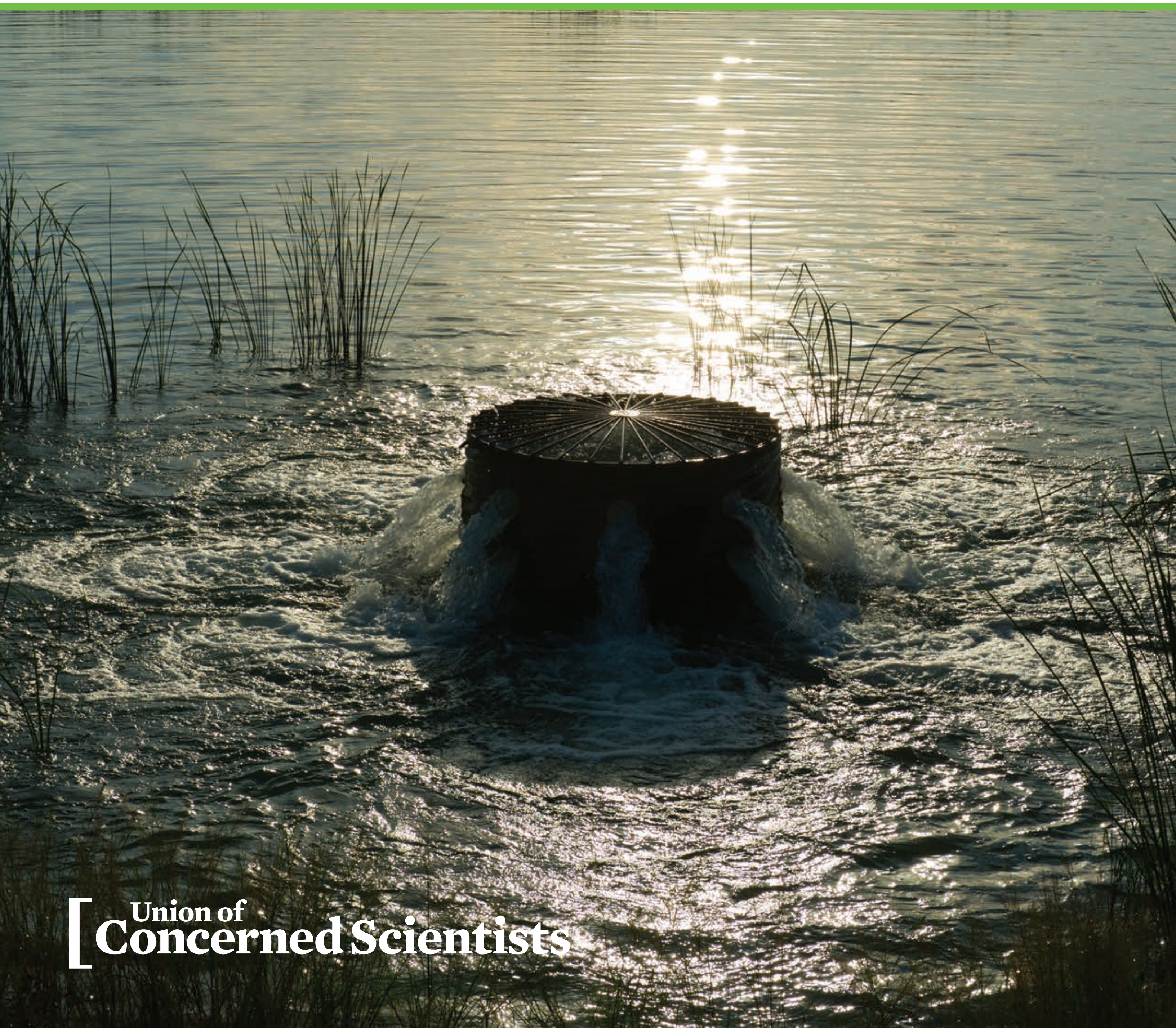
Measuring What Matters

Setting Measurable Objectives to Achieve Sustainable Groundwater Management in California



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Setting Measurable Objectives to Achieve Sustainable Groundwater Management in California

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Union of Concerned Scientists

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Over the last century, groundwater extraction in many parts of California has been largely unregulated. California's ongoing drought helped spur the passage in 2014 of the Sustainable Groundwater Management Act (SGMA), the first-ever statewide requirement for groundwater management.

SGMA requires local groundwater sustainability agencies (GSAs) to develop groundwater sustainability plans (GSPs) by 2020 or 2022.

California Water Code Section 10727.2(b)(2) requires GSAs to set "measurable objectives" in their plans to achieve "the sustainability goal for the basin." Yet the legislation does not specifically define measurable objectives or how they should be set or evaluated over time. Rather, the legislation directs GSAs to set measurable objectives that will avoid what SGMA refers to as "undesirable results" (such as the chronic lowering of groundwater levels).

To understand how GSAs might develop effective measurable objectives and to inform the GSP regulations currently under development by the Department of Water Resources (DWR), this report provides a review of the state of knowledge and practice related to setting measurable objectives for groundwater management. This review of relevant literature and existing groundwater management plans indicates that effective measurable objectives do the following:

- **Define clear baselines**. In order to understand how to get to where you are going, you must know where you have been. Consistent baselines can be particularly useful when managing a shared resource, such as groundwater. Clear baselines can help ensure fairness and transparency and avoid unnecessary conflict arising due to different definitions of the starting point for management.
- **Set quantitative thresholds.** Adaptive management literature emphasizes the need for objectives to be measurable and quantitative for two purposes: first, so progress can be assessed; second, so performance that deviates from objectives can prompt a change in management. Thresholds represent a defined target level or state that will avoid unacceptable outcomes. When a monitored variable approaches or crosses its threshold, a management entity may respond with a variety of reasonable actions to reverse the trend to avoid unacceptable outcomes.
- **Develop protective triggers.** Triggers act as a warning system, ensuring that a threshold is not crossed. GSAs may identify triggers along a continuum that corresponds with risk, as with green-, yellow-, and red-light triggers. Furthermore, triggers should be directly tied to management actions to avoid undesirable results.
- **Incorporate regular measurement and monitoring.** Monitoring, and learning from what is found, is what fundamentally differentiates adaptive management from trial and error. There are a number of direct and indirect approaches to measurement. Although indirect approaches may be preferred in some cases, they inherently introduce additional uncertainty, which must be explicitly acknowledged.

- **Account for uncertainty.** Although uncertainty is inherent in any long-term planning process, it is critical that management entities explicitly account for uncertainty and develop a suite of proactive responses to improve or bracket information.
- **Adapt to changing conditions and new information.** Adaptive management is a process centered on learning, in which natural resource management actions are taken not only to manage, but also explicitly to learn about the processes affecting the system. Adaptive management is not only a scientific or technical process, but also a social one, which requires institutional structures that allow for greater transparency and flexibility.

The Union of Concerned Scientists (UCS), in partnership with the California Water Foundation (CWF), convened a multi-stakeholder roundtable to inform this review. The roundtable, convened twice, in June and July 2015, involved voices from counties, water suppliers, agriculture, underrepresented communities, and environmental interests throughout California. Based on the dialogue, UCS developed the following conclusions and recommendations to inform California's approach to defining measurable objectives:

- **Develop a state framework.** There is need for a common framework for setting thresholds and interim milestones. This framework must rely on state standards and policies where they exist and create common rules and methodologies where there are no state standards (and where basins have great flexibility for setting thresholds). State regulations need to be written so as not to discourage basins interested in exceeding the SGMA-required thresholds that include state minimum standards or local thresholds associated with undesirable results.
- **Identify existing data sources for basin conditions.** The state has an important role to play in identifying existing data sources that should be used in GSPs. It also should lead efforts to improve groundwater data and monitoring networks where data gaps or inconsistencies currently exist. In order to treat all basins fairly, the state should require that GSAs have access to some consistent data when assessing their groundwater conditions over time.
- **Require consistent assumptions to develop sustainable yield.** SGMA requires that basins achieve a sustainable yield by 2040; thus, most basins will use models to project how changing land and water uses, management approaches, and other factors will affect the basin's water budget and will use that information to develop a sustainable yield. Because assumptions drive modeling efforts, it will be critical for the state to define some common assumptions for use when developing sustainable yield.
- **Develop common metrics and transparent data management and reporting protocols.** Local agencies need state guidance to ensure that basins are using some common metrics to describe undesirable results and are reporting information in a standardized manner to support improved interbasin and intrabasin coordination as well as to protect all basin water users. Additionally, local agencies should be collecting similar types of data and reporting data in a format that allows the DWR to enter it into publicly available, regional scale modeling tools used to develop water budgets.

The challenges involved in implementing sustainable groundwater programs are significant—for the state, in putting forward a framework that promotes consistent standards and approaches while allowing (where necessary) for local flexibility, and for each GSA, in understanding and then effectively managing its groundwater usage to avoid undesirable results and achieve sustainable yield. To assist, this review of the state of knowledge and practice as well as of discussions with roundtable participants provides the outlines of a consistent state framework and approach that will provide greater regulatory certainty and a roadmap for implementation.

*[**To meet the SGMA goal of sustainable yield by 2040, California must set measurable objectives.**]*

[CHAPTER ONE]

Measuring Sustainability

Groundwater supplies between 30 and 50 percent of California's water supply, depending on precipitation, and represents a storage reservoir that is over three times greater than available surface water storage. The California Water Action Plan (CNRA, CDFA, and CEPA 2014) identifies groundwater as "a critical buffer to the impacts of prolonged dry periods and climate change on our water system."

Many groundwater basins have historically experienced significant chronic overdraft and related negative impacts. California's ongoing drought helped spur the state to enact legislation to strengthen local control and management of groundwater basins. Governor Jerry Brown signed the three-bill package (AB 1739, SB 1168, SB 1319), known as the Sustainable Groundwater Management Act (SGMA), into law on September 16, 2014. SGMA represents California's attempt to regulate groundwater comprehensively for the first time in the state's history.

SGMA, which went into effect on January 1, 2015, lays out a process and a timeline for local agencies to achieve sustainable management of groundwater basins (see Box 1). It also provides tools, authorities, and deadlines meant to lead to achievement of the legislation's purpose. For local agencies involved in implementation, the requirements are significant and are expected to take many years to accomplish.

While setting measurable objectives is a new requirement, it is by no means a new concept in natural resource management. This report summarizes the theory and practice of setting measurable objectives for groundwater management, using examples from California and elsewhere. The goal is to begin to develop a shared knowledge base and to identify key features of effective measurable objectives.

BOX 1.

Phases of Sustainable Groundwater Management Act Implementation

The following phases represent a simplified overview of how SGMA will be implemented. The State Water Resources Control Board (SWRCB) and Department of Water Resources (DWR) have developed a complete timeline of activities and deadlines for compliance with SGMA.

Phase 1: Formation of governing bodies.
Local agencies must form local groundwater sustainability agencies (GSAs) by June 2017.

Phase 2: Establishment of plans.
GSAs in basins deemed high or medium priority must adopt groundwater sustainability plans (GSPs) within five to seven years (2020–2022), depending on whether a basin is in critical overdraft.

Phase 3: Implementation of plans.
Once GSPs are adopted and approved by the DWR, GSAs have 20 years (2040–2042) to implement them fully and achieve the sustainability goal.

The DWR and SWRCB may intervene if locals do not form a GSA and/or fail to adopt and implement a GSP.

Background

Groundwater planning is not new to California. Nearly 120 groundwater management plans have been developed over the last few decades; yet, these plans were voluntary, unenforceable by the state, and did not easily provide new authorities, such as controlling extractions from the groundwater basin, to local entities. They did, however, enable eligibility for certain state funding. Existing plans range widely in quality, but some current groundwater management plans contain helpful elements. Some groundwater sustainability agencies (GSAs) will likely use these existing plans as a starting point for developing their groundwater sustainability plans (GSPs). Therefore, it is important to understand the difference between them in planning requirements.

The GSP requirements outlined in SGMA represent a dramatic leap forward for groundwater planning in California. Box 2 is a simple comparison of the old requirements of groundwater management plans developed in compliance with AB 3030 and SB 1938 and the additional measures required for a GSP to be in compliance with SGMA.

BOX 2.

Groundwater Management Plans Are Improving Under SGMA

AB 3030 and SB 1938 Required Plans to Include:

- basin management objectives;
- basin maps and hydrology;
- monitoring of groundwater;
- plan to involve other agencies; and
- documentation of public involvement.

SGMA Requires Plans to Include:

- measurable objectives and interim objective;
- description of how these objectives will be achieved;
- physical description of the basin (water level, quality, etc.);
- monitoring and management provisions;
- documentation of how the plan will incorporate other county/city plans; and
- documentation of how the planning process will encourage the active involvement of diverse interests.

