DRAFT WORK PRODUCT

Borrego Valley Groundwater Basin
Borrego Springs Subbasin
Borrego Valley Groundwater Model / Water Budget Update

Borrego Valley Groundwater Basin Sustainability Plan

August 31, 2018

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Presentation Topics

1. Introduction
2. Groundwater Model
3. Water Budget and Groundwater Model Update
4. Groundwater Model Update Results and Uncertainty
5. Steps to Improve Groundwater Model Accuracy
6. Next Steps

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Groundwater Model: One-Water Hydrologic Flow Model

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- **MODFLOW** – developed by the USGS, MODFLOW is considered an international standard for simulating and predicting groundwater conditions.
- **Farm Process (FMP)** – Estimates dynamically integrated supply and demand components of irrigated agriculture in the absence of reported agriculture irrigation production data.
- **One-Water Hydrologic Flow Model (MF-OWHM)** – a MODFLOW-based model designed for the analysis of a broad range of integrated groundwater and surface water issues.

Source: USGS 2017

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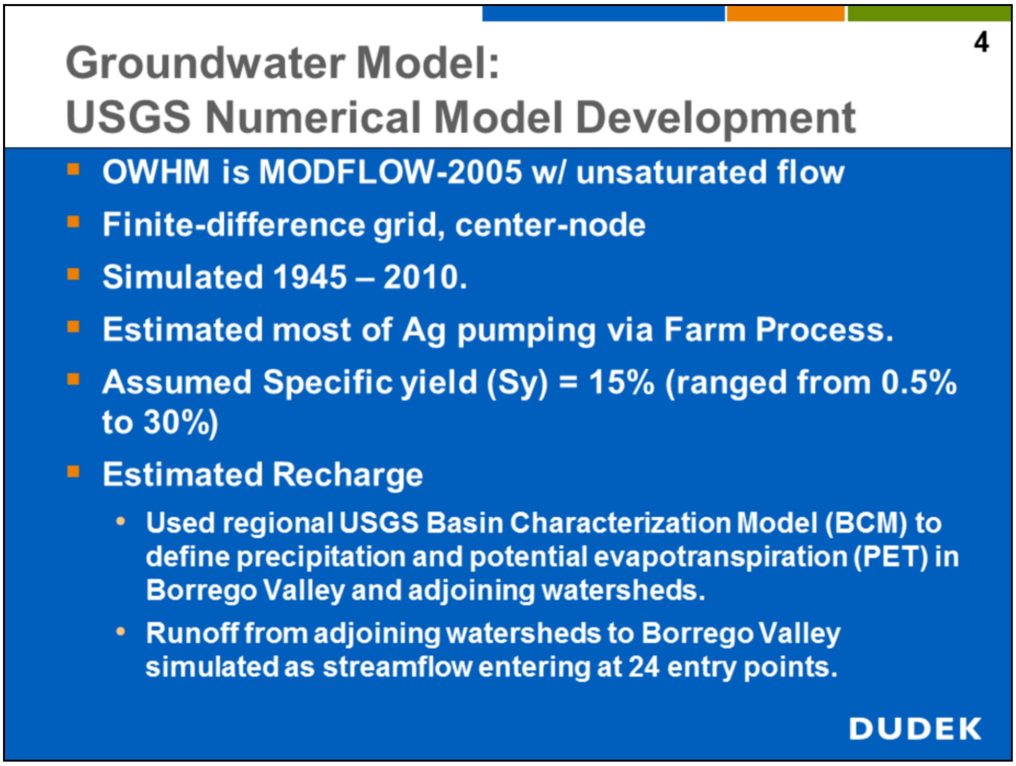
Introduction to computer programs used to make water model.

Dudek obtained the U.S. Geological Survey (USGS) numerical model files for the Borrego Valley Hydrologic Model (BVHM), which was developed in 2014 using the USGS code One-Water Hydrologic Flow Model (OWHM). OWHM is a MODFLOW-based numerical model code designed for the analysis of a broad range of integrated groundwater and surface water issues. OWHM includes a new model package, called the Farm Process that estimates dynamically integrated supply and demand components of irrigated agriculture in the absence of historical metered data. The USGS developed the BVHM to simulate hydrologic conditions in a portion of the Borrego Valley Groundwater Basin that includes the Borrego Springs Subbasin from 1945 to 2010.



