

Technical Documentation for the Central Arizona Project Service Area Model (CAP:SAM)

This document describes the operations of the Central Arizona Project Service Area Model (CAP:SAM). CAP:SAM simulates water demands for more than 100 major water users in the CAP service area, and 16 different supply types used to meet their demands. The model, which is under continuous development, operates on an annual timestep and can be used to simulate a wide range of future conditions. The model performs a large number of interrelated calculations, broadly organized into four conceptually simple steps:

- 1) **Project Demands**
- 2) **Determine Available Supplies**
- 3) **Request Supplies**
- 4) **Fulfill Demands**

These steps are performed for water users that are classified into five categories: **Municipal, Agricultural, Industrial, Tribal and Institutional.**

CAP:SAM was developed using GoldSim software, which is a graphical, object-based modeling environment that allows complex mathematical relationships to be defined and calculations to be performed that would be difficult or impractical to implement using spreadsheets or traditional computer code. The model also relies heavily on data managed in a relational database—RPA.db—also developed by CAP's Resource Planning & Analysis department.

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1.) **Project Demands**

CAP:SAM produces individual projections for 80 public and private water providers in the CAP service area, including all Large Water Providers (i.e., serving 250 AF or more), as well as Small Providers that are either CAP subcontractors or providers serving CAGR Member Lands. These providers account for more than 99% of the demand in the municipal sector. For each of these providers, the model separately considers their existing and new demands.

Existing Demand

Existing municipal demand is the water use associated with demands that were in existence for the most recent (non-projection) year. The initial existing demand is based on the volume reported by each provider to ADWR. That demand (in acre-feet) and the count of housing units for that year are used to generate an initial Gallons Per Housing Unit per Day (GPHUD) value. The model allows the user to modify that GPHUD by specifying an annual rate of change (+ or -, in %), along with both a cumulative maximum change (in %), and a minimum "floor" (in GPHUD). The floor prevents the modified GPHUD value from dropping to unrealistically low values (if a negative rate of change has been specified). If an initial GPHUD is below the floor, its value is held constant at the initial value. The model then generates a projection of existing demand by multiplying the modified GPHUD, which can vary every year, by the number of existing housing units, which remain fixed.

New Demand

CAP:SAM simulates new demand on the basis of housing units that are projected to be built in each water providers' service area. Each projected housing unit is multiplied by a provider-specific GPHUD that represent the demand from the housing unit itself as well as a fraction of the ancillary demands (e.g., new parks, commercial land uses, etc.).

This projection is accomplished in the following series of steps:

- 1) Develop Housing Unit Projection
- 2) Spatially Distribute Housing Units Among Water Providers
- 3) Convert Housing Units to Demand
- 4) Calculate Member Land Demands
- 5) Calculate Non-Potable Demand