It is impossible to achieve sustainability without defining what it means and how it will be evaluated.

GSPs, once completed, must be submitted to the Department of Water Resources (DWR) for review. Within two years of submission, the DWR will evaluate each GSP and issue an assessment that may include corrective actions to address deficiencies (California Water Code Section 10733.4). If the DWR, in consultation with the board, determines that a groundwater sustainability plan is inadequate or that the groundwater sustainability program is not being implemented in a manner that will likely achieve the sustainability goal, the state may intervene (California Water Code Section 10735.2). The DWR is required to develop GSP regulations by June 2016. In its recently released strategic plan, the DWR committed to providing guidance on how it will evaluate GSPs and technical assistance for the development of plans by the June deadline.

Implementation of SGMA hinges on a number of critical elements of groundwater management, some of which are not clearly defined by the statutory language. One such element is "measurable objectives." This report argues that measurable objectives are essential as it is impossible to achieve sustainability without defining what it means and how it will be evaluated.

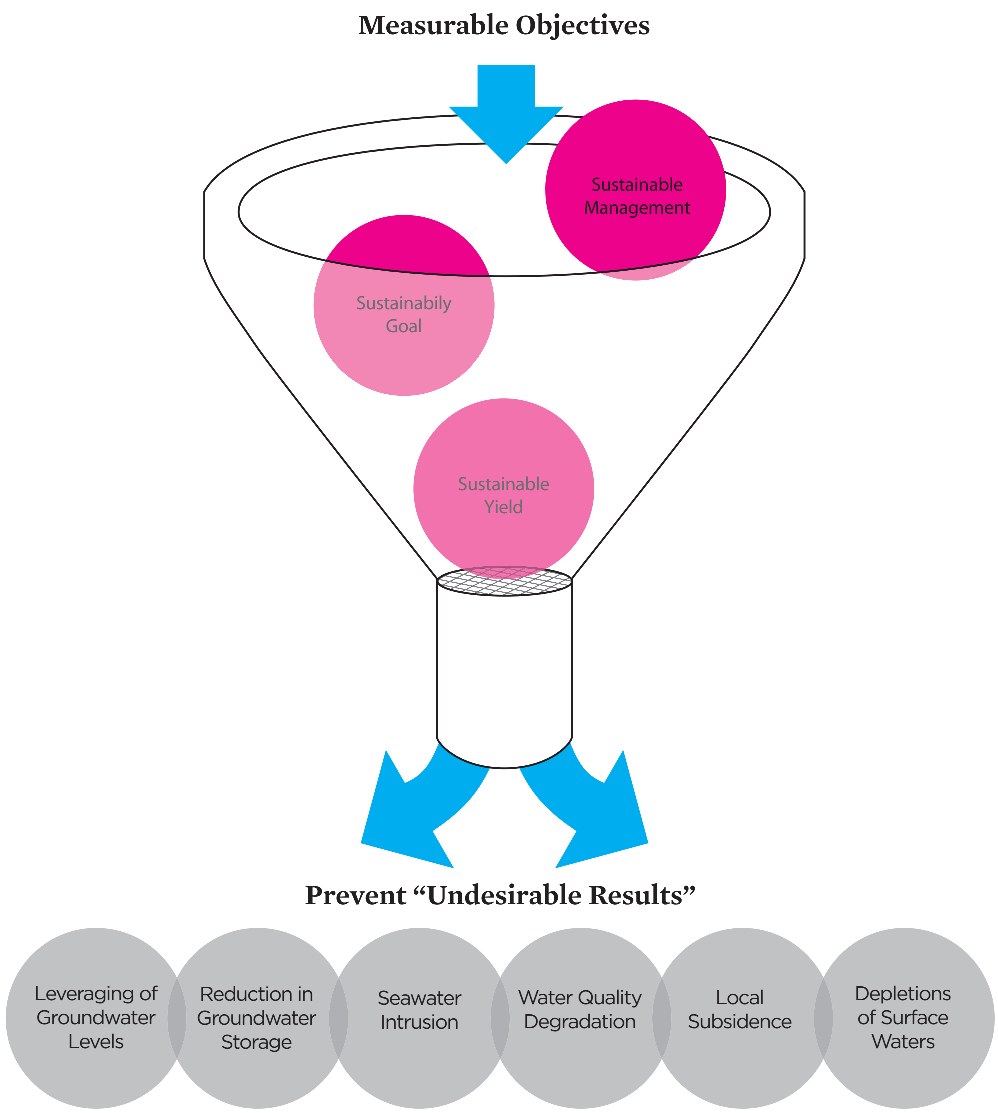
Measurable Objectives and SGMA

California Water Code Section 10727.2(b)(2) requires GSAs to set "measurable objectives" in their GSPs. Measurable objectives are important for a number of reasons, including:

- to measure progress;
- to provide a framework within which "undesirable results" will be avoided or remedied (see Figure 1);
- to define sustainable yield for each groundwater basin (see Box 3, p. 7).

Indeed, measurable objectives and sustainable yield are interdependent because SGMA defines sustainable yield, in part, as avoiding undesirable results (see Glossary, p 36, for definitions of *sustainability goal, sustainable groundwater management,* and *sustainable yield*). Yet the legislation does not specifically define measurable objectives or the process by which they should be set and monitored over time. Instead, SGMA requires the DWR to adopt regulations to further define what needs to be included in a GSP, including measurable objectives. This report explores the implications of measurable objectives in SGMA, proposing a series of criteria for establishing effective measurable objectives and a preliminary framework for how they may be developed and included in GSPs in order to inform local implementation and state regulations.

FIGURE 1. Groundwater Sustainability in SGMA



Measurable objectives define the sustainability goal, sustainable management, and sustainable yield, which are intended to prevent undesirable results, such as seawater intrusion and land subsidence. Many undesirable results are interconnected and are therefore displayed as overlapping circles.

SOURCE: DWR 2015.

Review of the State of Knowledge and Practice

To better understand how GSAs might develop measurable objectives and to inform the development of the GSP regulations, we conducted an in-depth review of the current state of practice in California and beyond. Our research suggests that measurable objectives play a crucial role in evaluating performance, reducing uncertainty, and improving resource management through time. If objectives are not clear, measurable, and agreed upon at the outset, it will be difficult for resource managers to assess progress and make management decisions.

Our review of existing groundwater management plans and literature regarding groundwater management and adaptive management indicates that effective measurable objectives do the following:

- define clear baselines;
- set quantitative thresholds;
- develop protective triggers that require action before reaching a threshold;
- incorporate regular measurement and monitoring;
- account for uncertainty; and
- adapt to changing conditions and new information.

The following section describes each of these aspects of effective measurable objectives in greater detail.

Define Clear Baselines

In order to understand how to get to where you are going, you must know where you have been. Consistent baselines can be particularly useful when managing a shared resource such as groundwater. Clear baselines can help ensure transparency and avoid unnecessary conflict arising due to different definitions of the starting point for management. Baselines are the reference points against which GSAs will evaluate change when setting thresholds and triggers (see the next sections for more information about thresholds and triggers).

The baseline is the starting point or current and historic condition of a groundwater basin that GSAs will use for setting future measurable objectives and evaluating progress and performance. Thus, baselines will inform the path to sustainability. There are two primary ways baselines are discussed in SGMA:

> ***California Water Code Section 10727.2 (b)(4)***
> *The plan may, but is not required to, address undesirable results that occurred before, and have not been corrected by, January 1, 2015.*

> ***California Water Code Section 10733.2 (b)(2)***
> *The regulations adopted pursuant to paragraph (1) of subdivision (a) shall identify appropriate methodologies and assumptions for baseline conditions concerning hydrology, water demand, regulatory restrictions that affect the availability of surface water, and unreliability of, or reductions in, surface water deliveries to the agency or water users in the basin, and the impact of those conditions on achieving sustainability. The baseline for measuring unreliability and reductions shall include the historic average reliability and deliveries of surface water to the agency or water users in the basin.*

According to these definitions, the baseline for defining sustainable yield is a representative assessment of historic and current long-term hydrologic, geologic, and management conditions in the basin, and the DWR is tasked with identifying appropriate methodologies and assumptions for describing and assessing these baseline conditions in its GSP regulations. However, the baselines for addressing undesirable results in specific basins may be different because GSAs have discretion to address undesirable results occurring before January 1, 2015. SGMA requires GSAs to address undesirable results occurring after January 1, 2015. It is worth noting that January 1, 2015, occurs in the fourth year of an exceptional drought and therefore may best serve as a baseline for drought-year conditions.

Once baselines are established, GSAs have discretion when defining what constitutes a "significant and unreasonable" undesirable result and will have a 20-year timeline to achieve compliance. However, here again the DWR has an important role in reviewing GSPs to determine whether they are "likely to achieve the sustainability goal for the basin" and also "whether a GSP adversely affects the ability of an adjacent basin to implement their GSP or impedes achievement of sustainability goals in an adjacent basin" (California Water Code Section 10733). Thus, the DWR may choose to limit local discretion in order to ensure that sustainable groundwater management can, and will, be achieved statewide.

Set Quantitative Thresholds

Past groundwater basin management objectives (BMOs) are defined as "specific criteria defining the desired state of the basin." Reviews of existing groundwater management plans found that most lacked well-defined targets (RMC 2014, Nelson 2011). BMOs were often qualitative statements rather than quantitative targets. For example, a BMO included in a plan may be "to protect and enhance the quality of the groundwater." Such broad-brush statements are difficult to measure and track over time and do not clearly define success.

Adaptive management literature and practice emphasize the need for objectives to be measurable and quantitative for two purposes: first, so progress toward their achievement can be assessed; second, so performance that deviates from objectives can trigger a change in management direction (Williams, Szaro, and Shapiro 2009). Explicit articulation of measurable objectives helps to separate adaptive management from trial

Reviews of existing groundwater management plans found most lacked well-defined targets.

BOX 3.

Sustainable Yield versus Safe Yield

Safe yield and sustainable yield are two prominent concepts in groundwater management. Both concepts, generally, prescribe a relationship between groundwater withdrawal (outputs) and groundwater recharge (inputs). Safe yield, as commonly interpreted, is focused primarily on groundwater storage and levels. The objective of safe yield has often been to match groundwater withdrawal to groundwater recharge (Alley, Reilly, and Franke 1999). This objective overly simplified the complex hydrological, ecological, and social context of groundwater management, leading to management challenges. For instance, several groundwater districts in Kansas originally put in place safe yield policies that took a mass balance approach (matching long-term average recharge rates to groundwater extraction rates). Unfortunately, this led to the dewatering of streams because recharge rates were overestimated and did not take into account naturally occurring discharge, such as groundwater that contributes to streams. The districts therefore revised their policies to require sustainable yield, which incorporates the needs of the environment. Bredehoeft, Papadopulos, and Cooper (1982) first referred to this oversimplification as the "water budget myth" and the term has since been adopted widely.

In the late 1980s, the concept of sustainable development—meeting the needs of the present without compromising the ability of future generations to meet their needs—informed a shift to the concept of sustainable yield. Broadly, sustainable yield is an attempt to determine a metric that can ensure the long-term resilience of a groundwater system (Rudestam and Langridge 2014). Sustainable yield protects not just groundwater levels but also the multiple ecological and social benefits that groundwater provides, such as contributing to stream baseflow, maintaining groundwater-dependent ecosystems, and serving as a protection against land subsidence and seawater intrusion (Maimone 2004). Therefore, sustainable yield typically allows only a portion of groundwater recharge to be withdrawn; it can be thought of as a more conservative approach than safe yield.

SGMA defines sustainable yield as "the maximum quantity of water...that can be withdrawn annually from a groundwater supply without causing an undesirable result," such as chronic lowering of groundwater levels, reduction of groundwater storage, seawater intrusion, degraded water quality, land subsidence, or depletions of interconnected surface waters. Therefore, the avoidance of undesirable results as defined in SGMA is what separates sustainable yield from safe yield.

Anaheim Lake is one of Orange County Water District's groundwater recharge ponds. Orange County Water District treats wastewater to high standards and then uses the recycled water to fill recharge ponds, like Anaheim Lake, to replenish the groundwater aquifer below.

and error, because the use of measurable objectives directs and justifies exploration of management options over time (Williams, Szaro, and Shapiro 2009).

