Appendix 3-D

Groundwater Dependent Ecosystems in the South American Subbasin
(April 21, 2021)

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SUMMARY

The Sustainable Groundwater Management Act (SGMA) requires Groundwater Sustainability Plans (GSPs) to identify and consider impacts to Groundwater Dependent Ecosystems (GDEs). GDEs are complex ecosystems that rely on a connection to groundwater to sustain their health and function. GDEs provide various ecosystem services (e.g., supporting habitat for life stages of State and federal special status species, providing habitat for migratory fish), and recreational amenities (e.g., parks and waterways). Groundwater Sustainability Agencies (GSAs) are required to manage GDEs and their associated beneficial uses and users consistent with the strategies outlined in the GSP to avoid "undesirable effects" resulting from unsustainable groundwater management. Despite the significant presence of GDEs in the South American Subbasin (SASb)[1] and the ecological value they provide to beneficial users of groundwater, they remain poorly understood. To support these valuable ecosystems, they must be considered in terms of scale and spatial distribution, the plant and animal communities that rely on them, best practices to monitor their condition, and how their functions may be supported through groundwater management.

The SASb's extensive vegetation communities and natural features associated with both surface and groundwater expressions were identified and classified as to their potential GDE status using a multi-faceted approach. First, potential GDEs were identified using available datasets in a geographic information system (GIS). Next, an analysis was carried out to determine if the most deeply rooted local species could reasonably reach groundwater throughout the historical period from 2005 to 2019 which contains wet, above normal, below normal, dry, and critical water year types. Then, surface vegetation health was evaluated with satellite imagery to assess the possibility of broad, rapid, and cost-effective characterization of GDE health. Finally, results were synthesized into quantitative metrics that may be monitored within the SGMA framework, and which provide reasonable assurance that undesirable results to GDEs in the SASb are avoided.

In following sections present: a brief background on GDEs in SGMA; methods used to classify and map GDEs via groundwater level and satellite imagery; management approaches (including definition and identification of Undesirable Results, and Measurable Objectives); a discussion of GDE-associated beneficial users; a discussion of study limitations; and a discussion of potential projects and management actions that may interact with GDEs in the SASb.

[1] The South American Subbasin is defined by Bulletin 118.

SGMA requires consideration of the interests of all beneficial uses and users of groundwater in the development and implementation of GSPs (CAL. WATER CODE § 10723.2). These interests explicitly include environmental users. As a result, ecosystems dependent on groundwater must be evaluated in GSPs. The identification and subsequent management of GDEs is closely related to two SGMA sustainability indicators: lowering of groundwater levels and depletion of interconnected surface waters (CAL. WATER CODE § 10721(x)).[2] Thus, SGMA requires that GSPs consider GDEs, which are a beneficial user of both groundwater and interconnected surface water.

SGMA defines GDEs as "ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface" (CAL. CODE REGS. tit. 23 § 351(m)). Hence, GDEs are habitats and populations of species whose health relies on access to groundwater. SGMA details the specific conditions and considerations that every GSP must address. These include identifying GDEs within the basin as well as evaluating the potential for adverse impacts to interconnected surface waters (ISW) (CAL. CODE REGS. tit. 23 §§ 354.8(5), .16(g), .28(6)). The ISW analysis for the SASb is presented separately in an accompanying technical memo: "Interconnected Surface Water in the South American Subbasin: Historical and Present-day Characterization, and Approaches for Monitoring and Management." SGMA requires the GSP to define an approach to monitor and manage significant and unreasonable impacts to GDEs. The identification of GDEs is based on the "best available science" and requires "the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice" (CAL. CODE REGS. tit. 23 § 351(h)). The following effort has been designed and undertaken in accordance with these requirements and standards in order to provide a thorough and reliable analysis of GDEs in the SASb.

METHODS

Classes of GDEs

Applying legal standards defined by statutes, this analysis considers GDEs as ecosystems that meet the scientific framework for classification based on data available at the subbasin scale, including depth to groundwater or the presence or absence of an associated mapped vegetation community. Scientific literature identifies three GDE classes (Eamus 2006; Eamus & Froend 2006; Eamus et al. 2006, 2015):

- Class 1: Underground aquifer and cave systems hosting stygofauna (species adapted to living in underground water)
- Class 2: Ecosystems that rely on surface expressions of groundwater, including springs, perennial wetlands, and rivers whose flow is augmented by groundwater
- Class 3: Ecosystems that rely on sub-surface groundwater, including phreatophytes (Greek for "well plant", or plants with roots that reach into saturated groundwater)

[2] GDEs may or may not be reliant on the "primary aquifer" but this does not change the definition for GSP purposes.

In the SASb, only class 2 and 3 ecosystems are present (see Section 2 of the GSP, Plan Area), and hence, in this memo, references to “GDEs” indicate both class 2 and 3 GDEs.

Within GDEs, microbial and invertebrate communities that could interact with surface water systems can reside at groundwater depths to 230 ft (White 1993; Kawanishi 2013; Sorensen 2013; Korbel 2017). According to California’s Bulletin 118, this hyporheic zone consists of the fully saturated sediments beneath and beside the active channel, which contains a proportion of surface water that was part of the flow in the surface channel that went back underground where it mixed with groundwater (California DWR 2003). The hyporheic zone links surface and groundwater to integrate and modulate stream ecological processes, and thereby serves as a refuge and habitat for a diverse range of aquatic organisms, from bacteria to invertebrates to aquatic worms. It also can influence river water quality due to substantial surface area contact with microbial communities and the gradient from oxygenated to unoxygenated waters that can transform and trap nutrients and organic compounds. A conceptual diagram of a hyporheic zone in a gaining stream reach where groundwater is contributing to surface water flows is presented in Figure 1. Note that although a gaining stream is shown in the conceptual diagram, a hyporheic zone also exists in losing (but still interconnected) streams where stream-aquifer interaction is present.

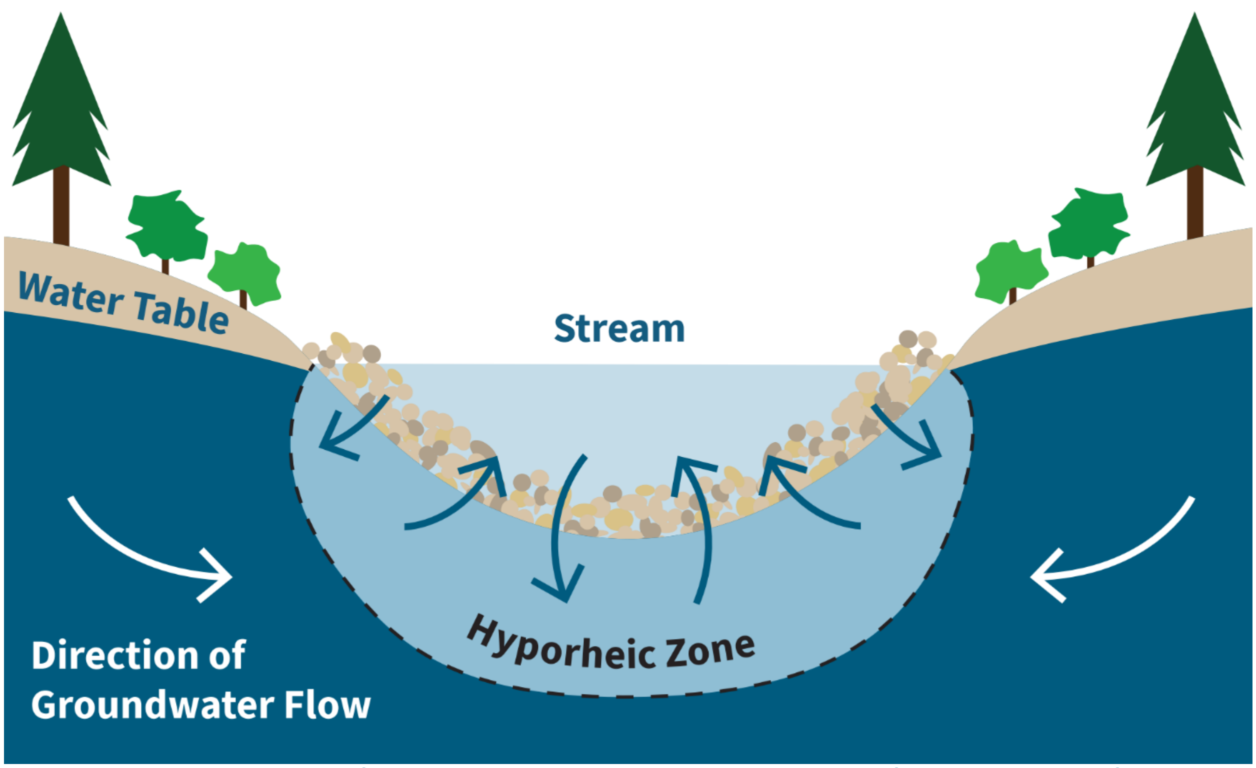

Figure 1: Conceptual Diagram of a Saturated Hyporheic Zone Surrounding a Surface Water Channel for a Graining Reach

The hyporheic zone may connect surface and groundwater when groundwater elevations are sufficiently high enough to intersect the subsurface streambed, and thus constitute ISWs. SGMA regulations define an ISW as "surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted." (CAL. CODE REGS. tit. 23 § 351(o)). Accordingly, the presence of an ISW implies high water levels which may support fish passage by adding water to the stream via baseflow. Moreover, an ISW allows for the transfer of nutrients dissolved in groundwater to the stream. Both GDEs and ISWs are connected to groundwater over some vertical extent: for ISW, the streambed clogging layer must reach into saturated groundwater in order to be interconnected, and for GDEs, the rooting depth must reach into saturated groundwater to be "groundwater-dependent" (CAL. CODE REGS. tit. 23 § 354.16).

