

Accounting for Climate Change and Drought in Implementing Sustainable Groundwater Management

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Abstract Groundwater provides close to 40% of California’s overall water supply under average hydrologic conditions. It is a critical source of backup during drought when increased pumping occurs to compensate for reduced surface supplies and decreased soil moisture. The conundrum is that in regions of the state where groundwater dependence is already high and rates of recharge are low, over the long term the volume withdrawn, particularly during droughts, generally exceeds replenishment in many regions. The result is overdraft - ongoing declines in groundwater levels over the long-term. To facilitate the reduction or cessation of long-term groundwater overdraft, this paper proposes that sustainable groundwater management must include the development of a drought reserve. The reserve, ideally sourced, sited and used locally, would encompass sufficient water for use during a drought such that the increased withdrawals during a drought do not result in unrecoverable groundwater declines and concomitant negative impacts. The objective is to reduce vulnerability to the state’s periodic droughts, as opposed to mitigating seasonal variations in precipitation. This paper first summarizes the issues associated with developing drought reserves, and then examines in detail how two California groundwater management agencies approach establishing and implementing a drought reserve.

Keywords Groundwater · Drought · Drought reserve · California

1 Introduction

Groundwater provides approximately 40% of California’s overall water supply under average hydrologic conditions (California Department of Water Resources (DWR) 2015). It is a critical source of backup during drought when increased pumping occurs to compensate for reduced

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surface supplies and decreased soil moisture (Alley et al. 1999; Bartolone 2014; DWR 2015). The conundrum is that in regions of the state where groundwater dependence is already high and rates of recharge are low, over the long term the volume withdrawn, particularly during droughts, generally exceeded replenishment in many regions. The result was overdraft - ongoing declines in groundwater levels over the long-term (Famiglietti et al. 2011, Scanlon et al. 2012, LAO 2014, DWR 2015). Higher temperatures and the potential for more extreme droughts predicted under climate change will exacerbate these declines and associated impacts (Faunt et al. 2009, IPCC 2013). Since 2010, some areas of the state already see “alarming declines in groundwater levels,” with concomitant negative impacts including irreversible land subsidence and seawater intrusion, reduced surface flows and the permanent loss of capacity to store water as groundwater (DWR 2014, 2015).

To facilitate the reduction or cessation of long-term groundwater overdraft, the author proposes that sustainable groundwater management must include the development of a drought buffer, e.g. a drought reserve (Langridge 2012; Rudestam and Langridge 2013; Langridge et al. 2012). Ideally, a drought reserve would be sourced, sited and used locally, and would encompass sufficient water for use during a drought such that the increased withdrawals during a drought do not result in unrecoverable groundwater declines and associated negative impacts.

The traditional approach to drought management is reactive, typically waiting until a drought is already in progress to monitor weather conditions and implement water shortage contingency plans. A groundwater reserve can clearly increase resilience to drought. Many scholars and practitioners discuss the role of groundwater during drought and the need for proactive mitigation (Wilhite 1993; Walker et al. 1991; Dinar 2001; Wilhite 2014), yet there are limited examples to guide how to establish and maintain a drought reserve. This paper first summarizes the issues associated with developing drought reserves, and then examines in detail how two California groundwater management agencies are approaching the establishment and maintenance of a drought reserve.

To reduce vulnerability to the state’s periodic droughts and the more extreme droughts predicted under climate change, and achieve drought protection requires:

1. A definition of unacceptable impacts of overdraft in a basin
2. Development of a basin’s water budget that provides for groundwater levels that will avoid unacceptable overdraft impacts under normal climatic conditions
3. Calculation of an additional “drought reserve” needed to avoid exacerbated declines in groundwater levels during a prolonged drought when withdrawals increase, and where levels have historically failed to recover over the long term
4. Development of a management approach to a) reduce and eventually halt overdraft, b) recover groundwater levels to avoid future unrecoverable declines during a drought, and c) develop and sustain the drought reserve.