Measurable objectives will need to be identified in every GSP to avoid and manage each applicable undesirable result listed in SGMA. It is important to note that SGMA does not simply define the presence of a potentially adverse effect, such as chronic lowering of groundwater tables, as undesirable. Rather, it requires that it be a "significant and unreasonable" effect to constitute an undesirable result. In other words, seawater intrusion is not necessarily by itself an undesirable result, but seawater intrusion beyond a certain location or above a certain rate may be defined as a "significant and unreasonable" level of seawater intrusion. Thus, each GSP will need to define quantitative thresholds that communicate when an undesirable result becomes "significant and unreasonable."

A general definition of a threshold is "a defined target level or state based on the avoidance of unacceptable outcomes or an ecologically defined shift in system status" (Polasky et al. 2011). Thresholds represent a condition beyond which the potential for adverse impact is considered unacceptable or undesirable. Scientific and managerial interest in using thresholds for managing natural resources and ecosystems within an adaptive management framework has grown over the last decade (Groffman et al. 2006). When an essential monitored variable approaches or crosses its threshold value, a management agency may respond with a variety of reasonable actions to reverse the trend to avoid unacceptable outcomes.

Setting quantitative thresholds is not new to groundwater management. A number of existing groundwater management plans and other planning documents in California and throughout the United States use thresholds to determine sustainable management practices. In Texas, for example, thresholds are used to determine "desired future conditions" and represent specific goals for conditions, such as groundwater level, groundwater storage volume, or spring flow (Mace et al. 2008). Once desired future conditions are determined, they are entered into groundwater models to

> ***Triggers identify in advance how, when, and why management actions take place.***

estimate the maximum pumping rates allowable to achieve the desired future condition. And throughout various regions in Australia, thresholds are called "resource condition limits" and are used to determine sustainable yield (Anderson et al. 2014).

Table 1 (p. 10) includes examples of thresholds currently in use and is organized around the six undesirable results outlined in SGMA. The examples provided in Table 1 are not meant to represent thresholds that would meet the requirements of SGMA; rather, they are provided only to demonstrate the diverse forms thresholds can take.

Develop Protective Triggers

A common problem with using thresholds in natural resource management is the tendency to manage at a point just shy of an undesirable outcome (Montgomery 1995). For example, some laws and regulations are designed so that nothing happens until a threshold is crossed (Nie and Schulz 2012). In almost all cases, management entities such as GSAs will want to alter management practices before reaching a potentially irreversible or undesirable tipping point. When dealing with uncertainty, managers should develop a warning system and take action in response, thus ensuring that a threshold is not crossed. Triggers provide an adaptive, yet more structured, decision-making framework by identifying in advance precisely how, when, and why management actions take place (Nie and Schulz 2012). GSAs may want to identify triggers along a continuum, including green-, yellow-, and red-light triggers.

When managing a resource, it is important to estimate when an undesirable outcome might occur (threshold) and points at which investigative or preventive management actions should be taken (triggers). When a trigger is reached, certain legal and/or management actions are initiated. GSAs can outline in their GSPs what actions will be taken at each trigger. This would work toward satisfying the requirements of California Water Code Section 10727.2(b)(2).

Thresholds have been used to manage groundwater quantity and quality. Water quality triggers are probably the most widely adopted method of managing the impacts of extraction on groundwater quality. In Nebraska, triggers are most commonly based on spring groundwater level declines (Korus and Burbach 2009). In Australia, triggers are used for a multitude of measured variables that correspond with groundwater levels, water quality, and ecosystem health indicators (Anderson et al. 2014). Table 2 (p. 12) contains a number of trigger examples.

Thresholds and triggers can be set at a fixed value, a range of values, a trend, or a range of probabilities. For groundwater management, it is important to note that thresholds and triggers may vary spatially across a basin, depending on localized conditions and aquifer characteristics.

FIXED TRIGGERS

As groundwater levels fall and rise throughout the year, corresponding with dry and wet seasons or growing and nongrowing seasons, the trigger levels remain constant. Figure 2 (p. 10) is an example of setting fixed triggers for groundwater elevation to avoid crossing a threshold set at the groundwater table's historic low. There is a yellow-light trigger set at one standard deviation below the average groundwater elevation, which corresponds to a set of actions to slow or reverse the trend. There is a red-light trigger set at two standard deviations below the average groundwater elevation, which corresponds to immediate actions to halt any further lowering of groundwater levels. Fixed triggers facilitate planning and are easier to communicate.

FLEXIBLE TRIGGERS

As the water level within the basin rises and falls seasonally, the trigger values rise and fall as well. For instance, here, the red-light trigger during wet years is one standard deviation below the average groundwater elevation since, in this example, the basin has a goal of refilling the aquifer during wet years to maintain a drought buffer. Flexible triggers can respond to inter- and intra-annual variability, requiring different levels of protection in wet periods than in dry periods. This approach may optimize groundwater use temporally. However, it may make planning more difficult and could be confusing to stakeholders.

Incorporate Regular Measurement and Monitoring

The purpose of a measurable objective is to be a guide to achieving management goals; therefore, monitoring the status of a measurable objective so that it can be directly related to triggers and thresholds is important. Monitoring is the cornerstone of adaptive management (Lyons et al. 2008). The importance of monitoring, and of learning from information collected, is what fundamentally differentiates adaptive management from trial and error.

TABLE 1. Examples of Measurable Objectives and Corresponding Thresholds in Groundwater Management

Measurable Objective	Document	Threshold Example
Groundwater Levels		
Limit groundwater extraction.	Central Sacramento County Groundwater Management Plan	The long-term average groundwater extraction rate should not exceed 273,000 acre-feet (AF)/year.
	Orange County Water District (OCWD) Groundwater Management Plan	OCWD does not have a "hard cap" on groundwater extractions, but uses economic disincentives to encourage groundwater producers to limit production to the amount established by OCWD.
	Madera Regional Groundwater Management Plan	Reduce groundwater extractions by 150,000 AF/year.
Limit the decline in groundwater elevation to provide for sustainable yield.	Groundwater Management Area 1: Desired Future Conditions (Dockum Aquifer)	Average decline in groundwater levels must not exceed 30 feet over the next 50 years.
Groundwater Storage		
Achieve a target storage volume in the future.	Monterey Peninsula Water Management District	27,360 AF of usable storage required.
	Groundwater Management Area 1: Desired Future Conditions (Blaine Aquifer)	50% of the volume in storage will remain in 50 years.
	Orange County Water District Groundwater Management Plan	Managed groundwater basin within a 500,000 AF volume with triggers when storage levels reach various points, including reducing pumping.
	Eastern San Joaquin Integrated Regional Water Management Plan	70,000 AF/year is needed to stabilize the basin and an average of 140,000 AF/year is needed to refill the basin to 1986-1992 conditions.
Achieve a target reduction in the "remaining life of storage".	Santa Barbara County	Available storage/net overdraft + x = remaining life of storage * 0.97 (allows a 3% loss in the remaining life of storage).
Seawater Intrusion		
Maintain groundwater elevations that prevent further seawater intrusion.	Fox County Groundwater Management Agency Groundwater Management Plan	Groundwater elevations in monitoring wells at the coastline must average at least 5 feet above sea level to prevent seawater intrusion.
Maintain chloride concentrations within a range defined by historic maximums.	South Westside Basin Groundwater Management Plan	The threshold is set at approximately 10% above the historical maximum concentration over the past 20 years of sampling (1991–2010, with probable outliers removed).
Water Quality		
Maintain high-quality groundwater by limiting contaminant concentrations.	Central Sacramento County Groundwater Management Plan	TDS concentration should not exceed 1,000 mg/L. NO_3 concentration should not exceed 45 mg/L. Any measurable trace of VOCs in a private or public well should be considered significant.

TABLE 1. Examples of Measurable Objectives and Corresponding Thresholds in Groundwater Management (cont.)

Measurable Objective	Document	Threshold Example
Land Subsidence		
Restrict the amount of allowable subsidence.	Central Sacramento County Groundwater Management Plan	Protect against any potential inelastic land surface subsidence by limiting subsidence to no more than 0.007 feet per 1 foot of drawdown in the groundwater basin.
Reduce the rate of subsidence.	Madera Regional Groundwater Management Plan	Reduce the rate of subsidence by half.
Depletions of Interconnected Surface Water		
Groundwater flows will support functioning wetlands.	Water Allocation Plan for the Tindall Limestone Aquifer, Katherine (Australia)	Water level decline at the groundwater dependent ecosystem should not exceed 0.05 m/year.

While all GSPs should include measurable objectives and corresponding thresholds to avoid undesirable groundwater conditions, these elements can vary widely from plan to plan.

Note: Thresholds are only illustrative; they are not necessarily thresholds that would meet the requirements of SGMA.

SOURCES: CITY OF CHOWCHILLA ET AL. 2014; ESJCGBA 2014; SAN FRANCISCO PUBLIC UTILITIES COMMISSION 2012; TWDB 2010; MPWMD 2009; WOODSIDE AND WESTROPP 2009; COUNTY OF SANTA BARBARA 2008; FCGMA, UWCD, AND CMWD 2007; WATER FORUM 2006; NORTH TERRITORY GOVERNMENT N.D.

There are a variety of measurement approaches for each undesirable result (see Table 3, p. 15). For example, SGMA prohibits chronic groundwater overdraft but does not specify the most appropriate metric for assessing groundwater overdraft. A metric is the method of measurement used to assess measurable objectives quantitatively, to set triggers, and to set a threshold. A GSA could choose to assess groundwater overdraft by measuring groundwater extraction or changes in groundwater elevations, or by employing modeling techniques. For example, remotely sensed data or electricity consumption may be used as a proxy for groundwater extraction. It is important to remember that more indirect measurement techniques will inherently have higher levels of uncertainty.

Account for Uncertainty

Uncertainty is inherent in any long-term planning process. Groundwater is a particularly pertinent example because it cannot be seen and there are limitations on the precision and accuracy of modeling and measurement techniques. As GSAs develop plans, they will need first to determine baselines by looking at historical data, reading reports and assessments (which may be incomplete), and then projecting how changing future conditions (e.g., land use, climate change, management approaches, water reliability) will impact groundwater, with the goal of avoiding undesirable results. Through this process, managers should be explicit regarding the level and location of uncertainty.

[Uncertainty is inherent in long-term planning, including groundwater management.]

Some uncertainties are relatively small; for instance, agricultural water measurement devices are required to be accurate only within a range of plus or minus 12 percent (California Code of Regulations Section 597.3(a)(1)). Other uncertainties are typically larger and often less well quantified, such as uncertainty in our knowledge of aquifer geology, future land uses, future water uses, and the impacts of climate change on water systems. For example, many studies suggest that climate impacts are having relevant and severe impacts on hydrology and water systems (DWR 2008). Although science cannot predict the precise form of these changes, outcomes can be bracketed (e.g., best-case and worst-case scenarios), and these risks need to be managed.

Adaptive management provides a process for coping with uncertainty, but it is necessary to identify where uncertainty lies and to develop approaches to address it explicitly. Triggers may be set conservatively to provide for an adequate

TABLE 2. Examples of Triggers in Groundwater Management

Measurable Objective	Document	Trigger Example
Groundwater Levels		
Reduce decline in groundwater elevation.	Basin Management Objective, Glenn County, sub-area 8	**Trigger 1:** when any measured Spring groundwater surface elevation is below 1 Standard Deviation from the Average of the time of record utilized for the corresponding BMO Key Well **Trigger 2:** on the second and subsequent sequential years, when any measured Spring groundwater surface elevation is below 1 Standard Deviation from the Average of the time of record utilized for the corresponding BMO Key Well **Trigger 3:** when any measured Spring groundwater surface elevation is below 2 Standard Deviations from the Average of the time of record utilized for the corresponding BMO Key Well **Trigger 1, 2, and 3 actions** shall be rescinded by the WAC when the measured groundwater surface elevations return to an elevation above 1 Standard Deviation for the corresponding BMO.
	South Westside Basin Groundwater Management Plan	**Trigger 1:** the historical low minus five feet, rounded down to the nearest five **Trigger 2:** 10 feet below Trigger 1 for all wells
	Lower Platte South Natural Resources District: Rules & Regulations for the Nebraska Groundwater Management and Protection Act	**Phase I Trigger** has been designated District-wide and the District has established educational programs, groundwater monitoring and best management practices. **Phase II Trigger** shall occur when spring static groundwater elevations in 30% of the monitoring network wells have declined from the established upper elevation of the saturated thickness to an elevation that represents greater than or equal to a percent reduction in the saturated thickness and has remained below that elevation for a two consecutive year period. **Phase III Trigger** shall occur when spring static water elevation in 50% of the monitoring network wells have declined from the established upper elevation of the saturated thickness to an elevation that represents greater than or equal to a percent reduction in the saturated thickness and has remained below that elevation for a two consecutive year period.
Seawater Intrusion		
Maintain groundwater elevations to prevent further seawater intrusion.	South Westside Basin Groundwater Management Plan	For wells designated for seawater intrusion monitoring: **Trigger 1** is the historical low minus two feet, rounded down. **Trigger 2** is 10 feet below Trigger 1 for all wells.

