Addressing Regional Surface Water Depletions in California

A PROPOSED APPROACH FOR COMPLIANCE WITH THE SUSTAINABLE GROUNDWATER MANAGEMENT ACT

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Introduction

Successful implementation of the Sustainable Groundwater Management Act (SGMA), including its provision to avoid significant and unreasonable depletion of interconnected surface water, is a high priority for the Environmental Defense Fund (EDF). The lack of established mechanisms for addressing depletions of interconnected surface water makes the implementation of this aspect of SGMA especially challenging. Accordingly, EDF offers recommendations to address the requirements of the law related to depletion of interconnected surface water, commonly referred to as "Undesirable Result No. 6" (UR #6). We propose an approach that we believe provides a reasonable balance among the conflicting factors of rigor, cost, uncertainty, and enforceability that weigh on the implementation of this requirement. Our goal is to offer a pathway to achieve the fundamental and critical objective of UR#6, which aims to prevent significant impacts to water users and ecosystems that depend on streams and rivers that may be depleted by groundwater withdrawals, in a way that is not unreasonably costly or unproductively burdensome on the Groundwater Sustainability Agencies (GSAs), water users, and state agencies who will bear most of the burden of complying with—or ensuring compliance with—SGMA.

We are putting this approach forward to prompt a robust conversation about how to address this important requirement of SGMA. We offer this as a starting point for one possible approach to addressing UR#6. The recommendations presented here have no official standing, and there may be other reasonable approaches worth considering. There are many details yet to be worked out in our proposed approach, and we invite cooperation with thoughtful partners to work through these details and refine the approach to help pave the way for successful SGMA implementation in areas where interconnected surface waters are a significant consideration in groundwater sustainability.

Our proposed approach targets only the surface water depletion conditions required by SGMA. GSAs can choose to address surface water depletion impacts that occurred prior to January 1, 2015, and other laws and regulations, such as the Endangered Species Act, may obligate a GSA to consider requirements beyond the basic requirements of SGMA (Belin, L., forthcoming). In addition, the approach proposed here is intended to address regional drawdown of groundwater levels from dispersed pumping centers and does not account for the special impacts from and behaviors of near-stream pumping wells.

The basic premise underlying our proposed approach is as follows: if groundwater levels in the vicinity of a stream or river are not lower than they were prior to January 1, 2015 (allowing for inter-annual and seasonal variability), then it can be assumed that groundwater pumping is not causing significant and unreasonable depletions of surface water that must be addressed under SGMA. Accordingly, if a GSA manages their basin so that the groundwater levels in the vicinity of the stream are no lower than they were prior to 2015, it is reasonable to conclude under this approach that SGMA's requirements related to UR #6 have been satisfied.

Proposed compliance condition for surface water depletion

For purposes of this discussion, we define a "compliance condition" as a condition, which, if demonstrated to be true to a reasonable level of confidence and according to the best available information, is reasonably adequate to demonstrate that groundwater conditions are not causing depletions of interconnected surface water (ISW) that have significant and unreasonable adverse impacts on beneficial uses of surface water (UR #6).

We propose the condition of compliance for UR #6, relative to regional drawdown, is that the groundwater levels in the area intermediate between a stream and a regional pumping center are no lower than they were prior to 2015. Relevant to the following discussion is the provision of SGMA that says, "The plan may, but is not required to, address undesirable results that occurred before, and have not been corrected by, January 1, 2015" (WAT 10727.2(4), 2014). Practically speaking—for SGMA compliance, at least—this means that the provisions for avoiding surface water depletions should avoid depleting surface waters beyond the level of depletions that occurred prior to January 1, 2015. Additionally, the California Code of Regulations pertaining to the development of SGMA plans state that "an Agency may establish a representative minimum threshold for groundwater elevation to serve as the value for multiple sustainability indicators, where the Agency can demonstrate that the representative value is a reasonable proxy for multiple individual minimum thresholds as supported by adequate evidence" (23 CCR 354.28(d)).

