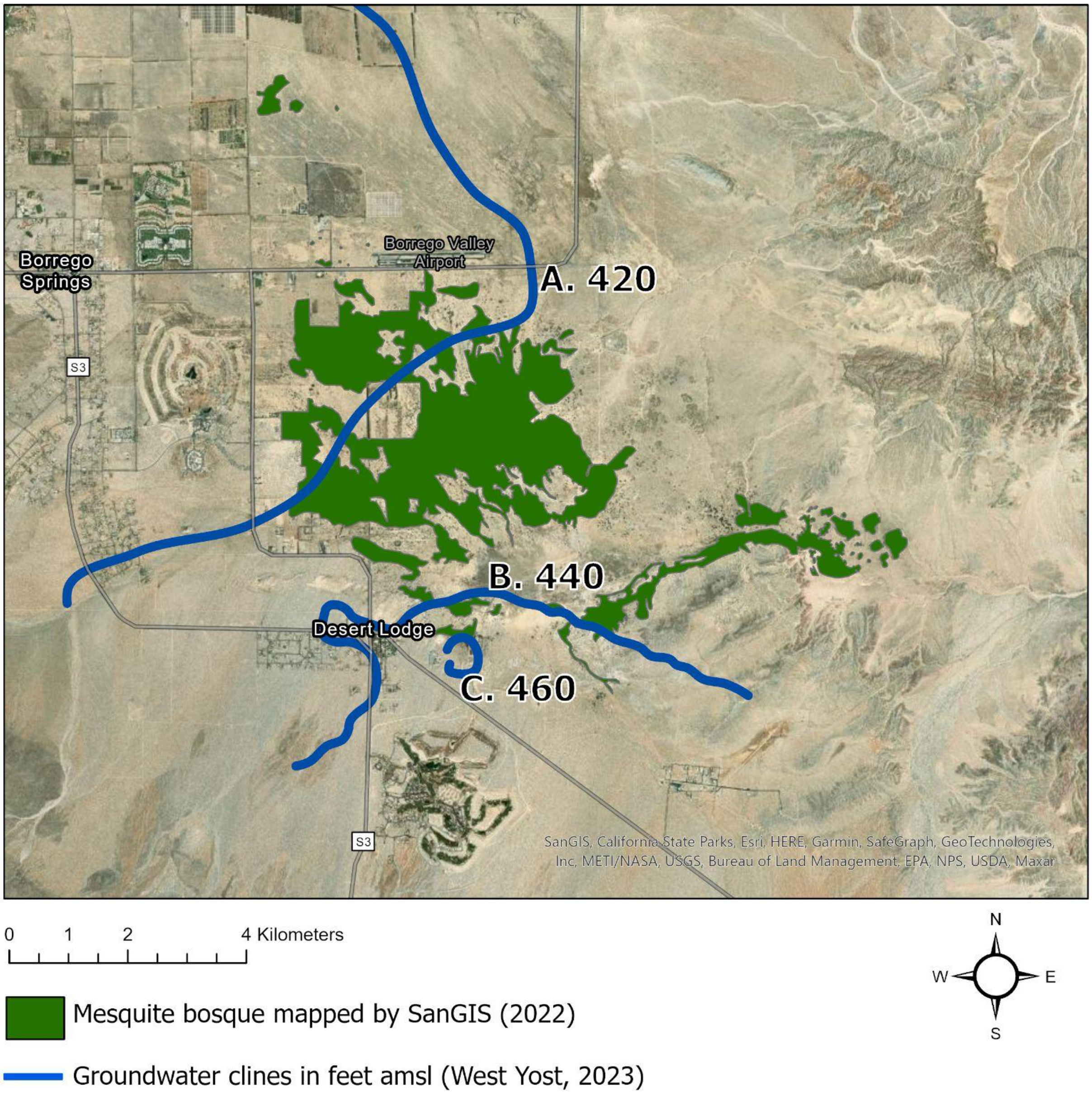

Figure 2. Groundwater clines from the draft Water Year 2022 Annual Report for the Borrego Springs Subbasin (West Yost, 2023) in the vicinity of the mesquite bosque as mapped by SanGIS (2022). The clines which overlap the mesquite bosque are labeled as A (420 feet amsl), B (440 feet amsl), and C (460 feet amsl).