Identifying Mapped Potential GDEs

A series of geospatial datasets were used to identify potential GDEs in this analysis. These datasets and the geospatial processing steps used to translate them into an integrated representation of mapped potential GDEs within the SASb are presented in this section.

Class 1 - Aquifer Cave Systems

Aquifer cave systems are typically found in karstic limestone formations, where mineral dissolution creates caves that fill with groundwater. These systems are included here for completeness, but do not exist in the fluvial-alluvial clastic sedimentary deposits of California's Central Valley, as defined in the SASb's Hydrogeologic Conceptual Model (Chapter 2 of the GSP, Plan Area), and therefore are not identified or mapped in this study.

Class 2 - Wetlands

The second class of GDEs, referred to here as wetlands, are those ecosystems that rely on a surface expression of groundwater, such as natural springs, perennial wetlands, and rivers supplemented by groundwater. Three datasets were combined to create a representation of assumed mapped potential wetland GDE polygons including the:

- National Wetlands Inventory (NWI) developed and distributed by US Fish & Wildlife;[3]
- California Aquatic Resource Inventory (CARI) developed and distributed by the San Francisco Estuary Institute;[4] and
- Natural Communities Commonly Associated with Groundwater Wetlands (NCCAG-W) dataset developed by a working group comprised of California Department of Water Resources (DWR), California Department of Fish and Wildlife (CDFW), and The Nature Conservancy (TNC) distributed by California DWR.[5]

The NCCAG-W and CARI datasets incorporated the NWI during their development, yielding a number of mapped potential wetland GDEs identified by more than one dataset. The NWI dataset was included in this analysis for completeness. The CARI dataset incorporates the U.S. Geological Survey (USGS) National Hydrography Dataset as well as Sacramento County wetland and stream mapping from the U.S. Army

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[3] *Available at* https://www.fws.gov/wetlands/Data/Data-Download.html.
[4] *Available at* https://www.sfei.org/cari.
[5] *Available at* https://data.cnra.ca.gov/dataset/natural-communities-commonly-associated-with-groundwater.

Corps of Engineers.[6] A summary of the areas of mapped potential wetland GDEs identified by each dataset and combination of datasets is presented in Table 1 with spatial distribution of each class presented in Figure 2. A series of four figures presenting the spatial distribution of mapped potential wetland GDEs at a zoomed in extent are presented in Appendix A. Geospatial processing ensured that overlapping areas were not double or triple counted in summaries.

Table 1. Mapped Potential Wetland GDEs Identified by Data Source and Combination of Data Sources in the South American Subbasin

Data Source[7]	Area (acres)	% of Mapped Potential Wetland GDE Area (Total)
NWI* + CARI** (overlap)	6,005	28.8%
CARI ** (no overlap)	5,959	28.6%
NCCAG-W* + CARI** + NWI*** (overlap)	4,693	22.5%
NWI* (no overlap)	3,153	15.1%
NCCAG-W* + NWI*** (overlap)	1,051	5.0%
NCCAG-W*** (no overlap)	0	0.0%
NCCAG-W* + CARI**** (overlap)	0	0.0%
Total	20,861	100%

*National Wetland Inventory (NWI) (total acres; 14,902)
** California Aquatic Resource Inventory (CARI) (total acres; 16,657)
*** Natural Communities Commonly Associated with Groundwater– Wetlands (NCCAG-W) (total acres; 5,744)

[6] *Available at* https://www.sfei.org/projects/six-county-aquatic-resource-inventory.
[7] “Overlap” indicates the intersection of two datasets for purposes of analysis that are not additive in acreage; “no overlap” indicates there is no intersection between datasets.

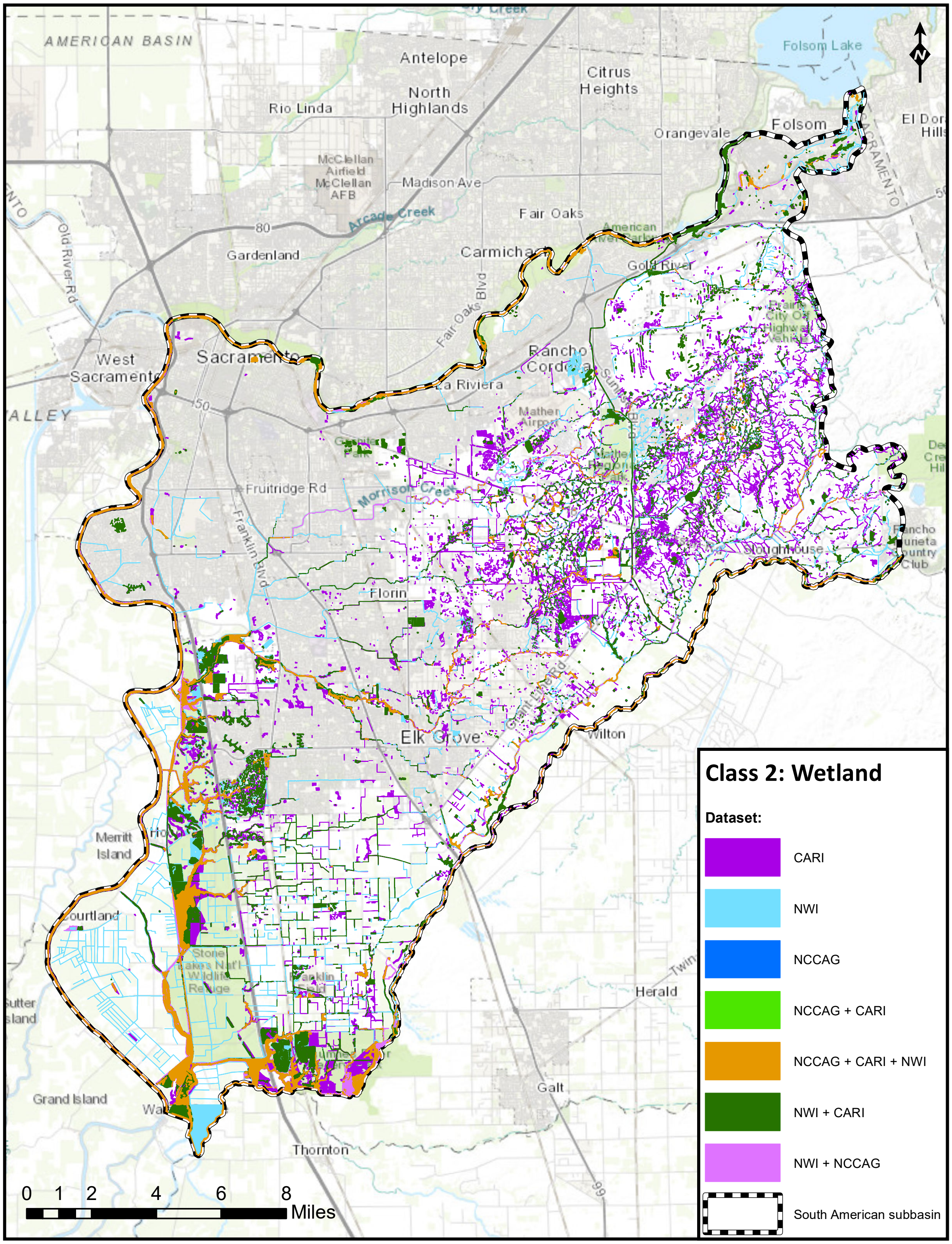

Figure 2: Mapped Potential Wetland GDEs Identified by Data Source and Combination of Data Sources in the South American Subbasin