While California has no permit requirement for withdrawals, the recent passage of the 2014 Sustainable Groundwater Management Act (SGMA) (AB 1739, SB 1168, SB 1319) now requires actions for sustainable management of groundwater basins designated by the California Statewide Groundwater Elevation Monitoring System (CASGEM: SBx7-6, AB 1152, 2017) as high or medium priority. The SGMA defines sustainable management as: “The management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results”. Undesirable results are

defined as one or more of the following effects caused by groundwater conditions occurring throughout the basin: chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply; significant and unreasonable reduction of groundwater storage; significant and unreasonable seawater intrusion; significant and unreasonable degraded water quality; significant and unreasonable land subsidence; depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of surface water (California Water Code 2014).

A major issue is that while the SGMA requires “basin stabilization,” and promotes “management of regional water resources for regional self-sufficiency and drought resilience,” there are no specific requirements or incentives to recover levels or to establish drought reserves, only that full recovery of a groundwater system may be possible. Moreover, the baseline for sustainable management is a groundwater level existing when the law was passed in 2014, failing to account for the already serious groundwater level declines in many areas of the state at that time.

In May 2015, the State Water Resources Control Board (SWRCB) adopted an emergency regulation addressing drought vulnerability that required an immediate 25% reduction in overall potable urban water use that incorporated a sliding scale for setting conservation standards for 411 water districts. In May 2016, the SWRCB eliminated these mandatory standards for 379 districts, allowing them to now temporarily set their own conservation standards through January 2017 (SWRCB 2016). However a district currently only has to self-report that it has a sufficient supply available to prevent shortages during a three-year drought, as opposed to a supply sufficient to support the development of a long-term drought reserve. Moreover, the role of groundwater in calculating the voluntary standards is not clarified, and agriculture water users are not included.

2 Definition and Calculation Issues

A metric to determine the amount of groundwater that can be pumped from a basin to balance inflows and outflows and avoid long-term groundwater declines is the sustainable yield of the basin. While the earlier concept of safe yield emphasized aquifer dynamics (Bredehoeft 1997; Kalf and Woolley 2005), sustainable yield also incorporates societal inputs regarding both unacceptable impacts and the goals for management of a groundwater basin (Alley and Leake 2004; Gleeson et al. 2012; Rudestam and Langridge 2013). Key issues are that both determining a water budget and calculating the sustainable yield of a basin are complex and challenging processes that can require modeling studies and fieldwork, along with a definition of unacceptable impacts from pumping (Rudestam and Langridge 2013). This complexity can be seen by the lack of a definition of, and technical agreement about, the safe/sustainable yield in many adjudicated groundwater basins in California where quantification is generally required pursuant to a court decree (Langridge et al. 2016), as well as in non-adjudicated basins where water managers frequently attempt to quantify the sustainable yield.

One goal of sustainable groundwater management is to establish the protective groundwater levels necessary to avoid defined unacceptable impacts during normal climatic conditions. These protective levels are often averaged over a reasonable time period to try to accommodate California’s annual variability in precipitation. But to avoid declining groundwater levels that can be significant during a prolonged and/or intensive drought, and that are not likely to recover over the long term, it is also necessary to calculate the amount needed for a drought

reserve. To do this, it is first necessary to specify the degree of drought risk. Combining a range of drought lengths in years together with a range of drought intensities can provide metrics for potential target droughts. Additionally, the identification of past historical droughts can be used to determine risk for a specific location. The effect of future climate change on any increase in drought severity or frequency of a similar future drought also needs to be considered.

Water managers also need to estimate water supply shortfall under a range of potential droughts. This includes estimating the depth to which groundwater can be withdrawn without unacceptable impacts, multiplied by aquifer volume to that depth and the aquifer's specific yield. Calculation of the specific yield can illuminate how much water can actually be extracted without unacceptable impacts. Additionally, water demands during a drought generally increase, but some water usage curtailment may also be instituted. Subtracting anticipated water demands during a drought from likely supplies provides the shortfall for specified drought years. The sum of these shortfalls across the duration of the target drought provides the total drought water shortfall. A drought reserve would need to accommodate this quantity to protect against unacceptable impacts for a specified target drought.