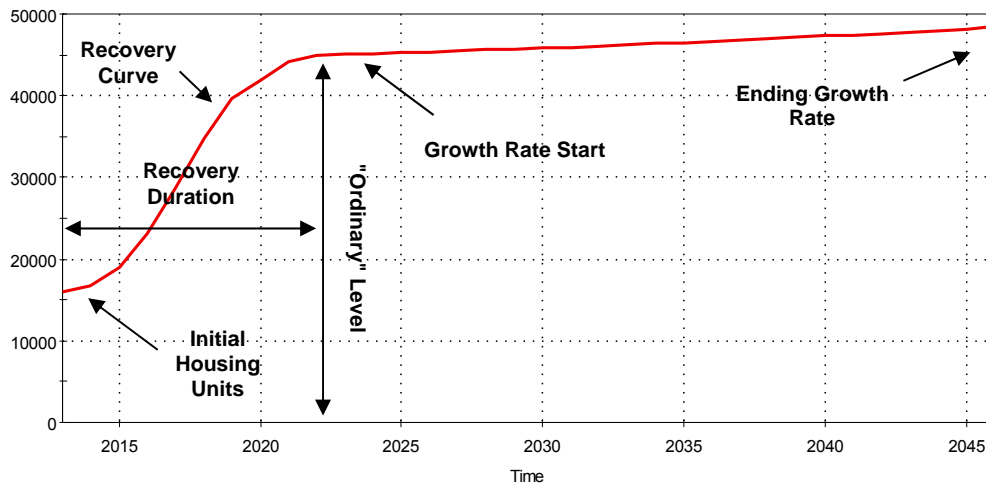
Develop Housing Unit Projection

The calculation of new municipal demand begins with an annual projection of new housing units for the entire CAP Service Area. To account for the lingering effects of the housing collapse, and to allow users to test a wide range of growth scenarios, CAP:SAM allows the user to define a number of components of the annual growth projection:

- a) The initial rate of housing units (HUs per year)
- b) The duration of the housing recovery (years)
- c) The housing recovery curve
- d) The post-recovery "ordinary" rate of housing units (HUs per year)
- e) The percentage growth rate (+ or -, in %) following the housing recovery
- f) The percentage growth rate (+ or -, in %) at end of 50 years

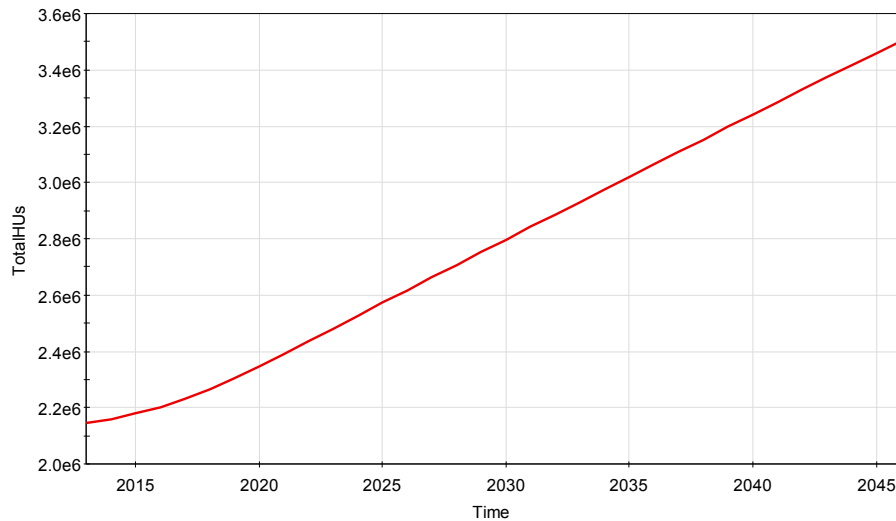
A graphical example of these components is shown below (Figure 1).

Figure 1. Components of Annual Housing Unit Projection



The cumulative results of an example annual projection are shown in Figure 2.

Figure 2. Cumulative Housing Unit Projection



Spatially Distribute Housing Units Among Water Providers

CAP:SAM spatially distributes housing units based on a reference projection of housing units by provider, by time. CAP:SAM is capable of utilizing any reference projection, including official geographic forecasts developed by the Associations of Governments (MAG, CAG, and PAG). The Associations' forecasts are referenced to the years 2010, 2020, 2030 and 2040, but the model stores these as generic index values (1, 2, 3, 4, etc.), which allows it to accept any time interval or duration.

To accommodate a variety of growth rates, while maintaining the integrity of the spatial growth pattern, CAP:SAM adjusts the timing of the reference projection to match the housing units generated by the model using the parameters specified by the user in the annual housing unit projection. For example, a particular model run might project 2.8 million housing units for 2030, but the reference projection might have projected 2.9 million for 2030. CAP:SAM accounts for this by estimating the point within the reference projection at which 2.8 million units were distributed, and then applies that estimate to each water provider. This process occurs in two steps.

