Groundwater Dependent Ecosystems under the Sustainable Groundwater Management Act

GUIDANCE FOR PREPARING GROUNDWATER SUSTAINABILITY PLANS

The Nature Conservancy

Cover: Egrets and pelicans forage in shallow waters at Cougar Wetlands along the Sacramento River, California. © Mary Ann Griggs/The Nature Conservancy

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Lush riparian forest surrounding Dye Creek in the Dye Creek Preserve, part of the Lassen Foothills Project where The Nature Conservancy administers restorative land management and conservation-compatible ranching techniques on behalf of the state of California. © Ian Shive

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The Nature Conservancy is a global non-profit conservation organization whose mission is to

CONSERVE THE LANDS AND WATERS ON WHICH ALL LIFE DEPENDS.

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ABBREVIATIONS AND ACRONYMS

7DADM	Seven-Day Average of Daily Maximum
ACE	Areas of Conservation Emphasis
BGS	Below Ground Surface
CCR	California Code of Regulations
CFS	Cubic Feet per Second
CPAD	California Protected Areas Database
CNDDB	California Natural Diversity Database
CRAM	California Rapid Assessment Method
DFW	California Department of Fish and Wildlife
DWR	California Department of Water Resources
ECOS	Environmental Conservation Online System
EPA	Environmental Protection Agency
EWR	Environmental Water Requirement
FCGMA	Fox Canyon Groundwater Management Agency
GDE	Groundwater Dependent Ecosystem
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
iGDE	Indicators of Groundwater Dependent Ecosystems
NAIP	National Agriculture Imagery Program
NDWI	Normalized Difference Water Index
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NWI	National Wetlands Inventory
SEAP	Springs Ecosystem Assessment Protocol
SGMA	Sustainable Groundwater Management Act
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

NAVIGATING THE STEPS

This guidance uses the following boxes throughout the document to highlight additional resources, guidance, and key take-away items.

SUPPORTING INFORMATION

Contains relevant background information to complete a step.

WHAT YOU NEED

Includes a list of data and information necessary to complete a step.

GSP REPORTING

Provides suggestions on how to incorporate analysis and conclusions from a step into a Groundwater Sustainability Plan.

WHAT'S IN THIS STEP?

An overview of what a step will entail and how it relates to previous and subsequent steps.

WORKSHEETS FOR THIS STEP:

A list of relevant worksheets from Appendix III for completing a step.

PRODUCTS FROM THIS STEP:

A list of outputs from a step that can be used in a GSP.

WHY THIS STEP?

A list of relevant legal and regulatory provisions that provides the basis for conducting the step.

OVERVIEW

"Coming together is a beginning; keeping together is a process; working together is success."

—HENRY FORD

The Sustainable Groundwater Management Act (SGMA) of 2014 is landmark legislation in California that empowers local agencies, known as groundwater sustainability agencies (GSAs), to sustainably manage groundwater resources for current and future social, economic, and environmental benefits. In addition to balancing these multiple benefits, SGMA includes specific requirements to identify and consider impacts to groundwater dependent ecosystems (GDEs). Recognizing data and resource limitations, The Nature Conservancy developed this guidance document based on best available science to help agencies, consultants, and stakeholders efficiently incorporate GDEs into groundwater sustainability plans (GSPs). The Nature Conservancy's tools and resources are intended to reduce costs, shorten timelines, and increase benefits for both people and nature.

WHAT ARE GDEs AND WHY DO THEY MATTER?

The plants, animals, and natural communities that rely on groundwater to sustain all or a portion of their water needs are collectively known as GDEs (Box 1). California is home to a diverse range of GDEs that include palm oases in the Sonoran Desert, hot springs in the Mojave Desert, seasonal wetlands in the Central Valley, the Sacramento and San Joaquin Rivers and their perennial riparian forests, and estuaries along the coast and in the Delta. These ecosystems rely on groundwater under California's semi-arid and Mediterranean climate, especially during dry summers and periods of drought. However, unsustainable groundwater use can threaten the water quantity and quality that GDEs depend on to survive.

Today, GDEs are found in almost all of California's groundwater basins but are likely to have been more prevalent in the recent past. An ecological assessment of the Central Valley reported that less than 5% of historical wetlands and 6% of riparian vegetation remain (The Bay Institute 1998). The loss of this native habitat over the last century has largely been caused by human activities, such as land conversion and intensive groundwater pumping. Intensive groundwater pumping in California's Central Valley has caused declines in groundwater levels, baseflow to rivers, and surface water flow (The Nature Conservancy 2014). These impacts can alter the extent and quality of riparian and instream habitats by reducing access to groundwater for vegetation and altering temperature and flow regimes necessary for spawning or rearing habitat for native fish.

Impacts to GDEs are problematic for people because GDEs serve society by providing a wide range of ecosystem services (Schuyt & Brander 2004; CGIAR 2015). These ecosystem services include water purification, soil preservation, carbon sequestration, flood risk reduction, and recreational opportunities. When groundwater is unsustainably managed, ecosystems can suffer, compromising these public benefits and the economic opportunities they provide.

BOX 1. SUPPORTING INFORMATION

GDEs are specifically defined under SGMA as "ecological communities of species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface" (23 CCR § 351(m)).

To learn more about GDEs, where they exist, and how groundwater conditions can impact them, visit http://www.groundwaterresourcehub.org.

MEETING SGMA REQUIREMENTS FOR GDEs

SGMA requires that all beneficial uses and users, including GDEs, be considered in the development and implementation of GSPs (Water Code § 10723.2). The GSP Regulations include specific requirements to identify GDEs and consider them when determining whether groundwater conditions are having potential effects on beneficial uses and users. GSAs must also assess whether sustainable management criteria (including minimum thresholds and measurable objectives) may cause adverse impacts to beneficial uses. In addition, monitoring networks should be designed to detect potential adverse impacts to beneficial uses. Visit the website for the California Department of Water Resources (DWR) (https://www.water.ca.gov/Programs/Groundwater-Management) for more guidance on addressing GDEs under SGMA. Relevant requirements from the SGMA statute and regulations are identified throughout this guidance, and legal references are available in Appendix I.

GUIDANCE STRUCTURE

This guidance follows the outline provided by DWR in its GSP Regulations (23 CCR § 350 et seq.). Since many GSAs will be identifying and considering GDEs for the first time, this guidance provides a systematic and defensible approach to identify GDEs, determine whether potential effects on GDEs are occurring or may occur due to groundwater conditions, and consider GDEs when setting sustainable management criteria. This guidance recommends setting sustainable management criteria based on the conditions necessary to avoid adverse impacts to GDEs and undesirable results in the basin, especially where conservation of species and habitats within GDEs is required by other laws, such as the Endangered Species Act (refer to Appendix II for a list of other relevant laws).

This document is designed to inform local decision making, consistent with SGMA's emphasis on local control. Rather than prescribing approaches or outcomes, this guidance provides a flexible process meant to enable GSAs and stakeholders to make decisions based on the best available science in a manner that promotes transparency and accountability. This guidance is structured to answer the following five key questions (Figure 1):

1. Where are GDEs?
2. Are GDEs being impacted by current groundwater conditions, and could they be impacted by future groundwater conditions?
3. How can management achieve sustainability and avoid adverse impacts to GDEs?
4. How can progress and success be tracked through a monitoring network?
5. What actions can be taken to achieve sustainability?

Each step provides information on current data sources and methods to inform how local agencies can meet SGMA requirements. In addition, for those who seek to sustain and improve GDEs—sometimes by going beyond the actions required in SGMA—recommendations for enhanced measures are provided throughout this document. While voluntary, these recommendations can provide a host of benefits, including improved water supply resiliency, reduced surface water depletions, and improved water quality.

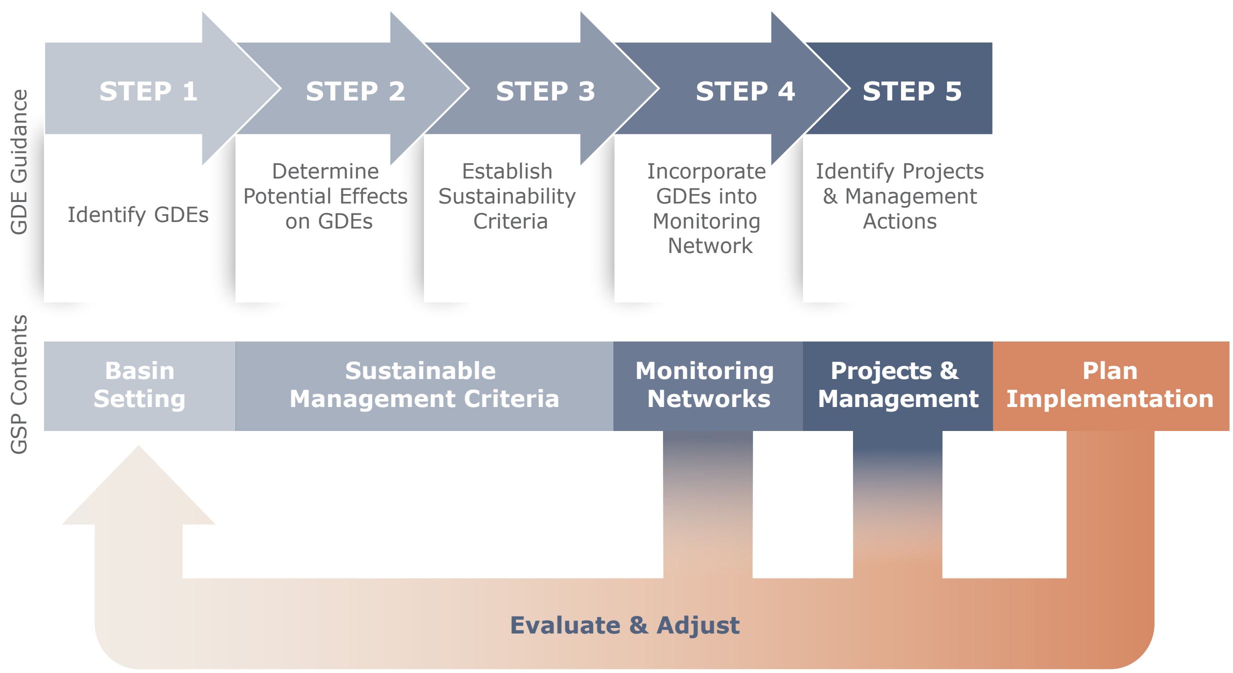


Figure 1. Overview of the GDE guidance and how it can be used to inform the GSP process.

Step 1. Identify GDEs

Step 1 helps GSAs locate where GDEs exist in the basin and aids in describing the hydrologic and ecological conditions within GDEs.

Step 2. Determine Potential Effects on GDEs

This step uses baseline hydrologic data to evaluate whether potential effects on GDEs from current or future groundwater conditions are occurring or may occur. If hydrologic data are insufficient to determine a baseline, then Step 2.2 provides an approach for selecting biological data to evaluate potential effects that may be occurring within a GDE. Step 2.3 provides a conceptual model of how hydrologic and biological data can be combined to reveal cause-and-effect relationships and evaluate whether potential effects are adverse. If adverse impacts on GDEs are apparent due to a groundwater condition, this may indicate an undesirable result.

Step 3. Consider GDEs When Establishing Sustainable Management Criteria

Step 3.1 provides guiding questions to define biological or ecological goals that GSAs may decide to include in their sustainability goal. This step also provides methods to establish minimum thresholds (Step 3.2) and measurable objectives (Step 3.3) for the sustainability indicators that are protective of GDEs.

Step 4. Incorporate GDEs into the Monitoring Network

Step 4 provides recommendations to incorporate hydrologic and biological data into the monitoring network, enabling GSAs to monitor whether GDEs are being impacted by changing groundwater conditions.

Step 5. Identify Projects and Management Actions to Maintain or Improve GDEs

Step 5 provides recommendations to increase groundwater supply and reduce demand through projects and management actions relevant to GDEs.

HOW TO USE THIS GUIDANCE

The Nature Conservancy recognizes that there will be a broad range of GSAs using this guidance, with some GSAs having a longer management history, access to long-term groundwater data, and/or ecologists on staff and other GSAs managing groundwater basins for the first time with little data to work with. Although this guidance may appear to be a linear step-by-step process, it is intended to be an iterative process that improves data-driven decision making for GDEs with each GSP through adaptive management. Adaptive management is embedded within SGMA and provides a process to work toward sustainability over time by beginning with the best available information to make initial decisions, monitoring the results of those decisions, and using the data collected through monitoring to revise decisions in the future.

Considering GDEs is inherently multidisciplinary, combining multiple sciences, including hydrology and biology. While most GSAs are unlikely to have biologists or GDE experts on staff, academic institutions, non-governmental organizations (NGOs), interested stakeholders, citizen scientists, and state and federal wildlife or resource management agencies can provide the needed expertise.

Gathering specimens at Dye Creek Preserve, California. © Ian Shive

In addition, addressing GDEs can potentially enable GSAs to access non-traditional funding sources, such as conservation funding, to support groundwater management projects that integrate species and habitat benefits.

Given the inherent uncertainty about GDEs and their groundwater needs, The Nature Conservancy recommends a conservative approach erring on the side of preserving sufficient groundwater levels and supplies to sustain GDEs because the alternative could result in irreversible or costly impacts to GDEs—including loss of species.

OBJECTIVE AND APPROACH

The Nature Conservancy developed this guidance with expert review from local water agencies, state agencies, academics, technical consultants, and NGOs. Many of the core concepts incorporated into this document were adopted from approaches established in Australia, the European Union, and South Africa (Rohde et al. 2017). In developing this document, The Nature Conservancy has tailored these approaches to fit the California context.

The objective of this document is to assist local, state, federal, and multi-state agencies, consultants, and stakeholders to identify and consider GDEs in sustainable groundwater management.

To achieve this objective, this guidance is based on three key principles:

1. Apply the best available ecological and hydrologic science to address GDEs under SGMA.
2. Provide standardized guidance that can be applied statewide while allowing for diverse local conditions and local decision making.
3. Develop guidance that is realistic and feasible given resource and data limitations.

USE AND LIMITATIONS

The Nature Conservancy provides this document only as guidance. The Nature Conservancy is neither dispensing legal advice nor warranting any outcome that could result from the use of this guidance. Following this guidance does not guarantee approval of a GSP or compliance with SGMA, both of which will be determined by DWR and the State Water Resources Control Board.

All references to SGMA relate to California Water Code sections in Division 6, Part 2.74. All references to the GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2 (23 CCR § 350 et seq.).

This document is not a substitute for SGMA, the GSP Regulations, or DWR's Best Management Practices and Guidance documents but rather is designed to complement them. Information on DWR's Best Management Practices and Guidance documents can be found at https://www.water.ca.gov/Programs/Groundwater-Management.

Step 1. Identify GDEs

WHAT'S IN THIS STEP?

There are two objectives in this step: map (Step 1.1) and characterize (Step 1.2) GDEs in the basin. Identification of GDEs will be used to inform current and historical groundwater conditions as part of the Basin Setting section of the GSP. The results from this step will be used to consider GDEs in other parts of the GSP, including establishing sustainable management criteria (Step 3) and assessing the monitoring network (Step 4).

The mapping process in Step 1.1 begins with an easily accessible statewide database of GDE indicators. This statewide database is then refined using local information to ensure the map accurately reflects local conditions. Once a connection from the GDE indicators to groundwater is determined, the basin's GDE map can be finalized. GDEs are characterized in Step 1.2 by their hydrologic and ecological conditions. Step 1.2 helps agencies rank GDEs based on their conservation value so GDEs can be prioritized when determining potential effects (Step 2), establishing sustainable management criteria (Step 3), and assessing monitoring networks (Step 4).

WORKSHEETS FOR THIS STEP:

Worksheet 1: Assess a Connection to Groundwater

Worksheet 2: GDE Ecological Inventory

PRODUCTS FROM THIS STEP:

1. A local GDE map containing color-coded polygons that record the results of the evaluation (i.e., kept, added, removed).
2. A description of current and historical groundwater conditions for each GDE.
3. An inventory of important species and habitats within each GDE.

WHY THIS STEP?

SGMA requires agencies to identify and include the impacts of groundwater use on GDEs in their GSPs. This step identifies the GDEs in the basin—where they exist and what comprises them. Relevant regulatory provisions include 23 CCR § 354.16(g), Water Code § 10723.2, and Water Code § 10727.4 (see Appendix I for details).

STEP 1.1. MAP GDEs

Create Basin Map from Statewide Database of GDE Indicators

Start with the statewide GDE indicators (iGDE) database, which is available at https://www.water.ca.gov/Programs/Groundwater-Management. The statewide iGDE database was developed by The Nature Conservancy in partnership with the California Department of Fish and Wildlife (DFW) and DWR using the best available statewide data on springs and seeps, wetlands, and vegetation known to use groundwater.

Since this map is largely based on publicly available statewide and regional datasets, it may contain inaccuracies that may be clarified with local information. California's GDEs have a range of groundwater dependence, meaning a particular plant species may be highly dependent on groundwater in one place but rely on surface water sources in other places. Given California's diversity of conditions, determining what is truly groundwater dependent is best addressed at the local level. Step 1 provides guidance on how local information can verify whether data contained in the iGDE database depend on groundwater and can be considered as actual GDEs (Figure 2).

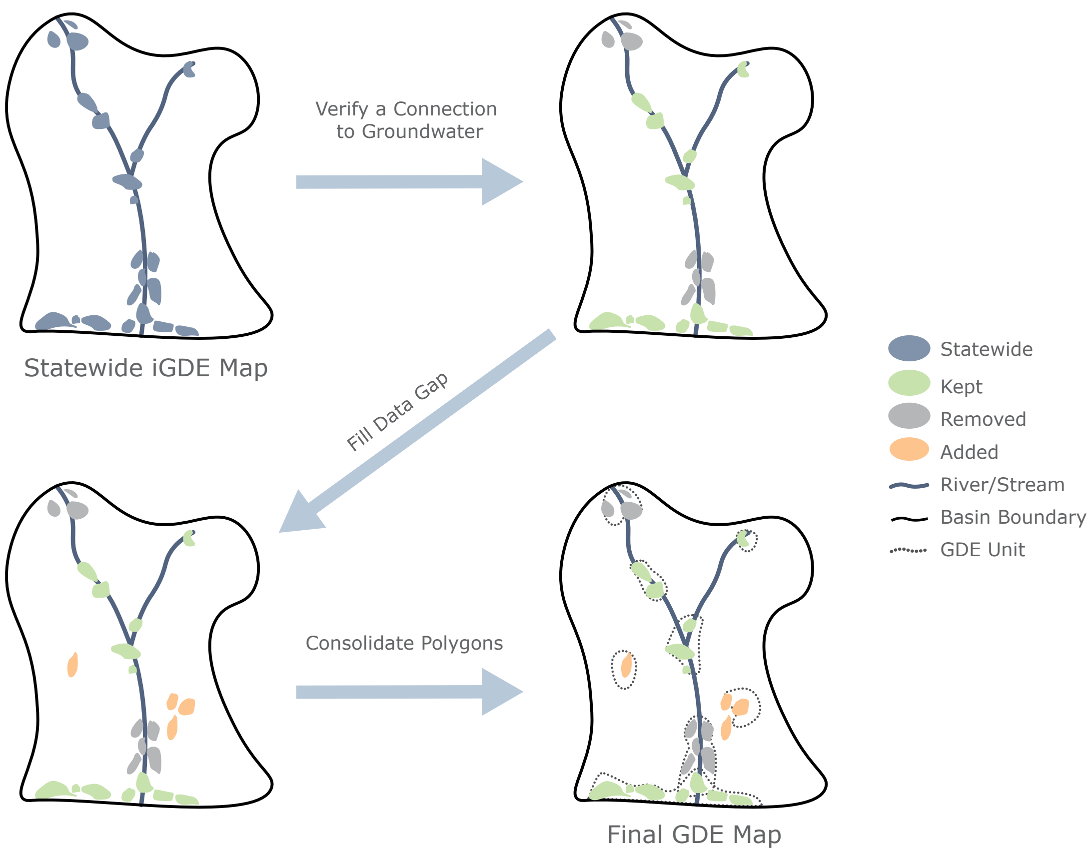


Figure 2. Creating a local GDE map using local information (Step 1.1).

To develop a GDE map specific to the basin, access the statewide iGDE database using ArcGIS or similar open source software, such as QGIS (for step-by-step technical instructions on creating a basin GDE map, visit http://www.groundwaterresourcehub.org). The map will identify polygons where GDEs may be present. To confirm whether each iGDE polygon is connected to groundwater, utilize the hydrologic information assembled as part of the Basin Setting section in the GSP. If hydrologic data are missing or insufficient, Worksheet 1 (Appendix III) offers some guiding questions to help with the assessment.

BOX 2. WHAT YOU NEED

Compile the following data to verify, add, or eliminate polygons identified within the statewide iGDE database. For step-by-step technical instructions, visit http://www.groundwaterresourcehub.org.

Aerial Photos

The U.S. Department of Agriculture (USDA) provides freely available high-resolution aerial photography through the National Agriculture Imagery Program (NAIP). For instructions on how to download or view the imagery, see http://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/.

Vegetation Maps/Databases

Compile locally available vegetation maps or data, such as those found in habitat conservation plans, environmental documents, vegetative surveys conducted by local research institutions or NGOs, and plans and monitoring reports on endangered species.