3 Establishing a Drought Buffer –Case Studies

Two California water districts illustrate different approaches to groundwater management that include consideration of a drought reserve. The Goleta Water District (GWD) incorporates drought protection as a component of the sustainable management of its groundwater basin. The parameters of a drought reserve are defined for the Soquel Creek Water District (SqCWD), which is currently exploring a number of options to avoid seawater intrusion into its water supply.

3.1 Goleta Water District

The Goleta Groundwater Basin, located along California's south-central coast, is an alluvial plain about eight miles long and three miles wide with southeastern foothills that are over 500 ft above sea level - Fig. 1.

Annual average rainfall within the basin ranges from about 16 in. at the coast to about 20 in. in the foothills of the Santa Ynez Mountains. Surface drainage is to the south where several creeks empty into the ocean (Santa Barbara County Groundwater Report, 2011).

Shallow wells were drilled in the Goleta Groundwater Basin as early as 1890. By the late 1930s, deeper wells were being used to develop fruit and nut orchards and groundwater use was estimated to be approximately 3000–6000 AFY (Upson 1951).¹ Urbanization gradually replaced agriculture, and public water producers became a larger factor in groundwater withdrawals. In 1944, the Goleta Water District (GWD) was formed to provide water to the Goleta Valley. Covering 29,000 acres, the GWD relied solely on local groundwater until the U.S. Bureau of Reclamation's Federal Cachuma Project on the Santa Ynez River began making water deliveries in 1955. By 1970, rapid population growth in the valley and a long-term drought from 1940 to 1970 had reduced water supplies. The GWD adopted several ordinances to restrict water use, including Ordinance 72–2 in 1973 that began a moratorium on new water service connections (Bachman 2010).

¹ 3,699,000–7,398,000 cubic meters (1000 Acre Feet =1,233,000 cubic meters)

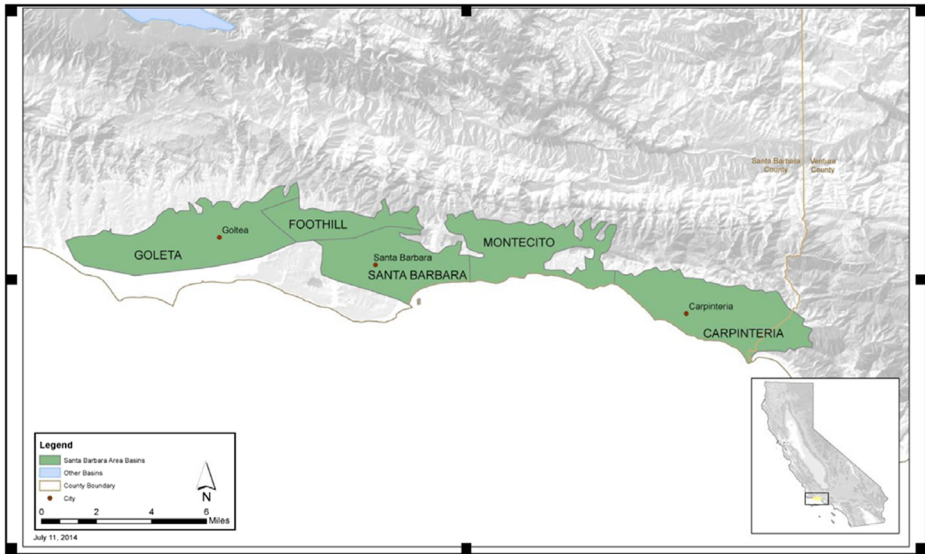


Fig. 1 Goleta groundwater basin (RMC water and environment 2014)

In 1973 a group of overlying landowners in the North-Central basin sued the GWD to adjudicate water rights in the north-central part of the groundwater basin (Wright et al., 1989). After an initial determination by the trial court of both water rights in the basin and the basin's safe yield, the appellate court reversed and remanded the initial judgment back to the trial court, who issued its revised judgment in 1989. Importantly, the GWD was provided with storage and recovery rights in the basin.

