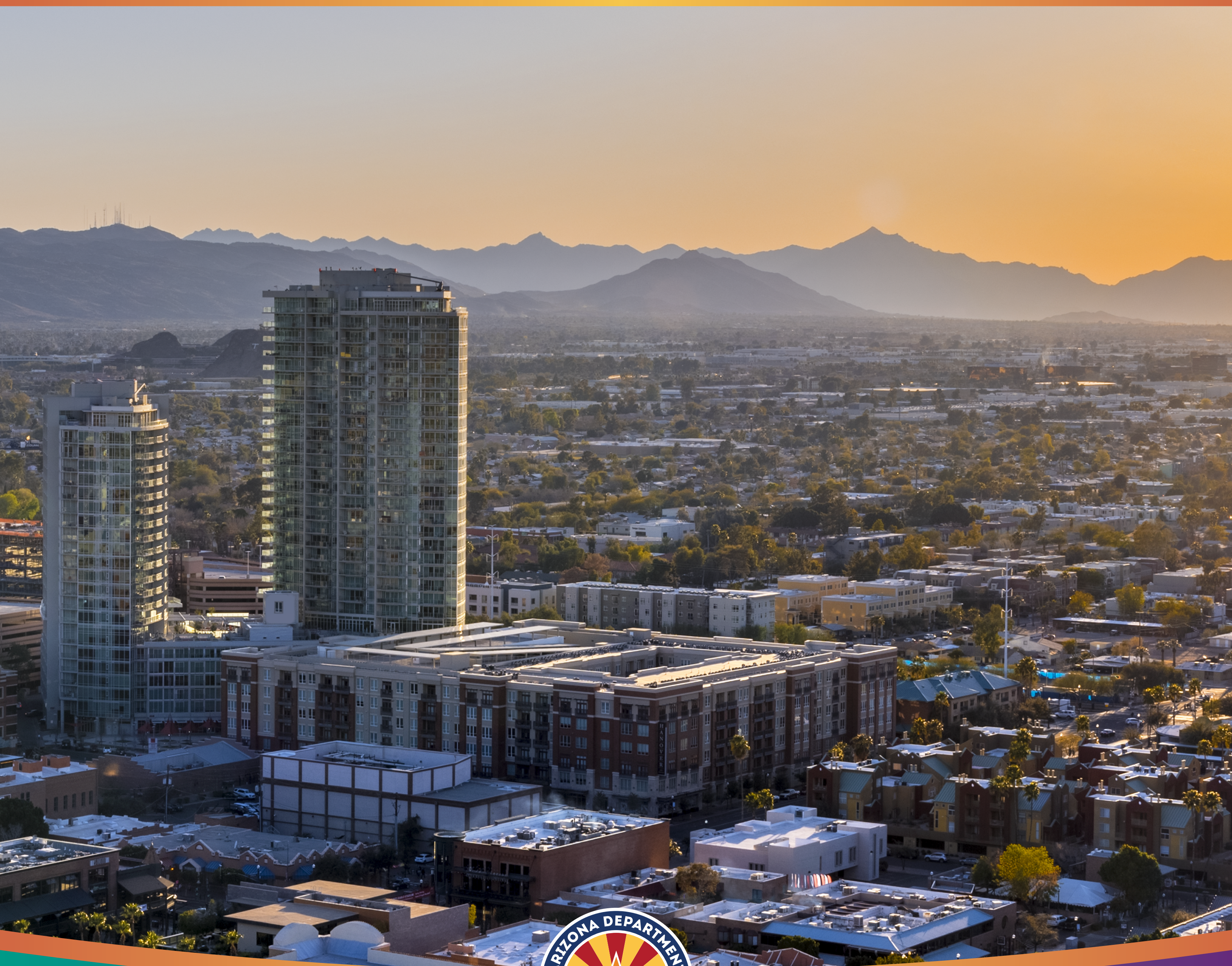
OVERDRAFT, SAFE-YIELD, AND THE MANAGEMENT GOALS OF ARIZONA'S ACTIVE MANAGEMENT AREAS

JANUARY 2022



EMAIL: MANAGEMENTPLANS@AZWATER.GOV
TEL: 602-771-8585

ADDRESS: 1110 W. WASHINGTON STREET,
SUITE 310, PHOENIX, AZ 85007

Acknowledgements

ADWR Staff

Director Thomas Buschatzke

Amanda Long

Carol Ward

Emily LoDolce

Jeff Inwood

Kyle Miller

Makenna Welsch

Maggie Martin

Natalie Mast

Olga Hart

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1. Executive Summary

The 1980 Groundwater Management Act established a goal for the Phoenix, Prescott, and Tucson Active Management Areas (AMAs): to achieve, and thereafter maintain, safe-yield—a long-term balance between groundwater withdrawals and recharge--by 2025. Safe-yield is a part of the management goal for Santa Cruz AMA, and although the Pinal AMA has a unique goal, aspects of the safe-yield analysis can also be informative in understanding progress towards that goal. The statutory definition of safe-yield is deceptively simple and leaves room for interpretation. Over the course of the management plans, safe-yield has been inconsistently discussed and evaluated. In recognition of this, the Arizona Department of Water Resources (ADWR), with the assistance of stakeholders, undertook a process to clarify the concept of safe-yield by refining how it is evaluated and developing a means to better communicate progress towards the goal. To that end, a safe-yield technical subgroup was created as part of the Management Plans Work Group process, the public stakeholder process for the development of the fifth management plans (5MPs).

The goal of this report is to summarize the safe-yield technical subgroup process and results, enable a greater understanding of safe-yield, and provide an assessment of progress toward the management goal in each AMA. The report begins with a discussion of the definition of safe-yield and how it has been discussed in prior management plans. The bulk of the report then summarizes the safe-yield technical subgroup process, the components of the annual and long-term overdraft calculations, and the strategy to communicate safe-yield. As a complement to the discussion on the components of the overdraft calculations, further details are provided in a technical appendix and in a data dashboard. A comprehensive assessment of the progress toward the management goal in each AMA is also included—an outcome of the communication strategy. For the Pinal AMA, long-term overdraft and qualitative influences are evaluated in the context of that AMA's specific management goal. For the Santa Cruz AMA, additional qualitative context is provided to evaluate the additional piece of the AMA's goal. The report concludes with a discussion of the obstacles to achieving the management goal, safe-yield as a management goal, and ongoing discussions regarding safe-yield and the management goal of the AMAs.

The comprehensive assessment in this report concluded that more progress is needed in every AMA in terms of the management goal. As of 2019, the Prescott, Phoenix, Pinal, and Santa Cruz AMAs are in a long-term state of overdraft. The Tucson AMA, although in a long-term state of balance, faces significant obstacles to maintaining that balance.

As Arizona heads into a drier future, it is unlikely that safe-yield will be met and thereafter maintained in any AMA where that is the goal. There are several obstacles to meeting the safe-yield goal that are outside the influence of the management plans that may lessen the effectiveness of existing tools, including how safe-yield was itself defined in statute. Still, the goal of safe-yield has been a productive metric and has undoubtedly guided the AMAs towards a more resilient future than would otherwise be the case. Conservation and the existing management tools will not be sufficient for the AMAs to meet their goals, and climate change is intensifying the complexity of the water management challenges ahead. A renewed commitment to the goal, to strengthening existing strategies, and to developing and implementing new strategies to address both the long-standing and new challenges to water security are necessary. Creative and collaborative discussions with input from a broad base of stakeholders will be essential to understanding the impacts and reach of any solution sets. The discussions underway in the Post-2025 AMAs Committee of the Governor's Water Augmentation, Innovation, and Conservation Council (Council) (https://new.azwater.gov/gwaicc) are an important step forward.

2. What is Safe-Yield?

A.R.S. § 45-561(12)

"'Safe-yield' means a groundwater management goal which attempts to achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn in an active management area and the annual amount of natural and artificial recharge in the active management area."

Safe-yield is defined in Arizona Revised Statute (A.R.S.) § 45-561(12). It is a groundwater focused objective which attempts to achieve an equilibrium between groundwater withdrawals and recharge in order to prevent unsustainable groundwater declines, preserve groundwater for future use, and to protect the state's economy and welfare. The management goal of each AMA, as defined by A.R.S. § 45-562 and summarized in Table 1, is not safe-yield in all AMAs. However, elements of safe-yield, which will be discussed in this report, can be helpful in assessing progress towards the management goal even in the Pinal AMA where safe-yield is not the goal.

Table 1: Summary of the Management Goal in each AMA

AMA	Management Goal
Prescott (PrAMA)	Safe-yield by January 1, 2025 (A.R.S. § 45-562(A))
Phoenix (PhxAMA)	Safe-yield by January 1, 2025 (A.R.S. § 45-562(A))
Pinal (PAMA)	To allow development of non-irrigation use and to preserve existing agricultural economies for as long as feasible, consistent with the necessity to preserve future water supplies for non-irrigation uses (A.R.S. § 45-562(B))
Tucson (TAMA)	Safe-yield by January 1, 2025 (A.R.S. § 45-562(A))
Santa Cruz (SCAMA)	Maintain safe-yield condition and to prevent local water tables from experiencing long-term declines (A.R.S. § 45-562(C))

Assessing safe-yield is complex, but simplistically, it means that the water that is withdrawn from, or exits, aquifers in the AMA (outflows) is balanced in the long term by what enters or is recharged into the aquifers (inflows), and that balance is maintained going forward. Achieving the goal does not require a balance to be maintained every single year, but there should be a balance in the long term. Achievement of safe-yield also does not mean that no groundwater can be withdrawn from the aquifer. Safe-yield is also not a set volume defined by statute, as it is a balance between inflows and outflows that can vary over time, regardless of the volume. Similarly, statue does not define "long-term", which will be a topic of discussion in this report.

Safe-yield and overdraft are often, and incorrectly, used interchangeably. Overdraft is a condition in which the volume of groundwater coming out of the aquifer is greater than the volume of recharge going into the aquifer over an annual or long-term time frame. Overdraft is a quantitative metric, which is one aspect used to assess safe-yield. To understand safe-yield, we must first look at overdraft annually and in the long term, then evaluate that information in the context of other factors to assess the ability of an AMA to achieve and thereafter maintain safe-yield. Although the factors that might impact the ability for an AMA to achieve and maintain safe-yield can be quantified, that quantification has a high level of uncertainty. Quantitative projections have been made in the past and could be used to estimate the impacts to future groundwater inflows and outflows, but the assumptions used in those projections are variable and conditions may change rapidly. Rather than quantifying the potential future impacts, it is more relevant to have a qualitative discussion about the factors that may impact the ability of an AMA to reach and maintain safe-yield. Safe-yield, as defined by statute, is halting overdraft in the long-term to achieve a balance between inflows and outflows, and then maintaining that balance over time. This means that an AMA may have no overdraft in a single year, but this would not necessarily mean safe-yield has been achieved in that AMA if there is not a balance in the longer-term. Conversely, a number of years in overdraft could be balanced out with above average inflows to the aquifer, allowing for the achievement and maintenance of a balance, in the long term. Furthermore, even if an AMA is in a state of long-term balance, if the AMA is unable to maintain that balance going forward due to factors, discussed in this report qualitatively, such as future supply or demand changes, safe-yield may also not be met. This report will detail the quantitative annual and long-term calculation of overdraft before proposing a communication strategy to bring quantitative and qualitative factors together in a comprehensive analysis of safe-yield.

Safe-yield was established with the objective of slowing and halting long-term overdraft. It does not reverse the cumulative overdraft accrued from many decades of unsustainable groundwater pumping. This is not to deny or dismiss the significance of historic or cumulative overdraft and its impacts on the aquifer and the AMAs, but instead intended to be more realistic and achievable by finding a balance under which remaining supplies are preserved. Safe-yield is forward-looking, preventing the further depletion of groundwater supplies by achieving and maintaining a balance of inflows and outflows into the future. Correcting the overdraft of the past would be ideal, but it is not physically possible, due to reductions in aquifer storage capacity caused by subsidence, nor is it practical, due the significance of the volume of water that would need to be replaced.

Safe-yield only pertains to those components that are legally classified as groundwater. The quantitative calculation of overdraft is a budget exercise, a combination of groundwater-focused hydrologic and legal accounting. This is due to considerations around underground storage and recovery, under which some water that is stored underground is not legally classified as groundwater. For example, Colorado River water stored in an underground storage facility retains its legal characteristic as Colorado River water, despite physically being underground, and it retains its legal characteristic as Colorado River water when that stored water is eventually pumped to recover those credits. Safe-yield is a legal concept, applied at an AMA-wide scale. It is only one way to measure the health of an aquifer and does not guarantee that local water levels will be stable.