First, the model determines the index value at which the housing units in the model projection are equal to the sum of housing units in the reference projection. The model does this with linear interpolation of the housing units associated with the known (i.e., index) values. CAP:SAM uses GoldSim's `vindex()` function to perform this, but it also may be written as follows,

$$\text{Index}_n = \text{Index}_a + \frac{\text{HU}_n - \text{HU}_a}{\text{HU}_{a+1} - \text{HU}_a}$$

where,

Index_n = interpolated index value associated with the model projection in year N

$Index_a$ = index value from a known year in the reference projection in which the sum of housing units (HU_a) is closest, but does not exceed, the projected housing units (HU_n),

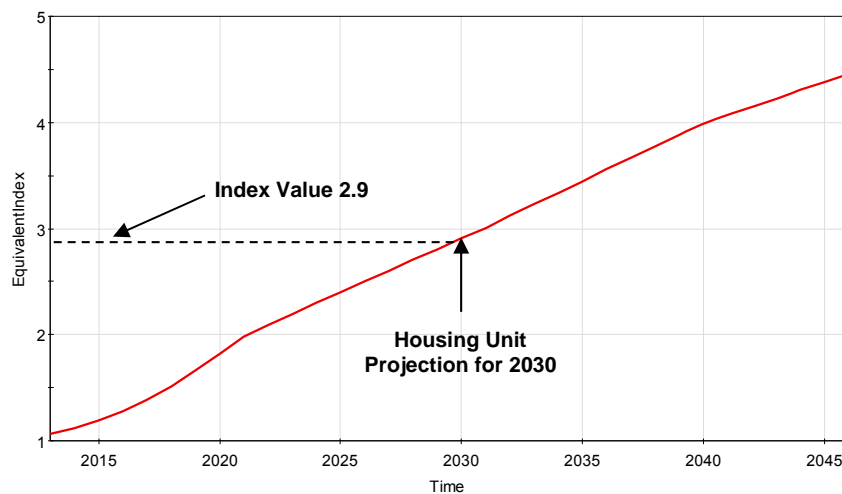
HU_n = total housing units in year N from the model projection

HU_a = total housing units in a known year in the reference projection in which the sum of housing units is closest, but does not exceed, the projected housing units (HU_n)

HU_{a+1} = total housing units in a known year in the reference projection in which the sum of the housing units is closest, but exceeds, the projected housing units (HU_n)

In the example shown in Figure 3, the cumulative growth up to 2030 has been slightly lagging the reference projection, so the housing unit projection for 2030 in the model corresponds with an index of 2.9 (i.e., the year 2029) in the reference projection.

Figure 3. Index Value of Housing Unit Projection



In the second step, CAP:SAM applies the interpolated index value to the housing unit projection for each of the water providers. In our example, a 2029 projection is developed for each provider. To accomplish this, the model uses GoldSim's vinterp() function, which performs linear interpolation between the housing unit totals in known years in the reference projection. In equation form, this may be written as follows,

$$HU_n = HU_a + (HU_{a+1} - HU_a) \times (Index_n - Index_a)$$

where,

HU_n = housing units for a provider at year N

$HU_{a,a+1}$ = housing units in the two closest known reference projection years

$Index_n$ = interpolated index value from previous step

$Index_a$ = indices for the two closest known reference projection years

These steps are performed for each water provider, at each model timestep. This allows CAP:SAM to allocate housing units among the water providers under any growth scenario.

Convert Housing Units to Demand

New municipal demand is calculated by multiplying the cumulative projected new housing units for each provider by a set of provider-specific GPHUDs. The GPHUDs for new demand are

developed outside of the model, and are separate from the ones derived within the model for existing demand. CAP:SAM can be loaded with multiple sets of GPHUDs for new demand, and the user can select from among them via a drop-down list. As with the Existing Demand, the user can modify the initial New Demand GPHUDs by specifying an annual rate of change (+ or -, in %), along with both a cumulative maximum change (in %), and a minimum "floor" (in GPHUD). These parameters are also independent of those specified for Existing Demand.