However, groundwater withdrawals continued while the adjudication was going on, and the drought in the 1980s and early 1990s resulted in water supplies for Santa Barbara County's south coast reaching a critically low level. The GWD had to rely more heavily on groundwater to supply its customers, and groundwater elevations reached historically low levels.

In response to concerns about the groundwater overdraft and the future of its water supplies, in 1991 GWD customers, in a close vote, approved the Safe Water Supplies Ordinance (SAFE) (amended in 1994). SAFE authorizes the importation of State Water Project (SWP) water, but specifies that the water be initially used to replenish the basin (4500 AFY)² and to establish a drought buffer (an additional 2500 AFY).³ The buffer can only be used for delivery to existing customers when a regional drought results in a reduction in GWD deliveries from Lake Cachuma. Once the basin is recovered to 1972 levels and all other obligations for water delivery are met, the GWD can again provide new service connections up to 1 % of the total potable water supply. But notably, when a new service is connected, the annual storage commitment made to the drought buffer is required to permanently increase by two thirds of any release for new or additional uses "so that safe water supplies in times of drought shall not be endangered by any new or additional demands." Thus, under SAFE, the GWD can pump its stored water only when groundwater elevations in the basins are above 1972 levels or when a regional drought results in a reduction in the GWD's annual surface water deliveries (SAFE

² 5,548,500 cubic meters

³ 3,082,500 cubic meters

Ordinances No. 91–0, 94–03 2017), and, the drought buffer is defined not by the amount of stored water, but by the increase in groundwater elevations.

The GWD's management approach is to carefully monitor the basin in collaboration with the USGS, and use Basin Management Objectives (BMO) to set quantitative groundwater level targets at the lowest measured historical static non-pumping groundwater elevation in each BMO well. When groundwater elevations fall below this target, they do not meet the BMO. This criteria was based on the observation that a groundwater elevation that low in the well in the past did not harm the basin, but a groundwater elevation below that BMO could create potential unacceptable impacts (Bachman 2011).⁴

The results are positive. Beginning in the 1990s, basin pumping declined largely due to the Wright Judgment and the SAFE Ordinance, and in 2008 water levels were near the highest levels recorded in the basin. The value of the drought buffer was especially apparent during the 2012–2015 drought. While many groundwater basins in the state saw a significant decline in groundwater levels (DWR 2015), in 2014, Goleta basin levels remained relatively stable. In 2015, a 16% reduction in GWD's projected 12-month supply after 3 yrs. of drought as well as the new state emergency regulations resulted in GWD instituting water use restrictions that first required 25% cutbacks in water use, that were then increased to 35%. Additionally, to comply with the SAFE Ordinance, approvals of any additional potable water connections were prohibited because water delivery from Lake Cachuma was below 100%. In 2015, despite 2014 and 2015 SWP deliveries of only 5% and 20% of contracted water respectively, and Lake Cachuma only providing 45% of its normal deliveries, GWD's groundwater wells were able to provide over 50% of their water deliveries, made possible because of the ongoing investment in its reserves (Goleta Water District 2015).

Today, the District provides water to more than 16,600 municipal and industrial user accounts and 165 agricultural accounts. Water supplies include local surface water from Lake Cachuma (~76%), SWP water (~16%), recycled water (6%) and basin groundwater (2%). The proportion of each of these supplies has varied over time, with SWP water used more recently in lieu of groundwater.

One question is whether GWD should maintain groundwater elevations above or only slightly above 1972 levels during non-drought periods to enhance drought protection for customers. This would result in more costly and less reliable SWP water being used in lieu of groundwater to serve existing and potentially new customers. Modeling studies suggest that maintaining the buffer would be particularly valuable in a long-term drought (Bachman 2011).⁵

3.2 Soquel Creek Water District

The Soquel Creek Water District (SqCWD), Fig. 2, is located along California's central coast, and it serves a residential community that is wholly dependent on groundwater.