TABLE 2. Examples of Triggers in Groundwater Management (cont.)

Measurable Objective	Document	Trigger Example
Water Quality		
Reduce or eliminate contaminants.	Lower Platte South Natural Resources District: Rules & Regulations for the Nebraska Groundwater Management and Protection Act	**Phase I Trigger** has been designated District-wide and the District has established educational programs, groundwater monitoring and best management practices. **Phase II Trigger** shall occur when at least 50% of the monitoring wells in the network are at or above 50% of the Maximum Contaminant Level for a contaminant. **Phase III Trigger** shall occur when at least 80% of the monitoring wells in the network are at or above 80% of the Maximum Contaminant Level for a contaminant.
Depletions of Interconnected Surface Water		
Limit the loss of interconnected surface flows.	Central Sacramento County Groundwater Management Plan	**Trigger Point 1:** Monitoring of losses of river water to groundwater shows a 5 percent increase over the current loss rate based on total flow in the river. **Trigger Point 2:** Monitoring of losses of river water to groundwater shows a 25 percent increase over the current loss rate based on total flow in the river.

Triggers can be used to manage groundwater resources and can be particularly helpful when there are little data or high levels of uncertainty.

Note: Triggers are only illustrative; they are not necessarily triggers that would meet the requirements of SGMA.

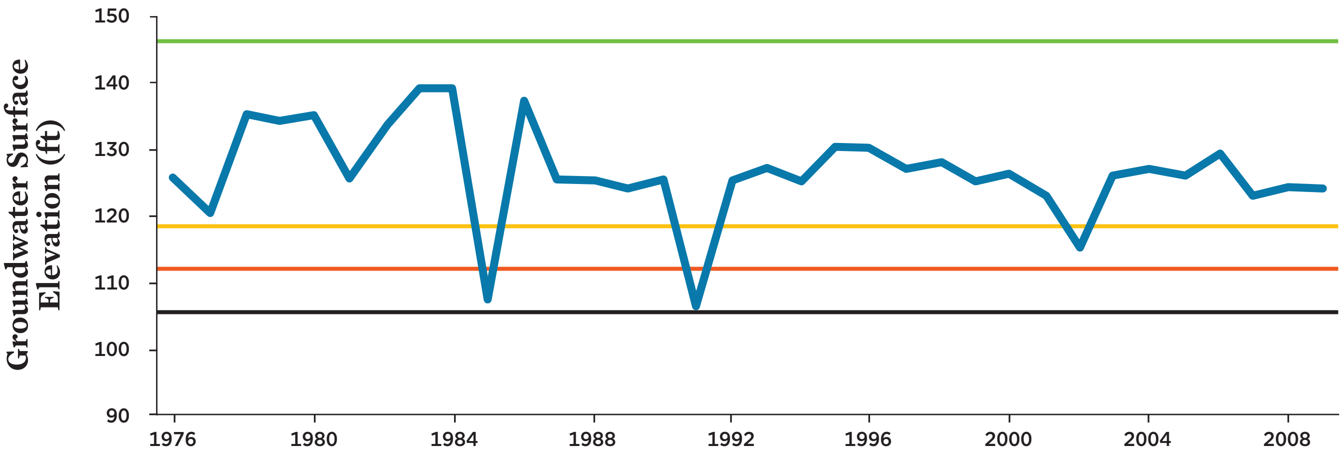
SOURCES: LOWER PLATTE SOUTH NATURAL RESOURCES DISTRICT 2014; SAN FRANCISCO PUBLIC UTILITIES COMMISSION 2012; GLENN COUNTY DEPARTMENT OF WATER RESOURCES 2010; WATER FORUM 2006.

margin of safety to account for uncertain system responses (Korus and Burbach 2009). Measurable objectives with proper metrics and with appropriate triggers and thresholds are designed to respond to such uncertainty and help the decision-making process under uncertainty.

It is extremely important that triggers be set to account for the fact that many management actions (e.g., increasing recharge) require significant time to implement to avoid the large direct and indirect cost of emergency measures. Uncertainty means that the beneficial effects of an action may be lower (or higher) than expected, which in turn may (or may not) require further action and additional time. Uncertainty may therefore increase the time spent finding the appropriate response to a potentially unsustainable situation. In areas of a basin that are particularly sensitive, or where a large degree of uncertainty exists about the system, triggers well above the threshold to undesirable results may be set. They can be used as one way to warn early of unforeseen system responses that might lead to undesirable outcomes. For example, precautionary buffers are used in Australia's Murray-Darling basin. Certain groundwater basins have less data or lower measurement accuracies associated with available data. In those areas, the amount of total groundwater extraction is reduced in order to ensure that management actions err on the side of being more rather than less protective. The size of the buffer is roughly proportional to the level of uncertainty present (see Box 4, p. 16).

Scenario-based planning, which examines different options under a range of possible future conditions, is another way to account for uncertainty. In order to address data uncertainties, groundwater resources impact studies usually include alternative analyses of different reasonable scenarios and/or sensitivity analyses that evaluate a range of possible outcomes to provide perspective on the range and likelihood of potential impacts. Scenario-based planning tools may also allow for stochastic modeling that provides probabilistic error bars around possible consequences of particular scenarios (Kiparsky, Milman, and Vicuña 2012).

FIGURE 2. Fixed Triggers for Groundwater Management



In this example, the threshold for chronic lowering of groundwater levels is the lowest groundwater elevation recorded (black line). Fixed triggers have been set at the land surface elevation (green-light trigger), one standard deviation (yellow-light trigger), and two standard deviations (red-light trigger) below the average groundwater elevation. The blue line represents the data, which are recorded depth-to-groundwater measurements over time.

SonoranDesertNPS/Creative Commons (Flickr)

Comprehensive and consistent monitoring and measurement is the cornerstone of adaptive management. The device shown here is used to measure depth-to-groundwater.

Adapt to Changing Conditions and New Information

Adapting to new information is a key strategy for implementing effective measurable objectives. Although such adaptation is not explicitly mentioned in SGMA, the legislation includes numerous requirements that are part of an adaptive management framework (see Table 4, p. 18). For example, SGMA requires GSPs to develop interim milestones that help track progress toward sustainability goals and provoke course change, if necessary.

Several years ago, a group of influential water scientists wrote a paper that challenged the idea of stationarity in an era of global climate change:

> *"Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. . . In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as*

TABLE 3. Different Metrics Used to Assess Groundwater Levels and Storage

Groundwater Levels and Groundwater Storage		
Metric	**Document/Tool**	**Description**
Metering groundwater extraction	North Texas Groundwater Conservation District	All nonexempt wells must install a meter or water-flow-measuring device that can measure within plus or minus 5% accuracy.
Monitoring groundwater wells	Sacramento Central Groundwater Authority Groundwater Elevation Monitoring Plan	Operates 29 monitoring wells, which it monitors biannually (1 week before and after the 15th of each April and October). These months represent the typical seasonal high and low for groundwater levels in the basin based on historical data.
	Kings River Conservation District (KRCD)	Operates a satellite internet telemetry system at several groundwater monitoring wells. Each consists of a water-level-monitoring device that collects groundwater elevations daily and a data transmitter, which sends that data via satellite to the KRCD.
Modeling groundwater usage	GRACE: Gravity Recovery and Climate Experiment	Satellite measures variations in water stored at all levels above and within the land surface. However, the spatial (>150,000 km2) and temporal (monthly with a significant time lag) resolutions of the GRACE fields limit their fine-scale application for sub-basin water balance assessment.
	SEBAL: Surface Energy Balance Algorithm for Land	Uses Landsat satellite data to estimate water used for evapo-transpiration (ET).*
	METRIC: Mapping EvapoTranspiration at high Resolution with Internalized Calibration EvapoTranspiration at high Resolution with Internalized Calibration	Uses Landsat satellite data to estimate water used for ET.*
Metering electricity usage	Electricity meters on groundwater wells	Uses electrical consumption to estimate groundwater pumped from individual wells.

Because groundwater cannot be plainly seen, there are a variety of metrics used to assess groundwater levels and storage, including measuring extraction or employing modeling.

Note: *Both SEBAL and METRIC require estimating the ratio of groundwater vs. surface water used to meet modeled evapo-transpiration.

SOURCES: NTGCD 2010; SACRAMENTO CENTRAL GROUNDWATER AUTHORITY 2012; ZAITCHIK, RODELL, AND REICHLE 2008; ALLEN, MASAHIRO, AND TREZZA 2007; WATER FORUM 2006; BASTIAANSSEN ET AL. 2005; KRCD 2005.

a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate" (Milly et al. 2008).

In addition to the environment not having stationary characteristics, other factors may result in groundwater conditions falling outside expected variability, such as changing economic conditions.

Adaptive management is both a technique and a philosophy that integrates changing conditions in order to manage natural resources and ecosystems more successfully (McGowan, Lyons, and Smith 2015; Bormann, Haynes, and Martin 2007; Bormann et al. 1994). Adaptive management relies on setting objectives, scrupulously measuring the success of attempts to meet those objectives, and then modifying a management plan and its implementation to achieve the desired objectives. Over short time spans, adaptive management encourages flexibility, responsiveness, and local decision-making in order to adapt resource planning to the rapidly changing conditions and needs of the environment. Over longer time periods, as new information is developed, adaptive management results in modification and updating of management plans.

The adaptive management framework encompasses three broad phases: Plan, Do, and Evaluate and Respond. These phases include a number of steps that are part of the iterative cycle (see Figure 3). Table 4 (p. 18) demonstrates how each phase of the adaptive management process relates to SGMA requirements. SGMA may represent a new frontier for groundwater management in California; however, the adaptive management framework it is built upon has been used for more than 40 years to manage natural resources, including water. In the United States, adaptive management became a popular strategy for federal water and science agencies during the 1990s (Institute for Water Resources 2013).

Although many managers understand the concept of adaptive management, fewer are familiar with adaptive governance. Adaptive governance facilitates the ability of a management entity to react to change (Dietz, Ostrom, and Stern 2003). Adaptive management alone will not ensure resilient and sustainable outcomes, particularly if management entities are not able to incorporate new information and respond to changing conditions (Folke et al. 2005). Therefore, it is unwise to consider adaptive management as solely a scientific or technical process; it is also inherently a social process that requires institutional structures that allow for greater transparency and flexibility.

BOX 4.

Accounting for Uncertainty in the Murray-Darling Basin, Australia

"[In] areas where minimal information regarding the groundwater resource is available, less information was input to the RRAM [Recharge Risk Assessment Methodology] calculation process and hence a higher uncertainty was associated with the area. For such areas the sustainability factor [or groundwater extraction amount] was reduced, to make an allowance for the potential margin of error associated with the extraction limit determined for that unit and in summary:

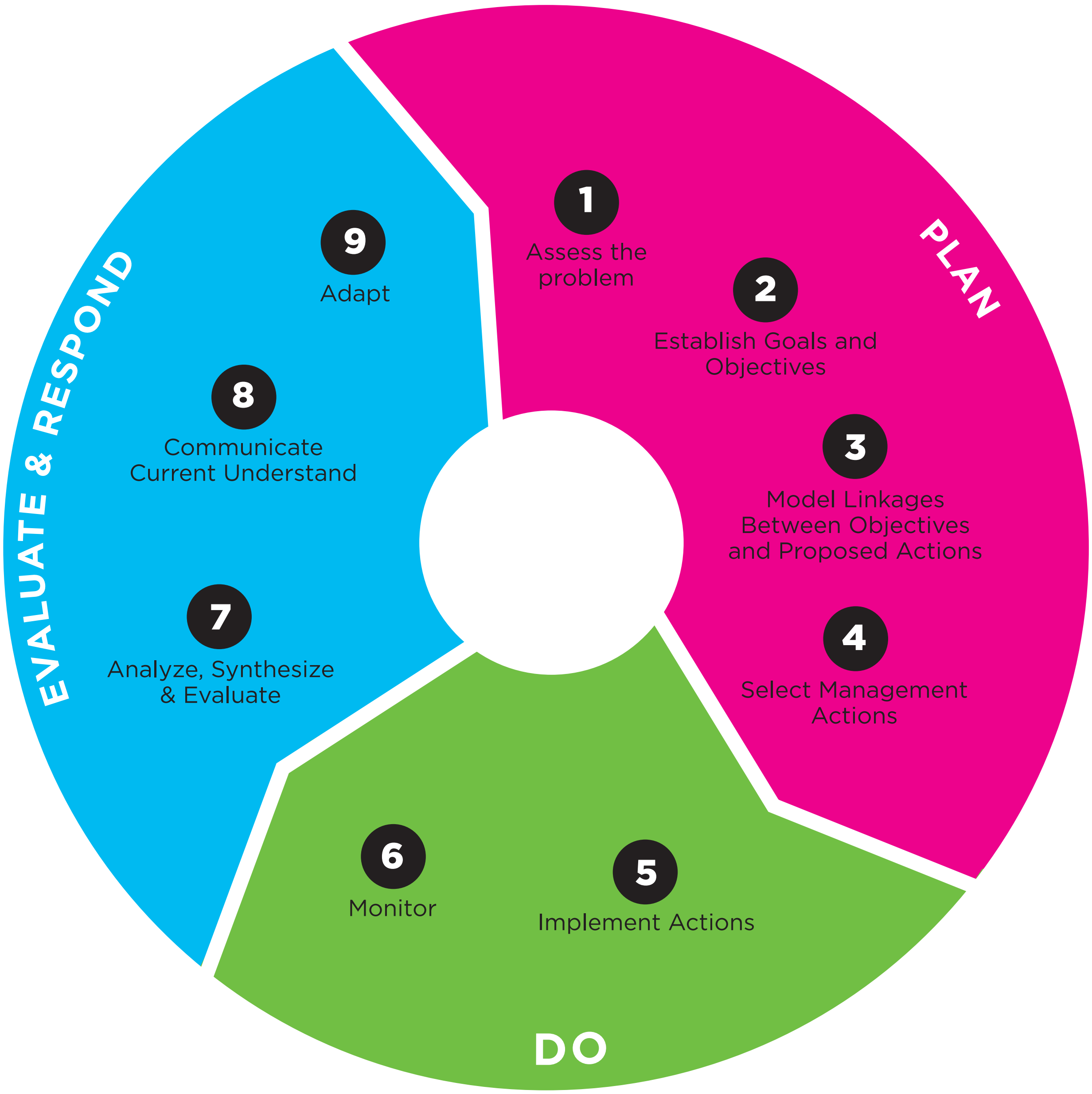
- The SF [groundwater extraction amount] associated with an area with an overall high-risk ranking was reduced by 50 percent.
- The SF [groundwater extraction amount] associated with an area with an overall medium risk ranking was reduced by 50 percent.
- The SF [groundwater extraction amount] associated with an area with an overall low risk ranking are reduced by 25 percent."

SOURCE: CSIRO AND SKM 2010

Hullwarren/Creative Commons (Wikimedia)

Proper groundwater management can help facilitate agriculture irrigation, like for the cotton seen here in the Murray-Darling Basin, Australia.

FIGURE 3. The Adaptive Management Cycle



The adaptive management cycle has three phases: Plan, Do, and Evaluate and Respond. Monitoring, measurement, and structured learning are what distinguish adaptive management from trial-and-error.

TABLE 4. Applying an Adaptive Management Framework to SGMA

	Adaptive Management Framework	SGMA Requirements
Plan	**1. Assess the problem:** Define the spatial scale, temporal scale, and range of factors (values) to be considered.	**Section 10727.2.a:** GSPs must contain a description of the physical basin and characteristics of the aquifer system underlying the basin.
	2. Establish goals and objectives: Identify clear, measurable, and agreed-upon management objectives to guide decision-making and evaluate management effectiveness over time.	**Section 10727.2.b.1:** GSPs must set measurable objectives, as well as interim milestones in increments of 5 years, to achieve the sustainability goals in the basin within 20 years of the implementation plan.
	3. Model linkages between objectives and proposed actions: Develop a model to describe the relationship between actions and objectives. Use the model to explore the effects of alternative actions.	**Section 10727.2.b.2:** GSPs must describe how the plan helps meet each objective and how each objective is intended to achieve the sustainability goal for the basin for long-term beneficial uses of groundwater.
	4. Select management actions: Identify a set of potential management actions for decision-making.	
Do	**5. Implement actions:** Initiate actions based on management objectives, resource conditions, and enhanced understanding of the resource.	**Section 10727.2.e:** GSPs must contain a summary of the type of monitoring sites, types of measurement, and the frequency of monitoring for each location monitoring groundwater levels, water quality, etc.
	6. Monitor: Monitor for implementation or compliance (following plan); effectiveness (meeting objectives); and validation of model parameters and relationships.	**Section 102727.2.f:** GSPs must contain monitoring protocols that are designed to detect changes in groundwater levels, water quality, etc. The monitoring protocols shall be designed to generate information that promotes efficient and effective groundwater management.

John Chacon/CA DWR

Groundwater can provide up to 50 percent of California's water supplies in dry years. Yet, in many cases groundwater data are limited, particularly where no one is tracking groundwater pumping or use.

TABLE 4. Applying an Adaptive Management Framework to SGMA (cont.)

	Adaptive Management Framework	SGMA Requirements
Evaluate & Respond	**8. Communicate current understanding:** Results, whether expected or unexpected, must be documented and communicated so that knowledge and experience are passed on to others facing similar problems.	**Section 20728.2:** GSAs must submit an annual report to the DWR containing the following information about the basin managed in the GSP: (a) Groundwater elevation data. (b) Annual aggregated data identifying groundwater extraction for the preceding water year. (c) Surface water supply used for or available for use for groundwater recharge or in-lieu use. (d) Total water use. (e) Change in groundwater storage. **Section 10727.8:** Requires GSAs to encourage the active involvement of diverse social, cultural, and economic elements of the population within the groundwater basin prior to and during the development and implementation of the GSP.
	9. Adapt: Where appropriate, cycle back to steps 1–6 to adjust objectives, models, actions, etc., to improve the resource management strategy.	**Section 10733.8:** Every 5 years, the DWR shall review GSPs to assess progress in achieving the sustainability goal within the basin. The assessment may include recommended corrective actions to address any deficiencies identified in the assessment.
	7. Analyze, synthesize, and evaluate: Data should be analyzed and results compared to forecasts and objectives. The evaluation should explain why results occurred and include recommendation for future action.	**Section 10728.2:** A GSA shall periodically evaluate its GSP, assess changing conditions in the basin that may warrant modification of the plan or management objectives, and may adjust components in the plan. An evaluation of the plan shall focus on determining whether the actions under the plan are meeting the plan's management objectives and whether those objectives are meeting the sustainability goal in the basin.

SGMA may represent a new frontier for groundwater management in California; however, the adaptive management framework it is built upon has been used for more than 40 years to manage natural resources, including water..

[***The adaptive management framework has been used for more than 40 years to manage natural resources, including water.***]

A Preliminary Framework for Setting Thresholds for Measurable Objectives

The review described above helps clarify how to set effective measurable objectives in general. Because this report is concerned specifically with the requirements of SGMA, we will now consider how to set measurable objectives and associated quantitative thresholds that will comply with the Act. SGMA requires that basins avoid undesirable results and achieve the sustainability goal, which is defined as operating the basin within its sustainable yield by 2040 (2042 for some basins). This means that GSAs need to choose thresholds for "significant and unreasonable" undesirable results that support the principles of sustainable yield.

While it is clear that local flexibility is necessary when setting thresholds, a clear and credible process for evaluating thresholds is crucial to ensuring that they comply with existing state standards and the intent of SGMA to achieve sustainable yield statewide. If the process is clear, consistent, and scientifically and legally defensible, then it is less likely to lead to conflict locally and between neighboring basins. Here, we propose a preliminary framework for basins considering how to establish a consistent process for identifying and setting thresholds for "significant and unreasonable" undesirable results (Figure 4).

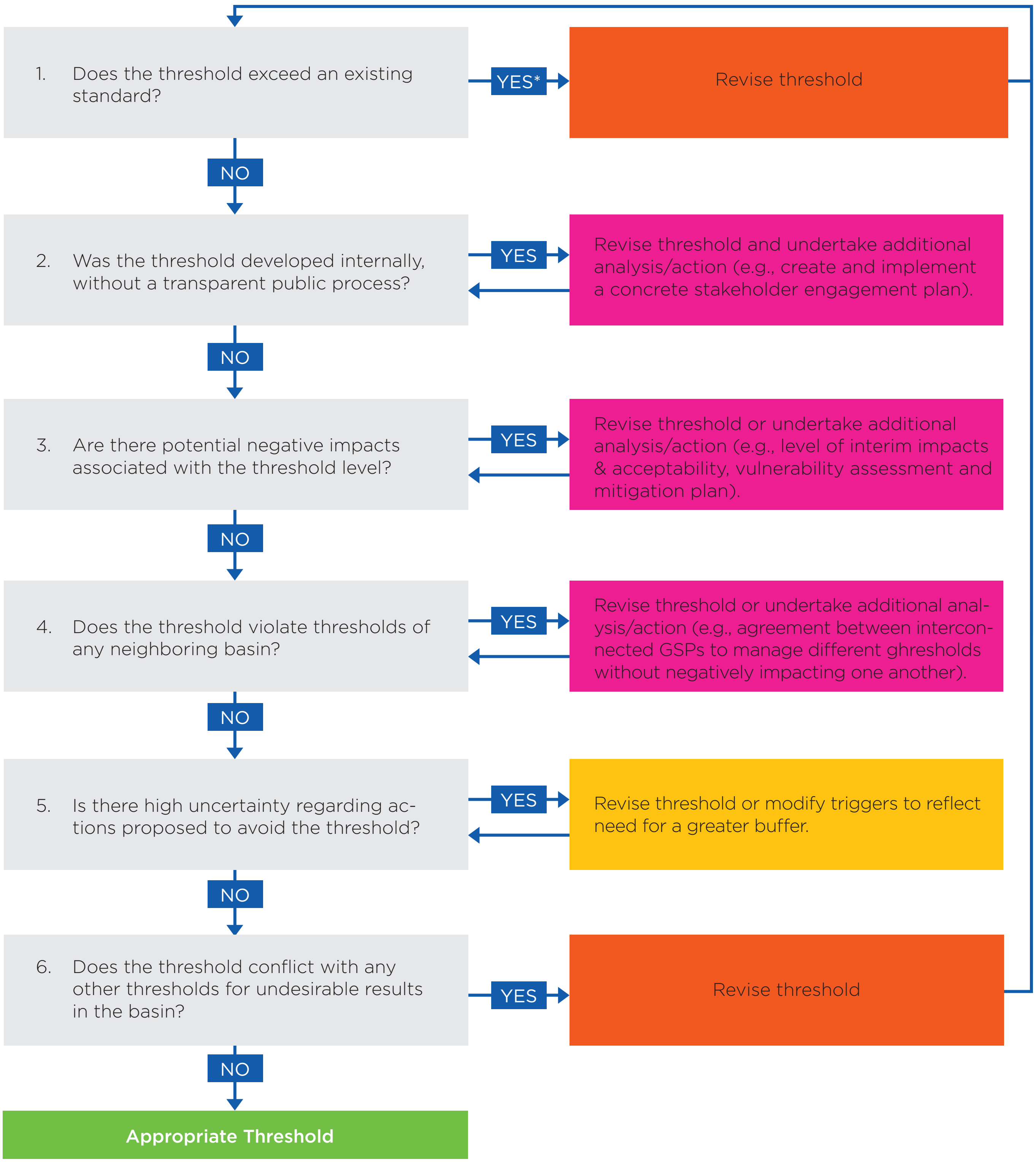
[***Processes that are clear, consistent, and legally and scientifically defensible are less likely to lead to conflict locally and between neighboring basins.***]

The framework, developed with input from the roundtable dialogue described earlier and in the appendix (p. 36), offers a useful approach to thinking through how to meet the requirements of SGMA while incorporating local values and addressing potential impacts. It is important to underscore that this preliminary framework is intended only to be illustrative and requires further refinement.

A few points to note about this preliminary framework:

- The framework is intended to help GSAs identify potential thresholds for each undesirable result and can be applied iteratively until finding a suitable threshold.
- Thresholds that do not exceed existing standards, are developed through a transparent public process, identify and address significant adverse impacts (if any), do not violate thresholds of neighboring basins, and have fairly high levels of certainty associated with proposed actions are likely to progress through the framework easily.
- Thresholds that exceed existing state regulatory standards, or conflict with thresholds for other undesirable results within the basin, will need to be revised. Thresholds that were not developed through a transparent public process, may have significant adverse impacts, or violate the thresholds of neighboring basins may require additional analysis or actions before they will be able to progress through the framework.
- Finally, GSAs setting thresholds that rely on actions that have a high level of uncertainty may need to consider more protective triggers in order to avoid inadvertently crossing the threshold.