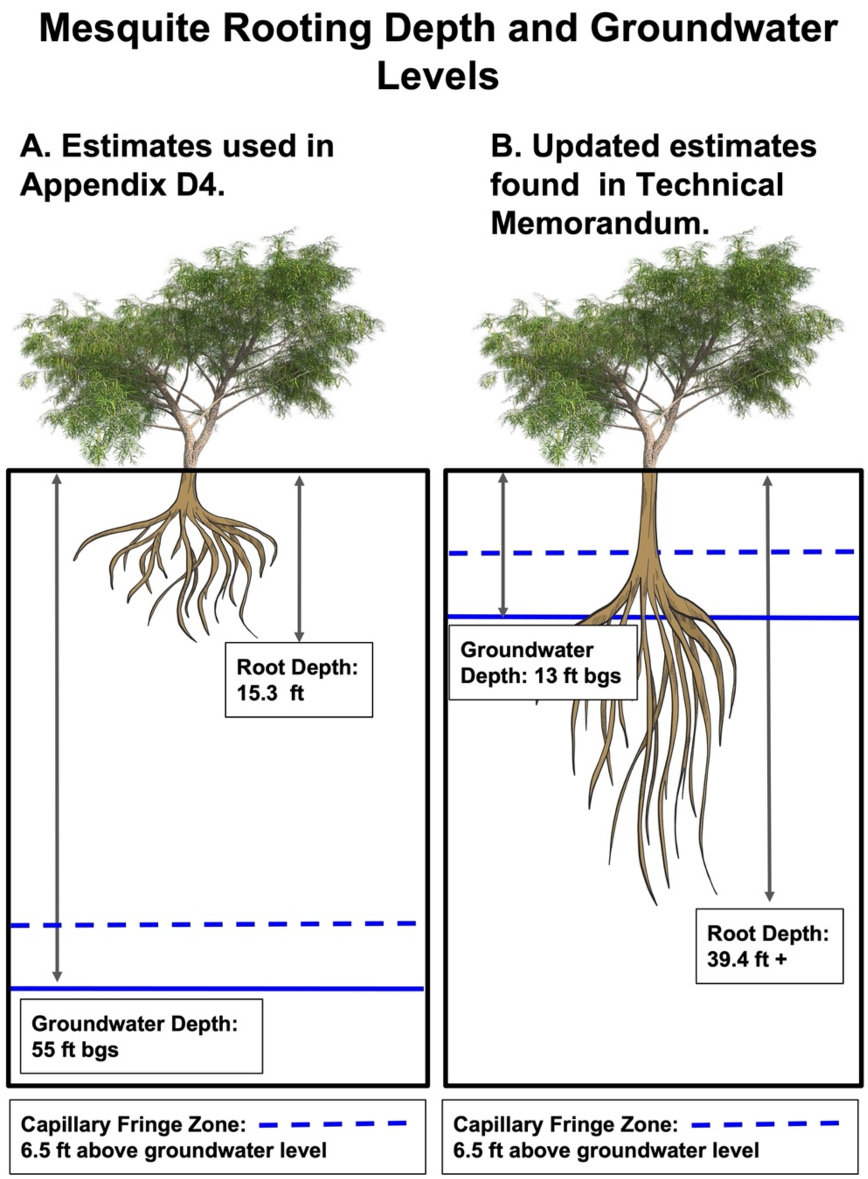

Figure 3. Conceptual representation of the bounding data for mesquite root depth and groundwater depth (A) in Appendix D4 from the GMP, which implies a disconnection of 39.7 feet between mesquite roots and groundwater, and (B) from the estimates determined in the analyses described in this technical memorandum, which show a potential 26.4-foot overlap between roots and groundwater. Mesquite typically take up water from the capillary fringe rather than below the groundwater table due to the anoxic conditions found in the latter, but we show the overlap of the mesquite roots and groundwater in (B) for illustration purposes. Capillary fringe zone estimates of 6.5 feet have been added to both figures. Root and tree configuration renderings are conceptual artist concepts.

Evapotranspiration

Additional evidence of the mismatch between mesquite rooting depth and groundwater depth is provided by the assertion in Appendix D4 that evapotranspiration values of the mesquite bosque have steeply declined: "[n]atural discharge determined from the Borrego Valley Hydrologic Model (BVHM) attributable to evapotranspiration was approximately 6,500 acre-feet per year prior to development, but has been virtually zero in the last several decades (1990- 2010) (USGS, 2015)" (Appendix D4, 2020, p. 17). Evapotranspiration is the combined process of transpiration (loss of water from plants' leaves) and evaporation (loss of water from the soil surface), and the behavior of water loss through evapotranspiration is a function of root access to different water sources. Hence, the low levels of evapotranspiration referenced in Appendix D4 contribute to the narrative that mesquite have disconnected from groundwater.

