SWIM 2 Sustainable Water through Integrated Modeling

User Manual

Water Balance Model

Hydroeconomic Model

Revision 0.9

Policies

UTEP Web Privacy Policy
https://www.utep.edu/information-resources/iso/policies/web-privacy-policies.html

SWIM Web Privacy Policy
https://swim.cybershare.utep.edu/en/policy

Acknowledgements

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User Manual Overview

This User Manual is intended as a non-technical resource for the end user community of SWIM. It will document the basic SWIM website navigation, development and execution of “canned” and custom scenario models inquiring into input parameters and output variables for the two currently integrated SWIM models: **The Water Balance Model** and the **Hydroeconomic Optimization Model.**

SWIM, an acronym for **Sustainable Water through Integrated Modeling**, is designed for the water resource user community to advance water sustainability research capabilities through the integration, execution and interpretation of water models and participatory reasoning processes. SWIM is available at http://purl.org/swim

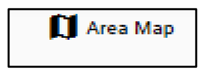
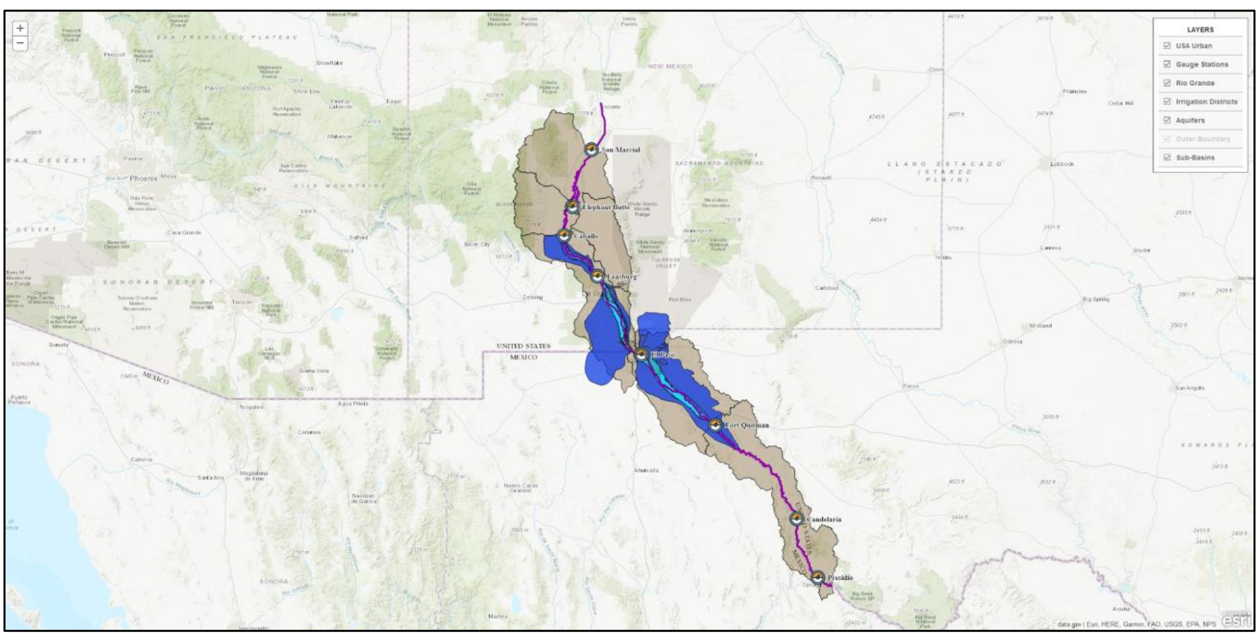
Using the meaning of data and models, SWIM facilitates interpretations of water availability in the US Southwest and North of Mexico for stakeholder-driven analysis from the socio-environmental perspective and specifically for the Middle Rio Grande region (below) from the inlet to Elephant Butte at San Marcial south to Fort Quitman, Texas. An interactive version of the map is available at https://water.cybershare.utep.edu/map/riogrande or it can be accessed by the **Area Map** tab on the top right of the model scenario creation screen. 

***Figure 1**: Project Area of Coverage. Web map generated with SWIM via ESRI. Layer attributions to UTEP, UACJ, TAMU, NMSU and data.gov*

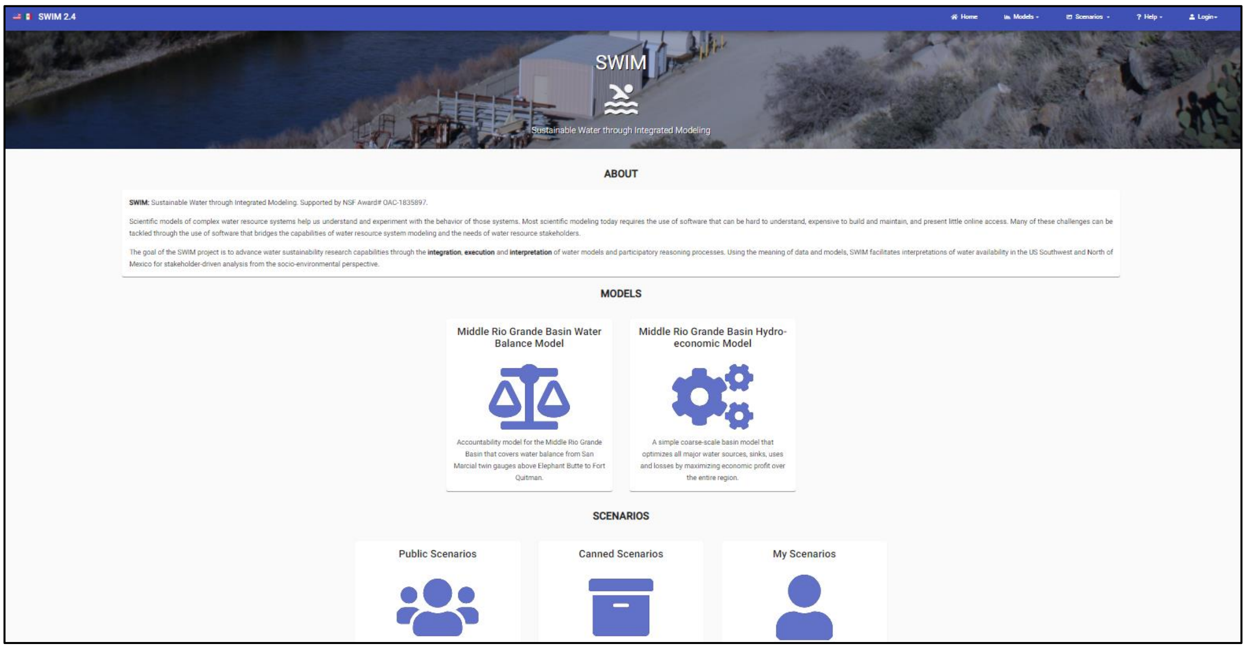


SWIM 2 Website Overview

SWIM 2 Home Page

SWIM is accessible at http://purl.org/swim, so go to that URL and bring up the SWIM home page **Navigation Bar** as seen below. The recommended browser is Mozilla Firefox.

Figure 2: *Screenshot of the SWIM 2 home page.*



Language Selection

The website language defaults to your web browser language. But, starting in the upper left-hand corner you can change the language of the website from English to Spanish by clicking on the corresponding flag logo.

Model Selection

Two models are currently available as seen on the SWIM Home Page and they are accessible from the drop-down menu on the top navigation bar. These are the Water Balance Model and the Hydroeconomic Model. When you click on the selected model you will be taken to the landing page of the model with further descriptive information as seen below for the Water Balance Model.

Figure 3: *Model selection on nav bar*

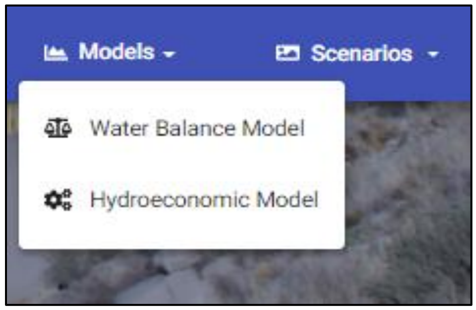
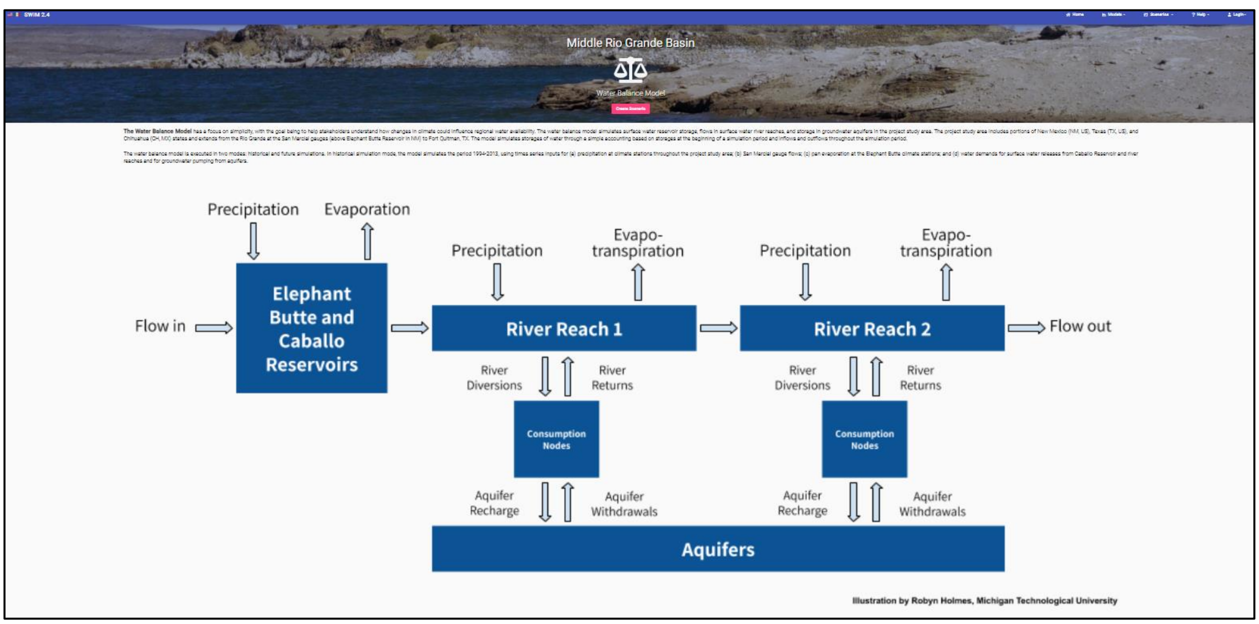


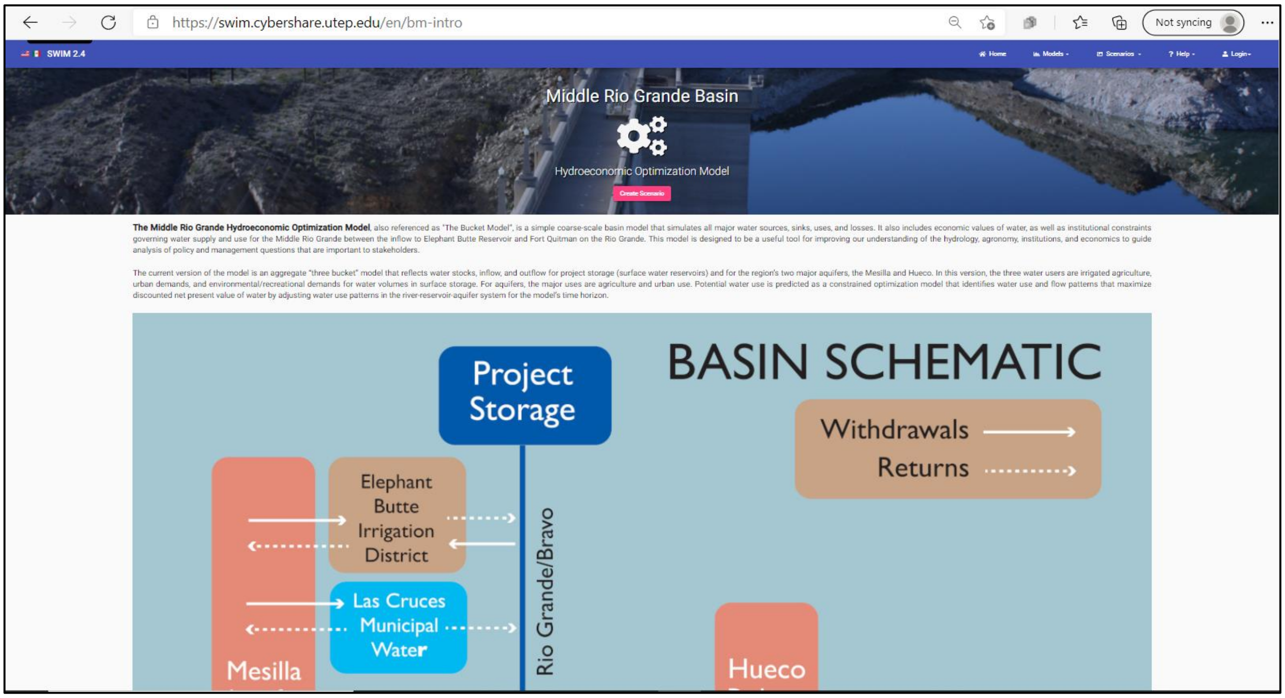
Figure 4: *Screenshot of the Water Balance landing page on SWIM 2*



This includes the model engine and contact information as well as a link to more detailed technical information.

The same holds for the Hydroeconomic Model and its landing page as seen below.

Figure 5: *Screenshot of the Hydroeconomic Model landing page*



Create Scenario and Scenario Selection

Each of the models has a **Create Scenario** tab that will be explained in more detail later in this Manual.

For now, clicking on the **Scenarios Tab** on the main Navigation Bar leads to pre-executed scenario options. When you click on the **Canned Scenarios** tab, it will land you on a tableau of specific scenarios from which to choose, as seen below. More on this topic later.

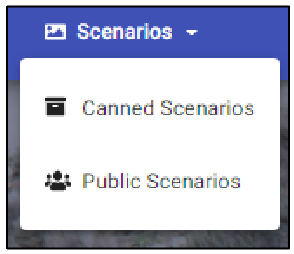
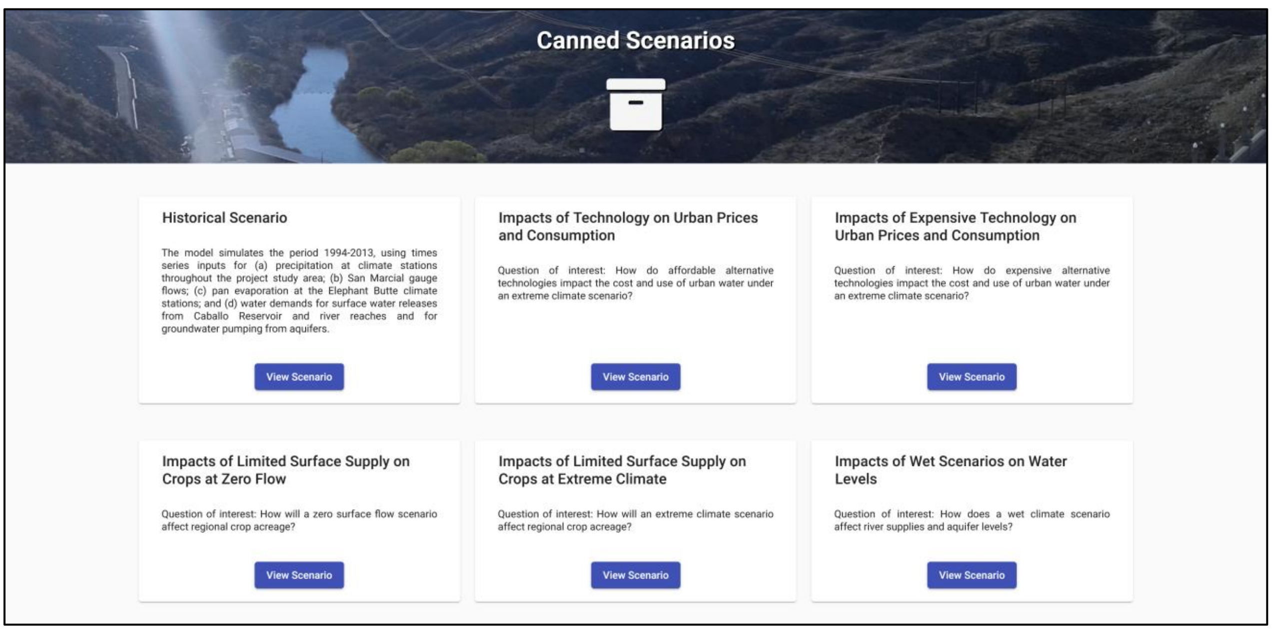
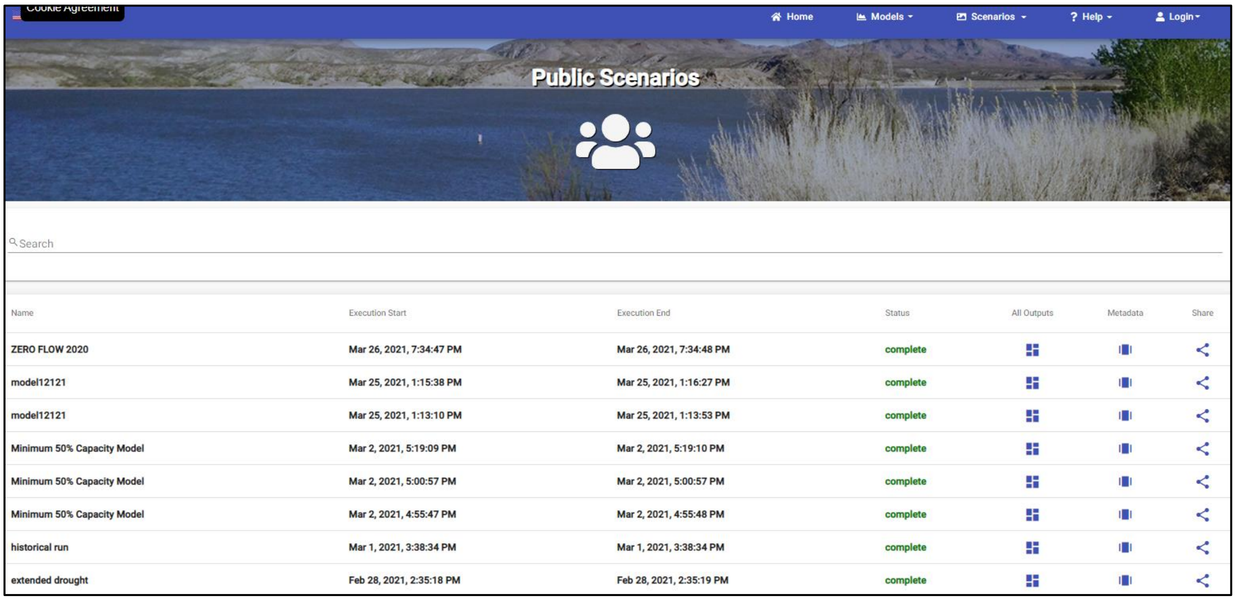


Figure 6: *Screenshot of the canned scenarios page in SWIM 2*



Similarly, clicking on the **Public Scenarios** tab yields a list of model executions by other SWIM users which have been made available for general use, as seen below.

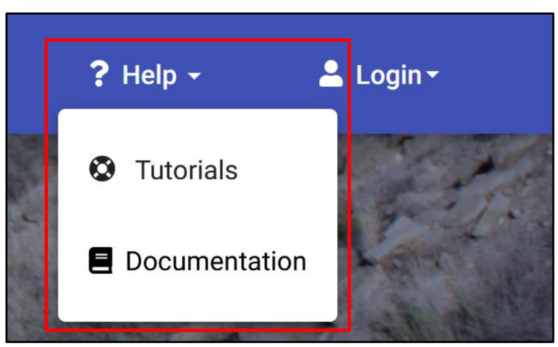
Figure 7: *Screenshot of the Public Scenarios section in SWIM 2*



The columns on this page describe public model scenarios outputs and metadata. If you click on these tabs, you will see these effects. They are the work of other users and can be shared with someone whom you want to send the scenario that might even be your own.

Help Section

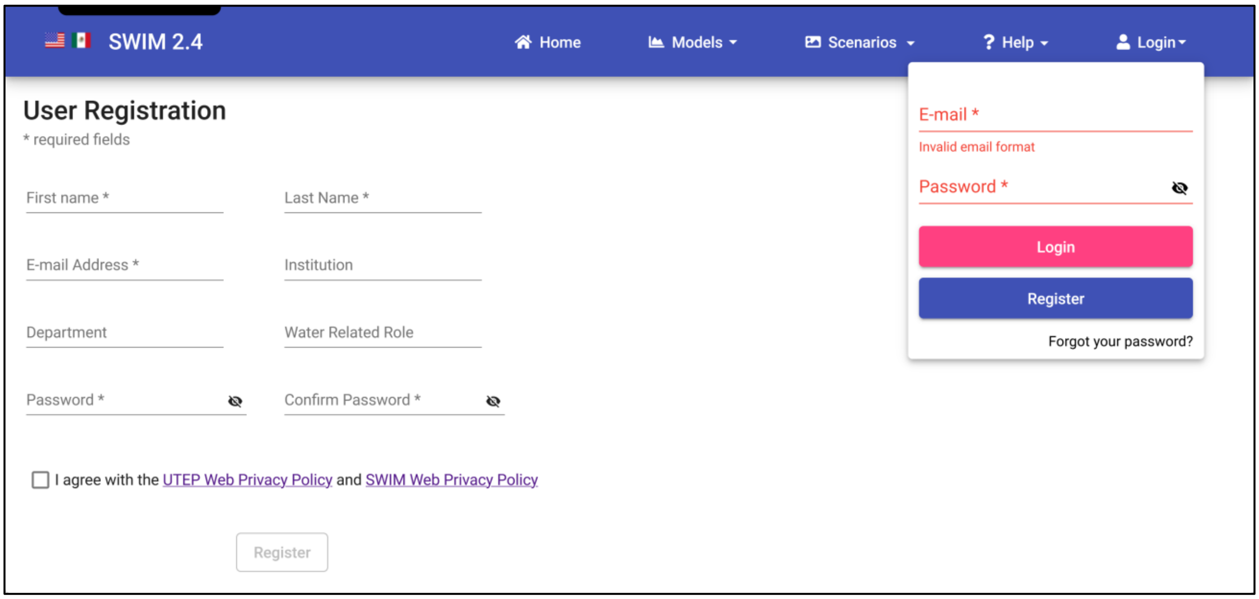
On the Navigation bar is the **Help Section** tab. Click on this for Tutorials and Documentation for the system architecture and other technical information.



User Login and Registration

Finally, there is the **User Login** tab at the far right of the Navigation bar. If you select to register, fill out the form (below) and click on the agreement with the UTEP and SWIM web privacy policies, then you can create scenarios and save them or make them public.

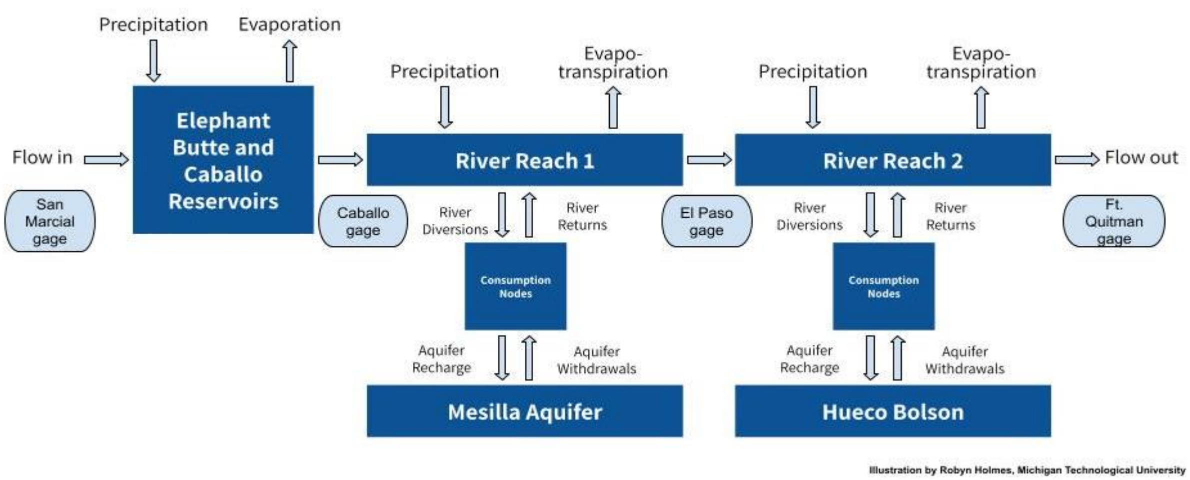
Figure 8: *Screenshot of User Login and Registration screen on SWIM 2*



Water Balance Model Operation

The Water Balance Model (Mayer et al.) has a focus on simplicity, with the goal being to help stakeholders understand how changes in climate could influence regional water availability. The water balance model simulates surface water reservoir storage, flows in surface water river reaches, and storage in groundwater aquifers in the project study area. The project study area includes portions of New Mexico (NM, US), Texas (TX, US), and Chihuahua (CH, MX) states and extends from the Rio Grande at the San Marcial gauges (above Elephant Butte Reservoir in NM) to Fort Quitman, TX. The model simulates storages of water through a simple accounting based on storages at the beginning of a simulation period and inflows and outflows throughout the simulation period. The figure below illustrates the basic hydrologic structure of the Water Balance Model.

Figure 9: *Hydrologic diagram of the Middle Rio Grande Water Balance Model*



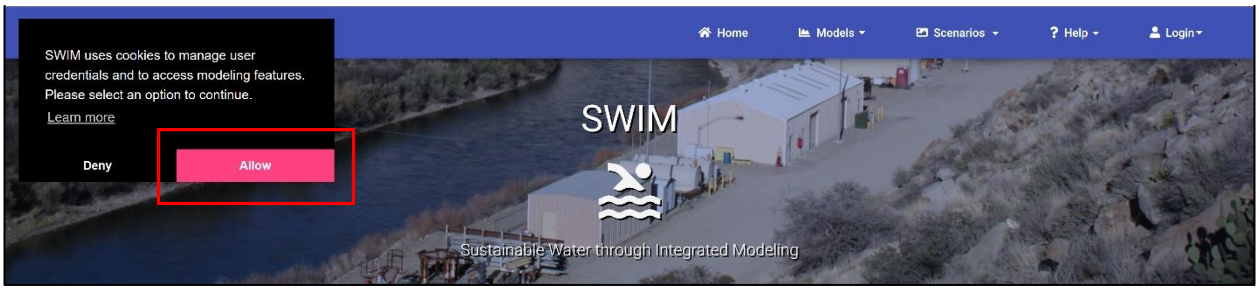
The water balance model is executed in two modes: historical and future simulations. In historical simulation mode, the model simulates the period 1994-2013, using time series inputs for (a) precipitation at climate stations throughout the project study area; (b) San Marcial gauge flows; (c) pan evaporation at the Elephant Butte climate stations; and (d) water demands for surface water releases from Caballo Reservoir and river reaches and for groundwater pumping from aquifers. The **2008 Operating Agreement for the Rio Grande Project** provides much of the governing framework for how water is allocated in the project area.

In future simulation mode, the model simulates future time periods, using similar time series inputs. Demands for surface water releases from Caballo Reservoir are assumed to be the maximum available under the Rio Grande Project 2008 Operating Agreement, which bases releases on water stored in Elephant Butte and Caballo reservoirs and treaty and compact requirements for sharing water between TX (US), NM (US), and CH (MX). Demands from groundwater aquifers are calculated using a base rate of groundwater pumping from each aquifer, based on historical pumping rates, combined with a variable rate, based on historical replacement of surface water shortages with groundwater pumping.

Getting Started

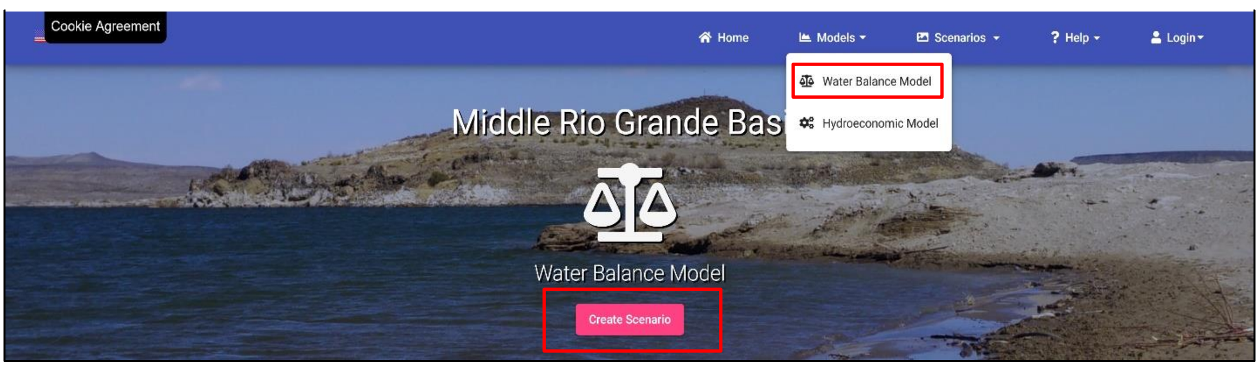
Click on **the Cookie Agreement** hidden at upper left navigation bar and select the **Allow Cookie** button to enable access to model data and functions. This will give you access to data and execution interfaces for the different models.

Figure 10: *Screenshot of cookie agreement popup in SWIM 2*



Select **Water Balance Model** from the Navigation menu and go to the **Create Scenario** tab and click on it.

Figure 11: *Screenshot of the Water Balance landing page banner on SWIM 2*

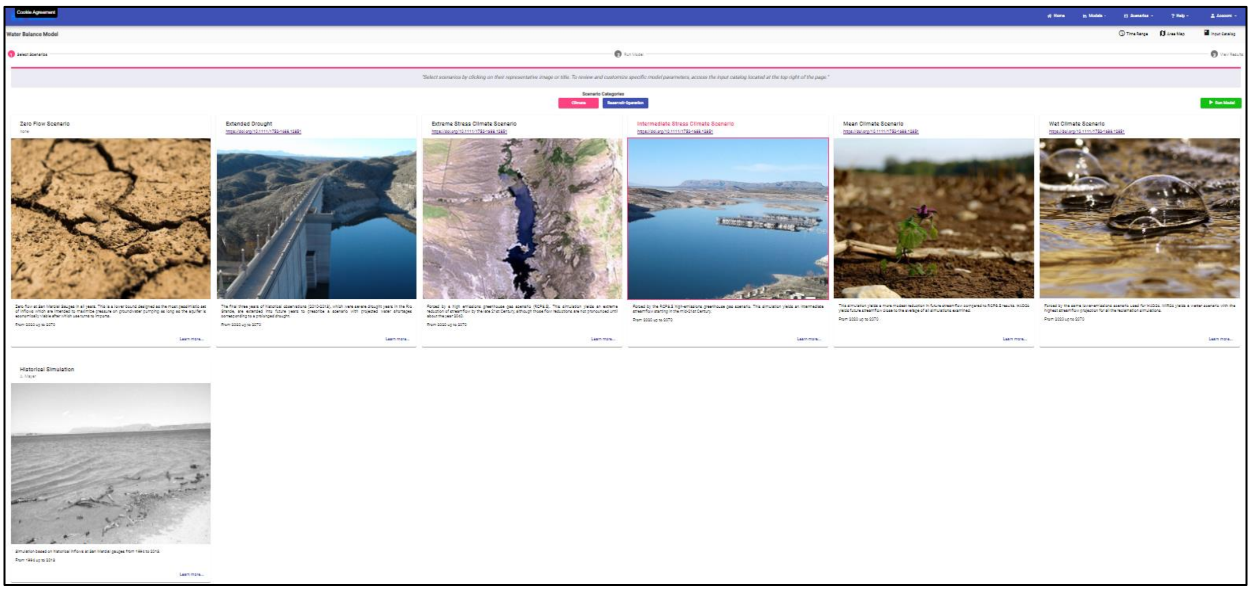


Predefined Scenario Categories

There is a simple three step process to create a model: Select the scenario; Run the model; View the results. **Create Scenario** gives you seven different predefined climate scenarios to work with as seen below.