Halting long-term overdraft and meeting safe-yield protects groundwater resources that are critical to Arizona. Groundwater is a non-renewable source of water; natural replenishment is minimal or extremely slow, often on geologic time-scales. The Arizona Legislature recognized the importance and potential impacts of this in the "Declaration of policy" for the Groundwater Code: "…(W)ithdrawal of groundwater… in excess of safe annual yield… is threatening to destroy the economy of certain areas of this state and is threatening to do substantial injury to the general economy and welfare of this state and its citizens…. (I)n the interest of protecting and stabilizing the general economy and welfare of this state and its citizens it is necessary to conserve, protect and allocate the use of groundwater resources of the state and to provide a framework for the comprehensive management and regulation of the withdrawal, transportation, use, conservation and conveyance of rights to use the groundwater in this state." (A.R.S. § 45-401).

Beyond the risk to future supplies, continuing overdraft can have additional consequences. Diminished physical ability can create obstacles for future Assured Water Supply (AWS) determinations. Deeper water tends to decrease in quality, leading to increased treatment costs, and the need to deepen wells as water levels drop is costly. Additionally, there are also issues related to subsidence and fissures, potential for surface flows connected to those groundwater sources to decline, and potential issues with water availability for other uses such as wild flora and fauna or recreation. Efforts to achieve and maintain safe-yield may help to avoid these impacts, conserve this critical supply of water, and move the AMAs toward sustainable groundwater use.

3. Discussions of Safe-Yield in Prior Management Plans

Safe-yield and overdraft have been described in each management plan; however, the approaches used to assess and describe the status of safe-yield and the management goal in the AMAs and to calculate it have not been consistent between plans. Past plans often included a description of the goal and annual water budgets in every year. Some plans also included projections of water demand and supply in future years and/or analyses of various long-term scenarios. However, past management plans often did not include a clear determination of the status of safe-yield or the management goal, but rather a summary of the current impediments to and the potential of meeting the management goal under various scenarios.

Although projections were included in many of the past management plans and arguments may be made about the value despite the uncertainty, the range of potential variables, assumptions, and policies are shifting rapidly as various supply pressures have become more evident. As the management plans are a static document covering a management period, it may not be appropriate place to include extensive projections which have often become outdated by the time the plan is adopted. Because of this uncertainty, ADWR has moved to decouple these projections from the management plans. ADWR is refocusing staff on the research, analysis, collaboration, and outreach needed for planning activities, and intends to engage stakeholders as planning processes are developed and expanded, with an end goal of developing a process for more continuous updates to projection scenarios and to avoid placing undue reliance on any single set of assumptions.

4. 5th Management Plans Work Group Meetings

The Management Plan Work Group was established as an ADWR-led stakeholder forum for the development of the 5th management plans. The initial work group meeting took place July 2019, with subsequent meetings held through mid-2021. The general goals for the work groups were:

1. Assess existing conservation programs
2. Update existing management strategies

3. Develop new management strategies

Initially, one work group was established per sector (Agricultural, Municipal, and Industrial). With stakeholder input, two additional subgroups were developed, one for turf-related facilities, and one for safe-yield.

The goals of the safe-yield subgroup differed from those of the sector subgroups and instead focused on technical calculation and assessment of the management goal, following the three main aspects of the statutory definition: "annual amount of groundwater withdrawn... and [recharged]", "long-term balance", and "attempts to achieve and thereafter maintain"(A.R.S. § 45-561(12)). The next sections (5-7) of this report follow the framework formed by the goals of the safe-yield technical subgroup listed below:

1. Assess each component of overdraft to establish a consistent quantitative annual overdraft calculation (section 5)
2. Develop a consistent quantitative method to assess and calculate long-term overdraft (section 6)
3. Develop a consistent strategy for ADWR to communicate a comprehensive picture of both quantitative and qualitative aspects of the status of safe-yield and/or the management goal in each AMA to stakeholders and the public (section 7)

All meetings were recorded and can be found online at https://new.azwater.gov/5MP. In addition, ADWR developed a webpage which includes relevant materials for the concepts and proposals discussed in the work group and subgroup meetings. The webpage has a section devoted to the concepts discussed during the safe-yield technical subgroup meetings and can be found online at: https://new.azwater.gov/5MP/plans-concepts.

5. Annual Overdraft Calculation

The annual overdraft calculation is comprised of multiple inflows and outflow components, which are added together to create an annual water budget. Inflows represent sources of groundwater that are recharging the AMA aquifers, while outflows represent groundwater removed from an AMA's aquifer for use or water exiting the AMA. This quantitative annual overdraft calculation is then analyzed over time to understand the long-term quantitative balance of inflows and outflows, which is later combined with the qualitative assessment of the potential for the maintenance of that balance for a comprehensive analysis of safe-yield. Annual and long-term overdraft can also be instructive in analyzing the progress towards the PAMA management goal, as reducing annual overdraft would contribute to extending the agricultural economy and preserving water for future non-irrigation uses that goal requires. For additional discussion of how these calculations can be used to better understand progress toward the PAMA goal, see Section 8 of this report.

ADWR held four 5MP safe-yield technical subgroup meetings in which the components of the overdraft calculation were discussed. Topics of discussion included describing and defining each component, considering available data sources or calculations for the component, and discussing whether a given component should or should not be included in the overdraft calculation. Items that were not included in the current calculation were also considered. Each of the overdraft components were discussed independently, with the intent to review each component in an objective manner without the influence of a predetermined impact to the overall overdraft calculation. As a result of these meetings, the method of calculating two of these components, incidental recharge for the municipal and agricultural sectors, was adjusted. These adjustments will be incorporated into the calculation of overdraft moving forward. The calculation of the remaining components will remain unchanged. A list of the inflow (Table 2) and outflow (Table 4) components included in the overdraft calculation, their method of calculation, and a summary of the discussion had in the safe-yield technical subgroup are included in this section.

To aid stakeholders in this discussion, ADWR created an interactive Overdraft Method Development Dashboard. The dashboard enabled the user to explore the data by AMA, chosen timeframe (between 1985-2015), sector, and/or the individual annual water budget components. Although the Overdraft Method Development Dashboard has since been replaced with the Overdraft Data Dashboard, a copy the development dashboard and data can be found on the ADWR website at https://new.azwater.gov/5MP/plans-concepts .

There are two main sources for the annual water budget components included in the overdraft calculation: Annual Water Withdrawal and Use Reports (annual reports) and the ADWR Regional Groundwater Flow Models (the model). Filing of an Annual Water Withdrawal and Use Report to ADWR is required for most persons who own or lease a right or permit to withdraw, receive, or use groundwater for each right or permit they hold (A.R.S. § 45-632). These reports include information on water withdrawn, delivered, received, and used. ADWR develops regional scale groundwater flow models to provide a common basis for understanding the state's groundwater resources. The models are built to represent long-term changes in groundwater conditions across large portions of the state.

For the purposes of the overdraft calculation and this report, components were categorized as "artificial" or "natural". However, in a context outside of overdraft and safe-yield in the AMAs, the components may be categorized otherwise. Most components that are derived from the annual reports are labelled in this report as "artificial," meaning they are a result of human actions. Whereas most components derived from the model are labelled in this report as "natural," meaning they are naturally-occurring. As many components of the overdraft calculation are derived from the ADWR regional groundwater flow models, detailed information of those components and the regional groundwater flow model is included in an appendix of this report.

The next two sections of the report summarize the inflow and outflow components used in the annual and long-term overdraft calculations.

i. Annual Inflow Components

Table 2 summarizes the inflow components included in previous annual overdraft calculations. The table includes component definitions, the method of calculation used prior to the safe-yield technical subgroup discussions, and the feedback that was received during the subgroup process. Although included in Table 2, not all suggestions and comments were incorporated into analysis in this report. Responses to stakeholder feedback as well as the rationale for excluding or adjusting components are included following the table.

TABLE 2. Summary of Inflow Components included in the Overdraft Calculation

Component	**Natural/ Artificial**	**Method**	**Definition**	**Stakeholder Comments**
Groundwater Inflow	Natural	Regional Groundwater Flow Model*	Subsurface flow of groundwater from one groundwater basin or sub-basin into another, sometimes referred to as underflow.	
Streambed Recharge	Natural	Regional Groundwater Flow Model*	Occurs as channelized surface flows, particularly during large runoff (flood) events, infiltrates through the riverbed and reaches the aquifer.	• As overdraft is an accounting exercise, time lagging may not be appropriate • ADWR should access more streambed data, especially in areas where there are few or no gauges
Mountain Front Recharge	Natural	Regional Groundwater Flow Model*	The infiltration of precipitation falling in the mountains surrounding a basin, which flows downgradient and in time recharges the aquifer.	
Agricultural Incidental Recharge	Artificial	Regional Groundwater Flow Model*	The amount of water estimated to have percolated to an aquifer after the water has been withdrawn, diverted, received, or otherwise used (including consumptive use of plants and soil evaporation) for agricultural areas.	• ADWR could reach out to Tribal communities to get better estimates about water use • As overdraft is an accounting exercise, time lagging may not be appropriate • Should use information/data on irrigation systems • Consideration should be made for adoption/changes in irrigation methods due to technology • More information from the agricultural sector is needed • Consideration of crop type and crop coefficients. • A percentage of total use should be considered. The percentage could use data at the irrigation district level, rather than at the AMA scale, and be revisited periodically to ensure accuracy

**See Appendix A for more information.*

Component	Natural/ Artificial	Method	Definition	Stakeholder Comments
Industrial Incidental Recharge	Artificial	A percentage from Annual Reports	The amount of water estimated to have percolated to an aquifer after the water has been withdrawn, diverted, received, or otherwise used for industrial purposes.	
Municipal Incidental Recharge	Artificial	A percentage from Annual Reports	The amount of water estimated to have percolated to an aquifer after the water has been withdrawn, diverted, or received for municipal purposes.	• Municipal incidental recharge was not previously included for the Prescott and Santa Cruz AMAs, but should be included for the purpose of analyzing safe-yield moving forward
Canal Seepage	Artificial	Regional Groundwater Flow Model*	The portion of water that infiltrates and recharges the aquifer as it is conveyed through a canal or other conveyance system.	• Consider getting data from the Gila River Indian Community on canal lining efforts • May need to confirm whether there is any double counting with agricultural incidental recharge
Cut to the Aquifer	Artificial	A percentage of water delivered to a permitted recharge facility	A legally determined percentage of water deducted from the volume of stored water. This ranges from 0-50 percent based on type of water, type of storage facility, and whether the storage is long-term or will be recovered in the same year.	
Central Arizona Groundwater Replenishment District (CAGRD) Replenishment	Artificial	CAGRD Replenishment Obligation Annual Reports	The volume of replenishment obligation incurred in each year by CAGRD member lands and member service areas, which is required to be replenished by the CAGRD within 3 years.	

**See Appendix A for more information.*

ii. Discussion of Annual Inflow Components

a. Underground Storage

The exclusion of underground storage from the overdraft calculation was a topic of discussion during the safe-yield subgroup process. Although underground storage may contribute to localized increase in water levels, it is not included in the calculation of safe-yield. Underground storage of water is a mechanism created to ensure full utilization of renewable supplies. Those renewable supplies could then be recovered, as needed. Through the administrative reporting process, water placed in storage at underground storage facilities, although physically underground, is not legally classified as groundwater. Furthermore, in the same reporting process, when this stored water is withdrawn, it retains the same legal classification as when it was stored. Because safe-yield is a groundwater focused metric, this water will continue to not be included as a component of the overdraft calculation.

b. Municipal Incidental Recharge

The exclusion of municipal incidental recharge in the overdraft calculation for Prescott and Santa Cruz AMAs was discussed in the safe-yield subgroup. Under the AWS rules for the Phoenix, Pinal, and Tucson AMAs, a four percent municipal incidental recharge credit of the total water use is added to groundwater allowances each year. Groundwater allowance is the volume of water which may be calculated for a certificate or designation of AWS in each AMA. However, there is no such credit in the Prescott and Santa Cruz AMA (as of 2021, AWS rules for the Santa Cruz AMA have not been promulgated), and a four percent municipal incidental recharge was not previously included in the overdraft calculation for those AMAs. From a practical standpoint, it is not accurate to say that Prescott and Santa Cruz do not have municipal incidental recharge simply due to the absence of this rule. As a result of the safe-yield technical subgroup's discussions on this point, municipal incidental recharge will be included in all AMAs for the purpose of the overdraft calculation and management goal analysis, to be calculated as four percent of total municipal demand, including all sources of water use.

c. Agricultural Incidental Recharge

How agricultural incidental recharge was derived was discussed during the subgroup meetings, and as a result, agricultural incidental recharge for the purpose of overdraft and safe-yield will be calculated as a percent of total demand. As the approach to overdraft is more closely related to a water budget, tracking the changes in inflows and outflows, rather than groundwater conditions, the lagging represented in regional groundwater flow models is not applicable. The calculation for agricultural incidental recharge, as discussion in the safe-yield technical subgroup will be:

$$Agricultural\ Incidental\ Recharge =$$

$$Total\ Agricultural\ Demand\ \times (\%\ Transmission\ Losses +\ \%\ Application\ Losses)$$

$$where\ \ \%Application\ Losses = 100\% - Irrigation\ Efficiency$$

$$\%Transmission\ Losses = \%\ Lost\ and\ Unaccounted\ for\ water - \%Evaporation$$

Starting with the transmission losses, the percent lost and unaccounted for was calculated with a starting point of 10 percent, which is the high end of what is used in the management plans. Since 10 percent is at the higher end, the department proposed using a lower amount of eight percent. To account for evaporation, a quarter of the percent loss and unaccounted for was used, which is the same amount that is used in the Pinal AMA model. To calculate transmission losses, two percent (a quarter of 8 percent) was subtracted from the eight percent. Therefore, the department proposed using six percent transmission losses.