Once a hydrologic connection between each iGDE polygon and groundwater is confirmed, the polygons can be designated as actual GDEs. Examples of hydrologically connected GDEs may include those located in gaining reaches of rivers and streams, seeps and springs, and wetlands located in groundwater discharge areas. The Nature Conservancy recommends that iGDEs with insufficient hydrologic data also be considered GDEs but should be flagged for further investigation. Depending on capacity and interest, more in-depth analyses can be done to confirm reliance on groundwater using approaches provided in Appendix IV.

Next, use recent aerial photos and local knowledge (Box 2) to visually scan the remaining GDE polygons for changes in land use that may not be reflected in the iGDE database, such as the following:

1. Recent urban, commercial, or industrial development (e.g., parking lots, solar power plants, residential/commercial buildings)
2. Cultivated agricultural land
3. Obvious human-made features (e.g., spreading basins, drainage ditches, golf courses, reservoirs, eucalyptus groves used for agricultural windbreaks)

Remove GDE polygons where appropriate and add any other locally recognized GDEs not already included on the map. Obvious omissions may be gaining reaches of rivers and streams, seeps and springs, and managed or natural wetlands located in groundwater discharge areas.

Record which iGDE polygons have been removed, added, or kept the same using color coding in the final basin GDE map (see example in Figure 3).

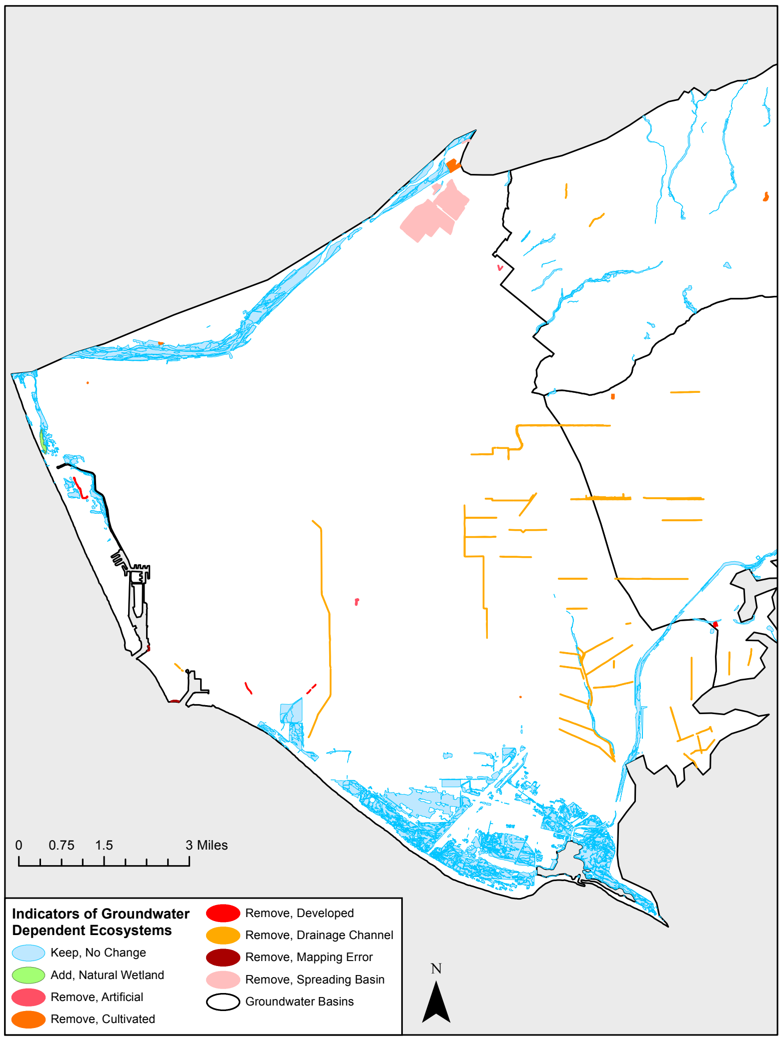


Figure 3. Example of a local GDE map developed through Step 1.1.

Consolidate GDE Polygons

At this point, there are likely multiple GDE polygons that can be grouped together based on their proximity to each other, GDE type (Box 3), and association to the same aquifer. Based on information from DWR's Bulletin 118 and local geologic information, group proximate GDE polygons in the basin by aquifer. Grouping multiple GDE polygons into larger units by location and aquifer will reduce the number of steps moving forward. If in subsequent steps it appears that GDE polygons within a consolidated unit are connected to groundwater differently, it may be necessary to disaggregate the unit.

Figure 4 provides a hypothetical situation along an interconnected river where multiple GDE polygons can be consolidated into two units. The GDE polygons associated with the unconfined aquifer are consolidated into GDE Unit #1, and GDE polygons associated with the semi-perched aquifer are consolidated into GDE Unit #2.

BOX 3. SUPPORTING INFORMATION

GDEs can be classified into several ecosystem types based on the role groundwater plays in maintaining the associated plants and animals. The four GDE types most applicable to SGMA include the following:

1. Seeps and Springs
2. Wetlands and Lakes
3. Terrestrial Vegetation
4. Rivers, Streams, and Estuaries

For more information on these different GDE types and how they depend on groundwater, refer to the glossary of terms (located at the back of this document) and visit the Groundwater Resource Hub at http://www.groundwaterresourcehub.org.

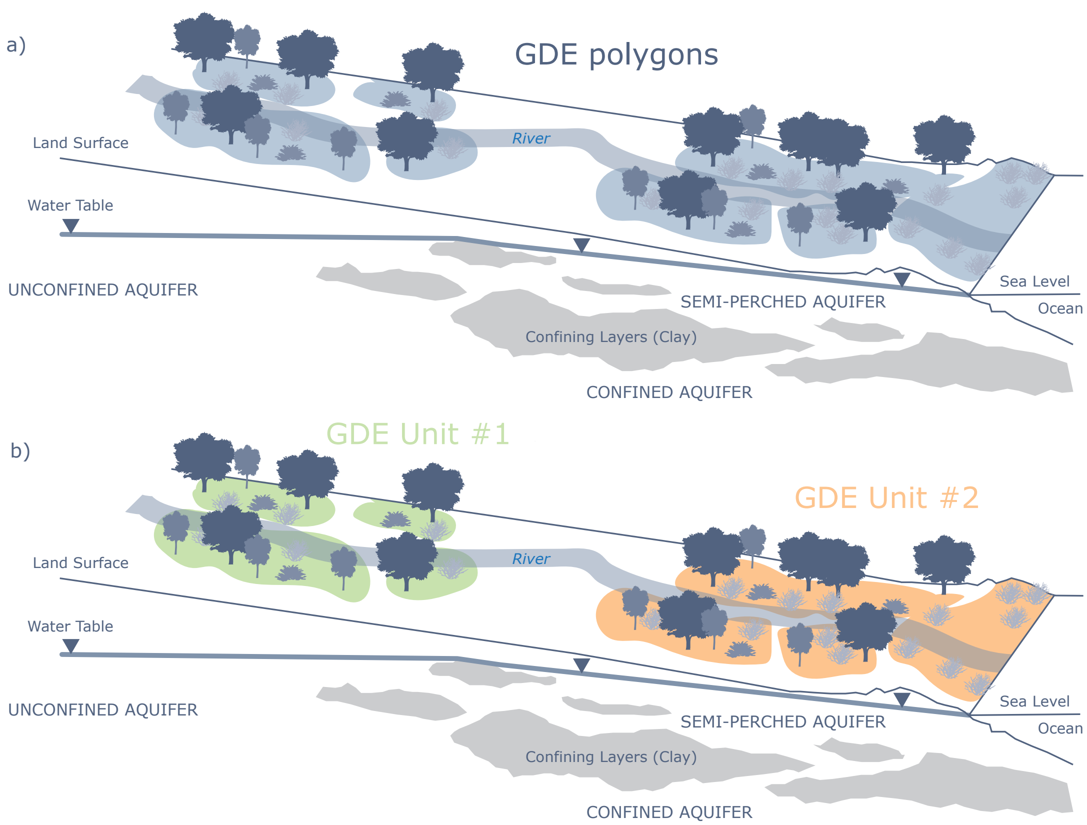


Figure 4. Consolidating GDEs: a) statewide iGDE map showing eight separate GDE polygons and b) final GDE map showing GDEs consolidated into two GDE units.

STEP 1.2. CHARACTERIZE GDE CONDITION

Describe the Hydrologic Regime Associated with GDE Units

Using the data and information available from groundwater monitoring networks and compiled for the Basin Setting section of the GSP (Box 4), briefly describe (one to two paragraphs) the historical and current hydrologic regime within each GDE unit. The questions below can be used to inform a brief description for each GDE, including information about aquifer conditions and the connectivity between the GDE unit and the aquifer. The questions are meant to help guide your thinking. If data gaps and large uncertainties exist, document these, and guidance will be provided to address these through the monitoring network in Step 4.

BOX 4. WHAT YOU NEED

Compile information and data from the Basin Setting section of the GSP:

Hydrogeologic Conceptual Model (23 CCR § 354.14)

- Maps and descriptions of aquifers in the basin
- Conceptual drawings of how groundwater flows in/out/between aquifers
- Map of recharge/discharge zones in the basin (including significant active springs, seeps, and wetlands)

Groundwater Conditions (23 CCR § 354.16)

- Groundwater elevation contour maps (converted into depth to water using a digital elevation map) from nearby shallow monitoring wells that can depict seasonal highs and lows over time
- Groundwater quality data
- Isohaline contoured maps (if applicable)
- Interconnected surface water maps (including gaining and losing reach delineations) and any relevant stream hydrographs

Aquifer Conditions

1. Is the aquifer connected to the GDE unconfined, perched, semi-confined, or confined?
2. How does the aquifer connected to the GDE interact with the basin's other principal aquifers? What is known about the groundwater flow and residence time?
3. If the aquifer is perched, identify how groundwater flows between the perched aquifer and the regional unconfined aquifer.
4. What is the lithology (e.g., clay, silt, sand, gravel) comprising the aquifer and unsaturated zone? What are the hydraulic properties (e.g., hydraulic conductivity, porosity, specific yield)?

View of Cougar Wetlands along the Cosumnes River, California. © Mike Eaton/The Nature Conservancy

Water Availability

1. How much consumptive use occurs within each GDE?
2. What are the depths to groundwater?
3. Are there any seasonal (summer/winter), inter-annual (wet/dry/average years), or long-term trends in groundwater levels?
4. Is there any spatial variability in groundwater levels within the GDE? If so, what is the general direction of flow and the cause of that flow?
5. For GDEs with water emerging at the Earth's surface (e.g., rivers, streams, wetlands, seeps, springs, estuaries),
    a. Is there any spatial or temporal variability in the gaining and/or losing conditions of the surface water and groundwater interconnection?
    b. What are the main sources of surface water (e.g., natural runoff, urban stormwater runoff, treated wastewater effluent)? What are the timing and flow dynamics? Does the GSA have authority to manage this water?
    c. Are there any seasonal (winter/summer), inter-annual (wet/dry/average years), or long-term trends in the stream hydrograph?
6. According to the basin's projected water budget, prepared for the Basin Setting section of the GSP, how may climate change impact future water availability in the GDE?

Water Quality

1. Are there any known water quality issues (e.g., temperature, dissolved oxygen, nutrients, salinity, pH) with the groundwater?
2. Are there any known water quality issues (e.g., temperature, dissolved oxygen, nutrient, salinity, pH) with the main source of surface water?
3. Are there any known contaminant plumes in the groundwater under the GDE?

Human Alteration

1. Is there any current or anticipated pumping from the aquifer that supports the GDE?
2. If the aquifer supporting the GDE is perched, has the underlying aquitard been compromised by well bores or other construction activities?
3. What beneficial uses and users of groundwater are designated in relation to GDEs? (Refer to the applicable Regional Water Quality Control Board Plan for a list of designated beneficial uses.)
4. Is the aquifer supporting the GDE actively monitored or managed?
5. If the groundwater or main source of surface water supporting the GDE has been contaminated, has remediation occurred? What agency has the authority to regulate the clean up?
6. Is any of the surface water interconnected with groundwater supporting the GDE being diverted, regulated, or used for other beneficial uses and users? If so, what is the variability in the timing and flow?

Describe the Ecological Condition

Not all GDEs are created equal. Some GDEs may contain legally protected species or ecologically rich communities, whereas other GDEs may be highly degraded with little conservation value. The ecological value of a GDE is higher for those that possess more natural or near-natural conditions or include species or habitats that have legal protection (Serov et al. 2012). Identifying the ecological value of each GDE can help to prioritize limited resources when considering GDEs as well as prioritize legally protected species or habitat that may need special consideration when setting sustainable management criteria (Step 3; see Appendix II for potentially relevant legal references).

To assess the ecological condition of each GDE, download the datasets available at the websites shown in Box 5. In addition, there are some helpful data provided in the statewide iGDE database used in Step 1.1 to create the GDE map. These data include spatial information on whether GDE polygons are characterized as a wetland under the National Wetlands Inventory (NWI) and whether they contain vegetation that is native to California. For step-by-step instructions on how to create a map and inventory species, habitats, and protected lands with ecological importance, visit http://www.groundwaterresourcehub.org.

BOX 5. WHAT YOU NEED

STATEWIDE DATA

- **Critical Habitat for Threatened and Endangered Species**
  The Environmental Conservation Online System (ECOS) contains spatial data of critical habitat for threatened and endangered species. The ECOS spatial data can be downloaded as shapefiles.

  http://ecos.fws.gov/ecp/report/table/critical-habitat.html

- **California Special Status Species**
  The California National Diversity Database (CNDDB) contains text and spatial information on California's special status species. The CNDDB spatial data can be downloaded as a shapefile or accessed via the BIOS Data Viewer. Users must have a CNDDB subscription to access RareFind and CNDDB spatial data downloads.

  https://www.wildlife.ca.gov/Data/CNDDB/Maps-and-Data#43018407-rarefind-5

- **California Protected Areas**
  The California Protected Areas Data Portal (CPAD) contains spatial information about lands that are protected for open space purposes by more than 1,000 public agencies or non-profit organizations. The CPAD spatial downloadable GIS data contain shapefiles and geodatabases.

  http://www.calands.org/data

- **Areas of Conservation Emphasis**
  The Areas of Conservation Emphasis (ACE) Project contains spatial data on native species richness, rarity, endemism, and sensitive habitats for six taxonomic groups: birds, fish, amphibians, plants, mammals, and reptiles. Information on the location of four sensitive habitat types (i.e., wetlands, riparian habitat, rare upland natural communities, and high-value salmonid habitat) are also summarized. The ACE dataset is available statewide at a 2.5-square-mile hexagon grid. The ACE spatial data are available online or downloadable for GIS.

  https://www.wildlife.ca.gov/Data/Analysis/ACE

LOCAL DATA

- **Beneficial Use Designations**
  Regional Water Quality Control Board basin plans contain a list of beneficial uses of surface waters, groundwater, marshes, and wetlands that pertain to water quality objectives. According to the State Water Resources Control Board, "beneficial use designations for any given water body do not rule out the possibility that other beneficial uses exist or have the potential to exist."

  http://www.waterboards.ca.gov/plans_policies/#plans

- **Local Plans or Studies**
  Local plans or studies (e.g., habitat conservation plans, conservation plans, wildlife corridor plans, ecological and biological assessment studies, natural resource management plans developed for specific areas) often contain descriptions and assessments of the species and habitat for specific areas.

For each GDE unit, identify and inventory species, habitat, and protected lands by visually inspecting the recommended datasets and consulting the monitoring network, any local relevant reports, and/or local experts. Describe the species composition, habitat condition, size and extent of the GDE unit, and any other relevant information in Worksheet 2. Document the condition of each GDE unit by taking on-site photos and recording the GPS coordinates, date the photo was taken, and direction the camera was aimed.

After the composition of each GDE unit has been inventoried, characterize the condition of the GDE unit as having high, moderate, or low ecological value. Values can be assessed by considering the following criteria. In addition, a local biologist or ecologist may also be consulted. Record the results in Worksheet 2.

High Ecological Value

- All or part of the GDE unit has been designated as having important significance by environmental agencies, by other laws, in international agreements, or by local GSA stakeholders (e.g., federal or state endangered species or land designations, such as critical habitat, national conservation lands; see Appendix II for more detail).
- Contains species that are entirely dependent on groundwater (obligate) for their survival, are extremely sensitive to environmental characteristics provided by groundwater, or are rare or unique.
- Contains species or ecological communities that are vulnerable to slight to moderate changes in groundwater discharge or groundwater levels that would result in a substantial change in their distribution, species composition, and/or health.

Moderate Ecological Value

- The species or ecological communities within the GDE are not legally protected but may have been designated as a beneficial use and/or as having important significance by environmental agencies, local conservation plans, or local stakeholders.
- Contains mostly species that are partially dependent on groundwater (facultative).
- Contains species or ecological communities that are somewhat vulnerable to slight to moderate changes in groundwater discharge or groundwater levels that would result in some change(s) in their distribution, species composition, and/or health.

Low Ecological Value

- The species or ecological communities within the GDE are not legally protected and have not been designated as having important significance by other environmental agencies, local conservation plans, or local stakeholders.
- Contains only species that are partially dependent on groundwater (facultative).
- Contains species or ecological communities that are not vulnerable to slight to moderate changes in groundwater discharge or water tables, resulting in minimal change(s) in their distribution, species composition, and/or health.

WHAT GOES IN THE GSP?

Which Section of the GSP?

The description of current and historical groundwater conditions includes a requirement to identify GDEs (23 CCR § 354.16) within the Basin Setting section (GSP Section 2.2.2).

SGMA also requires GSAs to include a water budget in the GSP that quantifies the current, historical, and projected water budget for the basin (23 CCR § 354.18; see Appendix I for details). The GDE map developed in Step 1 will help estimate consumptive water use by groundwater dependent native vegetation in the basin water budget. In addition, the information gathered to this point will allow for the inclusion of GDEs in development of the water budget and will ensure that the basin operates within sustainable yield. Refer to DWR's Best Management Practices document on water budgets for more information.

What Could Be Included?

The following products from Step 1 can be used when identifying GDEs:

1. Final GDE map with GDE units (indicating which polygons were kept, removed, and added).
2. The descriptions of and data on historical and current groundwater conditions for each GDE. This could include long-term hydrographs depicting depth to groundwater levels from nearby shallow monitoring wells.
3. Inventory of species, habitats, and protected lands for each GDE unit with ecological importance (Worksheet 2).
4. Photos of each GDE unit.

Step 2. Determine Potential Effects on GDEs

WHAT'S IN THIS STEP?

This step explores whether groundwater conditions in the basin may have potential effects on GDEs and whether undesirable results may result. Determining potential effects on GDEs will help set minimum thresholds in Step 3 that can prevent adverse impacts to GDEs (a beneficial use and user of groundwater) and can inform which indicators and targets could be incorporated into the basin's monitoring network (Step 4).

Step 2 first uses hydrologic data to observe changes in groundwater conditions to help define whether potential effects on GDEs are occurring or may occur. This step assumes that if little to no change in groundwater conditions have occurred from baseline conditions, then there are likely no "significant and unreasonable" effects on GDEs for the corresponding sustainability indicator.

If changes in groundwater conditions from baseline conditions are evident or if there are insufficient data to detect such changes, then groundwater conditions could be causing potential effects on the GDE. If this is the case, The Nature Conservancy recommends using biological data in combination with hydrologic data to evaluate whether groundwater conditions are causing effects on a GDE. Step 2.3 then provides a conceptual model to determine whether those effects are adverse.

WORKSHEETS FOR THIS STEP:

Worksheet 3: Potential Effects on GDE Summary

Worksheet 4: Biological Change Assessment

PRODUCTS FROM THIS STEP:

1. An assessment of how susceptible GDEs are to changing groundwater conditions.
2. A description of potential effects on GDEs that may occur or are occurring from groundwater conditions in the basin.

WHY THIS STEP?

SGMA requires agencies to describe potential effects on GDEs (a beneficial use and user of groundwater) that may occur or are occurring from the six groundwater conditions being used to evaluate sustainability. Relevant regulatory provisions include 23 CCR §§ 354.26(a) and 354.26(b)(3) (see Appendix I for details).

Potential effects on GDEs caused by groundwater conditions include various biological responses that range in severity from water stress to habitat loss or, in the worst-case scenario, ecosystem collapse. A GDE's biological response to groundwater conditions will vary depending on its reliance on groundwater (Step 1.2) as well as the magnitude and rate of change in groundwater conditions (Step 2.1). This step assumes that GDEs are more susceptible to potential effects if current or future groundwater conditions change from baseline conditions.

Baselines provide a useful reference point as they enable changes in groundwater conditions to be evaluated. Step 2.1 provides an approach for using hydrologic data to evaluate whether current or future groundwater conditions are changing compared to baseline conditions. If baseline data for any of the hydrologic data are insufficient (e.g., limited data, certain water years are missing), The Nature Conservancy recommends that this data gap be addressed by the monitoring network (Step 4). Step 2.2 provides recommendations for selecting biological data that can be paired with hydrologic data. Step 2.3 then combines the biological and hydrologic data to further evaluate potential effects and better assess cause-and-effect relationships. Results from Step 2 can be documented in Worksheet 3 and referenced when establishing sustainable management criteria (Step 3).

Mt. Shasta, California. © Harold E. Malde

STEP 2.1. ASSESS HYDROLOGIC DATA

Under SGMA, the six groundwater conditions that could lead to undesirable results include the following:

1. Chronic lowering of groundwater levels
2. Reduction of groundwater storage
3. Seawater intrusion
4. Degraded water quality
5. Land subsidence
6. Depletions of interconnected surface water

In most cases, the three groundwater conditions that are most likely to result in direct effects on GDEs are chronic lowering of groundwater levels, degraded water quality, and depletions of interconnected surface water. Step 2 focuses on determining potential effects for these three. However, if other groundwater conditions are locally determined to have potential effects on GDEs, then they can also be included in the assessment below. If adverse impacts on GDEs are apparent due to a groundwater condition, a GSA may determine that an undesirable result is occurring.