Calculate Member Land Demands

In addition to demand at the water provider level, CAP:SAM estimates demand associated with current and future CAGR Member Land subdivisions. The first model step selects only undesignated providers; both those currently serving Member Lands, and those that may in the future. CAP:SAM contains a table of initial AWS/CAGR status for each water provider, and the model allows the user to modify that status through time, so this determination is made at each model timestep.

The next calculation step distributes projected housing units for each undesignated provider among five CAGR enrollment categories:

Table 1. CAGR Enrollment Categories

Notation	Enrollment Category
E	Exempt (e.g., pre-95 subdivisions, infill lots, etc.)
P1	Plan 1 ("Initial Plan")
P2	Plan 2 ("2005 Plan")
P3	Plan 3 ("2015 Plan")
PP3	Post-Plan 3

The model contains user-selectable sets of reference distribution ratios among those five categories that can vary through time. This functionality allows different assumptions about new versus existing enrollment to be made. CAP:SAM also contains a beginning inventory of enrolled but unconstructed Member Land lots, differentiated by provider and Plan Period (i.e., "Initial Plan" or "2005 Plan").

Projected housing units for each undesignated provider are first multiplied by the "Exempt" ratio (note: CAP:SAM allows fractional housing units in these steps). The model then attempts to distribute the remaining projected housing units among the other four categories based on the reference distribution ratios. Depending on the remaining inventory of enrolled but unconstructed Member Land lots for each provider, there are four possible allocation scenarios;

Table 2. Scenarios for Member Land Housing Inventory

Notation	Allocation Scenario	Result
a	Sufficient inventory	Units are allocated based on the reference ratios
b	Insufficient Plan 1 inventory	Unallocated Plan 1 units are reallocated to Plan 2, Plan 3 and Post-Plan 3
c	Insufficient Plan 2 inventory	Unallocated Plan 2 units are reallocated to Plan 1, Plan 3 and Post-Plan 3
d	Insufficient Plan 1 & Plan 2 inventory	Unallocated Plan 1 & 2 units are reallocated to Plan 3 and Post-Plan 3

It is not possible to know ahead of time which allocation scenario applies, so CAP:SAM evaluates each of them. This is accomplished in three steps: calculate a coefficient for each of these outcomes; apply those coefficients to allocation formulae; select the correct coefficient. The coefficients in step one are calculated as follows;

$$CO_a = 1.0$$

$$CO_b = \frac{T - U_{P1}}{T \times (R_{P2} + R_{P3} + R_{PP3})}$$

$$CO_c = \frac{T - U_{P2}}{T \times (R_{P1} + R_{P3} + R_{PP3})}$$

$$CO_d = \frac{T - (U_{P1} + U_{P2})}{T \times (R_{P3} + R_{PP3})}$$

where,

$CO_{a,b,c,d}$ = each the four possible coefficients

T = total housing units to be allocated

$U_{P1,P2}$ = unbuilt inventory from Plan 1, and Plan 2

$R_{P1,P2,P3,PP3}$ = reference distribution ratios for Plan 1, Plan 2, Plan 3, and Post-Plan 3

In the second step, each of these coefficients is applied to the four allocation formulae below;

$$A_{P1} = \min (U_{P1}, (T \times R_{P1} \times CO_x))$$

$$A_{P2} = \min (U_{P2}, (T \times R_{P2} \times CO_x))$$

$$A_{P3} = (T \times R_{P3} \times CO_x)$$

$$A_{PP3} = (T \times R_{PP3} \times CO_x)$$

where,

$A_{P1,P2,P3,PP3}$ = allocated units for Plan 1, Plan 2, Plan 3, and Post-Plan 3

CO_x = one of the four possible coefficients (a, b, c or d)