Class 3 – Non-Wetland Vegetation

The third class of GDEs are non-wetland vegetation that rely on at least temporary connection to groundwater. Three datasets were combined to create a representation of assumed mapped potential non-wetland GDEs polygons including the:

- Natural Communities Commonly Associated with Groundwater Vegetation (NCCAG-V) developed by a working group comprised of California Department of Water Resources (DWR), California Department of Fish and Wildlife (CDFW), and The Nature Conservancy (TNC) distributed by California DWR;[8]
- South Sacramento Habitat Conservation Plan (SSHCP) landcover,[9] and
- CDFW Vegetation augmented with project-based mapping for a landscape management scenario analysis.[10]

A summary of the areas of mapped potential wetland GDEs identified by each dataset and combination of datasets is presented in Table 2 with spatial distribution of each class presented in Figure 3. A series of four figures presenting the spatial distribution of mapped potential non-wetland GDEs at a zoomed in extent are presented in Appendix B. There is notable overlap between these datasets and distinct polygons from each source. Notably, the SSHCP/Underwood dataset incorporates many more stands of isolated trees.[11] The relative acreage of those mapped GDE features demonstrates that riparian species occupy double the area of underwood species. For the purpose of this analysis, the presence of a non-wetland potential mapped GDE polygon was considered to be an initial indicator of the presence of this class of GDE. The absence of vegetation in otherwise appropriate locations in near contact with shallow groundwater does not preclude classification as a GDE if additional evidence indicates the existence of a GDE.

Table 2. Mapped Potential Non-Wetland GDEs Identified by Data Source in the South American Subbasin

Data Source[12]	Area (acres)	% of Mapped Potential Non-Wetland GDE Area (Total)
NCCAG-V* (no overlap)	4,166	40.2%
SSHCP/Underwood** (overlap)	2,033	19.6%
NCCAG-V & SSHCP (overlap)	4,168	40.2%
Total	10,367	100%

*Natural Communities Commonly Associated with Groundwater – Vegetation (total acres; 8,334)
**South Sacramento Habitat Conservation Plan (total acres; 6,201)

[8] *Available at* https://data.cnra.ca.gov/dataset/natural-communities-commonly-associated-with-groundwater.
[9] This dataset is referred to as SSHCP/Underwood as the data was provided by E. Underwood and R. Hutchinson. *Available at* https://escholarship.org/uc/item/8700x95f.
[10] *Available at* https://wildlife.ca.gov/Data/VegCAMP.
[11] This is perhaps due to the focus of the landscape management planning on carbon storage and 16 local bird species.
[12] "Overlap" indicates the intersection of two datasets for purposes of analysis that are not additive in acreage; "no overlap" indicates there is no intersection between datasets.

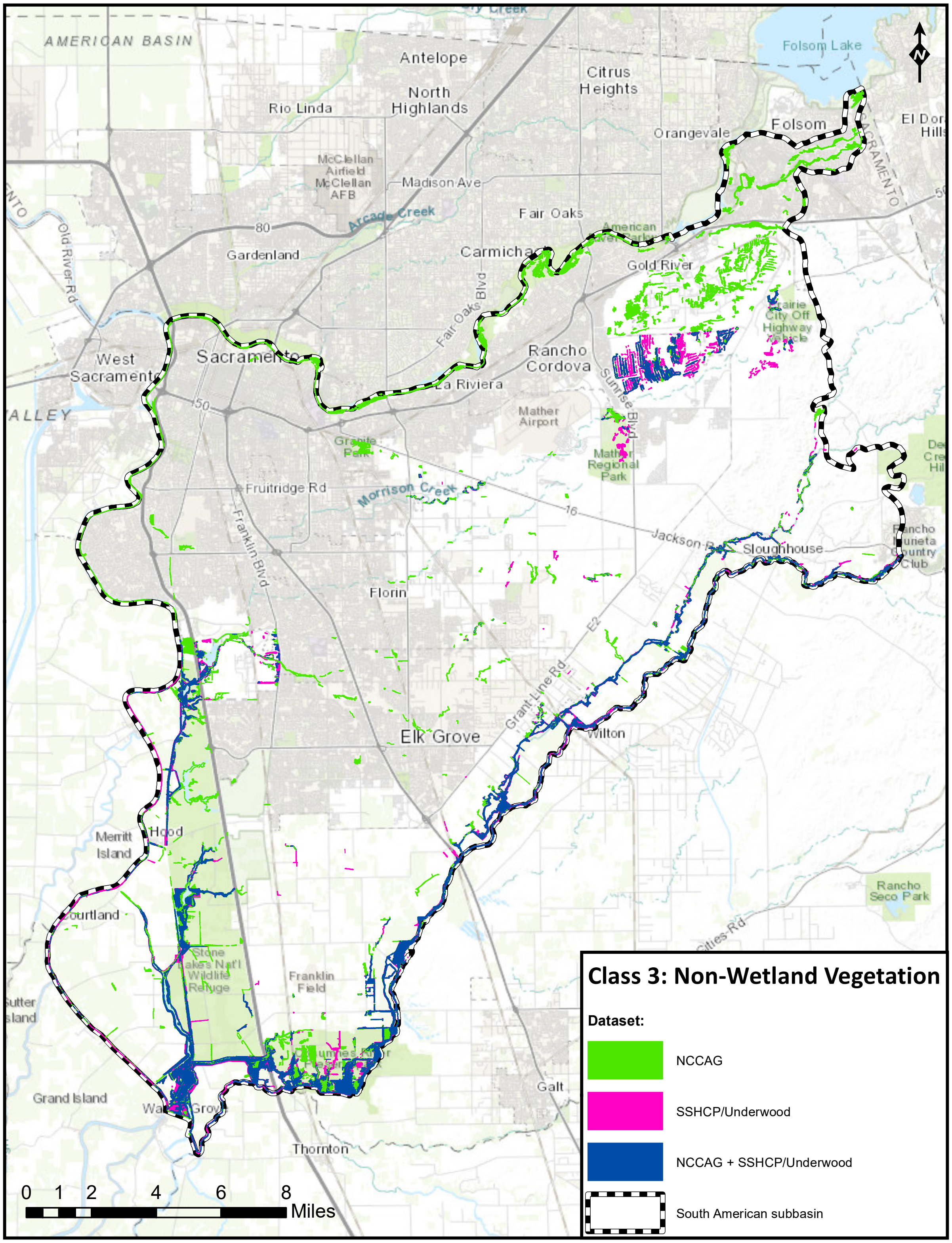

Figure 3: Mapped Potential Non-Wetland GDEs Identified by Data Source in the South American Subbasin

Rooting Zone Depth Threshold

Roots and rooting depths help plants maintain access to water. Although the rooting depths of mature vegetation may be relatively static, groundwater level fluctuations caused by pumping may temporarily or permanently disconnect roots from saturated groundwater, which may impact plant health. The California Department of Fish and Wildlife (CDFW), in collaboration with other entities, has collected data from a variety of sources to create a comprehensive list of phreatophytes, or plants that require significant contact with the groundwater table, and assigned maximum rooting zone depths by species based on available literature. This State-wide CDFW dataset was revised to more effectively reflect the vegetative communities within the SASb and is presented in Appendix C. Deeply rooted species not typically found in the region (e.g., desert species) and species that lacked rooting depth data were excluded. Plants were included if found locally, if they were native, and if their plant family or *Genus* had a reported rooting depth.

The maximum reported rooting depths of the plant species found in the SASb range from near-surface for grasses like creeping wildrye (3.84 feet) to deep-rooted trees like the Valley Oak (24.31 feet). Rooting depths of species within the SASb were evaluated, and the Valley Oak (*Quercus lobata*) was found to exhibit the largest rooting depth[13]. Because plants can extract moisture from pore spaces away from the roots themselves, a threshold depth of 30 feet was used as a cutoff for the maximum depth of groundwater that could reasonably be accessed by a GDE within the SASb. Areas within the SASb where depth to groundwater is consistently greater than 30 feet are therefore assumed incapable of supporting non-wetland GDE communities and by extension, any GDEs. In the context of identifying GDEs, this 30-foot depth threshold is very conservative and overly inclusive as shallower groundwater is likely required to support a broader array of healthy GDEs in most circumstances.

Depth to Groundwater

Available groundwater monitoring datasets were used to develop statistical representations of groundwater elevation for 12 four-year running periods for both spring and fall between 2005 and 2008 (e.g., spring 2005, 2006, 2007, and 2008 representing spring 2005 – 2008). These groundwater elevations[14] were developed by interpolating mean observed groundwater for each season with ordinary kriging. Seasonal, four-year running mean interpolated groundwater elevations in the SASb from spring 2005 to fall 2019 (Figure 4) show seasonal oscillation, with generally higher (blue) groundwater elevation in spring, and generally lower (red) groundwater elevation in the fall. Groundwater flows from areas of high (blue) to low (red) groundwater elevation. Groundwater elevation mapping indicates groundwater flow inwards towards the center of the basin, coincident with areas of groundwater pumping.