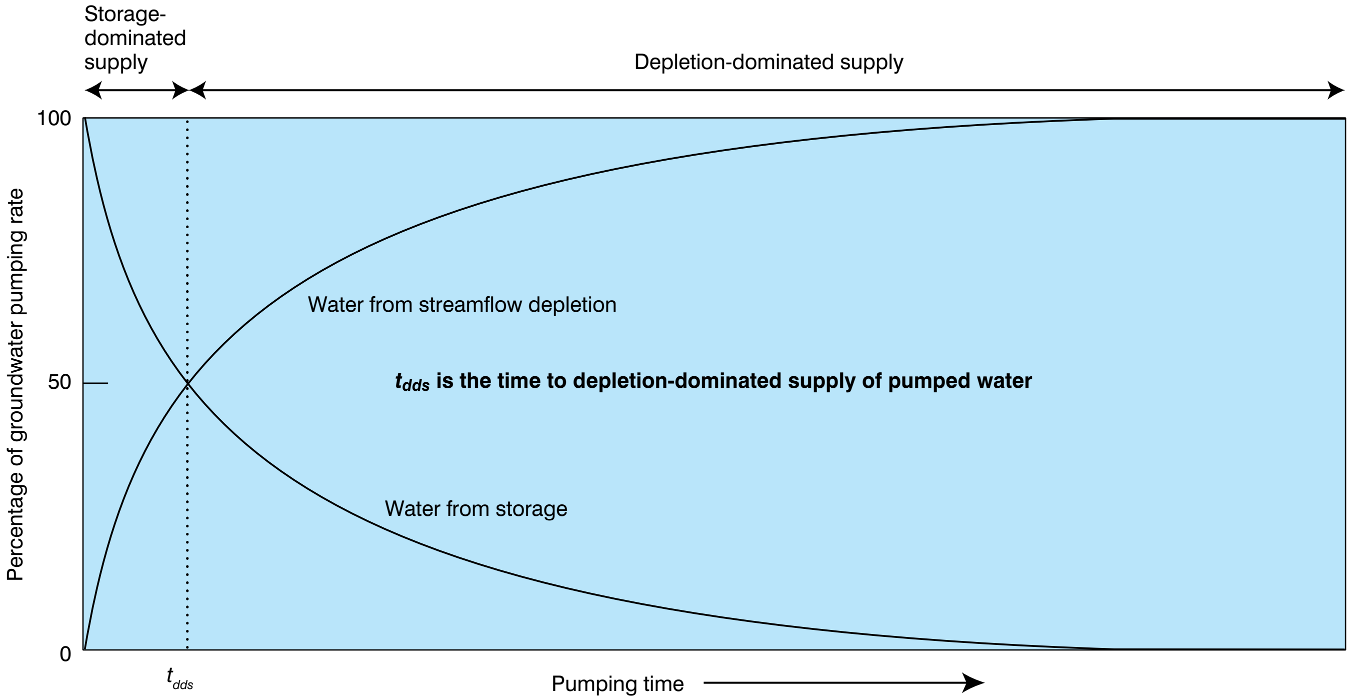
Of course, many questions need to be answered to provide confidence that this condition is being met. The following discussion describes what we think is a reasonable approach for documenting the compliance condition.

Scientific basis for proposed method

Steady groundwater flow is governed by Darcy's Law, which states that groundwater flow is proportional to the difference between groundwater levels (head) for different points along a flow path. Groundwater flow to a stream, or flow from a stream to an aquifer, is approximated as being proportional to the difference in water level between the stream and the

FIGURE 1

Sources of water to a pumped well



Source: Barlow and Leake, 2012

water level at some point in the adjacent aquifer. By making the assumption that aquifer properties and water level in the stream are relatively stable, changes in interchange of water between the stream and aquifer are driven by changes in water level in the aquifer. Our proposed method therefore focuses on determination of changes in groundwater levels near streams and rivers as indicators of streamflow depletions caused by groundwater conditions.

The depletion condition applies equally to gaining and losing reaches of streams. If a stream reach is gaining, lowering of groundwater levels results in a reduction of inflows to the stream, with a corresponding depletion of stream flow. The same applies, of course, in the case of a losing reach of stream. As long as the stream is hydraulically connected to groundwater, lowering of groundwater levels results in an increase in leakage from the stream (i.e., a depletion in surface flows).