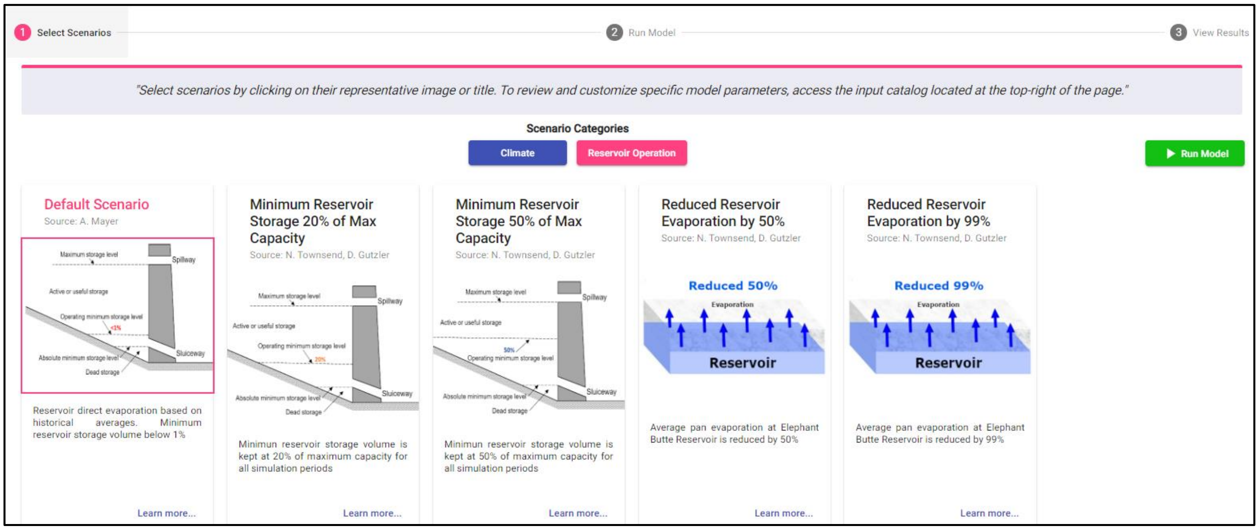
There are two categories of scenarios: **Climate**-based scenarios and **Reservoir Operation**. Each scenario affects the input parameters that go into the model, as would be expected since a ***Mean Climate*** scenario will be very different from an ***Extended Drought*** scenario in most parameter data sets.

Figure 12: *Screenshot of the Create Scenario workflow for the Water Balance Model on SWIM 2*



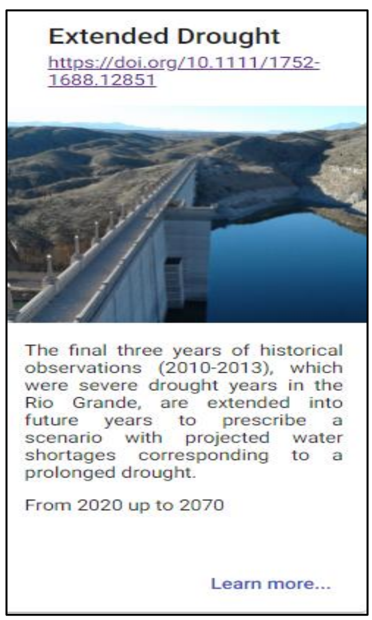
You can also combine climate scenarios with reservoir policies to see how they interact, e.g., a ***Mean Climate Scenario*** with a ***Minimum Reservoir Storage of 50% of Max Capacity*** scenario. The example below shows the five available reservoir policy selections.

Figure 13: *Screenshot of Reservoir Operation scenarios for the Water Balance Model*



Exploring the Climate Scenarios

A Climate Scenario is based on naturalized flow data projected by the Bureau of Reclamation under different greenhouse effect scenarios (Townsend & Gutzler, 2020). Each scenario is depicted as seen below in the ***Extended Drought*** scenario.



The URL under the scenario name links to the source of the scenario parameter data and rationale https://doi.org/10.1111/1752-1688.12851 that yields, in this case:


Technical Paper

Adaptation of Climate Model Projections of Streamflow to Account for Upstream Anthropogenic Impairments

Nolan T. Townsend, David S. Gutzler

First published: 13 May 2020 | https://doi.org/10.1111/1752-1688.12851

Paper No. JAWRA-19-0067-P of the *Journal of the American Water Resources Association* (JAWRA).
Discussions are open until six months from issue publication.
Research Impact Statement: Accounting for anthropogenic flow impairments using statistical techniques allows for climate influenced streamflow projections to be investigated from a water management standpoint.

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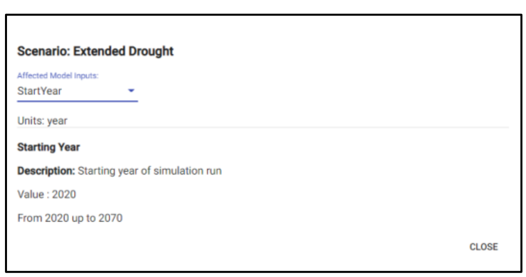
Abstract

A statistical procedure is developed to adjust natural streamflows simulated by dynamical models in downstream reaches, to account for anthropogenic impairments to flow that are not considered in the model. The resulting normalized downstream flows are appropriate for use in assessments of future anthropogenically impaired flows in downstream reaches. The normalization is applied to assess the potential effects of climate change on future water availability on the Rio Grande at a gage just above the major storage reservoir on the river. Model-simulated streamflow values were normalized using a statistical parameterization based on two constants that relate observed and simulated flows over a 50-year historical baseline period (1964–2013). The first normalization constant is a ratio of the means, and the second constant is the ratio of interannual standard deviations between annual gaged and simulated flows. This procedure forces the gaged and simulated flows to have the same mean and variance over the baseline period. The normalization constants can be kept fixed for future flows, which effectively assumes that upstream water management does not change in the future, or projected management changes can be parameterized by adjusting the constants. At the gage considered in this study, the effect of the normalization is to reduce simulated historical flow values by an average of 72% over an ensemble of simulations, indicative of the large fraction of natural flow diverted from the river upstream from the gage. A weak tendency for declining flow emerges upon averaging over a large ensemble, with tremendous variability among the simulations. By the end of the 21st Century the higher-emission scenarios show more pronounced declines in streamflow.

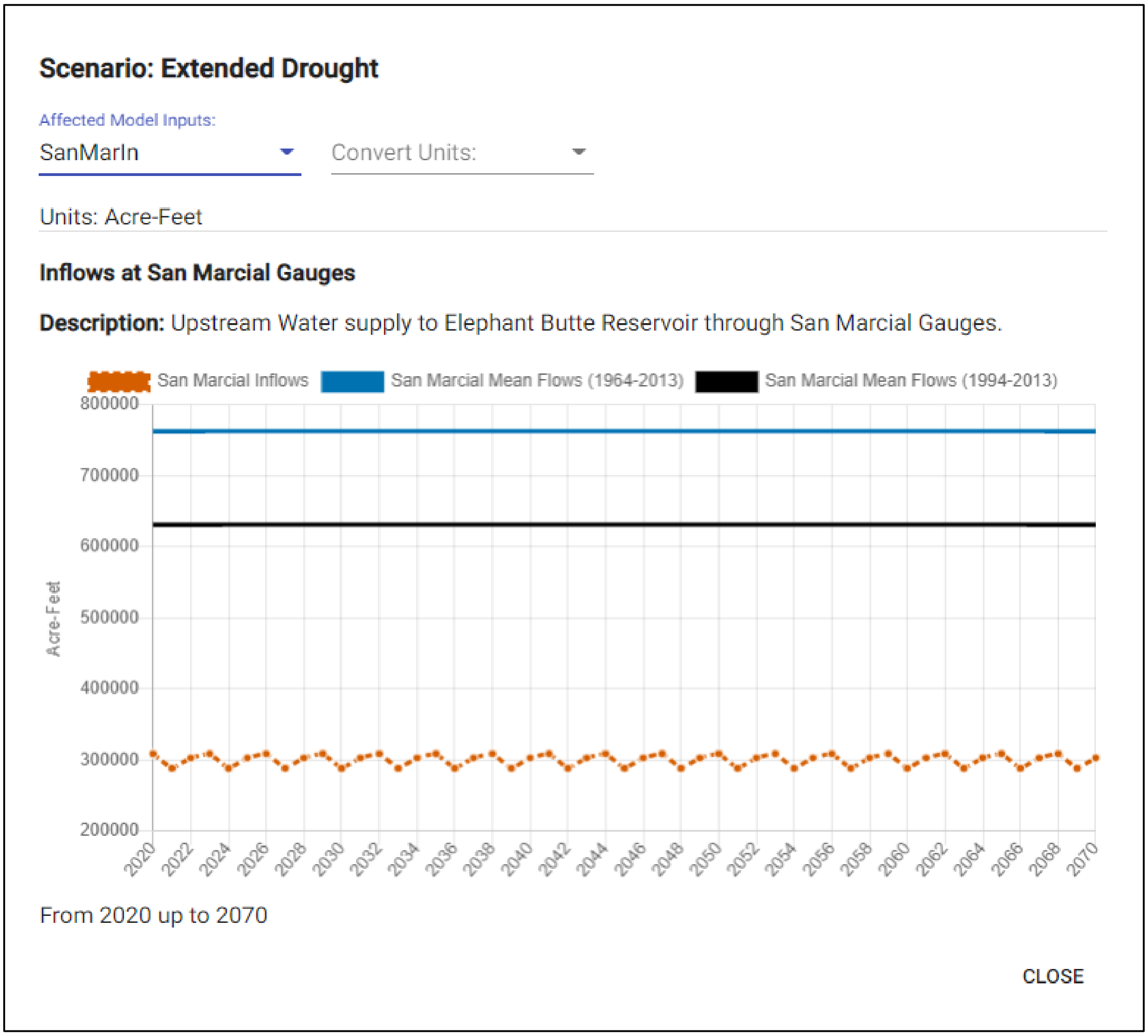
The parameter values are normalized to consider policy decisions and actions made upstream to create the effects of the selected scenario which is done by clicking on the photo. There is also a description of the scenario under its photo representation and the time range that the input parameters for the scenario include.

If you want to learn more about the scenario, that can be done by clicking on the **Learn more...**tab at the bottom of the scenario which in this case yields:

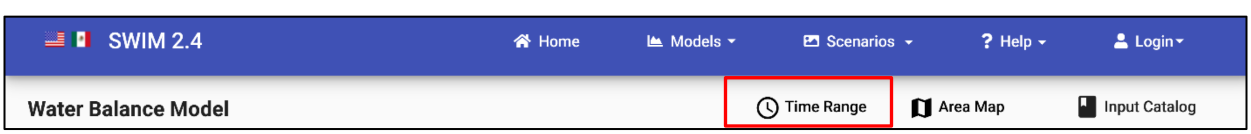


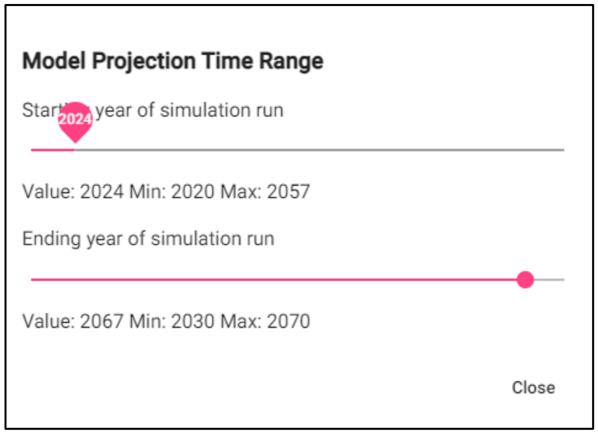
This provides a dropdown menu of the input parameters of this scenario, as seen here below:

Figure 14: *Screenshot of scenario details window on SWIM 2*



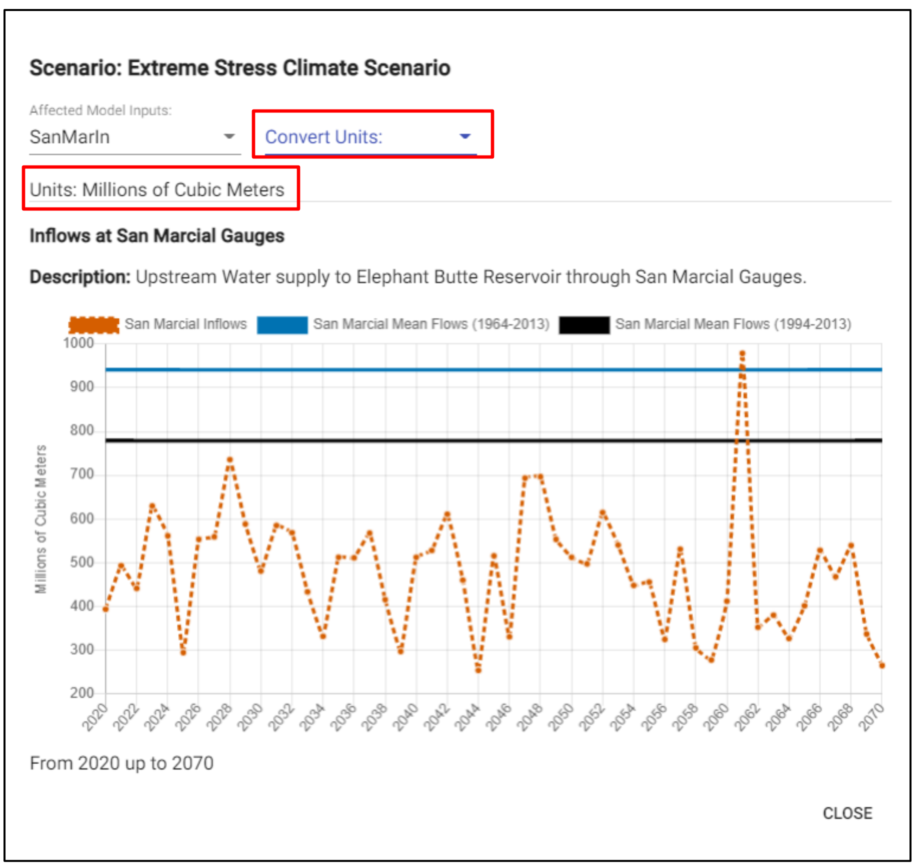
The selected scenario changes the inflow parameters at the San Marcial gauge to mimic the effects of an extended drought for the purposes of the model's calculations. The timeframe here is 2020 to 2070 but this can be changed by clicking on the **Time Range** symbol at the upper right of the screen as seen below and using the slide adjustment to select different start or end dates for the model scenario.





The same can be done with the other scenarios and what the model is doing then is to simulate the downstream effects on flow and storage given the input parameters and the demands of the selected scenario. The default unit of measurement is acre-feet, but the **Convert Units** tab lets us switch to millions of cubic meters, as shown below for the Extreme Stress Climate Scenario.

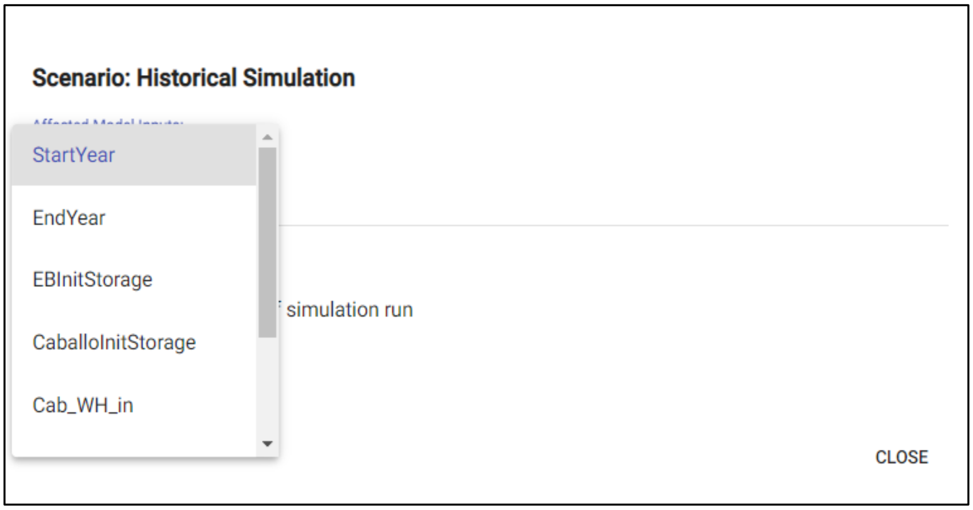
Figure 15: *Screenshot of extreme stress scenario details when applying unit conversion to the input data.*



Historical Simulation

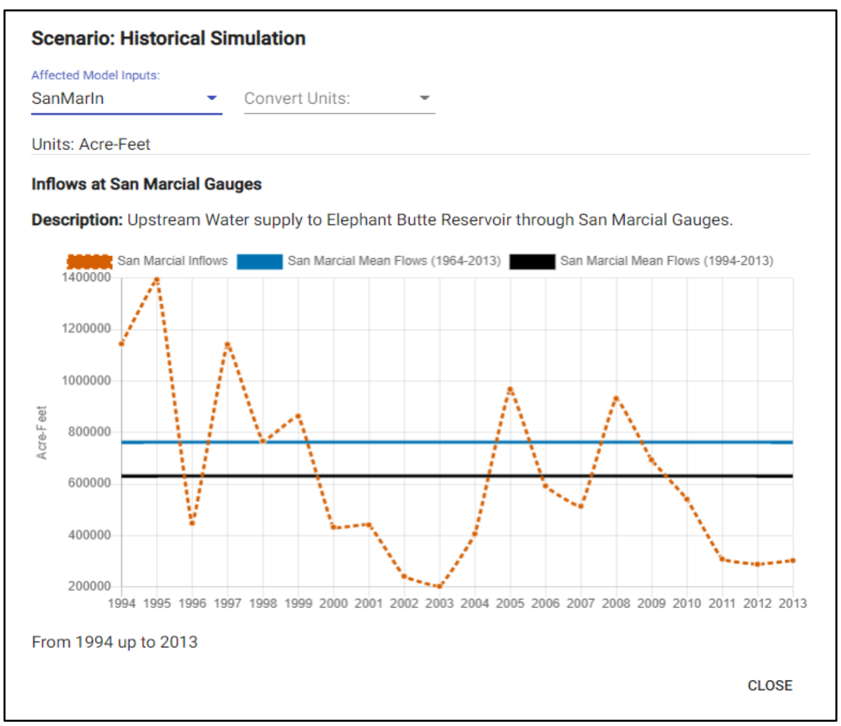
Apart from the climate scenario simulations, the model also includes an historical simulation based on the inflows at San Marcial from 1994 to 2013 in which the model attempts to simulate what has already occurred in the basin trying to replicate what happened historically. Clicking on **Learn More**...and then the **Start Year** of the dropdown menu presents a range of historical parameters.

Figure 16: *Dropdown list of parameters for a historical simulation scenario.*



If we click on the San Marcial Inflows, we see the actual observed data for the historical timeframe.

Figure 17: *San Marcial Inflows for replication of a historical scenario.*



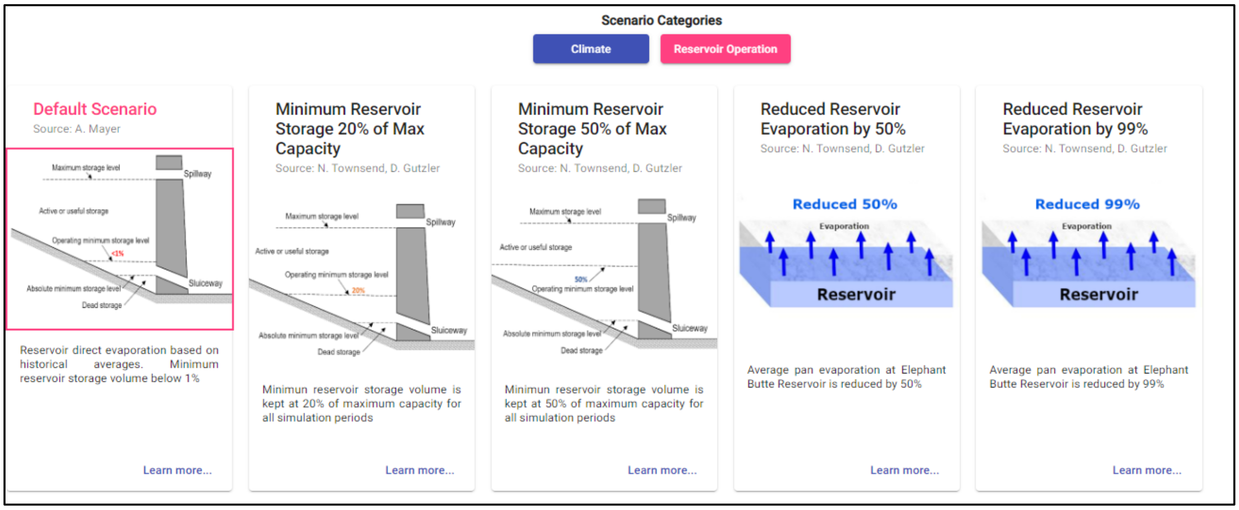
If we subsequently run this model by clicking on the **Run Model** tab it will use the historical data to predict downstream effects and these will be presented to us as a dashboard (below). More on this later.

Figure 18: *Screenshot of summary dashboard for a historical simulation of the Water Balance Model.*

Navigating Reservoir Operation Scenarios

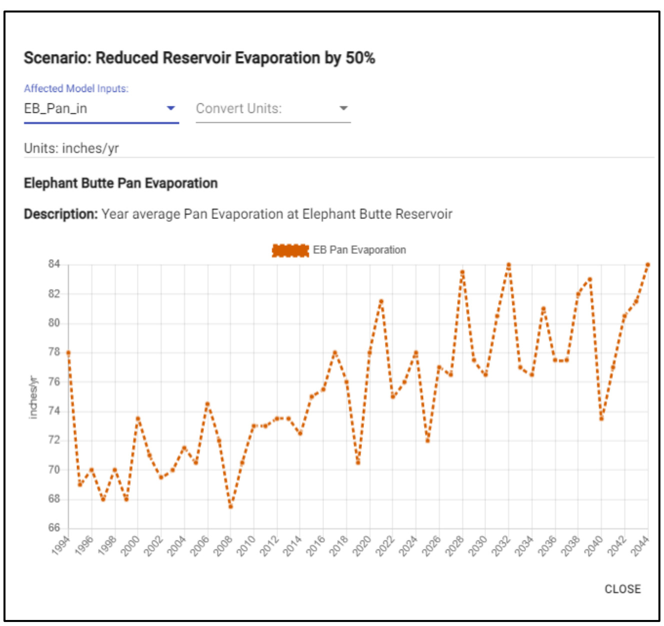
On the Scenarios Categories page, click on **Reservoir Operations**. This will present us with five operational policy scenarios for the Elephant Butte Reservoir.

Figure 19: *Reservoir Operation scenario options for the Water Balance Model*



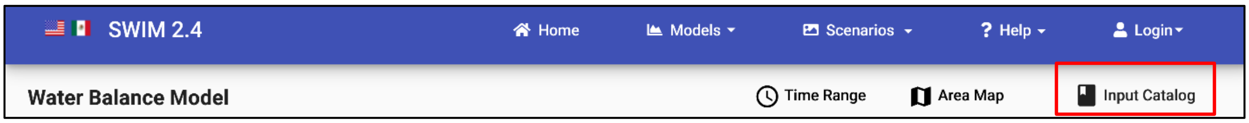
The ***Default Scenario*** is the management of the reservoir under the rules currently established, i.e., in the 2008 Rio Grande Compact. The other scenarios present options that could be exercised including reducing evaporation loss, perhaps by applying some technology-based solution. If we click on the **Learn more** button for the Reduced 50% scenario, we get a projection of *Pan Evaporation* for both the historical period and going forward based on reducing this input by 50%.

Figure 20: *Reduction of pan evaporation rate by 50% of projected values.*



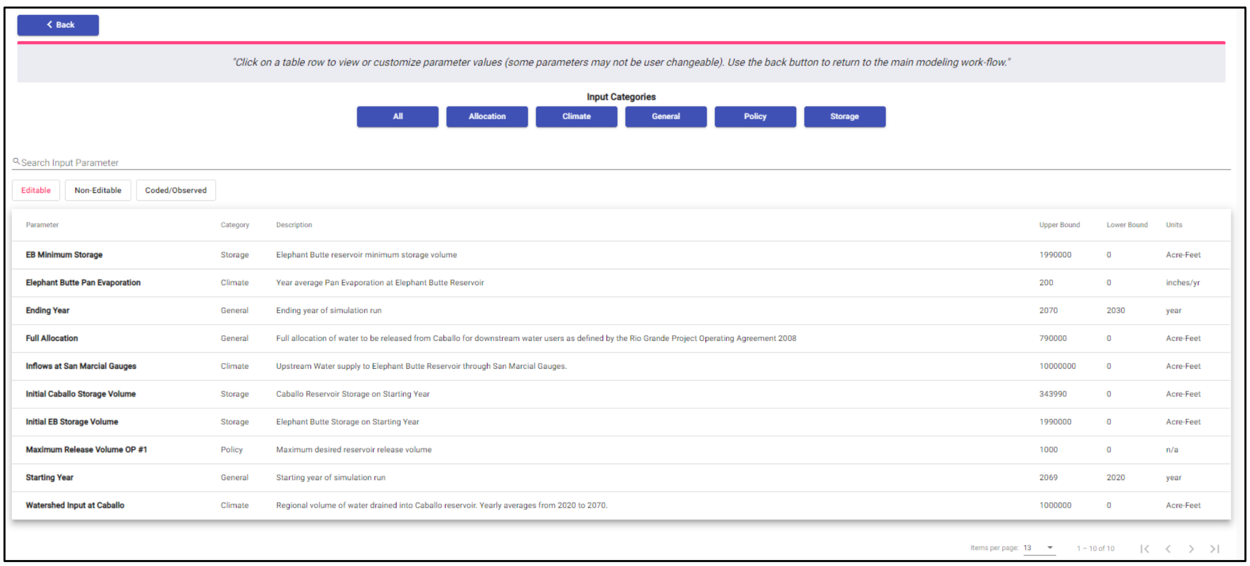
Exploring the Input Parameters

SWIM includes an extensive data library of input parameters to drive the model scenarios. It is possible to explore the inputs for a model scenario by selecting individual input parameters for graphing and comparison. This is done by clicking on the **Input Catalog** tab in the upper right-hand corner of the model screen.



For the Water Balance Model, clicking on the **Input Catalog** presents the following page of options with input parameter categories.

Figure 21: *Screenshot of the Input Catalog for the Water Balance Model on SWIM 2*



The bar across the top of the table allows the user to reduce the view of input parameters (there are pages of parameters) according to the category selected, for example, selecting the **Policy** tab will result in only three parameters being displayed. Selecting **Climate** will display eight climate parameters used as input to the model. Clicking on **Editable** will display input parameters that can be modified.

NOTE: When navigating back and forth in the model, be sure to use the **Back** tab when it is presented. Otherwise, you risk losing the current model.

The parameters can be shown in different ways: as a table, line, or bar chart. In this example, the **Climate** tab was selected, and eight parameters displayed.

Figure 22: *Screenshot of the Water Balance input catalog filtered by Climate category.*

Editable | Non-Editable | Coded/Observed

show non-editable inputs that are loaded to the model

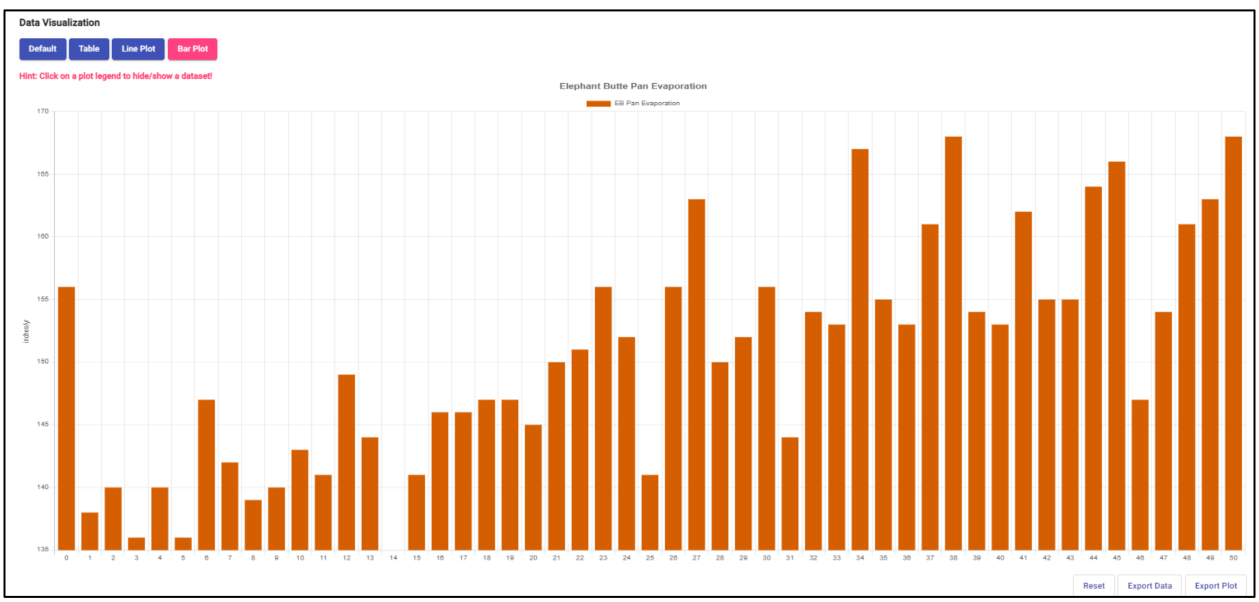
Parameter	Category	Description	Upper Bound	Lower Bound	Units
Elephant Butte Pan Evaporation	Climate	Year average Pan Evaporation at Elephant Butte Reservoir	200	0	inches/yr
Inflows at San Marcial Gauges	Climate	Upstream Water supply to Elephant Butte Reservoir through San Marcial Gauges.	10000000	0	Acre-Feet
Observed Elephant Butte Pan Evaporation	Climate	Year average observed Pan Evaporation at Elephant Butte Reservoir between 1994 and 2013	200	0	inches/yr
Observed Inflows at San Marcial Gauges	Climate	Observed upstream Water supply to Elephant Butte Reservoir through San Marcial Combined Gauges (1994-2013).	10000000	0	Acre-Feet
Observed Precipitation at Elephant Butte	Climate	Yearly observed localized precipitation at Elephant Butte reservoir from 1994 to 2013	100	0	inches/yr
Observed Watershed Input at Caballo	Climate	Observed Regional volume of water drained into Caballo reservoir. Yearly averages from 1994 to 2013.	1000000	0	Acre-Feet
Precipitation at Elephant Butte	Climate	Yearly localized precipitation at Elephant Butte reservoir in inches	100	0	inches/yr
Watershed Input at Caballo	Climate	Regional volume of water drained into Caballo reservoir. Yearly averages from 2020 to 2070.	1000000	0	Acre-Feet

Items per page: 13 1 - 8 of 8

Visualize Input Parameters

To visualize a parameter, just click on it; in this example *Elephant Butte Pan Evaporation* was selected by clicking on it. The default view is a table, but you can also view the variable as a line or bar plot by clicking on the **Visualization Type** tab. Selecting a bar chart results in the presentation below for a data view of the Elephant Butte Pan Evaporation parameter.