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[13] Coast Live Oak (*Querus agrifolia*) is also present in the SASb and has an average maximum rooting depth of 35.1 feet, however, it occupies 2.3 acres, and is thus neglected. By comparison, Valley Oak (*Quercus lobata*) has an area of 2937.0 acres, thus we use the Valley Oak to set the upper bound of maximum rooting depth expected in the SASb.

[14] The full methodology for groundwater level interpolation is discussed in the accompanying technical memo, "Interconnected Surface Water in the South American Subbasin: Historical and Present-day Characterization, and Approaches for Monitoring and Management" and a brief summary is presented here.

The seasonal summary of interpolated groundwater elevations (Figure 5) shows oscillating seasonal medians, with consistently higher groundwater elevations in spring, and lower groundwater elevation in fall. Median fall groundwater elevation decreases over the period of record and reaches its lowest value during the average period of 2013-2016 due to the combined impact of four years of drought. After this minimum, spring and fall median groundwater levels trend upward.

Groundwater elevations were translated into depth to water by subtracting kriged groundwater elevations from the elevation of the land surface represented by Sacramento County's one-foot resolution digital elevation model (DEM).

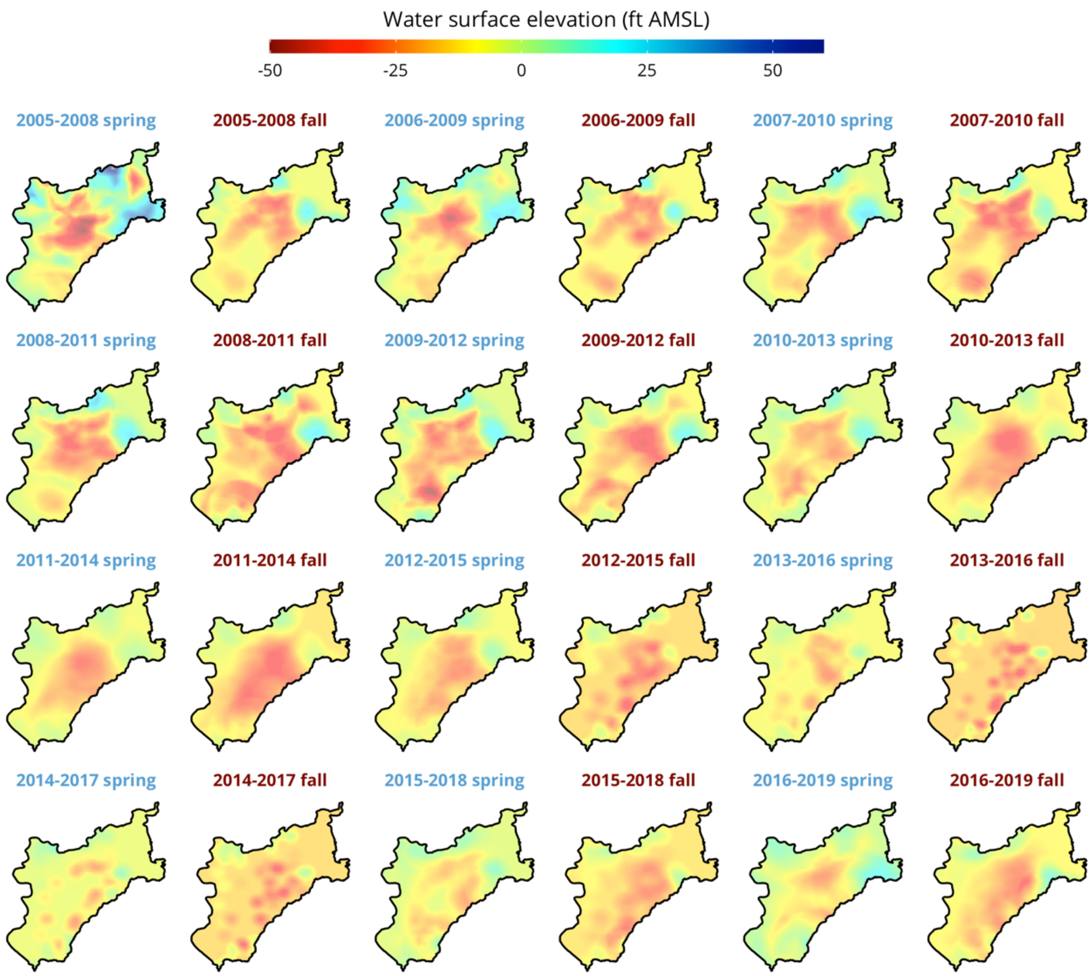

Figure 4. Groundwater Elevation (feet above mean sea level) for Four-Year Running Seasonal Groundwater Level Mean in the South American Subbasin

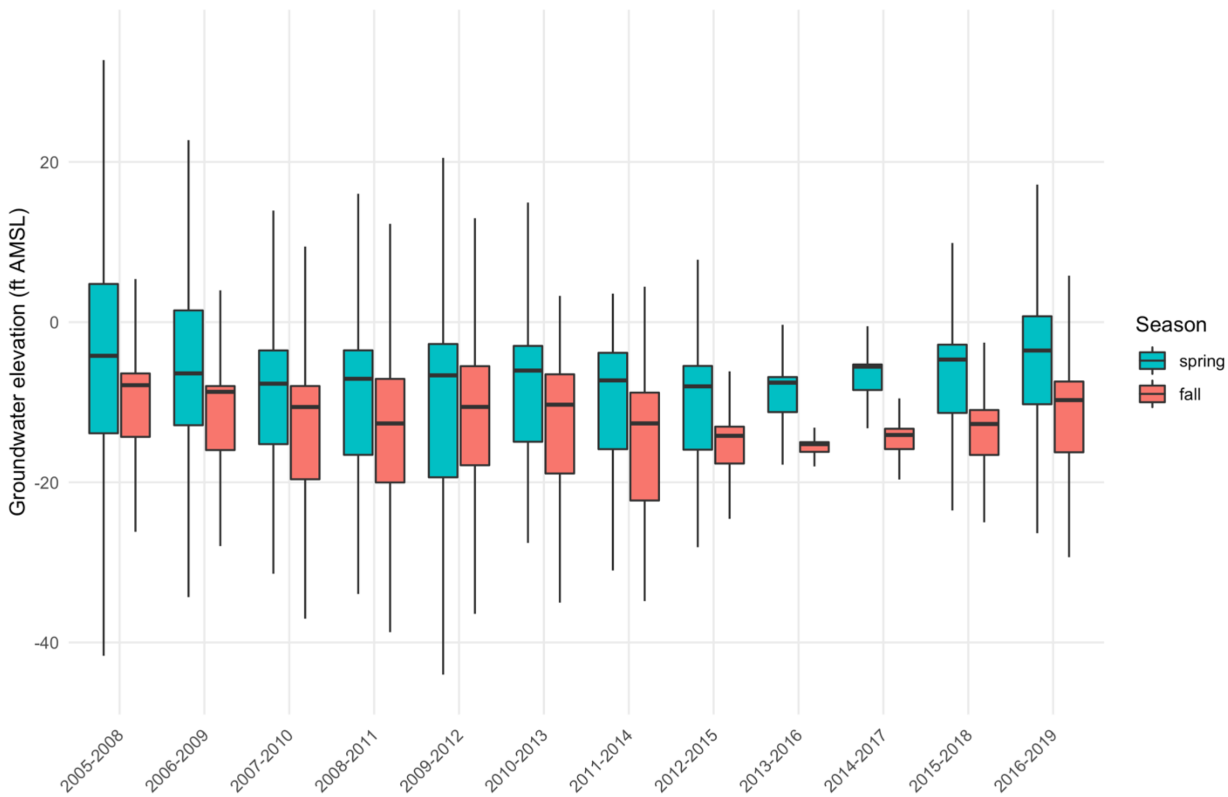

Figure 5. Box Plot Summary of Groundwater Elevations for Four-Year Running Mean Values by Season for the South American Subbasin

Mapped Potential GDE Classification

The maximum assumed extent of all mapped potential GDEs was established by combining class 2 mapped potential wetland GDEs (Figure 2) and class 3 mapped potential non-wetland GDEs (Figure 3). A two-tier classification approach (Figure 6) was developed and applied to classify GDE based on assumed access to groundwater.