Implications of time lag in streamflow depletion

Downward trends in water levels indicate that the system is not in steady state and future streamflow depletion from pumping will eventually occur if no actions are taken to counter that depletion. When a well or group of wells begins to pump, all pumped water comes from reduction of groundwater storage. As the cone of depression moves and intersects streams, lakes, and springs, the pumped water is increasingly supplied by streamflow depletion. This happens by reducing outflows from the aquifer to these surface water features and (or) inducing inflows from these features to the aquifer. The process is illustrated with the two curves on Figure 1. Assuming constant pumping, with enough pumping time, the system will reach steady state, which corresponds to the rightmost portion of the graph in which 100 percent of the pumped water is being supplied by streamflow depletion. As long as the stream can supply the pumped groundwater (meaning that rivers do not become disconnected or go dry), the streamflow-depletion curve will have the shape shown on Figure 1. That shape is unaffected by aquifer properties and changes in system fluxes such as recharge. What is highly variable, however, is the time over which a steady-state condition is reached. The single most important factor in that timing is the distance from the groundwater pumping to the surface-water boundary. Aquifer geometry and hydraulic properties also play a role in that timing. The transition shown could take place over time scales from months to centuries. If water levels in an area of pumping are still declining, additional streamflow depletion will eventually occur because the system is not at steady state; however, determination of when that depletion might occur requires site-specific analysis with numerical or analytical techniques.

Addressing beneficial use and significance issues

SGMA requires that sustainable management avoid "depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water" (WAT 10721(6), 2014). Many discussions have been circulating around what "significant and unreasonable" means as applied to UR #6, as well as around the definition of beneficial uses of surface water. For example, how does a GSA document the beneficial uses of surface water and then show that those beneficial uses of surface water are not being significantly and unreasonably impacted? In this case, the intent of the law seems reasonably clear: don't allow groundwater pumping to impact the beneficial uses of the surface water, but in some cases, some impacts—maybe even significant ones—might be allowable, provided that they are not unreasonable. However, characterizing beneficial uses and the level of impact streamflow depletion has had on them is a challenging task with considerable uncertainty and subjectivity in all but the simplest physical circumstances.

Some simplifying assumptions about beneficial uses

For an example of how the question of beneficial use impacts might be addressed, it is helpful to look at rivers in the Central Valley. In the Central Valley, during large portions of most years, flows are being released from various dams and reservoirs into streams to meet water quality and environmental requirements in the Delta; this is referred to as the Delta being "in balance." Under this condition, there is no unallocated water in the streams; all of the flow, whether in a small tributary or in a major river, is being beneficially used, either for water supply, water quality, or environmental flows. Accordingly, during these times, any amount of stream depletion will affect the beneficial uses of surface water, either by reducing deliveries of water that is beneficially used or resulting in increased reservoir releases in order to meet the required conditions downstream (in the Delta for Central Valley streams). So, it is reasonable to say that during times when all of the flows are allocated – for Central Valley streams, this means when the Delta is in balance – any additional depletion of surface water affects the beneficial uses of that surface water. For the most heavily developed streams, including those in the Central Valley, ***it is therefore not necessary to characterize the various beneficial uses of the surface water along a reach of stream hydraulically connected to the groundwater basin in question, since all of the water in the stream is being beneficially used during some time periods***. In this situation, any additional depletion of surface water flows caused by groundwater conditions in excess of conditions as they were in 2015 would likely be an undesirable result that must be addressed under SGMA.

A question remains of how to handle situations when all of the flow in a stream is not fully allocated, such as when the Delta is not in balance and flows in excess of water quality requirements are passing into San Francisco Bay. These periods do happen, and in some years, like 2017, there are substantial periods when there is unallocated flow in the system. That said, during the periods when the Delta is not in balance, some stream reaches are fully allocated. For example, the San Joaquin River and all of its tributaries upstream of the Delta may be fully allocated—either for water supply, in-stream flows, or water quality criteria—when unallocated flows from other tributaries result in a net increment of flow in excess of what is required flowing to the Bay. Similarly, all of the flow in a particular tributary may be fully allocated. In times when the Delta is not in balance, the determination of a fully allocated stream reach involves a complex set of factors, including how much storage is available upstream of that reach, what instream flow requirements might be in effect upstream or downstream from that reach, and how Delta operations are playing out—a complex, and highly unpredictable milieu in itself.