The numerical model simulated pumping at Borrego Water District (BWD) wells using metered data, estimated agriculture (Ag) pumping based on water demands estimated for irrigated agriculture using the Farm Process package, and estimated water input from precipitation and streamflow using data extracted from the USGS Basin Characterization Model (BCM). The BCM is a regional hydrologic model that uses historical climate data to calculate a monthly water balance for water years from 1896 to 2016. Water balance elements in the BCM used in the Borrego Valley Hydrologic Model (BVHM) include precipitation, runoff, recharge, and evapotranspiration. The BCM covers all of the California hydrologic region, with inputs for the BVHM extracted from the larger BCM.

The hydraulic conductivity and specific yield of the groundwater basin were estimated based on limited aquifer test data. Hydraulic conductivity characterizes the ability of the aquifer to transmit water. Specific yield, for unconfined aquifers, characterizes an aquifer’s ability to store and release water. Specific yield ranged from 30 percent for the coarse-grained parts of the upper aquifer to 0.5 percent for the fine-grained parts of the lower aquifer (USGS 2015). The assumed specific yield was 15 percent in both the upper and middle aquifers (USGS 2015).

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Farm Process Package (FMP)

- Exclusive to MODFLOW-OWHM
- Calculates water demand based on inputs, then supplies water via pumping to meet demand
- Inputs Include:
  - Land use type
  - Rooting depth
  - Soil type
  - Soil water content by crop
  - Precipitation and PET
  - Farm efficiency factor

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The farm process package is the primary driver for the USGS to use MODFLOW-OWHM, since it dynamically estimates pumping based on calculations of water demands. Water demands are calculated by the farm package from several inputs to the model, including land use type, soil type, soil moisture demands by crop, crop rooting depth, monthly precipitation and evapotranspiration, and an assigned efficiency factor by crop type. The BVHM is set up to supply the total calculated water demand from groundwater pumping.

Crop Inputs

Land-use type (index number)	Irrigated	Root depth, in feet	Root uptake pressure heads, in feet				Fraction of surface-water runoff from precipitation (left) and irrigation (right)	
			Anoxia	Lower optimal range	Upper optimal range	Wilting	(Dimensionless)	
Golf courses (1, 3)	Yes	3.28	–0.13	–0.28	–11.40	–80.00	0.06	0.14
Residential/urban (2)	No	0.82	–0.13	–0.28	–11.40	–80.00	0.06	na
Phreatophytes (4)	No	15.27	0.50	0.13	–8.25	–115.00	0.05	na
Fallow/livestock (5, 6)	No	0.82	–0.08	–0.20	–8.25	–115.00	0.40	na
Row and other crops (7)	Yes	1.64	–0.15	–0.30	–5.45	–80.00	0.25	0.06
Grapes (8)	Yes	6.56	–0.15	–0.30	–7.25	–80.00	0.06	0.05
Non-irrigated grapes (9)	No	6.56	–0.15	–0.30	–7.25	–80.00	0.06	na
Citrus (11)	Yes	4.00	–0.15	–0.30	–6.00	–80.00	0.06	0.25
Dates, palms, nursery (10, 12, 13)	Yes	4.92	–0.15	–0.30	–6.00	–80.00	0.09	0.13
Potatoes (14)	Yes	3.28	–0.15	–0.30	–52.10	–80.00	0.28	0.06
Native (15)	No	14.47	–0.08	–0.20	–8.25	–115.00	0.40	na

Source: USGS 2015

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Root depth, uptake pressure heads, and surface water precipitation runoff inputs to the BVHM.

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Crop Coefficients

Land-use type (Farm process crop index number)	Irrigated[1]	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Golf courses (1, 3)	Yes	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Residential/urban (2)	No	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.50	0.75	0.80	0.85
Phreatophytes (4)	No	1.00	1.00	1.00	0.48	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50
Fallow/livestock (5, 6)	No	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Row and other crops (7)	Yes	0.90	0.90	0.90	0.90	0.90	0.75	0.70	0.90	0.70	0.90	0.90	0.90
Grapes (8)	Yes	0.35	0.35	0.75	0.80	0.81	0.81	0.81	0.81	0.75	0.50	0.50	0.35
Non-irrigated grapes (9)	No	0.30	0.30	0.75	0.80	0.81	0.81	0.81	0.81	0.75	0.50	0.35	0.33
Citrus (11)	Yes	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Dates, palms, nursery (10, 12, 13)	Yes	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Potatoes (14)	Yes	0.70	0.90	1.15	1.15	0.90	0.75	0.10	0.10	0.10	0.10	0.10	0.51
Native (15)	No	0.80	0.80	0.80	0.40	0.10	0.10	0.10	0.10	0.10	0.10	0.40	0.50

[1]Crop coefficients are adjusted by season with multipliers (see "Model Calibration" section of this report).