Figure 23: *Bar Plot visualization of Elephant Butte Pan Evaporation parameter values.*



Edit Input Parameters

The tableau for input parameters also allows us to select those that are editable in the overall table. Clicking on the **Editable** tab gives us a view of the parameters that can be manually changed.

Elephant Butte Pan Evaporation is one of them. For example, the first value in the time series for *Elephant Butte Pan Evaporation* is 156 that can be seen in the default Table View.

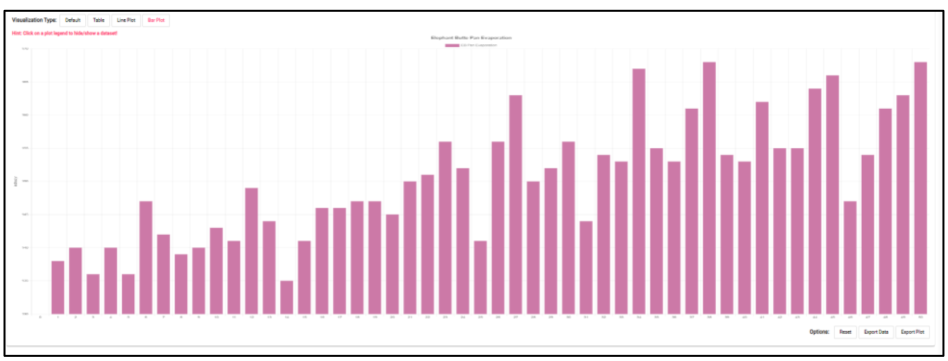
EB_Pan_in (inches/yr)
156
138
140
136

Let us assume that we have a reason to set this beginning variable to a value of 130 which is below the lowest value on the default graph. Click on the variable in the table and enter in 130 over it, clicking to make 156 to 130.

EB_Pan_in (inches/yr)
130
138
140
136
140

Now look at the bar plot again. Note that it has changed color to reflect a different input set.

***Figure 24**: Bar Plot Visualization after data value change.*

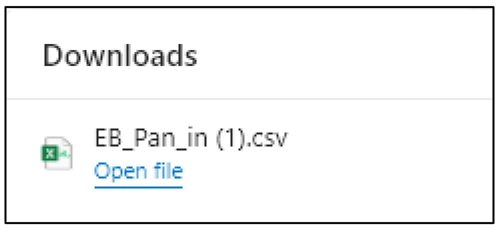


Do not worry that you have corrupted the data set. You can always return it to its original value by clicking the **Reset** tab at the bottom of the display. Now that we have navigated the overall model and explored the Input Parameters, we are able to begin working with our own water balance scenarios.

Export Input Parameters

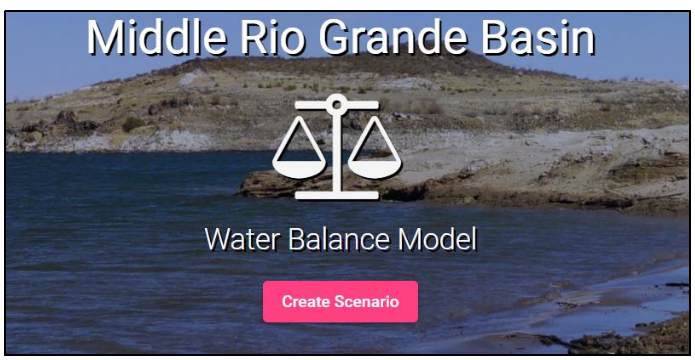
We can also export an input data set. Looking at the current Elephant Butte Pan Evaporation input parameter, we can click on Export Data in the lower right-hand corner of the table as shown below.

This will give us a download option to save the input parameter dataset as a CSV file.



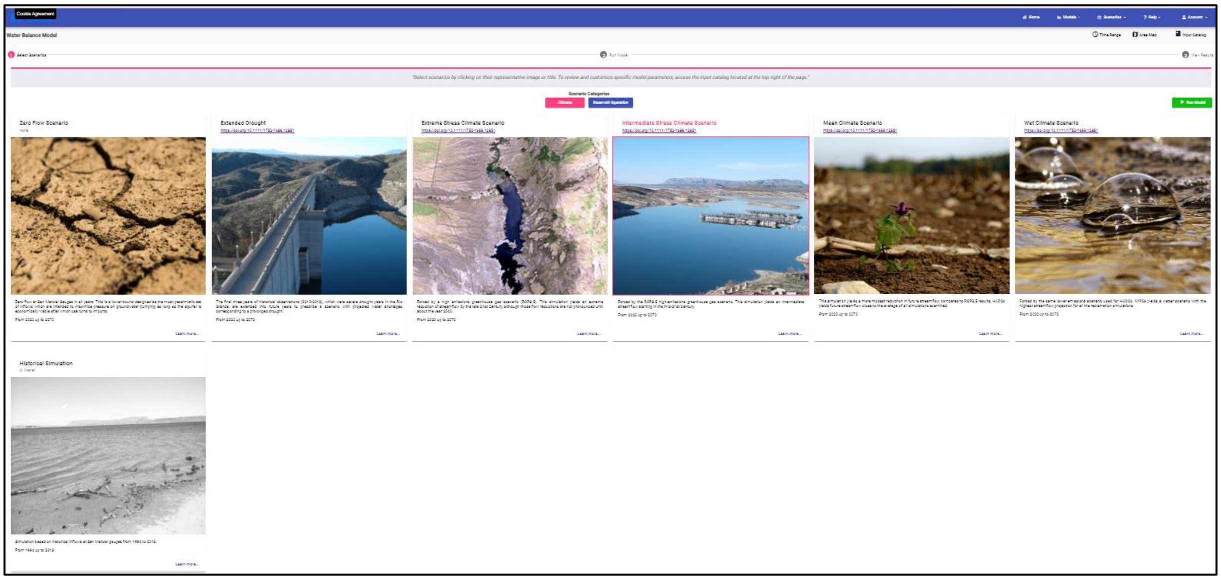
Creating Your Own Water Balance Scenarios

As a way of integrating what has been illustrated so far, you can create a private or public Water Balance scenario for your own research that combines climate forecasts with reservoir policy options by going to the home page, selecting **Water Balance Model** in the Models drop down menu and then selecting the **Create Scenario** option as seen below.



This selection will generate the same seven scenarios (below) and it gives you the option to apply the scenario to either **Climate** and/or **Reservoir Operation.** The “mechanics” for these options are mostly the same as for the previous exercise, but SWIM now allows you to name and save a particular model instance. The following example will be for climate alone, then we will combine it with reservoir operations. We will create a Water Balance model and examine its operation and inquire into its input parameters and output variables.

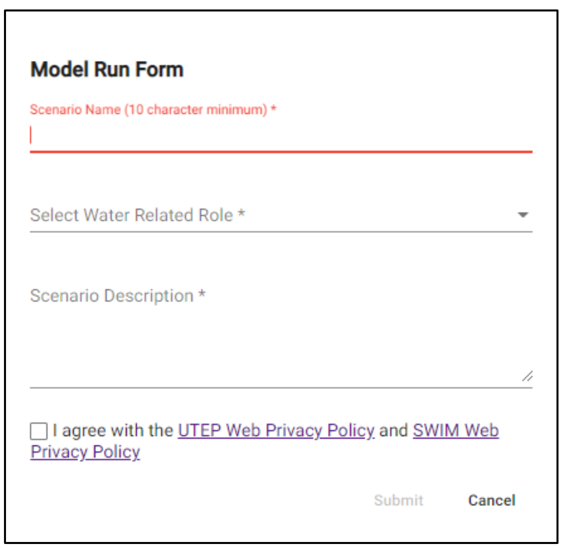
Figure 25: *Create scenario workflow for the Water Balance Model showing climate scenario category options.*



Select and Run a Climate Model

This time, choose the ***Mean Climate Scenario*** then click on the **Run Model** tab. This will bring up the following **Model Run Form**.

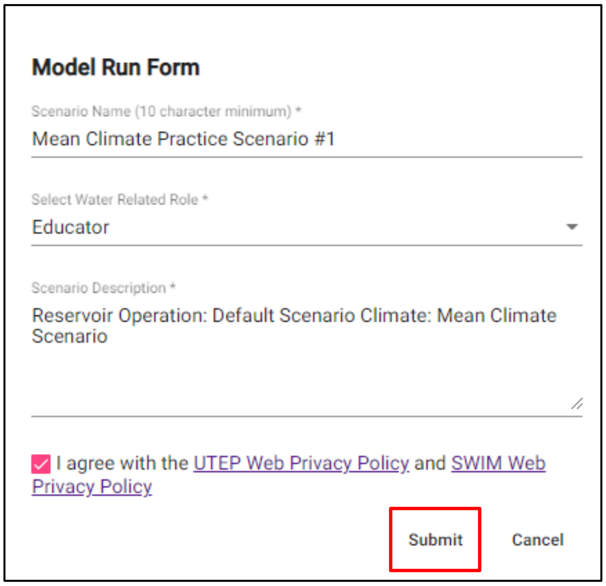
Figure 26: *Empty model run form before executing custom scenario.*



Let us name the model the **Mean Climate Practice Scenario #1** and choose our **Water Related Role** from the dropdown menu as *Educator*. The click on the agreement tab for privacy policies.

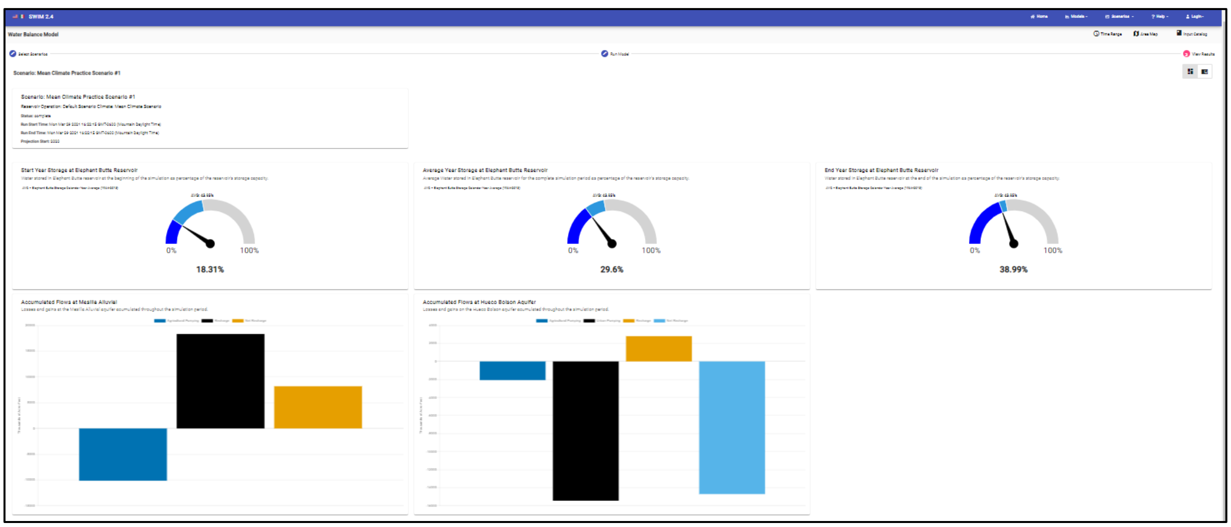
Future releases of SWIM will present views appropriate to different water related roles.

Figure 27: Filled model run form before executing custom scenario.



Click on **Submit** to complete running the model scenario. This will result in the following screen dashboard view.

Figure 28: *Scenario run summary dashboard for a mean climate scenario of the Water Balance Model.*



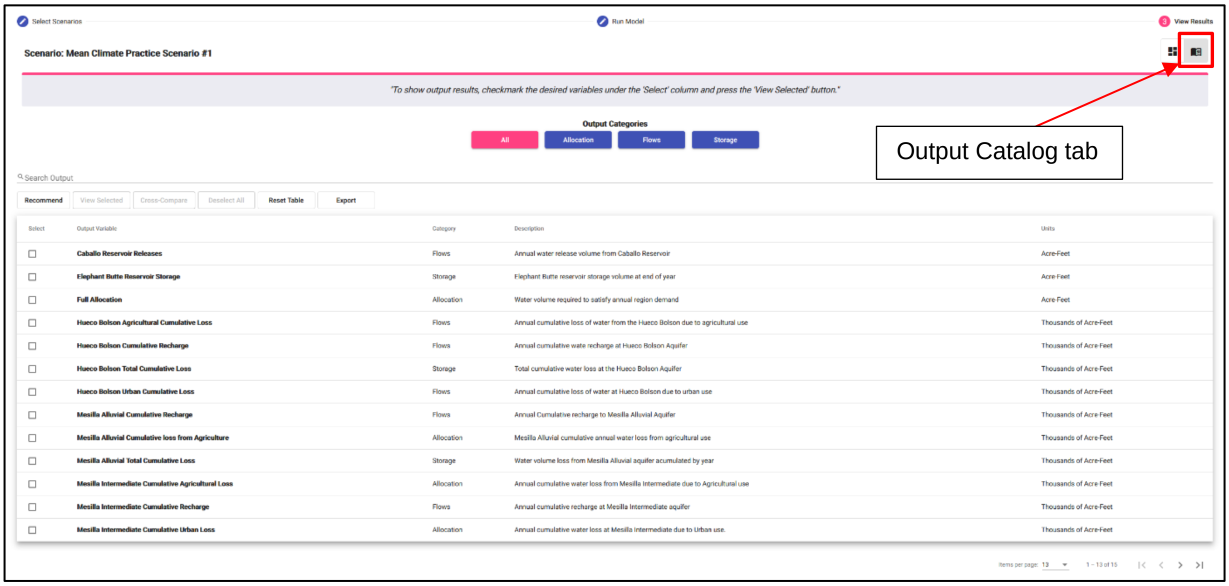
The dashboard shows how the reservoir responds to the conditions of the climate model scenario, with a *Start Year* percentage of the reservoir's storage capacity, *Average Water* stored in Elephant Butte reservoir for the complete simulation period as percentage of the reservoir's storage capacity and finally, *Water* stored in Elephant Butte reservoir at the end of the simulation as percentage of the reservoir's storage capacity.

The bar charts show how the aquifers respond with losses and gains at the aquifers accumulated throughout the simulation period.

Query Output Variables

At this point, we can further query the model execution's output variables from the resulting screen view. This view can be reduced by selecting the **Output Catalog** in the upper right corner. This will yield the following page of variable groups for inquiry.

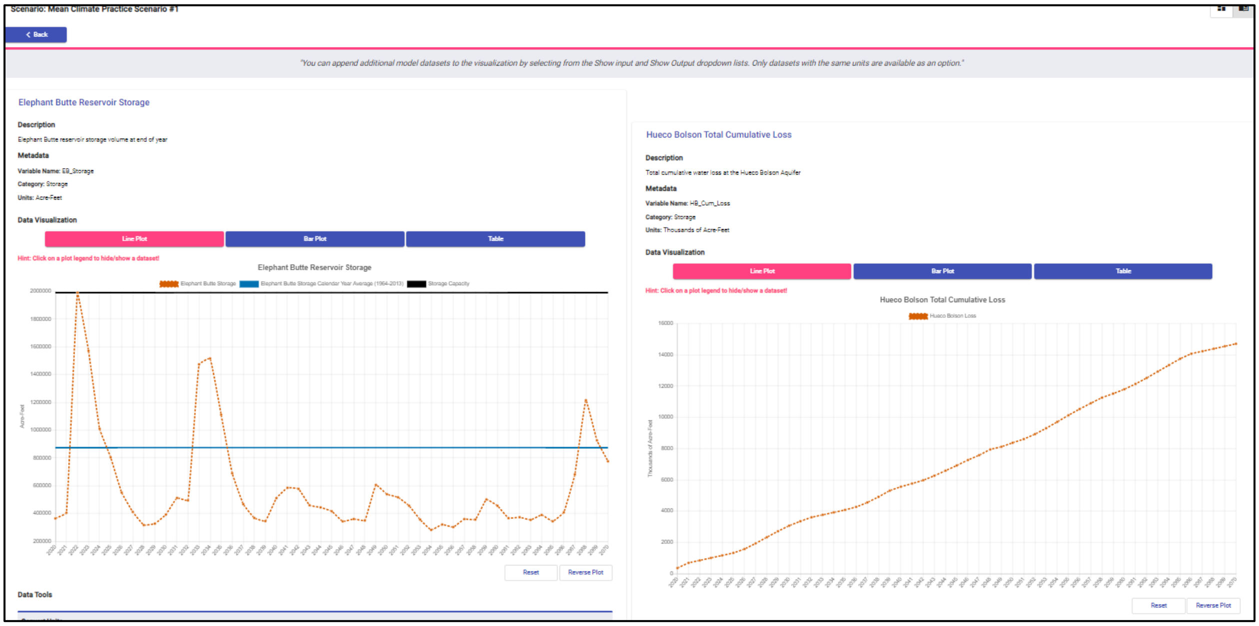
Figure 29: *Screenshot of the Output Catalog screen for the Water Balance Model on SWIM 2*



This view of 15 total output variables can be reduced by selecting one of the **Output Categories** from the control bar. There is also a **Search** box for general named inquiries and a **Recommend** box reduces the list to what might be appropriate for the **Water Related Role** chosen for the model execution.

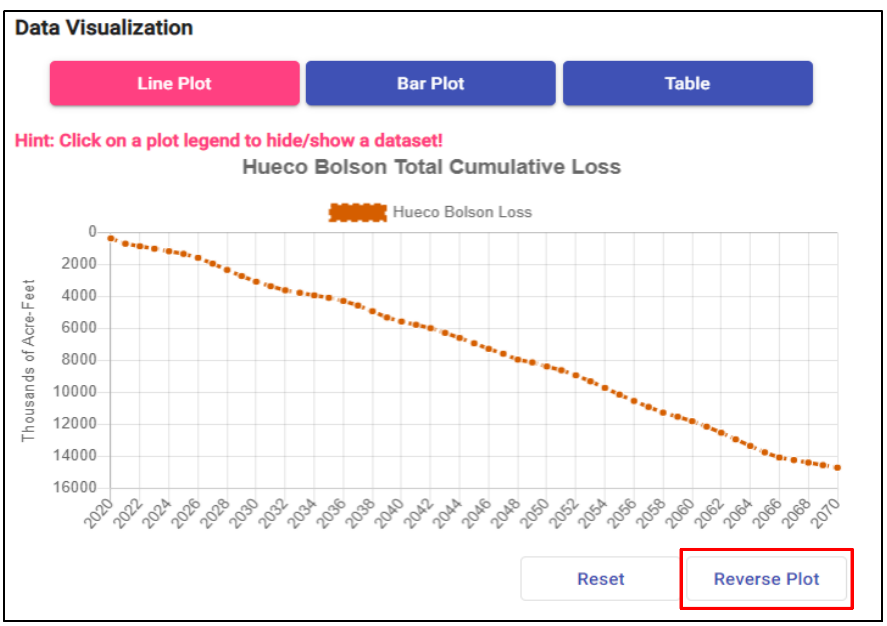
For example, select the **Storage** category on the bar and the view shrinks from 15 to five variables. Select the first four variables in the table for this example and then click on **View Selected** to create the following (partial) output dashboard that can display a line, bar, or table plot solely for the four current **Mean Climate Scenario #1** model storage variables. It can be done with all the output variables, not just the four here.

Figure 30: *Screenshot of two selected variables for detail visualization.*



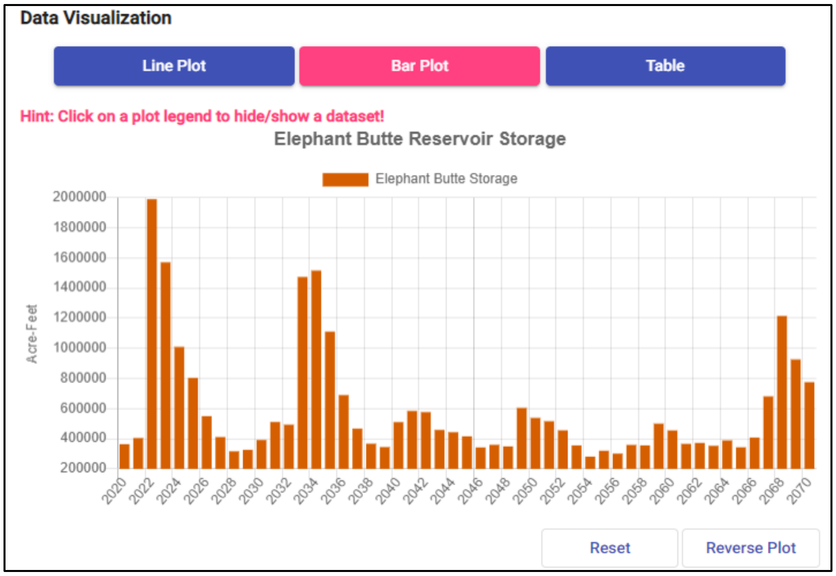
Data Visualization enables us to display a line chart, bar plot or table view (data) of the results. On figure 30 we see *Elephant Butte Reservoir Storage* compared to *Hueco Bolson Total Cumulative Loss*. We can make this comparison more relevant by clicking on the **Reverse Plot** box for the *Hueco Bolson* at the bottom right corner. This will flip the graph's Y axis, so it shows the Bolson declining, a little easier to visualize.

Figure 31: *Line plot view of variable data flipped over Y axis*



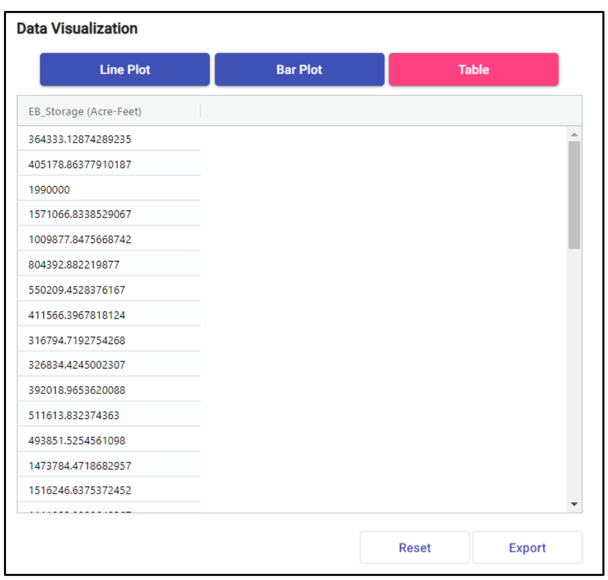
A line plot is the default but clicking on a bar plot yields a different graphic of the visualization, as seen below for the first graph, Elephant Butte Reservoir Storage. If there is more than one data set showing and you want to limit the graph to less than the total number, then click in the plot legend and it will nullify the view of the selected data set.

Figure 32: *Bar Plot visualization for Elephant Butte Reservoir Storage.*



If we choose the **Table** view tab, the following data appears that offers an **Export** option to save the table data as a .csv file.

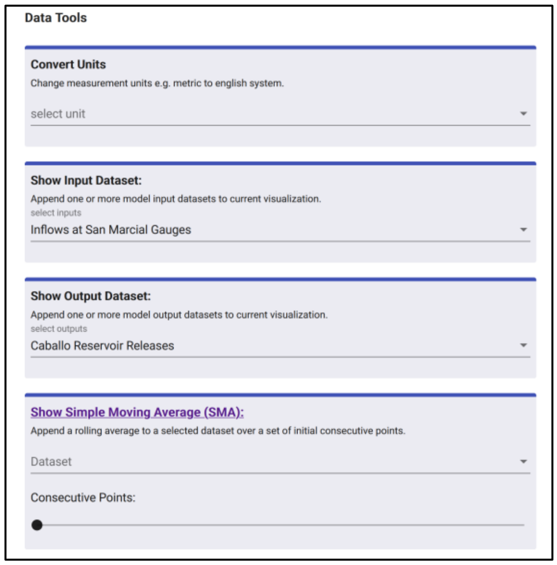
Figure 33: *Data Table visualization for Elephant Butte Reservoir Storage.*



Digging Down

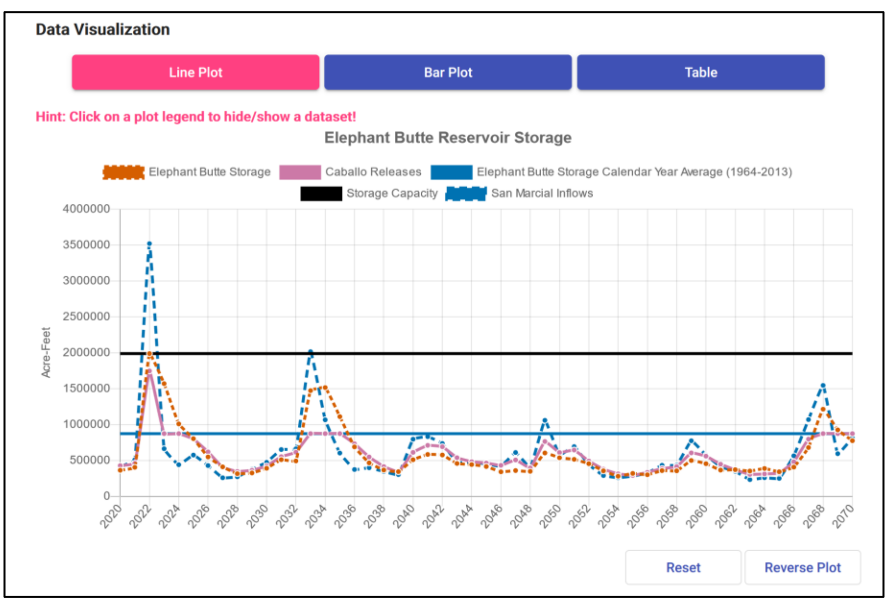
Beneath the Line Plot graph is a **Data Tools** menu, seen below. Data Tools enables us to append additional data sets to the Line Plot graph to see how the variables behave in parallel. Let us select *Inflows at San Marcial Gauges* from the **Show Input Dataset** menu, and *Caballo Reservoir Releases* from the **Show Output Dataset** menu, as seen below.

Figure 34: *Data Tools available for output variable details on SWIM 2*



Then, look at how the graph has changed to incorporate the datasets for visualizing comparison over time.

Figure 35*: Line plot visualization with appended datasets.*



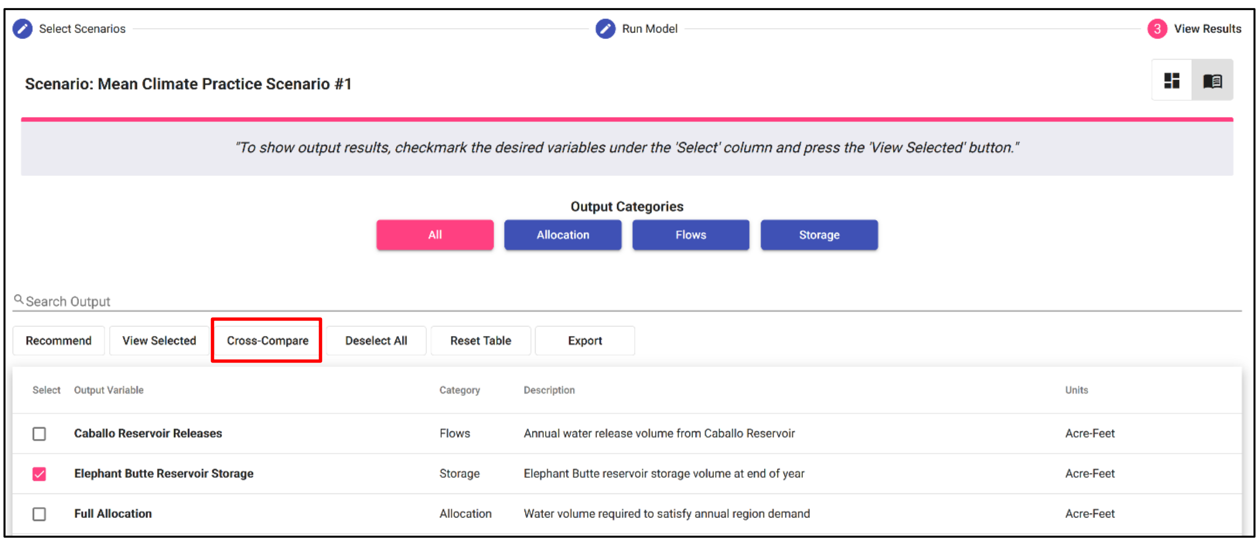
These operations on the model’s output variables give further visual insight to how the variables behave over time and with respect to each other in the selected scenario.

Cross Compare

We are still in the Output Catalog of the current **Mean Climate Scenario #1** model that was created earlier, and we are analyzing the four output variable results of just this model. SWIM makes it possible to select **Cross Compare** that will result in the choice of which other model scenarios you wish to compare the current output against, both Public and Private user scenarios.

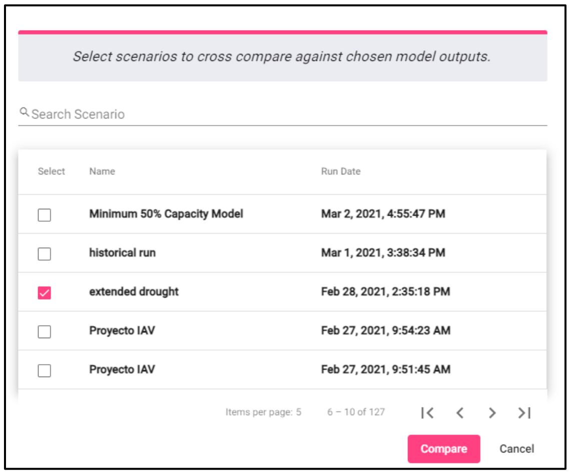
First, let us return to the **Output Categories** data set view by clicking on the **Back** tab. Let us select a previously Public Scenario model, **extended drought,** and click the Cross **Compare** tab as seen below.

Figure 36: *Selection of Cross-Compare from the Output Catalog screen.*



Click the **Compare** tab as seen below to cross compare the model outputs.

Figure 37: *Cross-compare scenario selection window.*



This results in a cross-comparison of the current variables in two different model scenarios: **Mean Climate** (current model) and **extended drought**. The ability to cross-compare scenarios is a powerful tool for examining the impact of different policies in varying climate scenarios.

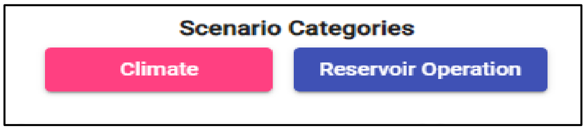
Below are the comparison results on *Elephant Butte Reservoir Storage* for the two climate scenarios with **extended drough**t on the left and **Mean Climate** on the right side.