To calculate application losses, irrigation efficiency for each AMA was calculated using a combination of United States Geology Survey (USGS) data sources. Through a partnership with the USGS, ADWR periodically receives data on irrigation methods and efficiency. USGS collects these data through analysis of satellite imagery and field verification and provides their analysis to ADWR. However, this field verification for a given basin is not typically done annually, with basins rotating based on priority and available funding and with a prioritization of non-AMA basins where data is more limited. Field verification of an AMA was most recently done in 2018 for the Pinal AMA. The dataset provided is large, aligns with current knowledge of irrigation methods and efficiencies, and therefore was used as a starting point to calculate irrigation efficiencies for the remaining AMAs. The efficiencies of irrigation methods in the Pinal AMA are shown in Table 3. To calculate the remaining AMAs, USGS county-level data on acreage of crop irrigation methods (USGS, 2015) was extrapolated to the AMA level. This county-level irrigation method data was then used to customize the Pinal AMA irrigation efficiencies to each AMA.

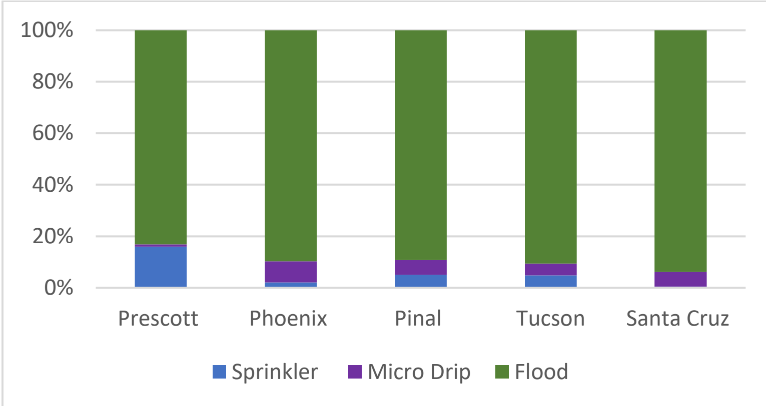
The dominant irrigation method in each AMA is flood, where the method constitutes 83 to 94 percent of irrigation, as shown in Figure 1. As a result, the calculated irrigation efficiency in each AMA was similar and ranged from 75.9 to76.6 percent. Therefore, AWDR proposed using an irrigation efficiency of 76 percent.

TABLE 3: Pinal AMA Average Irrigation Efficiencies by Irrigation Method:

Irrigation Method	**Irrigation Efficiency**
Sprinkler	85%
Micro Drip	90%
Flood	75%

Source: USGS Pinal AMA Data compiled for ADWR, 2018

FIGURE 1. Percent of Irrigation Method by AMA



Source: USGS, 2015

Taking all this into consideration, ADWR proposed calculating agricultural incidental recharge as 30 percent of total agricultural demand as seen below:

$$Agriculatural\ Incidental\ Recharge =$$

$$Total\ Agricultural\ Demand\ \times (6\% +\ 24\%)$$

$$\text{where } \%Application\ Losses = 100\% - 76\%$$

$$\%Transmission\ Losses = 8\% - 25\%(8\%)$$

Safe-yield technical subgroup members identified some concerns related to the percentage used to calculate agricultural incidental recharge. It was suggested to ADWR to source data on irrigation methods and efficiency at a finer scale, such as irrigation district. Another concern was the potential for irrigation methods, and therefore irrigation efficiencies, to change over time as operators adopt new technology and practices. At present, irrigation district level data is not available to ADWR. However, if the data was available at a finer scale, the results may be similar as a result of the high proportion of flood irrigation in each of the AMAs. Additionally, many irrigation grandfathered rights fall outside of an irrigation district, meaning that multiple methods would be necessary to calculate the irrigation efficiency, an added complexity that could result in inaccurate results. As technologies, crop types, and practices used in the agricultural sector may evolve over time, to ensure that the most accurate data (including efficiency, crop type, crop coefficient, and consumptive use) and irrigation methods are accounted for, ADWR will revisit the agricultural incidental recharge calculation with every subsequent management plan or alternative conservation requirement as established by the legislature. ADWR will also reference the estimates of agricultural incidental recharge derived from the regional groundwater models to identify any significant variations.

The agricultural incidental recharge that was calculated using the method described above was reviewed by ADWR hydrology staff for use in the overdraft calculation. As compared to the modeled values, the results calculated with the method described above followed similar trends, were in the same order of magnitude, and as a portion of the overall water budget are considered appropriate to use for the purposes of safe-yield.

There were also questions in the safe-yield technical subgroup regarding potential double-counting between the transmission loss component of the agricultural incidental recharge calculation and the transmission losses associated with for canal seepage. Canal seepage and agricultural incidental recharge are separated into off-farm and on-farm (no additional canal seepage) zones in the regional groundwater flow models, and not double-counted. Canal seepage occurs off-farm and terminates at the farm or irrigation district boundary. Agricultural incidental recharge occurs on-farm within the farm or irrigation district boundary.

d. Streambed Recharge

In relation to streambed recharge, there were two main points of discussion during the subgroup: retrieving more stream gage data and the inclusion of time-lagging.

ADWR will continue using the regional groundwater flow models for streambed recharge data as these are currently the best available tools for estimating this component of the overdraft. At present, retrieving data through additional streambed gauges is not viable, however the department is open to considering additional data and data sources in the future. Stakeholders expressed concern over potential time-lagging in streambed recharge component data, which would delay counting volumes from streambed recharge until the year when those volumes would be estimated to reach the regional aquifer. As the overdraft calculation is structured as an annual water budget, stakeholders argued that time lagging would be inappropriate. Although there were discussions of time-lagging in the data, the current streambed recharge package used in the most recently published regional groundwater models does not include time lagging. Therefore, the streambed recharge data derived from the models and used in the overdraft calculation will not include time-lagging.

iii. Annual Outflow Components

Table 3 summarizes the outflow components included in previous annual overdraft calculations. The table includes component definitions, the method of calculation used prior to the safe- yield technical subgroup discussions, and the comments that was received during the subgroup process. Although included in Table 3, not all suggestions and feedback were incorporated into the analysis in this report. Responses to stakeholder feedback as well as the rationale for excluding or adjusting components are included following the table.

TABLE 3. Summary of Outflow Components included in the Overdraft Calculation

Component	**Natural/ Artificial**	**Method**	**Definition**	**Stakeholder Comments**
Groundwater Outflow	Natural	Regional Groundwater Flow Model	Water that flows out of a groundwater basin to another basin as a part of natural geologic structures or processes, sometimes referred to as underflow.	• Natural outflows should not be considered, according to statute
Riparian Demand	Natural	Regional Groundwater Flow Model	A component of groundwater models and of the calculation of safe-yield or overdraft which estimates groundwater demands due to evapotranspiration in riparian areas. Evapotranspiration refers to the sum of soil evaporation and plant transpiration.	• Riparian demand is a use of water, not a groundwater withdrawal and therefore should not be included in the safe-yield calculation • Concerns that riparian demand may be double-counting streambed recharge
Sector Groundwater Demands	Artificial	Annual Reports	Water pumped from a well by the user, or received from primary or secondary irrigation district, or received or diverted from other sources, with the exception of water that is accounted for as recovery of stored water.	• Potential for Tribal demand estimate errors, as their proportion of surface water use is high • ADWR could reach out to Tribes to get better estimates about water use • ADWR could consider other ways to get Tribal groundwater demand estimates (multiple land uses, settlement agreements)
Remediated Groundwater	Artificial	Annual Reports	Includes groundwater that must be remediated as a part of a formal remediation process. Typically involves sites with groundwater contamination such as Superfund sites.	
Poor Quality Groundwater	Artificial	Annual Reports	Groundwater that because of its poor quality has no other present time beneficial use. ADWR may issue permits to withdraw this type of water and this water may be exempt from conservation requirements.	

**See Appendix A for more information.*

iv. Discussion of Annual Outflow Components

a. Riparian Demand and Groundwater Outflow

Stakeholders raised several concerns in relation to the inclusion of riparian demand and groundwater outflow in the overdraft calculation. Riparian demand and groundwater outflow will continue to be included in the overdraft calculation. These components are both natural sources of groundwater outflows, and therefore would be part of the net natural recharge described in the statutory definition of safe-yield.

Stakeholders also expressed concern over potential double-counting of riparian demand within the streambed recharge calculation. Riparian demand and streambed recharge are separate components of the water budget. Because streambed recharge is an inflow and riparian demand as an outflow there is no double counting.

More information on the components that are derived from the regional groundwater flow models for the purpose of the safe-yield calculation can be found in Appendix A of this report.

b. Estimated Tribal Groundwater Demands

The source of tribal groundwater demand data was discussed during the subgroup process and several alternative sources were suggested. As sovereign nations, Tribal water users are not subject the requirements of the Groundwater Management Act and management plans and are not required to submit annual water use reports to ADWR under those regulations. Certain legal settlements do require Tribal water users to submit certain types of water use information, but those requirements are not consistent across settlements, do not always specify type of water used, and do not always separate the water use by AMA. While the Department recognizes the value of receiving directly reported information regarding Tribal water use from those communities, in the interest of consistency and clarity, ADWR currently creates estimates for this demand. The estimated uses are primarily agricultural in nature, and ADWR derives estimates of Tribal demand from several sources, including historical communications with individual Tribal water users, federal documents, and annual reports from regulated entities who have agreements with Tribal water users. If more accurate and comprehensive information regarding Tribal water use becomes available in the future, including settlement information that is specific to groundwater use, ADWR will update their method of Tribal demand estimates used for overdraft and statewide water use estimates. Until that time, the Department will continue to use estimates of Tribal water use.

6. Long-term Overdraft Calculation

A.R.S. § 45-561(12)

"'Safe-yield' means a groundwater management goal which attempts to achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn in an active management area and the annual amount of natural and artificial recharge in the active management area."

The statutory definition of safe-yield requires a long-term balance of annual components. Assessing the long-term balance or whether or not there is long-term overdraft is difficult due to the variability in inflows, outflows, and therefore the overdraft, that exists over time in each AMA. In addition, statute does not define "long-term," and long-term overdraft was not explicitly or consistently assessed and described in the management plans. One of the goals of the safe-yield technical subgroup was to develop a consistent quantitative method to assess and calculate long-term overdraft. There were three meetings in which the safe-yield technical subgroup discussed possible methods for calculating long-term overdraft.

i. Potential Long-term Overdraft Calculations

The method for calculating long-term overdraft would utilize the inflow and outflow components of the annual overdraft calculation, as discussed in section 5 of this report. As the annual inflows and outflows are variable over time, the method would attempt to remove the variability of the annual data so that long terms trends could be identified, but in a way that did not mask the progress, or lack of progress, that has been made towards a long-term balance. The long-term calculation would produce a single overdraft number in every year, but also allows longer term trends and directionality to be clearly observed. Several potential methods were discussed in the safe-yield technical subgroup, and are described, along with relevant comments, in Table 5 below. These potential methods used the annual overdraft calculation, as described in section 5, to calculate a water budget in every year for each AMA. The annual overdraft data was adjusted based on the method as described in Table 5.

As with the annual overdraft components, to assist stakeholders with this discussion, pages were added to the Overdraft Method Development Dashboard to display the results of the potential long-term overdraft calculations. Once a final method was proposed, the Overdraft Method Development Dashboard was replaced with the final Overdraft Data Dashboard discussed in section 7. A copy of the Overdraft Method Development Dashboard has been included on the 5MP Concepts Page, available at https://new.azwater.gov/5MP/plans-concepts.

TABLE 5: Potential Methods for the Long-Term Overdraft Calculation

Method	Description	Comments
Identifying cause for trends	• Identifying factors that could be causing variability or trends in the annual inflows and outflows and normalizing them. • Several factors were considered including climate, temperature, precipitation, and economy	• A strong correlation was related to groundwater demand
Averaging Components	• Averaging all inflows and outflows by a specific time period • Considered one total average as well as 5-, 10-, and 20-year running averages	• Averaging all components by the same method had very strong masking effects that may hide progress or lack of progress in each AMA
Averaging Natural Components	• As natural components contribute to the variability that can be seen year to year (e.g. 1993 flood year), this method averages only those components • Considered several methods including one average for all years, 5- to 20-year running averages, and removing outliers	• This method removed some of the variability in the data, but as groundwater sector demand has a large impact, significant variability sill remained
Long-term overdraft by sector	• Acknowledging that each sector has a role to play in safe-yield, this method looks at the long-term overdraft in each of the sectors (Agricultural, Industrial, and Municipal) • As natural components are not by sector, the division of natural components was considered by percent of total demand, percent of renewable water demand, and equally	• Difficult to divide natural components by sector and divisions could reward or be punitive towards sectors based on use • Could assign responsibility to any one sector • Safe-yield is an AMA-scale goal, not a local or sector level goal
Time Period	• This method attempted to define a specific period as long-term • Considered 5, 10, 15, and 20 years, as well as the period of each management plan	• Using a specific time period would not remove the variability in the inflow and outflow data, so the resulting data would still be difficult to assess.