Source: USGS 2015

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Crop coefficient inputs from the BVHM.

Farm Efficiency

Land-use type (FMP crop index number)[1,2]	Base	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
Golf courses (1, 3)	0.75	0.75	0.83	0.86	0.86	0.86	0.88	0.90	0.94
Residential/urban (2)	0.75	0.75	0.83	0.86	0.86	0.86	0.88	0.90	0.94
Phreatophytes (4)	na	na	na	na	na	na	na	na	na
Fallow/livestock (5, 6)	na	na	na	na	na	na	na	na	na
Row and other crops (7)	0.74	0.75	0.83	0.86	0.86	0.86	0.88	0.90	0.93
Grapes (8)	0.77	0.75	0.83	0.86	0.86	0.86	0.88	0.90	0.96
Non-irrigated grapes (9)	na	na	na	na	na	na	na	na	0.94
Citrus (11)	0.78	0.75	0.83	0.86	0.86	0.86	0.88	0.90	0.98
Dates, palms, nursery (10, 12, 13)	0.79	0.75	0.83	0.86	0.86	0.86	0.88	0.90	0.99
Potatoes (14)	0.79	0.75	0.83	0.86	0.86	0.86	0.88	0.90	0.99
Native (15)	na	na	na	na	na	na	na	na	na

[1]Efficiencies were adjusted by decades with multipliers (see "Model Calibration" section of this report).

[2]Efficiencies were specified but were not used for nonirrigated land use.

Source: USGS 2015

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Farm efficiency inputs from the BVHM.

Specific Yield

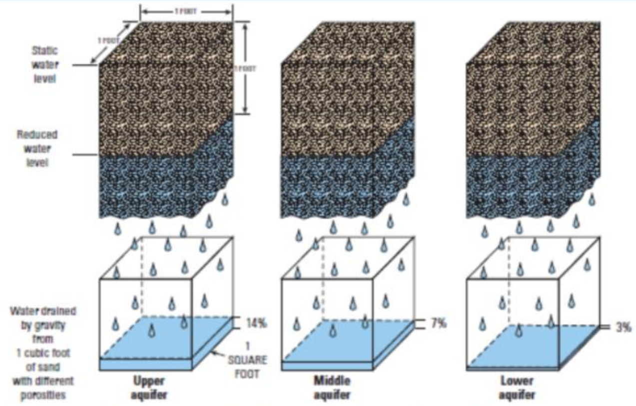

Figure 35. Schematic diagram showing magnitudes (%, percent) of specific yield for the upper, middle, and lower aquifers, Borrego Valley, California.