The results come as no surprise.

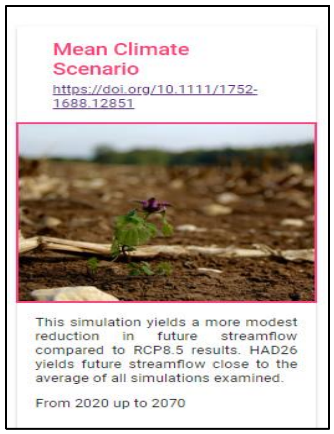
Figure 38: *Comparison of Elephant Butte Reservoir Storage between an **extended drought scenario** and a **mean climate scenario**.*

Reservoir Operation Scenarios

Returning to the *Scenario Categories* home page, we also have the option to model reservoir operations.

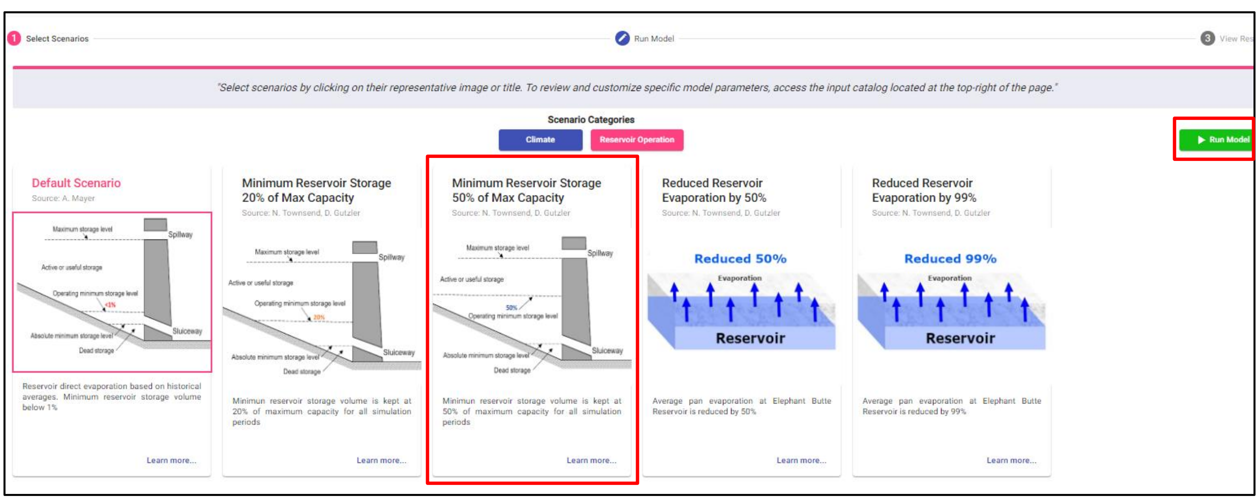


We will keep the same climate scenario as previously, ***Mean Climate Scenario***, but it could be others.



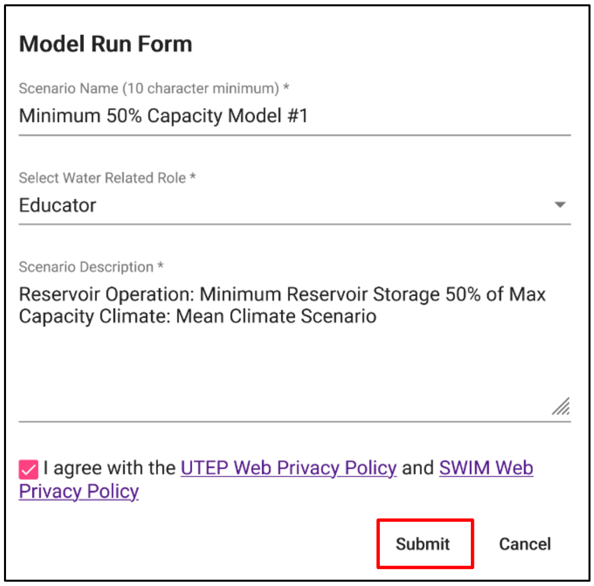
Selecting **Reservoir Operations** tab yields the following policy options for modeling. Let us model the third scenario, *Minimum Reservoir Storage 50% of Max Capacity* or what is needed to maintain a minimum 50% of maximum reservoir capacity in a ***Mean Climate Scenario*** as seen below. Then click on **Run Model**.

Figure 39: *Reservoir Operation predefines scenarios of the Water Balance Model.*



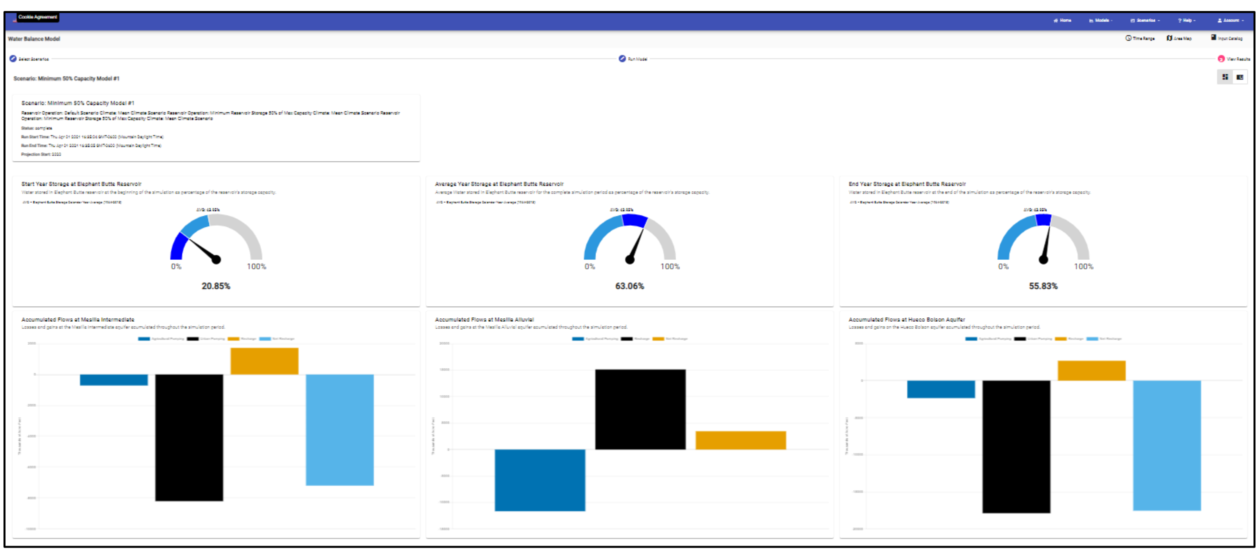
This will give us our Model Run Form to complete naming our model, Minimum 50% Capacity Model #1, and select a water related role (Educator) and Submit.

Figure 40: *Filled model execution form of a Water Balance Model Scenario with mean climate and 50% minimum reservoir storage.*



This yields the following dashboard report of *Reservoir Operation: Minimum Reservoir Storage 50% of Max Capacity Climate: Mean Climate Scenario*.

Figure 41: *Result summary dashboard of a Water Balance Model scenario with a minimum of 50% surface storage capacity.*



Subsequently, we can query the Output and Input Catalogs to change and edit parameters and variables and analyze and cross-compare variables as we did earlier.

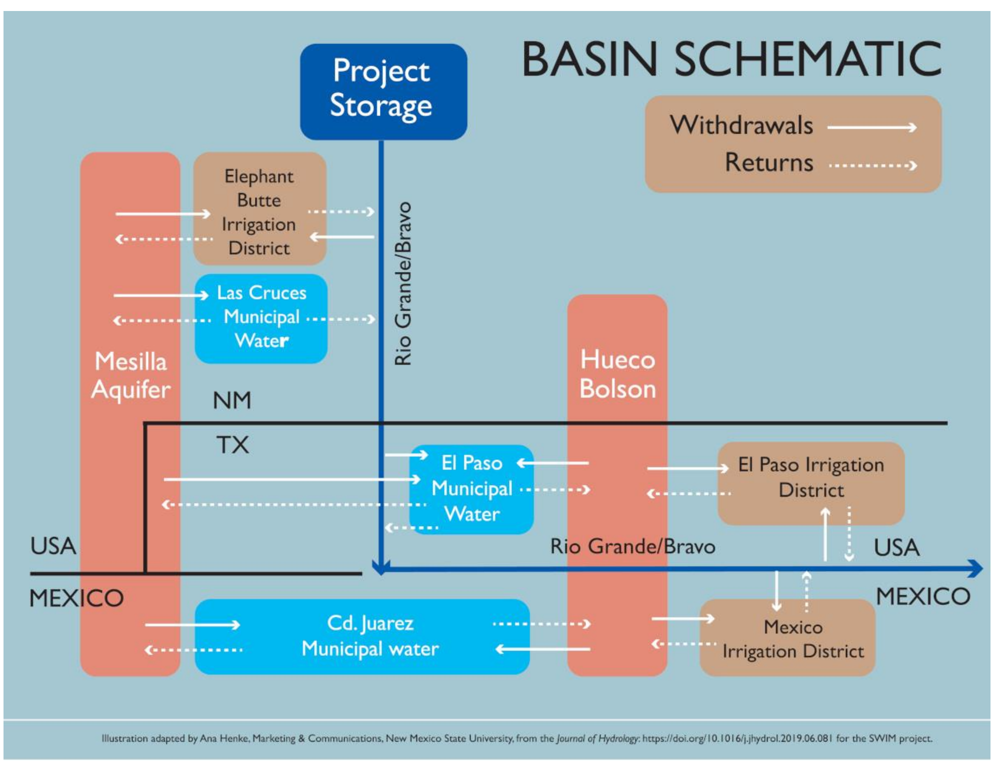
The dashboard reveals that it is possible to maintain a 50% minimum reservoir storage capacity in the Elephant Butte Reservoir during a Mean Climate Scenario while meeting the delivery demands of the 2008 Operating Agreement. And in these dry times, don't we all wish it were that easy!

Hydroeconomic Model Operation

The Middle Rio Grande Hydroeconomic Optimization Model (Ward et al., 2019), also referenced as "The Bucket Model", is a simple coarse-scale basin model that simulates all major water sources, sinks, uses, and losses. It also includes economic values of water, as well as institutional constraints governing water supply and use for the Middle Rio Grande between the inflow to Elephant Butte Reservoir and Fort Quitman on the Rio Grande. This model is designed to be a useful tool for improving our understanding of the hydrology, agronomy, institutions, and economics to guide analysis of policy and management questions that are important to stakeholders.

The current version of the model is an aggregate “three bucket” model that reflects water stocks, inflow, and outflow for project storage (surface water reservoirs) and for the region’s two major aquifers, the Mesilla and Hueco. In this version, the three water users are irrigated agriculture, urban demands, and environmental/recreational demands for water volumes in surface storage. For aquifers, the major uses are agriculture and urban use. Potential water use is predicted as a constrained optimization model that identifies water use and flow patterns that maximize discounted net present value of water by adjusting water use patterns in the river-reservoir-aquifer system for the model’s time horizon. The figure below illustrates the basic structure of the Hydroeconomic Model.

Figure 42: *Structural basin schematic of the coverage area of the Middle Rio Grande Hydroeconomic Model.*



Required inputs include hydrologic data such as surface inflows to storage, crop water requirements by crop, surface treaty delivery requirements from the U.S. to Mexico, evaporation rates from surface reservoir storage, and reservoir capacity. Water use demand data include crop yields, costs of production, crop price, price elasticity of demand, and urban population.

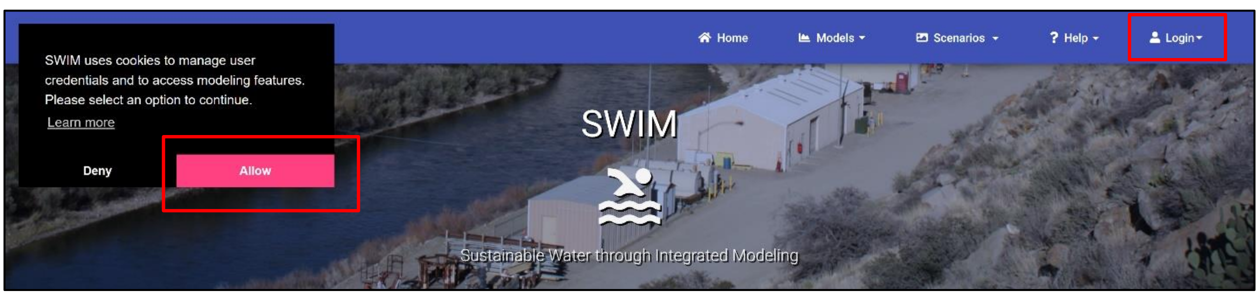
Model outputs include total farm income, recreation economic benefits, total urban net benefits, reservoir releases, surface storage volume, groundwater pumping and recharge, 1906 Treaty deliveries by the U.S. to Mexico, reservoir surface evaporation, total water use, and the discounted net present value of total economic benefits and its distribution among major water users.

Getting Started

This section of the User Manual builds on the **SWIM Website Overview** above and the site navigation techniques described in that section. Click on **SWIM** at upper left navigation bar and select the **Allow Cookie** button to enable you to access model data and functions. This will give you access to data from the models.

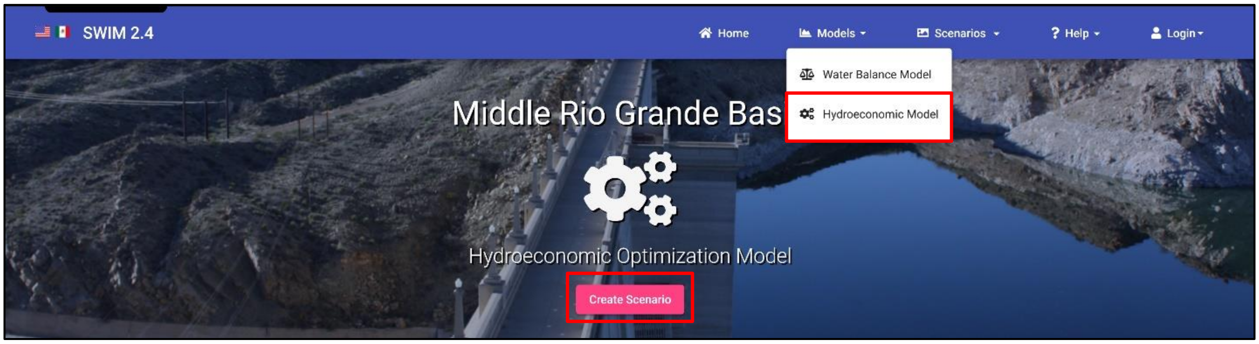
Login into SWIM at the upper right corner of the Navigation Page.

Figure 43*: Cookie agreement and login on SWIM 2.*



Select **Hydroeconomic Model** from the Navigation menu and go to the **Create Scenario** tab and click on it. This section of the User Manual will navigate through the functions of the Hydroeconomic Model and display scenario dashboard outputs and query further into output parameters for most scenarios. The intent is that the user will gain an understanding of how the model works generally so that, for a specific modeling scenario the user has in mind, the user will understand the tools the model provides to explore his/her policy issues.

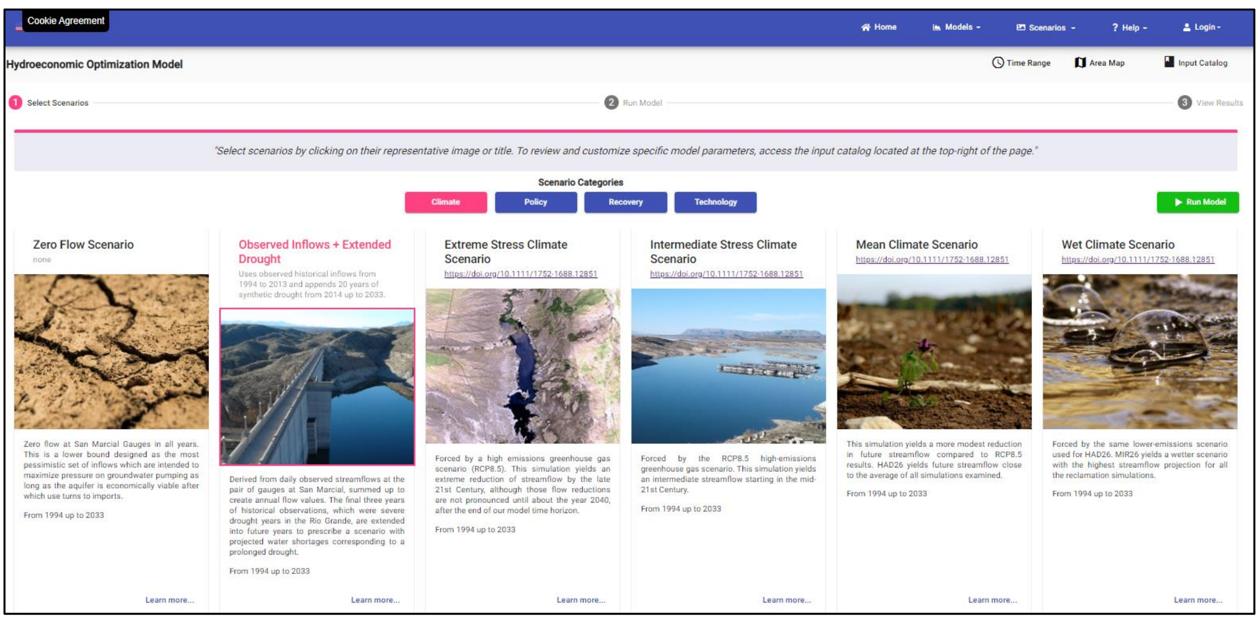
__Figure 44:__ Selection of Hydroeconomic Model on SWIM 2.



Scenario Categories

Create Scenario yields four categories of model scenarios: *Climate, Policy, Recovery* and *Technology* based scenarios. Each of these categories can be explored using predefined data sets and model assumptions and operations that affect the input parameters that go into the model.

__Figure 45__: Predefined scenario selection screen of the Hydroeconomic Model in SWIM 2.



Selecting and Running a Scenario

There is a simple three step process to create a model: Select a combination of predefined scenarios; run the model; view the results.

By highlighting one of the six climate scenarios above, you make it the climate scenario against which Policy, Recovery and Technology based scenarios are executed. The default is the second climate scenario - *Observed Inflows + Extended Drought* - and this will be used if no other climate scenario is selected prior to running one of these. This will be illustrated below as we deal with the other Hydroeconomic model scenarios.

Input Categories

The Hydroeconomic Model currently includes 44 datasets as input parameters. These are accessible from the **Input Catalog** in the upper right-hand corner of the model's workflow page. It is possible to expand a selected scenario view by viewing individual input parameters for graphing and comparison. Clicking on the **Input Catalog** tab in the upper right-hand corner of the model screen presents the following page of options with input parameter categories, somewhat different than in the previous Water Balance Model.

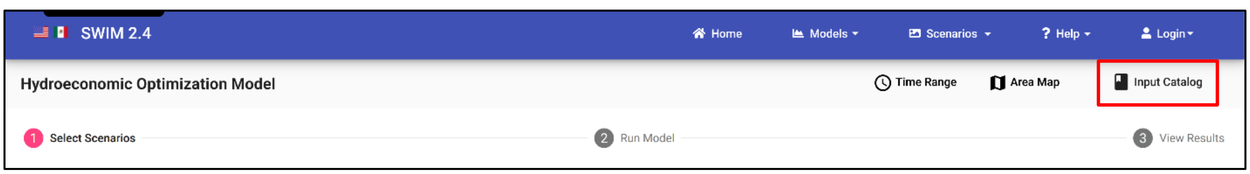
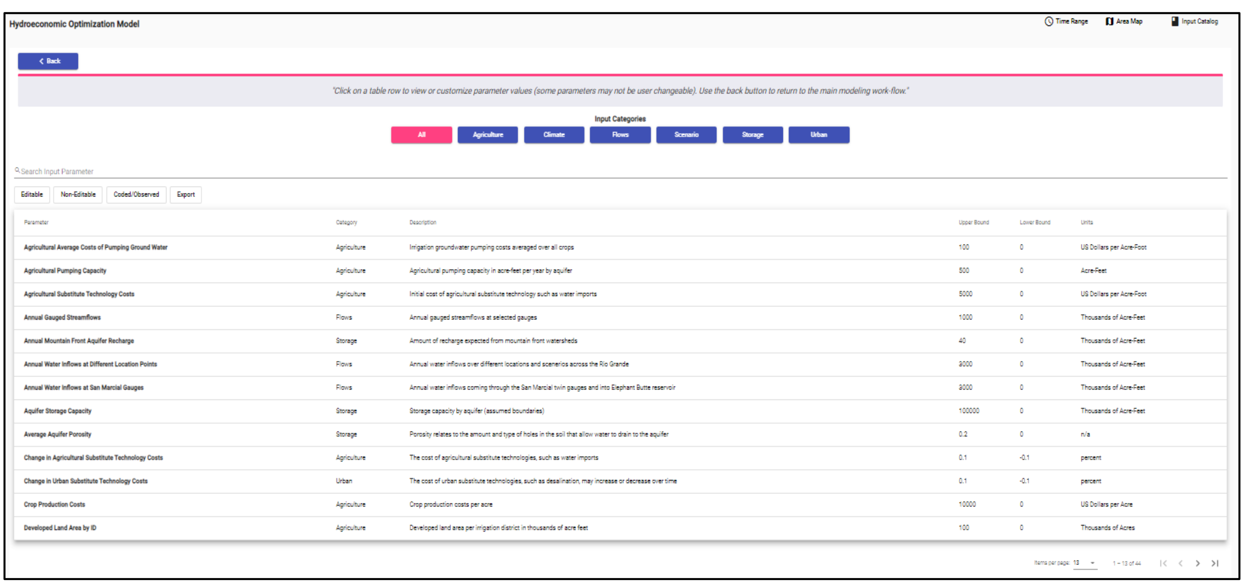


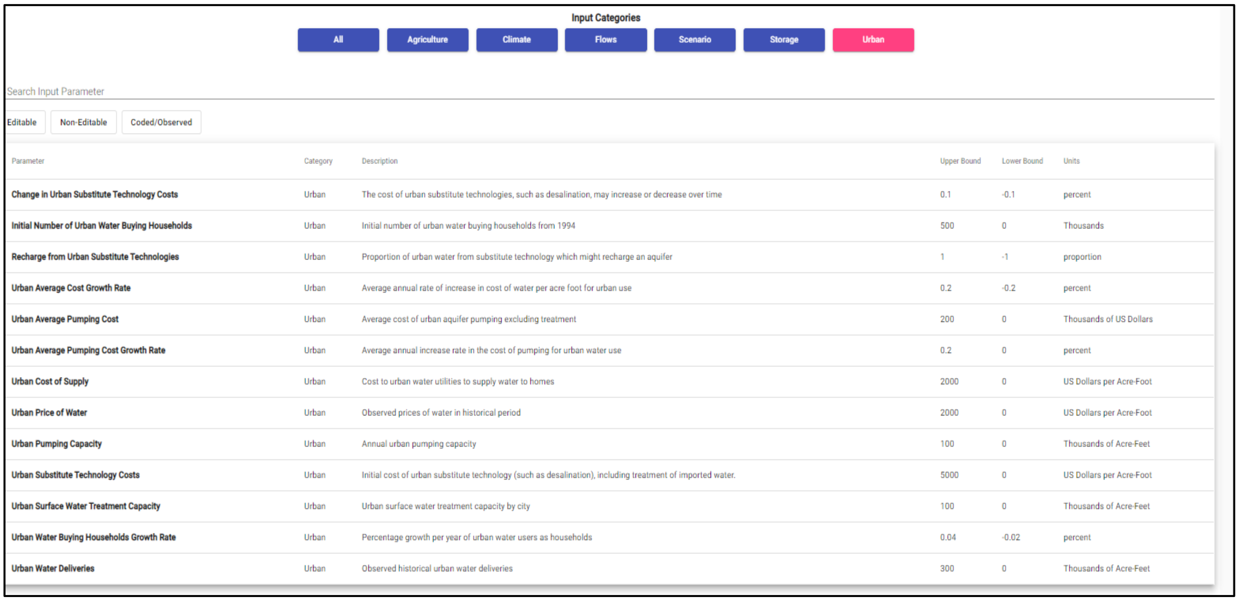
Figure 46: *Input Catalog for the Hydroeconomic Model in SWIM 2.*



Parameter	Category	Description	Upper Bound	Lower Bound	Units
Agricultural Average Costs of Pumping Ground Water	Agriculture	Irrigation groundwater pumping costs averaged over all crops	100	0	US Dollars per Acre-Foot
Agricultural Pumping Capacity	Agriculture	Agricultural pumping capacity in acre-feet per year by aquifer	500	0	Acre-Feet
Agricultural Substitute Technology Costs	Agriculture	Initial cost of agricultural substitute technology such as water imports	5000	0	US Dollars per Acre-Foot
Annual Gauged Streamflows	Flows	Annual gauged streamflows at selected gauges	1000	0	Thousands of Acre-Feet
Annual Mountain Front Aquifer Recharge	Storage	Amount of recharge expected from mountain front watersheds	40	0	Thousands of Acre-Feet
Annual Water Inflows at Different Location Points	Flows	Annual water inflows over different locations and scenerios across the Rio Grande	3000	0	Thousands of Acre-Feet
Annual Water Inflows at San Marcial Gauges	Flows	Annual water inflows coming through the San Marcial twin gauges and into Elephant Butte reservoir	3000	0	Thousands of Acre-Feet
Aquifer Storage Capacity	Storage	Storage capacity by aquifer (assumed boundaries)	100000	0	Thousands of Acre-Feet
Average Aquifer Porosity	Storage	Porosity relates to the amount and type of holes in the soil that allow water to drain to the aquifer	0.2	0	n/a
Change in Agricultural Substitute Technology Costs	Agriculture	The cost of agricultural substitute technologies, such as water imports	0.1	-0.1	percent
Change in Urban Substitute Technology Costs	Urban	The cost of urban substitute technologies, such as desalination, may increase or decrease over time	0.1	-0.1	percent
Crop Production Costs	Agriculture	Crop production costs per acre	10000	0	US Dollars per Acre
Developed Land Area by ID	Agriculture	Developed land area per irrigation district in thousands of acre feet	100	0	Thousands of Acres

The bar across the top of the table allows the user to reduce the view of input parameters (there are pages of parameters) according to the category selected, for example, selecting the **Agriculture** tab will result in only ten parameters being displayed. Selecting **Climate** will display two climate parameters used as input to the model. Going back to the **All** tab and clicking on **Editable** will display input parameters that can be modified, currently 13. Here, for example, clicking on the **Urban** tab results in an array of 14 input parameter data sets, as seen here below.

Figure 47: *List of input parameters filtered by the Urban category for the Hydroeconomic Model.*



Parameter	Category	Description	Upper Bound	Lower Bound	Units
Change in Urban Substitute Technology Costs	Urban	The cost of urban substitute technologies, such as desalination, may increase or decrease over time	0.1	-0.1	percent
Initial Number of Urban Water Buying Households	Urban	Initial number of urban water buying households from 1994	500	0	Thousands
Recharge from Urban Substitute Technologies	Urban	Proportion of urban water from substitute technology which might recharge an aquifer	1	-1	proportion
Urban Average Cost Growth Rate	Urban	Average annual rate of increase in cost of water per acre foot for urban use	0.2	-0.2	percent
Urban Average Pumping Cost	Urban	Average cost of urban aquifer pumping excluding treatment	200	0	Thousands of US Dollars
Urban Average Pumping Cost Growth Rate	Urban	Average annual increase rate in the cost of pumping for urban water use	0.2	0	percent
Urban Cost of Supply	Urban	Cost to urban water utilities to supply water to homes	2000	0	US Dollars per Acre-Foot
Urban Price of Water	Urban	Observed prices of water in historical period	2000	0	US Dollars per Acre-Foot
Urban Pumping Capacity	Urban	Annual urban pumping capacity	100	0	Thousands of Acre-Feet
Urban Substitute Technology Costs	Urban	Initial cost of urban substitute technology (such as desalination), including treatment of imported water.	5000	0	US Dollars per Acre-Foot
Urban Surface Water Treatment Capacity	Urban	Urban surface water treatment capacity by city	100	0	Thousands of Acre-Feet
Urban Water Buying Households Growth Rate	Urban	Percentage growth per year of urban water users as households	0.04	-0.02	percent
Urban Water Deliveries	Urban	Observed historical urban water deliveries	300	0	Thousands of Acre-Feet

There are different presentations of the datasets, as well. Clicking on a dataset will show this including the ability to change the dataset by direct input or by scaling the parameter.

NOTE: When navigating back and forth in the model, be sure to use the **Back** tab when it is presented. Otherwise, you risk losing the current model.

Depending on which parameters, the parameter data sets can also be shown in different ways: as a table, line, or bar chart. In this example, the **Flows** tab was selected, and five parameters displayed. Clicking on, e.g., *Annual Gauged Streamflows*, presents a table of values that can be viewed as a table, line or bar chart by clicking on the appropriate tab.