In 2015, the USGS published a report in cooperation with the Borrego Water District entitled "Hydrogeology, Hydrologic Effects of Development, and Simulation of Groundwater Flow in the Borrego Valley, San Diego County, California," which details the development of an integrated hydrologic model the authors refer to as the "Borrego Valley Hydrologic Model" (BVHM) (USGS, 2015). The purpose of the BVHM is to serve as a basis for surface and groundwater availability and to inform water management decisions. The water budget of the BVHM accounts for evapotranspiration from the water table by phreatophytic vegetation using the Farm Process (FMP). Farm Process is a computer program that sets up and solves equations simulating the use and movement of water by vegetation, such as phreatophytes. While mesquite and *Tamarix* were both included within the category of phreatophytes, USGS (2015) acknowledge that the majority of phreatophytes in the Borrego Springs Subbasin are mesquite (p. 13). The FMP simulates evapotranspiration using parameters that include the thickness of the capillary fringe, rooting depth, crop-coefficients for phreatophytes, and the depth to groundwater (Schmid et al., 2006). USGS (2015) asserts that evapotranspiration by phreatophytes has declined nearly to zero because "the groundwater levels in the basin dropped below the reach of the mesquite in the basin" (USGS, 2015, p. 3). However, the rooting depth (23 feet), estimated during the automated calibration process rather than being set *a priori*[2], is less than values reported for mesquite near the Borrego Sink (39.4 ft). This suggests the calculation of evapotranspiration by mesquite is likely underestimated as a result of shallow rooting depth parameters that impact model performance. While the capillary fringe is estimated via calibration as being thicker than might be typical (16 feet), it is unclear how much weight in the model is given to the rooting depth and capillary fringe when calculating evapotranspiration. Overall, many of the parameters in the BVHM were calibrated rather than set *a priori*, which results in uncertainty in model output. Additionally, it is unclear if the Farm Process package is

[2] Calibrated parameters are solved for by the model whereas *a priori* parameters are input by the user.

appropriate to simulate the physiology associated with riparian species, where other MODFLOW schemes, such as RipET have been developed to understand impacts more accurately on water balance (Maddox et al., 2012). While the USGS report details the uncertainty and limitations inherent in its model (USGS, 2015, p. 113), this discussion is missing in Appendix D4. Hence, we suggest it is inappropriate to use simulated evapotranspiration values from the BVHM in assessing mesquite bosque connection to groundwater.

Data gaps related to rooting depth of the mesquite and the depth to groundwater

Our current understanding of mesquite connection to groundwater is limited by a lack of data. Rather than inferring mesquite connection to groundwater through rooting depths and groundwater level, mesquite use of groundwater can be measured using isotopic analyses of ecosystem water sources. We will pair the isotopic analyses with measurements of water potential to assess the composition and depth of water sources used by mesquite trees near the Borrego Sink on a seasonal basis, as documented in the literature (Brunel et al., 1991, Ehleringer & Dawson 1992, O'Grady et al., 2006, Richardson et al., 2011). Additionally, our understanding of evapotranspiration could be enhanced through the installation of an eddy covariance flux tower to directly measure evapotranspiration in the mesquite bosque or by scaling from branch- or leaf-level measurements.

2. Mesquite bosque extent and mapping

Historical extent of the mesquite bosque

Appendix D4 uses two different sources to define the historical extent of the mesquite bosque near the Borrego Sink. The document first cites USGS (2015) to define the historical extent of mesquite trees near the Borrego Sink "prior to development" as 450 acres (Appendix D4, 2020, p. 15). One paragraph later, the authors describe accounts of the mesquite habitat near the Borrego Sink that estimate a coverage of 4 square miles, or 2,560 acres (Appendix D4, 2020, p. 15). This discrepancy of 2,110 acres is not acknowledged nor discussed in the text. To better understand this mapping discrepancy, we reviewed the cited literature. The calculation of 450 acres from USGS (2015) stems from a footnote in Table 6 of a 1982 USGS report (Moyle, 1982). Table 6 estimates the acreage of mesquite and tamarisk in 1980 as 4,510 acres and states that trees cover about 10% of the ground, leading to an estimate of 450 acres. This estimate includes all mesquite and tamarisk found within the Borrego Springs Subbasin as well as near Clark Dry Lake, which is outside of the Borrego Springs Subbasin (Moyle, 1982, Plate 8b accessible from https://pubs.usgs.gov/of/1982/0855/plate-08.pdf). When only the mesquite bosque around the Borrego Sink is considered these yields 4,100 acres, which is reduced to 410 acres using the same conversion factor of 10%. This type of calculation using estimates of percent tree canopy cover is not typical of current vegetation mapping methods. The estimate of 4 square miles, or 2,560 acres, is from Appendix A of the General Plan Groundwater Update

Study by the County of San Diego (2010), which uses the SanGIS dataset (2022) to identify mesquite around and north of the Borrego Sink and is provided as a contemporary rather than historical extent (County of San Diego, 2010, p. 7). The number of 4 square miles provided by the report is an estimation; the full spatial extent of the mesquite bosque near the Borrego Sink defined by the SanGIS map equals 2,800 acres (or 4.4 square miles). Together these findings suggest that the earliest mapped (1982) extent of the mesquite bosque near the Borrego Sink was closer to 4,100 acres and that this estimate comes from post- rather than pre-development times in Borrego Springs. That being said, the SanGIS map is a more appropriate estimate of post-development mesquite bosque extent in the area due to the finer scale maps available during its creation in 1995 compared to 1982.