In many California streams and rivers outside the Central Valley, the situation with respect to full allocation is not as clear or as well monitored. Accordingly, for streams outside the Central Valley, a site-specific determination of when there are unallocated flows in the stream is needed. This may be a challenging task, given riparian and appropriative diversion rights of different priorities.

At times when there is unallocated flow in some stream reaches, some additional depletion of surface water from groundwater pumping may not affect the beneficial uses of that surface water. In some cases it might even be argued that in those times, additional depletions are desirable, since it would mean capturing more water in the groundwater basin without the undesirable effects on the surface water flows.

Unfortunately for groundwater managers, in most settings it is difficult to change the condition of groundwater in a way that would quickly turn on or turn off additional depletions. Accordingly, we propose that for SGMA compliance purposes, ***the default assumption is that any depletions of surface water beyond the level of depletion that occurred prior to 2015, as evidenced by reduction in groundwater levels, represent depletions that do impact beneficial uses***. If a responsible party believes that their increased depletions do not impact the beneficial uses of surface water, then evidence to the contrary should be presented. For instance, a GSA might be compelled to operate their basin in a way that would induce more inflow from surface water (or reduce outflow to surface water), recognizing that in some periods there is unallocated flow in the stream that is hydraulically connected to their basin. In such a case, where a GSA chooses to operate in a way that depletes surface flows when unallocated flows are available in connected streams, ***the GSA should provide convincing evidence that their additional depletions are less than the unallocated flows in the connected stream and that their depletions only occur during periods when the unallocated flows are available—or that they effectively mitigate for any impacts to flows that occur outside the period.***

Simplifying assumptions about "significant and unreasonable"

The significant and unreasonable clause in SGMA, like many other aspects of California water law and practice, introduces a number of challenges. How do we define what is significant and unreasonable? Also, with respect to the baseline condition for SGMA implementation, how do we assess whether or not significant and unreasonable depletions were occurring prior to January 1, 2015, in order to begin assessing whether or not further depletions, since that time, are significant and unreasonable?

According to fundamental principles of groundwater physics, all water pumped from groundwater comes from one of four sources: 1) a reduction of storage in the aquifer, 2) a reduction in connected surface flows out of a basin, 3) an increase in recharge that was previously rejected because of groundwater levels near the land surface, or 4) a reduction in other losses from the aquifer, such as water use by local wetlands, including phreatophytic vegetation. In the early days of groundwater development in California, some of the groundwater depletions in these basins would certainly have reduced the "rejected recharge" that occurred during storms by lowering groundwater levels so that there was less surface runoff due to saturated groundwater conditions near the soil surface. Similarly, we know that large areas of wetlands that flourished with high groundwater levels in the Central Valley (and elsewhere in California) have been lost due to declining groundwater levels, along with other factors.

However, in many, if not most, of the high and medium priority groundwater basins (the level of pumping is a significant factor in the prioritization of basins under SGMA), groundwater levels have dropped notably from pre-development levels. In most areas of the Central Valley, lowered groundwater levels have long since led to less inflow from groundwater to streams and rivers or, in areas where levels are lower than stream levels, direct depletion of surface flows. Even where early pumping was supplied from reduced storage in the affected aquifer, the cumulative pumping of many wells over many years has resulted in widespread lowering of water levels. Those lower water


Big Springs Creek, located in the Shasta Valley approximately 16 miles north of Mount Shasta, is a tributary of the Shasta River.

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levels—in most locations—have propagated to the vicinity of streams, with the cumulative effect of the pumping resulting in significant depletion of surface flows. In such cases, and assuming there is still connection between groundwater and the stream, any additional pumping will eventually result in further depletion of the surface flows unless deliberate actions are taken to avoid the propagation of the impacts of such additional pumping to the vicinity of the stream (such deliberate actions may include managed aquifer recharge programs or targeted pumping reductions at other times or places). In addition to being supported by an intuitive interpretation of fundamental groundwater principles, these assertions are clearly documented by the Department of Water Resources' (DWR) C2VSim model of the Central Valley (Brush and Dogrul, 2013) and the USGS's Central Valley Hydrologic Model (CVHM; Faunt and others, 2009)—our best holistic pictures of the groundwater-surface water conditions in the Central Valley, except where more detailed models have been developed by local agencies.