__Figure 48:__ Data table visualization of annual gauged streamflow for the Hydroeconomic model.

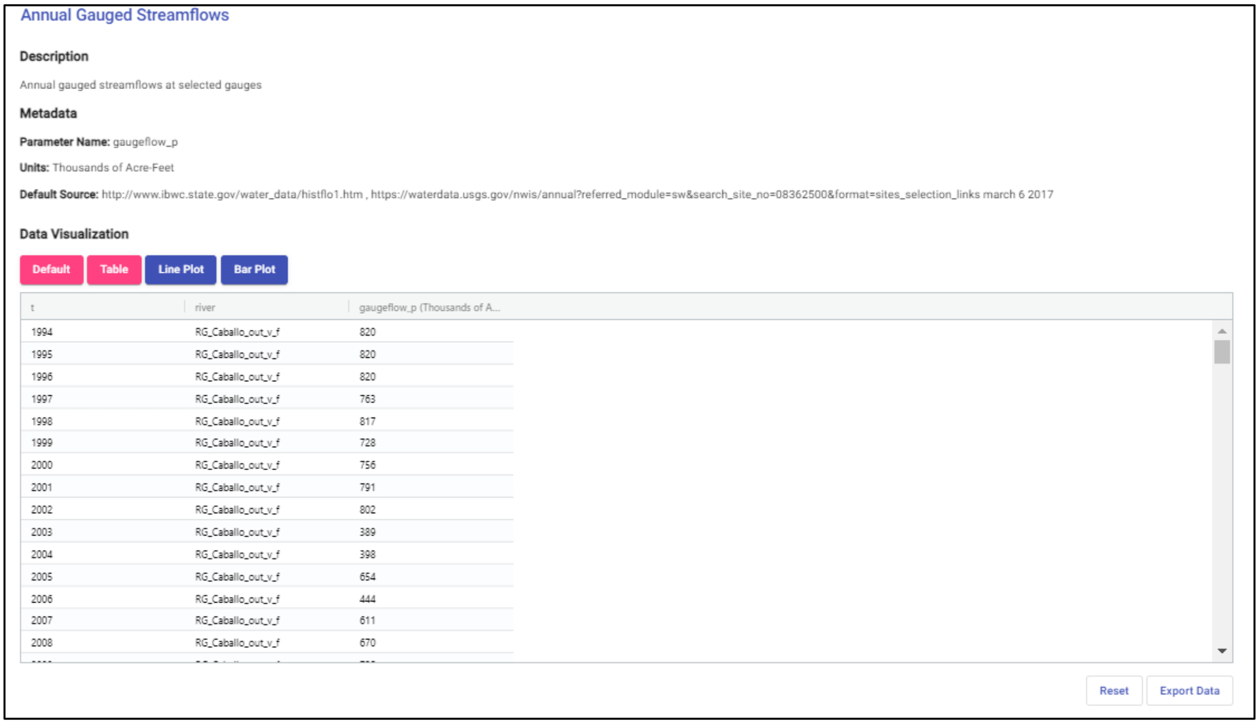
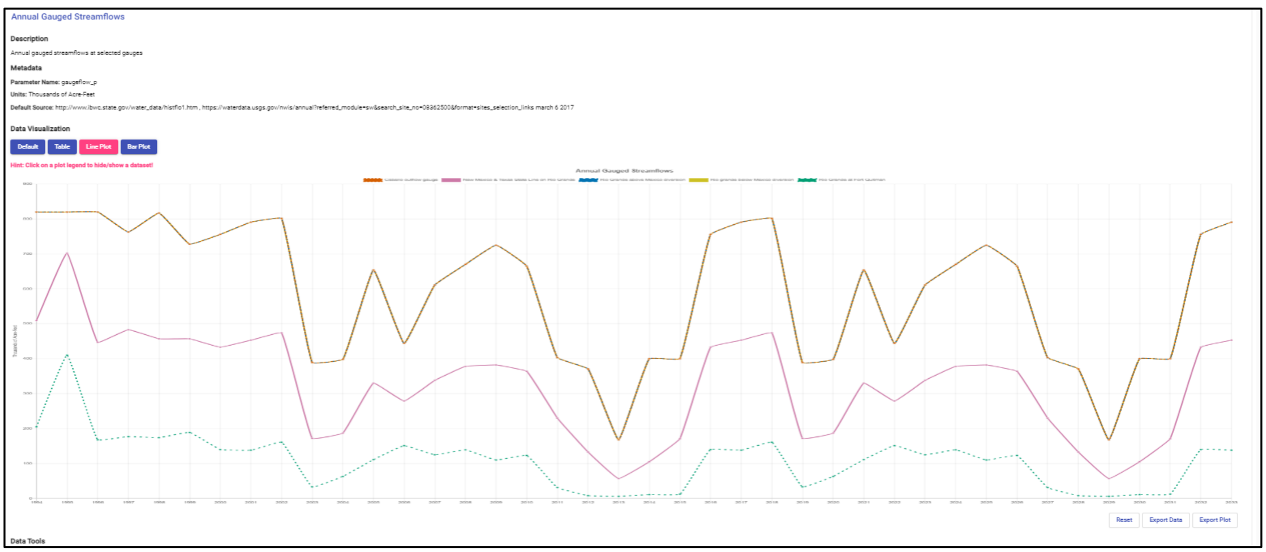


***Figure 49**: Line plot visualization of annual gauged streamflow for the Hydroeconomic model.*



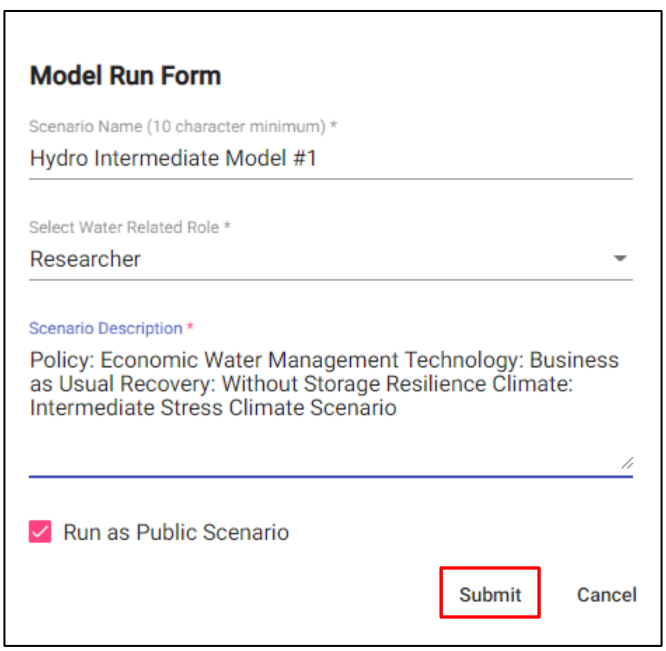
These are just a few of the ways to look into Input parameters and output variables in the model and to visualize them.

Running Climate Scenarios

As with the Water Balance Model, selecting a climate scenario will point the model to appropriate input data set parameters and projection simulations that create the scenarios and its effect on the basin. From the six possibilities, let us select the ***Intermediate Stress Climate Scenario*** that yields an intermediate streamflow starting in the mid-20th Century. From 1994 up to 2033.

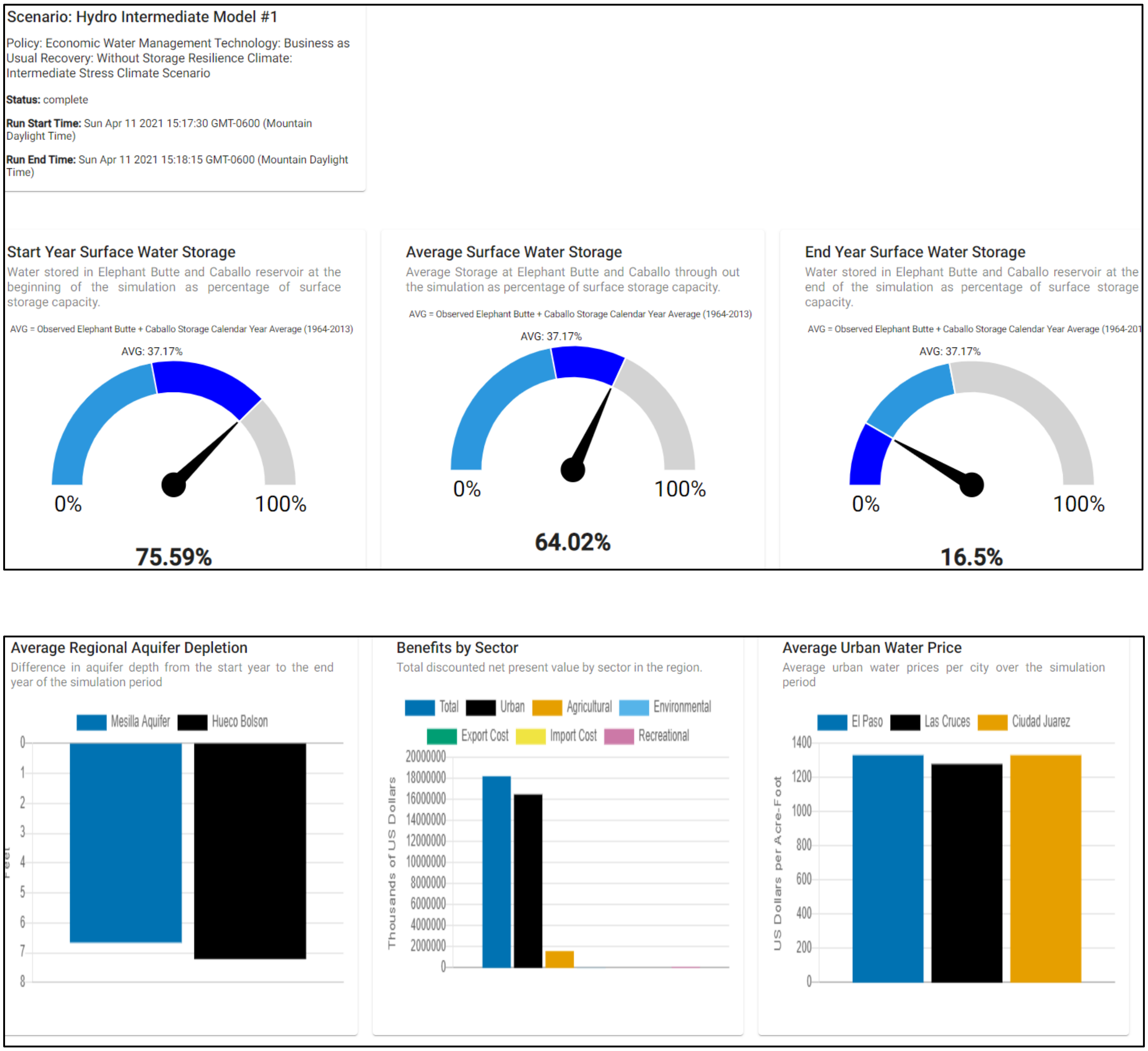
The URL link at the top of the scenario description https://doi.org/10.1111/1752-1688.12851 takes us to the source information for the scenario. At this point, click on the **Run Model** tab that will bring up the **Model Run Form**. We will give this the Scenario Name of **Hydro Intermediate Model #1** and select a **Water Related Role** of *Researcher* and submit the model to run as a **Public Scenario**.

Figure 50: *Filled model execution form for an intermediate climate scenario of the Hydroeconomic Model.*



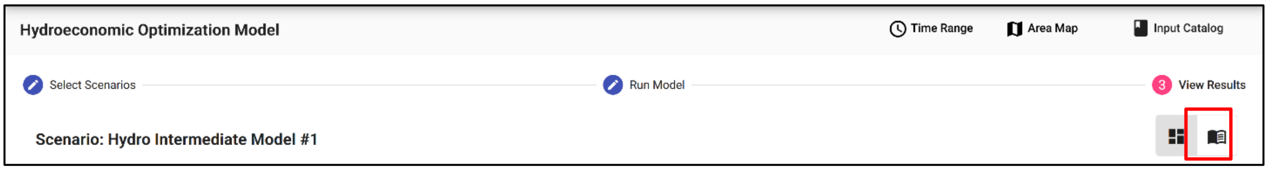
Like the Water Balance Model, this operation yields a summary dashboard with reservoir storage level information and with more information unique to the Hydroeconomic Model, as seen below.

Figure 51: *Result summary dashboard of an intermediate climate scenario of the Hydroeconomic model.*



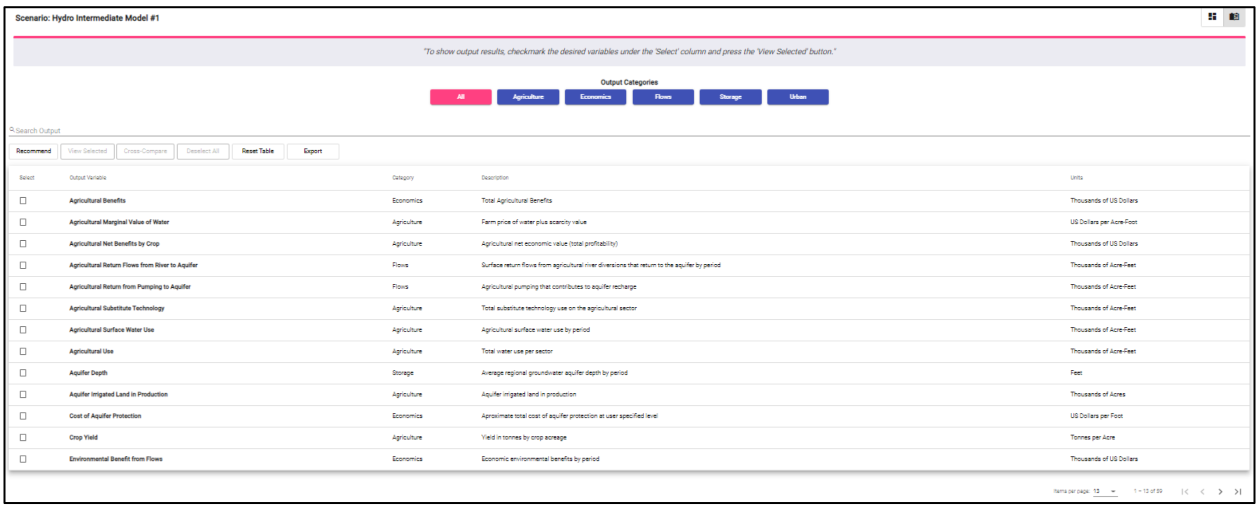
Query Output Variables

At this point, we can further query the model's output variables from the resulting screen view. This view can be reduced by selecting the **Output Catalog** in the upper right corner.



This will yield the following page of variable groups for inquiry.

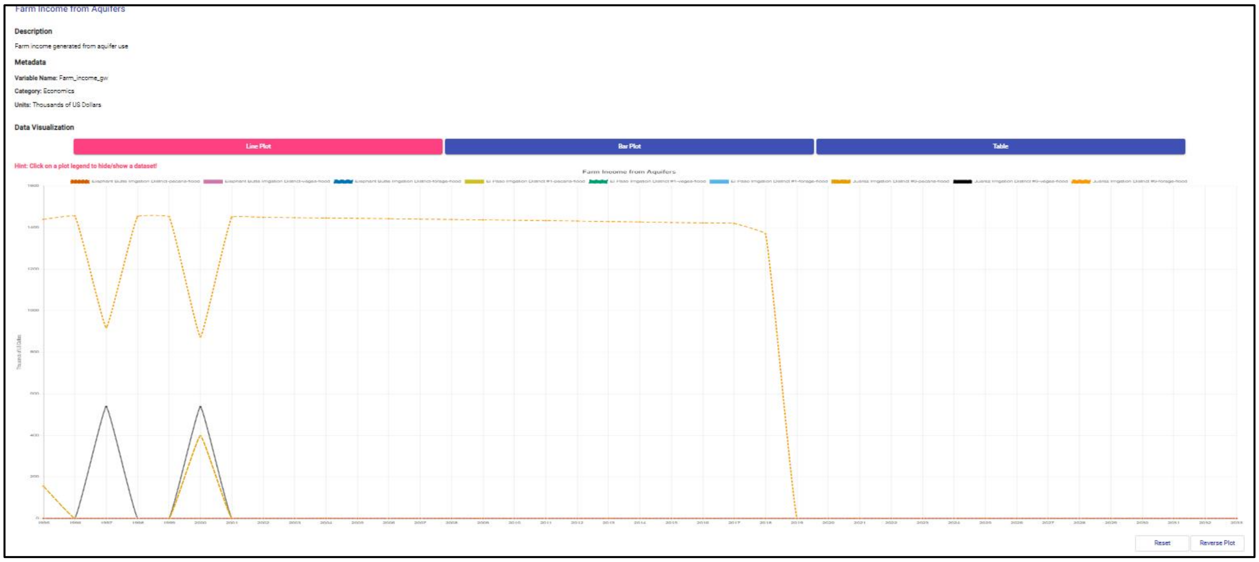
Figure 52: *Screenshot of the Output Catalog for a scenario execution of the Hydroeconomic Model.*



As we did with the Water Balance Model, this view of 59 total output variables can be reduced by selecting one of the **Output Categories** from the control bar. For example, select the **Economics** category tab on the bar and the view shrinks from 59 to 18 variables.

Select the variable *Farm Income from Aquifers* in the table for this example and then click on **View Selected** to create the following (partial) output dashboard that can display a line, bar, or table plot of the current **Hydro Intermediate Model #1** output variables. It can be done with all the Output Categories, not just this one, and compared side-by-side for other outputs, as well as cross-compared to other models as was done in the Water Balance Model example.

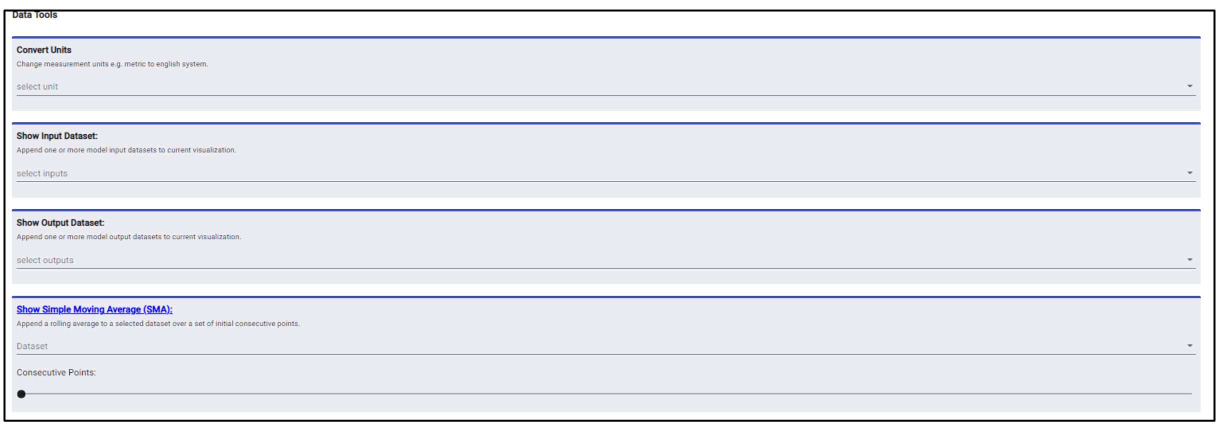
Figure 53: Detailed view of the variable Farm Income from Aquifers from a Hydroeconomic scenario run.



Digging Down

Beneath the Line Plot graph is a **Data Tools** menu, seen below. Data Tools enables us to append additional data sets to the Line Plot graph to see how the variables behave in parallel.

Figure 54: Data tools available for an output variable.



From the **Show Output Dataset** menu, select *Agricultural Net Benefits by Crop*. Notice how the dataset values now appear in the original graph alongside *Farm Income from Aquifers.* The graph has changed to incorporate the datasets for visualizing comparison over time. The values can also be seen in the **Table** view.

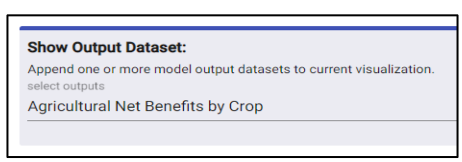
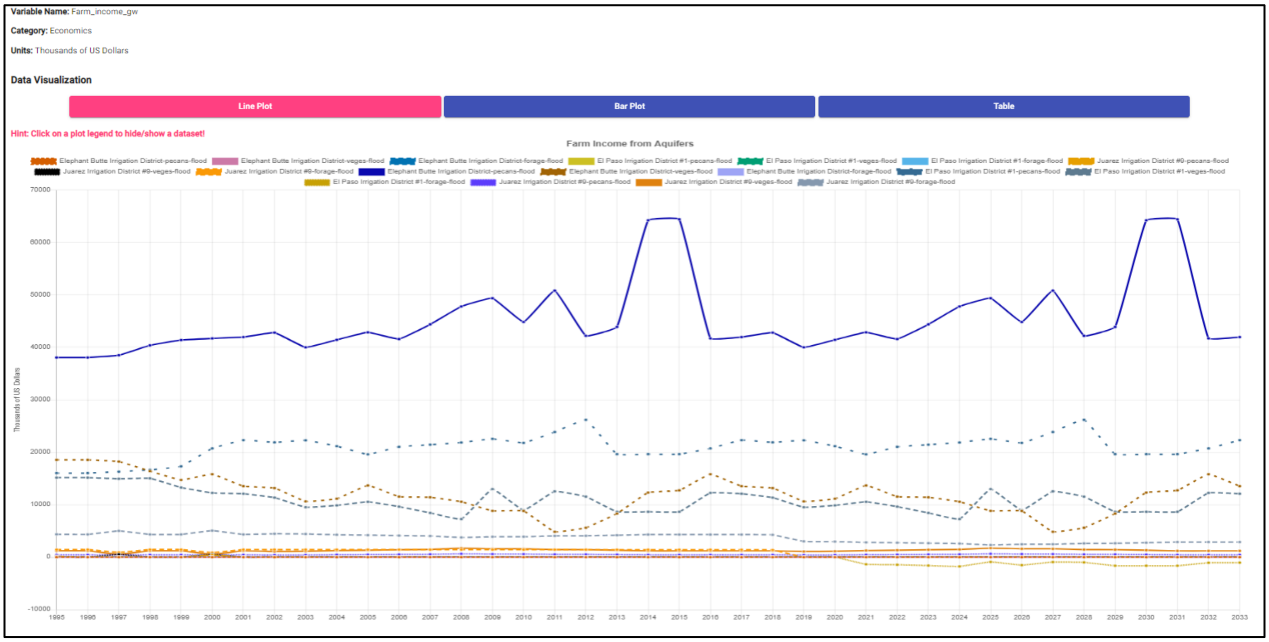


Figure 55: Line plot visualization of GW Farm Income with appended datasets from Agricultural Benefits by Crop.



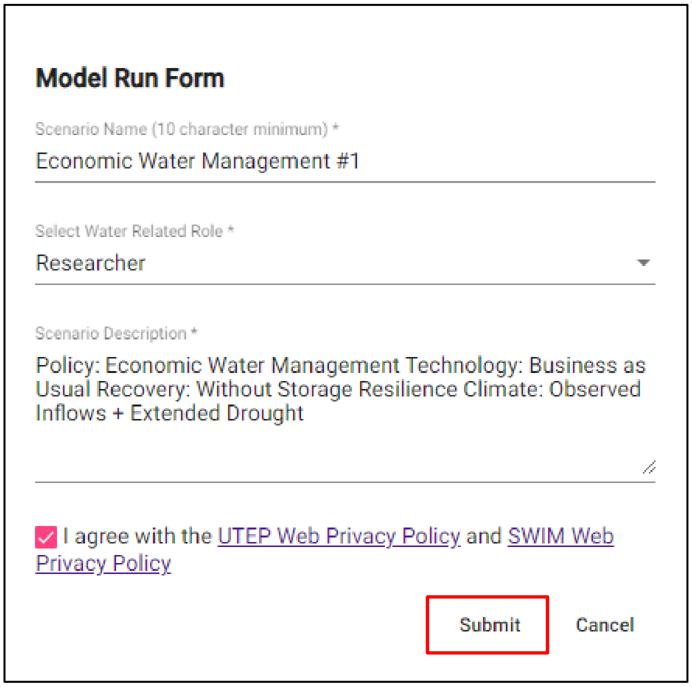
Policy Scenario

Click on **Select Scenarios** to return to the main page and then select the **Policy** scenario category that currently supports only one such scenario, ***Economic Water Management*,** as seen below.

In this scenario, constraints of the current policy agreements are relaxed, and water allocation is optimized to the highest economic values. Unless we select a specific Climate Scenario, the Policy model will assume that *Observed Inflows + Extended Drought* is the default background climate in which the Policy model executes.

Set up the model in the **Model Run Form** as **Economic Water Management #1** or whatever name you want, select a **Water Related Role** view, and click **Submit**.

Figure 56: *Filled scenario execution form for an economic management scenario with extended drought.*


Model Run Form

Scenario Name (10 character minimum) *

Economic Water Management #1

Select Water Related Role *

Researcher

Scenario Description *

Policy: Economic Water Management Technology: Business as Usual Recovery: Without Storage Resilience Climate: Observed Inflows + Extended Drought

I agree with the UTEP Web Privacy Policy and SWIM Web Privacy Policy

Submit Cancel

This will yield the following dashboard showing that you can start with a full reservoir and blow it by the end of the year and take both aquifers down seven feet, too!

Figure 57: *Result summary dashboard of economic water management over a prolonged drought scenario of the Hydroeconomic model.*

At this point, we can further query the model's output variables from the resulting screen view. Click on the **Output Catalog** icon, select the **Flows** category on the bar as in the previous model and select the variable *River Flows*; then click on **Storage** category and select *Aquifer Depth*.

Click on **View Selected** to create the following output graphic that can display a line, bar, or table plot of the selected **Economic Water Management #1** output variables. It can be done with the other Output Categories, too, not just these two, and compared side-by-side. The *Aquifer Depth* view is improved by reversing the plot and removing the *Average Depth* series for Mesilla and Hueco Bolson.

Figure 58: *Side by side details of selected variables from the output catalog.*

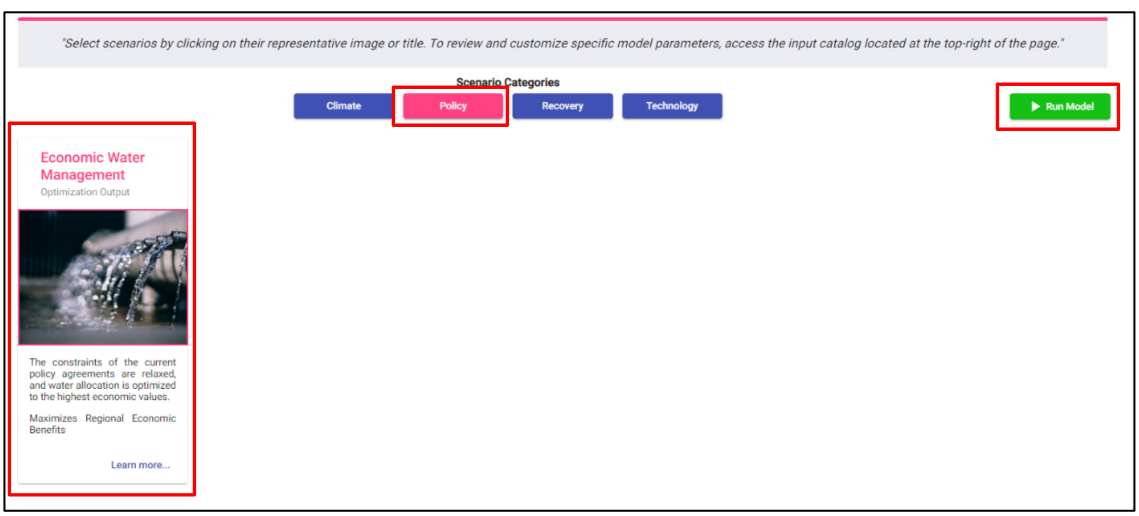
The model yields steadily declining river flows and more dramatic decline of the aquifer depths out to 2033 using the **Economic Water Management Policy #1** model if ***Observed Inflows + Extended Drought*** is the default background climate and *Business as Usual* assumptions apply. But what if we were enjoying a ***Wet Climate Scenario*** as has happened in the past? How would that affect these variables?

This comparison can be accomplished with a cross compare. To do this, create another scenario run by clicking on the **Select Scenarios** tab in the upper left-hand corner of the screen.

And from the tableau of climate scenarios, highlight by clicking on ***Wet Climate Scenario*.** This activates the scenario so we can use it rather than the default scenario to rerun the model. Do not click on the **Run Model** tab just yet.

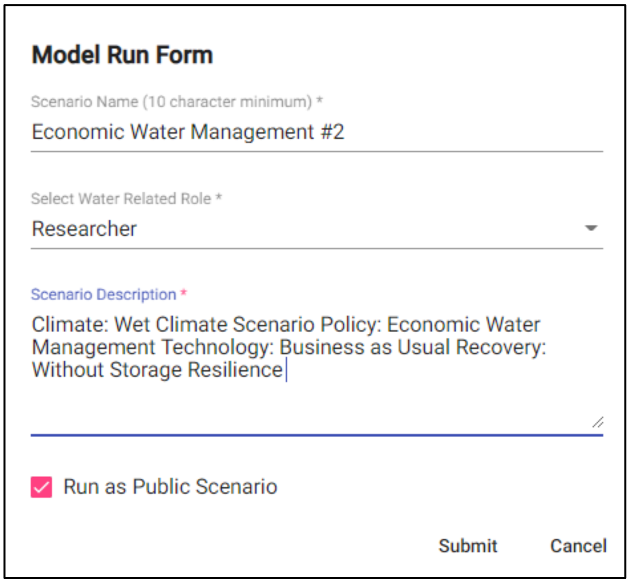
Then click on the **Policy** tab to get to the current model but with a different climate background. This returns us to the following page where we will now click on the **Policy** scenario and then **Run Model** tab.

Figure 59: *Policy selection with a wet climate scenario combination.*



We will have to complete a **Model Run Form** where we will name our alternate ***Wet Climate Policy*** Model **Economic Water Management #2.**

Figure 60: *Filled model execution with a wet climate and economic water management scenario combination.*



Click on **Submit** and we execute the same **Policy** model only in a ***Wet Climate Scenario*. This** will yield the following dashboard showing a very different outcome for the reservoir. at least, from the previous model.

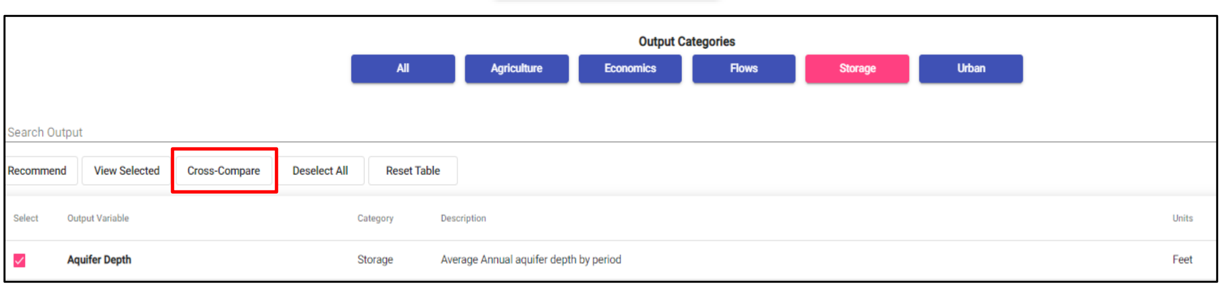
Figure 61: *Result summary dashboard for a wet climate with economic management scenario for the Hydroeconomic model.*

To explore how this change in background climate scenario affects the model, let's do a cross compare on the variables *River Flows* and *Aquifer Depth* by clicking on the **Output Catalog** tab and, as before, selecting the **Flows** Output Category and *River Flows* output variable. Then click the **Storage** Output Category and select the *Aquifer Depth* output variable. Click on **View Selected** to yield the following graph.

Figure 62: *Detailed view of selected output variables of a Hydroeconomic scenario run.*

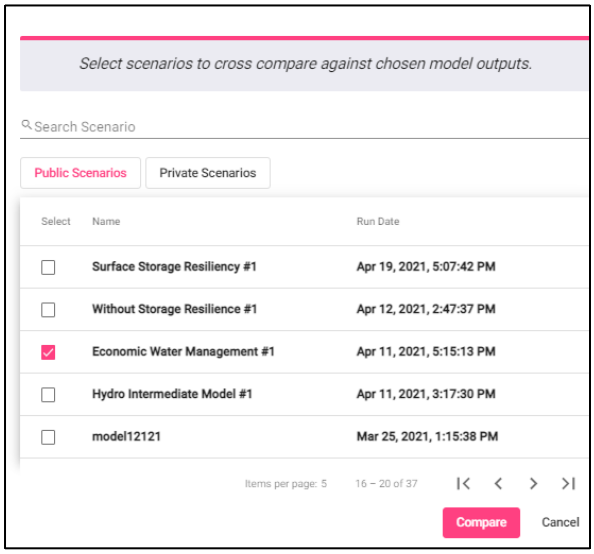
Again, the *Aquifer Depth* view is improved by reversing the plot and removing the *Average Depth* series for the Mesilla and Hueco Bolson. What we see is that the aquifers continue to decline but *River Flow* is somewhat more robust than in the previous extended drought scenario. The **Cross Compare** feature will give us a better picture of this.