Source: USGS 2015

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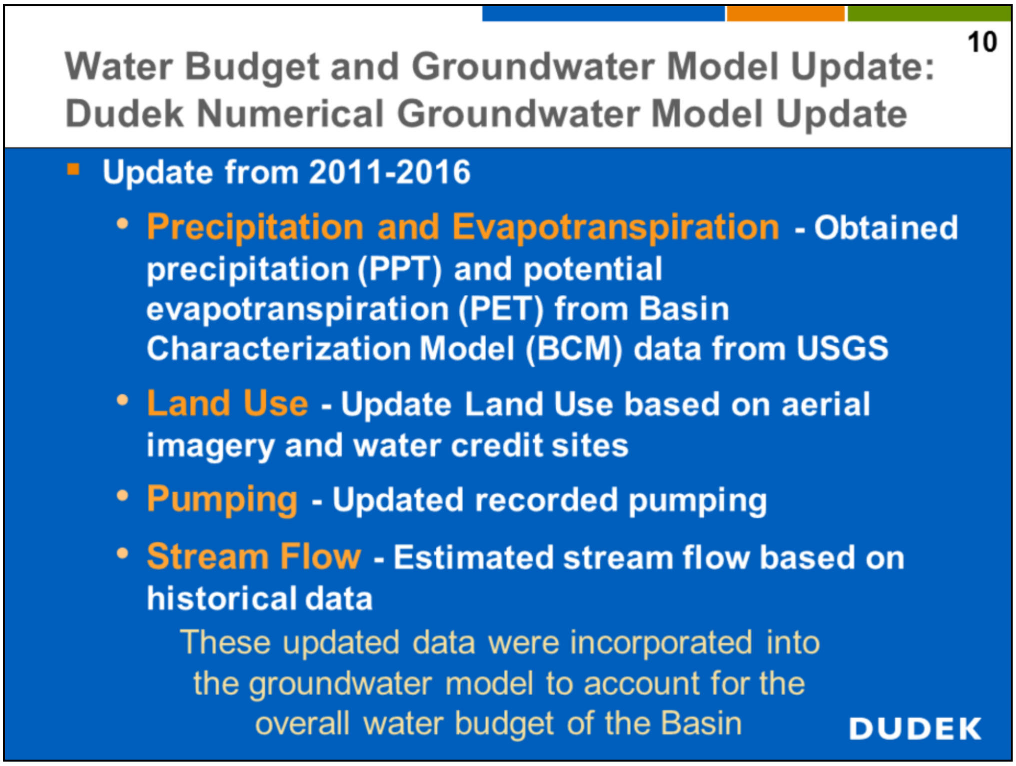
Figure illustrating the average specific yield for the upper, middle, and lower aquifers in the BVHM.



In order to validate the model, better understand the accuracy of modeled water budget outputs, and comply with SGMA requirements, Dudek extended the model input files to cover the period from January 2011 through September 2016. Four major items updated by Dudek to bring model into a usable method for use in GSP development.

Precipitation and evapotranspiration inputs were extended using data extracted from the BCM.

Land use – Updated Yearly based on reviewing aerial photographs and Borrego Water District (BWD) water credits data

Municipal pumping was extended using metered pumping data from the BWD. Recreational pumping from BWD wells was also used to update model pumping inputs.

Streamflow entering the basin was extended by comparing measured precipitation in the validation period to historical precipitation, then using historical stream gage data to get flows from months with similar precipitation amounts.

Water Budget and Groundwater Model Update: Model Characteristics

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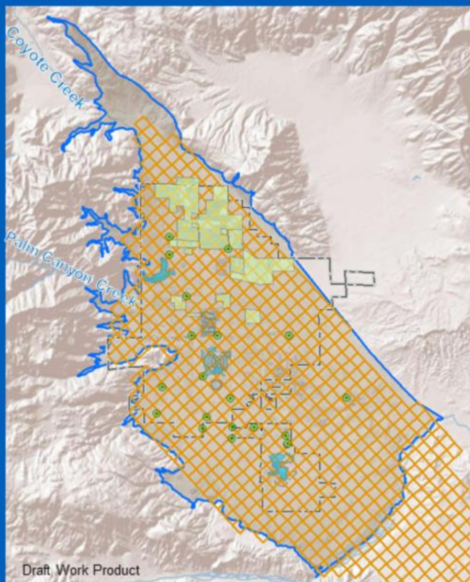

Major Inflow and Outflow

Inflow

Stream Flow: Coyote Creek, Palm Canyon

Outflow

Pumping:
Agriculture, BWD,
Golf Courses

These data are applied to a grid which represents the Basin.