To assess potential effects on GDEs due to groundwater conditions, select hydrologic data that are representative of the conditions for each GDE (Step 1.2). For example, when evaluating whether potential effects on GDEs may be occurring due to groundwater levels, select groundwater level data from the closest shallow monitoring well that can best represent fluctuations in groundwater levels in the GDE over time.

Table 1 summarizes the types of hydrologic data that can help assess potential effects on GDEs due to groundwater conditions. Different types of hydrologic data will be more appropriate depending on the type of GDE (i.e., wetland/lake, terrestrial vegetation, seep/spring, or river/stream/estuary) and the corresponding groundwater condition being evaluated. In most cases, these hydrologic data will already be compiled to complete the Basin Setting section of the GSP. If hydrologic data for groundwater conditions are insufficient for one or more GDEs, then the data gaps can be addressed by the monitoring network (Step 4).

BOX 6. SGMA'S BASELINE: POTENTIALLY UNHEALTHY CONDITIONS FOR GDEs

Under SGMA, undesirable results occur when "significant and unreasonable" effects are caused by groundwater conditions. To be consistent with this SGMA provision, this guidance assumes that if there is little to no change in groundwater conditions from baseline conditions, then there are likely no "significant and unreasonable" effects for the corresponding sustainability indicator. Baseline conditions refer to historical information that is used to evaluate the sustainable management practices of a basin.

However, from an ecohydrologic perspective, if baseline conditions for a given groundwater condition were already causing adverse impacts on GDEs in the pre-SGMA era (before 2015), then actual impacts will likely continue or worsen if no corrective action is taken. For example, a GDE consisting mostly of mature trees with low rates of reproduction and recruitment are at risk of ecosystem collapse in the future if baseline groundwater levels are contributing to an absence of seedlings and saplings taking root and replacing mature trees (Figure 5). Likewise, if baseline groundwater levels are resulting in the expansion of opportunistic non-native species that can outcompete native species, adverse impacts to GDEs may already be occurring. In these cases, the baseline conditions are not healthy for the GDE, and sustaining existing groundwater conditions for longer periods of time may result in adverse impacts (see Step 2.3).

SGMA empowers GSAs to address these pre-SGMA impacts. Properly identifying adverse impacts to GDEs early in the GSP development process can also help GSAs avoid costs associated with mitigating adverse impacts caused by groundwater conditions.

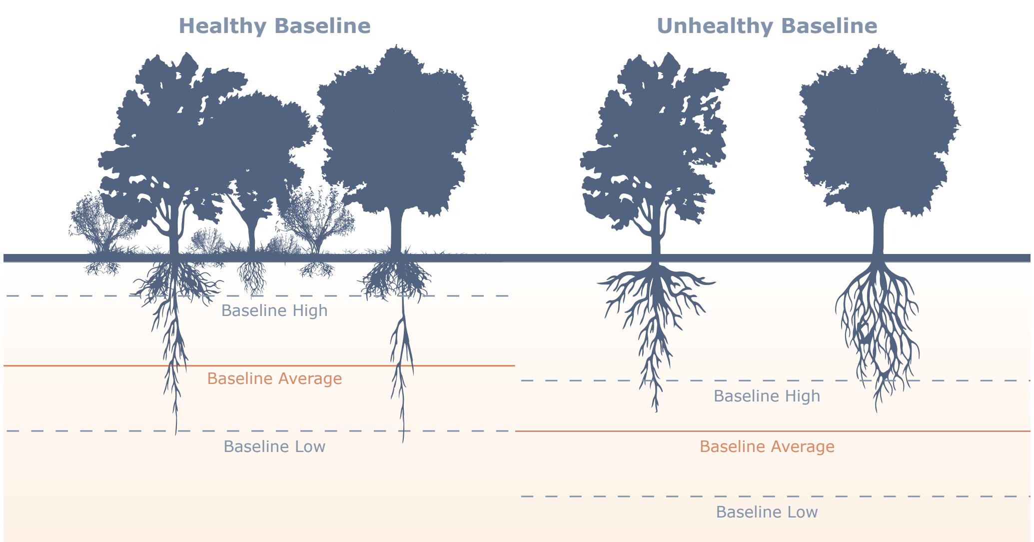


Figure 5. Healthy versus unhealthy baselines for GDEs. Based on whether baseline groundwater conditions are in a natural state (left) or a "new normal" state caused by historic groundwater pumping (right).

TABLE 1. Examples of hydrologic data to assess potential effects on GDEs due to groundwater conditions

HYDROLOGIC DATA				
	CORRESPONDING SUSTAINABILITY INDICATOR‡	**Groundwater Elevations** in the principal aquifer connected to each GDE. Dataset should capture seasonal highs and lows.	Any **Groundwater Quality** trends for water quality indicators to address known water quality issues.	**Interconnected Surface Water** (i.e., surface water discharge, surface water head, and baseflow contribution). Date/location of where intermittent or ephemeral streams/rivers cease to flow, temporal changes in conditions due to variations in stream discharge and regional groundwater extraction.
GDE TYPE	SEEP OR SPRING	**Groundwater Elevations**—depth to water.	**Water Chemistry**—depends on site, soil, and geology. Some indicators may include temperature, total dissolved solutes, stable isotopes. Site-specific requirements (e.g., total maximum daily load (TMDL); applicable local, state, and federal water quality standards) may apply.	**Groundwater Discharge**—variability (seasonal or annual) of discharge. **Groundwater Elevations**—depth to water.
GDE TYPE	WETLAND OR LAKE	**Groundwater Elevations**—depth to water.	**Water Chemistry**—depends on site, soil, geology, water budget, surface water source (if applicable), plant species composition; thus, no general indicator suggested. Nutrients (nitrate), total dissolved solids (TDSs), chloride, dissolved oxygen. Site-specific requirements (e.g., TMDLs; applicable local, state, and federal water quality standards) may apply.	**Groundwater Discharge**—continued presence of groundwater discharge or saturated soils throughout the growing season. **Groundwater Elevations**—depth to water.
GDE TYPE	TERRESTRIAL VEGETATION	**Groundwater Elevations**—fluctuation in depth to water.	**Water Chemistry**—depends on site, soils and geology, water budget, plant species composition; thus, no general indicator suggested. Site-specific requirements (e.g., TMDLs, local/state/federal water quality standards applicable) may apply.	**Groundwater Elevations**—depth to water.
GDE TYPE	RIVER, STREAM, OR ESTUARY	**Groundwater Elevations**—fluctuation in depth to water.	**Temperature**—maximum seven-day average of daily maximum (7DADM) surface water temperature. **Water Chemistry**—Nutrients (nitrate), TDSs, chloride, dissolved oxygen. Site-specific requirements (e.g., TMDLs, applicable local, state, and federal water quality standards) may apply.	**Surface Water Flow**—number of zero-flow days, trends in annual mean low flow, number and severity of flow-related fish migration passage impediments (if applicable), number of days and timing of sand bar breaching (if applicable). **Temperature**—maximum 7DADM surface water temperature. **Groundwater Discharge**—location and extent of gaining and losing reaches. **Groundwater Elevations**—depth to water.

‡Metrics defined under the Monitoring Network section of the 23 CCR § 354.34(c).

Assess Baseline Conditions

Once the hydrologic data for each GDE has been compiled, determine the baseline (Box 7) average and range for selected hydrologic data and record these values on Worksheet 3. Depending on the available data, there may be more than one type of hydrologic data (Table 1) to help determine whether an undesirable result is occurring or may occur. GSP Regulations state that undesirable results "occur when significant and unreasonable effects for any of the sustainability indicators are caused by groundwater conditions occurring throughout the basin" (23 CCR 354.26(a)).

This guidance assumes that "significant and unreasonable" effects to a beneficial use and user of groundwater (e.g., a GDE) *may* result when a deviation from baseline occurs. Thus, the baseline range is used to define groundwater conditions with little to no effect on GDEs. If current or future conditions (loosely defined as the next five years) exceed this range on the high or low end, then the GDE could potentially be affected. For example, if groundwater levels fall outside of the high or low ends of the baseline range, plants can be adversely impacted. Depths greater than the baseline range could prevent plants from accessing needed groundwater, while depths shallower than baseline range could drown plant roots.

To the extent possible, use available baseline information to identify long-term, inter-annual (i.e., wet, average, or dry years) and seasonal (i.e., summer and winter) trends as well as any trends on whether and when groundwater conditions recover from droughts.

BOX 7. SUPPORTING INFORMATION

Baseline is defined under the GSP regulations as "historic information used to project future conditions for hydrology, water demand, and availability of surface water and to evaluate potential sustainable management practices of a basin."

DWR's Best Management Practices document on water budgets recommends using 10 years of water supply and water budget information to describe how historical conditions have impacted the operation of the basin within sustainable yield, implying that a baseline could be determined based on data from 2005 and 2015. Consult DWR and local technical experts on how to sufficiently define a baseline period.

Assess GDE Susceptibility to Potential Effects

Assess how susceptible the GDE is to potential effects from each groundwater condition by comparing current groundwater conditions to the defined baseline range (Box 8). If a GDE unit is currently (after 2015) experiencing groundwater conditions that fall within the baseline range, there is likely little to no effect on the GDE caused by the groundwater condition under SGMA regulations. If a GDE unit is experiencing current groundwater conditions that fall outside the baseline range, the GDE is more susceptible to potential effects from groundwater conditions. If this is the case, potential effects to a GDE may occur from current or future groundwater conditions and could be "significant and unreasonable." Figure 6 illustrates three potential scenarios.

a. Little to No Change

If the current groundwater conditions for a GDE unit are relatively consistent over time and fall within the baseline range (Figure 6.a), then "significant and unreasonable" changes in groundwater conditions are most likely not occurring and the resulting assumption is that there is little to no effect to the GDE (see Box 6 for caveats). Continue monitoring the selected hydrologic parameter through the monitoring network (Step 4) and proceed to evaluate whether future groundwater conditions may cause the GDE to be susceptible to future effects.

b. Recent Changes

If recent trends (increasing/decreasing) in groundwater conditions deviate from baseline conditions (Figure 6.b), then effects to the GDE are likely occurring under current conditions. Please note that trends can either increase or decrease depending on the groundwater condition being investigated. For example, decreasing trends for groundwater levels and increasing concentrations for some water quality indicators (e.g., nutrients) can both lead to potentially adverse impacts to GDEs. Continue monitoring the selected hydrologic parameter through the monitoring network (Step 4) and proceed to evaluate whether future groundwater conditions may cause the GDE to be susceptible to future effects.

c. Insufficient Data or Long-Term Changes

If the data on groundwater conditions for a GDE are insufficient to detect changes from baseline conditions or if long-term trends exist (Figure 6.c) for the selected hydrologic data, then it may be difficult to determine the range of values in the dataset that would yield little to no effect to GDEs. Continue monitoring the selected hydrologic parameter (Step 4) and skip to Step 2.2.

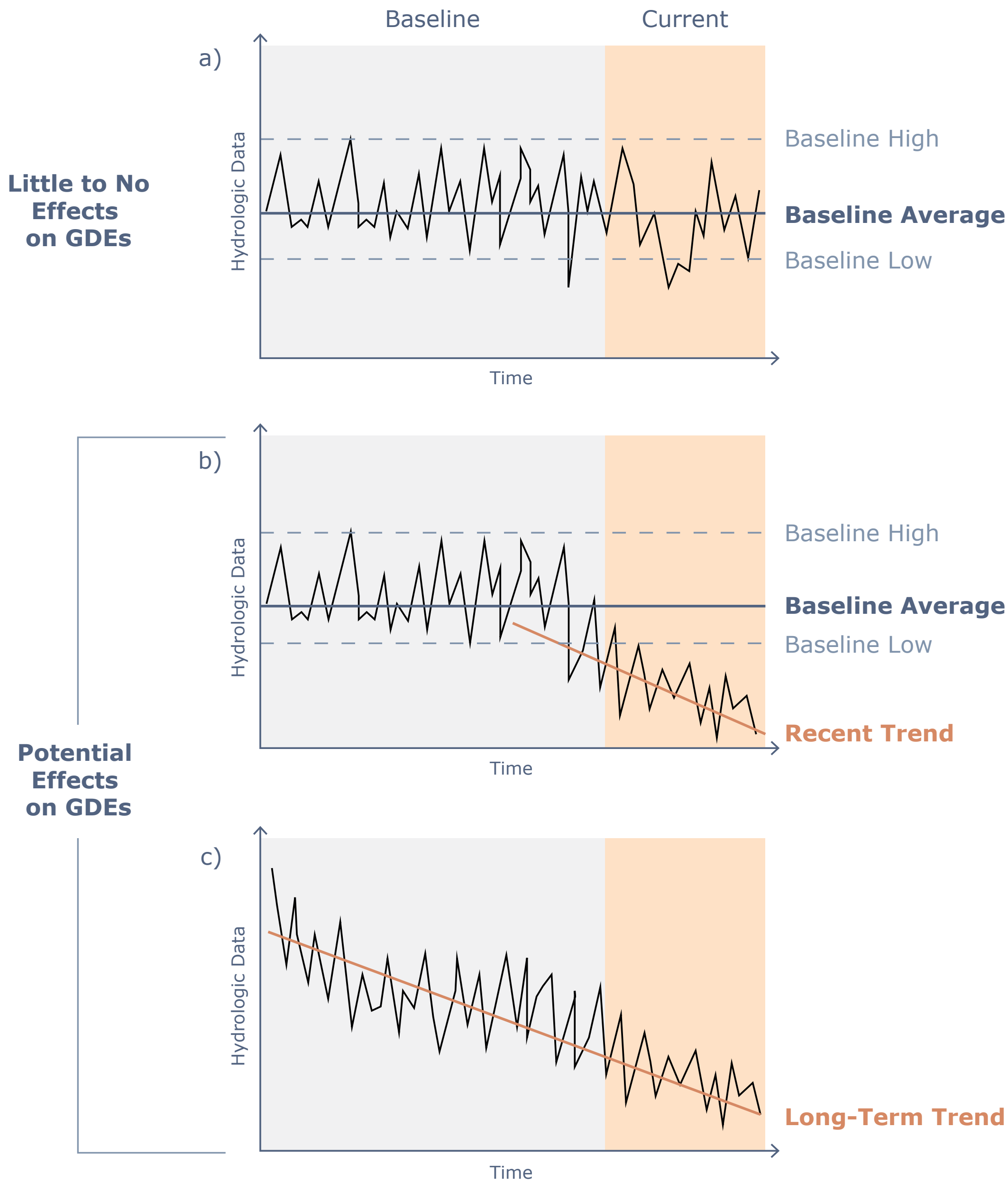


Figure 6. Using hydrologic data to assess potential effects on GDEs.

Assess whether anticipated changes may cause future groundwater conditions (e.g., over the next five-year GSP cycle) to fall outside the baseline range by comparing local information on each GDE's hydrologic regime from Step 1.2 with the projected water budget (prepared for the GSP pursuant to Regulation § 354.18(c)(3)), a numerical model, or other analytical approach. With this information, consider how climate change and groundwater use activities may impact future groundwater conditions in the GDE. Examples may include altered stream flow regimes due to changes in precipitation, shifting groundwater demand due to changes in land use or imported water supplies, and human activities (e.g., water trading, conjunctive management, recycled water projects) that may increase or shift groundwater production in the vicinity of a GDE. In addition, consider the potentially long delay between impacts, such as past pumping or the transport of groundwater contaminants, that can result in future changes in groundwater conditions.

Classify how susceptible (i.e., high, moderate, or low) each GDE is to changing groundwater conditions using the descriptions below and the hydrologic data gathered for comparing current and future conditions to baseline conditions (Figure 7).

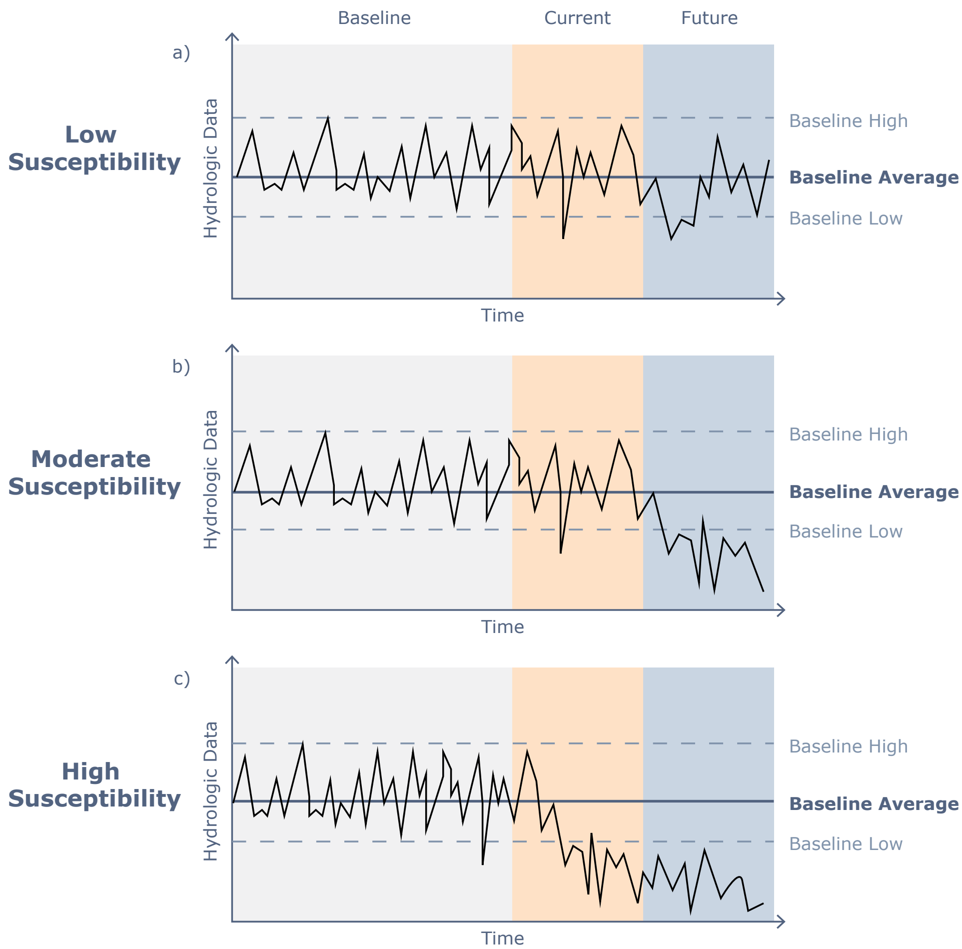


Figure 7. Assessing GDE susceptibility to changes in groundwater conditions. Please note that GDEs can be adversely impacted by increasing or decreasing trends depending on the groundwater condition being investigated. For example, decreasing trends for groundwater levels and increasing concentrations for some water quality indicators (e.g., salinity) can both lead to potentially adverse impacts to GDEs.

Record each GDE's susceptibility classification using Worksheet 3. The degree to which a GDE is susceptible to changing groundwater conditions will help determine which biological data (Step 2.2) may be used to further investigate potential effects on GDEs. This information may also be useful when setting sustainable management criteria (Step 3).

High Susceptibility

Classify GDE units as highly susceptible if current groundwater conditions for the selected hydrologic data fall outside the baseline range.

Moderate Susceptibility

Classify GDE units as moderately susceptible if current groundwater conditions for the selected hydrologic data fall within the baseline range but future changes in groundwater conditions are likely to cause it to fall outside the baseline range. The future conditions could be due to planned or anticipated activities that increase or shift groundwater production, causing a potential effect on a GDE.

Low Susceptibility

Classify GDE units as having low susceptibility if current groundwater conditions for the selected hydrologic data fall within the baseline range and no future changes in groundwater conditions are likely to cause the hydrologic data to fall outside the baseline range.

BOX 8. SUPPORTING INFORMATION

For more information on trend analysis using hydrologic time series data refer to the following resource:

Helsel, D. R., and R. M. Hirsch. 2002. Statistical methods in water resources. Page 522 in Techniques of water-resources investigations, Book 4, Chapter A3. U.S. Geological Survey. Available from https://pubs.usgs.gov/twri/twri4a3/html/toc.html.

STEP 2.2. SELECT BIOLOGICAL DATA

This step continues the investigation of potential effects on GDEs by incorporating biological datasets that can help indicate how GDEs are responding to groundwater conditions. Since it can be onerous to examine the biological response of *all* plants and animals within an ecosystem, groundwater dependent vegetation can be a good proxy to use in practice. This is because changes in groundwater conditions impacting the health of plants will subsequently impact the food supply and habitat conditions for animals within the ecosystem. However, if a GDE is a seep or spring with little vegetation associated with it or if there are known groundwater dependent species that would serve as better proxies, then include them in the analysis.

Biological data may include, but are not limited to, groundwater dependent vegetation rooting depth information, photography, remote sensing indexes, and biological surveys. These four biological data sources are discussed in more detail below in ascending order from less rigorous to more rigorous. These data types are recommended since they are relatively easy and inexpensive to use, provide information that will directly inform groundwater management actions, and provide an early warning of significant effects to GDEs. Biological data should be selected based on the GSA's capacity, available technical expertise, and local data. After selecting biological data, refer to Worksheet 4 for a series of guiding questions to evaluate whether the condition of a GDE is changing over time.