Current extent of the mesquite bosque

Appendix D4 describes the current extent of mesquite as limited to small patches east of the Borrego Sink that total 13.2 acres, as mapped by the Natural Communities Commonly Associated with Groundwater (NCCAG) dataset (see **Appendix** for full description of NCCAG mapping). However, the actual combined area of the NCCAG mesquite polygons in this area totals 142.2 acres. Appendix D4 appears to have used the same 10% calculation that was used in the 1982 USGS report (Moyle, 1982) to estimate the area covered by mesquite. This methodology is likely inappropriate for two reasons. One, the NCCAG dataset features much higher resolution mapping than the 1982 USGS report. Two, the areal cover of a species (i.e., the mesquite) is not equal to the areal cover of a land cover type (i.e., the mesquite bosque), which includes co-occurring species, appropriate bare-ground interspaces, and functionally interconnected landscape elements that are emergent of the system. Hence, taking 10% of an area to represent the cover of the mesquite bosque for a total of 13.2 acres is an underestimate of the mesquite bosque's current spatial extent.

Importantly, we have determined that the NCCAG dataset covering the Borrego Springs Subbasin also lacks spatial coverage as it uses source maps that almost exclusively cover Anza-Borrego Desert State Park (ABDSP) and do not cover privately owned land around Borrego Springs, which comprise the Borrego Springs Community Planning Area[1], though this is where much of the mesquite bosque near the Borrego Sink is found (Keeler-Wolf et al., 1998, p. 5) (Figure 4a; see **Appendix** for full description of ABDSP mapping). The boundary of the vegetation map runs through the eastern portion of the mesquite bosque near the Borrego Sink, causing the NCCAG dataset to omit the vast majority of the total mesquite areal extent that is found west of the mapping boundary (Figure 4b). The authors of Appendix D4 mention that mesquite west of the boundary was removed by the Department of Water Resources (DWR) as it no longer met the criteria to be included in the NCCAG dataset (Appendix D4, 2020, p. 6), and was thus deemed as "historical" extent. However, our communications with the lead author of the NCCAG dataset indicate this area was likely excluded by mistake (K. Klausmeyer, personal communication, 1 December 2022):

> The iGDE [NCCAG] mapping was done at the state scale several years ago, so there are certainly issues like this that pop up around the state. Based on the data you provided it appears that the high resolution vegetation mapping we used stopped at the state park border, and did not include the vegetation types outside the border. I do not think we incorporated the SanGIS data into our mapping. In this case, it looks like the SanGIS data is higher quality, so that is the better data to use. (K. Klausmeyer, personal communication, 1 December 2022)

The mapping limitations of the ABDSP dataset therefore limit the NCCAG dataset, causing a discrepancy in the spatial coverage of the mesquite bosque known as GDE Unit 3. A more accurate estimate of the current extent of mesquite bosque near the Borrego Sink comes from the SanGIS dataset. This dataset was originally created by the City and County of San Diego as well as the San Diego Association of Governments in 1995 and characterizes vegetation communities according to the Holland system (Holland 1986, SanGIS 2022). SanGIS (2022) maps the area of mesquite bosque as 2,800 acres. This mapping source is more accurate than the NCCAG dataset because it does not suffer from issues of artificial property ownership boundaries. Preliminary evidence confirms the presence of live mesquite across this area (Box 2) (L. Paul and R. Staehle, Tubb Canyon Desert Conservancy, Personal communication, 15 December 2022). Hence, Appendix D4 excludes 95% (all but 142.2 out of 2,800 acres) of the areal extent of extant mesquite bosque, as mapped by SanGIS, and excludes 99.5% (all but 13.2 out of 2,800 acres) of the reported acreage.