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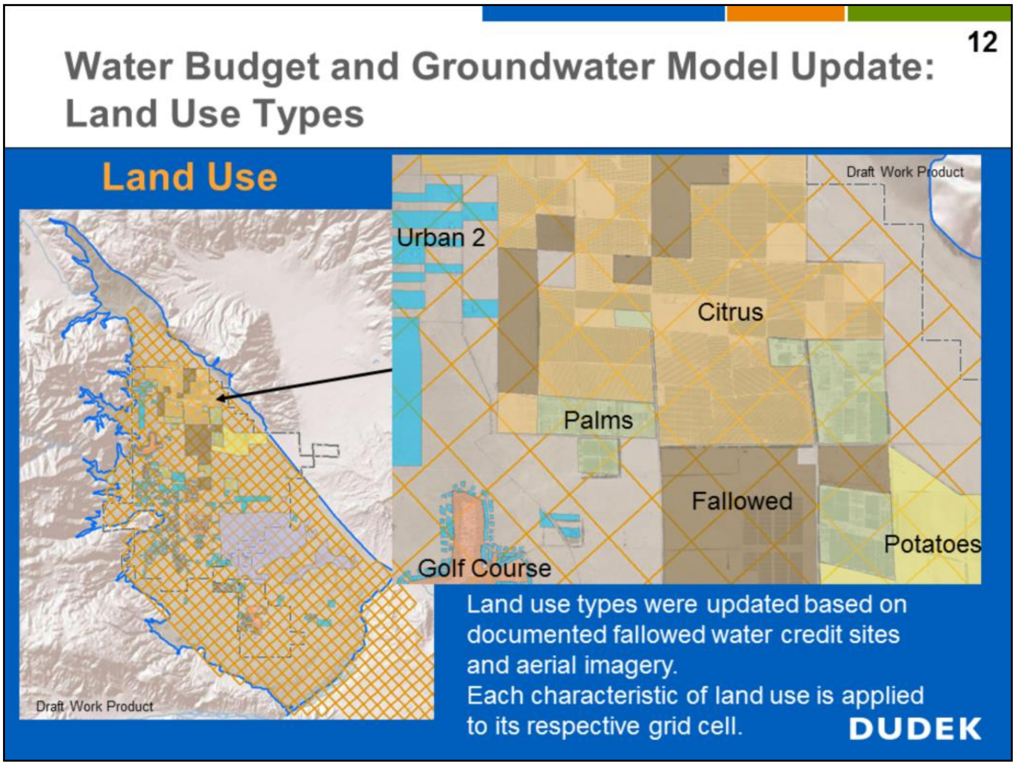
Map of the model grid from the BVHM. The following are represented on the map:

Model Grid: Orange
Ag Area: Green
Golf Courses: Blue
BWD Wells: Green points

Major inflows into the basin included in the model are stream flow (especially in Coyote Creek and Palm Canyon) and underflow from adjacent basins. The major source of outflow in the basin is pumping, primarily for agricultural and recreational use.



The grid cell size in the model (approximately 92 acres per cell) is larger than many of the irrigated plots in the basin. As a result, irrigated acres do not match grid cells exactly. As the Farm Process package uses the land use defined by grid cell to calculate pumping, the discrepancy between cell size and irrigated acreage contributes to uncertainty when estimating pumping.

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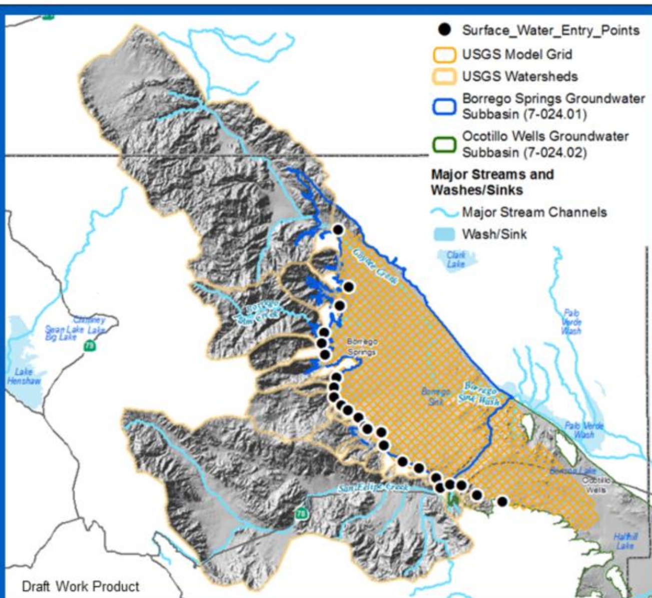
Water Budget and Groundwater Model Update: Surface Water Entry Points



Streamflow

Basin Characterization Model (BCM) estimates runoff outside of the One-Water Hydrologic Flow Model (OWHM) domain