Groundwater Dependent Vegetation Rooting Depth

Plants access groundwater through their roots, making the depths that their roots reach below ground a helpful way to explore whether GDEs are susceptible to potential effects due to changes in groundwater conditions (e.g., groundwater levels, surface water depletions). For example, if a patch of groundwater dependent willow trees has a maximum rooting depth of 10 feet, then the willows may not be able to access groundwater when groundwater depths exceed 10 feet below the surface. In other words, groundwater depths comparatively greater than the rooting depth will likely cause progressively adverse impacts to this GDE, such as reduced growth, reduced reproduction, or increased mortality.

Using the GDE database and map created in Step 1, create a list of the main groundwater dependent plants in each GDE unit. Next, refer to http://www.groundwaterresourcehub.org for a compilation of reported rooting depths for California's groundwater dependent vegetation. Reported rooting depths may vary across California for the same species due to site-specific conditions (e.g., soil moisture, porosity, land surface grade, adaptive capacity of vegetation), so rooting depth data should be locally confirmed by a qualified biologist through field work or based on local expertise.

Aerial and On-Site Photography

Aerial and on-site photography can reveal ecological conditions within a GDE. By visually observing imagery of the GDE unit over time, it is possible to detect changes in the size and extent of groundwater dependent vegetation or interconnected surface water bodies (e.g., wetlands, rivers or streams, estuaries). When coupled with local hydrologic data, the changes observed through photos can provide clues on how GDEs are responding to changes in groundwater conditions over time.

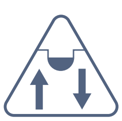
Airborne or satellite imagery can be freely accessed via the USDA's NAIP aerial imagery and Google Earth Engine (https://earthengine.google.com). Photos from a fixed point within the GDE (preferably in the summer when groundwater dependence is greatest) can also be used to document on-the-ground conditions. Another option for obtaining GDE photos is to export 3D images from Google Earth (http://www.google.com/earth). 3D images in Google Earth can be enabled by turning on the "3D Buildings" layer when viewing the GDE of interest. Compile images for each GDE and compare images from various years and across seasons to detect whether there are any spatial or temporal changes in the size and extent of GDEs. Using photos, it is possible to observe whether GDEs are responding to changes in groundwater conditions, especially when coupled with local hydrologic data. With the use of aerial and on-site photography, biological responses to the following undesirable results may be visually detected:

Chronic Lowering of Groundwater Levels

Changes in vegetation density (e.g., reduced tree canopy, reduced understory) and plant composition (e.g., shifts in vegetation type, such as herbaceous species to shrub species) may be an effect of changes in groundwater levels. Habitat loss (e.g., downed trees) and habitat fragmentation may also be detectable and could result from changes in groundwater levels. Surface water at discharge points (e.g., seeps and springs, rivers and streams, or wetlands) can also decrease in surface area and extent in response to lower groundwater levels.

Degraded Water Quality

Visually detectable declines in the health of terrestrial vegetation, such as reduced tree canopy, reduced understory, shifts in vegetation type, tree mortality, and habitat fragmentation, could result from degraded water quality. Degraded water quality due to nutrient loading from groundwater discharge may result in visible algal blooms on surface water bodies.



Depletions of Interconnected Surface Water

Reductions in the area and extent of surface water at discharge points, such as seeps and springs, rivers and streams, or wetlands may result from depletions due to lower groundwater levels. River or stream reaches may also become narrower or drier for longer periods due to depletions of surface water.

Remote Sensing Indexes

Remote sensing indexes can quantify changes in the rates and patterns of vegetation growth and moisture levels in plants within GDEs over time. Remote sensing indexes can be quantified by downloading freely accessible Landsat imagery into ArcGIS from https://earthexplorer.usgs.gov/ or by using Climate Engine (http://www.climateengine.org) or Google Earth Engine https://earthengine.google.com/. The following are examples of useful indexes:

The Normalized Difference Vegetation Index (NDVI) detects whether an area contains live green vegetation. NDVI ranges between -1 and 1, with an increase in NDVI values over time indicating an increase in vegetative growth and a decrease in NDVI indicating a decrease in vegetative growth. Negative NDVI values (approaching -1) indicate water bodies, and values closer to 0 (-0.1 to 0.1) indicate barren land.

The Normalized Difference Water Index (NDWI) detects moisture levels in plants. NDWI ranges between 0 and 1, with an increase in NDWI values over time indicating higher vegetation canopy moisture and lower drought stress and a decrease in NDWI indicating lower vegetation canopy moisture and higher drought stress.

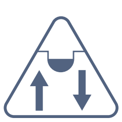
Using these indexes, biological responses to the following undesirable results may be detected:

Chronic Lowering of Groundwater Levels

A decline in NDVI and NDWI values over time could be associated with declines in the health of plants, including reduced tree canopy, reduced understory, shifts in vegetation type, tree mortality, and habitat fragmentation, all of which may be an effect of declining groundwater levels. In some cases, NDVI values may increase in response to declines in groundwater if more highly opportunistic non-native species replace native species. Reduced surface water at discharge points (e.g., seeps and springs, rivers and streams, or wetlands) in response to lower groundwater levels may also result in a decline in NDVI and NDWI values due to vegetation loss in and around these GDEs. Due to California’s climate, there will likely be normal fluctuations in groundwater elevations during the year as well as seasonal cycles in vegetative growth. In addition, some declines in the health of vegetation are a normal part of the plant life cycle.

Degraded Water Quality

A decline in NDVI and NDWI values over time indicating declines in plant health (e.g., reduced tree canopy, reduced understory, shifts in vegetation type, tree mortality, and habitat fragmentation) may also be due to degraded water quality. Degraded water quality due to nutrient loading (e.g., nitrate runoff) may result in an increase in NDVI values due to algal blooms on surface water bodies.



Depletions of Interconnected Surface Water

Reductions and shifts in the size and extent of water bodies detected by NDVI can result from depletions of surface waters. At the periphery of surface water bodies, vegetation loss due to depletions of surface water may be detectable from decreases in NDVI values. Due to California’s climate, there will likely be normal fluctuations in the size of water bodies during the wet and dry seasons.

BOX 9. SUPPORTING INFORMATION

Other approaches for evaluating the condition of GDEs may include the following:

WETLANDS

- **California Rapid Assessment Method (CRAM)**
  A cost-effective and scientifically defensible rapid assessment method for monitoring the conditions of wetlands in California

  http://www.cramwetlands.org/

SPRINGS AND SEEPS

Protocols for identifying, inventorying, and monitoring springs and seeps

- **Spring Inventory and Monitoring Protocols**
  Desert Research Institute

  https://www.dri.edu/images/stories/conferences_and_workshops/spring-fed-wetlands/spring-fed-wetlands-sada-pohlmann-protocol.pdf

- **Springs Ecosystem Assessment Protocol (SEAP)**
  Spring Stewardship Institute

  http://springstewardshipinstitute.org/springs-1

SPECIES SPECIFIC

- **DFW Survey and Monitoring Protocols and Guidelines**
  Best available methodologies and guidelines for surveying and monitoring individual plant, invertebrate, amphibian, reptile, bird, and mammal species

  https://www.wildlife.ca.gov/Conservation/Survey-Protocols

TERRESTRIAL VEGETATION

Protocols for sampling and measuring riparian and wetland vegetation to assess water needs

- **U.S. Forest Service**

  https://www.fs.fed.us/rm/pubs/rmrs_gtr282.pdf

Biological Surveys

Biological survey data can provide more detailed information for evaluating potential effects on GDEs. Pre-existing survey data can often be found in local plans or studies (e.g., habitat conservation plans, conservation plans, wildlife corridor plans, ecological and biological assessment studies, and natural resource management plans). Survey data may include species composition, population, density, spawning/rearing habitat conditions, and migration patterns. Biological surveys may be particularly useful when investigating instream habitat conditions or evaluating the status of rare, threatened, or endangered species. Survey data can help provide information on the status of GDEs and identify trends that may or may not be associated with changes in groundwater conditions. Refer to Appendix IV and Box 9 to learn more on how survey data can be used to assess the condition of a GDE.

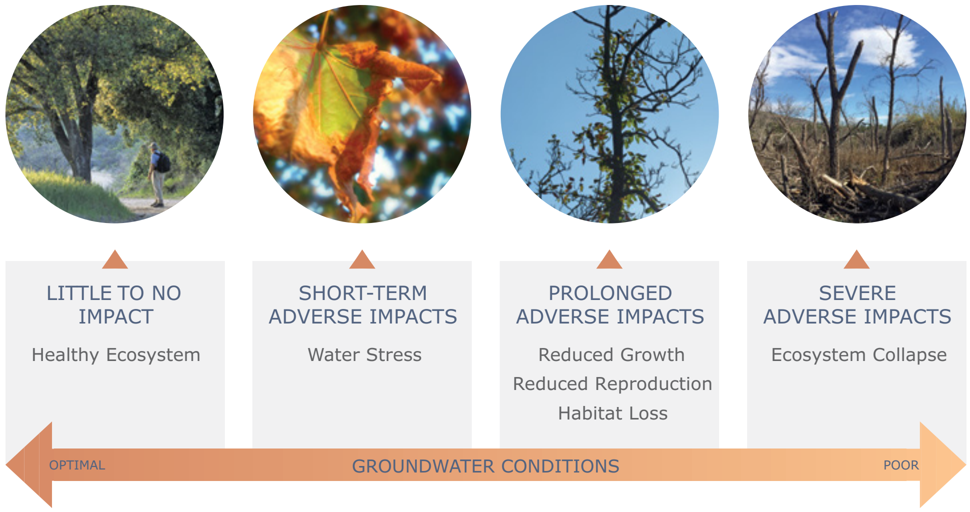
Selecting which biological data to use can be guided by the GDE's ecological value (Step 1.2) and susceptibility to changing groundwater conditions (Step 2.1). For example, if a GDE is designated as having low ecological value and low susceptibility to changing groundwater conditions, then less rigorous biological data, such as rooting depth information or photography, can be used. Conversely, if a GDE is determined as having a high ecological value and high susceptibility to changing groundwater conditions, then the more rigorous biological data, such as remote sensing indexes and biological surveys, are more appropriate.

If biological data are limited, The Nature Conservancy recommends prioritizing the collection of biological information that can be linked to hydrologic data with a focus on GDEs of high ecological value and GDEs that are more susceptible to changing groundwater conditions.

Black-necked stilts (*Himantopus mexicanus*) and an American Avocet (*Recurvirostra americana*). © Erika Nortemann/The Nature Conservancy

STEP 2.3. EVALUATE POTENTIAL EFFECTS ON GDEs

Groundwater conditions can yield a range of potential effects on GDEs from little to no to adverse impacts (Figure 8). GDEs are diverse and complex living systems that have a range of adaptation strategies to adjust to short-term stress due to changes in water quantity and quality. However, if stress is prolonged or abrupt, these adaptation strategies become inadequate, resulting in adverse impacts to GDEs. While some adverse effects to GDEs may be reversible, others may not be and could result in the permanent loss of some species or habitat. For example, declines in groundwater levels can make it difficult for plants and animals to access groundwater, and degraded water quality, such as changes in water temperature, can impact successful salmon spawning. In addition, depletions of interconnected surface water can impede fish migration by disrupting the timing or availability of sufficient flows for passage. For a more comprehensive explanation on how changing groundwater conditions can impact GDEs, visit http://www.groundwaterresourcehub.org.



Above, from left: © Bill Evarts/The Nature Conservancy, © whoaaitskeyanaa/Creative Commons, © Iain Turner/Creative Commons, © Kirk Klausmeyer/The Nature Conservancy

Figure 8. Range of potential effects on GDEs due to groundwater conditions.

To identify potential effects on GDEs and evaluate whether potential groundwater thresholds are sufficient to prevent adverse impacts, The Nature Conservancy recommends assessing the biological response of GDEs to changes in groundwater conditions. In general, aquatic ecosystems respond to stressors in a somewhat predictable and progressive pattern, making it possible to establish numeric thresholds by combining biological and hydrologic data (Davies & Jackson 2006). An example of a progression of biological responses is described in the Biological Condition Gradient, a conceptual scientific framework for interpreting biological responses to increasing effects of water quality stressors (USEPA 2016). The Biological Condition Gradient divides biological conditions along a generalized stressor-response curve into six levels ranging from observable biological conditions found at no or low levels of stressors (Level 1) to high levels of stressors (Level 6) (Figure 9). The gradient is offered by the Environmental Protection Agency as a tool to support Clean Water Act water quality management programs.

The Nature Conservancy proposes that the Biological Condition Gradient can be used as a conceptual framework for assessing potential effects on GDEs. For example, small and gradual changes in groundwater levels have been shown to result in minor adverse biological responses, such as a reduction in vegetative growth (Scott et al. 1999), whereas prolonged or abrupt changes in groundwater levels can result in major adverse biological responses, such as higher rates of vegetation mortality (Shafroth et al. 2000) and a higher prevalence of opportunistic non-native species that are better adapted to deeper groundwater than native species (Keddy & Reznicek 1986; Moore & Keddy 1988; Froend & Sommer 2010; Sommer & Froend 2014).

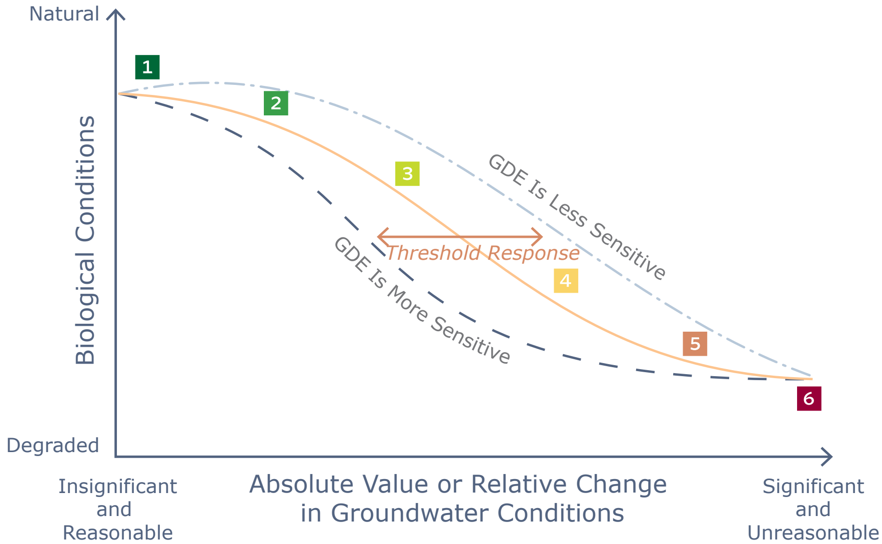


Figure 9. The Biological Condition Gradient in the context of evaluating whether groundwater conditions are causing effects on GDEs (modified from Davies & Jackson 2006).

A decline in a GDE's biological condition in response to a change in groundwater condition could fall into six levels (described in more detail below) depending on the GDE's threshold response (as indicated by the slope of the curve; modified from Davies & Jackson 2006). The GDE threshold depends on the ability of a GDE to adapt to groundwater changes as well as the rate and magnitude of the change in groundwater.

Level 1—Natural or Native Condition: Native structural, functional, and taxonomic integrity is preserved. Ecosystem function is preserved within the range of natural variability. Functions are processes required for the normal performance of a biological system and may be applied to any level of biological organization.

Level 2—Minimal Changes: Minimal changes in the structure of the biotic community and minimal changes in ecosystem function. Most native taxa are maintained with some changes in biomass and/or abundance. Ecosystem functions are fully maintained within the range of natural variability.

Level 3—Evident Changes: Evident changes in the structure of the biotic community and minimal changes in ecosystem function. Evident changes in the structure due to loss of some highly sensitive native taxa; shifts in relative abundance of taxa, but sensitive ubiquitous taxa are common and relatively abundant. Ecosystem functions are fully maintained through redundant attributes of the system.

Level 4—Moderate Changes: Moderate changes in the structure of the biotic community with minimal changes in ecosystem function. Moderate changes in the structure due to the replacement of some intermediate sensitive taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups. Ecosystem functions largely maintained through redundant attributes.

Level 5—Major Changes: Major changes in the structure of the biotic community and moderate changes in ecosystem function. Sensitive taxa are markedly diminished or missing; organism condition shows signs of physiological stress. Ecosystem function shows reduced complexity and redundancy.

Level 6—Severe Changes: Severe changes in the structure of the biotic community and major loss of ecosystem function. Extreme changes in structure, wholesale changes in taxonomic composition, extreme alterations from normal densities and distributions, and organism condition is often poor. Ecosystem functions are severely altered.

To assess whether groundwater conditions are having an effect on GDEs, refer to the hydrologic and biological data compiled in Steps 2.1 and 2.2 and Worksheet 4 to help assess whether the GDE is exhibiting a biological response to changing groundwater conditions. For example, if a GDE was identified as being susceptible to groundwater changes due to long-term and/or current groundwater conditions in Step 2.1, evaluate whether there are biological responses coinciding with the period of time when groundwater conditions changed. For example, has there been a reduction in vegetative growth, increased morality, species composition change, change in the size or extent of the GDE area, etc. (see Worksheet 4 for more details)?

To avoid adverse impacts to GDEs, The Nature Conservancy recommends identifying groundwater thresholds that correspond to GDE biological conditions reflected in Level 4 of the Biological Condition Gradient, where Levels 2 and 3 can be used to mark trigger points for groundwater management interventions to prevent and reverse declines in GDE health caused by groundwater conditions.

For each GDE unit, record a short description of any known cause-and-effect relationships based on the assessment from Step 2.3 between the groundwater conditions and adverse biological responses recorded in Worksheet 3. To the extent possible, use available baseline information to note whether there are any long-term, inter-annual, and/or seasonal trends that may be impacting species or the overall habitat and whether there is evidence of the GDEs recovering from past droughts.

Las Arenitas is a 250-acre wetland in Mexico's Sonoran Desert. It is sustained by treated wastewater from a treatment plant that services the city of Mexicali. Working with the treatment plant, Pronatura Noroeste and the Sonoran Institute constructed these wetlands to remove pollutants from the wastewater, giving it an additional cleansing before it is released into the Rio Hardy. This project has also helped restore vital Colorado River Delta habitat. © Erika Nortemann/The Nature Conservancy

WHAT GOES IN THE GSP?

Which Section of the GSP?

When describing undesirable results (GSP Section 3.2), GSAs are required to describe potential effects on the beneficial uses and users of groundwater and on land uses and property interests as well as other potential effects that may occur or are occurring (23 CCR § 354.26).

What Could Be Included?

The following products from Step 2 can be used to describe how potential effects on GDEs were considered in the establishment of the undesirable results:

1. Describe what groundwater conditions may result in little to no impact to each GDE using the baseline range of hydrologic data for each relevant sustainability indicator. Consider including the figures used to identify baseline and current conditions for relevant hydrologic data—Step 2.1 and Worksheet 3.
2. Specify how susceptible (i.e., high, moderate, low) each GDE is to potential effects based on current and/or future groundwater conditions (Step 2.1).
3. Report any known thresholds or triggers that can be used to identify when an adverse impact to a GDE may occur due to groundwater conditions (Step 2.3). Specify which hydrologic and biological data were used to evaluate cause and effects.

Step 3. Consider GDEs When Establishing Sustainable Management Criteria

WHAT'S IN THIS STEP?

The purpose of this step is to consider GDEs when establishing sustainable management criteria for the basin. This step draws upon the GDE data and map (Step 1) and the assessment of potential effects on GDEs (Step 2) to help establish a sustainability goal (Step 3.1), minimum thresholds (Step 3.2), and measurable objectives (Step 3.3). The objective in setting sustainable management criteria is to protect GDEs from adverse groundwater impacts while providing a reasonable margin of operational flexibility based on levels of uncertainty.

WORKSHEETS FOR THIS STEP:

Worksheet 5: Establishing the Sustainability Goal and Measurable Objectives as they Pertain to GDEs

PRODUCTS FROM THIS STEP:

1. A description of how GDEs fit into the basin's sustainability goal.
2. A description of how minimum thresholds for sustainability indicators consider GDEs.
3. Measurable objectives and five-year interim milestones for each sustainability indicator related to GDEs.

WHY THIS STEP?

When setting sustainable management criteria, GSAs must consider the beneficial uses and users of groundwater in their basin. SGMA requires agencies to establish a sustainability goal using information from the Basin Setting section of the GSP, including the identification of GDEs. In addition, SGMA requires agencies to consider beneficial uses and users of groundwater when setting minimum thresholds for each of the six sustainability indicators and to establish measurable objectives and five-year interim milestones for each sustainability indicator that can achieve the sustainability goal. Relevant regulatory provisions include Water Code § 113 and 23 CCR §§ 354.24, 354.28, and 354.30 (see Appendix I for details).

STEP 3.1. SET THE SUSTAINABILITY GOAL

Using information from Steps 1 and 2, answer the questions below. These guiding questions will inform local discussions with stakeholders (Box 10) on how to consider GDEs when determining the basin's sustainability goal.

- Are there particular species or habitats (Step 1.2) that have important legal, local, regional, statewide, or national significance?
- Are there certain ecological conditions (e.g., species composition, habitat condition, size and extent of the GDE unit, productivity of the ecosystem) within the GDE that must or should be maintained or potentially improved (Step 2)?
- Within 20 years, what GDE condition is achievable?
- How do GDEs relate to or support other beneficial uses and users?

