

GRAT: User Instructions and Modeling Documentation

Objective

The GRAT user interface has been designed to facilitate easy scenario creation and selection of recharge options. By working with MID and TID end users, we have focused on tool ease of use while maintaining tool functionality and flexibility. This includes having GRAT preset with a number of global defaults, thus reducing set-up time, while enabling unlimited scenarios and both automatic and manual site selections.

GRAT Modeling Overview

Underneath the simplified user interface and scenario creation process is a number of hydrologic and agronomic methodologies. This section provides a quick summary of the key facets that underpin the GRAT calculations. Figure 1 below shows a high-level tool schematic, which was designed around the actual water delivery process used by the irrigation districts. Here is a high-level overview of the approach used for each step:

- Source water. This is the water available for recharge (WAFR) functionality built directly into GRAT and specified by the user.
- Conveyance. Within GRAT we model actual canal or pipe conveyance and know which turnouts feed each of the field units. Fields are ranked by pipe size or canal turnout capacities, so that those with greater capacities are ranked higher for recharge.
- Site suitability. For each field, we use a Land IQ recharge suitability index that incorporates the UC Davis Soil Agriculture Groundwater Banking Index (SAGBI) along with subsurface geology characteristics from USGS and depth to groundwater from DWR.
- On-farm and fallow recharge. For any crop, we use a crop compatibility calendar that identifies total volume of water that can be applied by week to a crop for recharge. This applied water quantity assumes well drained soils consistent with highest two categories of SAGBI index to avoid risk of soil saturation. Potential recharge application quantities are reduced to allow for operational and cultural practices, by week for each crop. Allowable applied water is further reduced by weekly antecedent rainfall using data from 1998 to 2017 to represent typical weekly rainfall quantities across the five rain year types (consistent with Department of Water Resources classification for the San Joaquin Valley). The crop compatibility calendar was created in consultation with local agronomists and will be updated as new field-based research findings on crop compatibility become available.
- Dedicated basins. GRAT uses the locations, size and percolation rates of existing basins as specified by the irrigation districts
- Recharge benefit/cost. All financials are estimated based on local averages and figures, per reports commissioned by Sustainable Conservation with M.Cubed and Summers Engineering. These costs include on-site labor, berm construction, pumps, ripping and gypsum application.

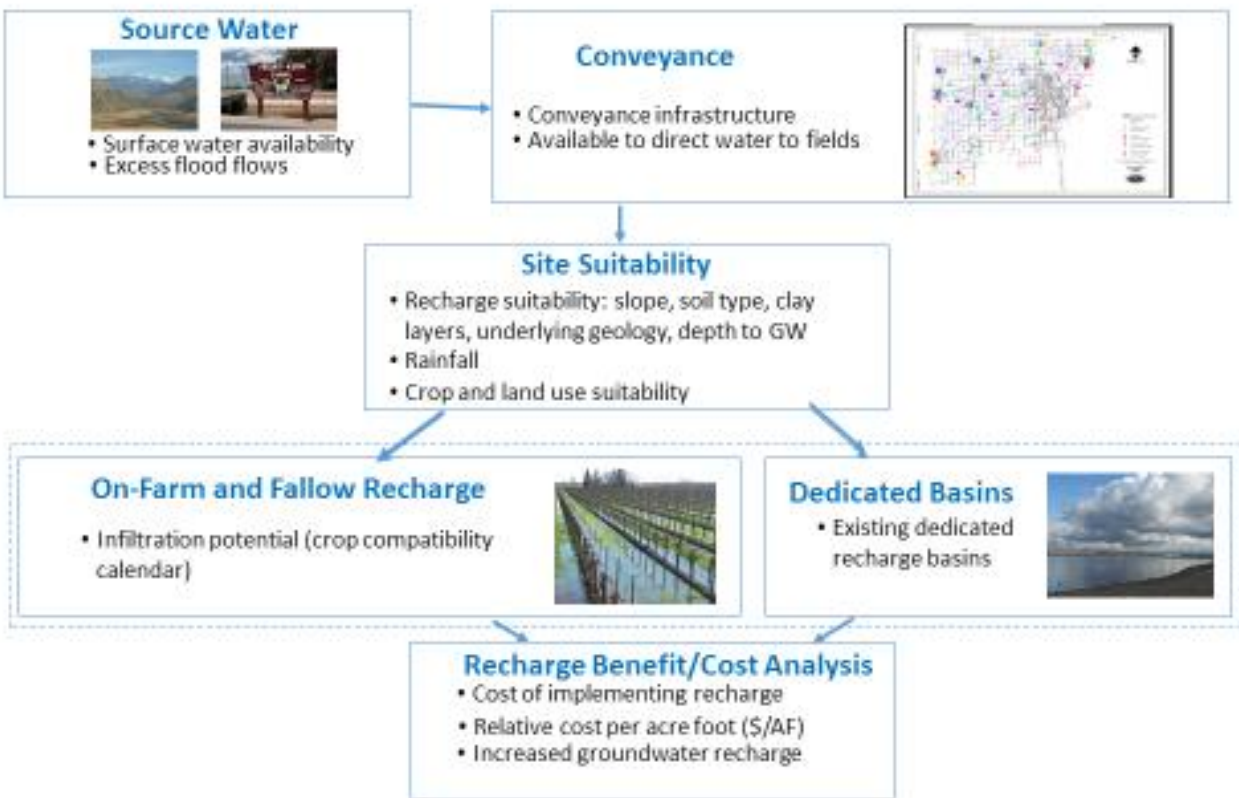


Figure 1. GRAT tool schematic and functionality

Starting up GRAT

GRAT can be accessed from any web browser that is connected to the Internet. No additional special software is required. Figure 2 shows the log-in screen for the application, which is password protected so proprietary data can only be accessed by the specified user.