The SqCWD's sole water source is the Soquel-Aptos groundwater basin that it shares with other pumpers including the City of Santa Cruz, Central Water District, small mutual water companies, and private well owners. The shared groundwater basin is currently in a

⁴ Bachman points to a range of groundwater elevations, depending on assumptions, over which the basin should be managed to avoid impacts when elevations rise too high or fall too low (Bachman 2011).

⁵ The modeling studies showed that when the 1986–1991 drought was extended by two years the drought buffer is only partially used, however it is utilized considerably at higher levels of water demand during a longer drought.

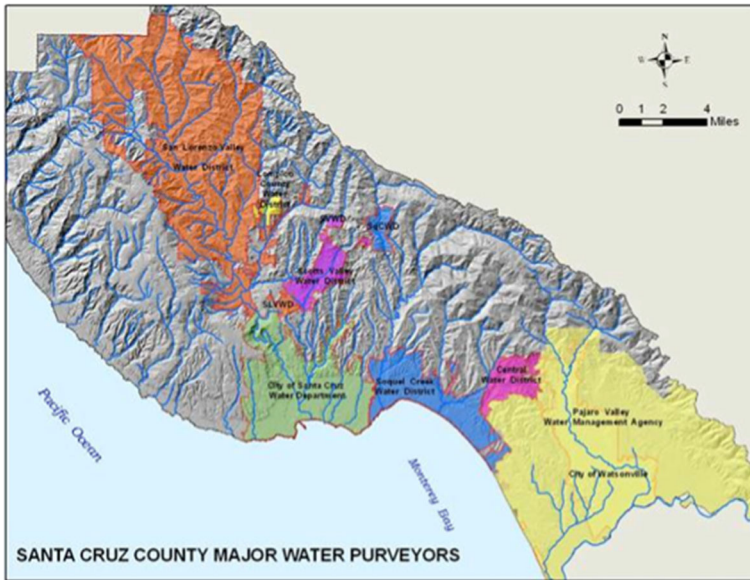


Fig. 2 Soquel creek water district. (<http://www.soquelcreekwater.org/who-we-are/facts-figures-and-maps>)

state of overdraft, with more water being extracted than is naturally replenished by rainfall. While short drought cycles have a minimal affect on SqCWD supplies, there is almost no groundwater recharge when annual precipitation drops below about 20 in./year (SqCWD UWMP 2005).

Long-term overdraft of the basin has led to an ongoing risk of seawater intrusion, already detected in 2014 at the SqCWD's coastline. In water year 2014, coastal groundwater levels in seven out of thirteen SqCWD and City of Santa Cruz monitoring wells screened in productive units remained below elevations that protect the aquifers from seawater intrusion. Recovery of the basin and overdraft requires pumping to be reduced so that coastal groundwater levels can rise to protective elevations at all coastal wells. If left unresolved, seawater will contaminate the district's groundwater wells and make them unusable to produce drinking water (Hydrometrics, 2014a, b).

To prevent cutting too deeply into groundwater supplies during a drought, SqCWD activates a percent reduction in usage, a characteristic response by most water agencies in the state to mitigate a drought. (SqCWD UWMP 2005:53). But to recover groundwater levels to protective elevations, SqCWD and other pumpers need to reduce pumping below the long-term sustainable yield. Additional supplies and the creation of a safety buffer for a drought reserve would also reduce the possibility of seawater intrusion during a severe drought.

The SqCWD has defined its assumptions regarding its "sustainable yield" as well as the additional buffer/reserve required to account for increased pumping during a drought. The quantity was specified as enough water for three years of drought, water demand calculated for future 2050 population growth, an expectation of a 15% drought curtailment of demand, and with just 4800 AF of a "sustainable" yield groundwater supply (excluding additional alternate supplies such as desalinated water). The "safe storage" and the reserve storage are both specified with respect to the groundwater levels needed to block any further inland seawater