BOX 10. SUPPORTING INFORMATION

SGMA requires that GSAs consider the interests of all beneficial uses and users of groundwater when developing a GSP (Water Code § 10723.2). The following documents provide guidance on how to integrate a wide range of stakeholders throughout the development of a GSP:

- **Guidance Document on Stakeholder Communication and Engagement (DWR 2017)**

  https://www.water.ca.gov/Programs/Groundwater-Management

- **Getting Involved in Groundwater: A Guide to California's Groundwater Sustainability Plans (Union of Concerned Scientists 2017)**

  www.ucsusa.org/CAgroundwatertoolkit

- **Collaborating for Success: Stakeholder Engagement for Sustainable Groundwater Management Act Implementation (Dobbin et al. 2015)**

  https://www.cleanwateraction.org/files/publications/ca/SGMA_Stakeholder_Engagement_White_Paper.pdf

Decide whether the sustainability goal for the basin will include a statement about maintaining and/or enhancing GDEs. When making this decision, consider the susceptibility to adverse impacts from groundwater conditions to each GDE unit (Step 2) as well as local environmental values expressed by stakeholders. If the sustainability goal includes maintaining and/or enhancing GDEs, record this using Worksheet 5. Worksheet 5 will be used in Step 3.3 when setting measurable objectives.

STEP 3.2. SET MINIMUM THRESHOLDS FOR SUSTAINABILITY INDICATORS

Setting locally suitable minimum thresholds for the six sustainability indicators requires the development of scientific and legally defensible thresholds that take multiple beneficial uses into consideration to avoid undesirable results. When setting minimum thresholds for the six sustainability indicators, consider GDEs by referring to the hydrologic and biological data collected in Step 2 and recorded in Worksheet 3 and by following the flowchart in Figure 10.

The Nature Conservancy recommends setting minimum thresholds for the six sustainability indicators at levels that prevent adverse impacts to GDEs and are consistent with any requirements under other laws (Appendix II). Figure 11 illustrates how hydrologic baseline conditions defined in Step 2 and recorded in Worksheet 3 can be used to set minimum thresholds and measurable objectives (more on this in Step 3.3) that are protective of GDEs. The Nature Conservancy recommends setting the minimum threshold for sustainability indicators that reflect the baseline low value identified within the GDE's baseline period for the corresponding hydrologic parameter (Step 2.1). If no baseline period was defined in Step 2.1 or if adverse impacts to GDEs were already occurring during baseline conditions (pre-SGMA; Box 6), then refer to Step 2.3 to determine what hydrologic conditions are necessary to avoid adverse impacts to GDEs and Step 4 to collect additional information in the monitoring network. Table 2 provides examples of groundwater thresholds and objectives that were adopted to protect GDEs under water management regimes outside SGMA. Recommendations on temperature thresholds for steelhead trout, coho salmon, and chinook salmon are also available in California (Carter 2005) and can be used to help inform minimum thresholds for SGMA's water quality sustainability indicator.

If areas comprising a GDE require more conservative minimum thresholds than other areas in the basin, the GDE can be designated as a "management area" under SGMA (Box 11). This provides flexibility to establish more protective sustainable management criteria, monitoring programs, and management actions to prevent adverse impacts to GDEs than otherwise set for the basin.

BOX 11. SUPPORTING INFORMATION

Management area refers to an area within a basin for which the GSP may identify different minimum thresholds, measurable objectives, monitoring, or projects and management actions based on differences in water use sector, water source type, geology, aquifer characteristics, or other factors (23 CCR §§ 351(r) and 354.20).

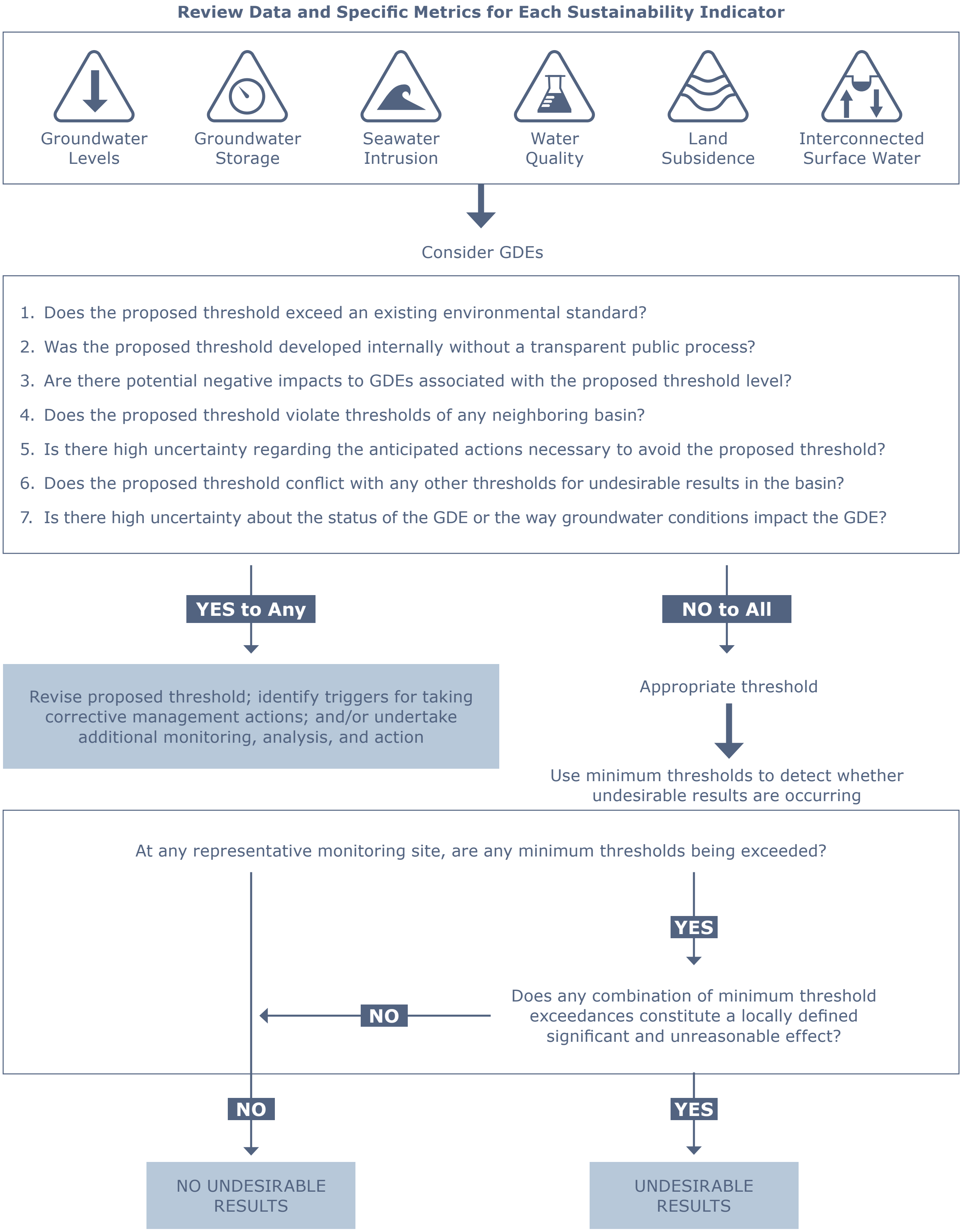


Figure 10. Flowchart for establishing and reviewing minimum thresholds (modified from Christian-Smith & Abhold 2015; DWR 2017b).

TABLE 2. Examples of measurable thresholds and objectives for GDEs under water management regimes outside SGMA.
Note: The thresholds listed here were compiled from published scientific literature or from water management standards and are provided as examples only. GDE thresholds are location specific and will vary based on differences in species composition, soil type, local climate, and hydrologic regime, among other factors.

Measurable Thresholds and Objectives	Observed Biological Change or Rationale	Location (Reference)
GROUNDWATER LEVELS		
Depth to water of 2 m for grasslands and 4 m for shrub	Maintain groundwater levels to support terrestrial vegetation based on maximum effective depth of rooting and confirmed by soil water and annual vegetation conditions.	Inyo County, California (Inyo County and City of Los Angeles 1990)
75th percentile of maximum depth to water table	Based on quantitative relationships between the position of the water table and wetland indicator plant species. A maximum depth to water table of 0.9–34.8 cm for fen plants and 16.6–32.2 cm for peat accretion can be tolerated in these wetlands.	Fremont-Winema National Forest, Oregon (Aldous & Bach 2014)
Average decline in groundwater levels must not exceed 30 feet over the next 50 years	Limit the decline in groundwater elevation to provide for sustainable yield.	Dockum Aquifer, Texas (TWDB 2016)
INTERCONNECTED SURFACE WATER		
Water level decline at the GDE level not to exceed 0.05 m/year	Groundwater flows will no longer support functioning wetlands due to chronic lowering of groundwater levels.	Tindall Limestone Aquifer, Katherine, Australia (Christian-Smith & Abhold 2015)

Measurable Thresholds and Objectives	Observed Biological Change or Rationale	Location (Reference)
WATER QUALITY		
Nutrients (Nitrate)		
4.43–8.86 mg/L	To prevent eutrophication and keep aquatic ecosystems in a "good ecological status."	Aquatic ecosystems in the United Kingdom and Poland (James et al. 2005)
13 mg/L	To protect aquatic organisms from being poisoned.	Freshwater environment in Canada (CCME 2012)
16 mg/L	To protect aquatic organisms from being poisoned.	Marine environment in Canada (CCME 2012)
440 µg TN/L	To prevent eutrophication.	Aquatic environment in Sweden (Carmargo & Álonso 2006)
< 45 mg/L	Maintain high-quality groundwater by limiting contaminant concentration.	Central Sacramento County, California (Water Forum 2006)
Salinity (Chloride and TDS)		
< 1,000 mg/L	Maintain high-quality groundwater by limiting contaminant concentration.	Central Sacramento County, California (Water Forum 2006)
Temperature		
2–3.5°C (3.6–6.3°F)	Drastic changes in the invertebrate community, species composition, timing of reproduction, and sex ratios of different species.	Coldwater springs in Ontario, Canada (Hogg & Williams 1996)
> 45°C (113°F)	Temperatures are too high for fish and macroinvertebrate species to be present. Community is dominated by microbes that tolerate extreme conditions.	Hot springs in Pacific Northwest (Brown et al. 2007)
> 70°C (158°F)	Photosynthesis ceases.	Hot springs in Yellowstone (Spear et al. 2005)

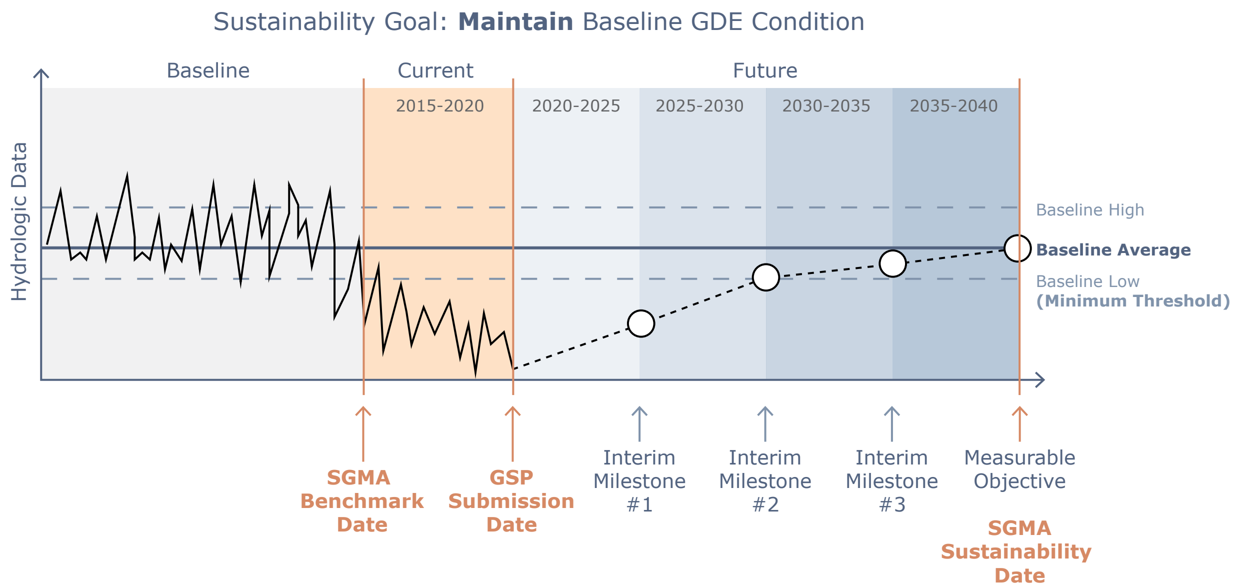
STEP 3.3. ESTABLISH MEASURABLE OBJECTIVES AND INTERIM MILESTONES

Measurable objectives that account for uncertainty and are clear, quantitative, and adaptable to changing conditions and new information are important for developing protective triggers that can promote action prior to reaching a threshold (Christian-Smith & Abhold 2015). With this in mind, refer to the basin's projected water budget, prepared for the Basin Setting section of the GSP, to consider how climate change may impact future groundwater conditions in the GDE. Then, refer to the basin sustainability goal as it pertains to GDEs (Step 3.1) and Worksheet 5 to see what hydrologic conditions are required to maintain or improve conditions for each GDE unit.

If the sustainability goal (Step 3.1) seeks to maintain or improve GDEs, then The Nature Conservancy recommends setting measurable objectives and five-year interim milestones that fall within the baseline range (Figure 11) and are sufficiently above the minimum thresholds to maintain the ecological health of GDEs.

If Step 2 revealed that adverse impacts on GDEs were already occurring during baseline conditions (pre-SGMA), then the GDEs may continue to or may progressively suffer (Figure 5). To improve the health of GDEs, The Nature Conservancy recommends setting measurable objectives and five-year interim milestones at levels optimal for GDE improvement.

If the sustainability goal is to improve GDEs, then The Nature Conservancy recommends setting measurable objectives that represent optimal hydrologic conditions for each GDE (Figure 11). Refer back to Step 2 and Worksheet 3 for location-specific information on past hydrologic conditions, such as the baseline range, that can inform five-year interim milestones. Table 2 provides examples of groundwater thresholds and objectives that were adopted to protect GDEs under water management regimes outside SGMA. Optimal hydrologic conditions for a GDE can also be determined by a historical assessment or knowledgeable ecologist.



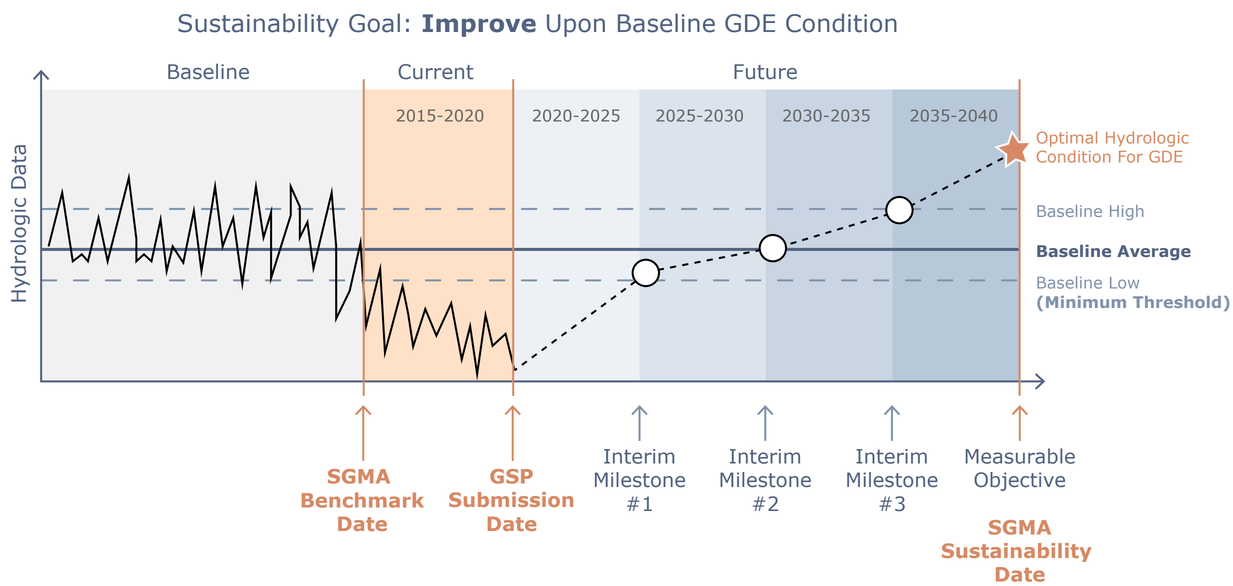


Figure 11. Setting minimum thresholds, measurable objectives, and five-year interim milestones for sustainable management criteria.

WHAT GOES IN THE GSP?

Which Section of the GSP?

Describe how the sustainability goal (GSP Section 3.1) reflects local environmental values and how information on GDEs from the Basin Setting section was used to establish the sustainability goal for the basin (23 CCR § 354.24).

Describe how GDEs were considered when setting minimum thresholds (GSP Section 3.3), including how minimum thresholds for sustainability indicators (1) avoid causing undesirable results; (2) may affect the interests of beneficial uses, including GDEs, or land uses (e.g., recreation) and property interests (e.g., conservation ownership); and (3) relate to state, federal, or local standards, noting the nature of and basis for any differences (23 CCR § 354.28).

When measurable objectives and interim milestones based on GDEs are deemed to be appropriate (23 CCR § 354.30(f)) or necessary to achieve the sustainability goal (23 CCR § 354.30(a)), results from this step could be included in the measurable objectives (GSP Section 3.4) description on how measurable objectives and five-year interim milestones (1) were established, (2) include a reasonable margin of operational flexibility, and (3) provide a reasonable path to achieve and maintain the sustainability goal (23 CCR § 354.30).

What Could Be Included?

1. A statement within the sustainability goal that addresses GDEs. The following is an example of a sentence that could be included in the sustainability goal:

   "The sustainability goal for [basin name] will [maintain/improve] the baseline condition of its groundwater dependent ecosystems."

   You may also wish to call out specific GDE units (Step 1.1) or species and habitats (Step 1.2) that are of particular concern or interest.

2. Include a short description of how selected minimum thresholds can prevent adverse impacts to GDEs from groundwater conditions. Using Worksheet 3, describe whether selected minimum thresholds for relevant sustainability indicators will avoid adverse impacts to GDEs. Describe any differences between the selected minimum threshold and any relevant state, federal, or local standards and describe how beneficial uses and users were considered when setting minimum thresholds.

3. Include a short narrative on how GDEs were considered when establishing measurable objectives and five-year interim milestones. Describe whether the consideration of GDEs helps work toward achieving and maintaining the sustainability goal.

Step 4. Incorporate GDEs into the Monitoring Network

WHAT'S IN THIS STEP?

The objectives for this step are to (1) assess and improve the hydrologic monitoring network to ensure groundwater conditions and sustainability indicators are sufficient to detect impacts to GDEs and (2) incorporate relevant biological data collection into the monitoring network to monitor GDE responses to changing groundwater conditions.

WORKSHEETS FOR THIS STEP:

Worksheet 6: Monitoring Data for GDEs

PRODUCTS FROM THIS STEP:

1. A plan to improve the monitoring of groundwater conditions and sustainability indicator metrics.
2. A list of hydrologic and biological metrics to monitor GDEs with a chosen spatial and temporal frequency.

WHY THIS STEP?

SGMA requires agencies to monitor impacts to beneficial users of groundwater (in this specific case, GDEs) with sufficient temporal and spatial detail to assess whether the sustainability goal is being achieved and adverse impacts to GDEs are being avoided. Relevant regulatory provisions include 23 CCR §§ 354.34(b) and 354.34(f)(3) (see Appendix I for details).

STEP 4.1. IMPROVE THE MONITORING NETWORK

This step helps assess and, if needed, improve the existing monitoring network such that groundwater conditions in GDEs and impacts to GDEs can be detected. Refer to Worksheet 3, created in Step 2, to identify which hydrologic and biological data types were used to assess groundwater conditions. Step 4.1 evaluates whether there are existing monitoring sites relevant to GDEs that can be incorporated into the monitoring network. Using Worksheet 6, record which types of hydrologic and biological data are currently being monitored in the basin. Once GDE-relevant monitoring metrics are listed in Worksheet 6, assess whether the existing hydrologic and biological data were collected with sufficient spatial and temporal coverage to adequately characterize a GDE's reliance on groundwater and monitor impacts to GDEs. There may be existing monitoring efforts by other agencies (e.g., academics, NGOs, water agencies, state or federal agencies) that can be incorporated into the monitoring effort. Indicate these wells on Worksheet 6.

For more guidance on determining whether spatial and temporal monitoring is sufficient, consult DWR's Best Management Practices document on monitoring networks and the identification of data gaps. For example, when determining well density to monitor a GDE, consider the GDE's susceptibility to changing groundwater conditions, the ecological value of species and habitat, geologic heterogeneity, and hydrologic uncertainty within the GDE. When susceptibility to changing groundwater conditions, ecological value, heterogeneity, and/or uncertainty are high, there may be a need to monitor site densities at or above the range of values presented in DWR's Best Management Practices document.

For those GDEs that lack sufficient data to assess potential effects from changing groundwater conditions, identify which metrics are necessary to fill data gaps and record this information in Worksheet 6. Refer to Worksheet 3, which identifies the GDEs that are missing hydrologic and biological data, to assess potential effects on GDEs.

If current monitoring wells or sampling points for selected monitoring criteria are deemed insufficient to represent spatial and/or temporal groundwater conditions for a GDE unit, The Nature Conservancy recommends including plans to install new monitoring wells or sampling points at GDEs in the GSP. The additional monitoring can be prioritized by considering the needs of GDEs with a higher ecological value and important species and habitats (Worksheet 2) as well as GDEs most susceptible to changing groundwater conditions (Worksheet 3).