In high and medium priority basins beyond the Central Valley, given that the level of pumping is a significant factor in determining a basin's priority under SGMA, it is likely that, for most cases, additional pumping will eventually result in further depletion of surface flows, absent corrective actions. Local conditions, however, may vary widely, and accordingly, more detailed local analyses are necessary to assess if local conditions match the general conditions described here.

Given these prevailing conditions, it is reasonable to start with the assumption that where surface waters are hydraulically connected to groundwater, significant depletion of surface waters are already occurring due to groundwater pumping. In line with these prevailing conditions, our recommended approach for addressing the question of whether depletions beyond the levels that occurred prior to January 1, 2015 are significant and unreasonable in routine SGMA implementation is to ***manage for no further depletion of surface flows, beyond the level of depletion that occurred prior to 2015 by monitoring regional groundwater levels in the vicinity of the stream***. Practically, this is equivalent to saying, if measurements and/or modeling suggests that depletions are occurring beyond pre-2015 conditions, then it is likely that those depletions are significant and unreasonable.

That said, it is important to consider that other management changes have occurred that could affect the aquifer water balance and therefore the amount of depletion of surface flows. Perhaps most notably, irrigation with surface water has undoubtedly increased groundwater recharge in large parts of the Central Valley (and other parts of California). In other places, recharge may have been increased by other means, including deliberate managed recharge through spreading basins. This increased recharge has, no doubt, resulted in higher groundwater levels than would have occurred without the additional recharge. In fact, some groundwater banking programs track this excess recharge and rigorously manage and account for the additional groundwater accrued from the recharge. In some cases, it is possible that the effect of additional recharge in balance with groundwater pumping has resulted in a net increase in groundwater stored, a corresponding raising of groundwater levels, and possibly increased the baseflow to surface water (the opposite of stream depletion).

Accordingly, a GSA may consider offsetting additional pumping through managed aquifer recharge (MAR), e.g., farm MAR, aquifer storage and recovery (ASR), and flood MAR, as a general strategy to offset additional pumping. As with pumping, the effect of recharge on increasing baseflow is subject to strong temporal dynamics. Excess stream flow may be available during and after storm events or in conjunction with reservoir reoperation for diversion to MAR operations. That recharge would, at some later time (weeks or months later), reduce stream depletion (or increase groundwater discharge to streams), given the right circumstances. With proactive recharge programs like these, a GSA can accommodate a wide range of future pumping scenarios, while avoiding depletion of surface flows beyond pre-2015 levels.

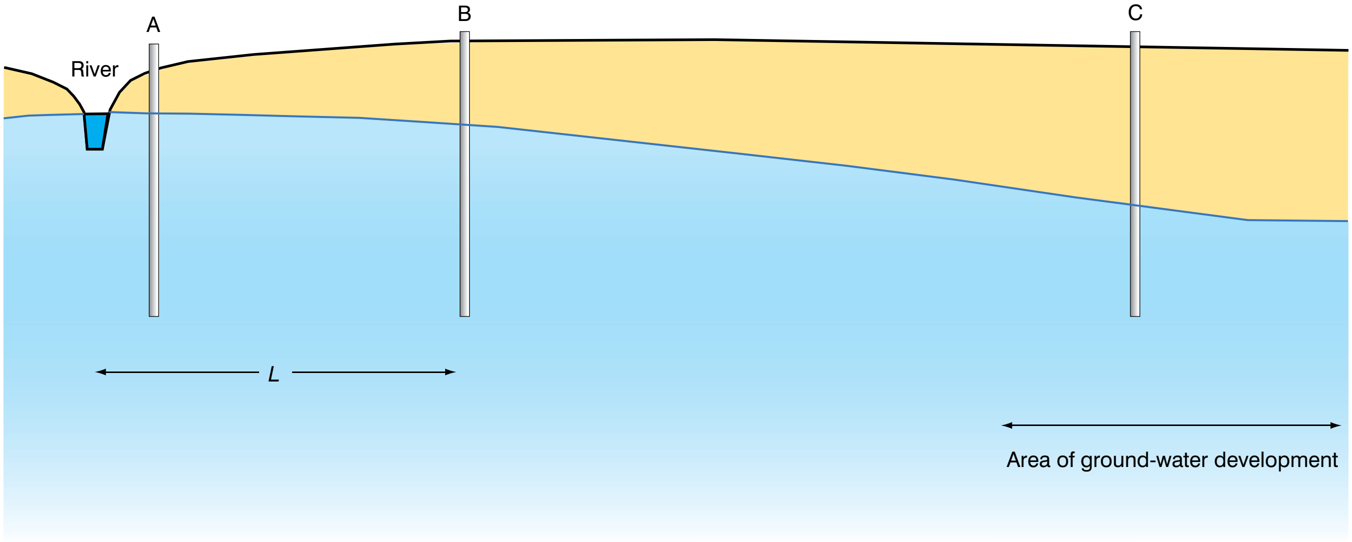
Approach for addressing surface water depletions