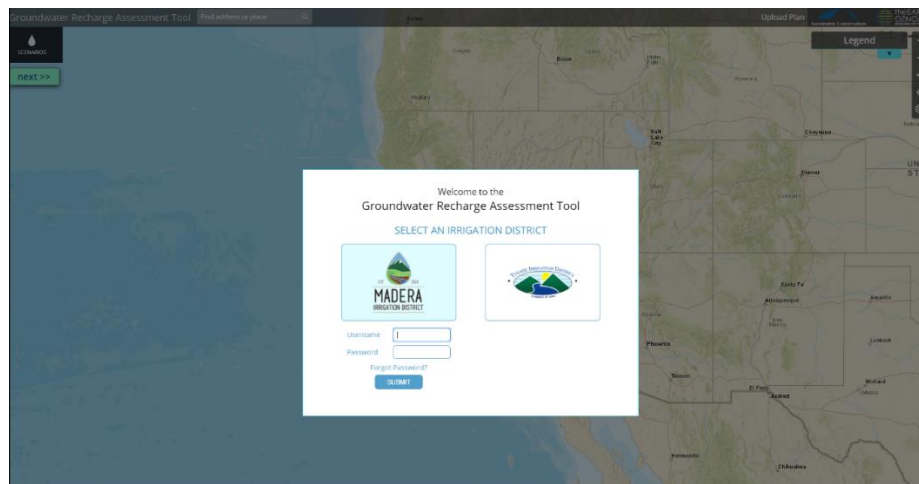
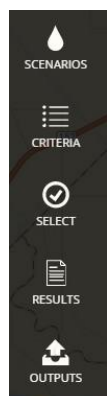


Figure 2. GRAT initial log-in screen (password protected)

Five tabs for scenario creation

Once signed in, the GRAT interface (left hand sidebar) shows five tabs for building out recharge plans. The tasks run from top to bottom, beginning with Scenarios and finishing with Outputs.



1. **Scenarios.** Define Water Available for Recharge (WAFR), select recharge type and crops for on-farm recharge.
2. **Criteria.** Define how field units are prioritized. Adjust importance weighting of different criteria.
3. **Select.** Auto selection of recharge locations based on target recharge amount or cost. Also allows for manual select processes.
4. **Results.** See estimated results (recharge volume, costs) based on scenarios, criteria, and selections. Iterative process (can go back and adjust settings in Tabs 1-3 as needed).
5. **Outputs.** PDF reports for sharing with key stakeholders.

The entire process is meant to be completed in 2-3 hours, depending on level of user specified input. It is likely the creation of additional scenarios will take significantly less time, based on ability to retrieve saved scenarios.

Tab 1. Scenarios

This first tab allows the user to create scenarios by setting the water available for recharge and recharge type options. Figure 3 shows the opening screen of the Scenarios tab.

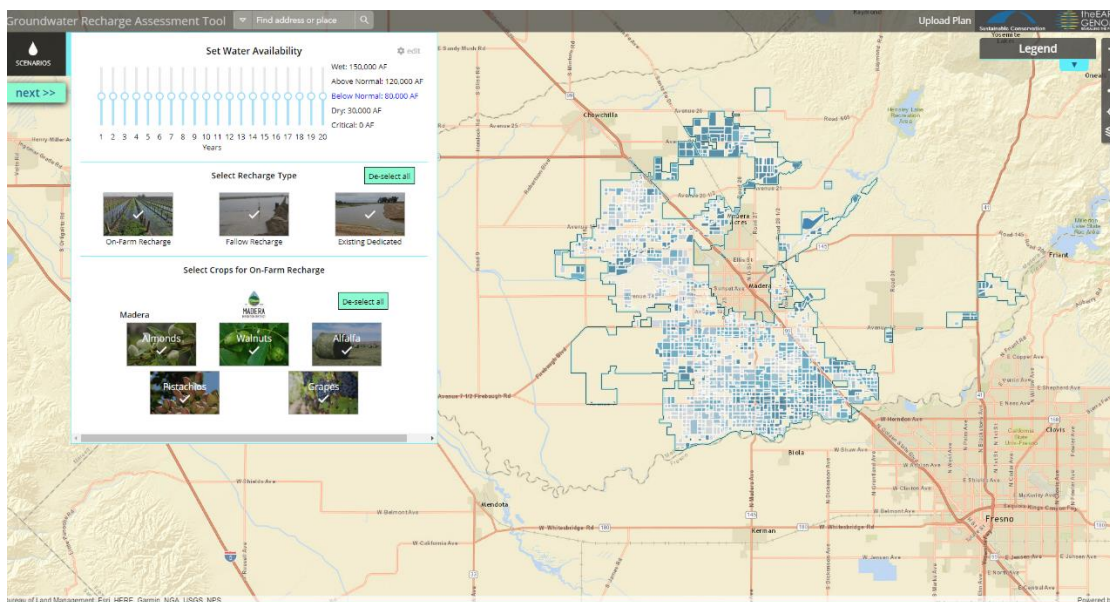
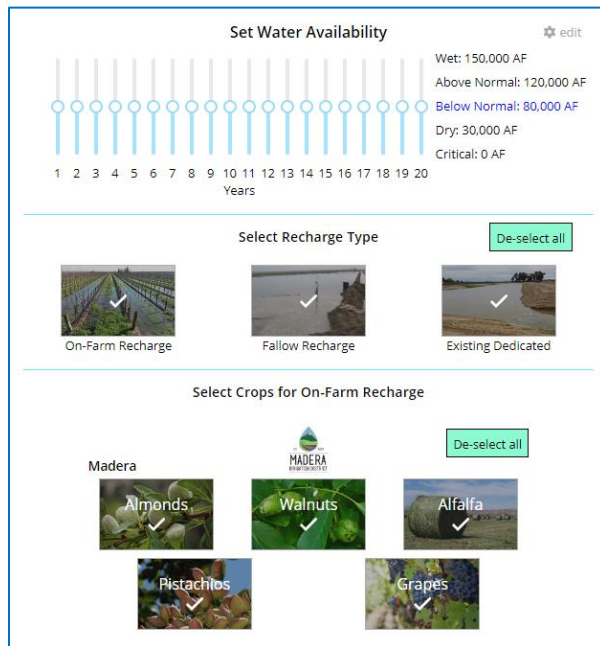


Figure 3. GRAT screen for scenario creation

Figure 4 shows the dialog box that allows the user to state what scenarios they would like to use for water available for recharge (WAFR), recharge type, and crops for on-farm recharge.



The dialog box is titled "Set Water Availability" and includes an "edit" icon. It features a horizontal slider for 20 years, with markers for "Wet: 150,000 AF", "Above Normal: 120,000 AF", "Below Normal: 80,000 AF", "Dry: 30,000 AF", and "Critical: 0 AF". Below the slider are three sections: "Select Recharge Type" with options "On-Farm Recharge", "Fallow Recharge", and "Existing Dedicated"; "Select Crops for On-Farm Recharge" with options "Almonds", "Walnuts", "Alfalfa", "Pistachios", and "Grapes"; and a "De-select all" button.