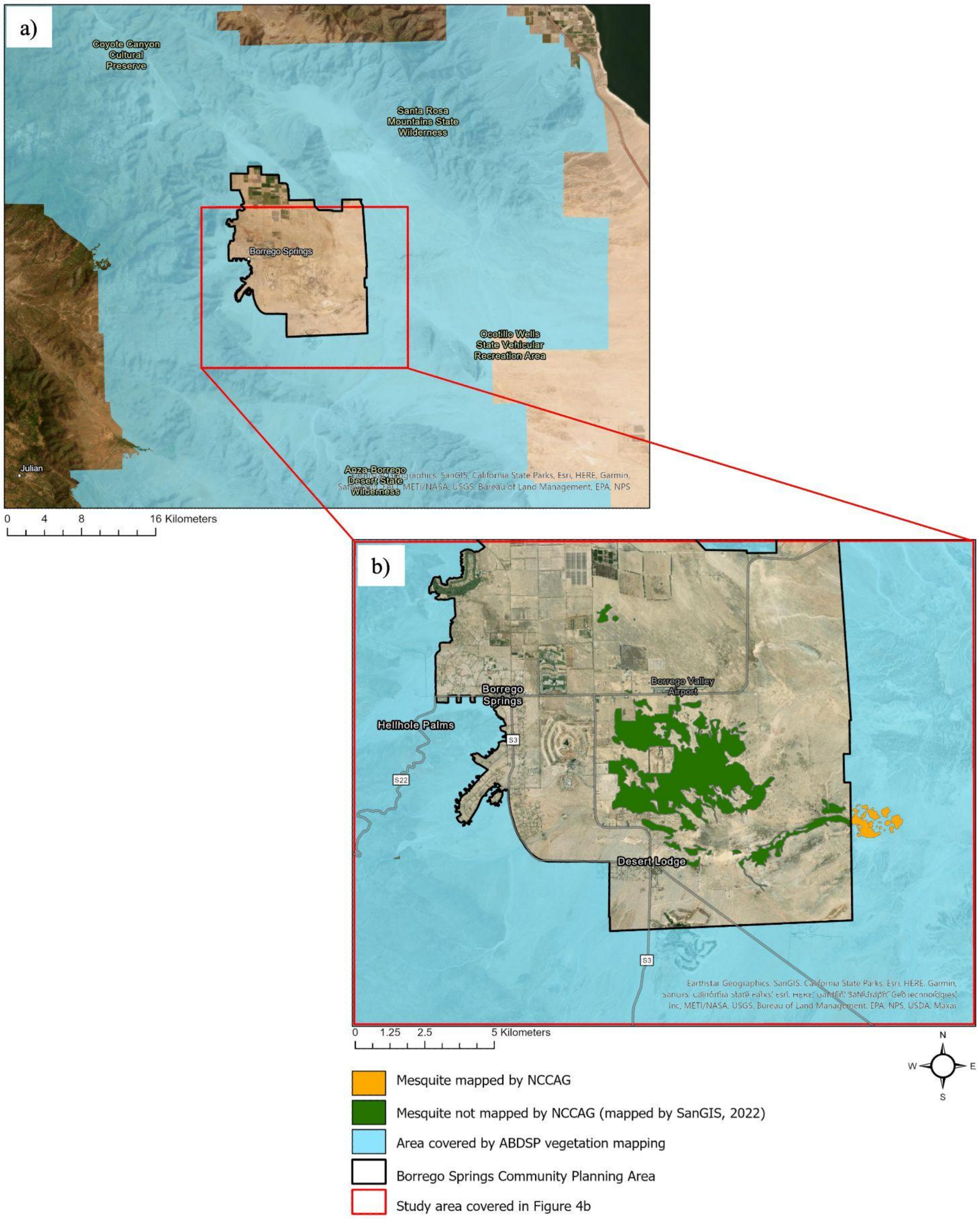

Figure 4. a) Anza-Borrego Desert State Park (ABDSP) vegetation map area used to identify potential GDEs in Borrego Valley in the Natural Communities Commonly Associated with Groundwater (NCCAG) dataset, which lacks spatial coverage of non-State Park lands in Borrego Springs, known in the San Diego County General plan as the Borrego Springs Community Planning Area[1]. b) Zoom in of the study area, showing discrepancies in mapping of the mesquite bosque due to the ABDSP boundary, which limits the spatial coverage of the NCCAG dataset. The SanGIS (2022) dataset, shown in green, maps mesquite regardless of property ownership boundaries.

Box 2. Confirming live mesquite in area mapped by the SanGIS dataset (2022).

Mesquite trees near the end of Yaqui Pass Rd. on 10 June 2019 (a) and mesquite foliage in the lower part of a mesquite tree northeast of Rango Wy. on 4 March 2022 (b). Credit: Sicco Rood (a); Lori Paul and Robert Staehle (b). (a) https://www.calflora.org/entry/occdetail.html?seq_num=mg87730

Mesquite bosque mapping data gaps

Maps of the "current extent" of mesquite bosque within Appendix D4 are truncated by the boundary restrictions related to the NCCAG dataset. In Appendix D4, this mapping discrepancy was described as a conscious decision by DWR related to mesquite decline west of the Park vegetation map boundary. However, our communications with the author of the NCCAG dataset indicate the source maps fail to capture the extent of mesquite found west of the Park boundary. For this reason, higher resolution data that covers the full extent of mesquite around the Borrego Sink should be used (K. Klausmeyer, TNC, Personal communication, 1 December 2022). The SanGIS vegetation mapping currently provides a solution to the need for high-resolution mapping as it identifies mesquite vegetation regardless of land ownership. However, this mapping was completed in 1995, nearly 30 years ago. A mapping effort that is more current, uses even higher resolution aerial imagery, and is ground truthed will enhance our understanding of the extent of the mesquite bosque.