T = total housing units to be allocated

$U_{P1,P2}$ = unbuilt inventory from Plan 1, and Plan 2

$R_{P1,P2,P3,PP3}$ = reference distribution ratios for Plan 1, Plan 2, Plan 3, and Post-Plan 3

This calculation step results in four allocation sets; one set for each coefficient. The final calculation step sums the sets of allocation formulae.

$$T = A_{P1} + A_{P2} + A_{P3} + A_{PP3}$$

For each provider, the correct coefficient is the one in which the sum of the allocation units is equal to the total units, "T", for that provider. Note that these calculation steps affect the distribution of housing units among CAGR Plan periods, but the total projected housing units are always the same.

To convert these housing unit projections to demand, the user specifies GPHUDs that are specific to Member Land demand. Because Member Land demand does not include ancillary non-subdivision demand, the Member Land GPHUDs are different from the water providers' overall New Demand GPHUD. The new demands for Member Land housing units are calculated separately as a subset of the overall new demands.

For each Member Land, a buildout demand estimate was generated. That estimate was then multiplied by the fraction of unbuilt lots ((Total – Built)/Total) for that subdivision. The sum of those demands, differentiated by Plan 1 and Plan 2, were then totaled by provider. Those totals

represent the demand from unbuilt lots associated with currently enrolled Member Lands. The demand totals were then converted to GPHUDs by dividing by the total number of unbuilt Member Land lots (differentiated by Plan). Note that for a water provider that serves Member Lands, there may be as many as five different GPHUDs (e.g., Existing, New, Plan 1, Plan 2, Plan 3+).

Calculate Non-Potable Demand

CAP:SAM projects non-potable demand as a subset of overall demand because that demand will only be satisfied with a subset of the providers' supplies—those that are non-potable. The model projection starts with existing non-potable use (i.e., the reported use in the last non-projection year), and then applies a user-selected annual change factor that is either zero (i.e., existing demand held constant) or linked to the overall rate of change in the providers' demand (e.g., changes at same rate, half the rate, etc.).

2.) Determine Supplies

The second major step of the CAP:SAM model determines the total legal and physical supply availability, by supply type, for each projection year.

Effluent

The overall supply of effluent is calculated using a user defined interior use ratio representing the percentage of total municipal demand that results in sewer flows. The model also allows for an annual change (in %) representing the changing balance over time between indoor and outdoor use. These ratios are applied across all water providers. Production of effluent is calculated as the sum of new and existing municipal multiplied by the modified interior use ratio.

Surface Water

CAP:SAM allows the user to input an SRP and non-SRP surface water supply amount as an annual total volume. Note that CAP:SAM accounts for water supplies based on ADWR Annual Reporting conventions, so this definition of surface water includes water that originates from wells, including AS&R.

CAP

CAP:SAM allows the user to input an annual diversion supply from the Colorado River, the total system losses, and the net storage to Lake Pleasant. The CAP supply is the sum of these values. CAP:SAM is also designed to accept externally generated CAP supply volumes (e.g., from CRSS).

CAP Long-Term Storage Credits (LTSC)

The supply of LTSCs is specific to each water provider, and is based on an initial balance, along with annual debits from recovery and additions based on individual storage preferences for any unused entitlement. A cut to the aquifer (in %) is taken when LTSCs are accrued.

Groundwater Allowances

CAP:SAM contains initial groundwater allowance account balances, that are then tracked as debits and credits occur through time. For Designated providers, Incidental Recharge is calculated and added to the balances. Pinal DAWS also include Base credits and pre-07 Extinguishment Credits. For Undesignated providers, the sum of Groundwater Allowances for the CAWS served are also tracked. These are described in more detail in the "Fulfill" section.

3.) Request Supplies

The third major CAP:SAM step accounts for the unique portfolio of supplies available to each provider, and the providers' preferences for the use of those supplies. The requests for supplies are made without consideration of the providers' annual demands; the actual amount of the supply used is determined in the "Fulfill" portion of the model. In essence, requests represent the maximum amount of a particular supply that the entity is willing and able to use, without consideration of the availability of the overall supply or the portion of demand that supply will satisfy.