Figure 4. GRAT dialog box on setting WAFR and recharge type options

WAFR is defined as the amount of water available for the district to use in excess of typical irrigation deliveries and under existing water rights limitations. The design of the settings for establishing WAFR is directly per irrigation district input. Given the great uncertainty in predicting timing and magnitude of future wet years, an interface was requested to allow GSA users to specify any combination of future rain year types. Figure 5 shows one example of how the “Set Water Availability” can be adjusted across the 20 year planning horizon, based on five rain year types. The user simply moves each individual slider, corresponding to each year, either up (for wetter years) or down (for dryer years). The user can also adjust the quantity of water available for recharge for each rain year type by clicking on “edit”. This will dictate the magnitude of excess flood waters available for optimization within GRAT.

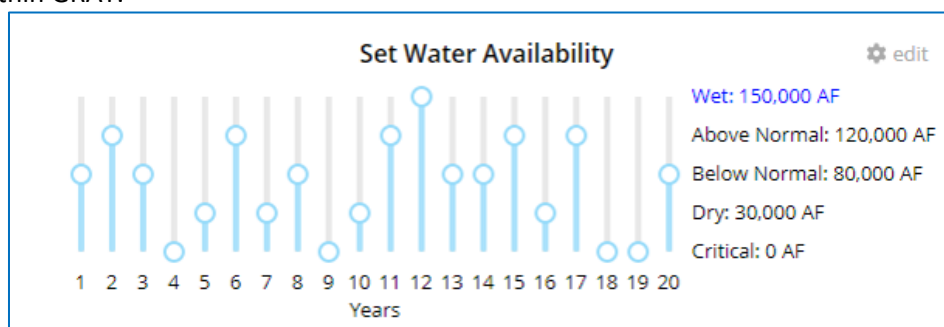
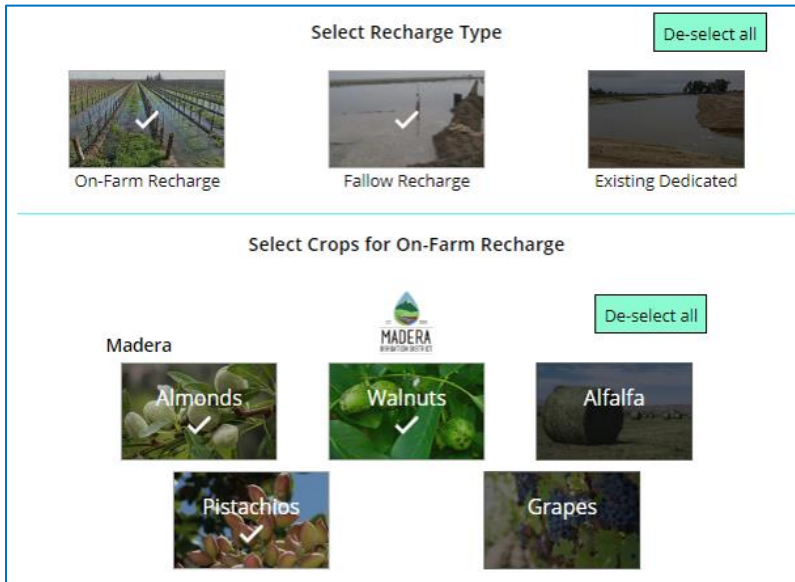


Figure 5. Sliders for setting WAFR timing (by year) and total volume of water (in acre-feet)

Below the WAFR setting sliders are visual pictures that allow the user to specify recharge types (on-farm, fallow fields and/or existing dedicated basins) and specific crops for on-farm recharge. These crops are specific to the area and are based on the most highly represented crop acreage that might be considered for on-farm recharge. As shown in Figure 6, the user clicks which boxes are relevant (a white checkmark will appear) and GRAT will include these in the optimization.



The screenshot shows two selection panels. The top panel, titled "Select Recharge Type", has a "De-select all" button and three options: "On-Farm Recharge" (with a checkmark), "Fallow Recharge" (with a checkmark), and "Existing Dedicated". The bottom panel, titled "Select Crops for On-Farm Recharge", also has a "De-select all" button and five options: "Madera" (with a checkmark), "Almonds" (with a checkmark), "Walnuts" (with a checkmark), "Alfalfa", "Pistachios" (with a checkmark), and "Grapes".

Figure 6. Check boxes for selecting recharge types and crops for on-farm recharge

Tab 2. Criteria

The second tab allows the end user to specify how GRAT prioritizes locations to be selected for recharge. Importantly, the tool evaluates individual field units (fields that are just one crop, usually smaller than a parcel) based on which crops are grown on those locations. The tool also knows the location of fallow land and dedicated recharge basins. Figure 7 below shows how the tool user can set the weighting criteria for how each field unit is ranked and color coded (darker color for high suitability, lighter color for low suitability) to have only certain locations highlighted.

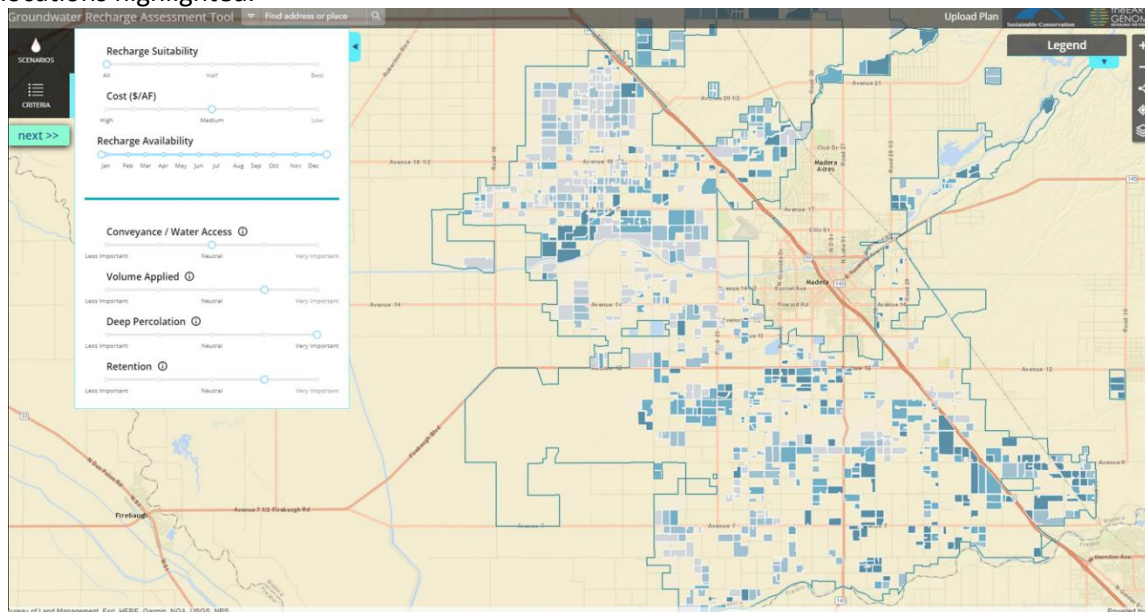


Figure 7. Criteria: Tells GRAT which locations to show and the importance of different criteria