**See Appendix A for more information.*

In discussing the potential methods to evaluate the long-term balance, ADWR suggested combining some of the methods in Table 5 to acknowledge the influence of the groundwater demand and natural components on the variability of the annual data. Based on feedback on potential combinations, ADWR further refined the method into a proposal.

The proposed approach acknowledges the longer-term cycles of natural components that may not align with the shorter-term cycles of artificial, or human caused components. A longer-term average for natural components helps to capture the variability of very wet and very dry years. Whereas a shorter-term average for artificial components was appropriate, as those components may follow cycles that are not as long, such as economic patterns. The components that are considered natural and artificial can be found in Tables 2 and 4, above.

The Overdraft Method Development Dashboard was updated to include the proposed method with multiple longer-term and shorter-term time periods options that users could filter. The natural components time period filters included a total average of all years, and a 20-year running average. The artificial components time period filters included three-, five-, and ten-year running averages.

In general, the feedback for using a combined approach was positive, with range of ideas for appropriate long- and short-term lengths. For the natural components, feedback included using the natural hydrologic cycles of the southwest, around 50 to 60 years. Other comments recommended a shorter 15 to 20 years to ensure a long-term view of hydrology and a time period that is short enough to react to climatic trends. For the artificial components, feedback included using a shorter time frame of around 3 to 5 years had support, as it would allow time to understand trends outside of hydrology, but not so much time that trends might be masked.

ii. Final Long-term Overdraft Calculation

After assessing the stakeholder feedback, ADWR determined the final long-term overdraft calculation will use three-year rolling averages for artificial components and 20-year rolling averages for natural components. Comments were received in favor of using both three and five years to average artificial components. Three years was chosen, in consideration of limiting any potential masking effects and to align with other AMA metrics such a municipal lost and unaccounted for water requirements. Twenty years for an average of natural components is long enough to smooth out the observed natural variability and allows for a reflection of the lower inflows seen in recent years.

There was discussion and disagreement in the safe-yield technical subgroup regarding the use of cumulative overdraft rather than the method described above, to measure progress toward safe-yield. As discussed in Section 2, while cumulative overdraft is a critically important consideration and should not be dismissed, the statutory goal of safe-yield is to achieve and maintain a balance between outflows and inflows over the long-term. Achieving safe-yield does not require reversing historical cumulative overdraft, although it could help expedite progress toward the goal. Assessing progress toward that goal requires additional analysis. ADWR will utilize the long-term method described in this section that demonstrates progress toward achieving and maintaining a groundwater supply and demand balance looking forward to accomplish that.

7. Communication Strategy

The concept of safe-yield isn't necessarily intuitive for water professionals, let along the public, and past interpretations have been inconsistent and difficult to understand and communicate. One of the goals of the safe-yield technical subgroup was to address this challenge by developing a strategy to communicate the status of safe-yield in each AMA in which it is a goal.

There were three meetings in which the safe-yield technical subgroup discussed the development of a strategy to assess and communicate progress toward safe-yield in a consistent and clear way for both technical staff and the general public. The strategy would utilize the quantitative methods described in section 5 and section 6, the annual inflow and outflow components, the calculations to be used to derive the annual components, and the method for analyzing the long-term balance of those components. The strategy would also incorporate the qualitative portion of safe-yield, factors that would contribute to or prevent the maintenance of the long-term balance.

i. Potential Communication Strategy

The safe-yield technical subgroup discussed several potential methods for incorporating the annual and long-term overdraft calculations into a safe-yield communication strategy. Table 6 summarizes the potential methods and comments given during the subgroup meeting. As each potential method had varying advantages, disadvantages, and levels of feasibility, not all were included in the final strategy.

TABLE 6: Potential Methods for Communicating Safe-Yield

Methods	Description	Comments
Infographics	• Qualitative • Use of infographics to communicate safe-yield	• This should be aimed at educating the general public on what safe-yield is
Target Number	• Quantitative • A target amount of groundwater withdrawals that cannot be exceeded in every year in order to meet safe-yield	• A target number would be difficult to determine with a large margin of error and variability over time • A target number may assign a lot of weight to one number
Directionality	• Qualitative, based off the long-term overdraft calculation • Whether or not the AMA is making progress towards a long-term balance in the preceding years.	• Directionality does not mean that an AMA is at or close to safe-yield. An AMA could have positive directionality and still be far from safe-yield or vice-versa.
How far from Safe-Yield or Long-Term Overdraft	The amount of groundwater necessary to achieve safe-yield, calculated using the long-term overdraft calculation.	• This method acknowledges the question that is often asked when discussing safe-yield, "How far are we from safe-yield?" • This amount could have a large margin of error and variability over time • This amount may assign too much weight to one number

ADWR received feedback on the potential methods and general comments on what and communication strategy should include. There were several comments on the need for an educational component to communicating safe-yield, including: its definition, hydrologic and legal nature, what safe-yield is and is not, and what is being done to meet safe-yield. Other suggestions included the use of infographics, using multiple methods, discussion of trends by sector, and using different methods for different audiences. There was also concern about employing or giving undue weight to a method that was too quantitatively focused and could mislead some audiences about the actual status of safe-yield. Finally, there was feedback on the need to include the path forward for safe-yield and an evaluation of the work that may be needed beyond the goal of safe-yield.

ii. Final Communication Strategy

As a result of feedback from the technical subgroup, ADWR considered two distinct audiences when developing the communication strategy: the general public and water resource professionals with a higher level of technical knowledge. Both audiences are equally important but would require different levels of background information and detail. The methods aimed at the general public would need to be educational in nature and include a high-level summary of the results of the analysis, while the more technically focused methods could provide significantly more detail for water resource professionals. A method for communicating to both audiences was included in the proposed strategy.

To communicate with the general public, ADWR developed educational infographics on overdraft and safe-yield and provide a basic metric on the status of the goal for each AMA. To communicate with technical audiences, that metric is expanded to the series of metrics shown in Table 6 below, due to feedback from stakeholders, which indicated that a comprehensive and balanced communication strategy would include both qualitative and quantitative metrics in order to provide a full picture of the status of safe-yield. Additionally, the potential methods listed in Table 5 would not acknowledge a crucial part of the safe-yield goal, which is to not only reach safe-yield but also "*thereafter maintain*" it. This forward-looking piece is then addressed qualitatively through this communication strategy.

The metric list below contains multiple quantitative and qualitative indicators that utilize the long-term method described in section 6. This metric list acknowledges that the status of safe-yield cannot be determined using a single metric and also addresses the maintenance portion of the statutory definition of safe-yield. Each metric is described in Table 6 below.

TABLE 6: Metrics included in the Overdraft Data Dashboard

Metric	**Method**	**Definition**
Annual	Qualitative (Yes/No)	A comparison of the number of years with and without annual overdraft. Yes (☑), indicates there are more years without overdraft than with. No (☒), indicates there more years with overdraft than without.
Long-Term Overdraft Status (status of most recent year)	Qualitative (Yes/No)	Using the long-term overdraft calculation, the status of long-term overdraft in the most recent year analyzed. Yes (☑), indicates overdraft, No (☒), indicates a balance or net recharge in the most recent year of the long-term overdraft calculation.
Long-Term Overdraft Directionality	Qualitative (Yes/No/Neither)	Using the long-term overdraft calculation, the direction of long-term overdraft in the past 3 years. Yes (☑), indicates decreasing overdraft, No (☒), indicates increasing overdraft, and (☐) indicates neither an increase or decrease.
Long-Term Overdraft (single year long-term)	Quantitative value	Using the long-term overdraft calculation, the volume of water necessary to eliminate overdraft in the most recent year analyzed.

Metric	Method	Definition
Long-Term Overdraft (as a percent of total demand)	Quantitative value	Using the long-term overdraft calculation, the volume of water necessary to eliminate overdraft in the most recent year analyzed as a percent of total water demand in the AMA.
Long-Term Overdraft (as a percent of groundwater demand)	Quantitative value	Using the long-term overdraft calculation, the percent of groundwater demand in the AMA necessary to eliminate overdraft in the most recent year analyzed.
Outlook	Qualitative (Description)	A description of expected impediments to reaching and thereafter maintaining safe-yield or the management goal.
Management Goal Status	Qualitative (Description)	A description of the overall status and combined evaluation of the above metrics.

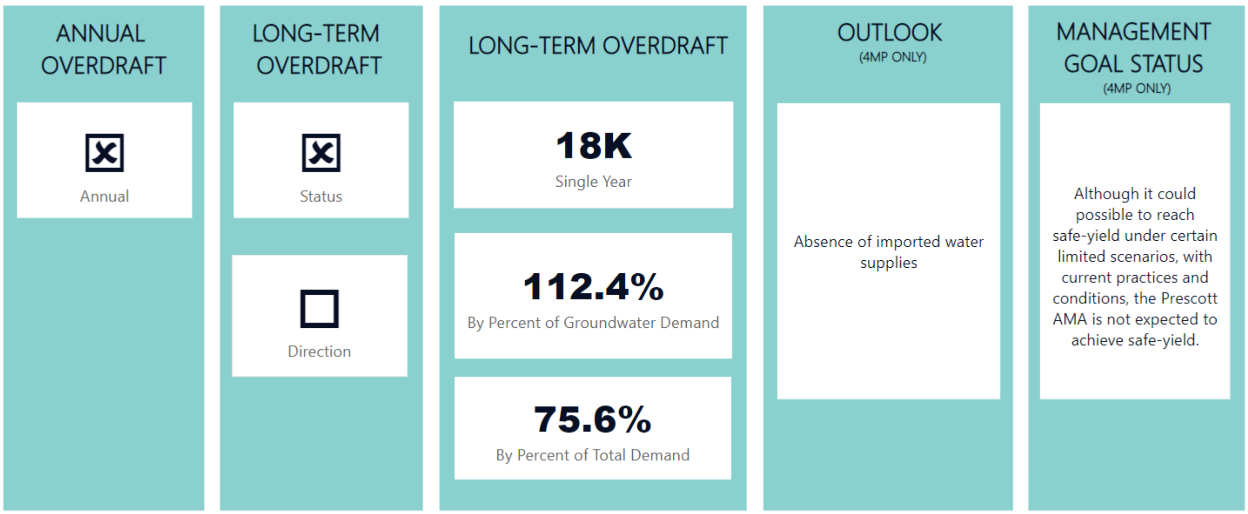
As a part of the communication strategy, ADWR has developed the Overdraft Data Dashboard, which will replace the Overdraft Method Development Dashboard used throughout the subgroup process. The Overdraft Data Dashboard can be found at https://new.azwater.gov/ama/ama-data. It is interactive and will included several pages of information that the user can filter by year, management period, and/or AMA. The first page will contain the annual data, calculated as discussed in section 5 of this report. The next page will have long-term overdraft data as calculated using the method discussed in section 6 of this report. There will also two pages displaying the infographics and metrics of the communication strategy, separated into the public and technically focused audiences. Finally, the dashboard will include relevant definitions and a link to this report.

8. Assessment of the Management Goal

The next section includes an assessment of the management goal for each AMA, utilizing metrics of the communication strategy described in section 7 with data from 1985 to 2019. As this report is a static document, the interpretation of these results is only appropriate for the time frame they are referencing. As mentioned above, ADWR has created an Overdraft Data Dashboard (available at: https://new.azwater.gov/ama/ama-data)that will be periodically updated to include the most up-to-date data. A snapshot of the communication strategy metrics from the Overdraft Data Dashboard is included in the assessment of the management goal of each AMA. Following each figure of metrics will be narrative expanding upon the management goal status including what may have led to that status, and impediments to meeting the goal moving forward.

i. Prescott AMA

FIGURE 2. Status of the Safe-Yield Management Goal in the Prescott AMA, 2019



Source: Overdraft Data Dashboard, available at: https://new.azwater.gov/ama/ama-data

Annually from 1985 to 2019, the PrAMA has been in overdraft for all but six years. As of 2019, the Prescott AMA was in a state of long-term overdraft, with no clear trend toward or away from overdraft in the three preceding years. In 2019, the volume of single year, long-term overdraft does not appear large as compared to the other AMAs, but this volume is three quarters of the PrAMA's total demand and greater than the groundwater demand.

The results of the PrAMA overdraft analysis show that natural outflows often create overdraft in the PrAMA, even absent additional groundwater pumping. The groundwater model and therefore the data used for the safe-yield analysis are dynamic, meaning as one component changes, it is unlikely that others will remain unchanged, and they may not necessarily change in direct correlation with one another. This further demonstrates the importance of looking at safe-yield as a comprehensive analysis, with considerations of annual overdraft, long-term overdraft, and the qualitive factors that influence the bigger picture of whether the PrAMA is expected to achieve and thereafter maintain its goal.