FIGURE 4. **Preliminary Framework for Setting Thresholds**



The framework, developed with input from the roundtable dialogue described in the appendix (p. 36), offers a useful approach to thinking through how to meet the requirements of SGMA while incorporating local values and addressing potential impacts. The state should consider developing a consistent process for identifying and setting thresholds for "significant and unreasonable" undesirable results across basins.

** See Table 5, p. 22*

TABLE 5. Relevant Policies to Inform Thresholds for Each Undesirable Result

Undesirable Result	Related Agency Policies			Related Case Law
	Federal	State	Regional/Local	
Water quality	Safe Drinking Water Act, which includes the Underground Injection Control Program (Environmental Protection Agency)	Porter-Cologne Water Quality Control Act, "Anti-degradation policy"; Resolution 68-16; Recycled Water Policy (all covered by the State Water Resources Control Board)	Basin Plans; Local Salt & Nutrient Management Plans; Total Maximum Daily Loads (all covered by the Regional Water Quality Control Boards)	*Asociación de Gente Unida por el Agua v. Central Valley Regional Water Quality Control Board* (waste discharge order regulating dairies was found to violate California's Anti-degradation Policy)
Seawater intrusion		Porter-Cologne Water Quality Control Act; Recycled Water Policy; Resolution 88-63, "Sources of Drinking Water" includes a salinity standard; Water Code Section 2100 (State Water Resources Control Board)	Local Salt & Nutrient Management Plans (Regional Water Quality Control Boards)	
Subsidence				*Los Osos Valley Associates v. City of San Luis Obispo* (economic impacts related to subsidence must be borne by groundwater pumpers)
Interconnected surface flows	Endangered Species Act (Fish and Wildlife Service); Clean Water Act (Environmental Protection Agency)	Public Trust Doctrine (State Water Resources Control Board)	Bay Delta Water Quality Control Plan (State Water Resources Control Board); Instream Flow Guidelines for Northern Coastal Streams (State Water Resources Control Board); Minimum flow standards developed for Deer and Mill Creeks (Department of Fish and Wildlife); TMDL-related flow requirements on Shasta and Scott Rivers (Regional Water Quality Control Boards)	*Pacific Coast Federation of Fishermen's Association v. SWRCB* (endorses the principle that groundwater removals affecting flows in a navigable stream are subject to the public trust doctrine); National Audubon Society v. Superior Court (recognized that the State Water Resources Control Board had a duty to consider public trust when administering water rights)

[***The framework helps to create GSP that meet the requirements of SGMA while incorporating local values and addressing potential impacts.***]

TABLE 5. Relevant Policies to Inform Thresholds for Each Undesirable Result (cont.)

Undesirable Result	Related Agency Policies			Related Case Law
	Federal	State	Regional/Local	
Lowering of groundwater tables/loss of storage		Article X of California Constitution—prohibition against waste and unreasonable use (State Water Resources Control Board); Urban Water Management Planning Act requires 3-year-drought contingency plans and asks for agencies to consider climate change (Department of Water Resources)	Stanislaus County groundwater ordinance (County Board of Supervisors); San Luis Obispo County groundwater ordinance (County Board of Supervisors)	

GSAs should consider relevant policies and case law that pertain to individual undesirable results when setting thresholds. These standards have the force of law and cannot be weakened, but may be strengthened, by SGMA.

Thresholds will need to be considered not only for each undesirable result, but also at different spatial scales because undesirable results may be present only in some areas of the basin or may have different characteristics across the basin.

Step 1: Does the Threshold Exceed an Existing Standard?

The first step in the framework ensures that when state policies have already set standards, these standards have the force of law and cannot be weakened by SGMA. Table 5 provides a summary of existing policies and case law related to each undesirable result. In some cases, such as water quality, there are already some standards and regulatory processes that may guide the threshold-setting process, while in others, such as land subsidence, there are fewer existing guideposts. In many cases, such as minimum in-stream flows, existing policy is based on managing surface water and has not been applied extensively to groundwater.

Step 2: Was the Threshold Developed through a Transparent Public Process?

The second step ensures that thresholds have been developed by following a transparent process that engages local agencies and stakeholders, as required by SGMA. SGMA specifically requires GSPs to consider existing planning documents, such as General Plans (Government Code Section 65350.5.), and to actively engage interested parties and diverse stakeholders (Box 5, p. 24).

Step 3: Are There Potential Negative Impacts Associated with the Threshold Level?

The third step in the framework requires an analysis of potential negative impacts associated with a particular threshold. If negative impacts are likely, the threshold may need to be revised. Alternatively, in some cases, it may be possible to mitigate these negative impacts if agreement is reached with the affected communities. This is also when the reversibility of negative impacts should be considered, as impacts that are irreversible will not be able to be mitigated.

Step 4: Does the Threshold Violate the Thresholds of Any Neighboring Basins?

Groundwater basins that are adjacent to one another can affect each other's groundwater balance and, therefore, impact each other's ability to comply with SGMA. SGMA requires the DWR to evaluate whether a GSP in one basin impedes the ability of another GSP to achieve its sustainability goals (California Water Code Section 10733(c)). Step 4 ensures communication occurs between neighboring basins that have chosen to manage to different thresholds so that each avoids unexpected impacts.

BOX 5.

Statutory Requirements for Stakeholder Involvement in SGMA

Summary of Statutory Requirements for Stakeholder Engagement in SGMA

During GSA Formation:

- "Before electing to be a groundwater sustainability agency… the local agency or agencies shall hold a public hearing" (CA Water Code Sec. 10723 (b)).
- "A list of interested parties [shall be] developed [along with] an explanation of how their interests will be considered"(CA Water Code Sec. 10723.8.(a)(4)).

During GSP Development and Implementation:

- "A groundwater sustainability agency may adopt or amend a groundwater sustainability plan after a public hearing" (CA Water Code Sec. 10728.4).
- "Prior to imposing or increasing a fee, a groundwater sustainability agency shall hold at least one public meeting" (CA Water Code Sec. 10730(b)(1)).
- "The groundwater sustainability agency shall establish and maintain a list of persons interested in receiving notices regarding plan preparation, meeting announcements, and availability of draft plans, maps, and other relevant documents" (CA Water Code Sec. 10723.4).
- "Any federally recognized Indian Tribe… may voluntarily agree to participate in the preparation or administration of a groundwater sustainability plan or groundwater management plan… A participating Tribe shall be eligible to participate fully in planning, financing, and management under this part" (CA Water Code Sec. 10720.3(c)).
- "The groundwater sustainability agency shall make available to the public and the department a written statement describing the manner in which interested parties may participate in the development and implementation of the groundwater sustainability plan" (CA Water Code Sec. 10727.8(a)).

Throughout SGMA Implementation:

- "The groundwater sustainability agency shall consider the interests of all beneficial uses and users of groundwater" (CA Water Code Sec. 10723.2).
- "The groundwater sustainability agency shall encourage the active involvement of diverse social, cultural, and economic elements of the population within the groundwater basin" (CA Water Code Sec. 10727.8(a)).

SOURCE: DOBBIN ET AL. 2015

Step 5: Is There High Uncertainty Regarding Actions Proposed to Avoid the Threshold?

As already discussed, any long-term planning process inherently involves uncertainty, and it is critical that such uncertainty be acknowledged. In cases in which there are few data points, there is a long time lag between an action and its consequence, or there is little ability to forecast future conditions, it is wise to develop more conservative thresholds and more protective triggers to avoid an undesirable result.

Step 6: Does the Threshold Conflict with Any Other Undesirable Result Thresholds?

The last step of the preliminary framework requires a more holistic view across undesirable results to ensure that the threshold set for one undesirable result is not negatively impacting another or conflicting with broader state water management policies or priorities.

BOX 6.

Applying the Preliminary Framework

For illustrative purposes, assume that we are in a coastal, agricultural basin that is experiencing seawater intrusion. On January 1, 2015, salt was present at a concentration of 250 parts per million (ppm) or milligrams per liter (mg/L) in monitoring wells. The coastal basin GSA is developing its GSP through a stakeholder process and proposes several thresholds for what could constitute "significant and unreasonable" seawater intrusion. Threshold A is 250 ppm at the monitoring wells, Threshold B is 800 ppm, and Threshold C is 200 ppm. Below, we run each of these thresholds through the framework for setting thresholds.

THRESHOLD A: MAINTAINING CURRENT CONDITIONS (250 PPM)

1. **Does the threshold exceed an existing standard?** Per the Safe Drinking Water Act, the secondary maximum contaminant level for salinity is 500 ppm. Thus, a concentration of 250 ppm does not violate existing water quality standards under the act. There are also broader state water policies that should be considered at this stage, such as the provision for reasonable and beneficial use of water and the Public Trust Doctrine.
2. **Was the threshold developed through a transparent public process?** Though we do not know the details, given that the GSA is defining a series of different thresholds for stakeholders to consider, let's assume the answer is yes.
3. **Are there potential negative impacts associated with the threshold level?** Yes. Although the concentration is below drinking water standards, it can affect salt-intolerant crops at this concentration. The framework suggests additional analysis or actions at this point, such as a vulnerability assessment and mitigation plan. Alternatively, the GSA could choose to revise the threshold.

THRESHOLD B: WORSENING CONDITIONS (800 PPM)

1. **Does the threshold exceed an existing standard?** Yes. The secondary maximum contaminant level for salinity is 800 ppm. In this case, threshold revision is required.

THRESHOLD C: IMPROVING CONDITIONS (200 PPM)

1. **Does the threshold exceed an existing standard?** A concentration of 200 ppm does not violate existing water quality standards under the Safe Drinking Water Act. However, again, there may be broader state water policies that should be considered at this stage, such as the provision for reasonable and beneficial use of water and the Public Trust Doctrine.
2. **Was the threshold developed through a transparent public process?** Though we do not know the details, given that the GSA is defining a series of different thresholds for stakeholders to consider, let's assume the answer is yes.
3. **Are there potential negative impacts associated with the threshold level?** Not at present. No crops currently grown in the basin are salt-sensitive at a concentration of 200 ppm. However, although 200 ppm does not threaten existing land uses, it limits future land uses as there are high-value agricultural crops that are sensitive to salt at a 200 ppm concentration. This issue may argue for a revised threshold.
4. **Does the threshold violate the thresholds of any neighboring basins?** For the purposes of this exercise, let's assume that 200 ppm does not violate the thresholds of any neighboring basins.
5. **Is there high uncertainty regarding actions proposed to avoid the threshold?** No, assuming that the actions taken to achieve and maintain a concentration of 200 ppm are focused on demand reduction, because the results of these actions tend to be fairly certain. However, if the actions to achieve and maintain a concentration of 200 ppm are focused on recharge with surplus surface water that is unreliable, the answer could be yes. In this case, the framework would suggest implications for triggers. For example, triggers could be more protective or require demand reduction at a particular point to ensure that the threshold is not crossed.
6. **Does the threshold conflict with any other undesirable result thresholds?** The threshold of 200 ppm may still be unacceptable for other reasons. For instance, there may be interconnected coastal surface waters that would be harmed by allowing any seawater intrusion, or the amount of groundwater extraction allowed at this threshold may contribute to inelastic land subsidence.

Recommendations

UCS, in partnership with the CWF, convened a multistakeholder roundtable to inform this report and compile a series of recommendations regarding measurable objectives. The roundtable involved voices from agriculture, water agencies, under-represented communities, environmental interests, and counties throughout California. UCS and the CWF are deeply appreciative of all who participated and shared their perspectives.

Based on this review of groundwater management literature and cases elsewhere, along with feedback from the roundtable process (see Appendix: Roundtable Findings on Measurable Objectives, p. 36), we put forward the following conclusions.

Common State Framework Needed

The state should develop a framework for setting thresholds, triggers, and interim milestones related to measurable objectives that rely on state standards and policies where they exist. It should also create common rules and methodologies when there are no state standards. The framework should list important considerations to be taken into account when developing measurable objectives, including:

- Current conditions for each undesirable result
- Existing state standards and policies. It is important for a basin first to identify any existing state standards and policies that will determine the local thresholds.
- Level of impacts and who and what would experience impact for each threshold. Environmental, social, and economic impacts are important considerations. A vulnerability assessment and, possibly, a mitigation plan may be required.
- Feasibility of reversing undesirable results
- Level of certainty regarding the basin condition and the ability of management actions to address the impacts.
- The time delay between proposed or existing actions and the corresponding impact should be considered.
- Impacts on neighboring basins and impacts caused by neighboring basins
- Interactions and dependencies between undesirable results

State regulations need to be written so as not to discourage GSAs interested in more protective thresholds and triggers than those required by state regulatory standards. For example, a basin may choose to set a threshold for seawater intrusion that is more protective than that required by state water quality standards in order to protect local production of salt-sensitive crops.