As seen in the top half of the dialogue box in Figure 8 below, there are three sliders to prioritize field units based on recharge suitability, cost, and timing:

Recharge Suitability: This slider tells GRAT to only show field units with the highest potential for recharge (measured as average volume of water recharged per year as total acre-feet)

Cost: This slider tells GRAT to only show field units that are the most cost-effective (lowest estimated \$/AF for on-site capital and operating costs to recharge on the field unit)

Moving either of these sliders to the right reduces the total field units shown on the map view, highlighting only those locations that have highest potential recharge or cost effectiveness. This allows a tool user to quickly see which few sites (out of thousands) are estimated to be the best sites.

Recharge Availability: This slider allows a tool user to see just the field units that have recharge potential in certain months of the year. The user can move the left end of the slider to specify the start month. The user can move the right end of the slider to specify the end month. The default setting is to see options for all 12 months of the year. This feature is useful for any end user who wants to see available recharge locations for just select weeks or months of the year (e.g. when excess water is most available). Individual field units will have varying availability to take water in certain months of the year, based on which crops are grown on that field. Note: Fallow fields and dedicated basins are assumed to be available all year around.

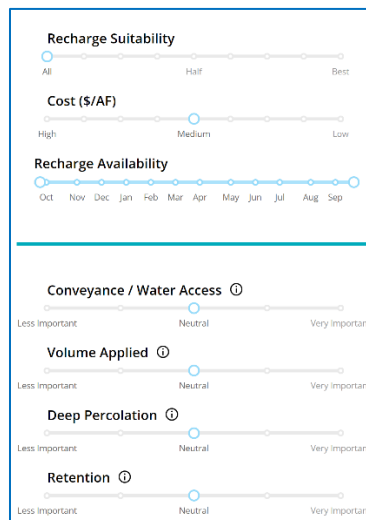


Figure 8. Criteria: Tells GRAT which locations to show and the importance of different criteria

The bottom portion of Figure 8 includes four importance sliders. The four criteria are Conveyance, Volume Applied, Deep Percolation, and Retention (see definitions and uses below). Each of these sliders can be moved farther to the right to specify greater relative importance. GRAT interprets this and calculates the relative suitability of any field unit (and hence the blue color coding) based on these settings. Each of the four sliders is tied to a specific dataset that has spatial variability.

Conveyance:

Definition: Ability of any field unit to receive recharge water from existing conveyance infrastructure (e.g. if the field unit is not served by conveyance or conveyance capacity to the field is constrained, it will be deprioritized).

Dataset used: Existing conveyance infrastructure and turnout information per the local irrigation district.

Slider use: Reducing the importance of this criteria allows user to identify fields that don't currently have good access to high volumes of water but that could be good recharge sites if investment in expanded conveyance infrastructure could be made.

Volume Applied:

Definition: Amount of recharge water that can be applied based on agronomic and management limitations of selected crop.

Dataset used: Crop compatibility calendars created by Sustainable Conservation given interviews with agronomists and ongoing field testing.

Slider use: Reducing the importance of this factor allows the user to evaluate the recharge potential of sites as fallow ground without current cropping constraints.

Deep Percolation:

Definition: Ability of water to percolate down to most depleted aquifer (e.g. below the top ~6 feet of soil layer, distinguishing between soil infiltration and vadose zone percolation to groundwater for aquifer recharge).

Dataset used: LandIQ index that incorporates UC Davis SAGBI data for infiltration plus USGS CVHM geologic texture data for percolation capacity and DWR depth to groundwater for groundwater storage capacity.

Slider use: Reducing the importance of this criteria allows the user to also consider potential of sites to capture water for recharge to shallower perched aquifers but sites should be evaluated in the field to avoid root zone saturation.

Retention:

Definition: Percentage of deep percolation water that is retained in the district as groundwater. All field units share the same value unless the field unit is within 100 yards of a downstream surface water body (is weighted in the index calculation as only 1/2 as attractive) or if the field unit is within 100 yards of a neighboring GSA boundary (is weighted at 1/5 as attractive).

Dataset used: Field unit and boundary information per the local irrigation district. Also topographic digital elevation maps.

Slider use: Reducing the importance of this criteria allows the user to include fields that may benefit recharge in the greater groundwater sub-basin in support of GSP development with other GSAs.

Tab 3. Select

The third tab is the critical functionality that allows the tool user to either use auto select for the best available recharge locations or manually specify exact locations for recharge. GRAT provides initial recommendations for which field units may be best suited according to user specifications. To do this, the end user needs to first specify the target amount of recharge volume (in acre-feet) or the total investment cost (cost required to implement the recharge). As shown on the left hand side of Figure 9, the user can type in a recharge volume target up to the volume available in the wettest year (as specified in the WAFR settings) or cost and then click the corresponding “Run” button. GRAT will then find the best available sites that sum to the specified criteria. These targets can be adjusted at any time, so an end user can specify any amount (e.g. 20,000 AF) to see the resulting site recommendations and then type in another figure (e.g. 30,000 AF) to see how the recommended sites change.

Recharge Target for Wettest Year

Volume, AF

Total Recharge: **0 AF**

Site Contribution to Recharge: **0 AF**

Recharge from Canal Seepage: **0 AF**

Net Impact of ET/Precip: **0 AF**

Cost

Total Cost: \$0

Recharge Type

Site:

Site Details

Crop:

Acres:

Permittee:

Parcel #:

Cost: \$NaN

Figure 9. After a user specifies a recharge target for volume or cost, GRAT offers site recommendations

This recommendation feature in GRAT is called “auto select”. Figure 10 below shows an example, including a listing of the locations auto selected and the map view that highlights (in green borders) the recommended sites.