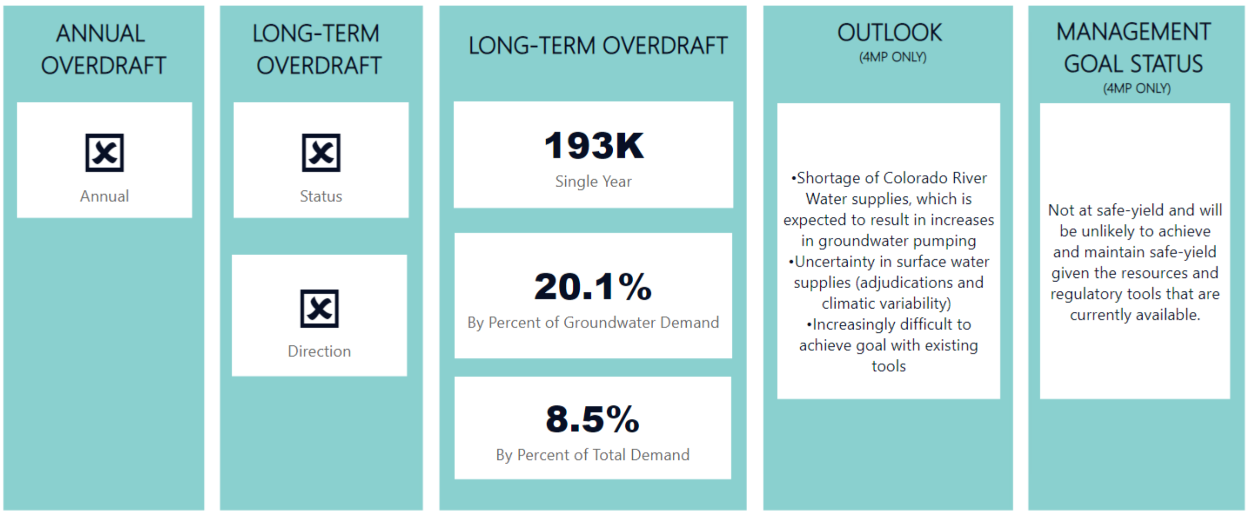
The PrAMA is heavily reliant on groundwater. Surface water supplies in the PrAMA are inconsistently available, subject to prior appropriation, prior agreements, and pending adjudications. Weather and climatic conditions may also become more unpredictable in the future, which may lead to additional inconsistency in surface water availability. There are not currently imported supplies of water in the PrAMA, but importation of water from the Big Chino sub-basin may occur in the future pursuant to A.R.S. § 45-555.

In the past, projections were completed for various potential scenarios and included in the management plans. It was predicted that in certain scenarios, safe-yield could be achieved in the PrAMA. One such scenario saw potential for safe-yield if the PrAMA used its authority to import water supplies from the Big Chino sub-basin of the Verde River groundwater basin. However, the timing and volume of delivery of that water to the PrAMA are uncertain due to practical and legal impediments related to importation. Discussions with other entities and the development of necessary infrastructure would be time and resource intensive.

Although it could be possible to reach safe-yield under certain limited scenarios, with current practices and conditions, the Prescott AMA is not expected to achieve safe-yield.

ii. Phoenix AMA

FIGURE 3: Status of the Safe-Yield Management Goal in the Phoenix AMA, 2019



Source: Overdraft Data Dashboard, available at: https://new.azwater.gov/ama/ama-data

Annually from 1985 to 2019, the Phoenix AMA has been in overdraft in all but six years. As of 2019, the PhxAMA was in a state of long-term overdraft, with increasing overdraft in the three proceeding years. The Phoenix AMA is the largest AMA in terms of population, square mileage, and of total water use - and that is reflected in the volume of long-term overdraft. In 2019, the volume of single year, long-term overdraft is just under a tenth of the AMA's total demand and a fifth of the AMA's groundwater demand.

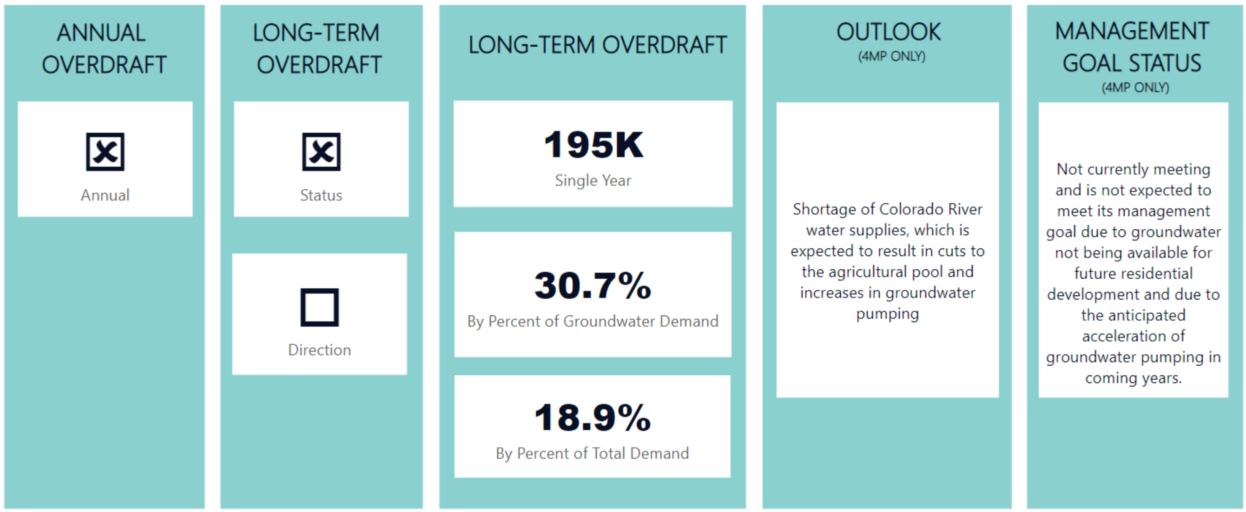
As the Phoenix AMA receives around 20 percent of its water supply in Colorado River water, the achievement of safe-yield is greatly impacted by drought and shortage conditions of the Colorado River Basin. Any level of shortage conditions to the Colorado River may result in reduced deliveries to storage facilities, increased recovery of storage credits, reduced supply of storage credits, and ultimately a greater pressure on groundwater supplies. A third of the Phoenix AMA's annual water supply is in-state surface water from the Gila, Salt, and Verde watersheds. While some surface water rights in the AMA are decreed, others will be subject to uncertainty until they have been adjudicated. The in-state surface water supplies may also be variable year to year, impacted by extensive drought and climate variability. In response to limitations of both Colorado River and in-state surface water supplies, groundwater pumping may increase to meet demand.

There are several factors affecting safe-yield that are outside the regulatory authority of ADWR. ADWR's authority to regulate water use in the AMAs is based on groundwater and does not apply to those entities not using groundwater. This means that there is additional competition for non-groundwater supplies that could otherwise be used to offset groundwater demands. Other factors that could drive additional groundwater use include population increase, industrial growth, and certain types of legally allowable new demands. Current conservation and increased efficiency are not sufficient to achieve safe-yield, and replenishment is not required for most water demands. In order to meet the management goal, ADWR may need to develop or utilize additional regulatory tools and potentially acquire additional statutory authority to meet the goal.

The Phoenix AMA is not at safe-yield and will be unlikely to achieve and maintain safe-yield given the resources and regulatory tools that are currently available.

iii. Pinal AMA

FIGURE 4: Analysis of Overdraft and the management goal in the Pinal AMA, 2019*



**Safe-yield is not the management goal of the Pinal AMA*
Source: Overdraft Data Dashboard, available at: https://new.azwater.gov/ama/ama-data

The management goal of the Pinal AMA is to allow the development of non-irrigation water uses and to preserve existing agricultural economies in the Pinal AMA for as long as feasible, consistent with the necessity to preserve future water supplies for non-irrigation uses (A.R.S. § 45-562(B)). Statute does not specify the length that agricultural economies should be preserved, nor does it specify non-irrigation uses. A balance is necessary between existing agricultural demands and future non-irrigation demands – if either aspect of the goal is not feasible, then the goal is not being met.

Although safe-yield is not the goal of the PAMA, aspects of the analysis are relevant. Understanding annual and long-term overdraft can be informative in analyzing the management goal in the PAMA. Efforts to reduce annual and long-term overdraft would extend the length of the agricultural economy while preserving water for future non-irrigation uses, and thus would be consistent with the management goal.

Annually from 1985 to 2019, the Pinal AMA has been in a state of annual overdraft in all but four years. As of 2019, PAMA is in state of long-term overdraft, with no clear trend toward or away from overdraft in the three preceding years. The Pinal AMA is the second largest AMA by water use, and that is reflected in the volume of overdraft. In 2019, the single year volume is of long-term overdraft is 19 percent of the AMA's total demand, and one-third of the AMA's groundwater demand.

As 30 to 40 percent of the PAMA's water supply is Colorado River water, both through direct deliveries and deliveries to Groundwater Savings Facilities (GSFs) [1], the ability to achieve the management goal will be further challenged by drought and shortage conditions in the Colorado River Basin. Under the 2007 Interim Guidelines and updated through the Drought Contingency Plan (DCP) in 2019, the Basin States,

[1] Water delivered to GSFs is accounted for as groundwater in the year of delivery to the GSF.

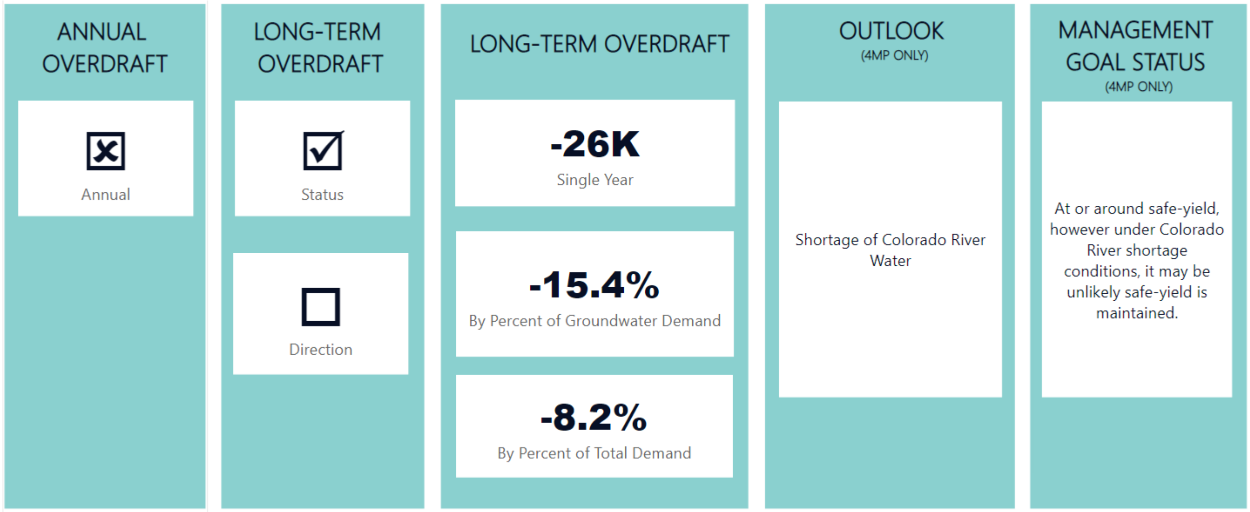
including Arizona, defined the method for distributing cuts at various reservoir elevations, with a goal of reducing the risk of severe reductions. For the first time, a Tier 1 Shortage was declared for 2022, with the potential for ongoing shortage declarations in subsequent years. Agricultural Pool users, who are concentrated in the Pinal AMA, will receive cuts earlier than the Pool's scheduled termination in 2030 under the Tier 1 Shortage. Although reductions in delivery of Colorado River water during the initial shortage period will be partially mitigated, those measures were not designed to be permanent. Furthermore, the 2007 Interim Guidelines and the DCP are scheduled to expire in 2026, and at this time there is uncertainty as to what a replacement regime for operating the Colorado River system may be. The shortage of Colorado River supplies is expected to result in reduced deliveries to storage facilities, and increased recovery of storage credits, leading to a reduced availability of credits. The reduction in availability of credits may also lead to increased groundwater pumping and will potentially reduce the Pinal AMA's ability to achieve its management goal in the future.

In 2019, ADWR published an update to the Pinal AMA regional groundwater model used for AWS purposes, which indicated that there was significant projected unmet groundwater demand. While this update led to extensive stakeholder discussions to consider solutions, ultimately, the result of the unmet demand is that additional AWS applications based on groundwater cannot be approved in the Pinal AMA.