3. Evaluation of remote sensing vegetation indices of mesquite health

On page 21, Appendix D4 introduces the evaluation of remotely sensed vegetation indices provided by the TNC GDE Pulse dataset (The Nature Conservancy, 2021 https://gde.codefornature.org/). The TNC GDE Pulse is an online dataset that provides analyses of remotely sensed Normalized Difference Vegetation Index (NDVI, a proxy for vegetation greenness) and Normalized Difference Moisture Index (NDMI, a proxy for vegetation moisture content) for all potential GDE polygons mapped by NCCAG. The dataset averages these vegetation health indices between 9 July - 7 September of each year from 1985 to 2018 to provide an estimate of vegetation health during the driest time of the year for most of California, when ecosystems would most likely be accessing groundwater (Klausmeyer et al., 2019). The dataset states vegetation that can maintain greenness or moisture during this dry period is likely connected to groundwater (Klausmeyer et al., 2019). It is important to note that April and May are the driest months of the year in Borrego Springs, and that the period from July - September contains significant rainfall in some years, partially due to the North American Monsoon (Figure 5). In addition to issues with the time frame provided by the TNC GDE Pulse dataset, it also only provides data for the polygons identified by the NCCAG dataset. As stated previously, the NCCAG dataset only maps 142.2 acres of the mesquite bosque out of the 2,800 acres of mesquite mapped by SanGIS in the Subbasin. This limited mapping causes the TNC GDE Pulse dataset to lack analyses for 95% of the mesquite bosque acreage mapped by SanGIS, therefore providing a severely limited assessment of remotely sensed health for mesquite and GDE Unit 3.

Appendix D4 specifically focuses on evaluating NDVI as an indicator of mesquite health across the time period from 1985 - 2018, during which groundwater declined by 21 ft (Appendix D4, 2020, p. 22). NDVI is based on the reflectance properties of green vegetation and is determined by the ratio of the amount of absorption by chlorophyll in the red wavelengths (600–700 nm) to the reflectance of the near infrared (720–1300 nm) radiation calculated from satellite imagery. NDVI is correlated to a number of biophysical ecosystem properties, and is used widely as a measure of vegetation greenness which is often interpreted in terms of vegetation health (Klausmeyer et al., 2019). The TNC GDE Pulse dataset used in Appendix D4 analyzes NDVI from satellite imagery collected by the Landsat program, which features 30 meter spatial resolution. Resolution refers to the smallest size an object can be represented clearly in imagery, meaning a 30 meter resolution only captures details greater in size than the 30 meter by 30 meter pixel, and all details smaller than 30 meter by 30 meter are averaged together within the pixel.

Appendix D4 includes a table of minimum, maximum, average, and change in NDVI by plant species and GDE area from 1985 - 2018 (Appendix D4, 2020, p. 23). They preface their evaluation with a citation from Klausmeyer et al. (2019) that states “healthy” vegetation typically has an NDVI around 0.72, and “unhealthy” vegetation has an NDVI of 0.14. The table indicates the average mesquite NDVI was 0.1161 and the average NDVI of GDE Unit 3 was 0.1002, which falls into the “unhealthy” category. However, desert landscapes are known to have low NDVI due to sparse, widely spaced vegetation coverage and low leaf area, especially in coarser resolution datasets, such as the 30 meter resolution provided by Landsat. The ranges for GDE Unit 3 and mesquite shown in Appendix D4 are typical of healthy desert vegetation, and are within range of recent regional assessments of Landsat NDVI in deserts (Hantson et al., 2021;

Weiss et al., 2004). It is likely that the NDVI ranges provided by Klausmeyer et al. (2019) were developed for ecosystems with denser vegetation, such as forests or wetlands.

Appendix D4 also proposes that "if potential GDEs were relying primarily on the regional groundwater table, one would expect to see a steady decline in community health over the 20 year period" (Appendix D4, 2020, p. 22). The authors make the following statements to support their theory (Appendix D4, 2020, p. 22):

1. "There is no correlation between the NDVI index and groundwater levels between 1985 and 2018. During this time frame, groundwater levels are estimated to have declined by 21 feet, based on groundwater level monitoring in Well MW-5A/B and in Sink Wells 12G1and 7N1."
2. "There is a moderately positive correlation between the NDVI index and precipitation."
3. "Changes in NCCAG plant health indices after 1985–throughout the Subbasin, and regardless of the time interval chosen–are on average flat, slightly increasing, or slightly decreasing."

These three statements feature flawed NDVI interpretation. Statement 1 assumes that the lack of correlation between NDVI and groundwater declines of 21 feet supports the theory that mesquite have disconnected from groundwater; however the alternative, that mesquite have maintained connection to groundwater through deep roots that reach past the 21 foot decline, would also lead to a lack of correlation. Additionally, some mesquite compensatory growth of roots to greater depth as groundwater levels declined would be expected and, thus, the relationship between groundwater decline and long term mesquite health should be non-linear.