The rationale for our recommended method starts with the basic principle, as summarized above, that the exchange of water between an aquifer and hydraulically connected surface waters is determined by the gradient across the boundary between the stream and the aquifer. Of course, the actual volume of the exchange is highly dependent on the physical properties of the streambed and aquifer materials. However, these properties are highly variable from place to place, often varying over orders of magnitude over short distances, and are notoriously difficult to accurately characterize. The characteristics of the aquifer and stream-bed materials are also relatively constant—that is, they change little over the time scales relevant to water management.

Over the timeframes relevant to SGMA, change in the hydraulic gradient between stream and the surrounding groundwater is the primary variable driving water exchange between the aquifer and the connected surface waters. Therefore, if you manage the gradient, you manage the exchange.

FIGURE 2

Potential water-level monitoring locations relative to a stream or river and an area of groundwater development



Location A is along the river bank, or perhaps no more than a few thousand feet from the river. Location B is intermediate between the river and the area of groundwater development, and location C is within or near the area of groundwater development (pumping).

Therefore, to comply with the basic requirements of SGMA, we propose that the GSA only needs to demonstrate that the gradient between the aquifer and the stream is not steeper in a downward direction away from the stream than it was prior to 2015, which can be accomplished by monitoring and managing regional groundwater levels. As a result, we propose that the GSA establish, based on the best available information or modeling, the regional groundwater levels near any interconnected surface stream as of January 1, 2015, accounting, of course, for seasonal and inter-annual variability, and then set these levels as the threshold levels to be maintained by the management plan.

This approach does present some complications that will need to be addressed, such as where, relative to the stream, does a GSA measure the reference groundwater levels, and how does a GSA establish threshold groundwater elevations? We propose below some general guidance, along with some explanation and rationale, on how to address these issues. We anticipate that the details of this guidance can be improved with input from other stakeholders, and we anticipate refining them over the coming months upon discussion and testing with thoughtful partners (Cantor, A., et al., 2018).

What is the appropriate distance from the river, for monitoring?

In a system with a stream or river connected to a developed aquifer, consider potential water-level monitor locations A, B, and C, as shown in Figure 2. Location A is along the river bank, or perhaps no more than a few thousand feet from the river. Location B is intermediate between the river and the area of groundwater development, and location C is within or near the area of groundwater development (pumping). The following sections describe some implications of using water levels at these locations to indicate streamflow.

Location A

Near the river, groundwater levels are controlled by the elevation of the connected surface water. Currell (2016) argues that drawdown triggers here are misguided. Harrington et al. (2017) agrees but makes the point that drawdown triggers more distant from the river can be useful. Small decreases in water levels in this area could be related to groundwater pumping, but changes in river stage would affect groundwater levels here as well. Large changes in water levels here would occur only with major streamflow depletion that caused the river to become disconnected from the aquifer. To indicate incipient streamflow depletion, therefore, water-level measurements in this zone, which for purposes here is estimated to be between 0 and 2000 feet for most Central Valley conditions, are not useful.