[*California should develop a framework for setting thresholds, triggers, and interim milestones related to measurable objectives.*]

All basins would benefit from a consistent set of rules regarding the data and methodologies that should be used to develop credible and coordinated thresholds across basins. The state framework should identify existing data sources, require consistent assumptions be used when developing sustainable yield estimates, and develop consistent metrics and data protocols.

IDENTIFY EXISTING DATA SOURCES FOR BASIN CONDITIONS

The amount and quality of data that groundwater basins currently collect vary greatly throughout the state. The state therefore has an important role to play in identifying existing data sources that should be used in GSPs and also in improving groundwater data and monitoring networks containing data gaps or inconsistencies. In order to treat all basins fairly, the state must require that basins have access to some consistent data in terms of assessing their groundwater conditions over time.

For example, the state could invest in expanding the California Statewide Groundwater Elevation Monitoring and Groundwater Ambient Monitoring and Assessment monitoring networks and require that GSAs assess groundwater level and groundwater quality using these networks unless a basin has a better local groundwater monitoring system. The state could require GSAs to use InSAR satellite data that the state provides unless a basin has a better local land subsidence monitoring system. Similarly, the state could require GSAs to use the Nature Conservancy's maps of gaining and losing streams in the Central Valley (TNC 2014) to establish where surface waters may be interconnected unless a basin has better data about the relationship of groundwater to surface flows.

REQUIRE CONSISTENT ASSUMPTIONS TO DEVELOP SUSTAINABLE YIELD

SGMA requires that basins achieve a sustainable yield by 2040 (or 2042); thus, most basins will use models to project how changing land and water uses, management approaches, and other factors will affect the basin's water budget and use that information to develop a sustainable yield. Because assumptions drive modeling efforts, it will be critical for the state to define some common assumptions that all basins are to use when developing sustainable yield. For example, when developing a water budget for sustainable yield, a basin should incorporate

- forecasts of growth and land uses based on the most recent plans (e.g., county general plans, State Department of Finance projections, water demand forecasts from urban water management plans, integrated regional water management plans, and the California Water Plan);

Kelly M. Grow/ CA DWR

Groundwater well driller in Smartsville, CA in May 2015. California's current drought has spurred a groundwater drilling boom in the Central Valley

- climate change forecasts made from a consistent set of scenarios (the state used IPCC Special Report on Emissions Scenarios A2 and B1 scenarios in the past); and
- a five-year-drought contingency plan (many urban water management plans already use a three-year-drought plan).

DEVELOP COMMON METRICS AND TRANSPARENT DATA MANAGEMENT AND REPORTING PROTOCOLS

Local agencies need state guidance to ensure that basins are using common metrics to describe undesirable results and are reporting information in a standardized manner that allows the DWR to enter it into publicly available, regional scale groundwater models to support improved interbasin and intrabasin coordination. For example, few groundwater basins monitor the contribution of groundwater to surface flows. Basins could use a variety of different metrics to develop a measurable objective related to the depletion of interconnected surface waters, such as the distance of a well from a surface water body or a stream-flow-depletion factor. While both of these metrics are currently in use, stream-flow-depletion factors are far more scientifically and legally defensible.

The development of transparent data management protocols is central to the success of shared resource management. Similar to the development of measurable objectives during GSP preparation, GSAs will need to work with diverse stakeholders to develop transparent protocols for data collection and analysis. These protocols provide resource management entities with a common set of data to inform manage-ment discussions and decisions. Providing all stakeholders with access to these data can avoid unnecessary conflict and confusion.

Summary

We are facing some of the hottest and driest conditions on record and the lowest levels of snowpack ever recorded. Responding to these conditions and others, SGMA represents a new chapter for water management in California. It will require unprecedented levels of groundwater information collection and analysis, new institutions and broader collaboration between existing institutions, and the active engagement of diverse interests. Although SGMA leaves much of the implementation of its requirements to local entities, it also requires the state to issue clear rules that, in effect, set the bar for what sustainability means in practice.

The challenges involved in implementing sustainable groundwater programs are significant—for the state, in putting forward a framework that promotes consistent standards and approaches while allowing (where necessary) for local flexibility, and for each GSA, in understanding and then effectively managing its groundwater usage to avoid undesirable results and achieve sustainable yield. This review of the state of knowledge and practice, as well as the discussions with roundtable participants, provides the outlines of a consistent state framework and approach that will provide greater regulatory certainty and a roadmap for implementation, thus lessening some of these challenges.

We hope this report contributes to the state's effort to establish a wise, effective, and sustainable groundwater management program that will enable water users statewide to rely on this valuable resource for many decades to come. The importance and urgency of this effort cannot be overstated. Sustainable groundwater management offers a new pathway that will allow the state both to mitigate and to adapt to climate change while also increasing water reliability in the future.

[***SGMA represents a new chapter for groundwater management in California, but the state must set the bar for what sustainability means in practice.***]

[APPENDIX]

Roundtable Findings on Measurable Objectives

(PREPARED BY THE CALIFORNIA WATER FOUNDATION)

In June and July 2015, the California Water Foundation convened a series of roundtable discussions with a diverse set of participants to create a shared knowledge base regarding the state of practice around measurable objectives for sustainable groundwater management. Specific dialogue objectives included:

- Take stock of the different approaches used in California and elsewhere (U.S. and abroad) to create measurable objectives for the six "undesirable results" identified in the SGMA.
- Provide a forum for integrating knowledge across stakeholders and agencies, drawing from a wide range of experiences and expertise; test participant concerns and preferences for different approaches based on the Roundtable deliberations.
- Better understand the need for and benefits of common statewide versus regional guidance for creating measurable objectives.
- Identify key findings and lessons learned from the participants' collective scan of different practices to inform the State's approach to defining measurable objectives; include discussion of other implementation considerations (data and modeling, financial, etc.).
- Share the summary of research and key findings from the roundtable process with state agencies and other stakeholders to inform the development of regulations to evaluate the Groundwater Sustainability Plans.

The discussions were intended primarily to inform the Union of Concerned Scientists' (UCS) drafting of a white paper summarizing theories and practices for defining the measurable objectives called for in the recently passed Sustainable Groundwater Management Act (SGMA). The discussions also generated a range of important perspectives and findings relevant to measurable objectives. Below is our synthesis of key themes that emerged from the June 15 and July 21 dialogues. This set of findings is not intended to be a summary of all issues raised nor suggest consensus on all issues among all participants. Rather, it is an opportunity to highlight key findings based on the roundtable dialogue. These findings have been reviewed and confirmed by all participants.

Participants in the Roundtable who reviewed and confirmed these findings are: Eric Averett, Kern Groundwater Authority; Mary Bannister, Pajaro Valley Groundwater Management Agency; Juliet Christian-Smith, Union of Concerned Scientists; Jennifer Clary, Clean Water Action; Paul Gosselin, Butte County; Sarge Green, California Water Institute at Fresno State; Thomas Harter, University of California, Davis; Adam Hutchinson, Orange County Water District; Peter Kavounas, Chino Basin Water Master; Sandi Matsumoto, The Nature Conservancy; Tara Moran, Stanford University; Steven Phillips, U.S. Geological Survey; Jeff Pratt, Fox Canyon Groundwater Agency; Derrik Williams , Hydro Metrics WRI; and Walt Ward, Stanislaus County.

The roundtable dialogue also included several contributors and observers. They are: Kristyn Abhold, Union of Concerned Scientists; Adrienne Alvord, Union of Concerned Scientists; Sam Boland-Brien, State Water Resources Control Board; Scott Cantrell, Department of Fish and Wildlife; Erik Ekdahl, State Water Resources Control Board; Trevor Joseph, Department of Water Resources; Michael Kiparsky, University of California, Berkeley; and Steven Springhorn, Department of Water Resources.

RELATED TO SETTING MEASURABLE OBJECTIVES THRESHOLDS AND TRIGGERS

1. **General guidance and terminology.** Measurable objectives and interim milestones are Sustainable Groundwater Management Act (SGMA) requirements and need to be quantitative and clear enough for groundwater sustainability agencies (GSAs) to determine progress and for the Department of Water Resources (DWR) to determine compliance. Triggers are early warning levels to signal to the GSA and the community that conditions are worsening. Triggers should be established for each threshold in a groundwater sustainability plan (GSP), as well as a

corresponding management action to be initiated when a trigger is crossed in order to realign basin conditions and avoid the threshold. Determining sustainable yield is valuable for groundwater management, but in and of itself it is not sufficient to confirm a GSA is avoiding undesirable results (URs).

2. **State framework.** The state should develop a framework for setting measurable objectives and related actions that rely on state (and federal) standards and policies where they exist, and create common rules and methodologies when there are no state standards. Local flexibility is needed for setting URs where there are no clear state standards. In such cases, consistent operational rules regarding data and methodologies (e.g., climate change forecasts, drought buffers) are important to foster the development of credible, coordinated, and verifiable thresholds statewide.

3. **State enforcement relative to measurable objectives and triggers.** Measurable objectives, interim milestones and associated thresholds are requirements under SGMA and subject to state oversight and intervention. Triggers set in the GSP to avoid thresholds are not a regulatory requirement.

4. **Common factors for State framework.** The following factors will need to be considered when setting measurable objectives, thresholds, and interim milestones:
   - Historic and current conditions for each UR.
   - Existing state standards and policies. It is important for a basin to first identify any existing state standards and policies that will determine the local thresholds to avoid undesirable results. State standards and policies exist for water quality and interconnected surface water bodies.
   - Relationship between current and historic conditions and any relevant state standards and the proposed local thresholds.
   - Level of impacts, to whom and what, for each threshold. Environmental, social, and economic impacts are important considerations. If impacts will continue, a mitigation plan should be proposed.
   - Time delay between the change in groundwater recharge/extraction/discharge and the corresponding benefit/impact.
   - Permanence of impacts or feasibility to reverse impacts.
   - Level of certainty of the basin condition and the ability of management actions to address the impacts.

   Additionally, each basin's use of the framework should be informed by its value-driven planning objectives. As well, a GSA will need to take a broad and coordinated approach across undesirable results to ensure that the threshold set for one undesirable result is not negatively impacting another or conflicting with broader state water management policies or priorities

5. **Local stakeholder engagement.** It is important to engage a diverse stakeholder group and the community with local agencies to help (1) develop the basin's value-driven planning objectives, (2) evaluate impacts (and any needed mitigation) associated with differing threshold levels, and (3) collaborate in a transparent process to develop the measurable objectives, thresholds and interim milestones that are avoiding significant and unreasonable impacts in the basin. A GSA should articulate the extent to which identified impacts are addressed and mitigated.

6. **Allowing for Greater Protections.** State rules need to be written so as to not discourage basins interested in establishing more protective thresholds than those that may be required by a state/local minimum standards. For example, a basin may choose to set a threshold related to seawater intrusion at a more protective level than required by state water quality standards to protect production of saline-sensitive crops. These more protective "management" thresholds should not be subject to state intervention.

7. **Living document.** A GSP is a living document and will need to be adjusted to account for new state standards, changing conditions, and updated assumptions and data.
   - Any intended changes are to be discussed first with basin stakeholders and then with the State as part of periodic reports and evaluations.
   - MO/Thresholds, even if modified, must be achieved within the 20-year-window required by SGMA.
   - Any change in a MO/threshold should be accompanied by a thorough assessment of impacts and consideration of needed mitigation.
   - It should be made clear to basin stakeholders at the outset that locally determined thresholds can be modified and can be distinct from state standards.

RELATED TO BASELINE CONDITIONS AND PATHWAYS TO SUSTAINABILITY

1. **Pathways to sustainability.** Due to the wide range of historic and current conditions), groundwater basins should be allowed to adopt different paths and timing (within

the 20-year period) to achieve the sustainability goal. The current conditions of a basin will affect the path and timing for achieving sustainability. For example if current conditions are:

a. Worse than the proposed threshold: Then a basin should provide a transition time of not more than 20/22 years that requires improvement in conditions with each interim milestone until the threshold is no longer crossed.

b. At or near the proposed threshold: Then a basin should either (1) maintain current management practices and controls, or (2) allow for worsening conditions in the short term until new management actions are initiated to reverse the trend. (In this scenario a buffer would need to be established in order to ensure the threshold is not crossed inadvertently.)

c. Better than the proposed threshold: Then a basin could maintain the current threshold or allow for worsening conditions over the 20/22 year transition time (glide path) as long as the threshold is not crossed.