Streamflow ultimately plays the largest role in recharge to the basin

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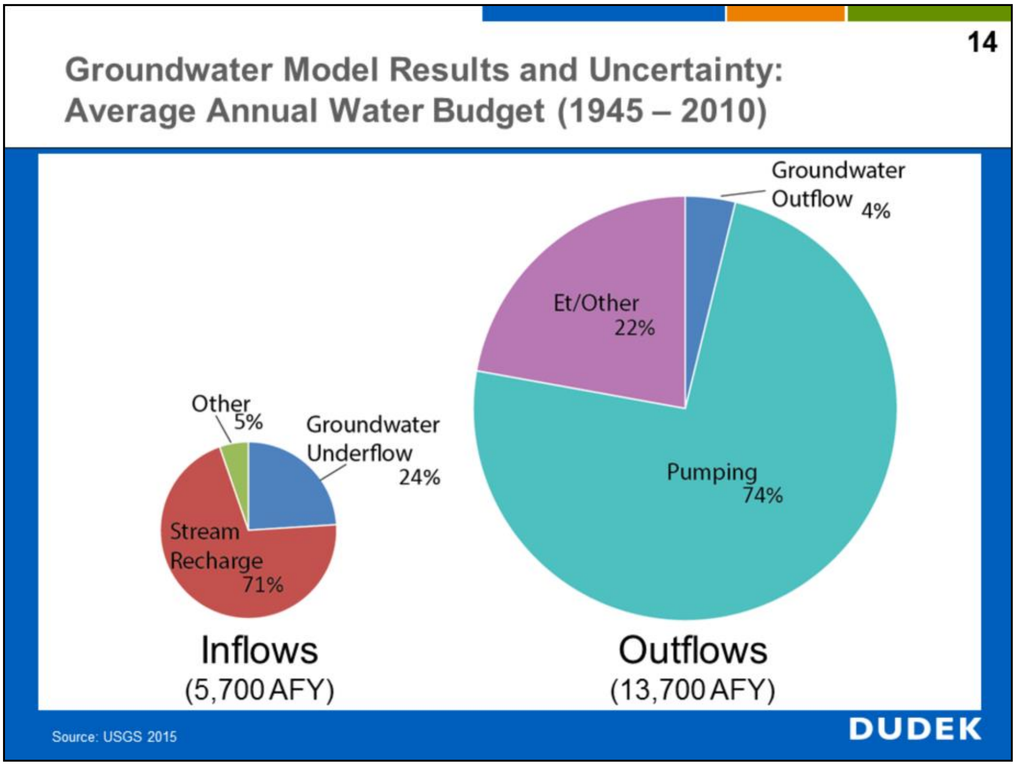
Water balance elements in the Basin Characterization Model (BCM) used in the BVHM include precipitation, runoff, recharge, and evapotranspiration. The BCM covers all of the California hydrologic region, with inputs for the Borrego Valley Hydrologic Model (BVHM) extracted from the larger BCM.

The BCM watershed model encompasses a larger area than the groundwater model. Runoff from the surrounding watershed enters the model in specific cells Not all streams and arroyos have stream gauges to calibrate model estimated runoff.



Charts showing average annual groundwater inflows and outflows in the Basin as calculated by the model for the period from 1945 to 2010. The inflows are the estimated natural recharge calculated by the USGS by running the model without any anthropogenic inputs. The average outflow over the period exceeds the average inflow by ~8,000 acre-feet per year. The average outflow for the last 20 years of the model run (1990-2010) is much higher (~17,300 acre feet per year). The average outflow for the last 10 years of the model run (2000-2010) is ~18,500 acre-feet per year, with average pumping of ~17,000 acre-feet per year (~93% of total groundwater outflow).