Due to groundwater not being available for future residential development, and due to the anticipated acceleration of groundwater pumping in coming years, the Pinal AMA is not currently meeting and is not expected to meet its management goal.

iv. Tucson AMA

FIGURE 5. Status of the Safe-Yield Management Goal in the Tucson AMA, 2019



Source: Overdraft Data Dashboard, available at: https://new.azwater.gov/ama/ama-data

Annually from 1985 to 2019, the Tucson AMA has been in overdraft in all but 11 years. As of 2019, the TAMA was not in a state of long-term overdraft and maintained that state in the three proceeding years. In 2019, there was a small single year long-term surplus of around 26 thousand AF, which is about eight percent of the TAMA's total water demand and 15 percent of the AMA's groundwater demand.

Tucson has made significant progress towards safe-yield, largely as a result of imported Colorado River water supplies that offset groundwater pumping, while total water demand remained flat or even slightly decreased. However, there is concern for the Tucson AMA's ability to maintain safe-yield. If deliveries of Colorado River water were to be cut under shortage conditions, it would be difficult for the TAMA to "*thereafter maintain*" its state of safe-yield.

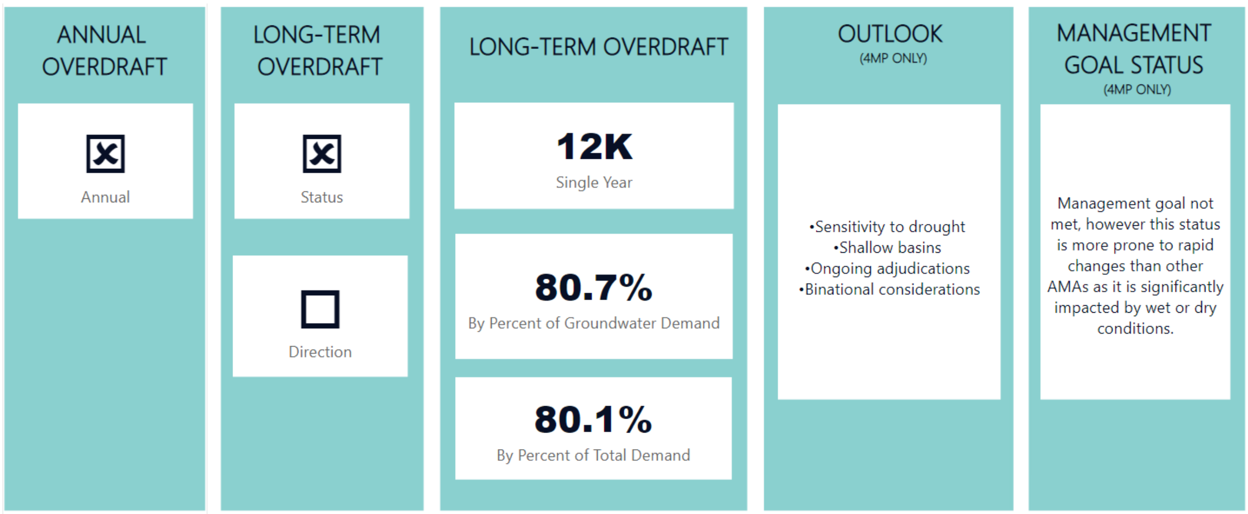
As the hydrology of the TAMA and SCAMA basins are uniquely intertwined, high water levels in the Santa Cruz AMA may impact underflow, an inflow used in the overdraft calculation, to the TAMA, and vice-versa. However, as the TAMA is much larger, the SCAMA is more likely to be impacted by underflow from TAMA. More information about the unique boundary conditions between the two AMAs can be found in the following section about the Santa Cruz AMA.

The Tucson AMA is at or around safe-yield, however under Colorado River shortage conditions, it may be challenging for the TAMA to maintain a safe-yield condition.

v. Santa Cruz AMA

Due to ongoing adjudications in the SCAMA and the statutory recognition of the interconnected nature of groundwater and surface water in the SCAMA, this section of the Safe-Yield Report will avoid referring to water below the land surface as "groundwater". Instead, it will refer to "water, other than stored water, withdrawn from a well", "underground water", or some other variation of these phrases.

FIGURE 6. Status of the Management Goal in the Santa Cruz AMA, 2019



Source: Overdraft Data Dashboard, available at: https://new.azwater.gov/ama/ama-data

Annually from 1985 to 2019, the Santa Cruz AMA has been in overdraft for all but four years. As of 2019, the SCAMA is in a state of long-term overdraft but has made some progress away from an overdraft state in the preceding three years. Although the long-term volume of overdraft in 2019 was not large, it does represent about 80 percent of both the total water and underground water demand in the AMA.

The Santa Cruz AMA management goal has two parts, to maintain safe-yield and to prevent local water tables from experiencing long-term declines ((A.R.S. § 45-562(C)). This goal reflects the unique hydrology in the AMA, where surface water and underground water supplies are closely intertwined. The dual goal was designed with the intent to sustain the Santa Cruz River by maintaining a hydraulic connection between river and aquifer. South of Tubac, water levels adjacent to the Santa Cruz River have largely continued to exist in a state of "dynamic equilibrium," varying seasonally and inter-annually, with wet years allowing water levels to periodically recover. North of Tubac, approaching the Santa Cruz/Tucson AMA boundary, water levels have been in a state of long-term decline from the 1990s through 2015. This is thought to be the result of a combination of increased growth and well pumping in the southern portion of the adjacent Tucson AMA and reduced precipitation and ensuing flood recharge along the northern reaches of the Santa Cruz River with the Santa Cruz AMA. Since 2015, approximately one-third of the decline (approximately 10 feet) has been reversed.

The ability for the Santa Cruz AMA to reach its management goal in the future is impacted by many variables. The narrow and shallow nature of the aquifers makes the Santa Cruz AMA particularly sensitive to the natural variability of precipitation and resulting streamflows. This same shallow aquifer system also supports the development of a beneficial riparian habitat, which provides important ecosystem services but also represents a water demand. Furthermore, because the storage capacity of the aquifer in the Santa Cruz AMA is limited and the aquifer materials are very transmissive, while a wet year can cause water levels to temporarily recover, the water is not 'banked' for the long term. There are also ongoing general stream adjudications of surface water rights claims, and the final outcome of those proceedings may impact the ability to pump water from certain wells in the SCAMA.

The Santa Cruz AMA's southern boundary is the United States-Mexico border. This is a political boundary but not a physical one, since the Santa Cruz River aquifer is continuous from its headwaters in Rafael Valley, Arizona, through Sonora, and into SCAMA. Consequently, water conditions in the Santa Cruz aquifer south of the international border in Sonora can impact water conditions north of the border in the SCAMA. Additionally, wastewater from both sides of the border is collected and treated at the Nogales International Wastewater Treatment Plant (NIWWTP). The treated effluent is discharged to the Santa Cruz River and, minus evaporation and riparian evapotranspiration, eventually infiltrates and recharges the Santa Cruz AMA aquifer. A majority of the wastewater treated at the NIWWTP and discharged as treated effluent into the Santa Cruz River comes from Nogales, Sonora, Mexico. Although plans to enter into negotiations are in progress, the absence of a formal agreement to ensure long-term availability of wastewater to the NIWWTP could result in significant reductions to the amount of effluent discharged into the SCAMA at any time. Treated effluent from the NIWWTP is not the largest source of recharge to the aquifer in the SCAMA, however, it is ecologically significant to the area of the Santa Cruz River in which discharges and may contribute to achievement of the management goal in the SCAMA.

SCAMA's northern boundary is the Santa Cruz-Pima County line, another political rather than physical boundary. The direction of groundwater flow is south to north so that outflow from SCAMA is inflow into TAMA. The volume of flow is proportional to the saturated thickness of the aquifer and the regional hydraulic gradient, both of which vary as water levels at the boundary and on both sides of it rise or fall. The steeper the gradient, i.e., the higher water levels in northern SCAMA are relative to their counterparts in southern TAMA, the more quickly groundwater will pass from SCAMA into TAMA (greater volume per year). The shallower the gradient, the slower the flow and the smaller the annual volume. In this way, groundwater conditions in either AMA can impact the other. However, it more likely that changes to water levels in the TAMA will impact the water levels in the SCAMA, on an AMA-wide basis. As a result, changes and development in the TAMA that impact the AMA's water levels may have the ability to impact the water levels and therefore the management goal in the SCAMA.

Unlike the Tucson, Pinal, and Phoenix AMAs, the Santa Cruz AMA does not have direct access to imported water supplies for consumption or recharge. Natural recharge from periodic runoff events along the Santa Cruz River constitutes the largest single source of inflow in wet years. Assuming pumping remains at historical levels and no new imported water supplies are introduced, both the safe-yield status of the AMA, and its river-adjacent water levels, will continue to hinge primarily on precipitation and streamflow.

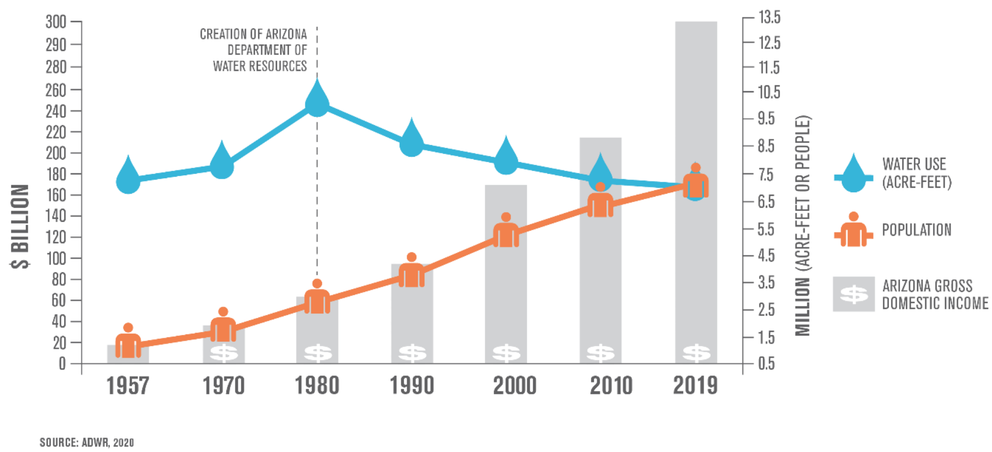
The Santa Cruz AMA has not met its management goal; however, this status is more prone to rapid changes than other AMAs as it is significantly impacted by wet or dry conditions.

9. Conclusion

This report has provided a comprehensive method of assessing overdraft and safe-yield, in each AMA for which it is a goal, including both quantitative and qualitative aspects of the statutory language. The quantitative portion included a consistent method for calculating overdraft on an annual and long-term basis; the qualitative portion addressed the potential barriers to and factors that might influence an AMA's ability to achieve or maintain safe-yield into the future. This report also includes a determination of the status of the management goal in each AMA. For the Pinal AMA, where safe-yield is not the goal, an analysis of long-term overdraft and qualitative influences are evaluated in the context of that AMA's management goal. For the Santa Cruz AMA, additional qualitative context is provided to evaluate the additional piece of the AMA's goal.

The assessment included in this report concluded that more progress is necessary in terms of achieving the management goal in all AMAs. However, the AMAs have made considerable progress since 1980, driven in part by the requirements of the management plans and the guidance of the management goals. Even without achievement of the management goal in every AMA, there has still been improvement in reducing groundwater withdrawals as compared to the trajectory of groundwater use prior to the Groundwater Management Act. Total water use in Arizona has decreased even though there has been an increase in both population and economic growth, as seen in Figure 7 below. Absent achievement in every AMA where it is a goal, safe-yield has still proved to be a valuable guiding principle for the AMAs and management plans.

FIGURE 7. Arizona's Water Management Success



As Arizona heads into a drier future, it is unlikely that safe-yield will be met and thereafter maintained in any AMA. There are several obstacles to meeting the safe-yield goal that are outside the influence of the management plans that may lessen the effectiveness of existing tools. The management goals have had value in guiding the path towards reducing groundwater withdrawals and have undoubtedly resulted in the AMAs being in a stronger, more resilient place than they would have been absent the goal. Still, it is worthwhile to analyze the goal itself as 2025 and the end of the management periods approaches. The remainder of this report will explore some of the obstacles to achieving a safe-yield management goal and will discuss the positive and negative aspects of safe-yield as a management goal. The report will conclude with the future of safe-yield discussions.

i. Obstacles to Achieving the Management Goal

The management plans, although a valuable tool for groundwater conservation, are limited in their ability to move the AMAs towards their management goal due to in part to the obstacles that are outside the plans' influence. These include the influence of other water types, allowable pumping included under the groundwater code, interactions with the implementation of other water conservation programs, and the scope of existing authorities available under the plan itself.

Influence of Other Water Types

The context of the management plans is limited by the statutory focus on groundwater for the conservation requirements. While ADWR regulates total water use for those users who use groundwater under the principle of stacking (for more information on stacking, see Chapter 7 of the 5MP for each AMA), there is no enforcement authority for those that do not use groundwater. However, water of all sources is interrelated and interconnected, and a change in total water use or in the use of another type of water may influence the utilization of groundwater. For example, an increase in the availability and use of surface water could offset the use of groundwater. Similarly, a shortage of surface waters could result in the increase in reliance on groundwater use. This is expected to become increasingly evident in coming years, as changes to Colorado River deliveries due to shortage are anticipated to have a significant impact to groundwater use in Arizona.