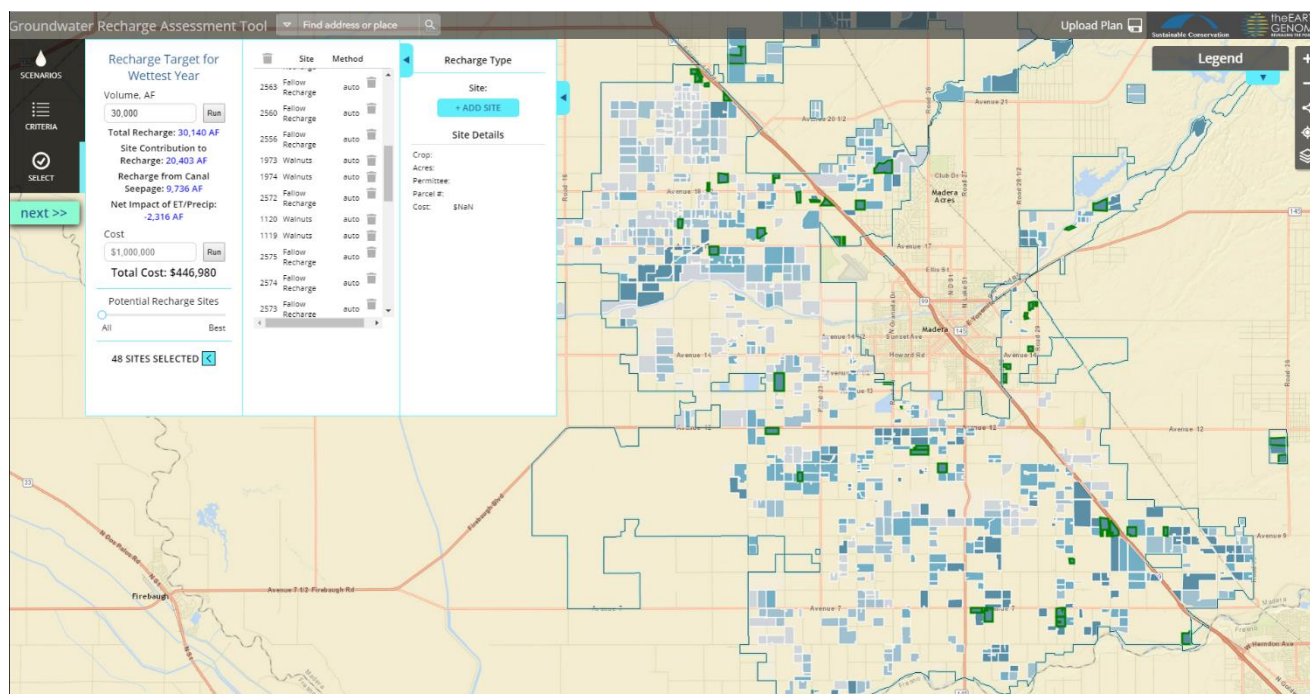


Figure 10. Results of auto select, showing locations in both list view and also in map view.

In this map view, the user can also manually select any field unit and see the details of those sites. This shows up as a solid highlighted green field, as shown above in Figure 10. Importantly, the user can manually add or remove any field unit as shown in Figure 11 and Figure 12. This process allows manual adjustment of the field units recommended by GRAT. It is assumed that some manual selection (adding in local area knowledge and experience) is needed to find the best potential recharge locations. The manual review of selected sites for recharge is an essential step in the optimization.

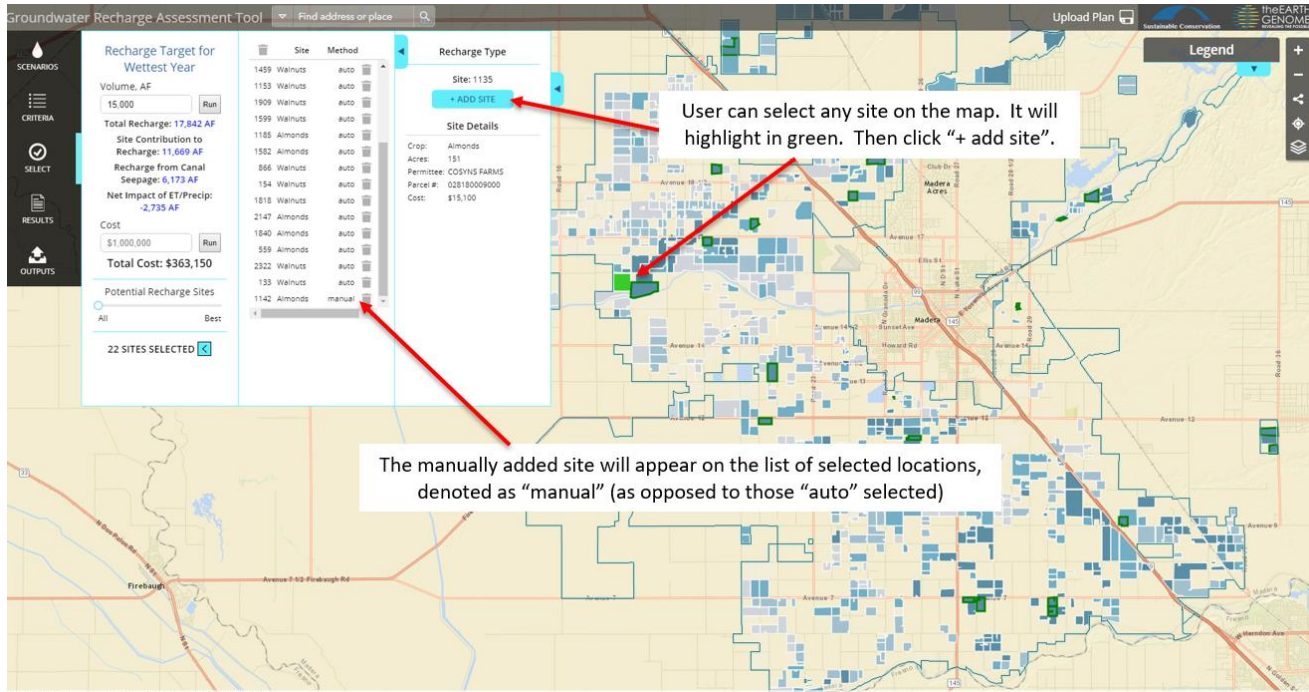


Figure 11. Manually adding sites via clicking on map and "+ ADD SITE".