Requests are constrained by a provider's maximum entitlement for each supply (e.g., contracts, rights, etc.). CAP:SAM contains an initial set of entitlement data, which is then modified through time based on user-defined adjustments that reflect transfers, leases, exchanges, reallocations, and priority conversions. Individual providers' requests can be further modified by specifying preferences (in %) for an amount less than their full entitlement. These adjustments can be used to reconcile instances in which a provider has an entitlement, but has policy or financial constraints for using that supply (e.g., an undesignated provider with a CAP subcontract). The availability of supplies can also be influenced by the provider's AWS/CAGR status, so this section of the model allows that status to be modified through time.

4. Fulfill Demand

In the final model step—fulfillment—information from each of the other steps is brought together and reconciled. So while those other steps do not need to be performed sequentially, they must be completed before fulfillment. The model steps through each supply type in a defined sequence, incrementally satisfying the demand of each provider based on their request and their volume of unsatisfied demand. The model fulfillment order is as follows;

- 1) Effluent
- 2) Groundwater, Exempt (Designated)
- 3) Surface Water
- 4) CAP Water (by Priority)
- 5) CAP Long-Term Storage Credits
- 6) Groundwater Allowances
- 7) Excess Groundwater
- 8) Groundwater, Exempt (Undesignated)
- 9) Unknown

For each municipal provider, demand fulfillment with a particular supply is based on the lesser of either the demand not yet met with other supplies, or the request (if any) for that particular supply. If the total supply available is not sufficient to meet the sum of the requests, a proportional reduction is applied. This process can be represented as follows:

Scenario	Fulfillment Formula
$S_p \geq R_p$	$\text{Min} (R_p, D_p)$
$S_p < R_p$	$\text{Min} (R_p, D_p) \times (S_p / R_p)$

where,

S_p = available supply by provider at each fulfillment step
 R_p = request for each supply by provider at each fulfillment step
 D_p = remaining demand by provider from previous fulfillment step

At the end of each fulfillment step, the demands from the start of the step are recalculated by subtracting the amount that was fulfilled. Those recalculated (unfulfilled) demands are then passed to the next fulfillment step.

Supply 1: Effluent

Effluent fulfillment is based on a providers' calculated non-potable demand from the Demand step, the amount of that demand to be met with effluent as specified in the Request step, and the effluent production from the Supply step. Proportional reductions are applied if the effluent supply is insufficient to meet the request.

Supply 2: Exempt Groundwater, DAWS

Designated water providers with an AWS exemption to pump groundwater pursuant to a required remediation project have their requests for that water fulfilled early in the modeling sequence. This is based on the assumption that they will pump and deliver that water even if they have renewable supplies available. This water is exempt from the AMA goal consistency requirements, and therefore does not affect the providers' groundwater allowance balance.

Supply 3: Surface Water

For those providers that have surface water supplies, they are typically among the least expensive supplies available, and therefore they fall early in the fulfillment sequence. Fulfillment is constrained by total supply availability, as well as legal entitlements and use preferences.

Supply 4: CAP Water

CAP requests are fulfilled in the following priority order: 1) P3; 2) Indian Priority; 3) M&I Priority; 4) NIA Priority; 5) Ag Pool; 6) Other Excess.

In addition to the recalculation of demand described above, as CAP:SAM steps through the CAP priorities it calculates how much of the remaining CAP supply is available based on the how much has been used by the preceding priorities. Note that this calculation accounts for the use by all sectors (i.e., Muni, Tribal, Institutional, etc.). Note too that this step separately considers CAP water used to satisfy annual demands and the volume that is directed towards the accrual of Long-Term Storage Credits.