The first-tier classification involved computing an area-weighted statistical representation of depth to groundwater for each mapped potential vegetative GDE area using the zonal statistics function available in many GIS programs. This zonal statistics function identifies what cells of the depth to groundwater grid or raster dataset fall within the bounds of each mapped potential GDE and then computes an area-weighted average for that area. The 30-foot depth to groundwater threshold discussed in the Rooting Zone section above was applied to each of the 24 four-year running depth to groundwater rasters for fall and spring independently to separate mapped potential GDEs into two classes: "Assumed GDE" and "Assumed Not GDE." Areas where the area-weighted depth to groundwater was less than or equal to 30 feet were classified as "Assumed GDE" for that single four-year running representation of groundwater conditions. Conversely, areas where the area-weighted depth to groundwater was greater than 30 feet were classified as "Assumed Not GDE" for that single representation of groundwater conditions. A box plot summarizing the proportion of mapped potential GDEs split into "Assumed GDE" and "Assumed Not GDE" classes for each seasonal four-year running depth to groundwater raster or grid is presented in

Figure 7. Figures showing the spatial distribution of the classification of mapped potential GDEs into "Assumed GDE" and "Assumed Not GDE" classes for each of the four-year running depth to groundwater rasters or grids are presented in Appendix D. The difference in spring (blue) and fall (red) GDE proportion ranges from 0.4 – 7.3% (hovering text boxes) and represents natural historic seasonal and interannual variance across the period of record evaluated. The largest differences in the seasonal range occur during running means that contain years within the 2012 – 2016 drought and suggest that dry conditions may cause desiccation of mapped potential GDEs. Over the period of record evaluated, the area classified as "Assumed GDE" ranges, at a maximum, from around 44% to 54%.

The second tier of the assessment further classifies "Assumed GDE" and "Assumed Not GDE" polygons into GDE likelihood classes based on how often groundwater was within 30 feet of the polygon during the 2005-2019 record examined (**Error! Reference source not found.**). A tabular summary of GDE likelihood classes is presented in Table 4 and the spatial distribution of each category presented in Figure 8. The key difference between the Tier 1 and Tier 2 classification is that multiple representations of depth to groundwater are incorporated into the second tier of the analysis to evaluate longer term trends or persistent conditions.

Table 3. GDE Likelihood Class Descriptions

Class	Definition
GDE	Areas classified as "Assumed GDE" for 100% of groundwater conditions from 2005-2019
Potential GDE - Likely	Areas classified as "Assumed GDE" for more than 50% of groundwater conditions from 2005-2019
Potential GDE - Unlikely	Areas classified as "Assumed GDE" for less than or equal to 50% of groundwater conditions from 2005-2019
Not GDE	Areas classified as "Assumed Not GDE" for 100 % of groundwater conditions from 2005-2019

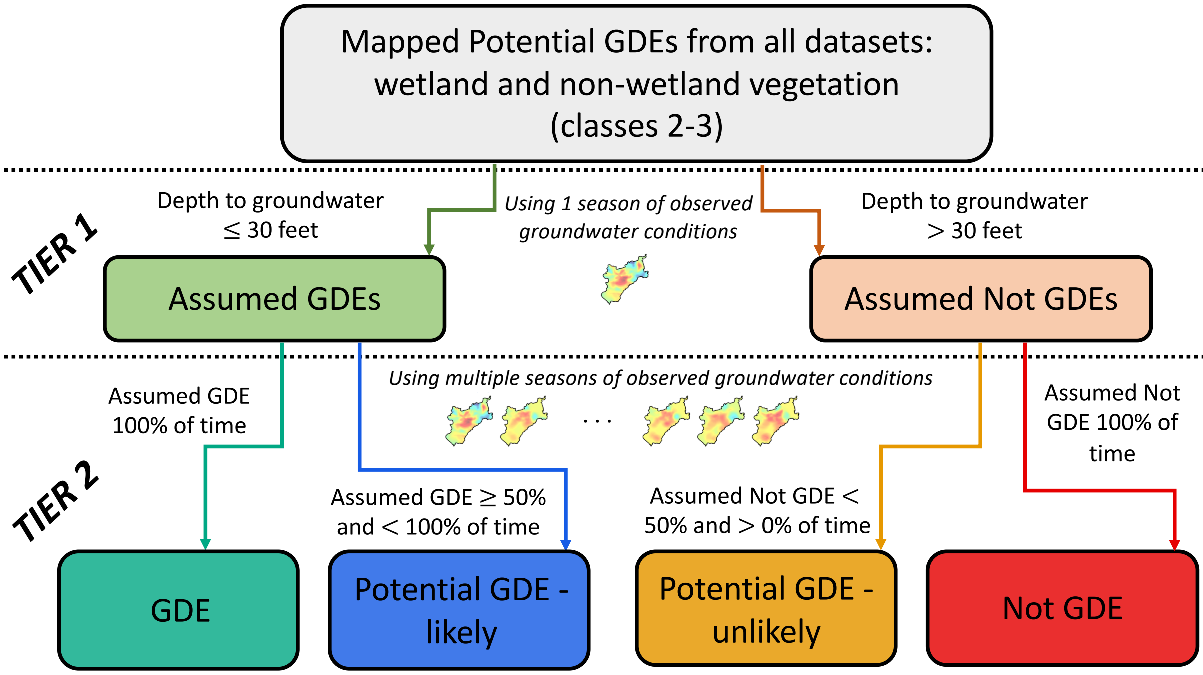

Figure 6. Conceptual Diagram Showing the Two-Tier GDE Classification Process

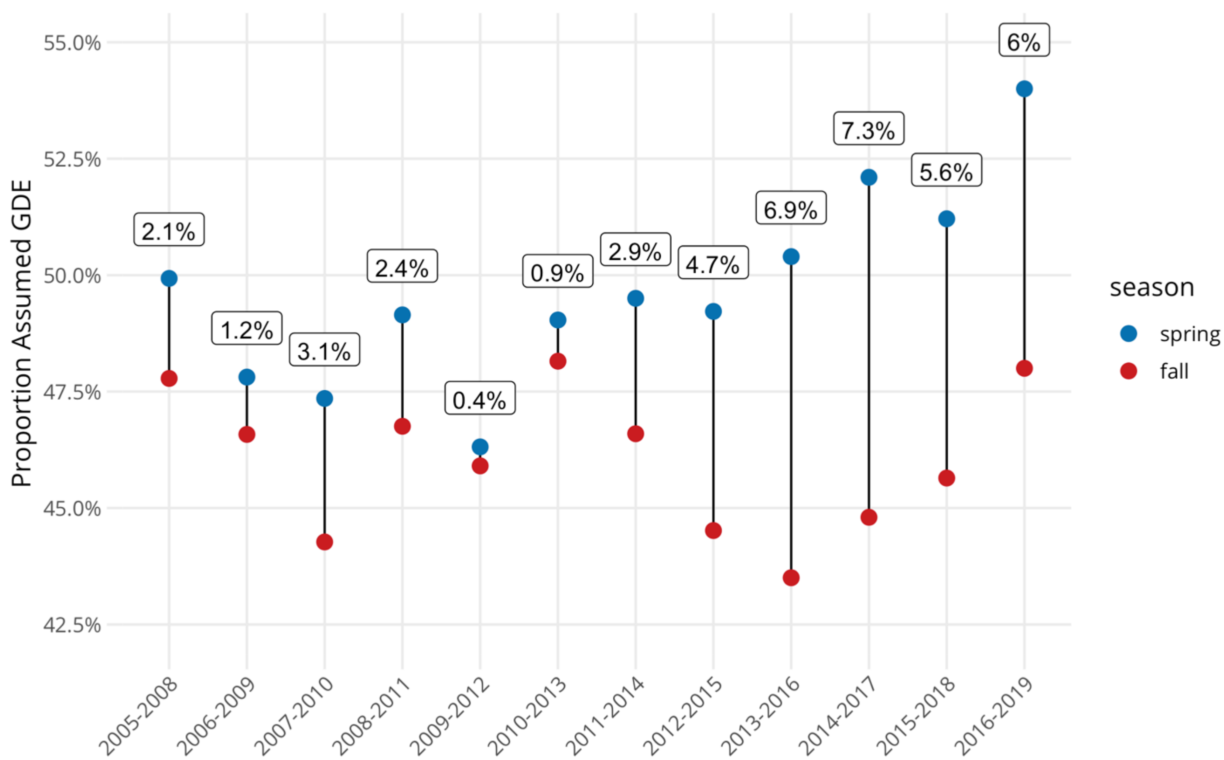

Figure 7. GDE Classification Based on the Application of a 30 ft. Depth to Groundwater Threshold on Mapped Potential GDEs

Table 4. GDE Likelihood Categorization Based All 4-year Groundwater Elevations from 2005-2019