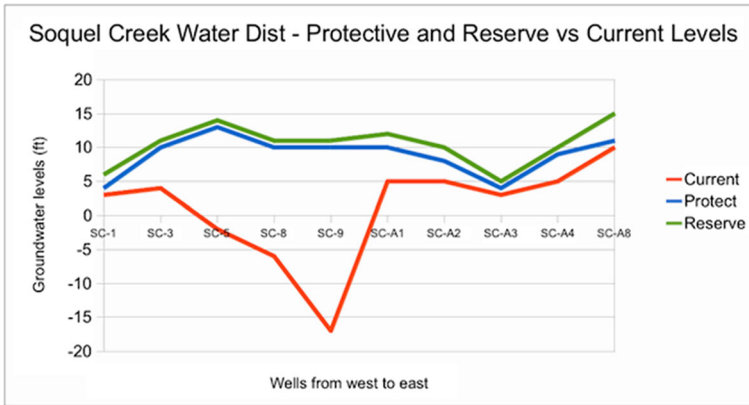


Fig. 3 SqCWD protective and reserve vs. current Levels. Source: data from soquel creek water district 2009. These groundwater level metrics can also be converted into values of acre-feet of storage in the aquifer

intrusion at the shoreline monitoring wells. This is illustrated in Fig. 3 based on 2009 data from the SqCWD, and Fig. 4 based on data from the 2013 SqCWD Groundwater Management Annual Report.

The largest obstacle to establishing a drought reserve for SqCWD is the need to first eliminate overdraft in the aquifers. Heightened public awareness about the importance of water conservation contributed to five years of low groundwater production beginning in 2009 and to significant conservation during the 2012–2015 drought, but coastal groundwater levels remain below elevations that can protect the aquifers from seawater intrusion. Based on



Fig. 4 Current levels vs. protective elevations (Hydrometrics 2015)

SqCWD's current pumping plans, the estimated time to eliminate an accumulated pumping deficit and recover the basin is 20 years (Hydrometrics 2014).

In 2015, SqCWD joined the City of Santa Cruz, the Central Water District, and the County of Santa Cruz to form the Santa Cruz Mid-County Groundwater Agency (MGA) with the intention that it would become the Groundwater Sustainability Agency (GSA) under SGMA for the basin. Both SqCWD and the adjacent City of Santa Cruz do not import any water and rely almost entirely on local water supplies. Both are vulnerable to multi-year droughts. Several alternatives are being considered to reduce drought vulnerability in the region including a collaborative project between the City of Santa Cruz and the SqCWD that would serve to develop a drought reserve for both areas. The City of Santa Cruz is dependent on local surface water for supply. It generally has a surplus during wet years and is extremely vulnerable to shortages during dry years. Santa Cruz would sell its surplus surface water to SqCWD during wet years. SqCWD would use the transferred water for active or in-lieu groundwater recharge enabling it to reduce the possibility of seawater intrusion and potentially develop a groundwater reserve. The reserve could be used by both entities during dry years when SqCWD could both tap into the reserve as needed as well as sell some of its groundwater to the City of Santa Cruz. A regional seawater desalination plant could similarly be used cooperatively to develop drought reserves. Water from the desalination plant during normal precipitation years would go to SqCWD in lieu of the SqCWD pumping groundwater. This would allow aquifers to recharge and build a drought reserve for use during a drought. During drought years the desalinated water would be fully utilized by Santa Cruz as its drought reserve.

4 Discussion

For most California regions either dependent on groundwater or where groundwater is a major component of the water supply system, local groundwater management emphasizes obtaining new supplies, generally from imported water, desalinated water, recycled water, or through water transfers. These new supplies are targeted in part to support water shortages during a drought and, where overdraft is present and normal rates of recharge are low, to recharge an aquifer through either direct or in-lieu processes. However, during normal and rainy cycles new supplies are often used for additional urban and agricultural development rather than to adequately recharge aquifers. The result is a need for increased water supplies during the next drought cycle, as well as a long-term failure to balance recharge and withdrawals and avoid groundwater levels trending down. Additionally, a common response to droughts is to drill more wells, a considerable investment that may actually lead to a permanent, unanticipated change in the level of groundwater development and exacerbate groundwater depletion (Alley et al. 1999).