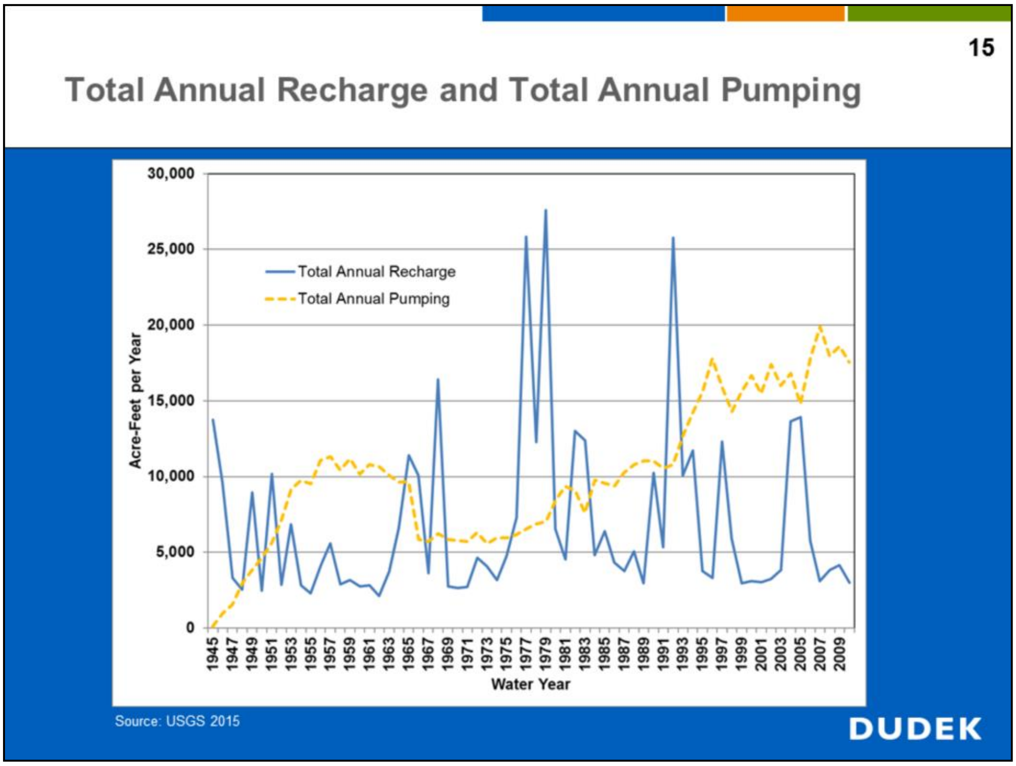
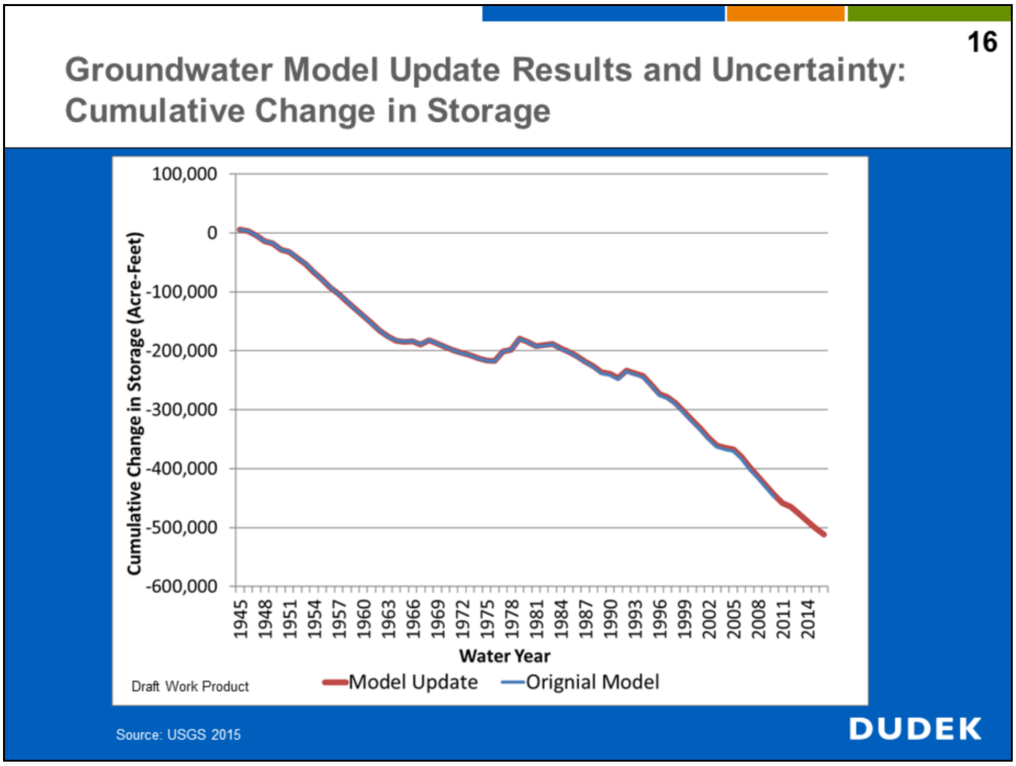