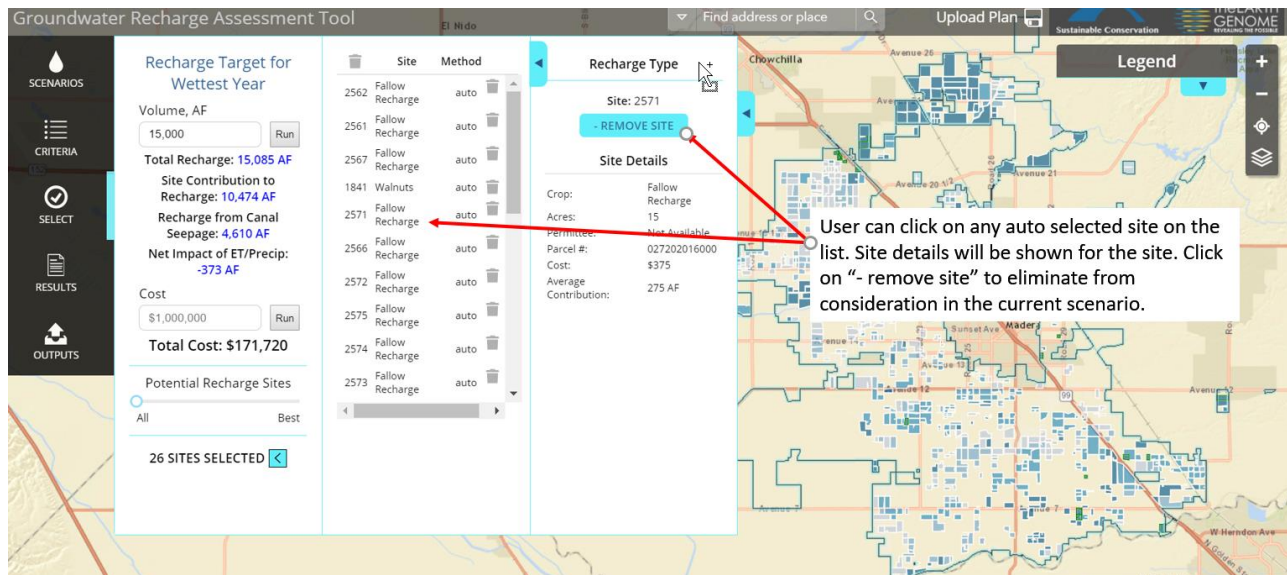


Figure 12. Manually removing sites via clicking on list and "- REMOVE SITE".

Tab 4. Results

The fourth tab allows the end user to see the estimated net results of their existing scenarios and location selections. Figure 13 below shows the five different graph options. Importantly, it also allows the end user to edit the total amount of annual groundwater pumpage for the GSA and compare that to the average annual recharge so far selected in GRAT.

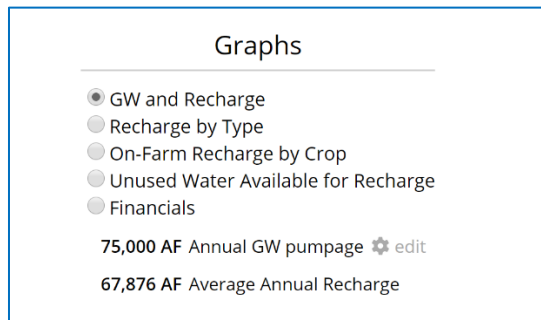
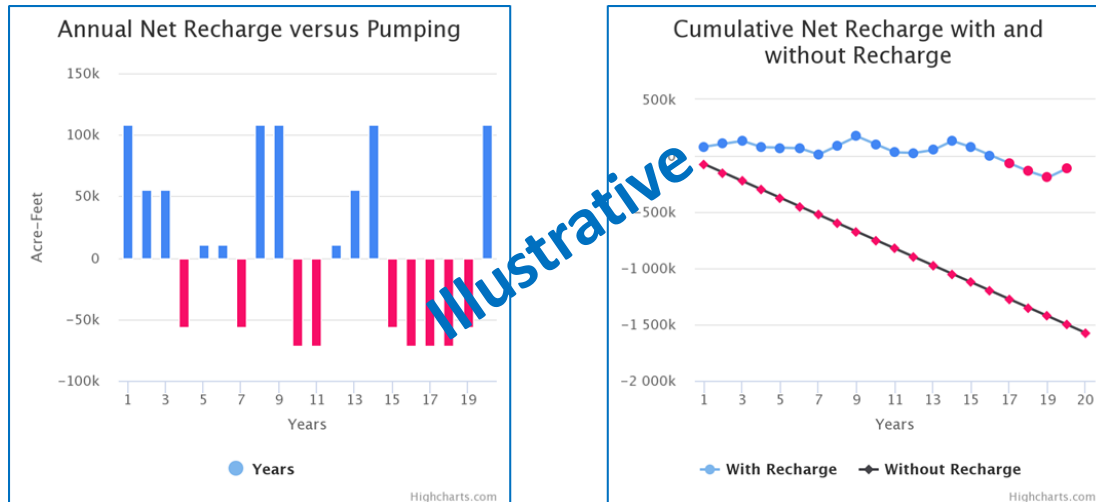


Figure 13. Options for showing the results of the current scenario

The figures below show the five graph options. These graphs help the tool user refine their scenarios and selections, enabling them to revise their selections on Tabs 1, 2, and 3 in an iterative fashion.

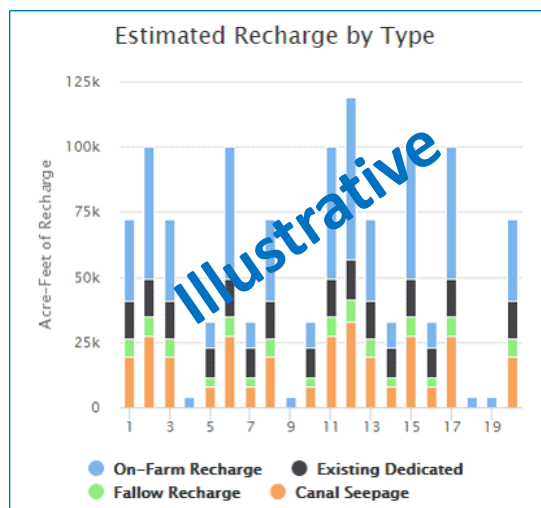
Graph #1: Total Cumulative Recharge. These graphs depict estimated annual and cumulative net groundwater change as a function of recharge. This is based on the site selections and the water availability specified in the WAFR equalizer. The color red denotes a year where groundwater was in deficit, while blue denotes a year with groundwater surplus. GRAT does not include the contribution of existing recharge sources such as over-irrigation of crops, canal leakage from irrigation water delivery, or natural recharge from rainfall or rivers. These are all considered baseline conditions that already determine average annual overdraft. GRAT is designed to show the incremental benefit of managed aquifer recharge.