Statement 2 proposes the moderately positive correlation between NDVI and annual precipitation demonstrates mesquite dependence on surface water from rainfall. The major flaw in this statement is that the TNC GDE Pulse dataset utilized by Appendix D4 analyzes data from July to September, a time frame that captures 15-20% of annual rainfall, including the monsoons that often fall in July through September in Borrego Springs (Figure 5). As mesquite are known to be facultative phreatophytes, meaning they have a dimorphic root system allowing them to use both groundwater and surface water, a correlation between annual precipitation and NDVI would be expected. Additionally, as the time frame covered by the NDVI analysis captures the monsoon, the NDVI signal may be impacted by increased growth and productivity of herbaceous annuals in the understory in response to the summer rains (Weiss et al., 2004; Mendez-Barroso et al., 2009). The most appropriate time frame for remote sensing analyses of mesquite groundwater use for Borrego Springs would be across the driest months of April and May, or during historically anomalous dry growing seasons, when near surface soil water is likely exhausted following the winter rainfall, and surface temperatures support mesquite leaf production (Figure 5).

Statement 3 indicates that NDVI remained relatively neutral throughout 1985 - 2018, suggesting that the mesquite are not groundwater dependent because their NDVI has not tracked with declines in groundwater. This interpretation oversimplifies the multitude of responses that vegetation can display in response to changing conditions. For example, if mesquite had been connected to groundwater in 1985 and remained connected to groundwater through compensatory growth of deep taproots, one would expect neutral or increasing NDVI over time, as suggested by the TNC GDE Pulse dataset (Klausmeyer et al., 2019). Additionally, NDVI decreases are not synonymous with groundwater decreases, nor with declines in vegetation health. Many biophysical factors are correlated with NDVI, including vegetation cover, biomass, leaf area, productivity, chlorophyll density and species composition of both the canopy and understory (Fiore et al., 2020). Therefore, the neutral, slight increasing, and slight decreasing NDVI across the mesquite bosque can indicate a variety of different factors, which underscores the need for direct measurement of vegetation properties in the field to accurately interpret NDVI (Fiore et al., 2020). Furthermore, a recent paper analyzing trends in NDVI across the Sonoran Desert, including the mesquite bosque, attributed NDVI decreases to climate warming (Hantson et al., 2021), further demonstrating that NDVI trends may be better correlated with factors other than groundwater decline or precipitation.

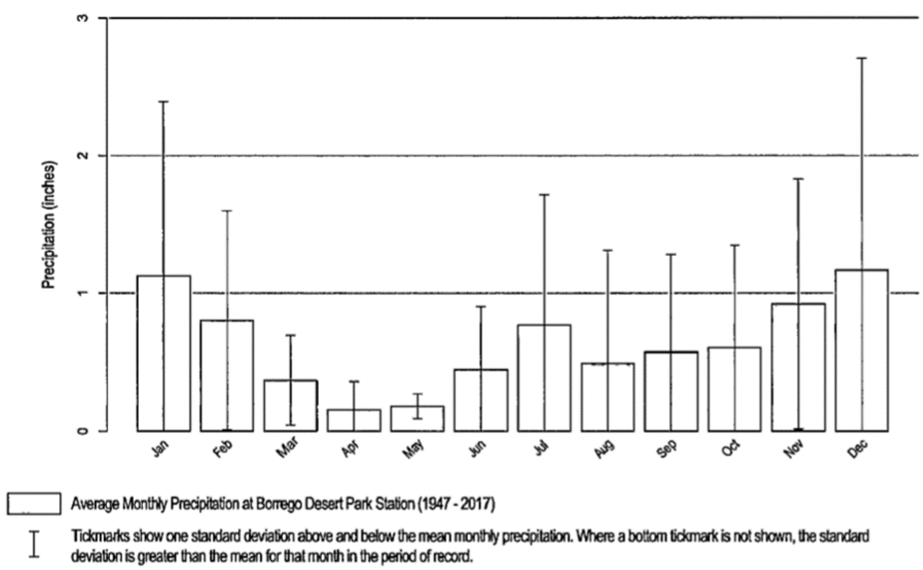

Figure 5. Average Monthly Precipitation at Borrego Desert State Park Station reproduced from the GMP (pg 161). Note that the large standard deviation means that in some individual months during this seventy year dataset, total rainfall at this measurement station was zero. It should also be noted that rainfall, especially during summer, in any particular geographic location can be highly variable, with one location receiving an inch of rain from a particular storm, whereas a location 2 miles away might get a small fraction of that, or zero.

Data gaps related to remote sensing of mesquite health

Improvements to remote sensing of mesquite bosque health would include analyses of remotely sensed indices for groundwater use across the full extent of the mesquite bosque during the driest months, April and May, and/or during historically anomalous dry growing seasons. Higher resolution imagery such as the National Agriculture Imagery Program (NAIP) one-meter resolution dataset can be used to analyze the mesquite bosque with 30 times greater detail than the Landsat analyses provided by Appendix D4. Furthermore, a full evaluation of NDVI verified by field measurements of vegetation health is necessary to best interpret remotely sensed vegetation indices.

Conclusions

In this technical memorandum we review the evidence in Appendix D4 related to the report's conclusion that there is not a connection between the mesquite bosque, GDE Unit 3, and the groundwater of the Borrego Spring Subbasin. We found discrepancies and data gaps which call into question the validity of such a conclusion. As Appendix D4 was written with limited time and budget (T. Driscoll, personal communication, 12 December 2022), we conclude it is warranted to further explore the potential that the mesquite bosque is a beneficial user of groundwater in the Borrego Springs Subbasin.