The proposed local drought reserve also differs from current groundwater banking approaches that sell water to banking partners generally located outside of the groundwater bank and where the focus is often on seasonal and short-term storage. Additionally the banks are heavily reliant on imported water and frequently involve unsustainable energy-intensive transmission systems. This is in contrast to emphasizing the long-term sustainable management of a region's groundwater and its water supply system.

In contrast, Goleta illuminates how conjunctive management of groundwater and surface water resources can be utilized to successfully mitigate the impacts of a drought and sustain a local groundwater basin over the long term. The GWD serves as a model because not only did

the region prioritize the recovery of its groundwater basin after years of declining levels, but it also recognized the need for a local drought reserve to account for the additional pumping that generally occurs during a drought. The result is that the GWD entered the 2012–2015 drought with a healthier groundwater basin, stored SWP supplies, a full allocation of water from Lake Cachuma, and consistent recycled water use to offset potable water use. The SqCWD's groundwater reserves provided increased water supply security, and unlike its neighboring districts of Santa Barbara and Montecito, the agency was able to wait until the fall to set up mandatory water use restrictions. (Magnoli 2014; Goleta Water District 2014).

Recharging an overdrafted aquifer without imported water is challenging. The SqCWD took the important step of calculating protective groundwater levels required to prevent seawater intrusion, and the levels required to sustain a drought reserve were also approximated (Hydrometrics 2013). However, without an additional source of water, implementation of these levels has not occurred. The SqCWD's plan to partner with the Santa Cruz Water Department to provide a drought supply for both areas, does suggest one way a region without imported supplies can develop a drought reserve, and other types of partnerships may be possible. Further studies are needed to see whether recycled water, water transfers, and/or conservation and demand management, if used first to recover a basin and provide a drought reserve, will prove sufficient for the SqCWD.

Physical droughts are a regular occurrence in California. They are predicted to increase in frequency and intensity with climate change. Moreover, recent work by Ault et al. (2014) point to a potential under-estimation of the risk of a decade-scale mega-drought in the coming century. Yet drought planning in the state is primarily responsive, focusing on curtailing water use after a drought is declared. In general there are limited requirements to plan for an extreme drought event in planning documents such as Urban Water Management Plans and Integrated Regional Water Management Plans, and only minimal requirements to plan for the droughts experienced in the state on a regular basis. Moreover, in its review of the 1991 drought response, DWR expressed concern with the effects of demand hardening on water agencies' ability to implement shortage contingency measures in the future (DWR 2015).⁶ To provide proactive drought protection, long-term management plans can and should be required to assess and implement drought buffers that go beyond instituting conservation rules during drought events. Determining what is a sufficient reserve is challenging, including uncertainties associated with future predictions of inflow and outflows in a basin that are dependent in part on potential land use, population changes and climate change impacts. But the state must assure that this critical resource is an important backup source when needed during a drought.

SGMA now requires the formation of Groundwater Sustainability Agencies for DWR designated medium and high priority groundwater basins. These agencies have expanded authority, and they are now directed to develop sustainable groundwater management plans with measurable objectives to achieve groundwater sustainability within 20 years. They are subject to DWR review including the filing of annual data reports, all of which will help move the state towards more sustainable groundwater management. But still absent are specific requirements and incentives to plan and importantly to implement strategies that will proactively mitigate anticipated future, and potentially more extreme, droughts. The state does provide large amounts of imported water to many local areas as well as funding for water

⁶ Demand hardening refers to water agencies implementing programs for plumbing fixture retrofits programs or low water use fixtures. It becomes increasingly difficult for the agencies to implement additional future rationing programs and achieve measurable savings without affecting customers' lifestyles.

management projects. Conditions to receive imported water could include that the imported water be prioritized for the recovery of overdrafted basins and the establishment of drought reserves during normal or rainy periods, similar to Goleta's approach. Additionally, funding could include more specific requirements and incentives to establish drought reserves at the local level.

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