2. **Mitigation.** Measurable objectives, interim milestones and associated thresholds that allow for worsening conditions over the 20/22 year timeframe should identify and address or mitigate the associated negative impacts as part of the GSP. These impacts (and any associated mitigation) should be identified and discussed with affected stakeholder communities in a transparent and inclusive manner.

RELATED TO COMMON METHODOLOGIES AND DATA

1. **Standardized data, assumptions and methodologies.** SGMA implementation needs to account for greatly varying degrees of existing data and internal capacity across basins. Local agencies need state guidance on data format, data standardization, and common assumptions to support improved interbasin and intrabasin coordination. Identification of existing statewide data sources (e.g., remote sensing for subsidence) will help basins with initial implementation and foster consistent data use within and across basins. For example a consistent state standard or rule would be helpful for, among other factors:

   a. Drought buffer incorporated to avoid regulatory thresholds; length of buffer to plan for

   b. Coordinated groundwater models

   c. Common climate change assumptions

   d. Baseline data sources to develop current baseline conditions for each basin.

   e. Hydrologic parameters to be used in determining available sources of supply (i.e. standard assumptions for effective precipitation, etc.) over the planning horizon.

2. **Monitoring requirements.** Basins that can demonstrate no URs now may face a lower monitoring burden. However, basins will need to continue monitoring and reporting periodically (i.e., 5-year check-ins) to reconfirm underlying assumptions of no URs.

3. **Interconnected basin considerations.** Measurable objectives and thresholds need to account for interconnected basin management considerations. Consistent and reliable methodology and state rules regarding key assumptions (e.g., drought buffer, growth factors, etc.) and inter-basin coordination are seen as strategies for accomplishing this.

4. **Certainty.** The less certainty a basin has on the potential for management actions to prevent URs, the greater the need for more robust monitoring requirements and precautionary triggers.

RELATED TO SEAWATER INTRUSION

1. State water quality standards may be viewed as the minimum threshold:
   - SWRCB's Resolution 8863 policy for water quality. All groundwater is considered for potential municipal use if salinity is less than 3000 ppm.
   - Drinking water standards: there are secondary standards for TDS and chloride.

2. Local thresholds. More protective thresholds to avoid impacts on other beneficial uses such as agriculture may be best decided at the local level.

3. Metrics. Chloride and groundwater levels may be the appropriate metrics to measure seawater intrusion

RELATED TO LAND SUBSIDENCE

1. **Possible State standards.** There are no existing standards for setting URs related to subsidence, however there was general agreement among roundtable participants that a SGMA state standard for undesirable results associated with subsidence should distinguish between areas experiencing subsidence and areas that are not. For areas that are experiencing subsidence there was agreement among many but not all participants that the historic low groundwater level should be the minimum state standard.

2. **Mitigation and monitoring.** If there is a local determination to allow for increased subsidence in the short-term, the GSA should articulate how it will mitigate for any anticipated impacts and the degree of stakeholder concurrence with its analysis and intended mitigation actions. Measuring and monitoring need to account for variability in subsidence impacts – both where it occurs (given underlying geology) and the potentially long lag time between pumping and land subsidence.
3. **Elastic v. inelastic subsidence.** Basins should distinguish between elastic and inelastic subsidence and then manage for inelastic when setting URs.
4. **Subsidence data needs.** If subsidence data are lacking in a basin, satellite data can be used to provide an initial understanding of changes in land elevations; and can be followed up with ground surveys; basins will need to identify if pumping is from confined or unconfined aquifers and relate these pumping patterns to potential subsidence impacts.

RELATED TO LOWERING OF GROUNDWATER LEVELS AND CHANGE IN STORAGE

1. **Elevation and storage related.** The objectives and thresholds for lowering groundwater levels are likely to be similar to the objectives and threshold for change in groundwater storage.
2. **Linkage to other URs.** No net change in basin-wide groundwater storage is not sufficient to confirm compliance with SGMA; GSA's need to manage to all URs and temporal/spatial heterogeneity within a basin.
3. **Factors driving the setting of objectives and thresholds.** Objectives and thresholds for chronic lowering of groundwater levels and reduction in storage will be informed and possibly constrained by several key factors:
    a. When data is available, thresholds for other undesirable results would likely be developed first. For example, a GSA that has current or potential problems with subsidence or seawater intrusion will likely first review and set measurable objectives for those undesirable results before setting thresholds for groundwater levels and storage.
    b. Key operating rules (common assumptions and parameters set by the State such as climate change projections, drought buffer noted in earlier finding, etc.).
    c. Considering and accounting for potential impacts to interconnected basins.
    d. Basin-wide planning and growth aspirations and assumptions over a 50-year-planning horizon.
4. **Adjusting thresholds.** A basin may opt to revise target thresholds related to elevation and storage due to changing circumstances, but – as noted elsewhere – any changes and associated impacts must be fully considered with potentially impacted stakeholders and by the State. A basin still has only 20 years to reach sustainability, even if it alters its threshold.
5. **Managing the rate of decline.** Roundtable members discussed the potential for a candidate minimum standard related to an allowable rate of decreased elevations. There was interest but no roundtable agreement on whether this would be a workable standard.

RELATED TO WATER QUALITY

1. **State water quality standards** (MCLs, TMDLs) adopted by the SWRCB and included in Regional Water Quality Control Board Basin Plans under authorities in Porter Cologne and the Clean Water Act, cover most of the water quality contaminants in a groundwater basin. Those existing standards should be the minimum standard/threshold for GSPs to define the significant and unreasonable impacts for water quality.
2. **Local threshold.** If a GSA chooses to, it can adopt a more stringent SGMA threshold than is required by an existing state water quality standard, particularly if it is to protect beneficial uses in the local groundwater basin.
3. **Interagency coordination.** GSAs and existing water quality agencies (e.g. Regional Water Quality Control Boards) need to coordinate implementation and enforcement actions to manage water quality in the basin. Both entities bring expertise and implementation/ enforcement authorities to help achieve water quality standards.
4. **Trajectory.** Water quality thresholds and milestones need to account for and track both trends and targets.

RELATED TO INTERCONNECTED SURFACE WATER

1. **State and federal standards** and policies exist for many surface water bodies that could be used to develop thresholds that avoid depletions of interconnected surface water bodies that have significant and unreasonable adverse impacts. Existing surface water standards and policies include:
    a. SWRCB instream flow requirements
    b. RWQCB Basin Plans

c. State and federal Endangered Species Act and associated biological opinions

d. Public Trust Doctrine

e. Clean Water Act

2. **State identification of sensitive areas.** GSAs would benefit from state assistance to identify where interconnected surface water bodies need to be protected. Many basins have little data and knowledge regarding the connection between surface and groundwater systems. Statewide guidance would clarify the GSA obligations and help local areas understand where there are surface water bodies of concern in their region. State guidance (included in the regulations where appropriate) could be provided in numerous ways including state mapping of sensitive areas, state notifications/ letters to GSAs in priority basins, and local GSA coordination with the relevant state agencies (Department Fish and Wildlife, RWQCB, and SWRCB).

3. **GW/SW modeling.** Basins may need to develop a stream flow model that provides an understanding of the relationship between changes in groundwater elevation and changes in stream flow and vegetation. Many regions do not have a groundwater-surface water model and will need to initially rely on existing data and reasonable assumptions about the groundwater-surface water relationship when setting initial thresholds, identifying monitoring station needs and adopting initial management actions.

4. **Metrics and thresholds.** A GSA may also need to set thresholds for groundwater elevations surrounding the surface water body and a threshold for the surface water body. A common metric to measure the level of impacts is the "stream flow depletion factor" which measures the "percent loss rate" in surface water bodies due to groundwater pumping. An additional metric to measure impacts is the measurement of native plant cover. State rules could specify the appropriate metric for GSPs in order to provide for consistency along the entire stream reach and between affected basins.

5. **Initial threshold and monitoring with minimum data.** Where there is little data to inform the development of an interconnected surface water body threshold, the State could provide recommended approaches, common assumptions, and monitoring protocols (e.g., well siting – horizontal and vertical) to assist local agencies, and ensure minimum protections for sensitive areas. These thresholds (initially set at conservative levels) may need "trueing up" as more is understood regarding the connection between ground- water management actions and interconnected surface waters.

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[GLOSSARY]

BASELINE

The baseline is a representative assessment of the historic and current conditions of a groundwater basin. The baseline is used as the basis for setting future measurable objectives and evaluating progress and performance.

Example: Baseline is the average point of seawater intrusion over the past 10 years.

COMPLIANCE DATE

The compliance date is the date by which basins are required to achieve the sustainability goal.

Example: In SGMA, the sustainability goal must be achieved by 2040 or 2042.

INTERIM MILESTONES

Interim milestones are measurable quantitative targets set at 2020 and at every five years at most thereafter to demonstrate progress toward achievement of the sustainability goal. Fewer interim milestones will be needed if the final sustainability goal is set to be achieved at an earlier date.

Example: If the final threshold is achievement of a groundwater elevation of 5 feet above sea level at mile X, the five-year interim milestones could be set at an average of 0 feet and 2.5 feet, respectively, above sea level.

MEASURABLE OBJECTIVES

Measurable objectives are the specific measures used to determine whether a basin is successful in achieving the sustainability goal and avoiding significant and unreasonable undesirable results.

Example: Halt seawater intrusion in the deep aquifer at mile X from the coastline.

METRIC

A metric is the method of measurement used to assess measurable objectives quantitatively, to set triggers, and to set a threshold.

Example: Seawater intrusion may be assessed by measuring elevation of groundwater near the coast. Seawater intrusion can also be assessed by measuring chloride concentration in a network of wells in the aquifer near the coast to determine the distance of saltwater intrusion into freshwater aquifers.

THRESHOLD

A threshold is a measurable quantitative target or condition set in order to avoid a significant and unreasonable undesirable result. The threshold is the level of the metric that cannot be crossed despite fluctuations due to dry and wet years.

Example: Groundwater elevations in monitoring wells at mile X must be at least five feet above sea level.

TRIGGERS

Triggers are measurable quantitative targets that provide early warning signals that basin conditions are approaching the threshold for an undesirable result. Triggers can guide a management agency's response to worsening conditions, prior to reaching the threshold.

Example: A management agency wants to avoid further seawater intrusion in its basin. The threshold is measured at mile X. Early monitoring wells are installed at various distances from mile X, and a trigger is set whenever groundwater elevations average one standard deviation below the average elevation. The trigger is tied to a clear management action, such as curtailment of groundwater pumping.

SUSTAINABILITY GOAL

(from California Water Code Section 10721 (t))

The existence and implementation of one or more groundwater sustainability plans that achieve sustainable groundwater management by identifying and causing the implementation of measures targeted to ensure that the applicable basin is operated within its sustainable yield.

Example: The sustainability goal, to be achieved at the compliance date, is to show that, even under worst conditions (e.g., long-term drought, sea-level rise), measures are in place to avoid the water level at mile X going any lower than five feet above sea level (the threshold at which undesirable results occur).

SUSTAINABLE GROUNDWATER MANAGEMENT

(from California Water Code Section 10721 (w))

The management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results, which are defined as any of the following:

1. Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.
2. Significant and unreasonable reduction of groundwater storage
3. Significant and unreasonable seawater intrusion
4. Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies
5. Significant and unreasonable land subsidence that substantially interferes with surface land uses
6. Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water

SUSTAINABILITY YIELD

(from California Water Code Section 10721 (v))

The maximum quantity of water, calculated over a basin 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.

Measuring What Matters

Setting Measurable Objectives to Achieve Sustainable Groundwater Management in California

California needs a consistent framework for developing measurable objectives to achieve sustainability.

Groundwater is a critical resource for California. It provides a crucial buffer against drought and the growing impacts of global warming, especially diminishing mountain snowpack that has historically been a linchpin of California's water supply. Over the last century, groundwater in California has been largely unregulated, leading to severe declines in groundwater levels in many places. California's ongoing drought helped spur the passage in 2014 of the Sustainable Groundwater Management Act (SGMA), the first-ever statewide requirement for groundwater management. SGMA requires local groundwater sustainability agencies to develop groundwater sustainability plans by 2020, but does not define how to set measurable objectives. This report is designed to inform regulations about how to measure sustainability so that we know when we are making progress and when we are off track. Measurement is key to achieving sustainable groundwater management, and this report describes how to create effective measurable objectives and recommends a consistent framework for achieving sustainability across California.

Union of Concerned Scientists

FIND THIS DOCUMENT ONLINE: www.ucsusa.org/measuringwhatmatters

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