Location B

In the area that is intermediate between the river and groundwater pumping centers, declines in water levels could indicate current and future streamflow depletion. Water levels with no long-term trends could indicate either (a) the system is at steady state and all of the pumped water is being supplied by streamflow depletion, or (b) the cone of depression from the pumping center has not yet reached this part of the groundwater system. In either case, no immediate increase in streamflow depletion is occurring, but in the case of (b), streamflow depletion will increase in the future. Increases in pumping will increase future streamflow depletion in either case. Location B should be beyond immediate influences of the river stage.

Groundwater flow models could be used to determine optimal distance L for monitoring water levels and a model could give insight into what a water-level change at a given location might mean in terms of current and future streamflow depletion (Harrington et al., 2017). In areas where local groundwater flow models are not available, regional groundwater flow models such as the Central Valley Hydrologic Model (Faunt, 2009) or C2VSim could be used. Alternatively, low-cost local superposition models could be constructed using aquifer and river geometry and aquifer properties derived from regional groundwater flow models or other sources. In actual practice, water-levels can only be evaluated where data exist. If water-level data are not available at optimal locations, data from sub-optimal locations may need to be used. In that case, models will especially be useful in relating changes in water levels at sub-optimal locations to expected corresponding streamflow depletion. Finally, in areas where no water levels exist, local or regional models must be relied upon to give insight to water levels and expected streamflow depletions. Models also will be helpful in planning locations of wells for future groundwater-level monitoring.

Location C

Evaluation of long-term water-level trends in the pumped area could help determine whether or not the system is in an approximate steady-state condition. With no current changes in water levels here, the system is in steady-state and pumped water is being supplied by streamflow depletion. If water-level trends are downwards, the system is not in steady-state and future increased streamflow depletion can be expected to occur.

How do we estimate threshold levels in absence of water-level measurements?

In some locations, existing monitoring wells may be available that are located appropriately to inform selection of ISW threshold levels, and perhaps these wells may also serve as ongoing monitoring wells for ISW compliance monitoring. However, these conditions are by far the exception. ***In the majority of situations, suitable monitoring wells do not currently exist, and little measured data is available to suggest what threshold levels should be.*** In these cases, the best available information (BAI) should be used to set initial target levels. This BAI may be from a regional groundwater model, such as the most recent versions of the DWR's C2VSim or USGS's CVHM in the Central Valley, or in some cases local agencies may have developed a more refined model for their local area. In the absence of local information or a detailed local model, we recommend that the most recent version of C2VSim or CVHM be used to define interim threshold levels at appropriate locations. These interim threshold levels would then be used to guide the management plan actions necessary to maintain compliance with the ISW provisions of SGMA. In most situations, these management prescriptions will be determined through traditional baseline and scenario modeling processes.

How do we address seasonal and inter-annual variability?

It is reasonable to assume that the pre-2015 levels in these threshold bands varied through time, likely with a significant annual cycle. Accordingly, threshold levels for compliance should be defined in a way that reflects that cycle—including seasonal thresholds as well as inter-annual thresholds that reflect how levels have historically behaved during dry and wet periods—again, using the best available information (DWR, 2016).

It is also important to recognize that the years immediately preceding 2015 were some of the driest on record. Accordingly, groundwater levels were likely unusually low due to limited surface water availability and/or heavier reliance on groundwater pumping during the drought period. Therefore, the levels during this drought period, or estimates of the levels, should be considered the low point in a wet-dry year cycle and should be adopted as the bottom of the allowable range.

Modeling of historic conditions with the best available information in the years leading up to 2015 could be used to establish a target operating range, at an appropriate level above the drought conditions, as well as a low-low threshold that allows for lower levels.

How dense, laterally along the stream, should ISW threshold locations be defined?

For GSAs with multiple pumped areas, or pumped areas that are extended parallel to the river, multiple monitoring locations should be used. As a starting point for Central Valley basins, a monitoring location every 4 to 6 miles along the stream is probably a reasonable balance between rigor and practicality. For example, it would not be unreasonable for a groundwater sub-basin in the Central Valley to have 50 miles of perennial stream traversing or bounding their basin. At 5-mile spacing, this would be 10 monitoring points. However, the actual number of monitoring wells should be determined by the GSA based on basin specific conditions.