Graph format: Change in groundwater as function of recharge and pumping over the 20 year time horizon

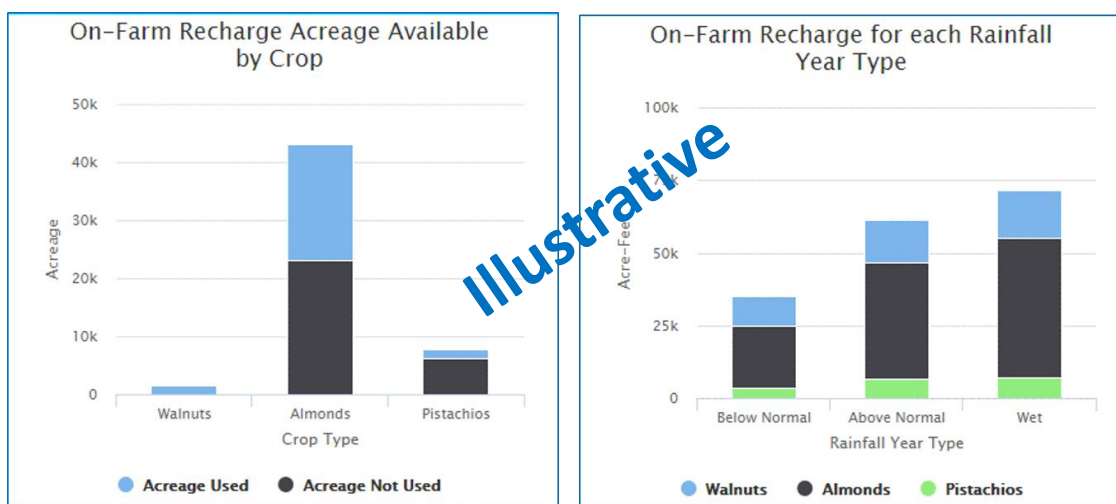
Key insight: Informs GSA on how close they are to groundwater sustainability

Graph #2: Recharge by Type. This graph depicts the specified recharge by type over the 20 year time horizon. Included are the on-farm, fallow and existing dedicated basins. Also shown is the estimated recharge via canal seepage that is incremental based on the WAFR specified.

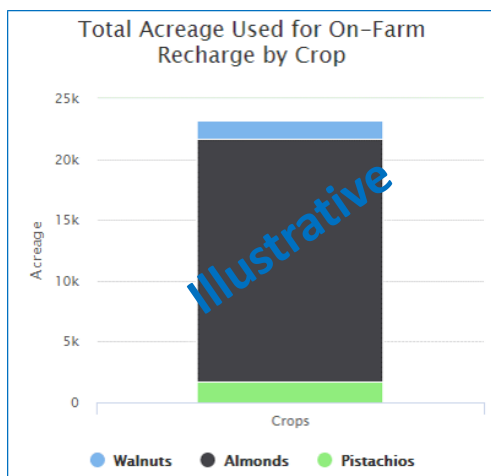


Graph format: Recharge volume by type: on-farm, fallow, dedicated basin and canal seepage over the 20 years
Key insight: Informs GSA on how the mix of recharge type varies with annual WAFR by rain year type

Graph #3: On-farm recharge by crop. These graphs depict the total acreage by crop (used or not used for on-farm recharge) and volume of recharge in different rain year types based on the water available for recharge specified.



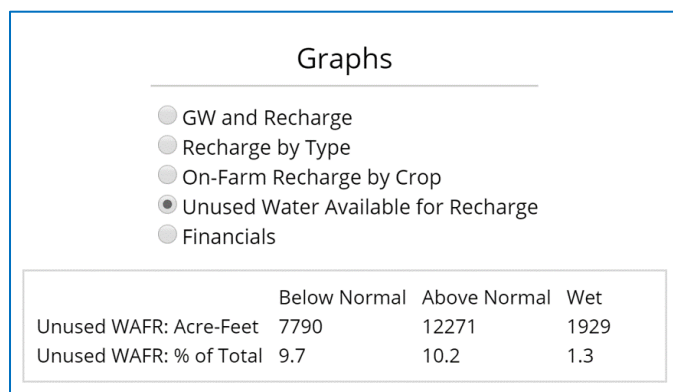
Graph format: Acreage by crop type in the GSA area, showing what is used or not used for on-farm recharge;
Estimated recharge in acre-feet by crop and rain year type



Graph format: Total acreage used for on-farm recharge by crop

Key insight: Informs GSA on crop acreage available and what is being used for on-farm recharge

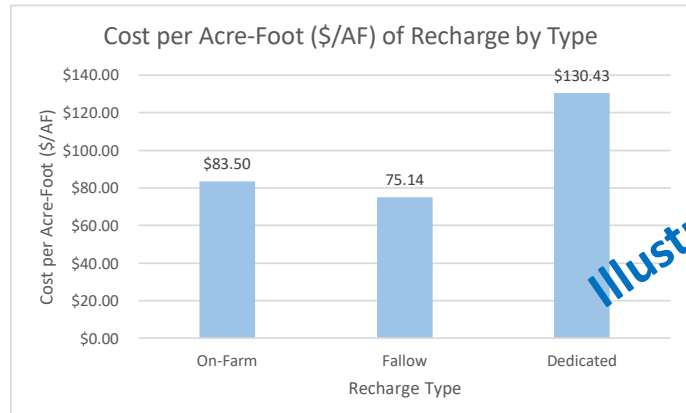
Graph #4: Unused water available for recharge. The fourth graph option includes a small table that depicts the water available for recharge that is not yet allocated to field units in GRAT. The acre feet and percentages shown, split by rain year type, tell the user how much additional recharge is possible given the specified WAFR scenarios and site selection. The tool user can then use this information to manually specify further field units that would be able to take available water to do recharge in the targeted weeks.



Graph format: Volume and % of water available for recharge by rain year type

Key insight: Informs GSA on how much more water could be recharged by adding additional field units or expanding conveyance infrastructure if all existing fields have been selected

Graph #5: Financials. The graphs below depict key financials of the GRAT scenarios. They show overall estimated cost per acre-foot of recharge (\$/AF) by recharge type, as well as the needed investment over the 20 year time horizon. Costs include all on-site expenses of capital improvements and operating costs but do not include cost of water or delivery to field location.