For technical assistance and guidance on monitoring protocols, refer to DWR's Best Management Practices document on monitoring protocols, standards, and sites.

HYDROLOGIC DATA RELEVANT TO GDEs

Shallow Monitoring Wells

Shallow monitoring wells can be used to monitor groundwater levels in or around GDEs. The density of these wells will depend on the heterogeneity of the aquifer system and whether the GDE is situated in or near interconnected surface waters, such as wetlands, rivers and streams, or seeps and springs. GDEs in or near a stream may benefit from a series of shallow monitoring wells that are co-located with stream gages and positioned perpendicular to the stream to better characterize the groundwater–surface water flow dynamics.

Shallow monitoring wells can be installed using relatively simple methods (e.g., jetting, hand augers, direct push), avoiding the need for larger machinery, which can be expensive and potentially harmful to surrounding habitat. Nested monitoring wells that can monitor multiple vertical layers of the aquifer are also useful for understanding the level of connectivity between the shallow aquifer and the deeper aquifer, which is particularly important in areas containing perched groundwater.

Basic Water Quality Metrics

Metrics such as water temperature, pH, electrical conductivity, dissolved oxygen, nutrients (nitrate concentrations), and salinity are useful for monitoring environmental conditions for GDEs with interconnected surface waters.

Stream Gauges

Stream gauges are important for monitoring instream flow conditions necessary to sustain GDEs in multiple ways, including, but not limited, to the following:

- Providing sufficient flow for fish passage during migratory periods
- Refreshing pool water quality for fish, insects, and amphibians
- Ensuring sufficient pool size, depth, and spawning and rearing characteristics for fish and amphibians
- Sustaining run habitat
- Providing dispersal mechanisms for stream-side or riparian vegetation

Geophysical Surveys

Geophysical methods, such as electrical resistivity tomography and electrical magnetism, can provide relatively inexpensive and high-resolution spatial data to identify and map regions of differing soils and water. Electrical resistivity tomography has been used to identify and map hydrogeologic conditions under groundwater-dependent riparian forest stands in the Central Valley (M.M.Rohde, unpublished data), monitor coastal seawater intrusion along the Monterey coast (Goebel et al. 2017), and investigate groundwater–surface water interactions in Sonoma County (Ulrich et al. 2015). Similarly, airborne electrical magnetism has also been used to identify and map hydrogeologic conditions over Tulare County (https://gemcenter.stanford.edu/) and has been used to monitor groundwater flow.

STEP 4.2. MONITOR IMPACTS TO GDEs

This step provides guidance on monitoring impacts on GDEs by incorporating biological metrics. As mentioned in Step 2, monitoring biological responses over time can help assess whether groundwater conditions are significantly impacting GDEs. The Nature Conservancy recommends monitoring both hydrologic and biological data as part of an iterative process of adaptive management. Collecting biological data can be an inexpensive way to detect whether existing hydrologic monitoring sites are sufficient in density and sampling frequency, minimum thresholds are sufficient to prevent adverse impacts to GDEs, and measurable objectives and interim milestones are on track to achieve the sustainability goal.

Biological monitoring varies in cost, efficiency, and logistical feasibility. Figure 12 provides suggestions for prioritizing the biological monitoring methods recommended in Step 2 listed in order from relatively simple and inexpensive to more complicated and costly. If the existing monitoring network has little or no biological monitoring, then The Nature Conservancy recommends beginning by incorporating simple monitoring methods on a biannual or annual basis. Examples of monitoring techniques include aerial and on-site photography, remote sensing applications, and field surveys, which can be used as a screening tool to observe changes in ecosystem responses.

BOX 12. SUPPLEMENTARY INFORMATION

Inyo County Water Department monitors both hydrologic and vegetation conditions in Owens Valley to inform management decisions on groundwater pumping that can avoid substantial declines in groundwater dependent vegetation. Vegetation monitoring is based on field sampling and remote sensing indexes. For more information visit the following:

- **Inyo County Water Department**

  http://www.inyowater.org/maps-data/vegetation/vegetation-monitoring/

- **Inyo County Case Study**

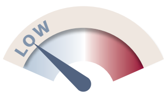
  http://www.groundwaterresourcehub.org

Advanced biological monitoring includes surveys of individual species over time. These species-specific methods may be appropriate if groundwater dependent species or habitat, such as endangered, threatened, and/or rare species, warrant specific attention.

In some cases, targeted research on GDEs may help better understand cause-and-effect relationships between groundwater conditions and GDEs. Refer to Appendix IV for guidance on which methodologies are most appropriate in meeting monitoring and management objectives.

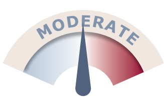
MONITORING GDEs AT VARIOUS RISK LEVELS

To prioritize biological monitoring actions, The Nature Conservancy recommends considering the GDE's ecological value and how susceptible the GDE is to changing groundwater conditions (Figure 12).



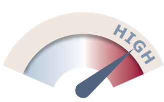
Low-Risk GDEs

GDEs characterized as having a low risk to adverse impacts caused by groundwater conditions are those with a lower ecological value (Step 1.2) and susceptibility to changing groundwater conditions (Step 2.1). Despite being at low risk, these GDEs could still be adversely affected if hydrologic data are not accurately reflecting groundwater conditions for GDEs or if baseline conditions are resulting in the progressive decline of GDEs. To guard against these uncertainties, The Nature Conservancy recommends incorporating simple biological monitoring of vegetative growth, which can help detect changes within GDEs in an inexpensive and simple manner. This can be done by taking photos from a fixed point within a GDE (preferably in the summer when groundwater dependence is greatest) and/or using remote sensing indexes to detect changes in vegetative growth on a biannual or annual basis.



Moderate-Risk GDEs

GDEs characterized as having a moderate risk to adverse impacts caused by groundwater conditions are those with moderate ecological value (Step 1.2) and susceptibility to changing groundwater conditions (Step 2.1). For these GDEs, The Nature Conservancy recommends integrating annual biological surveys (e.g., vegetation transects or other fish/invertebrate/vertebrate surveys) into the monitoring program to establish pre– and post–groundwater condition changes. In addition, simple biological indicators, such as remote sensing indexes, can be used to monitor changes in vegetative growth and the size and extent of the GDE.



High-Risk GDEs

GDEs characterized as having a high risk to adverse impacts caused by groundwater conditions are those with high ecological value (Step 1.2) and/or susceptibility to changing groundwater conditions (Step 2.1). Refer to Worksheets 2 and 3 to determine whether there are important groundwater dependent species and habitats that may require specific monitoring. For these GDEs, The Nature Conservancy also recommends integrating annual biological surveys into the monitoring program and simpler biological indicators, such as remote sensing indexes, to monitor changes in vegetative growth and the size and extent of the GDE.

GDEs with Insufficient Data

When hydrologic and biological monitoring are insufficient to detect the GDE's response to changing groundwater conditions, The Nature Conservancy recommends the monitoring network be improved to address this uncertainty. Priority should be given to the highest risk GDEs and GDEs supporting species protected by law. Additional actions can be prioritized for cost and feasibility based on the GDE's ecological value (Step 1.2) and susceptibility to changing groundwater conditions (Step 2.1).

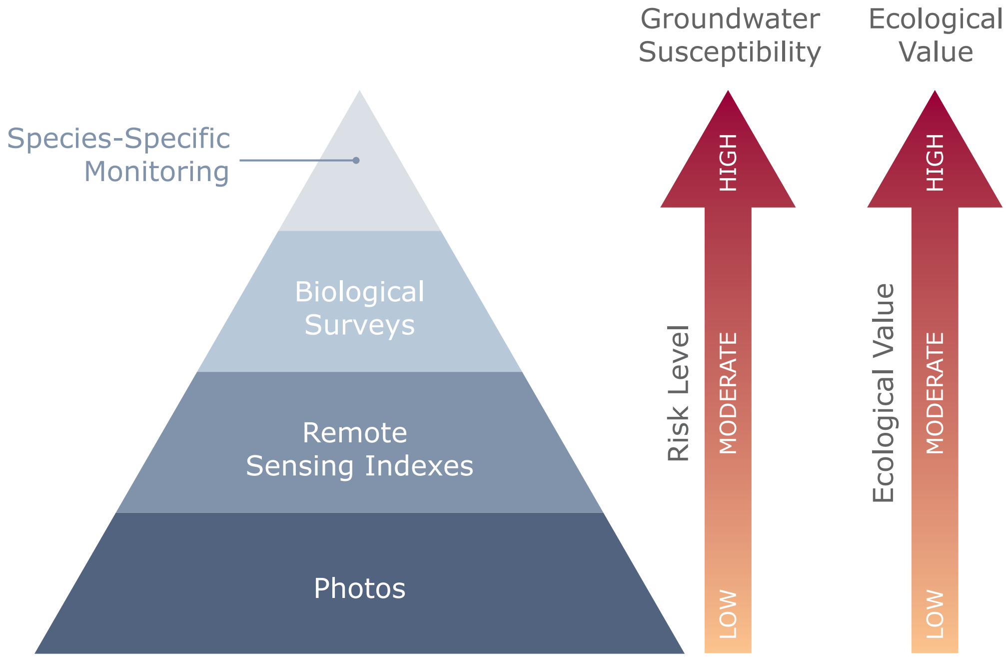


Figure 12. Use GDE susceptibility determined in Step 2.1 and ecological value determined in Step 1.2 to prioritize monitoring.

WHAT GOES IN THE GSP?

Which Section of the GSP?

Describe how the monitoring network objectives (GSP Section 3.5) make progress toward achieving measurable objectives, monitor impacts to GDEs, and monitor changes in groundwater conditions (23 CCR § 354.34).

What Could Be Included?

1. A short description of whether available hydrologic data (e.g., existing monitoring wells or sample points) are spatially and temporally sufficient to monitor groundwater conditions for each GDE unit (refer to Worksheet 6). If monitoring efforts are insufficient, provide a short description of how to reconcile data gaps.
2. A short description of how impacts to GDEs, as detected by biological responses, will be monitored. Describe which monitoring methods will be used to monitor each GDE and how biological data will be used in conjunction with hydrologic data to evaluate cause-and-effect relationships.

Step 5. Identify Projects and Management Actions to Maintain or Improve GDEs

WHAT'S IN THIS STEP?

Step 5 provides guidance on selecting projects and management actions that may help to maintain or improve GDEs to achieve the basin sustainability goal.

WORKSHEETS FOR THIS STEP:

None

PRODUCTS FROM THIS STEP:

1. A list of projects and management actions that will improve or maintain conditions for each GDE to achieve the sustainability goal in the basin.

WHY THIS STEP?

SGMA requires agencies to plan for projects and management actions that will enable the GSA to achieve the basin sustainability goal and meet sustainable management criteria (i.e., minimum thresholds, measurable objectives, interim milestones, and avoidance of undesirable results). Relevant regulatory provisions include GSP 23 CCR §§ 354.44(a) and 354.44(b) (see Appendix I for details).

Step 5 provides guidance on identifying potential supply and demand management strategies that can provide multiple benefits for GDEs and the basin. Multi-benefit projects, such as groundwater recharge, habitat restoration, and groundwater trading, are highlighted in this step as they are conducive to facilitating partnerships and financial opportunities (e.g., matched funds, grants, general bond obligations, water markets).

View of oak woodlands and riparian habitat along the Michigan Bar in the Cosumnes River watershed, CA. © Karen Gregg Elliott/The Nature Conservancy

STEP 5.1. SUPPLY MANAGEMENT STRATEGIES

This step recommends potential approaches for augmenting groundwater and interconnected surface water to maintain or improve GDEs while providing other benefits for the basin.

Groundwater Recharge

Groundwater recharge (i.e., managed aquifer recharge) projects can offer a wide range of multi-benefit opportunities (Perrone & Rohde 2016) for improving groundwater conditions. Some questions to consider when designing a recharge project are as follows:

1. What sources of water (i.e., surface water, floodwater, recycled water, urban stormwater) and methods of conveyance are available to support groundwater recharge projects? Are there any water quality issues associated with the source water?

2. Can existing local landscapes (e.g., floodplains, streams or rivers, agricultural fields) be used for recharge? If recharging via a stream, how will the recharge project affect instream flows or the stream ecosystem? Consult Sustainable Conservation's Groundwater Recharge Assessment Tool (www.suscon.org) or the Soil Agricultural Groundwater Banking Index (https://casoilresource.lawr.ucdavis.edu/sagbi/) to see how suitable agricultural land in your area is for groundwater recharge.

3. Is in-lieu recharge an option to provide alternative water sources (i.e., surface water or recycled water) to groundwater pumpers, resulting in less extraction?

4. Will the groundwater recharge project supply water into the principal aquifer being accessed by the GDE? Can GDEs benefit during the recharge process even if it eventually provides benefits to deeper aquifer systems?

5. How will the recharged water improve groundwater conditions for the GDE and the basin at large?

6. Will the recharge project help achieve sustainable management criteria (i.e., sustainability goal, minimum thresholds, measurable objectives, interim milestones)?

7. Can recharge projects be designed to provide more than one public benefit (e.g., improving drinking water quality for disadvantaged communities, maintaining groundwater levels for domestic drinking wells, flood risk management, recreational opportunities, aquaculture)?

8. Will the recharge basins or inundated land create new habitat for migratory birds and local flora or fauna? Projects providing multiple benefits may be eligible for additional sources of funding, such as through conservation funding programs.

9. Will the recharge basins or inundated land harm existing habitat? If so, how will these impacts be avoided, reduced, or mitigated?

Habitat Restoration

Reduce Consumptive Water Demand

In GDEs dominated by non-native plant species, invasive plant removal may help improve groundwater conditions by reducing water demand and creating an opportunity to restore native plants, both of which can improve the health of a GDE. Examples of water-intensive invasive plants include *Arundo donax* (commonly referred as giant reed), which is found throughout central and southern California, and *Tamarix* (commonly referred as tamarisk or salt cedar) found along riparian zones in desert and coastal areas. Since estimates of consumptive water use by *Arundo* and *Tamarix* can vary depending on the location and methodology used, GSAs may want to quantify the consumptive water use benefits locally.

Floodplain Restoration

In some areas, GDEs may occur on floodplains that have become separated from stream and river channels. Reconnecting rivers and streams to their floodplains reestablishes natural floodplain dynamics, including recharge that occurs when floodwaters spread over riverbanks. Floodplain restoration can provide additional benefits, such as reducing high stream flows (i.e., flood risk management), improving habitat, and improving nutrient exchange.

Open Space Preservation

In many cases, open space lands are important locations where natural recharge can occur. By preserving these land uses, either through easements or land designations, natural recharge areas can be maintained, and consumptive use related to more intensive uses of the land are avoided.

STEP 5.2. DEMAND MANAGEMENT STRATEGIES

While supply-side management may be generally preferred, GDEs that are experiencing adverse impacts may require proximate pumping reductions to achieve the sustainability goal, objectives, and thresholds for the basin. The following types of actions may be considered and implemented depending on local context:

- Specified minimum distance for pumping to buffer GDEs
- Specified maximum pumping rates for pumping around GDEs
- Restricted pumping during certain times of the year
- Restricted pumping at certain depths
- Well permitting and well density rules, including preclusion of new wells
- Where groundwater markets are developed, protective trading rules to ensure GDEs are not adversely impacted
- Offset requirements for impacts
- Domestic/farm/industrial conservation technologies or process changes

WHAT GOES IN THE GSP?

Which Section of the GSP?

For GDE-related projects and management actions, describe how projects and management actions (GSP Section 4.0) will make progress toward achieving a measurable objective, the expected benefits, how they will be evaluated, circumstances for implementation, permitting and regulatory requirements, how the project will be accomplished, timeline, legal authorities required, estimated costs, and management of groundwater extraction and recharge (23 CCR § 354.44).

What Could Be Included?

A description of each project or management action relevant to GDEs, how GDEs will benefit, and how the project(s) will be evaluated to assess whether adverse impacts to the GDE have been mitigated or prevented.

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LINKS TO THE FOLLOWING REFERENCES ARE AVAILABLE AT
http://www.groundwaterresourcehub.org

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APPENDIX I: LEGAL REFERENCES

SGMA was signed into law in 2014 and amended the Water Code (Part 2.74 of Division 6 of the Water Code, Sections 10720–10737.8). SGMA provides the framework for sustainable groundwater management planning and implementation. The GSP Regulations for the evaluation of GSPs and alternatives, the implementation of GSPs and alternatives, and coordination agreements between GSAs and/or stakeholders were approved by the California Water Commission on May 18, 2016, and are codified in the California Code of Regulations (CCR), Title 23, Division 2, Chapter 1.5, Subchapter 2.

Step 1: Identify GDEs

23 CCR § 354.16(g)
Each plan shall provide a description of current and historic groundwater conditions in the basin, including data from January 1, 2015, to current conditions, based on the best available information that includes […] identification of GDEs within the basin, utilizing data available from the Department, as specified in Section 353.2, or the best available information.

Water Code § 10723.2(e)
The GSA shall consider the interests of all beneficial uses and users of groundwater as well as those responsible for implementing GSPs. These interests include, but are not limited to, […] environmental users of groundwater.

Water Code § 10727.4
A GSP shall include, where appropriate and in collaboration with the appropriate local agencies, all of the following: […] impacts on GDEs.

WATER BUDGETS

23 CCR § 354.18(b)(1)
The water budget shall quantify the following, either through direct measurements or estimates based on data, […] total surface water entering and leaving a basin by water source type.

23 CCR § 354.18(b)(3)
The water budget shall quantify the following, either through direct measurements or estimates based on data, […] outflows from the groundwater system by water use sector, including evapotranspiration, groundwater extraction, groundwater discharge to surface water sources, and subsurface groundwater outflow.

23 CCR § 354.18(b)(7)
The water budget shall quantify the following, either through direct measurements or estimates based on data, […] an estimate of sustainable yield for the basin.

23 CCR § 354.18(c)
Each Plan shall quantify the current, historical, and projected water budget for the basin.

Step 2: Determine Potential Effects on GDEs

23 CCR § 354.26(a)
[…] Undesirable results occur when significant and unreasonable effects for any of the sustain- ability indicators are caused by groundwater conditions occurring throughout the basin.

23 CCR § 354.26(b)(3)
The description of undesirable results shall include […] potential effects on the beneficial uses and users of groundwater, on land uses and property interests, and other potential effects that may occur or are occurring from undesirable results.

Step 3: Consider GDEs When Establishing Sustainable Management Criteria

STEP 3.1 SUSTAINABILITY GOAL

Water Code § 113
It is the policy of the state that groundwater resources be managed sustainably for long-term reliability and multiple economic, social, and environmental benefits for current and future beneficial uses. Sustainable groundwater management is best achieved locally through the development, implementation, and updating of plans and programs based on the best available science.

23 CCR § 354.24
Each GSA shall establish in its plan a sustainability goal for the basin that culminates in the absence of undesirable results within 20 years of the applicable statutory deadline. The plan shall include a description of the sustainability goal, including information from the basin setting used to establish the sustainability goal, a discussion of the measures that will be implemented to ensure that the basin will be operated within its sustainable yield, and an explanation of how the sustainability goal is likely to be achieved within 20 years of plan implementation and is likely to be maintained through the planning and implementation horizon.

STEP 3.2 MINIMUM THRESHOLDS

23 CCR § 354.28(b)(1)

The description of minimum thresholds shall include [...] the justification for the minimum threshold shall be supported by information provided in the basin setting, and other data or models as appropriate, and qualified by uncertainty in the understanding of the basin setting.

23 CCR § 354.28(b)(4)

The description of minimum thresholds shall include [...] how minimum thresholds may affect the interests of beneficial uses and users of groundwater or land uses and property interests.

23 CCR § 354.28(b)(5)

The description of minimum thresholds shall include [...] how state, federal, or local standards relate to the relevant sustainability indicator. If the minimum threshold differs from other regulatory standards, the agency shall explain the nature of and basis for the difference.

Water Code § 10720.3(d)

In an adjudication of rights to the use of groundwater and in the management of a groundwater basin or sub-basin by a GSA or by the board, federally reserved water rights to groundwater shall be respected in full. In case of conflict between federal and state law in that adjudication or management, federal law shall prevail. The voluntary or involuntary participation of a holder of rights in that adjudication or management shall not subject that holder to state law regarding other proceedings or matters not authorized by federal law. This subdivision is declaratory of existing law.

Water Code § 10720.5(b)

Nothing in this part or in any groundwater management plan adopted pursuant to this part determines or alters surface water rights or groundwater rights under common law or any provision of law that determines or grants surface water rights.

STEP 3.3 MEASURABLE OBJECTIVES

23 CCR § 354.30(f)

Each plan may include measurable objectives and interim milestones for additional plan elements described in Water Code § 10727.4 where the agency determines such measures are appropriate for sustainable groundwater management in the basin.

Water Code § 10727.4

A GSP shall include, where appropriate and in collaboration with the appropriate local agencies, all of the following: [...] impacts on GDEs.

Step 4: Incorporate GDEs into the Monitoring Network

23 CCR § 354.34(b)

Each plan shall include a description of the monitoring network objectives for the basin, including an explanation of how the network will be developed and implemented to monitor groundwater and related surface conditions and the interconnection of surface water and groundwater, with sufficient temporal frequency and spatial density to evaluate the affects and effectiveness of plan implementation. The monitoring network objectives shall be implemented to accomplish the following:

1. Demonstrate progress toward achieving measurable objectives described in the plan.
2. Monitor impacts to the beneficial uses or users of groundwater.
3. Monitor changes in groundwater conditions relative to measurable objectives and minimum thresholds.
4. Quantify annual changes in water budget components.