Now, how does the *Wet Climate* scenario compare to the *Extended Drought* scenario in the same *business as Usual* policy framework. To accomplish this, we go back to our **Output Categories** view and select **Cross Compare.**



The variables we want to compare are already selected, so proceed to **Cross Compare** where we will select the prior **Economic Water Management #1** scenario to compare to the current against the current **Economic Water Management #2** that incorporates the Wet Climate. Then click on **Compare.**

Figure 63: *Scenario selection window for cross comparison.*

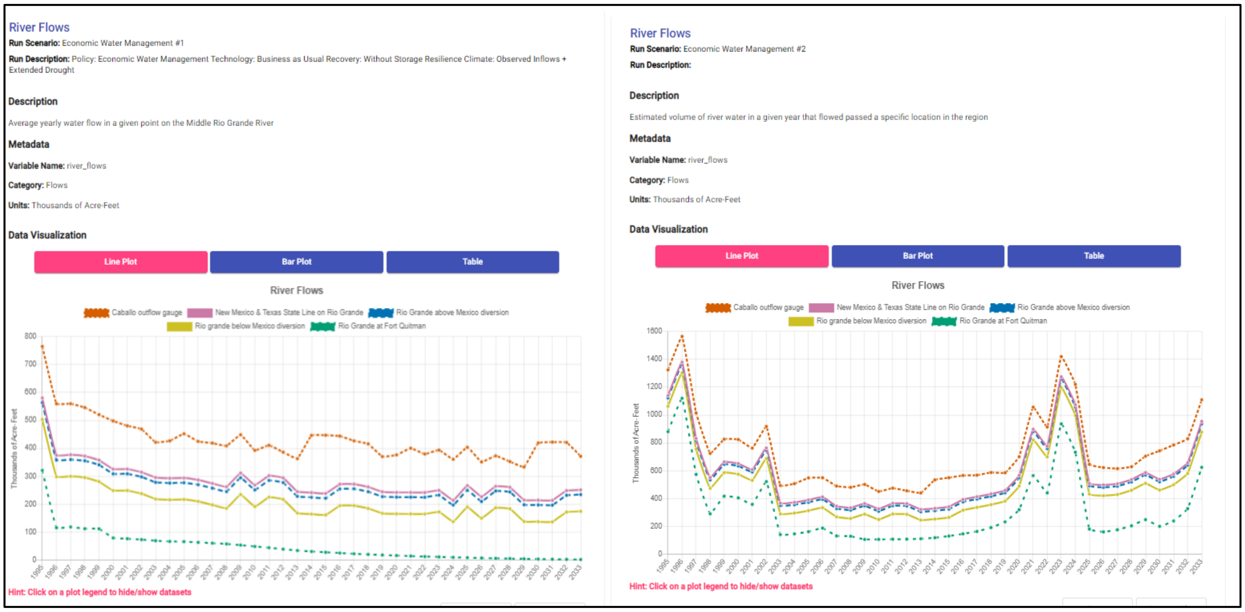


Surprisingly, the wet climate scenario makes little difference on Aquifer Depth over the model timeframe.

Figure 64: *Cross scenario comparison between water management # 1 and #2 over the Aquifer Depth variable.*

The difference between extended drought and wet climate scenarios is more pronounced in the *River Flows* output variable, as seen below. Some geological theory might explain the variance.

Figure 65*: Cross scenario comparison between water management # 1 and #2 over the River Flows variable.*

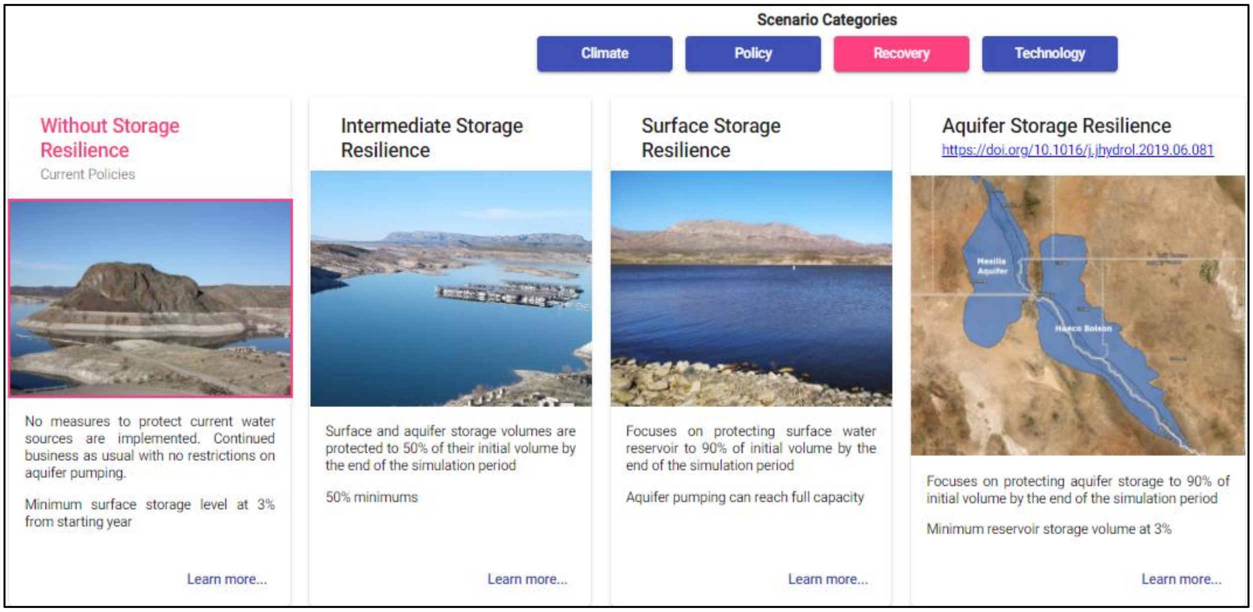


As we have noted before, Cross Compare is a powerful tool to see how different models and scenarios affect a single or more than one output variable especially when we want to see the difference that different background climate scenarios have on the model outputs.

Recovery Scenarios

Click on **Select Scenarios** to return to the main page and then select the **Recovery** scenario category to display the following choices. Recovery scenarios deal with a lower bound for water held in the reservoir or aquifers at the end of the model process as a percentage of a starting year value (1994). There are four such scenarios in the Hydroeconomic model.

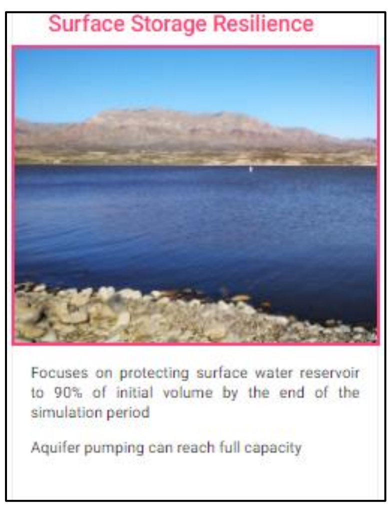
Figure 66: *Predefined recovery scenarios for the Hydroeconomic Model in SWIM 2.*



On the following sections we will explore the effects of surface storage vs aquifer storage resilience over the water supplies.

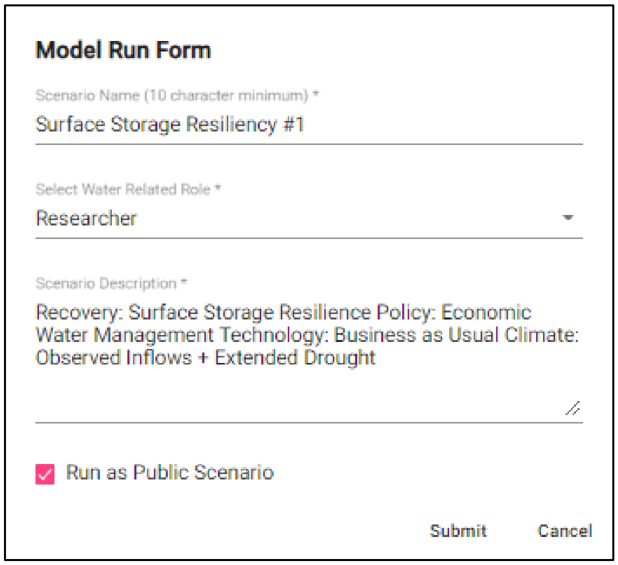
Surface Storage Resiliency

To create yet another recovery scenario, click on the **Select Scenario** tab for **Recovery Scenarios** and select the ***Surface Storage Resilience Scenario*** recovery scenario.



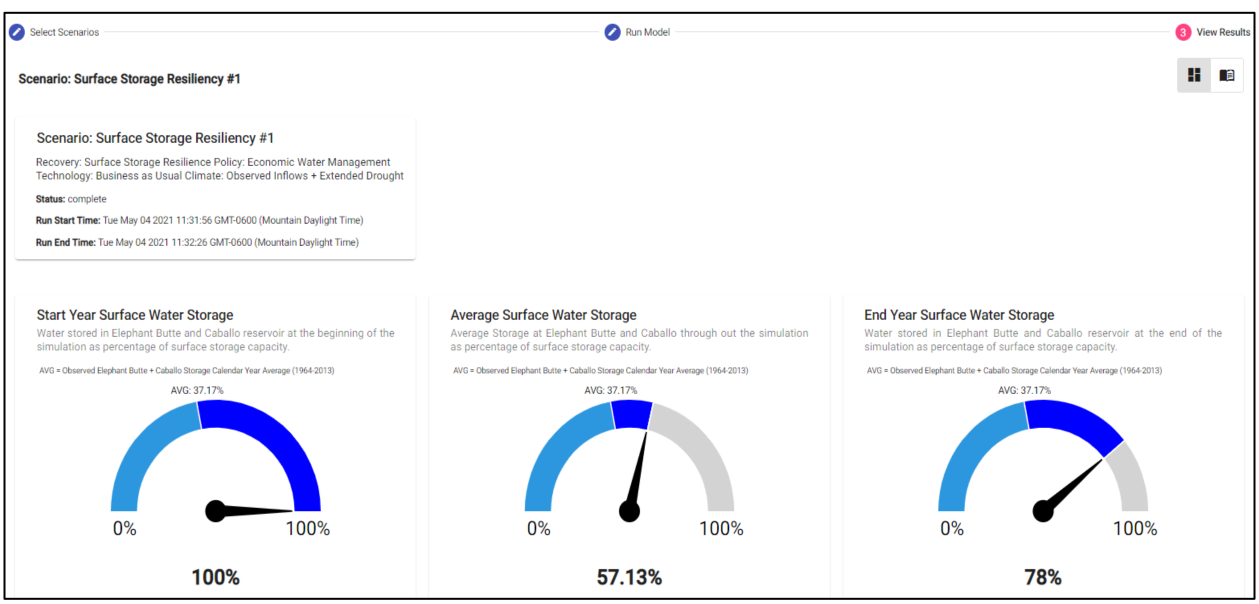
This is about protecting the surface water reservoir to 90% of initial volume by the end of the simulation period, a scenario that might be used to promote tourism at the reservoir by keeping it nearly full. It will also likely result in full pumping of aquifers to make up for the loss of surface water source. Aquifer pumping can reach full capacity. So, click on **Run Model** tab and complete the **Model Run Form** as seen below, selecting *Researcher* (or other role) as our **Water Related Role**, naming this model **Surface Storage Resilience #1** and click on **Submit.**

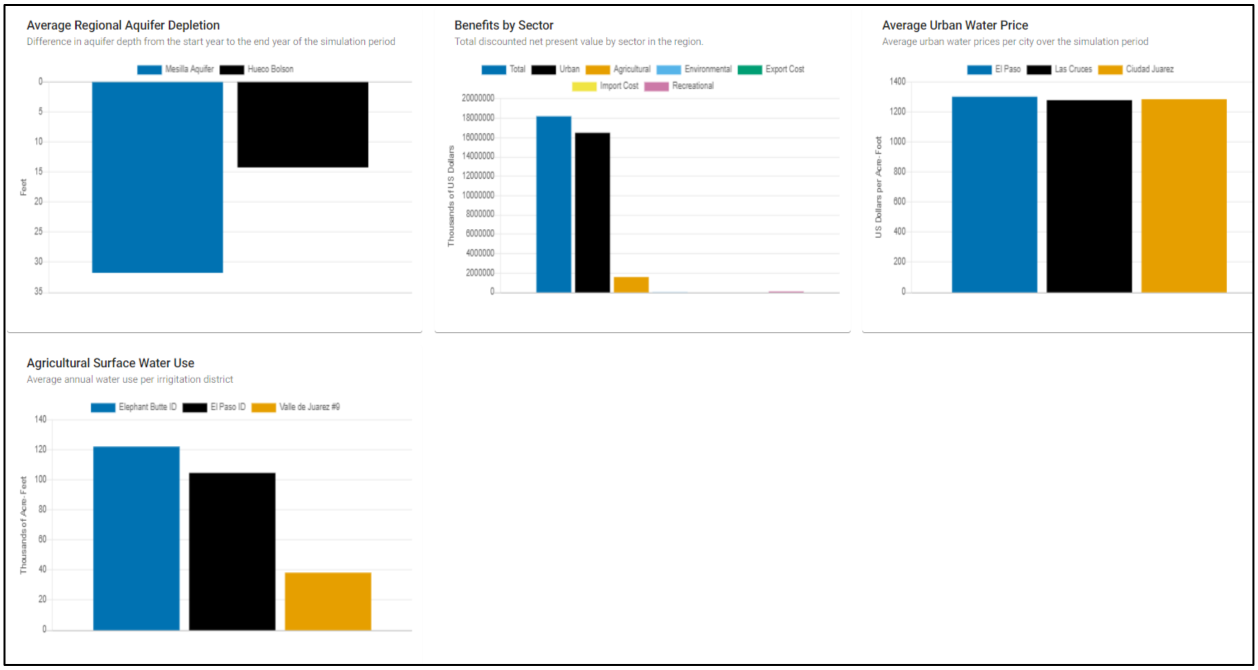
Figure 67: *Filled scenario execution form for a surface storage resiliency scenario.*



The model generates the following dashboard for this recovery scenario.

Figure 68: *Result summary dashboard of a surface storage resiliency scenario of the Hydroeconomic Model.*





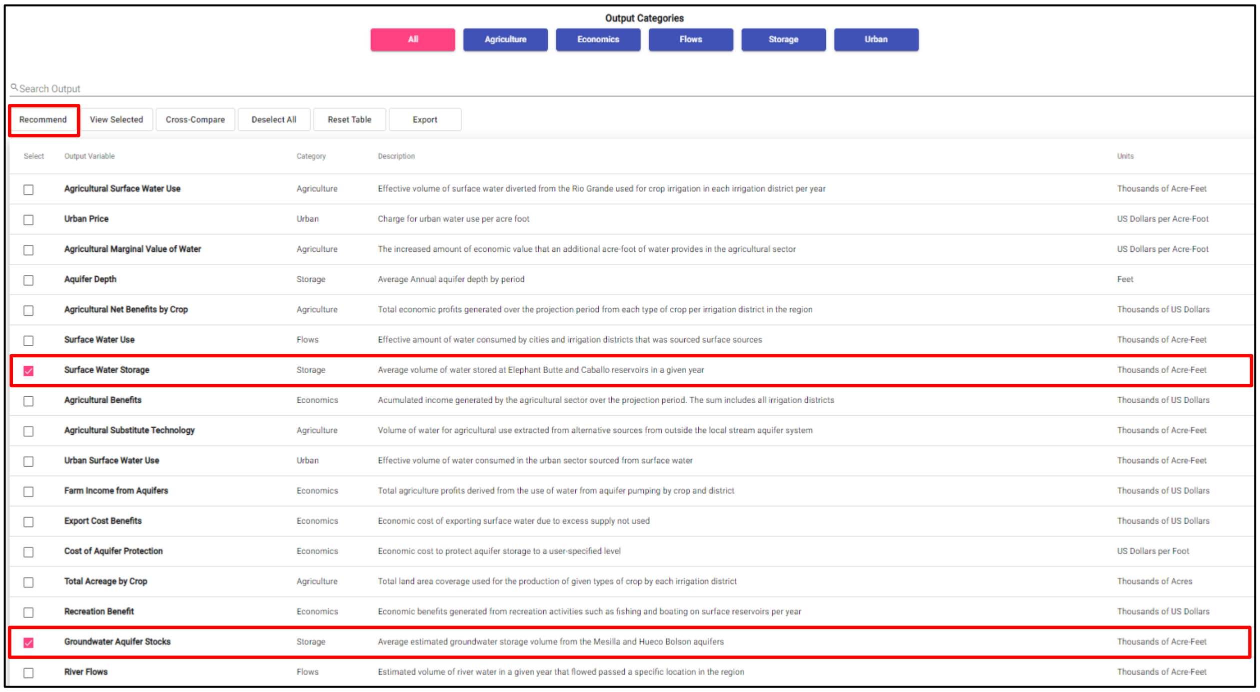
For the assumed ***Climate: Observed Inflows + Extended Drought*** *scenario* driving the model, the reservoir begins the year at 100% capacity and Average Surface Storage is 57.13%, or less than 90% of capacity at the start of the year. Both major aquifers drop because of presumed pumping. The largest economic benefit accrues to the Urban Sector. The scenario objective is not attainable.

Query Output Variables

As in previous scenarios, we can query the output variables of this model by clicking on the **Output Catalog** and looking at the many pages of data set Output Categories. An interesting feature here is the **Recommend** tab that reorders the list of Output Categories into a suggested query array for the selected **Water Related Role**.

Since we are interested in the relation between surface water storage and ground water usage under this Recovery Scenario, lets select *Surface Water Storage* and *Groundwater Aquifer Stocks* for comparison and click on **View Selected** to see how these graphs out.

Figure 69: *Screenshot of the Output Catalog for the Hydroeconomic Model.*



Output Categories

All | Agriculture | Economics | Flows | Storage | Urban

Search Output

Recommend | View Selected | Cross-Compare | Deselect All | Reset Table | Export

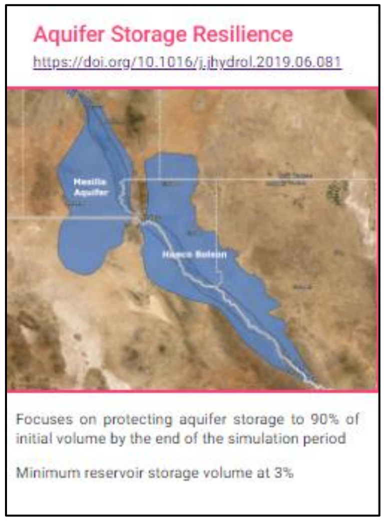
Select	Output Variable	Category	Description	Units
☐	Agricultural Surface Water Use	Agriculture	Effective volume of surface water diverted from the Rio Grande used for crop irrigation in each irrigation district per year	Thousands of Acre-Feet
☐	Urban Price	Urban	Charge for urban water use per acre foot	US Dollars per Acre-Foot
☐	Agricultural Marginal Value of Water	Agriculture	The increased amount of economic value that an additional acre-foot of water provides in the agricultural sector	US Dollars per Acre-Foot
☐	Aquifer Depth	Storage	Average Annual aquifer depth by period	Feet
☐	Agricultural Net Benefits by Crop	Agriculture	Total economic profits generated over the projection period from each type of crop per irrigation district in the region	Thousands of US Dollars
☐	Surface Water Use	Flows	Effective amount of water consumed by cities and irrigation districts that was sourced surface sources	Thousands of Acre-Feet
☑	Surface Water Storage	Storage	Average volume of water stored at Elephant Butte and Caballo reservoirs in a given year	Thousands of Acre-Feet
☐	Agricultural Benefits	Economics	Acumulated income generated by the agricultural sector over the projection period. The sum includes all irrigation districts	Thousands of US Dollars
☐	Agricultural Substitute Technology	Agriculture	Volume of water for agricultural use extracted from alternative sources from outside the local stream aquifer system	Thousands of Acre-Feet
☐	Urban Surface Water Use	Urban	Effective volume of water consumed in the urban sector sourced from surface water	Thousands of Acre-Feet
☐	Farm Income from Aquifers	Economics	Total agriculture profits derived from the use of water from aquifer pumping by crop and district	Thousands of US Dollars
☐	Export Cost Benefits	Economics	Economic cost of exporting surface water due to excess supply not used	Thousands of US Dollars
☐	Cost of Aquifer Protection	Economics	Economic cost to protect aquifer storage to a user-specified level	US Dollars per Foot
☐	Total Acreage by Crop	Agriculture	Total land area coverage used for the production of given types of crop by each irrigation district	Thousands of Acres
☐	Recreation Benefit	Economics	Economic benefits generated from recreation activities such as fishing and boating on surface reservoirs per year	Thousands of US Dollars
☑	Groundwater Aquifer Stocks	Storage	Average estimated groundwater storage volume from the Mesilla and Hueco Bolson aquifers	Thousands of Acre-Feet
☐	River Flows	Flows	Estimated volume of river water in a given year that flowed passed a specific location in the region	Thousands of Acre-Feet

This presents us with the following comparison that shows no surprises, given the recovery policy in effect. Keeping surface water high results in aquifer depletion over time.

Figure 70*: Screenshot of side-by-side detail windows for selected output variables from a Hydroeconomic Model scenario.*

Aquifer Storage Resiliency

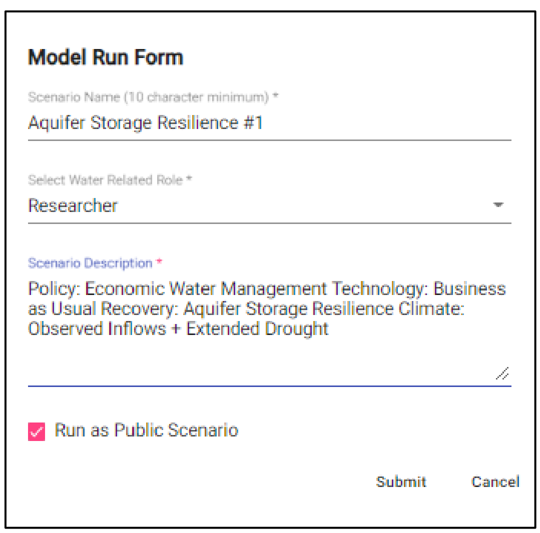
This recovery scenario focuses on protecting aquifer storage to 90% of initial volume by the end of the simulation period while maintaining minimum reservoir storage volume at 3%. So, it is a tradeoff between using surface water instead of more groundwater to protect the aquifers.



So, click on **Run Model** tab and complete the **Model Run Form** as seen below, selecting Researcher (or other role) as our Water Related Role, naming this model **Aquifer Storage Resilience #1.**

We see its description populated as: *Policy: Economic Water Management Technology: Business as Usual Recovery: Aquifer Storage Resilience Climate: Observed Inflows + Extended Drought.*

Figure 71: *Filled model execution form an aquifer resilience scenario of the Hydroeconomic Model.*


Model Run Form

Scenario Name (10 character minimum) *
Aquifer Storage Resilience #1

Select Water Related Role *
Researcher

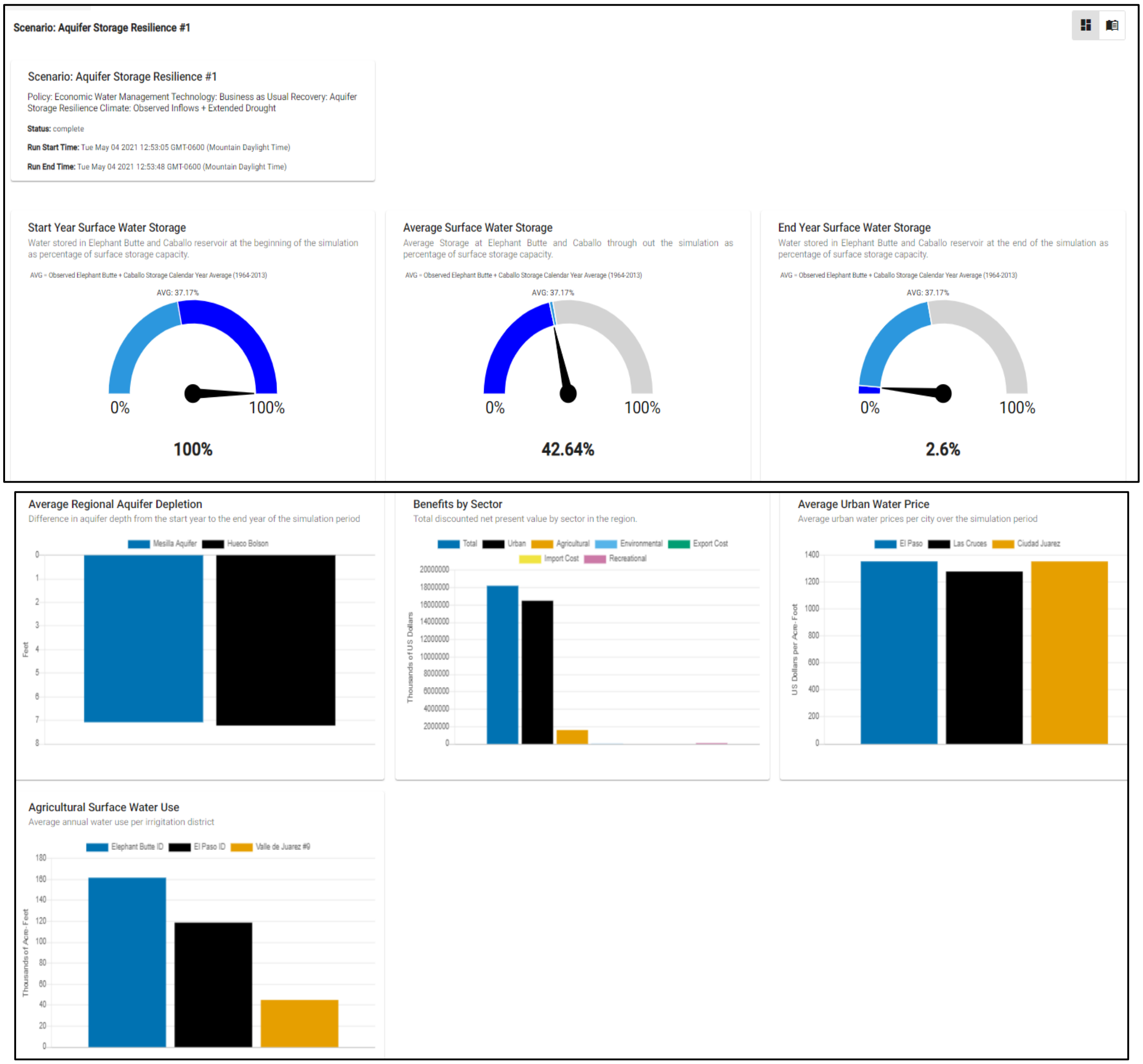
Scenario Description *
Policy: Economic Water Management Technology: Business as Usual Recovery: Aquifer Storage Resilience Climate: Observed Inflows + Extended Drought

☑ Run as Public Scenario

Submit   Cancel

Clicking on **Submit** gives us the following dashboard.

Figure 72: *Result summary dashboard for an aquifer storage resilience scenario for the Hydroeconomic Model.*

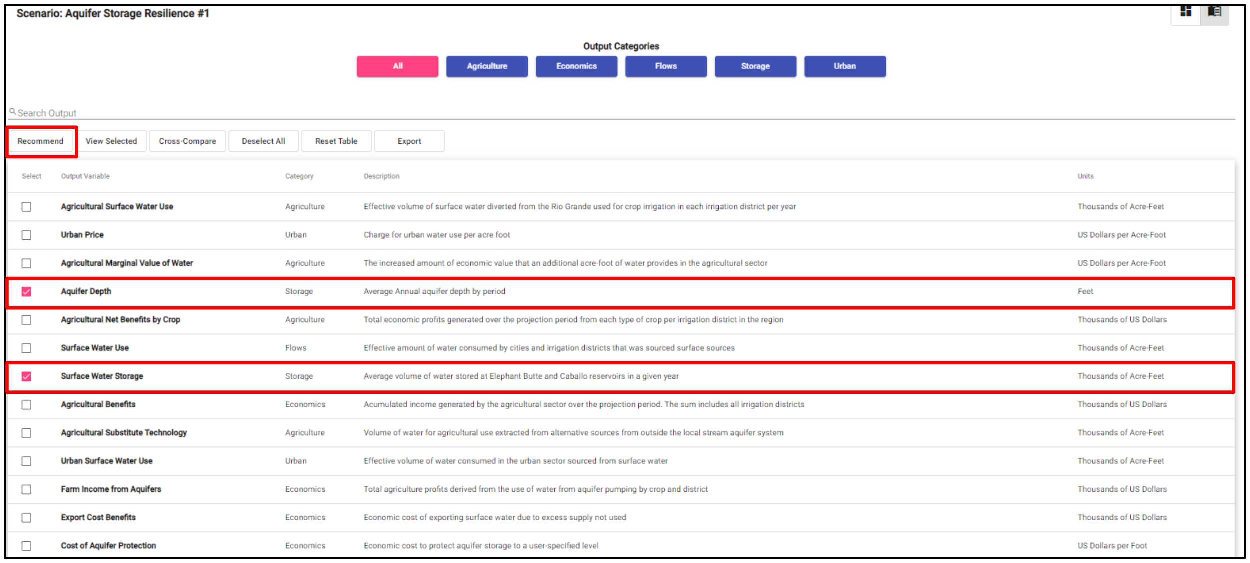


The more generous use of surface water results in less aquifer depletion than seen in previous scenarios, less than eight feet.

Query Output Variables

As in previous scenarios, we can query the output variables of this model by clicking on the **Output Catalog** and looking at the many pages of data set Output Categories. Or use the **Recommend** tab that reorders the list of Output Categories into a suggested query array.

Figure 73: *Screenshot of the Output Catalog for the Hydroeconomic Model with two selected variables.*



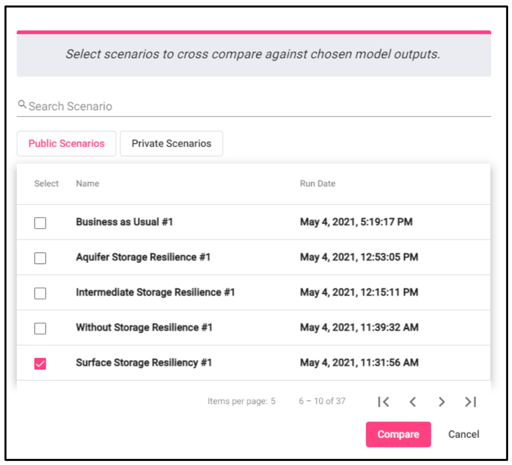
So, let us select two variables to graph as seen above: *Surface Water Storage* and *Aquifer Depth*. Then click on **View Selected** tab to yield the following graphs except when we view the graphs, we will minimize the long-term averages for both Mesilla and Hueco aquifers (by clicking on the descriptor) so we can look just at their projected depths over time.

Figure 74: *Screenshot of side-by-side details of selected output variables of the Hydroeconomic Model.*

This shows quite clearly that sacrificing surface water storage for aquifer storage over time does result in protecting both aquifers that, perhaps, slows the gradual deepening of the aquifers. A way to see if this is correct is to run a cross comparison of model scenarios: the current scenario against the previous **Surface Storage Resiliency #1** model that keeps the reservoir full.

Go back to the **Output Catalog** table and select **Cross Compare**. Then click on **Compare**.

Figure 75: *Cross-Compare scenario selection window.*



When the comparison graph appears, let us suppress the long-term averages to see the actual comparison of aquifer depths under the two scenarios.