We first address rooting depths and groundwater depths. Though Appendix D4 asserts that site specific evidence of mesquite rooting depth does not exist, we report on a 1988 study which measured mesquite rooting depth to at least 39.4 ft near the Borrego Sink (Jenkins et al., 1988). Recent groundwater level analyses indicate possible groundwater depths ranging from 13 to 94 feet bgs across the Borrego Sink (West Yost, 2023), which is well within the range of rooting depths for mesquite. The simulated values from the hydrological model which suggest nearly zero evapotranspiration from mesquite appear to be based on underestimated rooting depth, which was calibrated from the model rather than set *a priori*, limiting the conclusions one should draw from this model.

We then address the spatial extent of the mesquite bosque. The spatial extent presented by Appendix D4 was much smaller than current mapping estimates by SanGIS (2022). Appendix D4 seems to have taken 10% of the NCCAG mapped area in an effort to compare the data to the area of a 1982 map which was created using different methodology. Additionally, the NCCAG map omits 95% of the current extent of the mesquite bosque, which is captured in SanGIS (2022) mapping.

Finally, we address the analyses of remotely sensed health. The NDVI dataset analyzes only the area covered in the NCCAG dataset, thereby omitting an assessment of the health of 95% of the mesquite bosque. Additionally, we find three main issues with the NDVI interpretation: 1) a lack of correlation between NDVI and groundwater decline may simply suggest that mesquites maintained their connection to groundwater rather than their being disconnected, 2) a relationship between NDVI and precipitation only supports that mesquite are able to use surface water in addition to groundwater, and 3) NDVI is indicative of many metrics other than groundwater or vegetation decline (e.g. leaf area or species composition); and thus changes, or lack thereof, in NDVI may not directly relate to groundwater disconnection or vegetation decline.

Together, our review of the evidence provided in Appendix D4 suggests that the connection or disconnection of the mesquite bosque, GDE Unit 3, from groundwater cannot be inferred with confidence from the data relied upon by Appendix D4. We recommend updated vegetation mapping, in depth field research, and expanded remote sensing analyses to better assess groundwater use in the mesquite bosque.

Thus, we have found the existing data gaps are larger than those referred to in the original Groundwater Dependent Ecosystems (GDE) Identification, Assessment and Monitoring Program proposal (Staehle, Garmon, Huxman, Rebman, & Jorgensen, 2022). Our Workplan is being revised to account for this new information. We believe the scope and resources described in the original proposal are adequate to cover plan revisions and to reach a definitive conclusion regarding "if there is/are SGMA-defined Beneficial User(s) of Water in the Borrego Subbasin that has/have not to date been taken into consideration in the GMP," as cited in the project proposal.

Appendix

Natural Communities Commonly Associated with Groundwater (NCCAG) Potential GDE mapping description and limitations

The GMP and Appendix D4 utilized the NCCAG dataset to identify potential GDEs currently in the subbasin. The NCCAG dataset was created by DWR and The Nature Conservancy (TNC) to act as a starting point and initial reference dataset for Groundwater Sustainability Agencies (GSA) to identify potential GDEs within California's groundwater basins. The statewide dataset compiles 48 publicly available state and federal agency datasets that map phreatophytic vegetation, perennial streams, naturally flooded wetlands, and springs and seeps to identify locations that likely contain and depend on groundwater. The intention of the NCCAG dataset was not to eliminate potential GDE areas, but to assist in identifying those areas with readily available information. To identify areas of phreatophytic vegetation within the Borrego Valley Subbasin, the NCCAG dataset utilizes the Anza-Borrego Desert State Park (ABDSP) and Environs vegetation map (Klausmeyer et al., 2018; see section below). The NCCAG dataset requests that GSAs review, validate, and supplement the dataset with the best available local knowledge and resources such as higher resolution vegetation mapping and hydrologic and groundwater conditions to better identify potential GDEs (Klausmeyer et al., 2018). Presumably due to time and budget constraints, such review, validation, and supplementation did not occur during Appendix D4's analyses.

ABDSP and Environs vegetation map description and limitations

The ABDSP and Environs vegetation map was prepared by the California Department of Fish and Game (since renamed the California Department of Fish and Wildlife) to depict the location and distribution of 94 different vegetation types within the Park and surrounding areas as a component of the General Plan process for ABDSP (California Department of Fish and Game, 2011). The map was created using ground-based vegetation classification, aerial photo interpretation, and GIS editing and processing (Keeler-Wolf et al., 1998). As this mapping effort was prepared for applications specific to ABDSP, the mapping only covers the area within and immediately adjacent to ABDSP boundaries, and does not cover the area designated as the Borrego Springs Community Planning Area[1] in the Borrego Springs Community Plan and the San Diego General Plan (Figure 4a).

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