23 CCR § 354.34(f)(3)

The GSA shall determine the density of monitoring sites and frequency of measurements required to demonstrate short-term, seasonal, and long-term trends based upon [...] impacts to beneficial uses and users of groundwater and land uses, property interest affected by groundwater production, and adjacent basins that could affect the ability of that basin to meet the sustainability goal.

Step 5: Identify Projects and Management Actions to Maintain or Improve GDEs

23 CCR § 354.44(a)

Each plan shall include a description of the projects and management actions the GSA has determined will achieve the sustainability goal for the basin, including projects and management actions to respond to changing conditions in the basin.

23 CCR § 354.44(b)(1)

Each plan shall include a description of the projects and management actions that include […] a list of projects and management actions proposed in the plan with a description of the measurable objective that is expected to benefit from the project or management action. The list shall include projects or management actions that may be utilized to meet interim milestones, the exceedance of minimum thresholds, or undesirable results that have occurred or are imminent.

23 CCR § 354.44(b)(4)

Each plan shall include a description of the projects and management actions that include […] the status of each project and management action, including a timetable for expected initiation and completion, and the accrual of expected benefits.

23 CCR § 354.44(b)(5)

Each plan shall include a description of the projects and management actions that include […] an explanation of the benefits that are expected to be realized from the project or management action and how those benefits will be evaluated.

APPENDIX II: OTHER RELEVANT LAWS

PREEMPTION OF SGMA

Water Code § 10720.3(d)
In an adjudication of rights to the use of groundwater and in the management of a groundwater basin or sub-basin by a GSA or by the board, federally reserved water rights to groundwater shall be respected in full. In case of conflict between federal and state law in that adjudication or management, federal law shall prevail. The voluntary or involuntary participation of a holder of rights in that adjudication or management shall not subject that holder to state law regarding other proceedings or matters not authorized by federal law. This subdivision is declaratory of existing law.

Water Code § 10720.5(b)
Nothing in this part or in any groundwater management plan adopted pursuant to this part determines or alters surface water rights or groundwater rights under common law or any provision of law that determines or grants surface water rights.

FEDERAL

The Clean Water Act
The Clean Water Act (CWA) is also known as Federal Water Pollution Control Act (FWPCA) (33 USC § 1251 et seq.) and establishes the National Pollution Discharge Elimination System (§ 402), requiring permits for discharges to navigable water bodies, and a program to regulate discharge of dredge and fill material into waters of the United States, including wetlands (§ 404).

33 USC §§ 1311, 1342, and 1344. Regulations adopted by the U.S. Army Corps of Engineers and Environmental Protection Agency define "waters of the United States" and wetlands.

33 CFR § 328.3. Together these federal laws regulate point source discharge of pollutants, discharge of dredged or fill material, and water quality while largely leaving states to regulate non-point source pollution and discharges, such as storm water.

The Rivers and Harbors Act of 1899
The Rivers and Harbors Act of 1899 (33 USC § 401 et seq.) regulate "navigable waters of the United States" and prohibit the construction of any bridge, dam, dike, or causeway over or in navigable waterways without Congressional approval.

The Endangered Species Act

The Endangered Species Act (16 USC § 1531 et seq.) provides for the conservation of species that are endangered or threatened throughout all or a significant portion of their range and the conservation of the ecosystems on which they depend.

The Comprehensive Environmental Response, Compensation and Liability Act

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, also known as "Superfund," 42 USC § 9601 et seq.) provides federal authority to respond to releases or threatened releases of hazardous substances that may endanger public health or the environment.

The Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act (16 USC § 661 et seq.) requires federal agencies involved with the development of projects relating to water resources to consult with the U.S. Fish and Wildlife Service. It also requires study of the effects of domestic sewage, trade wastes, and other polluting substances on wildlife.

The National Environmental Policy Act

The National Environmental Policy Act (42 USC § 4321 et seq.) requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions.

STATE

Porter-Cologne Water Quality Act

The Porter-Cologne Water Quality Act (Water Code § 13000 et seq.) protects water quality and beneficial uses of water in California. Porter-Cologne applies to surface water, groundwater, wetlands, and point and non-point sources of pollution.

The State Water Resources Control Board is responsible for water usage, including the delivery of water under the state water project. Regional Water Quality Control Boards adopt basin plans and regulate storm water (Water Code § 13540), water reuse (Water Code § 13550 et seq.), and water recycling (Water Code § 13575 et seq.)

Fish and Game Code

California's Fish and Game Code (FGC § 1600 et seq.) requires lake or streambed alteration agreements for actions that affect rivers, lakes, and streams.

Surface Mining and Reclamation Act of 1975

The Surface Mining and Reclamation Act of 1975 (Public Resources Code § 2710 et seq.) regulates surface mining, reclamation, and the environmental effects of mining, including effects on water resources.

California Endangered Species Act

The California Endangered Species Act (Fish and Game Code § 2050 et seq.) protects plants and animals threatened with extinction, prohibiting the "take" of any species designated by the California Fish and Game Commission as candidate species, threatened, or endangered.

California Environmental Quality Act

The California Environmental Quality Act (CEQA) (Public Resources Code § 21000 et seq.) and accompanying guidelines (Code of Regulations, Title 14, § 15000 et seq.) requires local and state agencies to identify significant environmental impacts associated with the issuance of permits and the approval of projects and to avoid or mitigate those impacts.

LOCAL

County and Other Local Groundwater Regulation Ordinances

California Government Code §§ 65350.5 and 6535 requires city and county consideration of groundwater requirements in general plans.

APPENDIX III: WORKSHEETS

Downloadable worksheets are available at http://www.groundwaterresourcehub.org.

WORKSHEET 1. ASSESS A CONNECTION TO GROUNDWATER

Use the following questions to assess whether iGDE polygons are connected to groundwater.	**Yes**	**No**	**Insufficient Data**
GENERAL QUESTIONS FOR ALL GDE TYPES			
Is the iGDE underlain by a shallow unconfined or perched aquifer that has been delineated as being part of a Bulletin 118 principal aquifer in the basin?			
Is the depth to groundwater under the iGDE less than 30 feet?			
Is the iGDE located in an area known to discharge groundwater (e.g., springs/seeps)?			
*If you answer **Yes** to any of the above questions, then you likely have a GDE. Stop here. If you selected **No** or* **Insufficient Data** *or cannot confidently answer any of the above questions, then answer the following questions to infer groundwater dependency.*			
RIVERS, STREAMS, AND ESTUARIES			
Is the iGDE located in a portion of a river or stream that is likely a gaining reach?			
Are water temperatures around the iGDE relatively constant over time, indicating a potential for gaining conditions?			
Are there stable/permanent natural flows detected by stream gauges near the iGDE, indicating a potential for gaining conditions?			
Is there water or flows around the iGDE during summer months?			
For iGDEs near estuaries, does the salinity drop below that of seawater in the absence of surface water inputs (e.g., surface runoff or stormwater)?			
Are the isohaline contour lines of the saline wedge relatively constant under an iGDE?			

Use the following questions to assess whether iGDE polygons are connected to groundwater.	**Yes**	**No**	**Insufficient Data**
WETLANDS			
Is the level of water around the iGDE maintained during extended dry periods without surface water inflow or management?			
Is the location of the iGDE consistently associated with known areas of groundwater discharge (e.g., springs or seeps) in terrestrial and/or coastal environments?			
TERRESTRIAL VEGETATION			
Does vegetation in the iGDE remain green and physiologically active during extended dry periods of the year?			
Does the iGDE have higher evapotranspiration rates in summer months compared to other nearby vegetation unlikely to be dependent on groundwater?			
SEEPS AND SPRINGS			
Are there breaks in the slope of the land surface or areas of stratigraphic change causing groundwater to emerge or vegetation to congregate on the surface?			
Is there a presence of hydric (very wet) soils in areas with little summer precipitation, indicating persistent soil saturation throughout the year?			
Are there elevated surface water temperatures from an influx of geothermal groundwater discharge?			
*If you answered **Yes** to any of the questions above, then you likely have a GDE. If you answered **No** to all the questions, then you likely do not have a GDE. If you answered **Insufficient Data** to all the questions, then assume you have a GDE until sufficient data is collected. Refer to Appendix IV and Step 4.*			

WORKSHEET 2. GDE ECOLOGICAL INVENTORY

Ecological Inventory for GDE Unit ID_____________

		DESCRIPTION/NOTES
Species	☐ Locally Important or Endemic ☐ Special Status ☐ Rare ☐ Threatened ☐ Endangered Presence of ☐ Native_________% ☐ Non-Native_________%	
Habitat	☐ Critical Habitat ☐ Recognized Wetland ☐ Part of a Protected Area ☐ Part of Local Conservation Plan ☐ Part of a Wildlife Corridor Plan	
Environmental Beneficial Uses*	☐ Aquaculture ☐ Cold Freshwater Habitat ☐ Estuarine Habitat ☐ Inland Saline Water Habitat ☐ Marine Habitat ☐ Migration of Aquatic Organisms ☐ Preservation of Biological Habitats of Special Significance ☐ Rare, Threatened, or Endangered Species ☐ Protected/Special Status/Sensitive Species ☐ Spawning, Reproduction, and/or Early Development ☐ Warm Freshwater Habitat ☐ Wildlife Habitat ☐ Other_______________	

* Relevant environmental beneficial uses listed in Bulletin 118 (2003 update)—Appendix E.

WORKSHEET 3. POTENTIAL EFFECTS ON GDE SUMMARY

GDE Unit ID_____________

Ecological Value (Step 1.2)—*Check the one that applies* ☐ High ☐ Moderate ☐ Low ☐ Insufficient Data/Not Applicable

Susceptibility to Changing Groundwater Conditions (Step 2.1)—*Check the one that applies*

☐ High ☐ Moderate ☐ Low ☐ Insufficient Data/Not Applicable

Corresponding Sustainability Indicator	**Groundwater Levels**	**Groundwater Storage**	**Seawater Intrusion**	**Water Quality**	**Land Subsidence**	**Interconnected Surface Water**
Hydrologic Data (Step 2.1)	Example: Depth to water table (below ground surface [bgs])	(If applicable)	(If applicable)	Example: Water chemistry (nitrate concentrations)	(If applicable)	Example: Surface water flow (annual mean low flow in cubic feet per second [cfs])
Baseline Average (Step 2.1)	Example: 10 feet bgs	(If applicable)	(If applicable)	Example: 10 mg/L	(If applicable)	Example: 10 cfs
Baseline Range (Step 2.1)	Example: 5–15 feet bgs	(If applicable)	(If applicable)	Example: 8–12 mg/L	(If applicable)	Example: 3–30 cfs
Biological Data (Step 2.2)	Example: Rooting depth	(If applicable)	(If applicable)	Example: Surface water temperature requirements for spawning and rearing fish	(If applicable)	Example: Minimum flow requirements for migrating and over-summering fish
Description of Adverse Impacts to GDE (Step 2.3)	Example: Groundwater levels > 30 feet bgs has been as associated with 15% reduction in crown die-back of groundwater dependent vegetation and a shift of more than 10% of species composition shifts to non-native species	(If applicable)	(If applicable)	Example: Nitrate concentrations > 15 mg/L have been shown to trigger severe eutrophication and fish kills during in summer months; surface water temperatures that exceed fish and spawning and rearing requirements may result in death, diminished or failed spawning, or other "take" of listed species	(If applicable)	Example: Annual mean low flow < 30 cfs is associated with habitat loss for anadromous fish species, inhibited fish migration for 14 additional days, and/or at river mile 15

WORKSHEET 4. BIOLOGICAL CHANGE ASSESSMENT

GDE Unit ID_____________

Biological Response Type		Yes	No	Insufficient Data
Terrestrial Vegetation				
Growth & Productivity	Are there visible signs (i.e., less canopy cover) of reduced growth in native vegetation over time?			
Growth & Productivity	Are NDVI or NDWI levels in terrestrial wildlife habitat areas progressively becoming lower over time?			
Growth & Productivity	Is there a decrease in species listed as a sensitive, threatened, or endangered species associated with the GDE? Is there a measurable and persistent decline in vegetation cover or leaf area index?			
Reproduction & Recruitment	Is the terrestrial wildlife habitat mostly composed of old mature trees with few seedlings and saplings present to take their place?			
Reproduction & Recruitment	Is there a decrease in the populations of perennial resident species compared to baseline conditions?			
Reproduction & Recruitment	Is there a reduction in the understory vegetation?			
Mortality	During the last drought, did large proportions of terrestrial vegetation die or appear to decrease?			
Mortality	Has there been loss of a species endemic to the area or listed as a sensitive, threatened, or endangered species associated with the GDE?			
Ecosystem Structure & Function	Is there a growing trend of non-native species becoming present? Are there observable trends in the vegetation community toward more xeric (dry) vegetation?			
Ecosystem Structure & Function	Do NDVI or NDWI maps show terrestrial wildlife habitat areas recovering in the wet years that follow a drought/dry period?			
Ecosystem Structure & Function	Are groundwater levels more than 3–6 feet below the average rooting depth?			
River/Stream/Estuary				
Growth & Productivity	Are there visible signs (i.e., less canopy cover) of reduced growth in native riparian vegetation over time?			
Growth & Productivity	Are flow-related migration impediments or barriers increased in number and/or severity compared to baseline conditions?			
Growth & Productivity	Is there a decrease in endemic species or species listed as a sensitive, threatened, or endangered species associated with the GDE?			

Biological Response Type		Yes	No	Insufficient Data
River/Stream/Estuary				
Reproduction & Recruitment	Is the riparian habitat mostly composed of old mature trees with few seedlings and saplings present to take their place?			
Reproduction & Recruitment	Is there a decrease in the fish or amphibian rearing habitat for the GDE compared to baseline conditions?			
Reproduction & Recruitment	Is there a decrease in the population of certain animal classes (e.g., fish, amphibians, reptiles, mammals, birds, anthropods) compared to baseline conditions?			
Reproduction & Recruitment	Is there a decrease in the populations of perennial resident species compared to baseline conditions?			
Reproduction & Recruitment	Is there a decrease in the population of species seeking refuge during dry or drought periods compared to baseline conditions?			
Mortality	During the last drought, did large proportions of vegetation die or appear to decrease?			
Mortality	Has there been loss of a endemic species or species listed as a sensitive, threatened, or endangered species associated with the GDE?			
Ecosystem Structure & Function	Is there a growing density of non-native species?			
Ecosystem Structure & Function	Do NDVI or NDWI maps show a difference in terrestrial wildlife habitat areas in wet years and drought/dry periods?			
Ecosystem Structure & Function	Are portions of a stream that were once gaining groundwater now losing or disconnected systems?			
Ecosystem Structure & Function	Are portions of a stream that were once losing groundwater now disconnected systems?			
Ecosystem Structure & Function	Are groundwater levels more than 3–6 feet below the average rooting depth?			
Wetland/Seep/Spring				
Growth & Productivity	Are there visible signs (i.e., less canopy cover) of reduced growth in native vegetation over time?			
Growth & Productivity	Is there a decrease in the population of endemic species or species listed as a sensitive, threatened, or endangered species associated with the GDE?			

Biological Response Type		Yes	No	Insufficient Data
Wetland/Seep/Spring				
Reproduction & Recruitment	Is there a decrease in spawning habitat compared to baseline conditions?			
Reproduction & Recruitment	Is there a decrease in the fish or amphibian rearing habitat for the GDE compared to baseline conditions?			
Reproduction & Recruitment	Is there a decrease in the population of certain animal classes (e.g., fish, amphibians, reptiles, mammals, birds, anthropods) compared to baseline conditions?			
Reproduction & Recruitment	Is there a decrease in the populations of perennial resident species compared to baseline conditions?			
Reproduction & Recruitment	Is there a decrease in the population of species seeking refuge during dry or drought periods compared to baseline conditions?			
Mortality	During the last drought, did large proportions of vegetation die and/or did species population dwindle below average?			
Mortality	Has there been loss of a endemic species or species listed as a sensitive, threatened, or endangered species associated with the GDE?			
Ecosystem Structure & Function	Is there a growing density of non-native species?			
Ecosystem Structure & Function	Do NDVI or NDWI maps show vegetation areas recovering in the wet years that follow a drought/dry period?			

WORKSHEET 5. ESTABLISHING THE SUSTAINABILITY GOAL AND MEASURABLE OBJECTIVES AS THEY PERTAIN TO GDEs

GDE Unit ID	Important Species and Habitat (Step 1.2)	Susceptibility to Changing Groundwater Conditions (Step 2)			GDE Measurable Objective in Sustainability Goal (Step 3.1)	Hydrologic Conditions to Maintain or Improve GDE Condition (Step 2)		
		Lowering Groundwater Levels	Degraded Quality	Surface Water Depletion		Lowering Groundwater Levels	Degraded Quality	Surface Water Depletion
GDE #1	Steelhead trout, willow flycatcher, California red legged frog, willow	High	Low	High	Improve	Improve groundwater levels to baseline levels (5–10 feet bgs) at Monitoring Well 3	Maintain baseline nitrate concentrations 8–12 mg/L	Improve annual low flow average to 400 cfs
GDE #3	Western pond turtle, California red legged frog	Low	Low	Medium	Maintain	Maintain baseline levels of 2–3 feet bgs at Monitoring Well 14	Maintain baseline nitrate concentrations of 8–12 mg/L	Improve annual low flow average to 200 cfs

WORKSHEET 6. MONITORING DATA FOR GDEs

GDE Unit ID	Metric	Monitoring Site Location			Sampling Frequency	Agency	Relevant Sustainability Indicator
		Monitoring Well ID/Site Name	Latitude	Longitude			
Existing Monitoring Sites							
Example: GDE #1	Example: Depth to groundwater	Example: MW-5	Example: 37.7749 N	Example: 122.41914W	Example: Daily (via pressure transducer)	Example: National Park Service, Golden Gate Park	Example: Groundwater levels
Example: GDE #1	Example: Nitrate concentrations	Example: El Polín Spring	Example: 37.7749 N	Example: 122.41914W	Example: Quarterly	Example: The Nature Conservancy	Example: Water quality
Example: GDE#2	Example: Depth to groundwater	Example: MW-11	Example: 37.7749 N	Example: 122.41914W	Example: Quarterly	Example: Sunshine GSA (this GSA)	Example: Groundwater levels
New Monitoring Sites							
Example: GDE #1	Example: Stream flow	Example: SG-4	Example: 37.7749 N	Example: 122.41914W	Example: Quarterly	Example: Sunshine GSA (this GSA)	Example: Interconnected surface water
Example: GDE #1	Example: Depth to groundwater	Example: MW-10	Example: 37.7751 N	Example: 37.7749 N	Example: Bi-annually	Example: Sunshine GSA (this GSA)	Example: Groundwater levels

APPENDIX IV: GDE ASSESSMENT TOOLBOX

This table provides a summary of the methods and approaches used in Australia to identify GDEs and determine their reliance on groundwater (modified from Richardson et al. 2011). Citations for case study examples and key references related to the assessment tools below can be found in Richardson et al. (2011).