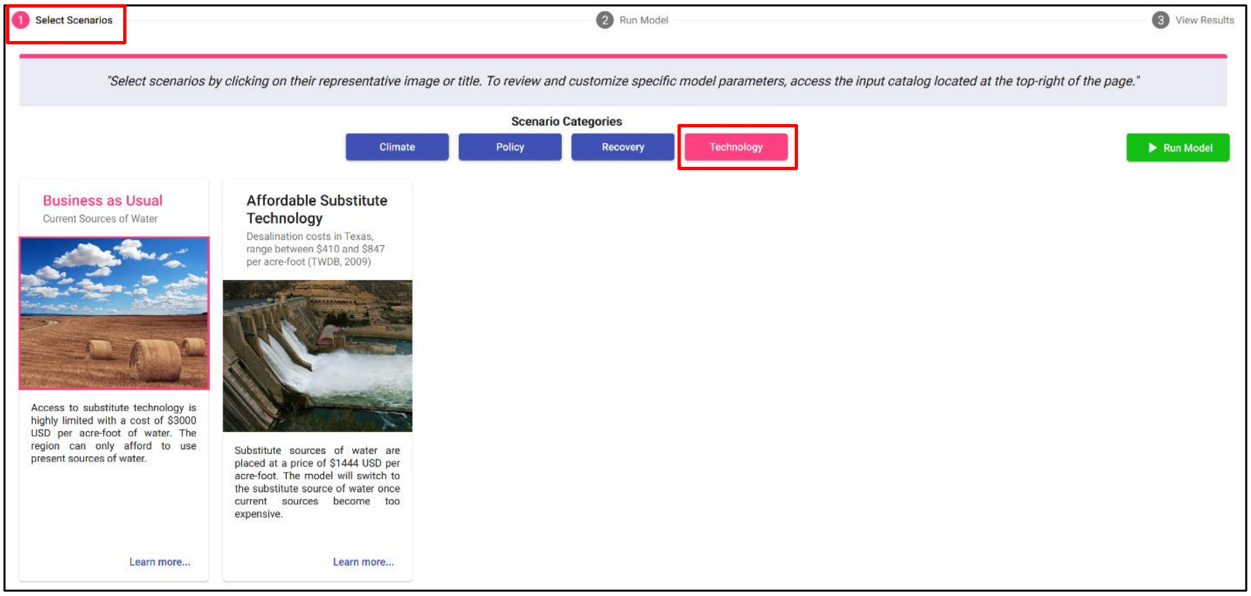
Figure 76: *Cross-Comparison of Aquifer Depth between surface resiliency and aquifer resiliency scenarios.*

It appears that the Aquifer Resiliency strategy (right side) that uses more surface water does indeed result in flattening the curve of aquifer depletion as measured by depth but not forever.

Technology Scenarios

Return to the **Select Scenarios** page and click on the **Technology** category to show scenarios based on the cost of urban and agricultural substitute technology (such as desalination), including treatment of imported water.

Figure 77: Screenshot of technology scenario options for the Hydroeconomic Model in SWIM 2.

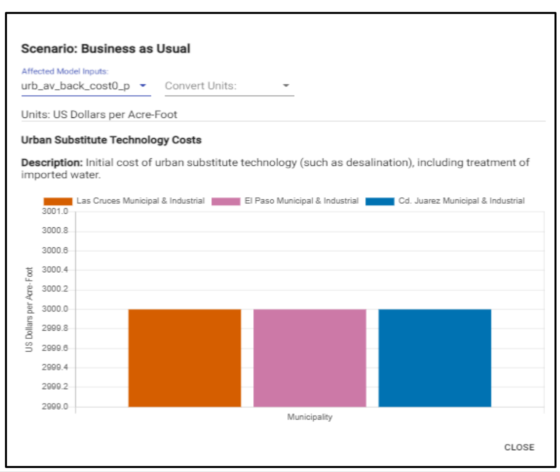


The model presents us with two scenarios: ***Business as Usual*** and ***Affordable Substitute Technology***.

Business as Usual

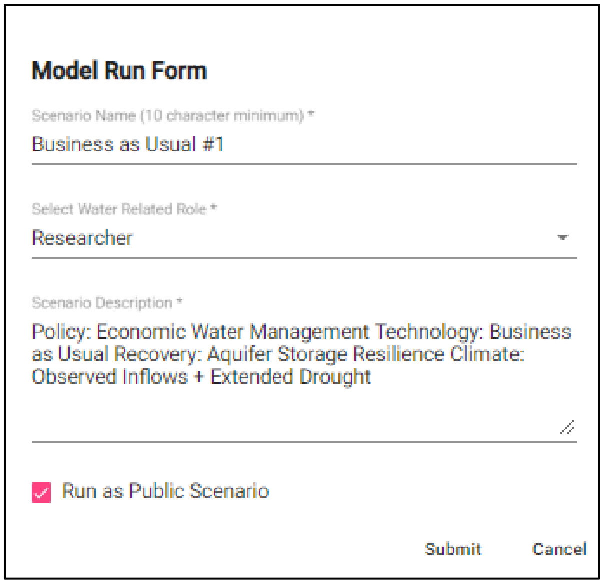
This scenario is based on access to substitute technology that is highly limited with a cost of $3000 USD per acre-foot of water. The region can only afford to use present sources of water. Clicking on **Learn more…** at the bottom of the icon gives us this graph for the three municipal water districts showing the costs.

Figure 78: *Business-as-usual technology scenario showing effect on Urban Substitute Technology Costs parameter.*



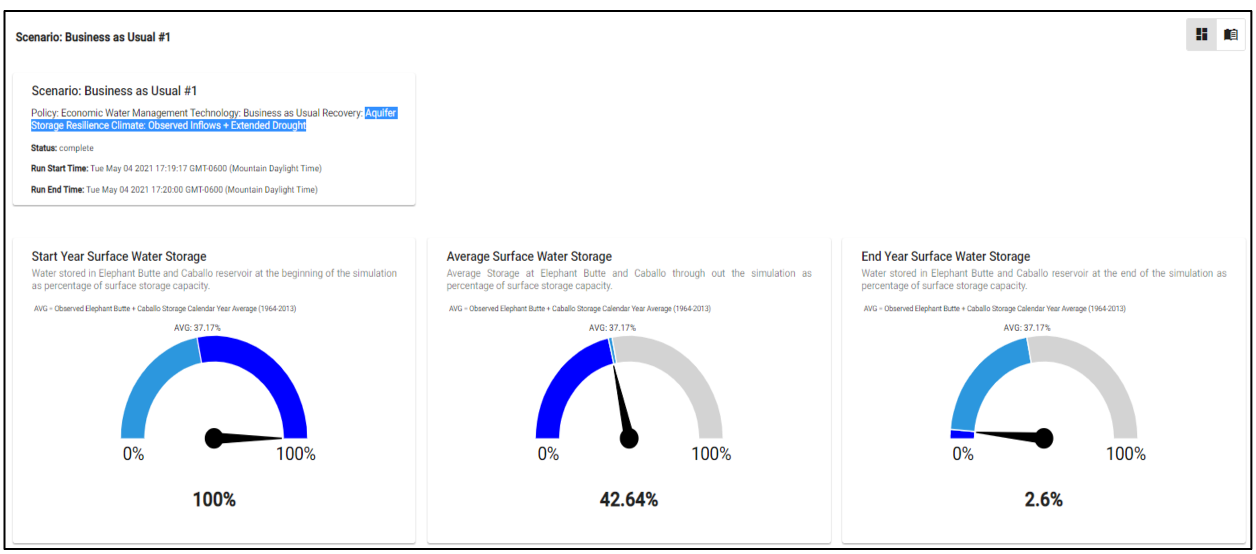
When we run the model, naming it **Business as Usual #1,** it is described as: *Policy: Economic Water Management Technology: Business as Usual Recovery: Aquifer Storage Resilience Climate: Observed Inflows + Extended Drought*.

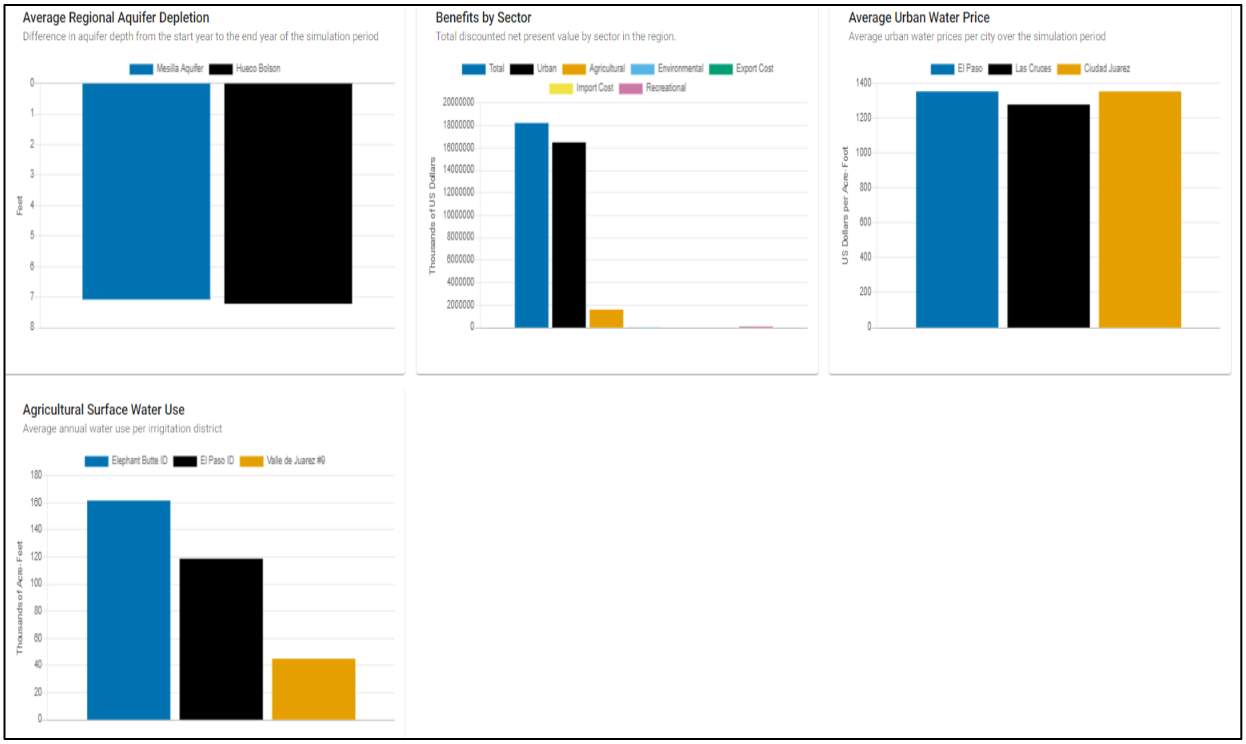
Figure 79: *Filled model execution form a business-as-usual scenario with extended drought and aquifer resilience.*



The model run under Technology: Business-as-Usual, Aquifer Resilience and *Climate: Observed Inflows + Extended Drought* scenario provides the following dashboard.

Figure 80: *Result summary dashboard for a business-as-Usual technology scenario with aquifer resilience and extended drought.*

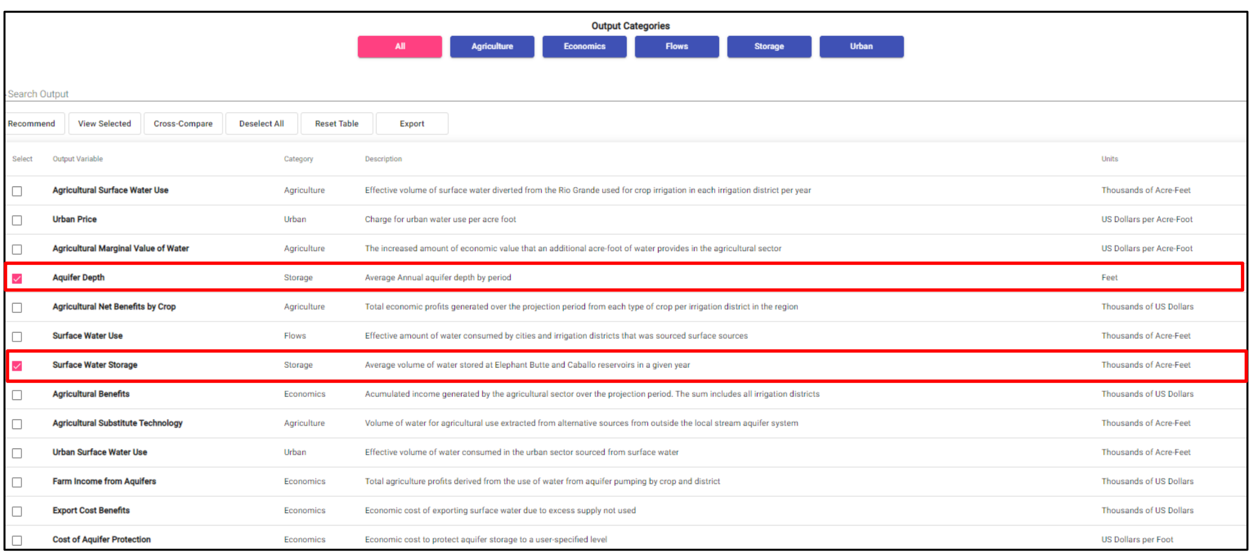




Query Output Variables

As in previous scenarios, we can query the output variables of this model by clicking on the **Output Catalog** and looking at the many pages of data set Output Categories. Or use the **Recommend** tab that reorders the list of Output Categories into a suggested query array.

Figure 81: *Output Catalog for Hydroeconomic model with two selected variables.*



Select	Output Variable	Category	Description	Units
☐	**Agricultural Surface Water Use**	Agriculture	Effective volume of surface water diverted from the Rio Grande used for crop irrigation in each irrigation district per year	Thousands of Acre-Feet
☐	**Urban Price**	Urban	Charge for urban water use per acre foot	US Dollars per Acre-Foot
☐	**Agricultural Marginal Value of Water**	Agriculture	The increased amount of economic value that an additional acre-foot of water provides in the agricultural sector	US Dollars per Acre-Foot
☑	**Aquifer Depth**	Storage	Average Annual aquifer depth by period	Feet
☐	**Agricultural Net Benefits by Crop**	Agriculture	Total economic profits generated over the projection period from each type of crop per irrigation district in the region	Thousands of US Dollars
☐	**Surface Water Use**	Flows	Effective amount of water consumed by cities and irrigation districts that was sourced surface sources	Thousands of Acre-Feet
☑	**Surface Water Storage**	Storage	Average volume of water stored at Elephant Butte and Caballo reservoirs in a given year	Thousands of Acre-Feet
☐	**Agricultural Benefits**	Economics	Acumulated income generated by the agricultural sector over the projection period. The sum includes all irrigation districts	Thousands of US Dollars
☐	**Agricultural Substitute Technology**	Agriculture	Volume of water for agricultural use extracted from alternative sources from outside the local stream aquifer system	Thousands of Acre-Feet
☐	**Urban Surface Water Use**	Urban	Effective volume of water consumed in the urban sector sourced from surface water	Thousands of Acre-Feet
☐	**Farm Income from Aquifers**	Economics	Total agriculture profits derived from the use of water from aquifer pumping by crop and district	Thousands of US Dollars
☐	**Export Cost Benefits**	Economics	Economic cost of exporting surface water due to excess supply not used	Thousands of US Dollars
☐	**Cost of Aquifer Protection**	Economics	Economic cost to protect aquifer storage to a user-specified level	US Dollars per Foot

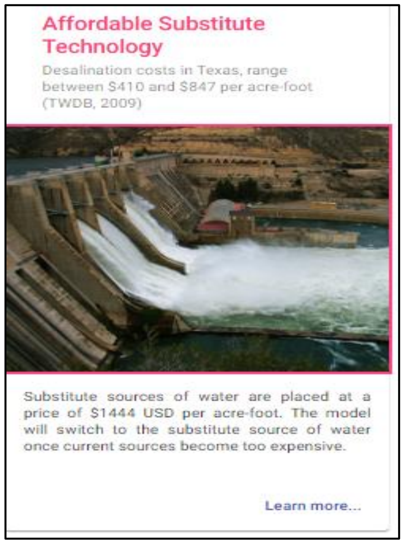
So, let us select two variables to graph as seen above: *Aquifer Depth* and *Surface Water Storage*. Then click on **View Selected** to yield the following graphs except when we view the graphs, we will minimize the Storage Capacity and Depth both Mesilla and Hueco aquifers (by clicking on the descriptor) as they are constants so we can look just at their projected depths over time. This yields the following comparison for a *Business-as-Usual Technology Scenario.*

Figure 82: *Side-by-side detailed view of selected output variables.*

Starting in around 2027 surface water declines rapidly and aquifer depth continues to drop under *Business as Usual.*

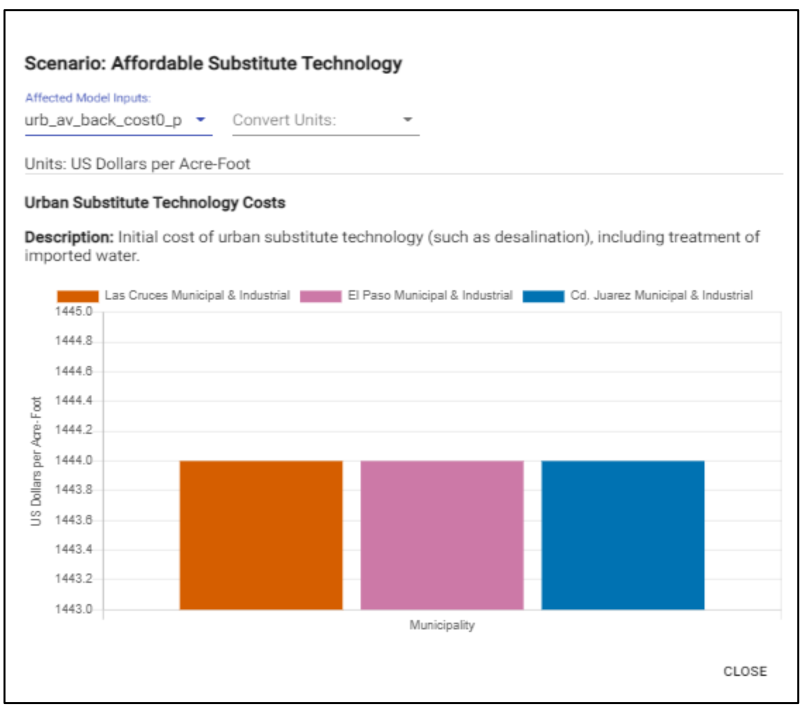
Affordable Substitute Technology

This scenario is based on access to substitute technology namely desalination with costs in Texas ranging between $410 and $847 per acre-foot (TWDB, 2009). Substitute sources of water are placed at a price of $1444 USD per acre-foot. The model will switch to the substitute source of water once current sources become too expensive.



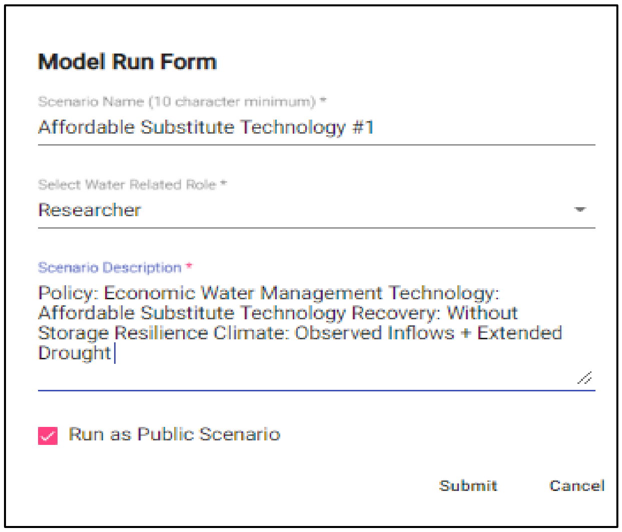
Clicking on **Learn more…** at the bottom of the icon gives us this graph for the three municipal water districts showing the costs.

Figure 83*: Effect of affordable technology scenario on Urban Substitute Technology Costs.*



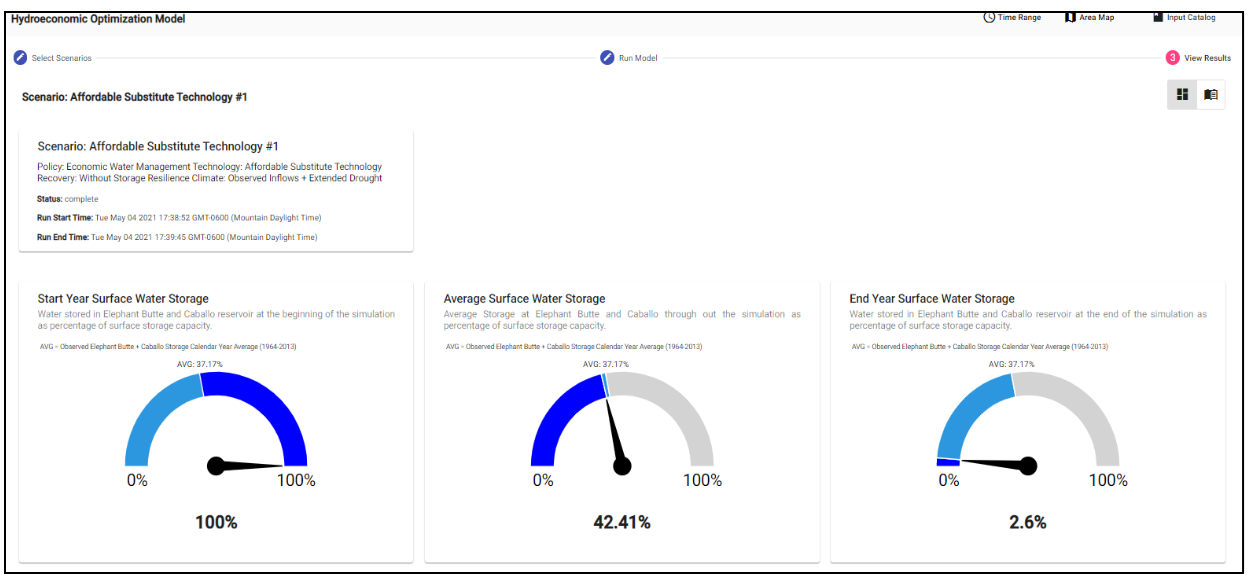
When we run the model, naming it **Affordable Substitute Technology #1**, it is described as*: Policy: Economic Water Management Technology: Affordable Substitute Technology Recovery: Without Storage Resilience Climate: Observed Inflows + Extended Drought.*

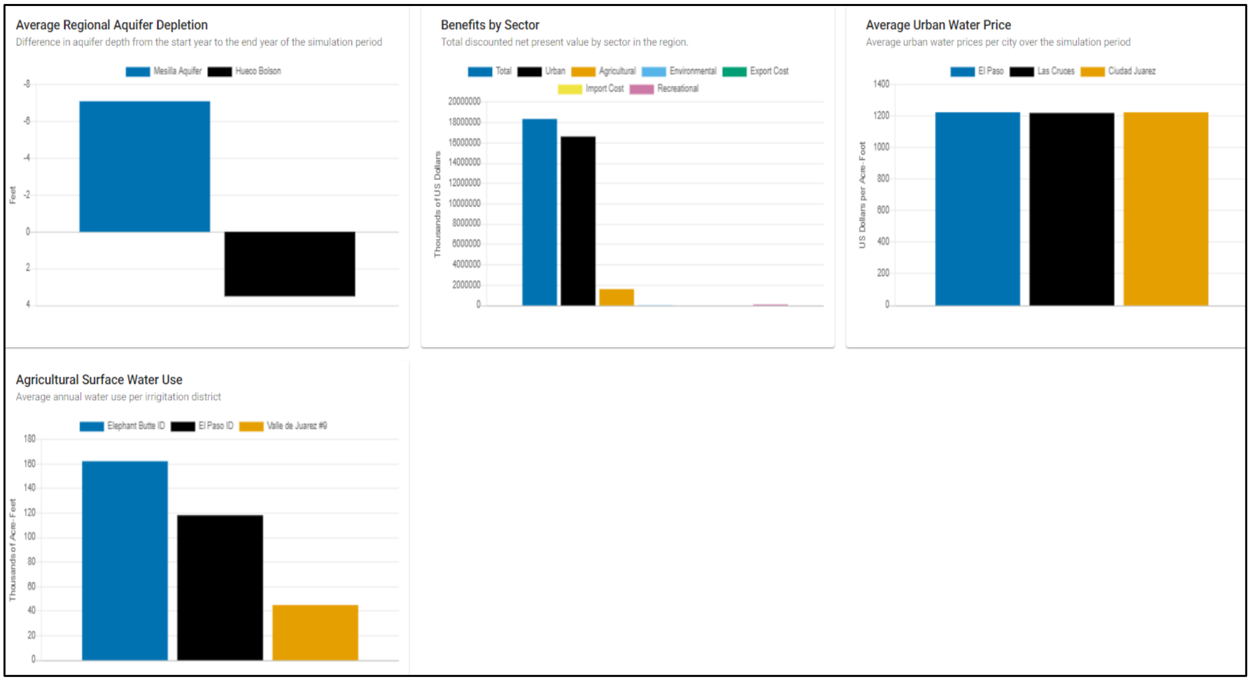
Figure 84: *Filled model execution form with an affordable substitute technology scenario, without resilience and extended drought.*



The model run provides the following dashboard.

Figure 85: *Result summary dashboard of an affordable substitute technology with extended drought scenario of the Hydroecomomic Model.*



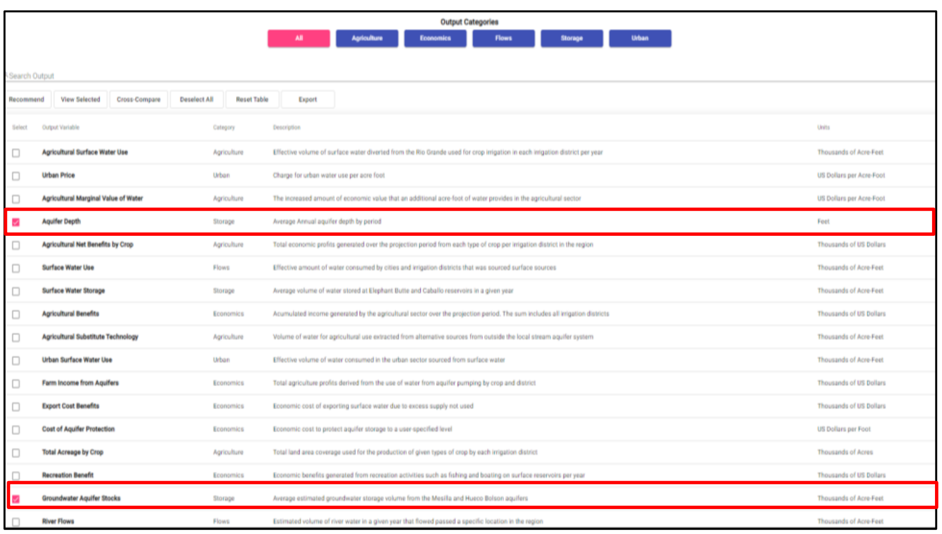


Note that the aquifer depletion profile of this scenario differs from the *Business-as-Usual* scenario presumably due to aquifer replenishment and/or conservation using desalination technology.

Query Output Variables

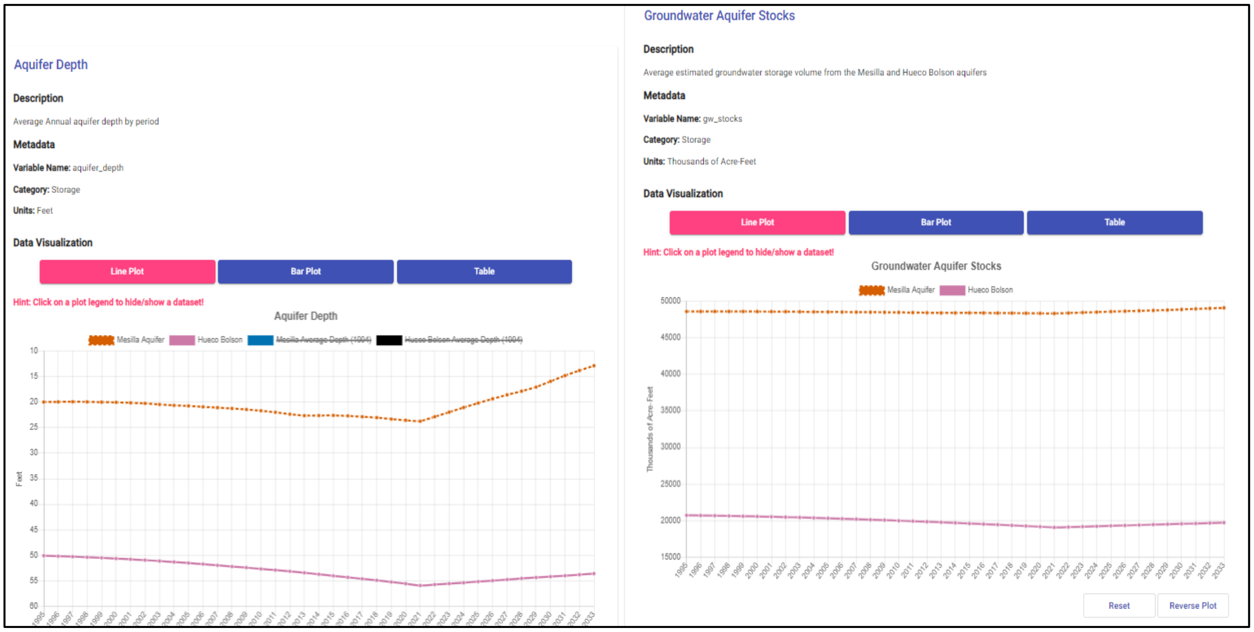
As in previous scenarios, we can query the output variables of this model by clicking on the **Output Catalog** and looking at the many pages of data set Output Categories. Or use the **Recommend** tab that reorders the list of Output Categories into a suggested query array. In this case, we will examine output variables for Storage capacity as seen below, specifically *Aquifer Depth* and *Groundwater Aquifer Stocks.*

Figure 86: *Screenshot of the Output Catalog with two selected variables of the Hydroeconomic Model.*



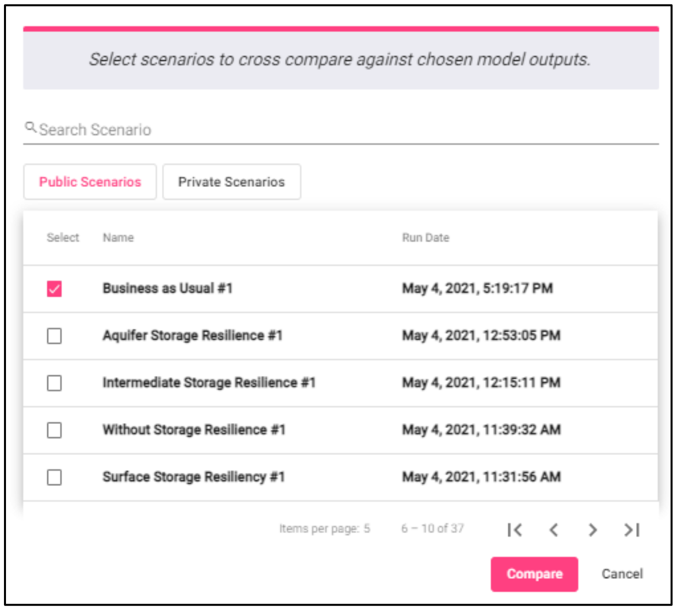
Then click on **View Selected** to yield the following graphs except when we view the graphs, we will minimize the Mesilla and Hueco Average Depth (by clicking on the descriptor) as they are constants so we can look just at their projected depths over time. This yields the following comparison for the Affordable Technology Scenario.