Category	Area (acres)	% of Mapped Potential GDE Area
GDE	11,340	43.2%
Potential GDE - Likely	1,695	6.5%
Potential GDE - Unlikely	914	3.5%
Not GDE	12,296	46.9%
Total	26,245	100%

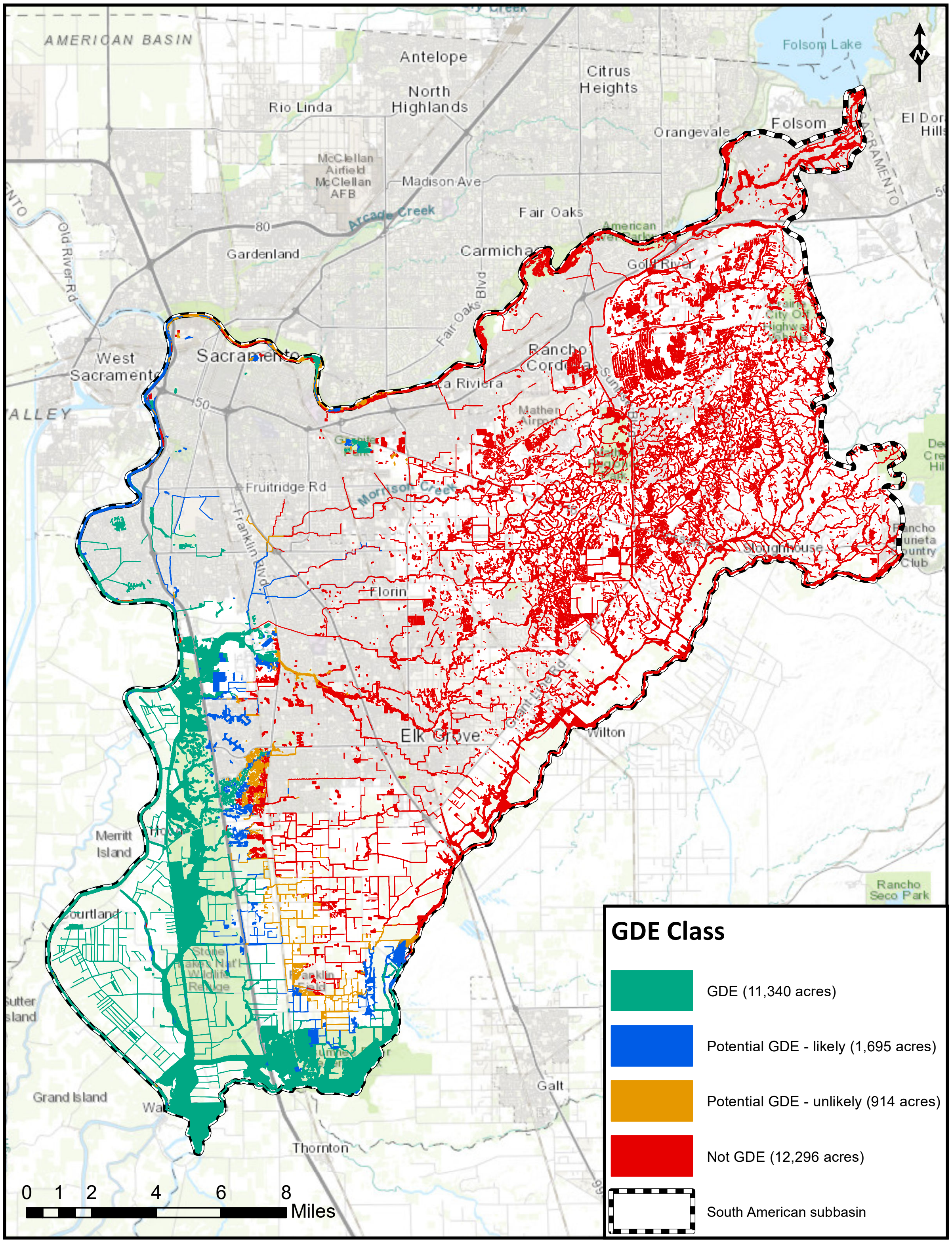

Figure 8. GDE Likelihood Classification of all Mapped Potential GDEs Over the Entire Period of Record (2005-2019)

GDE Categorization Through Aerial Imagery

An additional evaluation using aerial imagery and remote sensing techniques was carried out to validate, to the extent feasible, the Tier 2 GDE likelihood classification driven by the relationship of mapped potential GDE polygons to groundwater conditions. As previously discussed, the 30-foot depth to groundwater threshold is conservatively inclusive of GDE areas. In the SASb, only the Valley Oak would reasonably access groundwater close to 30 feet below ground surface. Thus the 30-foot threshold is most effective in identifying "Assumed Not GDE" areas based on SASb-scale representation of groundwater levels. A secondary evaluation of the classification of mapped potential GDEs into "GDE", "Potential GDE - Likely", "Potential GDE - Unlikely", and "Not GDE" classes was therefore required to account for the complex relationship between vegetation rooting depth and dynamic groundwater conditions.

Rooting depths for species vary over time as plants grow. Cottonwoods are a salient local example of the complex relationship between dynamic rooting zones and groundwater conditions because they are a relatively long-lived, deep-rooted and well-studied species commonly found in the SASb. Cottonwood seedlings require contact with moisture to sprout and elongate their roots rapidly to meet the groundwater or to follow it as water tables decline following floods. Mahoney and Rood (1992) identified that the maximum rate of root elongation was 0.47 inches per day (12 mm/day) for cottonwoods, with a 3.94 inch per day (10 cm/day) decline in experimental conditions, which matched field analysis on the cottonwood species (*P. fremontii*) found in this part of California. In other words, as groundwater levels fall, roots respond by elongating. Moreover, roots can access water through capillary action in soils with more fines (e.g., sand and smaller) and can be cut off more quickly in well-drained cobbles and boulder soils, highlighting the dependence of subsurface geology on root access to groundwater. The complexity of the root-water interface challenges measurable and scalable management criteria, thus we assume that above-ground differences in plant health (measured by plant "greenness" discussed below) are a reasonable proxy for unseen, below-ground processes. With all else being equal, greener plants presumably have greater access to groundwater, and drier plants have less access to groundwater.

An aerial imagery analysis was performed to evaluate the difference in Normalized Difference Vegetation Index (NDVI)[15] values between GDE likelihood classes. NDVI is a dimensionless measure of how surface vegetation reflects light in the visible and near-infrared parts of the electromagnetic spectrum and is a popular approach to estimate plant and community health at scale. The chlorophyll present in healthy plants absorbs visible light while the cellular structure of vibrant vegetation cover such as leaves strongly reflects near-infrared light. Healthy vegetation reflects more near infrared light and dry, unhealthy vegetation reflects more visible red light. NDVI exploits this material property of plants and is used to measure the relative health of vegetation in the SASb. Importantly, NDVI may be zero or negative for soil and water land cover classes, and NDVI can only be calculated at the scale of the pixel. Mixed pixels which contain vegetation, soil, and water have lower NDVI because soil and water do

[15] NDVI is calculated as (NIR-Red) / (NIR + Red), where NIR is reflectance measured in the near infrared portion of the electromagnetic spectrum (750 - 1400 nanometers), and Red is red visible light (625-740 nanometers).

not reflect as strongly in the near infrared; these pixels were included in this analysis, and a spectral unmixing analysis was not performed.