Assessment Tool	Description	Data Sources/Methods	Pros	Cons
Landscape Mapping	• Location and identification of ecosystems that are potentially groundwater dependent based on biophysical parameters (i.e., depth to water table, soil type, vegetation type) • Assessment of primary productivity, water relations, and/or condition of vegetation communities using remote sensing images to infer use of groundwater	• Native vegetation cover, wetlands, and drainage maps • Vegetation composition • Root depth • Geology and geological structure • Groundwater flow systems and elevations, depth to water table, and surface water level • Land use maps • Soil type maps • Vegetation condition • Leaf area index	• Provides a map/list of potential GDE areas • Utilizes available local, state, federal, and worldwide datasets • Mapping can be performed at the management scale units	• Analysis needs to be repeated over time since data offers one time slice • Some components rely on prior knowledge or datasets that may not be available • Further ground truth work is required to confirm groundwater dependency and determine environmental water requirement (EWR)
Conceptual Modeling	• Documentation of a conceptual understanding of the location of GDEs and interaction between ecosystems and groundwater • Qualitatively links hydrologic, soil, and climate processes to GDE elements and processes • Clarifies the relationships and interactions between hydrology and ecology	• Hydrogeology maps (aquifer boundaries, groundwater flow, groundwater elevation contours) • Climate data • Geology maps • Land use maps • Topographic maps (digital elevation models) • General site or study area description • Vegetation maps • Professional opinion from several disciplines • Scientific literature • AB 3030 Groundwater Management Plans	• An essential precursor to numerical models • Relatively low cost • Integrates knowledge and hypotheses from a wide range of experts and disciplines • Formalizes existing information and identifies knowledge gaps • Allows for some degree of scenario planning and prediction of different management interventions • Pictorial representations can assist in communication with stakeholders	• Not quantitative • Requires a good understanding of local hydrogeologic processes • Heavily reliant on professional judgment and skills, obvious clues of groundwater dependency, and existing data/documentation

Assessment Tool	Description	Data Sources/Methods	Pros	Cons
Pre-Dawn Leaf Water Potentials	• Identification of groundwater uptake by vegetation • Leaf water potential is a measure of the resistance of the pathway of water movement and is a function of soil water availability, evaporative demand, and the conductivity of the soil to leaf pathway • Pre-dawn measurements are used because conditions approach static overnight due to little or no transpiration of water (movement of water from soil to leaf) at night • Groundwater use is indicated for vegetation when leaf water potential values exceed (are less negative) than vadose zone soil water potential values	• Pre-dawn leaf water potential (site measurements with pressure bomb) • Soil profile water potentials (site measurements using gypsum blocks, tensiometers, laboratory analysis of soils from field site) • Soil profile water content (site measurements using neutron probes, time or frequency domain reflectometry, laboratory analysis of soils from field site)	• Rapid field-based method • Well-established approach and best suited for investigating the groundwater dependency of vegetation in a specific location • Inexpensive • Assesses how dry soils need to be to induce water stress in vegetation • Can be used to survey many species relatively easily	• Requires routine monitoring to detect changes in groundwater use over time and space • Extensive monitoring can become costly and labor intensive • Equipment is bulky • Does not, by itself, quantify the amount of groundwater used
Stable Isotopes of Water in Plants	• Naturally occurring stable isotopes (18O and 2H) can be used to identify sources of water used for plant transpiration • The isotopic composition of a plant's xylem is compared with various potential source waters to identify the relative contribution of each using a mixing model • Can provide an indication of the amount of groundwater used by the individual plant when this tool is used in conjunction with pre-dawn leaf potential data and a water balance	• Stable isotopes of water composition of xylem water and potential water sources (laboratory analysis of samples collected from field sites) • Water table depth (piezometers in the field) • Soil water content and/or matric potential, plant transpiration (site measurements using soil water content and/ or matric potential techniques	• Indicates the amount of groundwater use for a specific location and time	• Does not quantify how much water a plant requires (EWR) • Requires routine monitoring to detect changes in groundwater use over time and space • Distinct differences in the isotopic composition of the water sources is not always possible • Can be labor intensive and expensive • Requires technical expertise and access to an isotope ratio mass spectrometer

Assessment Tool	Description	Data Sources/Methods	Pros	Cons
Plant Water-Use Modeling	• Identification of sources and volumes of water used for plant transpiration using mathematical simulations of plant function • The model is developed around physical data from the site being evaluated and, once established, can be used to simulate conditions prior to changes in water availability	• Climate data • Transpiration (sap flow studies, eddy covariance studies, ventilated chambers) • Source water (measured using stable isotopes of water or pre-dawn leaf and soil water potentials) • Plant-soil-atmosphere interactions (literature, models, field measurements)	• Best suited to investigating the groundwater dependency of specific vegetation associations in specific locations	• Requires comprehensive information on site conditions and the characteristics of the vegetation to be modeled • Results are site specific • Multiple field measurement sites are required for broader scale assessments
Root Depth and Morphology	• Comparison of the depth and morphology of plant root systems with measured or estimated depth to the water table to assess the potential for groundwater uptake • Assumes that where plant roots are deep enough to interact with groundwater (in terrestrial vegetation communities, wetlands, and/or riparian vegetation along baseflow streams), there may be some reliance on groundwater by the vegetation • Potential GDEs are identified where root depth is within 1–2 meters of the water table	• Groundwater levels • Topography (digital elevation models) • Vegetation types and maps • Rooting depths (literature and field studies)	• Provides a good first-pass indication of potential for groundwater dependence depending on the quality of the depth to water table map	• May be unreliable and overestimate a terrestrial ecosystem's dependence on groundwater • Depth to water table maps depend on a sufficient monitoring well network and surface elevation data • Does not indicate quantity of groundwater dependency • May be inaccurate if significant heterogeneity in the lithology exists • Rooting depths of most tree species are poorly known and vary between site
Plant Groundwater Use Estimation	• Measures of leaf area index (LAI) and climatic data are used to estimate groundwater discharge from terrestrial ecosystems that have access to groundwater • LAI is a good indicator of the water availability regime an ecosystem is experiencing	• Climatic data (rainfall and evaporation) • LAI (remote sensing and field measurements)	• Provides a simple empirical approach that can be used in estimating the water requirements for terrestrial ecosystems	• LAI can vary considerably seasonally and on longer inter-annual time frames • High LAI is not itself an indicator of access to groundwater or groundwater dependency and needs to be considered in the context of the climate wetness index • This approach is best suited to terrestrial ecosystems and has limited application for other GDE types

Assessment Tool	Description	Data Sources/Methods	Pros	Cons
Water Balance Vegetation	• Use of water balance measurement and/or calculations to assess whether and to what extent plant water use is dependent on groundwater uptake • It is assumed that any plant water use that exceeds availability from rainfall and soil water (and surface water for vegetation fringing rivers and wetlands) is based on the use of groundwater	• Daily and seasonal precipitation • Interception (site measurements) • Transpiration • Soil evaporation (site measurements using mini-lysimeters) • Surface evaporation (transpiration and soil evaporation) • Soil water content • Plant-available water capacity (soil matric potential, depth of vadose zone)	• Very applicable for terrestrial systems • Most suited for site-scale applications	• Intensive sampling programs are often required to obtain data precision required for these studies • Usually costly due to (extended) duration of observations and instrumentation required • Requires high-level scientific and technical skills • Time frames can be very long to properly characterize groundwater dependency • Can be difficult to scale up from study site to larger area • Groundwater use is inferred by deduction of all other parameters, not by direct measurement • Error is inherent when estimating/measuring parameters
Stygofauna Sampling	• Techniques available to observe, monitor, and measure biological activity within the groundwater system • Measurements of the presence and composition of communities of aquatic fauna that occur in groundwater (known as stygofauna) can be used to describe the biodiversity values of aquifer ecosystems	• Sampling locations (drilling records, bore locations, groundwater level records, water quality records) • Knowledge of taxa with strong dependence on groundwater (literature, previous experience) • Presence and composition of stygofauna assemblage (field survey)	• Provides empirical evidence of ecosystem dependence on groundwater • Cost effective • Does not require lengthy training of field staff	• Site- and field-based method • Results can only be extrapolated to the regional scale after extensive field investigation

Assessment Tool	Description	Data Sources/Methods	Pros	Cons
Evaluation of Groundwater–Surface Water Interactions	• Analysis of the hydraulics (timing, direction, and volume) of groundwater–surface water interactions and the processes by which groundwater discharges into a surface water system • Provides insight into the nature of groundwater dependency in wetlands, baseflow river ecosystems, and the marine environment	• Surface water levels (site measurements using stream gauges and water level recorders) • Elevation of streams or wetlands (topographic surveys, digital elevation models, maps) • Aquifer properties (published reports, maps, site investigations)—saturated thickness, hydraulic conductivity, transmissivity, specific storage, storage coefficient, specific yield, hydraulic diffusivity	• Can be applied to a variety of scales depending on the extent of monitoring • Highly suited for systems dominated by groundwater discharge • Most valuable when applied at a site or watershed scale when appropriate/targeted monitoring is in place	• Depends on appropriate and targeted monitoring • Larger-scale projects require longer time frames and greater costs • Provides limited information on the dependency of surface water ecosystems and does not directly indicate ecological water requirements
Environmental Tracers	• Environmental tracers are physical or chemical properties of water or any substance dissolved in water that can be used to identify the origin or the age of groundwater and identify groundwater contribution to dependent ecosystems	• Water temperature • pH • Dissolved oxygen • Total dissolved solids • Electric conductivity (EC) • Major ions • Stable isotopes and radioisotopes	• Data may already be available from routine monitoring activities or previous studies • A good tool for identifying locations of groundwater influx to surface water systems • Can be a rapid assessment approach (especially for temperature and EC) • Identifies and quantifies groundwater inputs to surface water systems where hydraulic approaches might otherwise fail • Provides an independent means to calibrate regional groundwater models	• May only provide a snapshot in time, and routine monitoring may be required to account for seasonal or other temporal changes • Application can be labor intensive and expensive • May require inputs from other methods to interpret data
Analysis of Introduced Tracers	• Analysis of deliberately introduced hydrochemical tracers (solutes, dyes, stable isotopes, and radiotracers) to identify water sources and groundwater–surface water mixing relationships • Identification of the occurrence of groundwater discharge and the flux of groundwater in or out of the system	• Background tracer concentrations • Surface water levels in streams and wetlands • Groundwater levels • Elevation of streams or wetlands • Aquifer properties	• Can quantify complex groundwater exchange processes at significant spatial scales • Identifies and quantifies groundwater inputs to surface water systems where hydraulic approaches might otherwise fail	• Technically and logistically complex • Some tracers are not safe for drinking and irrigation water supplies • Does not define the ecological water requirement for GDEs

Assessment Tool	Description	Data Sources/Methods	Pros	Cons
Long-Term Observation of System Response to Change	• Long-term observations of GDEs to determine ecosystem responses to changes in groundwater regime due to climate or anthropogenic influences • Uses naturally occurring stable isotope of carbon (^{13}C) as an indicator of plant water use efficiency, which can indicate stress or change in water use habits that may be related to changes in the groundwater system supporting the GDE	• Climate • Plant size and growth • Ecological function • Groundwater regime • Human activity • ^{13}C of leaf material for riparian and terrestrial vegetation (field measurements and existing reports)	• Can contribute to an adaptive management approach for EWR determination • Provides empirical observation on how an ecosystem responds to changes in groundwater availability • Strong and robust scientific literature on the relationship between water use efficiency and ^{13}C	• Attributing cause and effect may be difficult and identifying primary factors in ecosystem decline may be difficult (e.g., pest/non-native species versus altered groundwater regime) • Application can be labor intensive and expensive • Technically and logistically complex
Numerical Groundwater Modeling	• Construction of mathematical models to simulate groundwater flow systems in response to climate and/or management • Explores the availability of groundwater to ecosystems in response to management actions	• Surface water levels and flows • Groundwater levels • Elevation of streams or wetlands • Aquifer properties • Groundwater water chemistry, including salinity • Vegetation type and health data (maps and remote sensing data)	• Effects of longer-term changes on groundwater availability to ecosystems can be modeled • Provides a means to quantify spatial distributions of groundwater levels and flows • Enables analysis of system responses to a variety of changes in system stresses (e.g., recharge, groundwater extraction, surface water flow diversions)	• Accuracy relies on the initial conceptualization and model parameterization • Model outputs may be unreliable if data inputs are limited • Requires specialist and technical skills, although numerical models are now inexpensive and commonly used

KEY TERMS*

Agency is a SGMA definition that "refers to a groundwater sustainability GSA as defined in the Act."

Aquifer is defined in Bulletin 118 as "a body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells and springs."

Aquitard is defined in Bulletin 118 as "a confining bed and/or formation composed of rock or sediment that retards but does not prevent the flow of water to or from an adjacent aquifer. It does not readily yield water to wells or springs, but stores groundwater."

Baseflow is defined by the USGS as "that part of streamflow that is sustained primarily by groundwater discharge. It is not attributable to direct runoff from precipitation or melting snow."

Baseline conditions ("Baseline") is a SGMA definition referring "to historic information used to project future conditions for hydrology, water demand, and availability of surface water and to evaluate potential sustainable groundwater management practices of a basin."

Basin is a SGMA definition that "means a groundwater basin or subbasin identified and defined in Bulletin 118 or as modified pursuant to Water Code 10722 et seq."

Basin setting is a SGMA definition that "refers to the information about the physical setting, characteristics, and current conditions of the basin as described by the GSA in the hydrogeologic conceptual model, the groundwater conditions, and the water budget, pursuant to Subarticle 2 of Article 5."

Beneficial use is defined in Bulletin 118 as "one of many ways that water can be used either directly by people or for their overall benefit. The State Water Resources Control Board recognizes 23 types of beneficial use with water quality criteria for those uses established by the Regional Water Quality Control Boards."

Best available science is a SGMA definition that "refers to 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."

* Bulletin 118 is a SGMA definition that refers to DWR's report titled "California's Groundwater: Bulletin 118," which was last updated in 2003. It may be subsequently updated or revised in accordance with CA Water Code § 12924.

Best management practice is a SGMA definition that "refers to a practice, or combination of practices, that are designed to achieve sustainable groundwater management and have been determined to be technologically and economically effective, practicable, and based on best available science."

Confined aquifer is defined in Bulletin 118 as "an aquifer that is bounded above and below by formations of distinctly lower permeability than that of the aquifer itself. An aquifer containing confined ground water."

Data gap is a SGMA definition that "refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of GSP implementation, and could limit the ability to assess whether a basin is being sustainably managed."

Drought is defined in Bulletin 118 as "hydrological conditions during a defined period when rainfall and runoff are much less than average."

DWR (California Department of Water Resources). 2013. California's Groundwater: Bulletin 118. DWR, Sacramento.

Ecosystem is a biological community of interacting organisms and their physical environment.

Ecosystem function refers to the biological, geochemical, and physical processes that result in the flow of energy and cycling of materials within an ecosystem.

Ecosystem structure refers to the organisms (biotic) and physical (abiotic) features of an ecosystem. The structure of an ecosystem is related to species diversity.

Estuary is a semi-enclosed coastal water body that exists where freshwater rivers meet the ocean and create a unique environment containing brackish water.

Flora are the plants of a region, habitat, or geological period.

Fauna are the animals of a particular region, habitat, or geological period.

Gaining stream is a stream or reach of a stream that is gaining water from groundwater flow.

Groundwater is defined in Bulletin 118 as "water that occurs beneath the land surface and fills the pore spaces of the alluvium, soil, or rock formation in which it is situated. It excludes soil moisture, which refers to water held by capillary action in the upper unsaturated zones of soil or rock."

Groundwater dependent ecosystem is a SGMA definition that "refers to ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface."

Groundwater flow is a SGMA definition that "refers to the volume and direction of groundwater movement into, out of, or throughout a basin."

Groundwater recharge is defined in Bulletin 118 as "the natural or intentional infiltration of surface water into the zone of saturation."

Groundwater table ("water table") is defined in Bulletin 118 as "the upper surface of the zone of saturation in an unconfined aquifer."

Habitat is an ecological or environmental area that is inhabited by a species of animal, plant, or other type of organism.

Habitat fragmentation is the process of habitat loss that results in larger continuous habitats dividing into smaller more isolated remnants.

Hydraulic conductivity is defined in Bulletin 118 as "a measure of the capacity for a rock or soil to transmit water; generally, has the units of feet/day or cm/sec."

Hyporheic zone is defined in Bulletin 118 as "the region of saturated sediments beneath and beside the active channel and that contain some proportion of surface water that was part of the flow in the surface channel and went back underground and can mix with groundwater."

In-lieu recharge is defined in Bulletin 118 as "the practice of providing surplus surface water to historic groundwater users, thereby leaving groundwater in storage for later use."

Interconnected surface water is a SGMA definition that "refers to 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."

Interim milestone is a SGMA definition that "refers to a target value representing measurable groundwater conditions, in increments of five years, set by a GSA as part of a Plan."

Land subsidence is defined in Bulletin 118 as "the lowering of the natural land surface due to groundwater (or oil and gas) extraction."

Lithologic log is defined in Bulletin 118 as "a record of the lithology of the soils, sediments and/or rock encountered in a borehole from the surface to the bottom."

Lithology is defined in Bulletin 118 as "the description of rocks, especially in hand specimen and in outcrop, on the basis of such characteristics as color, mineralogic composition, and grain size."

Losing stream is defined in Bulletin 118 as "a stream or reach of a stream that is losing water by seepage into the ground."

Management area is a SGMA definition that "refers to an area within a basin for which the GSP may identify different minimum thresholds, measurable objectives, monitoring, or projects and management actions based on differences in water use sector, water source type, geology, aquifer characteristics, or other factors."

Measurable objective is a SGMA definition that "refers to specific, quantifiable goals for the maintenance or improvement of specified groundwater conditions that have been included in an adopted Plan to achieve the sustainability goal for the basin."

Minimum threshold is a SGMA definition that "refers to a numeric value for each sustainability indicator used to define undesirable results."

Natural recharge is defined in Bulletin 118 as the "natural replenishment of an aquifer generally from snowmelt and runoff; through seepage from the surface."

Normalized Difference Moisture Index (NDMI) is a numerical indicator that uses the near infrared and short wave infrared spectral bands to capture variation in moisture in vegetated areas.

Normalized Difference Vegetation Index (NDVI) is a numerical indicator that uses the visible and near infrared bands of the electromagnetic spectrum and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not.

Perched groundwater is defined in Bulletin 118 as "groundwater supported by a zone of material of low permeability located above an underlying main body of groundwater."

Phreatophyte is a deep-rooted plant that obtains water that it needs from the phreatic zone (zone of saturation) or the capillary fringe above the phreatic zone.

Plan is a SGMA definition that "refers to a groundwater sustainability plan as defined in the Act."

Porosity is defined in Bulletin 118 as "the ratio of the voids or open spaces in alluvium and rocks to the total volume of the alluvium or rock mass."

Principal aquifers is a SGMA definition that "refers to aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems."

Recharge is defined in Bulletin 118 as "water added to an aquifer or the process of adding water to an aquifer. Groundwater recharge occurs either naturally as the net gain from precipitation, or artificially as the result of human influence ('artificial recharge')."

Recharge basin is defined in Bulletin 118 as "a surface facility constructed to infiltrate surface water into a groundwater basin."

Remote sensing is the scanning of the earth by satellite or high-flying aircraft to obtain information about it.

Representative monitoring is a SGMA definition that "refers to a monitoring site within a broader network of sites that typifies one or more conditions within the basin or an area of the basin."

Riparian relating to or situated on the banks of a river.

River is a natural waterway that flows across diverse landscapes starting in mountainous regions and usually terminates in a wetland, lake, or ocean. Rivers can interact with groundwater by either replenishing it or receiving additional surface flows.

Runoff is defined in Bulletin 118 as "the volume of surface flow from an area."

Salinity is defined in Bulletin 118 as "the concentration of mineral salts dissolved in water. Salinity may be expressed in terms of a concentration or as electrical conductivity. When describing salinity influenced by seawater, salinity often refers to the concentration of chlorides in the water."

Saturated zone is defined in Bulletin 118 as "the zone in which all interconnected openings are filled with water, usually underlying the unsaturated zone."

Seasonal high is a SGMA definition that "refers to the highest annual static groundwater elevation that is typically measured in the Spring and associated with stable aquifer conditions following a period of lowest annual groundwater demand."

Seasonal low is a SGMA definition that "refers to the lowest annual static groundwater elevation that is typically measured in the Summer or Fall, and associated with a period of stable aquifer conditions following a period of highest annual groundwater demand."

Seawater intrusion is a SGMA definition that "refers to the advancement of seawater into a groundwater supply that results in degradation of water quality in the basin, and includes seawater from any source."

Semi-confined aquifer is defined in Bulletin 118 as "an aquifer that has aquitards either above or below that allow water to leak into or out of the aquifer depending on the direction of the hydraulic gradient."

Stakeholder is a person, group, or organization that has an interest or concern about a particular activity, topic, or organization and can either affect or be affected by it.

Taxa are taxonomic categories or groups, such as phylum, order, family, genus, or species.

Taxonomic integrity refers to the biological assemblages that occur or are expected to occur in a given biogeophysical setting.

Transpiration is defined by the USGS as "the process by which water vapor escapes from the living plant, principally the leaves, and enters the atmosphere."

Seep is a place where groundwater emerges slowly out of the ground.

Species is a group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding.

Spring is defined in Bulletin 118 as "a location where groundwater flows naturally to the land surface or a surface water body."

Stream is defined by the USGS as a body of flowing water, which generally applies to the water flowing in a natural channel.

Surface water is defined by the USGS to be "water on the Earth's surface."

Sustainability is defined in Bulletin 118 as "of, relating to, or being a method of using a resource so that the resource is not depleted or permanently damaged."

Sustainability indicator is a SGMA definition that "refers to any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results, as described in Water Code Section 10721(x)." The six sustainability indicators include (1) chronic lowering of groundwater levels, (2) reduction of groundwater storage, (3) seawater intrusion, (4) degraded water quality, (5) land subsidence, and (6) depletions of interconnected surface water.

Sustainable yield is defined under SGMA as "the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result."

Terrestrial vegetation are plants that grow on, in, or from land.

Transpiration is defined in Bulletin 118 as "an essential physiological process in which plant tissues give off water vapor to the atmosphere."

Uncertainty is a SGMA definition that "refers to a lack of understanding of the basin setting that significantly affects an GSA's ability to develop sustainable management criteria and appropriate projects and management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed."

Unconfined aquifer is defined in Bulletin 118 as "an aquifer which is not bounded on top by an aquitard. The upper surface of an unconfined aquifer is the water table."

Undesirable result is a term used in SGMA to describe conditions that occur when significant and unreasonable effects for any of the sustainability indicators are caused by groundwater conditions occurring throughout the basin.

Unsaturated zone is defined in Bulletin 118 as "the zone below the land surface in which pore space contains both water and air."

Water use sector is a SGMA definition that "refers to categories of water demand based on the general land uses to which the water is applied, including urban, industrial, agricultural, managed wetlands, managed recharge, and native vegetation."

Water quality is defined by DWR as a "description of the chemical, physical, and biological characteristics of water, usually in regard to its suitability for a particular purpose or use."

Water source type is a SGMA definition that "represents the source from which water is derived to meet the applied beneficial uses, including groundwater, recycled water, reused water, and surface water sources identified as Central Valley Project, the State Water Project, the Colorado River Project, local supplies, and local imported supplies."

Water year is defined as the period from October 1 through the following September 30.

Water year type is a SGMA definition that "refers to the classification provided by the Department to assess the amount of annual precipitation in a basin."

Wetland is federally defined by the EPA and Army Corps of Engineers as "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."

Slow shutter, autumn view of rushing water at Deer Creek, one of a decreasing number of streams in California that provides habitat for the native trout, CA. © Ian Shive

The Nature Conservancy