Figure 87: *Screenshot of side-by-side detailed window of the selected output variables.*



Aquifer Depth does not appear to be as severely affected as in the previous model in this scenario. We can check that by running a cross compare on these two variables with the previous model. To do this, we return to the previous page with the **Output Category** table and click on **Cross Compare.** Then selecting the **Business as Usual #1** model to compare and clicking on the **Compare** tab.

Figure 88: *Cross-Compare scenario selection window.*

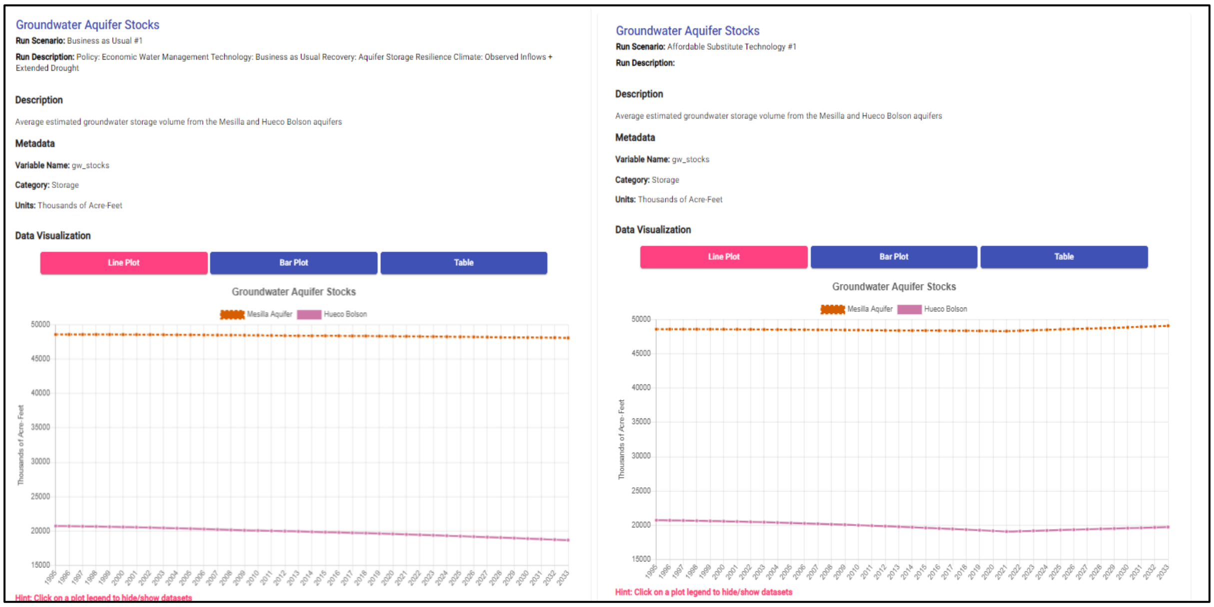


Then minimize the Mesilla and Hueco Average Depth (by clicking on the descriptor) as they are constants so we can look just at their projected depths over time. This yields the following comparison for the *Business-as-Usual Scenario* on the left versus the *Affordable Substitute Technology Scenario* on the right for Aquifer Depth.

Figure 89: *Side-by-side comparison of the Aquifer Depth variable over a business-as-usual and affordable technology scenario.*

Using affordable substitution technology does have a considerable recovery effect on the Aquifer Depth over time. For groundwater aquifer stocks, the effect is not as noticeable due to the full capacity range as seen in the graphs below.

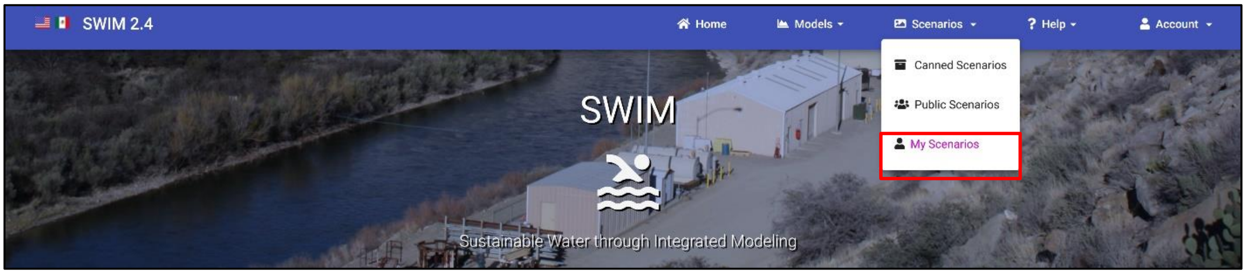
Figure 90: *Side-by-side comparison of the Groundwater Aquifer Stocks variable over a business-as-usual and affordable technology scenario.*



This time the *Affordable Substitute Technology Scenario* on the right versus the *Business-as-Usual Scenario* on the left side. Again, the model's power to compare alternative modeling scenarios graphically is seen here.

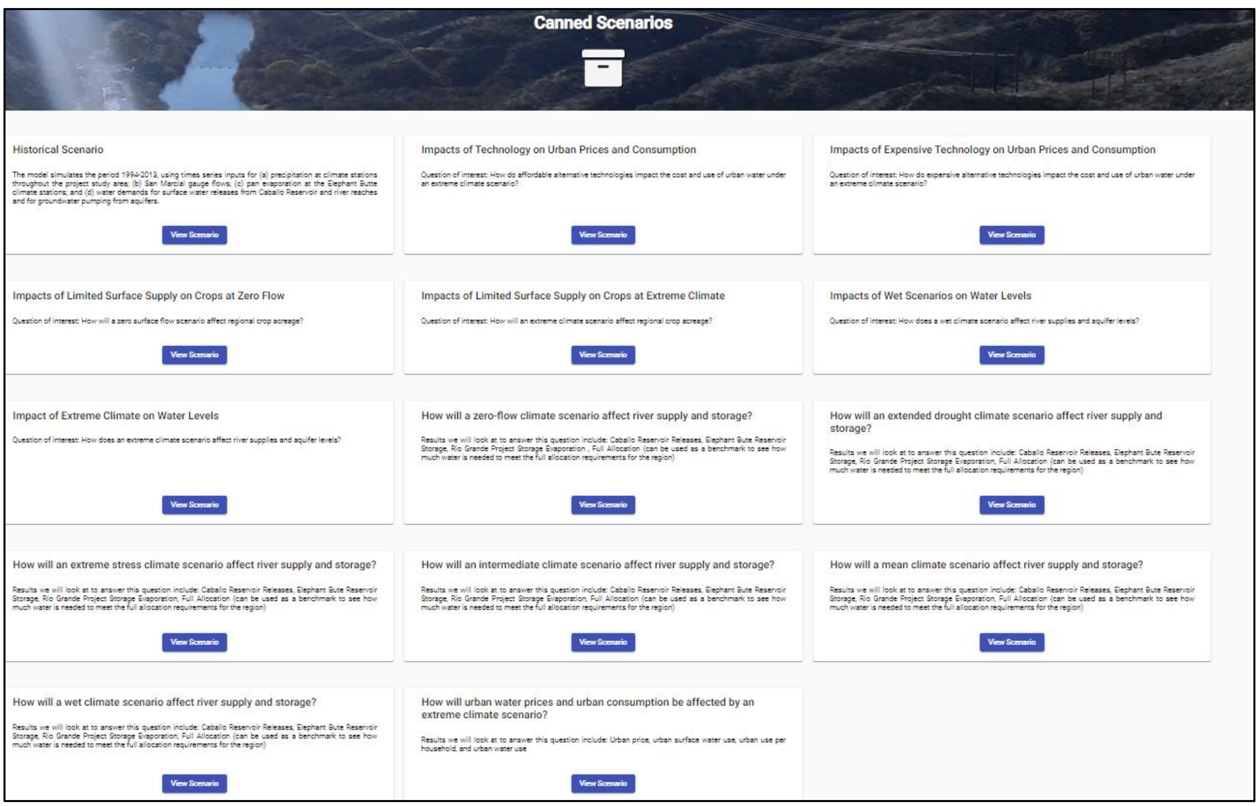
SWIM Canned Scenarios

In the SWIM Website Overview above, we briefly discussed the **Canned Scenarios** tab.



That, when selected, lands the user on a tableau of specific custom scenarios from which to choose, as seen below.

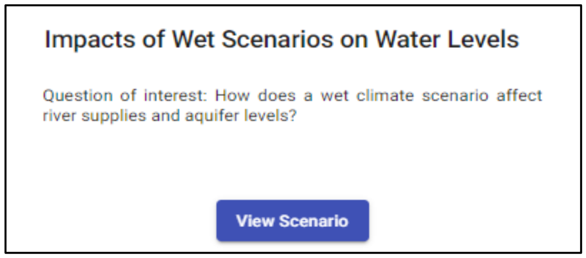
Figure 91: *Screenshot of the Canned Scenarios page available on SWIM 2*



The **Canned Scenarios** comprise a developing repertoire of models aimed at getting a quick answer to a specific question. Expect to see more of them in SWIM as it matures.

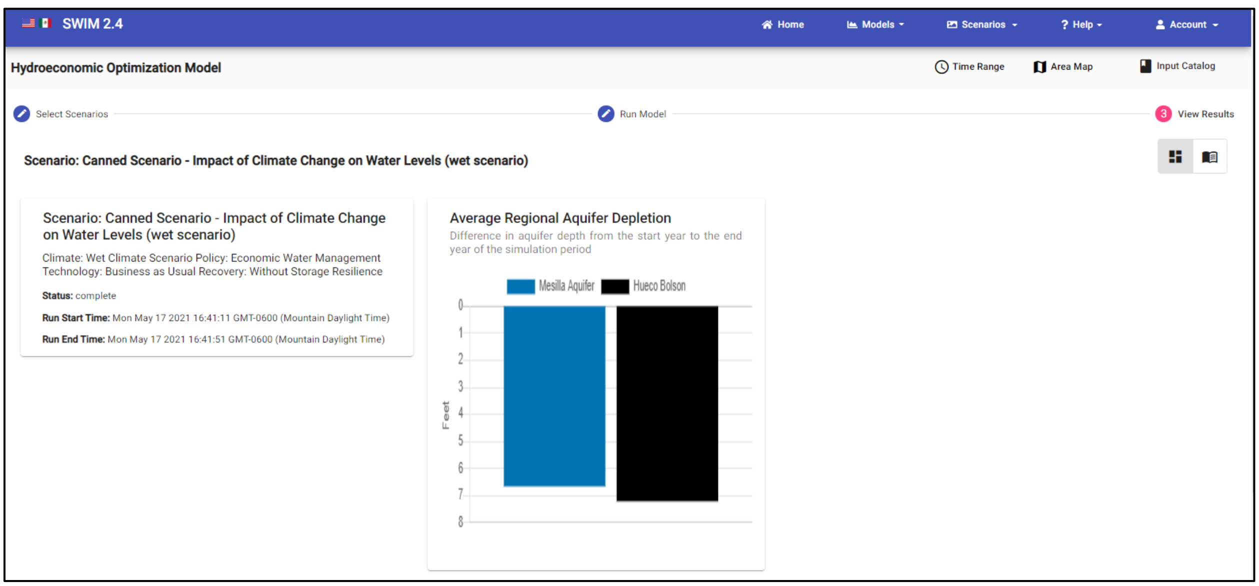
Hydroeconomic Model Canned Scenarios

For example, to quickly answer the question, "How does a wet climate scenario affect river supplies and aquifer levels?" you would select the Canned Scenario below.



Then, click on **View Scenario** and the following dashboard appears. This is a specific instance of the **Hydroeconomic Optimization Model**.

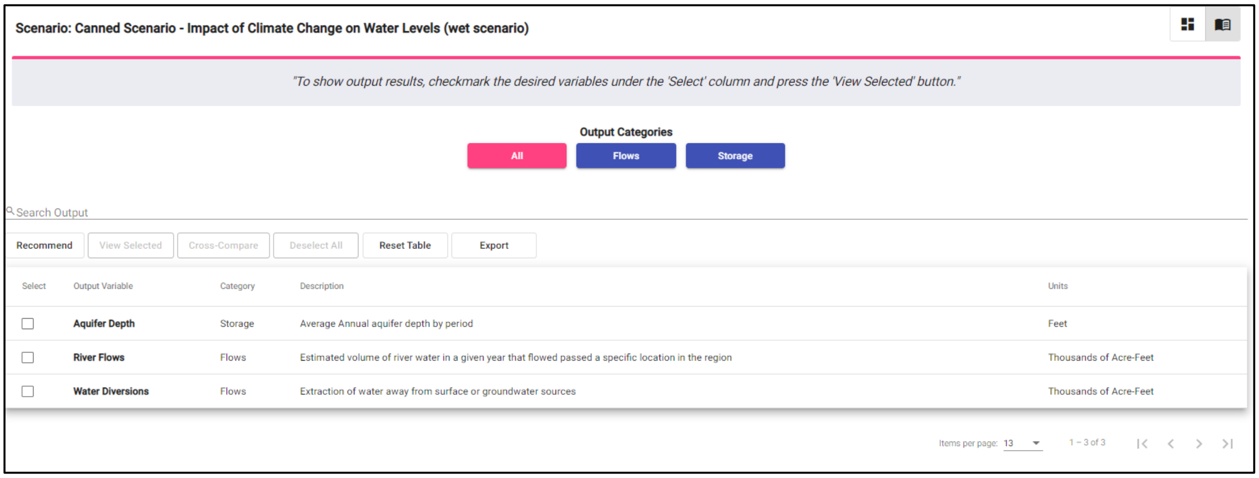
Figure 92: *Summary dashboard of a canned scenario derived from the Hydroeconomic Model.*



The model calculates aquifer depletion as the difference in aquifer depth from the start year to the end year of the simulation period.

A feature of the Canned Scenarios is that they can use fewer output variable data sets because the scope of the problem question is more focused than in a more generalized scenario. In the example above, the **Output Catalog** has only three variables, as seen below.

Figure 93: *Output catalog of the canned scenario: Impact of climate change on water levels.*

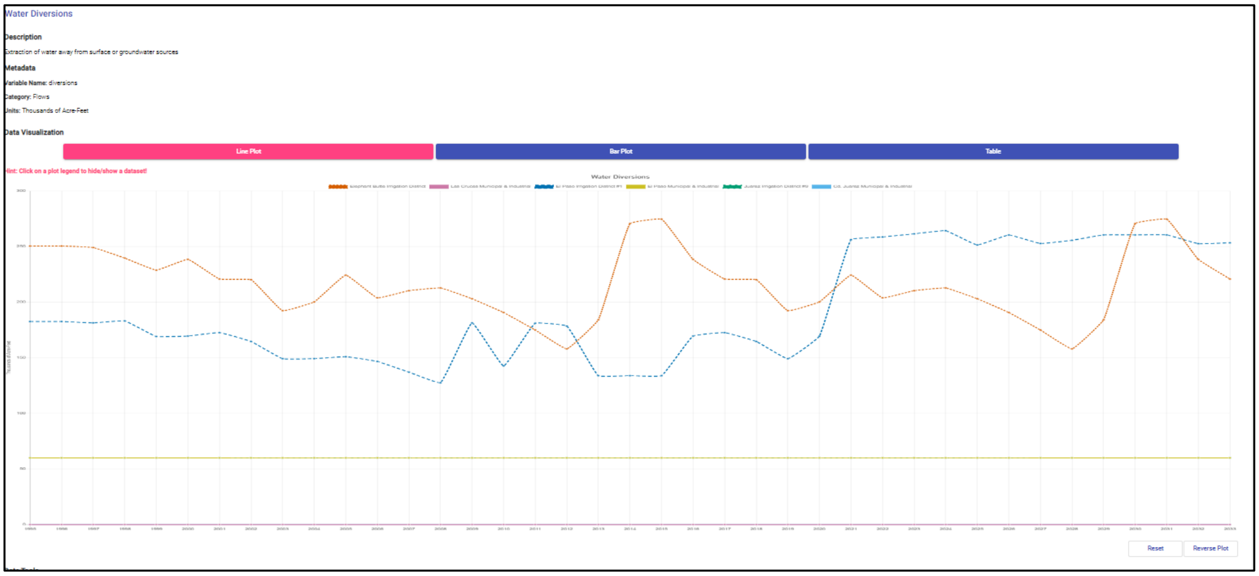


If we select the three variables and click on **View Selected**, we get a graphic depiction of the model solution.

Figure 94: *Detailed view of the selected output variables side by side.*

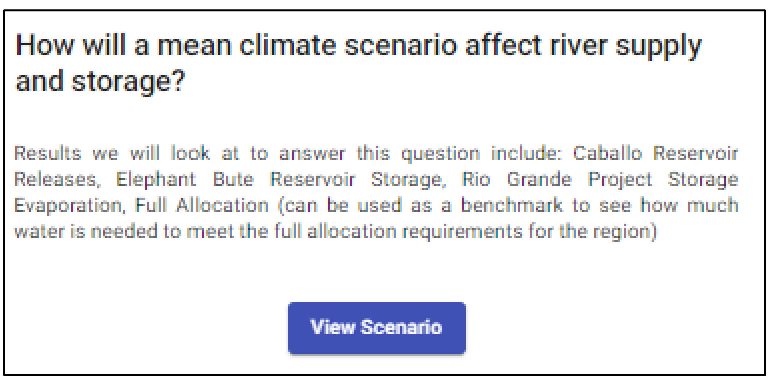
This view has been enhanced by reversing the plot of the aquifer depth to show it increasing downward over time, plus the long-term averages have been suppressed. The canned scenario also shows us predicted long term water diversions.

Figure 95: *Detailed view of the Water Diversions variable generated from the canned scenario.*



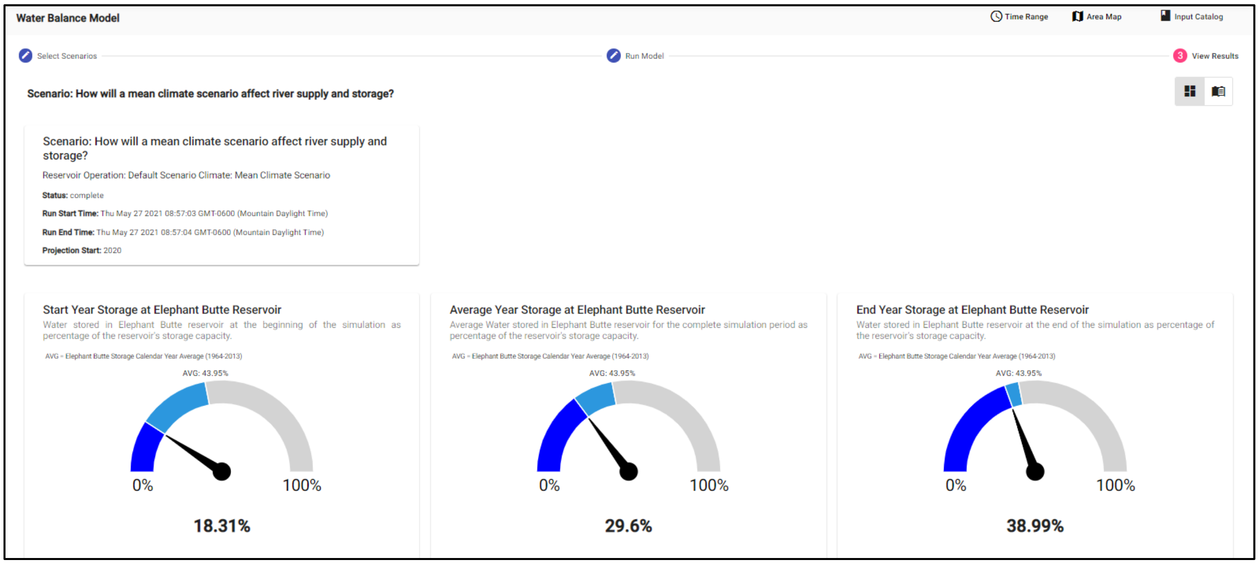
Water Balance Model Canned Scenarios

A canned scenario that uses the **Water Balance Model** is illustrated below.



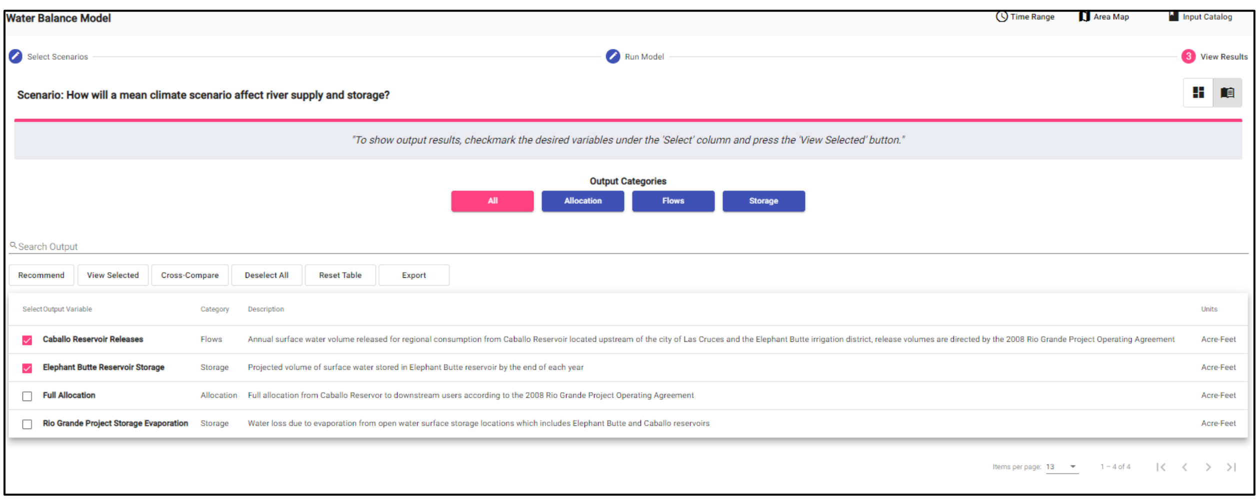
Then, click on **View Scenario** and the following appears. This is a specific instance of the **Water Balance Model** and yields the familiar dashboard below.

__Figure 96:__ Summary dashboard of a canned scenario derived from the Water Balance Model.



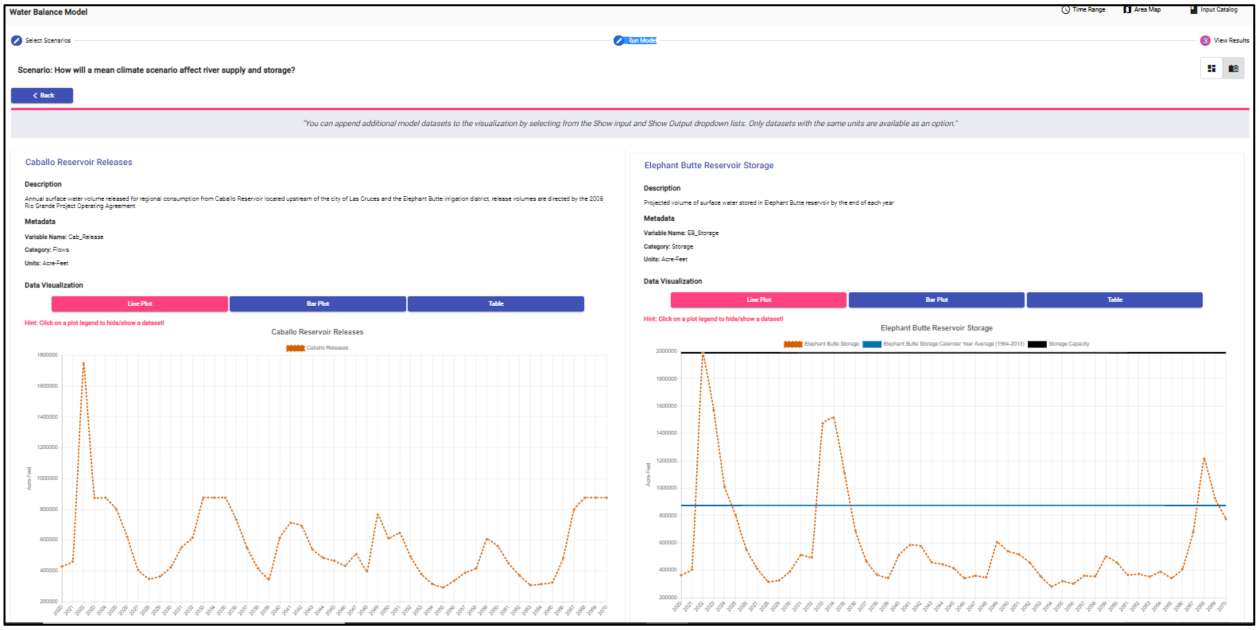
Checking the **Output Catalog** shows us the shorthand version of the model's four calculated variables.

__Figure 97:__ Output catalog of the canned scenario: How will a mean climate scenario affect river supply and storage?



If we select the first two variables and click on **View Selected**, we get a graphic depiction of the **Water Balance Model** solution.

__Figure 98:__ Detailed view of the selected output variables side by side.



These are just two examples of many **Canned Scenarios** now available in SWIM. Use them to get a quick answer to a specific question or to practice and teach the SWIM model functions to students.

Dictionary of SWIM Terms

Allocation - A total amount or proportion of water share assigned to a specific location or sector.

Aquifer - An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt). Groundwater from aquifers can be extracted using a water well. The main aquifers in the SWIM model are the Messila and the Hueco Bolson.
Source: https://water-research.nmsu.edu/files/2016/09/Operating-Agreement-original-March-2008-from-NMOSE.pdf

Acequia - An irrigation ditch that distributes water from the river and pumped storage (wells) to users, frequently governed under various cooperative local agreements.
Source: Wikipedia, https://en.wikipedia.org/wiki/Acequia

Beneficial Use - The basis of water rights in the west is that water should be put to productive (beneficial) economic use to establish a right to it. A corollary called; “prior use” states the first person to establish a water right by beneficial use has a right to obtain the full amount of water from available supplies.
Source: Reining in the Rio Grande - People, Land and Water by authors Fred M. Phillips, G. Emlen Hall and Mary ER. Black (2011, University of New Mexico Press).

Bosque - A type of forest habitat found along the riparian flood plains of stream and riverbanks in the southwestern United States., e.g., the Bosque del Apache near Socorro, NM.
Source: Wikipedia, https://en.wikipedia.org/wiki/Bosque

Bucket Model - The approach that reflects water stocks, inflow, and outflow for project storage (surface water reservoirs) and for the region’s two major aquifers, the Mesilla and Hueco.
Source: SWIM Models, https://water.cybershare.utep.edu/resources/docs/en2/models/bucket/

Caballo Reservoir - Located in Sierra County, New Mexico; south of Elephant Butte Dam. The reservoir acts a as buffer for water deliveries downstream on the Rio Grande.

Desalinization - A technology to remove salt from briney water, typically stored in aquifers. El Paso, Texas operates a large such plant that supplies up to a quarter of its daily water needs.
Source: https://www.epwater.org/cms/one.aspx?portalId=6843488&pageId=7422402

Diversion - A **water diversion** is the removal or transfer of **water** from one watershed to another. The term “consumptive use” is used to define **diversions** and exports, because the **water** is being “consumed” without then returning to its source.
Source: https://forloveofwater.org/programs/diversions-and-exports/

Economic Benefits - The monetary utility generated after removing costs from generated income. Can be also referred to as net income and revenue.
Source: https://marketbusinessnews.com

Elephant Butte Reservoir – Located to the north of Truth or Consequences, New Mexico. It is the main surface storage of the Rio Grande project to provide irrigation to south-central New Mexico, western Texas, and Valle de Juarez in Mexico.

Endangered Species Act of 1973 - The primary law in the United States for protecting critically imperiled species from extinction as a consequence of economic growth and development. It is relevant for the Middle Rio Grande for its protection of the Silvery Minnow and the impact this has had on river politics and water release policy.
Source: https://www.epa.gov/laws-regulations/summary-endangered-species-act

Irrigation Districts - A cooperative, self-governing public corporation set up as a subdivision of the State government, with definite geographic boundaries, organized, and having taxing power to obtain and distribute water for irrigation of lands within the district. There are three districts in the SWIM model: Elephant Butte Irrigation District, the El Paso County Water Improvement District No. 1 and Valle de Juarez No. 9.
Source: Wikipedia, https://en.wikipedia.org/wiki/Irrigation_district

Optimization - to make the best or most effective use of a situation or resource (e.g., water).
Source: Oxford Languages

Parameter - A value or set of values that affect the behavior of a model. These can derive from observed data, estimates or assumptions. In the context of SWIM, a parameter is an input value.

Reclamation Act of 1902 - This act established the federal government's control over large new water projects, E.G, Elephant Butte Dam, but gave the affected states the right to apportion water for their use.
Source: https://www.ntc.blm.gov/krc/uploads/538/Reclamation_Act_of_June_17_1902.pdf

Rio Grande Compact of 1938 - An agreement between Colorado, New Mexico and Texas ratified by Congress that governs the water supply each state would receive from the Rio Grande.
Source: Wikipedia, https://en.wikipedia.org/wiki/Rio_Grande_Compact

2008 Operating Agreement - An agreement between the Elephant Butte Irrigation District and the El Paso County Water Improvement District No. 1 setting out the terms and methods for release of water from the reservoirs and the responsibilities of the parties.
Source: https://usbr.gov/uc/albuq/rm/RGP/pdfs/Operating-Agreement2008.pdf

River Reach - A section of a stream or river along which similar hydrologic conditions exist, such as discharge, depth, area, and slope. The **Water Balance Model** recognizes two such reaches.
Source: https://www.usgs.gov/faqs/what-a-reach?qt-news_science_products=0#qt-news_science_products

San Marcial Gauges – A floodway gauging station located at the north of Elephant Butte Lake. San Marcial flow is highly influenced by upstream regulations, diversions and return flows. The Rio Grande Compact influences the quantity and timing of flow.
Source: Reclamation, https://www.usbr.gov/uc/albuq/envdocs/bo/ebutte/EB-Ops.pdf

Variable - A property that may assume any given value or set of values resulting from a model execution.

Water Balance Model - This is a simple mathematical hydrologic accountability model for the Middle Rio Grande Basin from the San Marcial Gauges above Elephant Butte Reservoir to Fort Quitman.
Source: SWIM Models, https://water.cybershare.utep.edu/resources/docs/en2/models/balance/

Watershed - A watershed is the area of land where all the water that falls in it and drains off goes to a common outlet (e.g., river or lake).
Source: https://www.oei2.org/our-watershed/definition-of-watershed/

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Townsend, N. T., & Gutzler, D. S. (2020). Adaptation of Climate Model Projections of Streamflow to Account for Upstream Anthropogenic Impairments. *JAWRA Journal of the American Water Resources Association*, *56*(4), 586–598. https://doi.org/10.1111/1752-1688.12851

Ward, F. A., Mayer, A. S., Garnica, L. A., Townsend, N. T., & Gutzler, D. S. (2019). The economics of aquifer protection plans under climate water stress: New insights from hydroeconomic modeling. *Journal of Hydrology*, *576*, 667–684. https://doi.org/10.1016/j.jhydrol.2019.06.081