The Russian River is California's second largest river, passing through Mendocino and Sonoma counties before flowing into the Pacific Ocean.

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Long-term monitoring and adjustment of targets

As early as possible, monitoring wells should be installed to detect changes in groundwater elevations at appropriate distances from the stream based on local hydrogeologic conditions and the guidance provided above. Then, as monitoring and modeling analyses progress and the system behavior is better understood, the threshold levels might reasonably be adjusted, in addition to accompanying changes in management prescriptions to maintain groundwater above the threshold levels.

The consideration of wet-dry cycles and seasonal variation should also be incorporated into how the adjustments of threshold levels are made once the GSA begins obtaining real groundwater level measurements at the newly established ISW monitoring wells. For instance, if the newly measured levels are 10 feet higher than originally estimated from the BAI, then a model hydrograph, using the most up-to-date calibrated model, should be used to establish a new range.

Another situation might emerge where some specific recent changes in management cause a change in groundwater levels in the zone surrounding an ISW threshold monitoring point. Say, for instance, a new conjunctive use program has been implemented. In such a case, the GSA should model the program and assess the program's impact on the water levels and appropriately incorporate this understanding into setting threshold levels and perhaps selecting adjusted threshold monitoring locations.

The special case of near-stream pumping wells

Near-stream pumping wells may be particularly problematic from the perspective of stream depletion management. Such wells may approach a nearly direct depletion of stream flow, and may do so with relatively little drawdown. The approach proposed here is intended to address regional drawdown of groundwater levels from dispersed pumping centers and does not account for the special impacts from and behaviors of near-stream pumping wells. Such near-stream wells will require special consideration by the GSAs as to their compliance with UR#6.

Summary recommendations regarding monitoring locations

Based on the above discussion, we offer the following general guidelines for selecting monitoring locations:

1. Monitoring locations on or within approximately 2000 feet of a river bank (Figure 2, Location A) should be avoided.

2. Monitoring locations within a regional pumping center (Figure 2, Location C) may be useful to determine whether or not the storage change in that portion of the aquifer is near zero. That condition would not, however, guarantee that the cone of depression was not propagating outward to the river at that time. These monitoring locations would not be optimal for determining compliance with UR#6.

3. Water levels between a river and a pumping center (Figure 2, Location B) would be best for determination of ISW compliance with SGMA. Stable water levels at these locations indicate that no additional significant streamflow depletion is occurring. Continued monitoring will inform the likelihood of future depletions. Groundwater models may be useful in determining the optimal distance (L) from monitoring wells to the stream (Figure 2).

4. At least one monitoring location between a river and a regional pumping center would be needed, but more locations in the direction parallel to the river would be required for GSAs with multiple pumped areas or with pumped areas that extend parallel to the river. A monitoring location every 4 to 6 miles along the stream is probably a reasonable balance between rigor and practicality.

5. Determination of threshold water levels should consider inter- and intra-annual water level variations driven by climate and pumping variations, considering a multi-year period prior to 2015.

Integrating the recommended approach with DWR regulations

DWR regulations require an estimate of the quantity and timing of surface water depletions, using the best available information. This quantification is an important part of a water balance and is a helpful estimation for management and stakeholder information purposes. However, the methods for estimating the actual volume, and even more so the timing, of depletions are notoriously inaccurate, except in the most unusual of circumstances. Accordingly, our recommendation is to use a groundwater level minimum threshold, as described above, as a surrogate for the rate or volume minimum thresholds, as currently called for in the regulations for Undesirable Result No. 6, section 354.28(c)(6).

We believe that our approach also has an additional benefit: groundwater managers are already familiar with the practice of managing water levels, and most communication about groundwater conditions and groundwater management tends to be about water levels. Groundwater levels are fairly easily conveyed in maps and figures, and less technically-inclined stakeholders in the process tend to understand groundwater levels and intuitively grasp the relationships between groundwater levels and other management activities, like pumping and recharge.

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