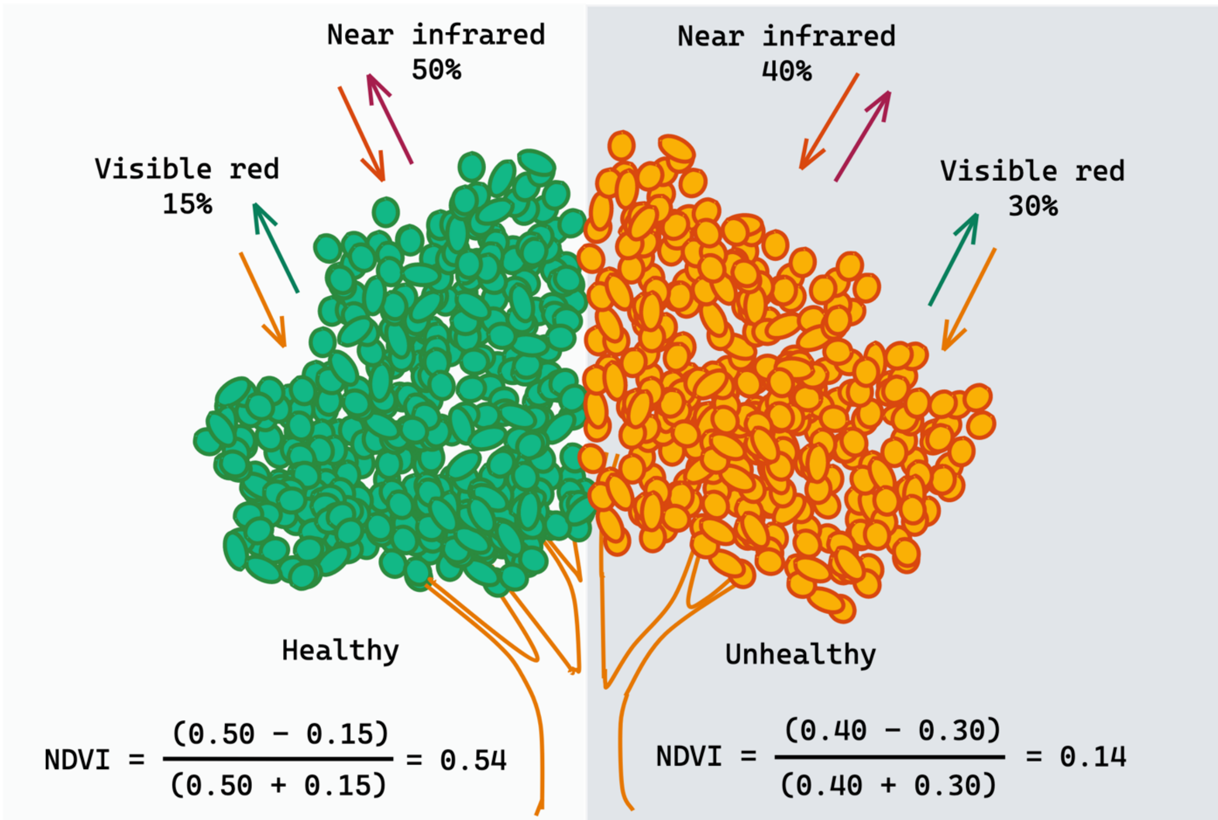

Figure 9: Normalized Difference Vegetation Index (NDVI) is higher for healthy vegetation and can be zero or less than zero for soil and water, and occurs when reflected red light exceeds reflected near infrared light.

Imagery from U.S. Department of Agriculture's (USDA) National Agriculture Imagery Program (NAIP) was obtained for summer dates from 2009-2020 when available (Table 5). NAIP imagery is generally available for a given area for one day a year during the growing season and was typically collected between late June and mid-July in the SASb. The previously discussed zonal statistics function within a GIS was used to compute grid-level NDVI values for each mapped potential GDE. NDVI values were summarized by GDE likelihood class for each NAIP imagery date (Figure 10). The NDVI distribution for areas classified as "GDE" consistently exhibit higher median NDVI compared to all other classes. Moreover, the "Potential GDE - likely" class tends to have the widest interquartile range across the years evaluated, which is unsurprising as this class is assumed to reflect vegetation where depth to groundwater is less than 30 feet in more than 50% of representations of groundwater conditions. The NDVI classification generally shows that areas assumed to have access to groundwater based on the Tier two GDE likelihood classification ("GDE" areas) have higher median and 75th percentile NDVI values (i.e., healthier vegetation) than other categories. This demonstrates that GDE can be used to separate Tier two "GDE" areas from other Tier two categories. Conversely, areas assumed to have limited or no access to groundwater based on the Tier two GDE likelihood classification such as "Not GDE", "Potential GDE -

Unlikely", "Potential GDE - Likely" classes are associated with lower median NDVI values and therefore are reasonably assumed to have less coverage, or less healthy vegetation. Moreover, class are relatively inseparable based solely on NDVI within these three non "GDE" Tier two classes.

Table 5. National Agriculture Imagery Program (NAIP) Image Dates used in this study

Calendar Year	Date
2009	June 21
2012	June 28
2014	June 5
2016	June 21
2018	July 14
2020	July 7

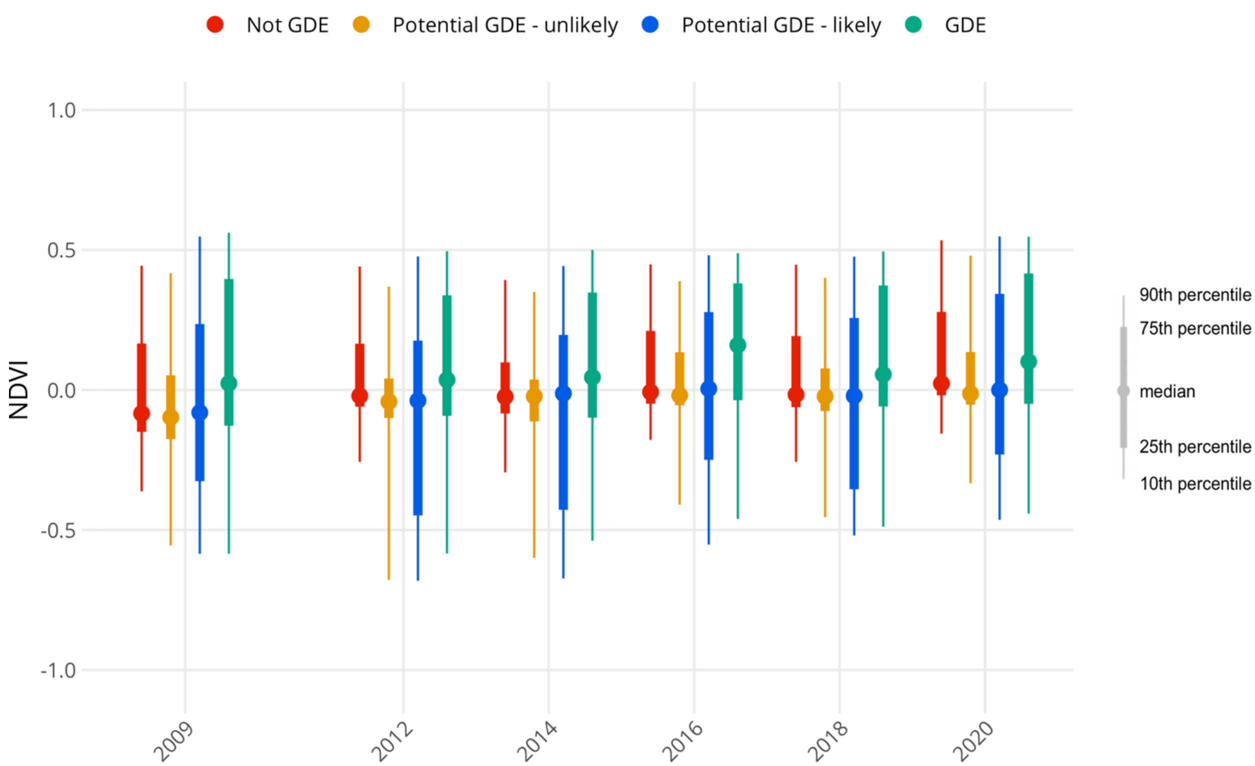

Figure 10. Distribution of Normalized Difference Vegetation Index (NDVI) Values by Tier two GDE Likelihood Class for Each National Agriculture Imagery Program (NAIP) Imagery Date

MANAGING GDEs

Wetland and non-wetland GDEs within the SASb are assumed to depend on shallow groundwater to support mature vegetation and seedling establishment (Rood et al., 2003). Shallow groundwater level decline may result in reduced plant growth and, in more severe cases, lead to plant mortality (Shafroth et al., 2000). Moreover, groundwater extraction can impact the shallow groundwater levels that support hydrophilic vegetation (Rood et al., 2003; Scott et al., 1999; Shafroth et al., 2000). For instance, Stromberg and colleagues (1996) found that mature cottonwood and willow trees required mean depths to groundwater in the range of nearly five feet and moderate, persistent reductions in groundwater level jeopardized the species' fitness. Moreover, seasonal fluctuations in groundwater levels are normal and once established, riparian species can survive periodic declines (Stromberg & Patten, 1992). Management of GDEs will therefore focus on defining Undesirable Results and setting measurable objectives (MOs) that account for the natural variability in depth to groundwater and surface vegetation composition represented by NDVI across the SASb. The governing philosophy of the proposed management criteria is to avoid previously un-observed conditions (defined by historical variability in groundwater and GDEs) – these criteria are measured in terms of groundwater level and NDVI.

Definition of Undesirable Results

Establishing a clear definition of Undesirable Results and the quantitative criteria by which these results are identified is a key outcome of the GDE management plan within the context of SGMA.

Undesirable Results for GDEs in the SASb are experienced when GDE area or plant health falls below 2015 minima, which indicate impacts to GDEs in excess of natural variability.

Bear in mind, the "natural variability" included in this contemporary historical range includes the impacts of the 2012-2016 drought, and pre-SGMA groundwater management.