Graph format: Financial graphs showing estimated costs and investments, based on scenario specified

Key insight: Estimated cost effectiveness of the specified recharge scenario. Costs can be compared with other potential recharge investments such as cost of constructing new dedicated recharge basins.

All the graphs above are automatically updated based on changes to the scenarios and sites selected. This allows the user to see the results from their selections, helping them optimize the best available recharge in quick fashion.

Tab 5. Outputs

The fifth and final tab allows the end user to quickly generate PDF files that contain graphs of the key recharge findings estimated by the tool. They are intended to be standalone documents shared with a diverse group of stakeholders. The output graphs are described in the Results section above. As GSAs determine the format of their Groundwater Sustainability Plans (GSPs) and other needs for these types of PDF outputs, we will evolve these graphs to ensure it is easy to directly use the PDF files to meet the GSAs' needs.

Saving and uploading scenarios

The user can create, save, and retrieve an unlimited number of scenarios. Figure 14 shows how to save a scenario (which includes WAFR scenarios, criteria settings, and site selections). The file will be automatically saved to the user's computer in the "downloads" folder. Uploading a saved scenario is done by simply clicking "Upload Plan" (next to the save icon) and then selecting the .json file to upload from the user's computer. Saving a scenario can be done once an actual scenario has been run with sites selected. Uploading a file can be done at any time and will most often be done after the opening screen log-in so the user can retrieve a previously saved scenario.

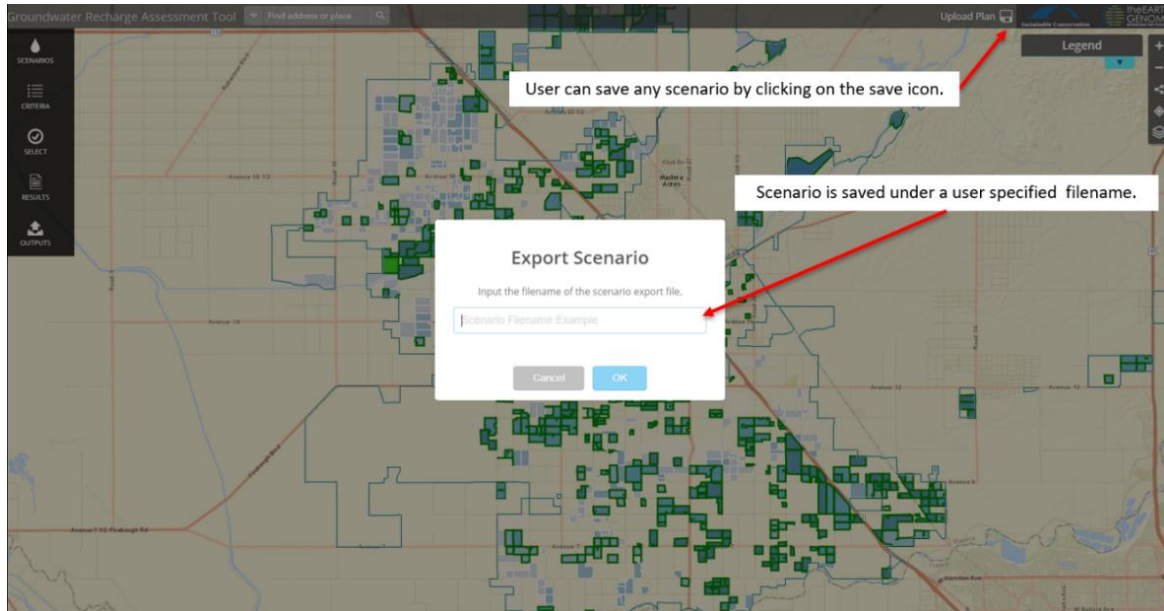


Figure 14. GRAT tool schematic and functionality

Key Assumptions and Modeling inputs

GRAT's methodology employs many assumptions that are built directly into the tool as default values. Some of these critical assumptions can be edited directly by the tool user in various sections of the tool, to ensure the end user can provide any local updates:

1. Water available for recharge (WAFR). This is specified by the tool user in the Scenario tab. User can specify the frequency and magnitude of years that have excess flood waters available for recharge.
2. Canal seepage. This factor accounts for the additional seepage of water being delivered to recharge locations while in the canals of the Irrigation District. This seepage that occurs in excess of the baseline seepage that occurs during delivery of water for irrigation purposes. It is assumed that any available WAFR must also account for seepage during transport. This figure is currently a specified % default for the conveyance system of each unique Irrigation District.
3. Retention factor. This is the % of water that is assumed to contribute to aquifer recharge in the planning unit of the Irrigation District or GSA using GRAT. The percentage value is applied to the water that gets below the root zone (net water applied via recharge) to estimate the amount of recharged water retained and not lost annually due to lateral aquifer gradient flow out of the planning unit. This figure is currently a specified % default for the entire planning area. The selected % should reflect local hydrologic modeling and/or water management policy and is unique to each Irrigation District or GSA.
4. Discount rate. This is the % used to discount the investments (to reach net present value) needed for the recharge. This figure is currently a specified % default, now set at 4.4% based on the 10-year average return on assets as reported by the USDA.

Datasets that will be updated on a recurring basis

The underlying datasets in GRAT should reflect best available data. The following datasets are presumed to be updated on a frequent basis, potentially each year, directly by the end-user. Once updated datasets are made available, Earth Genome can quickly upload these directly into GRAT.

1. Dedicated basins. Any updates to existing or new dedicated recharge basins should be incorporated into GRAT. This includes measured percolation rates.
2. Crop surveys. GRAT uses the most current crop survey data as provided by the irrigation districts. Updates based on the most recent County Ag Commissioner data, or another method used locally to track changes as farmers change their fields ideally would be done on an annual basis. This can be done by updating the crop survey GIS files, which are then easily uploaded into GRAT.
3. Latest ET and rainfall. GRAT uses the most recent CIMIS ETo (reference evapotranspiration), ETc (crop specific ET) and Kc (crop coefficients). It also uses the last ~20 years of rainfall according to NOAA rain gages in the local area. Each year, the datasets should be updated to reflect the most recent ET and rainfall patterns.

Conclusion: User instructions and model documentation

GRAT has been designed to quickly and efficiently enable GSAs to reach groundwater planning recommendations based on the best available information. The simple map based user interface allows unlimited user defined scenarios and quick auto selection of the highest potential for recharge locations. It empowers the user to see the net change of any changes in the modeling scenarios and assumptions, while also allowing easy updating and localization of key model defaults.