This model step also implements the shortage sharing provisions of the Arizona Water Settlements Act which determine the split between Indian and M&I priority based on the CAP supply available and the year. There are four possible allocation scenarios under this formula:

CAP Supply Scenario	AWSA Shortage Formula for Indian Priority
> 853,079 AF, pre-2044	$0.25438 \times \text{Available Supply} + 93,303 \text{ AF}$
≤ 853,079 AF, pre-2044	$0.3637518 \times \text{Available Supply}$
> 853,079 AF, 2044+	$0.18606 \times \text{Available Supply} + 151,585 \text{ AF}$
≤ 853,079 AF, 2044+	$0.3637518 \times \text{Available Supply}$

Supply 5: CAP Long-Term Storage Credits

The use of LTSCs as a supply is based on a user provided preference (% of total balance) for CAP credits to be recovered annually. The available supply of CAP LTSCs for each provider is accounted for in the Supply section of the model. Credits used in this fulfillment step are debited from the account balance.

Supply 6: Groundwater Allowances

The use of Groundwater Allowances to satisfy demand is considered separately for DAWS and CAWS, and among DAWS, is further differentiated by AMA and whether the provider is a CAGR Member Service Areas.

For MSAs in the Phoenix and Tucson AMAs, use of the GW Allowance is similar to the calculation for LTSCs—it is based on a user provided preference (% of total balance). For providers that are designated independently of the CAGR, the Allowance is used to satisfy any remaining demand the provider has. If a provider's balance is insufficient to meet all of the remaining demand, the unmet portion is sent to "Unknown."

For Designated providers in the Pinal AMA, the use of GW Allowances is modeled after ADWR's "Calculation Decision Tree" and related material from their April 15, 2014 presentation on "Pinal AMA Groundwater Allowance Calculations." The model begins with the Base ("Use it or Lose it") renewable allowances, and then adds the volume of Incidental Recharge (based on IR rate and previous year's demand). If there is unused Base and IR, the remainder is added to the non-renewable allowance balance ("savings account"). If there is remaining demand, it is satisfied with credits from the non-renewable allowance balance. Any credits used in this step are debited from the account. If there is still remaining demand, it is satisfied with any Pledged pre-2007 Extinguishment Credits. The entire volume of any of those credits that are unused is added each year to the non-renewable account balance. For Pinal AMA MSAs, any remaining demand is sent on to Excess Groundwater. For Pinal providers designated on their own, any remaining demand is sent on the "Unknown."

For Undesignated providers, the use of Groundwater Allowances is tied to the calculations of new and existing Member Land demands, differentiated by Plan Period, adjusted by the providers' annually calculated percent reliance on groundwater and their CAGR reporting percent. The Plan 1 & 2 GW allowance balances for each provider are tracked, and are used until they are exhausted (except for Pinal allowances, which are renewable). The simplified example for Plan 1 is as follows;

$$[\text{GW Allowance}_{P1}] = \text{minimum}([\text{ML Demand}_{P1}] * [\text{WP \% GW Reliance}]) * (1 - [\text{WP Reporting \%}]), [\text{GW Balance}_{P1}]$$

Supply 7: Excess Groundwater

For Member Service Areas, any remaining demand is satisfied with Excess Groundwater. For Member Land providers, all remaining ML *groundwater* demand after use of the GW allowances is fulfilled with Excess.

Supply 8: Groundwater, Exempt

For Undesignated providers, the demand remaining after the use of CAP LTSCs (supply 5) is presumed to be met with groundwater. That volume, less the amount of Excess Groundwater associated with the provider's Member Lands, is exempt from the AWS Rules. This includes pre-95 subdivisions, new and existing non-subdivision demand, lost & unaccounted for water, etc.

Supply 9: Unknown

Remaining demands after all of the other fulfillment steps are placed into Unknown. These represent demands for which a supply has yet to be identified. This category is used to identify potential supply/demand issues, and also to isolate subcategories of demand, such as the Member Land demands associated with post-Post 3 housing units.

[end of Municipal section]