Transfers of water within Arizona also have the potential to impact progress towards the management goals. In 2019, a request to transfer water from the Colorado River to aid in the Town of Queen Creek's long-term municipal water supply was made and a portion of the transfer was subsequently recommended by ADWR to the Bureau of Reclamation in 2020. Furthermore, A.R.S 45-552 to A.R.S 45-555 allows for groundwater transportation from specific groundwater basins or subbasins to the AMAs, however transportation pursuant to these statutes has not occurred on a large scale as of 2021.

Allowable Groundwater Demands

Achievement of safe-yield may still allow for groundwater withdrawals, as some level of pumping may be offset by natural recharge. However, a key assumption of the Groundwater Code was that less-intensive uses of groundwater would gradually replace agricultural or other types of intensive uses of groundwater use and that renewable supplies would be used to replace or offset groundwater demands. Under this assumption, significant groundwater demands were allowed to continue, and certain new demands were permitted. These authorities were compromises but have created practical impediments to the reducing groundwater withdrawals and reducing overdraft. The result of this assumption is that the Groundwater Code has allowed overall increases in total water use, and it has allowed some of the increase to occur on groundwater.

As an example, under the Groundwater Code, it was assumed that development of agricultural land into less water-intensive uses (such as residential or industrial uses) would occur, naturally leading to significant reductions in groundwater withdrawals. However, in many cases significant non-irrigation development has occurred without the anticipated offset of reduced irrigated acreage, with development occurring on raw desert land as opposed to development of historically agricultural lands.

Assured Water Supply (AWS) Criteria

The management goals are also referenced by used as a part of other regulatory programs, but they may be applied or interpreted differently for different purposes. For example, consistency with the management goal is one of the criteria that must be met to obtain an AWS determination. Consistency with the management goal for the safe-yield AMAs could include but is not limited to the use of renewable supplies. Extinguishment credits, utilization of groundwater allowances, and membership in the CAGRD may also be a factor in an applicant's meeting the consistency with the management goal criteria. However, meeting those conditions may still allow for continued overdraft in the AMA. Continued overdraft reduces physical availability, which can lead to additional challenges for AWS applicants.

External Influences

Outside the context of the management plans, there are many other factors that impact water demand. These factors may include climatic, economic, or demographic conditions. Arizona has been transitioning into a hotter, drier future. These conditions may change the demands of existing water users and impact the availability of existing supplies. This is evident in the expected ongoing nature of Colorado River shortage: changing climatic conditions has impacted the availability of Colorado River supplies, which comprises about 40% of Arizona's current water supplies.

In addition to climate impacts, many choices for the regulated community will be heavily influenced by economic considerations. Economic considerations may be a result of many factors that are outside the influence of the management plans, such as markets or incentives. For agricultural water users, crop prices have a large impact on the amount of land that farmers choose to irrigate and the crop type that farmers choose to plant, both of which impact the total amount of water used. For municipal and industrial developments, the location and extent of population growth and the subsequent increase in development could be a result of various non-water incentives and conditions within and outside of Arizona. Although the Groundwater Code established water conservation programs, the conservation potential of those programs may be limited due to the regulated community's economic ability to meet the requirements. Incremental progress toward achieving the management goal in each AMA is critical for the long-term sustainability of the AMAs, but it must also be achieved in a reasonable and balanced manner with regard to the economic impact for the regulated community.

One of the key assumptions in the Groundwater Code was that alternative renewable supplies would offset groundwater demands, thus reducing overdraft, and allowing each AMA to move toward safe-yield. However, as all supplies are anticipated to be more constrained in a drier future, progress toward the management goals will only be possible with focus on both augmenting supplies and managing and reducing demand in all sectors. Options for demand management with existing regulatory tools are limited though, with current provisions for allowable groundwater mining, increased non-irrigation development, and concerns related to the economic viability of the regulated community. As every sector contributes to groundwater use in the AMAs, all sectors must be responsible for contributing to an additive, incremental set of management solutions in order to move the AMAs towards their goals, and difficult decisions will have to be made in order to continue finding opportunities for that progress.

ii. Safe-Yield as the Management Goal

As we look toward future management plans or alternative structure that is determined by the legislature after the 5MPs, it is important to reflect on the goal of safe-yield for the AMAs. In the course of developing the 5MPs, stakeholders frequently had questions about the strength, relevance, and function of the safe-yield goal. While there is general agreement that the safe-yield goal has been helpful, this section will discuss two concerns which were frequently raised.

Accountability

The statutory definition of safe-yield includes the phrase "attempts to achieve", which reflects the compromises made in the Groundwater Management Act and reflects consideration for reasonability and economic feasibility as progress is made toward the safe-yield goal. This wording suggests that the goal was not meant to be achieved regardless of potential consequences, using any means necessary, and there are no statutory consequences for failing to achieve the AMA management goals. While there will be long-term environmental, social, and economic consequences for failing to meet water management objectives, without statutory accountability, there is concern that safe-yield may not provide the push needed to achieve groundwater sustainability in those AMAs. With growing awareness of water scarcity and significant risk of ongoing shortage, the safe-yield goal may not have the same impact as it was assumed it would 40 years ago.

One of the tools available within the management plans is demand management, however, increasing conservation requirements is challenging while considering feasibility for the wide range of water users regulated by those requirements. Demand reductions through conservation requirements are critical for preserving groundwater, but impacts do not always fall equitably across the diverse regulated community and changing water use practices may require investment that is more difficult for some users than others. Still, with climate impacts and changes in supply availability, it is clear that "business as usual" in terms of water use will have negative impacts on groundwater supplies and on long-term groundwater sustainability.

It is clear that reasonability and economic feasibility are important criteria in identifying solution sets for water management challenges. In light of increasing supply challenges though, it may be that the "attempts to achieve" phrasing is due for reconsideration. Additionally, while demand management has long been a portion of management strategies in the AMAs, much of the strategy for achieving management goals has historically focused on augmenting supplies. Supply side solutions will still be important, but those additional supplies are experiencing increased competition. While demand side solutions are also increasingly difficult to negotiate, a renewed focus on reducing total water use will be critical to balancing the supply/demand equation.

Changes to Local Water Levels

Although achieving safe-yield would create a balance between groundwater withdrawals and recharge, it may not prevent other adverse impacts the physical aquifer. Safe-yield is an AMA-level goal focused on groundwater; it does not consider differing impacts of groundwater use on a sub-AMA or more localized scale, and it does not account for changes in water levels due to underground storage, recovery, or replenishment. At this large geographic level, an AMA may achieve the goal and still experience localized water level declines. Although stable local water levels and a healthy aquifer may not have been the intent of the management goals, this is an important consideration for groundwater sustainability and for the prevention of negative impacts like subsidence and fissures.

iii. Ongoing Discussions

Safe-yield has been a productive metric for the AMAs and has undoubtedly guided the AMAs towards a more resilient future than would have been realized absent the goal. The framers of the Groundwater Management Act were visionary in building a path toward groundwater sustainability, and the challenges ahead will require bold, visionary actions to secure Arizona's water future. Conservation and augmentation the existing management tools will not be sufficient for the AMAs to meet their goals, and climate change is intensifying the complexity of the water management challenges ahead. This makes the discussion of the management goals and the tools available to achieve those goals increasingly important. Creative and collaborative discussions with input from a broad base of stakeholders will be essential to understanding the impacts and reaches of any solution sets.

These discussions have already begun in the Post 2025 AMAs Committee of the Governors Water Augmentation Innovation and Conservation Council (Council)[2]. The issues described in this conclusion such as allowable groundwater pumping, water levels in the AMAs, the assured water supply program, and the AMA management structure, including the management goal have been topics of discussion in the Post-2025 AMAs committee. Arizona has repeatedly demonstrated its ability to tackle difficult issues thoughtfully, creatively, and proactively, and continued discussion in the Council and in other forums will be critical to identifying and implementing the creative and collaborative solutions necessary to build a sustainable water future for Arizona.

[2] Information on the Council's subcommittees, meetings, and activities is available at: https://new.azwater.gov/gwaicc

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Appendix A: Modeled Components Used in the Calculation of Safe-Yield

Table of Contents

1. Introduction:

This appendix will provide details on Arizona Department of Water Resources (ADWR) regional groundwater flow modeling as it relates to the natural components that are used in the safe-yield calculation. The first section will discuss the regional groundwater flow model, why it is used, and why it is an appropriate tool from which to derive the natural components of a water budget. The second section of the appendix will go into detail on how the individual components that are used in the safe-yield calculation are derived. This appendix is not intended to be a comprehensive document on the ADWR regional groundwater models, which are specific to each AMA. More information about each ADWR regional groundwater model can be found at ADWR's modeling portal, accessible on the web at: https://new.azwater.gov/hydrology/groundwater-modeling/adwr-models

2. ADWR Regional Groundwater Flow Models

ADWR develops regional-scale groundwater flow models (the model(s)) to provide a common basis for understanding the state's groundwater aquifers. They are calibrated to a period of time ranging from several decades to more than a century, which means they are built to represent long-term changes in groundwater conditions across large areas of the state.

These models are then put to the task of providing answers to a variety of questions for different applications, including safe-yield. Other applications include determination of 100-year physical availability for the Assured and Adequate Water Supply program; the evaluation of waterlogged conditions in the Buckeye Water Logged Area; the stream adjudication process; as well as for external scientific, academic, and commercial projects concerned with groundwater supply.

ADWR's regional groundwater flow models are best suited for answering questions about groundwater conditions at large spatial scales, such as an AMA or a metropolitan area, provided the model is properly calibrated and the solutions are not adversely influenced by boundary conditions. They are less suited at local, or site-specific scales, such as an individual well or a single farm. Because safe-yield is calculated at the AMA-level, ADWR's regional groundwater flow models are well suited to provide reliable estimates of natural recharge components for this application.

The most recently published ADWR groundwater flow model represents the best available tool, at the time, available for a given AMA or model area. However, as additional data becomes available and the historical period of record expands, ADWR periodically updates its published models. In addition to extending the temporal period captured by the models via the introduction of new pumping, recharge, and other time-varying stresses to the aquifer, the models are also re-calibrated to an extended set of observations, such that more recent aquifer behavior is simulated appropriately. During such updates, models are also frequently refined. Refinements may be driven by a better understanding of aquifer geology or the hydrogeologic system due to newly-available information from aquifer tests, subsurface investigations, or geologic mapping, among others. They may also include the introduction of new MODFLOW packages which were not available during earlier modeling efforts (e.g., the simulation of subsidence in newer releases of the Pinal AMA model; the planned future introduction of the unsaturated zone flow (UZF) package) or the replacement of newer MODFLOW packages for older analogues (e.g., a transition from the traditional MODFLOW well package to the newer multi-node well package).

i. The Regional Groundwater Flow Model and Safe-Yield

Unlike the metering of a groundwater pump or inflow to a recharge basin at an Underground Storage Facility (USF) site, the "natural" components of the water budget are not reported to the Department. Nor are they measured directly in the field. Absent direct measurement and reporting, water budget components like mountainfront recharge, flood recharge, underflow at groundwater basin boundaries, evapotranspiration, and canal seepage must be estimated.

Rather than creating separate estimates or developing stand-alone models for each of the safe-yield components, ADWR relies on its regional groundwater flow models. These models necessarily simulate all components of the physical water budget and provide a representation of the intrinsic properties of the aquifer. They provide a numerical "reality check" on the values of each inflow or outflow by ensuring the estimates must individually and collectively obey the laws of physics. This allows for more cross-validation of any particular budget term (e.g., rates of evapotranspiration balanced by rates of flood recharge) and leverages the available observation data to apply to all processes, even if indirectly (e.g., rates of mountainfront recharge can be validated by observations of streamflow downgradient). In a well-constructed, well-calibrated groundwater flow model, water budget components, such as groundwater pumping or USF recharge, which are measured and thus known with higher degrees of certainty, provide additional constraint and certainty to the unmeasured (or unmeasurable) terms, such as basin underflow or mountainfront recharge, which can be estimated as the residuals. If the model is calibrated correctly, budget components such as recharge and underflow are indirectly based on data. Furthermore, in a properly constrained model, information about the reliability of those estimations is also available.

In short, natural components of the safe-yield calculation rely on models because direct measurements are not available. It is ADWR's position that its regional groundwater flow models provide these estimates at appropriate spatial and temporal scales.

ii. MODFLOW and Calibration

Throughout this appendix, there is reference to MODFLOW, its packages, and calibration. Both concepts are briefly explained below.