Identification of Undesirable Results

The identification of Undesirable Results is based on how depth to groundwater and NDVI relate to historical Tier 1 and Tier 2 GDE classifications (Figure 6): if Tier 1 "Assumed GDE" area or Tier 2 "GDE" health declines below historically observed (2005-2019) natural variability, Undesirable Results occur. If either of the following criteria occur for three consecutive years during the implementation horizon, Undesirable Results are identified:

- **Criteria A (based on Tier 1 classification):** The proportion of Tier 1 "Assumed GDE" class falls below 44% (the lowest historically observed proportion of "Assumed GDE" occurring in fall 2013-2016)
- **Criteria B (based on Tier 2 classification):** Median June NDVI across the Tier 2 "GDE" class falls below 0.023 (the lowest historical median NDVI value, observed in June 2009). The Tier 2 "GDE" class is computed using observed groundwater conditions from the previous five fall seasons.

Criteria A was defined by reviewing the GDE likelihood categorization based on the relationship between area-weighted depth to groundwater value and the 30-foot threshold. The fall seasonal depth to groundwater from 2013-2016 represented the lowest proportion of historically observed Tier 1 "Assumed GDE" and "Assumed Not GDE" classes, with 44% of mapped potential GDEs falling into the "Assumed GDE" category. Thus, this criterion stipulates that Undesirable Results are identified if the proportion of the area in the "Assumed GDE" class falls to levels roughly observed during the 2012-2016 drought and remains there for three consecutive years.

Criteria B was defined by identifying the lowest historical median NDVI value (0.023) for the Tier 2 "GDE" class observed in the June 2009 NAIP imagery (Figure 10). Notably, this date precedes the 2012-2016 drought and represents an NDVI minimum based on natural variability in GDE vegetation. If the median "GDE" NDVI falls below the historically observed median "GDE" NDVI (0.023) this equates to a reduction in median plant health previously unobserved in the SASb. The Tier 2 “GDE” class is computed using the previous five fall groundwater level conditions, to represent a running five-year window of relatively recent groundwater conditions. Using the entire historical record (2005 - present) was considered, but it was determined that a running five-year window would be more representative of present-day conditions during the implementation horizon.

Collectively, Criteria A and B are based on Tier one and two GDE classification, and measure changes to GDE area and health, respectively. Thus, during an implementation year, even if GDE area may appear constant according to Criteria A, Criteria B will provide a lens into GDE conditions. Similarly, if GDE conditions are constant according to Criteria B, Criteria A will provide a lens into how GDE area has changed.

Median NDVI close to zero may be misinterpreted as indicating unhealthy vegetation. In fact, NDVI values form a distribution. In the year with the lowest median NDVI (2009), half of NDVI values in areas identified as “GDE” exceed 0.023, and half fall below this value. These Tier two GDE areas (groundwater within 30 feet of land surface in 100% of times evaluated) include vegetated areas (NDVI > 0), non-vegetated areas like water and soil (NDVI ≤ 0), and mixed pixels that contain vegetation, soil, water, and other materials (NDVI ≤ 0, and sometimes > 0). Median NDVI in Tier two GDE areas that falls below 0.023 during the implementation time period indicates the areas which are consistently within 30 feet of groundwater have become less photosynthetic as a whole, which indicates loss of healthy vegetation in excess of historically observed natural variability in NDVI. If this criteria is observed, it should be considered alongside Criteria A, and change in NDVI maps should inform strategic field-based monitoring.

Table 6. Quantitative Definition of Undesirable Results

Identification of Undesirable Result	Historical minimum observed	Quantitative Metric
Criteria A: Proportion of Mapped Potential GDE Classified as “Assumed GDE” in Tier 1 GDE Likelihood Analysis	2013-2016 Fall	44%
Criteria B: Lowest Median NDVI for “GDE” in Tier 2 GDE Likelihood Analysis	June 2009	0.023

Both criteria to identify Undesirable Results use metrics based on evolving representations of mapped potential GDE areas and hence allow for the future addition or removal of mapped potential GDE areas as the composition of surface vegetation within the SASb is more comprehensively understood. Furthermore, future iterations of this GDE analysis can be carried out and compared to the period or dates associated with the quantitative definitions of Criteria A and B. In subsequent implementation years, a dataset representing the current understanding of the spatial distribution of class 2 wetland and class 3 non-wetland mapped potential GDEs will be developed and set the extent of the GDE analysis.

Mapped potential GDEs will be undergo Tier 1 classification into “Assumed GDE” and “Assumed Not GDE” classes by applying the 30-foot threshold based on the current representation of depth to groundwater (Figure 6). If the proportion of mapped potential GDEs classified as “Assumed GDE” in Tier 1 is less than 44% for 3 consecutive years, an Undesirable Result is observed. A comparison of “Assumed

GDE" Tier 1 class for the current year and the 2013-2016 Fall period will reveal areas where changes in groundwater conditions have moved areas into the "Assumed Not GDE" Tier 1 class.

Areas will then be further classified consistent with the Tier 2 criteria into GDE likelihood classes (**Error! Reference source not found.**). NDVI summary statistics will be computed for each Tier 2 GDE likelihood class based on groundwater conditions for five fall seasons (the year of the evaluation and the previous four years). If the median NDVI for areas that fall into the Tier 2 "GDE" class is less than 0.023, an Undesirable Result is observed. A map showing pixel NDVI change between the NDVI for the year in question with the June 2009 date used to establish the Undesired Result metric will show what areas have experienced vegetative condition change.

Measurable Objectives

Measurable objectives (MOs) are sustainable management targets to reach within the implementation horizon. The clear relationship between Tier 2 GDE likelihood classes based on depth to groundwater and NDVI (Figure 10) suggest that sustainable management criteria for groundwater which maintain groundwater levels within 30 feet of land surface in existing GDE areas will support GDE health.

Like the identification of Undesirable Results, MOs for GDE health are based on maintaining or exceeding the average historically observed GDE area proportion and NDVI. GDE MOs for the implementation horizon are summarized as follows:

- Tier 1 "Assumed GDE" class remains at 48% or higher (mean of GDE area proportion from 2005-2019)
- Median five-year running June NDVI for the Tier 2 "GDE" class remains at or above 0.07 (average median June NDVI over NAIP period of record evaluated in this study)

Stabilization at these levels implies GDE area and plant health consistent with average historical conditions.

GDE-ASSOCIATED BENEFICIAL USES & USERS

There are a variety of aquatic, amphibious and riparian species that may be associated with GDEs in the SASb. In order to better understand these users and their uses of aquatic and riparian habitat, the analysis includes a report from CDFW's Biogeographic Information and Observation System (BIOS), a database that provides a comprehensive list of special status species and some of their habitat in Sacramento County.[16] The database does not allow querying by Bulletin 118 subbasins. As such, it contains more species than are found in the SASb, as well as some species that are found in the general watershed but have not been identified as occupying this region. The complete list and an annotated list of those species and habitats that have known or likely relationships to GDEs are included in Appendix E. These environmental beneficial users have the potential to be impacted through chronic or acute lowering of water tables.

LIMITATIONS

[16] *Available at* https://wildlife.ca.gov/Data/BIOS.

The approach developed and carried out to identify and evaluate GDEs within the SASb represents a conservative application of best available science through the application of reasonable assumptions. Representations of mapped potential GDEs were developed based on available geospatial datasets, though these resources cannot be assumed to be definitive. The vegetation classes present in the datasets outlined in the Mapped Potential GDEs section above are broad and could reasonably represent a broad array of vegetation types precluding the reasonable and defensible assignment of assumed rooting zone depths. Groundwater conditions were represented by the interpolation of observed conditions in the Subbasin's well network. These interpolated groundwater elevations may not reflect smaller scale variations in conditions both in space (less than 500 meters) and time (sub-seasonal). Because the groundwater elevations used herein represent regional, seasonal trends, they cannot capture the impact of perched aquifers on GDE health. Moreover, regional groundwater models such as CoSANA were not incorporated into the analysis.

Notably, GDEs are not necessarily static and can vary in time and space depending on water year type and other environmental conditions. As such, this analysis is not intended to be a definitive cataloging of each class of GDE, but rather a survey of the maximum possible extent of above-ground, vegetated GDEs in the SASb. A physical determination of GDEs must show that roots are connected to groundwater, which would require an infeasible subsurface geophysical survey across the SASb.

NDVI analysis included data from 2009, 2012, 2014, 2016, 2018, and 2020. These 6 years are a sample of water year types and GDE conditions and may not reflect the entire range of natural variation in NDVI across the SASb. SGMA implementation will require the re-calculation of this metric, and over time, a better understanding of the variance in NDVI in Tier two GDE areas will be reached.

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