A regional groundwater flow model is a comprehensive, over-arching, unified representation (conceptualization) of the aquifer system. Various computational tools are available to translate a conceptual understanding of the aquifer system into a numerical one. ADWR relies on one of the more commonly used of these, called MODFLOW. MODFLOW is a computer code, or program, developed by the U.S. Geological Survey (USGS) to standardize the numerical representation (i.e., the creation of models) of groundwater systems and the solution of the groundwater flow equations. Different aspects of the groundwater system are handled by independent, modular pieces of code called packages. Each package addresses a specific feature of the hydrologic system, such as pumping from wells or flow across a model/basin boundary, or with a specific method of solving the set of simultaneous equations resulting from the finite-difference method. Packages are individual building blocks; they require input data (e.g., location of wells, their construction details, and pumping schedules) and contain the code needed to process that input. Together, the packages form the regional groundwater model. The MODFLOW code passes information between the packages and the model and calculates the effect of the processes represented by individual packages on overall heads and flows throughout the model area.

For a groundwater model to be a considered a valid representation of current or past conditions, or a reliable basis for future projections, it must successfully simulate observed (historical) aquifer behavior within some acceptable level of accuracy. Because the hydrogeology of regional aquifers and the stresses they are subject to over long periods of time are poorly known, initial estimates of aquifer structure, its hydrogeologic properties, and boundary conditions are frequently imperfect when a model is first constructed. During its subsequent development and refinement, field observation data can be used to help identify areas (or times) at which the model is more successful or less successful in representing observed aquifer behavior and serve as "targets" or guides for getting the model "on track." A calibrated model is one which can be relied on to produce outputs (heads, flows) which are reflective of observed (or inferred) conditions.

The basic definition of model calibration as the systematic adjustment of certain parameter values, like recharge and hydraulic conductivity, to incrementally improve the model's matching of observed heads and flows, while factually true, is limited. Parameter adjustment is only one aspect of model calibration. In the broader and more complete sense of the term, calibration is a search for a unifying conceptual and numeric model that best satisfies the available observations and prior knowledge of the aquifer system. Key aspects of the model, such as the conceptualization of the flow system, that influence the capability of the model to meet the problem objectives are also evaluated and adjusted as needed during calibration (Reilly and Harbaugh 2004[3]).

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[3] Reilly, T. E., & Harbaugh, A. W. (2004). *Guidelines for evaluating ground-water flow models*. US Department of the Interior, US Geological Survey.

iii. Model Confidence

Currently, ADWR uses an automated parameter estimation process to estimate those aquifer properties and stresses which are imperfectly known and cannot be specified a-priori with sufficient confidence. Just as with a manual trial-and-error calibration, the goal remains to arrive at a model which is more reflective of real-world conditions (or the true state of the simulated aquifer) by minimizing model error, or the discrepancy between synthetic (modeled) responses (changes in water levels, and flows, over time) and those directly observed (measured in the field).

One beneficial byproduct of the automated parameter estimation is that descriptive statistics, such as parameter sensitivities and correlations, are automatically produced. Together, parameter sensitivities and correlations are used to calculate 95% confidence intervals, which are useful for understanding just how likely the "most likely" (best fit) estimates are. However, confidence limits provide only an indication of parameter uncertainty. They rely on a linearity assumption which may not extend as far in parameter spaces as the confidence limits themselves (Doherty 2017[4]).

3. Modeled Components

i. Mountainfront Recharge

Mountainfront recharge refers to the infiltration of precipitation falling in the mountains surrounding a basin, which flows downgradient and in time recharges the aquifer. Initial estimates of mountainfront recharge may rely on regression-based estimates of recharge as a percentage of total precipitation (Anderson 1992[5]), prior modeling studies which typically calibrate the rate of recharge to available water level and flow data, or manual Darcy strip analysis (Wilson and Guan 2004)[6] which estimates recharge on the basis of observed hydraulic gradients and some assumed aquifer conductivity and saturated thickness values. However, because all such methods of estimating mountainfront recharge are inexact, and rely on their own untested assumptions, initial rates are calibrated to the latest period of record (observation data).

In groundwater flow models, historically, mountainfront recharge has been simulated to be essentially invariant over time (though not in space) due to the significant lag and attenuation imposed by the water's flow through the unsaturated zone before it reaches the regional aquifer. In ADWR's groundwater flow models, mountainfront recharge is specified using the MODFLOW Recharge package, which requires as an input the rate of recharge (length/time). The recharge rates are calibrated to available calibration targets over the model period, resulting in the most plausible long-term-average rate of recharge based on available data.

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[4] Doherty, J. (2017). PEST Model-Independent Parameter Estimation User Manual Part I: PEST, SENSAN and Global Optimisers. *Watermark Numerical Computing, Brisbane, Australia*, *pp* 3349.

[5] Anderson, T. W., Geoffrey W. Freethey, and Patrick Tucci, Geohydrology and Water Resources of Alluvial Basins in South Central Arizona and Parts of Adjacent States, U.S. Geological Survey Professional Paper 1406 -B, United States Government Printing Office, Washington, 1992.

[6] Wilson, J. L., & Guan, H. (2004). Mountain-block hydrology and mountain-front recharge. *Groundwater recharge in a desert environment: The Southwestern United States*, *9*.

ii. Stream Recharge

Stream recharge occurs as channelized surface flows, particularly during large runoff (flood) events, that infiltrates through the riverbed, and reaches the regional aquifer. Like the flows themselves, the recharge from stream/flood flows can vary widely from year to year and month to month. Many reaches of the rivers and streams in the state's AMAs flow only during, and immediately following, large precipitation events. In these reaches, stream recharge is particularly variable and keyed to large flood flows only, since there is not a "background" surface flow to provide a continual source of leakage to the aquifer.

The actual volume of stream recharge at a point in space and time depends on the amount of water available in the stream and the recharge capacity of the streambed and local aquifer. Because infiltration can be both rate and volume limited, highly transmissive aquifer sediments (e.g., young alluvium along the Santa Cruz River in SCAMA) will allow water to infiltrate quickly from stream to aquifer. They will thus accept more flood recharge than tighter, less transmissive sediments with a smaller recharge rate capacity. Conversely, areas where groundwater levels are at or near land surface (e.g., the Buckeye Water Logged Area along the Gila River in the Phoenix AMA) may well be composed of equally transmissive materials and pose no rate limitation to recharge. However, as the aquifer is nearly full, less additional recharge can be accommodated due to volume limitations. There is, therefore, a natural ceiling to the maximum potential flood recharge, beyond which additional flood flows will be unable to infiltrate locally and will flow downstream and/or be lost to evapotranspiration.

Some groundwater models treat streams only as boundaries along which groundwater can discharge from the aquifer (e.g., Pool and Dickinson 2007[7]). ADWR has treated them more explicitly, with channelized runoff permitted to infiltrate and contribute directly to the basin water budget. In this approach, even streams or river segments which typically run dry are given the opportunity to capture appreciable amounts of water because they have the storage space to accept large pulses of recharge during flood periods.

In ADWR's groundwater flow models, stream recharge is simulated using a combination of MODFLOW stream-routing packages (STR or SFR), and specified flux using the Recharge (RCH) package. The stream routing packages provide the elevation control that defines at what elevations the stream will act as a source of recharge to the aquifer or as a sink, discharging from the aquifer into the stream. The stream routing packages also include parameters that regulate the rate of infiltration (or exfiltration) through the riverbed, and the rate of downstream flow along the surface (via controlling for channel geometry, roughness, and slope). Where it occurs, treated effluent released to the stream is also generally included as an inflow in the stream routing packages. The effluent co-mingles with other "natural" flows and is routed downstream by the streamflow routing package. Discrete recharge pulses from flood flows can be included by ADWR in its models using the Modflow Recharge package. Initial timeseries of recharge may be based on analysis of streamflow, or in its absence, participation. The recharge timeseries are then calibrated to best match the available historic head and flow targets.

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[7] Pool, D. R., & Dickinson, J. E. (2007). *Ground-water flow model of the Sierra Vista subwatershed and Sonoran portions of the upper San Pedro basin, southeastern Arizona, United States, and northern Sonora, Mexico* (No. 2006-5228). Geological Survey (US).

iii. Underflow at Basin Boundaries

Underflow refers to the subsurface movement of groundwater from one groundwater basin or sub-basin to another. The rate and direction of groundwater flow is determined by the gradient in hydraulic head and saturated thickness. In unconfined aquifers, groundwater flows from areas of higher groundwater elevation to areas of lower groundwater elevation. This is a function of both subsurface topography (changes in the elevation of the top of bedrock) and water levels. Underflow occurs between adjacent AMA basins (SCAMA/TAMA; TAMA/Pinal; Pinal/Phoenix), between the AMA basins and adjoining basins outside the purview of the AMA program (e.g., Prescott/Upper Hassayampa; Prescott/Agua Fria; Phoenix/Agua Fria; Phoenix/Harquahala).

The rate of underflow can increase or decrease over time, or even change directions because it is based on differences in water levels. This rate change occurs if the water table gradient reverses and the water table in an area of previously higher heads is sufficiently lowered. Underflow rates may not be the dominant terms of AMA water budgets, but a greater rate of inflow into an AMA means that there is a 1:1 increase in the outflow from another basin. At some boundaries this may be a particularly sensitive issue. At the SCAMA/TAMA boundary, for example, the increasing rate of underflow into TAMA from SCAMA is a gain and has a positive, albeit relatively small, impact on the TAMA water budget and evaluation of safe yield. For the much smaller Santa Cruz AMA, this same rate, here an outflow or loss, represents a much larger portion of the total basin water budget and negatively impacts the AMA's safe yield standing.

In ADWR's models, the underflow rate at each flow boundary is either specified directly using MODFLOW recharge or well packages, or more indirectly represented by head dependent boundaries like MODFLOW's general or constant head boundary packages. The head dependent boundaries require an input of specified head over time, and an estimate of conductance. In this sense they are similar to the manual Darcy strip analysis, except that internal heads are computed dynamically by the model, and the conductance can be a calibrated parameter rather than estimated once. Whether underflow is parameterized as a directly specified flux, or whether it is represented by a head gradient and estimated conductance, the initial estimate is calibrated to available calibration targets over the entire model period.

iv. Evapotranspiration

Evapotranspiration refers to the sum of soil evaporation and plant transpiration. Plants uptake water from the subsurface for metabolic function. The water is released to the atmosphere by transpiration. Evapotranspiration tracks with the plant growth cycle, and for most natural riparian vegetation, is lowest in winter when plants are dormant and ramps up in spring and summer, peaking around monsoon season. Within the growing season evapotranspiration is both energy and water limited. However, in arid and semiarid environments like Arizona's AMAs, the availability of water and its depth relative to the reach of plant roots is the real driver behind changes in evapotranspiration from year to year. Because riparian vegetation and streams are co-located, there is some degree of (inverse) correlation between groundwater outflow as evapotranspiration and as stream discharge. Losses to the aquifer via evapotranspiration or via stream discharge will appear identical in water level targets. Additional flow targets can help constrain a plausible range of stream discharge rates, allowing the estimation of evapotranspiration as the residual. Nevertheless, collectively, the sum of simulated groundwater discharge and evapotranspiration are more reliable than either one of these components separately.

ADWR models simulate the withdrawals of groundwater by riparian vegetation through evapotranspiration using the MODFLOW Evapotranspiration package. ADWR generally has simulated only riparian evapotranspiration in its regional groundwater flow models, because only along rivers and streams are groundwater levels sufficiently high to support plant uptake of groundwater (rather than vadose zone). The MODFLOW Evapotranspiration package requires as inputs an extinction depth (analogous to root depth) and a maximum evapotranspiration rate. Both are usually obtained from literature, which may include prior modeling or physical (field-based) studies.

In the model, groundwater is lost to evapotranspiration at the specified maximum rate when simulated water levels are at land surface (when the aquifer is full). If water levels drop, the rate of evapotranspiration decreases proportionally, until the water level passes the extinction depth and evapotranspiration ceases entirely. Unless a reduction in subsequent years is explicitly specified by the modeler, when water levels recover and rise above the extinction depth, the simulation (calculation) of evapotranspiration will resume. While reductions in groundwater losses to evapotranspiration could be caused by changes in vegetation (natural die off, active management by clearing, etc.), because ADWR's representation of maximum potential evapotranspiration rates are typically held constant over the safe yield study period, reductions in model-simulated evapotranspiration losses over time mask dropping aquifer levels. Therefore, while decreasing groundwater outflows to evapotranspiration means fewer demands on the current safe yield calculation, they are indicative of a growing loss of water in storage – either as a result of increasing withdrawals to pumping, or to decreasing rates of net recharge, or a combination of both.

v. Canal Seepage

As water is conveyed along canals, a portion of the flow infiltrates and recharges the aquifer. With measurements of canal flow at an upstream and downstream location, and reporting of net diversions along the reach, the net loss to seepage and open water evaporation can be calculated as the remainder. By estimating open water evaporation, the residual can be attributed to seepage.

In ADWR's groundwater flow models the contribution of canal seepage to the aquifer is assigned as a specified flux using the MODFLOW Recharge package. ADWR staff do not measure canal flows. However, some entities, such as Central Arizona Project and San Carlos Irrigation Project, conduct their own field work and report estimates of canal seepage which ADWR applies in its groundwater flow models. In other cases, where reported canal seepage estimates are not available, ADWR makes its own estimates. The net rates of canal seepage (recharge) are calibrated to the full period of record.

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