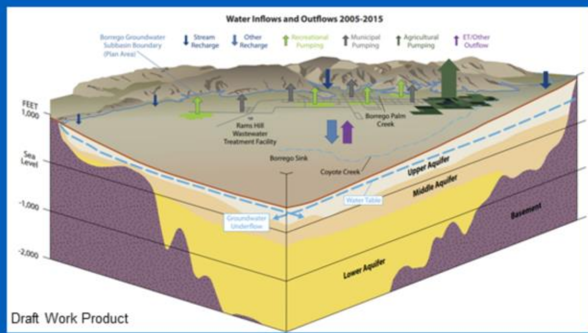
Chart showing total annual pumping and total annual recharge from USGS Borrego Valley Hydrologic Model (BVHM) (1945-2010). In most years, total pumping exceeds total recharge. Pumping has increased nearly every year since the 1960s, with pumping nearing 20,000 acre-feet per year in the mid-2000s.



Cumulative change in storage in the Borrego Valley Subbasin from 1945 to 2016. The updated model simulating conditions from 2011 to 2016 indicates a continuing decline in storage as more water is removed from the basin than enters it.

Hydrogeologic Conceptual Model

- **Hydrogeologic Conceptual Model**
  - **Updated with the following:**
    - **Current groundwater level data**
    - **Precipitation and evapotranspiration**
    - **Land use type**
    - **Stream flow**
    - **Pumping**
    - **Septic System Return Flows**



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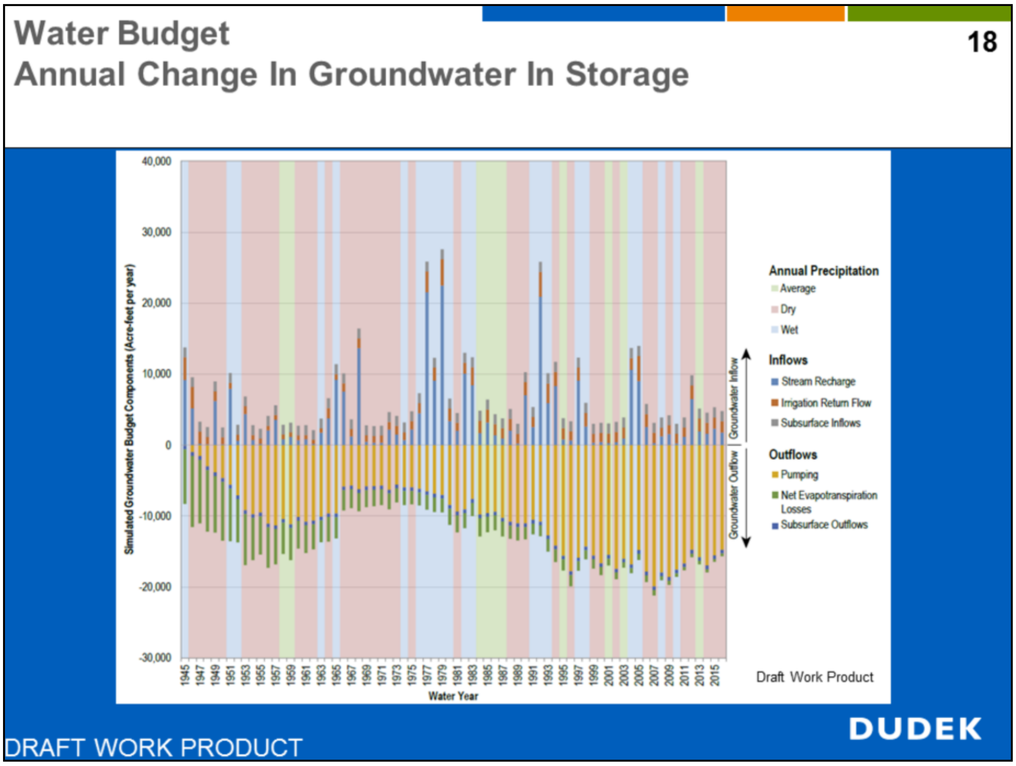
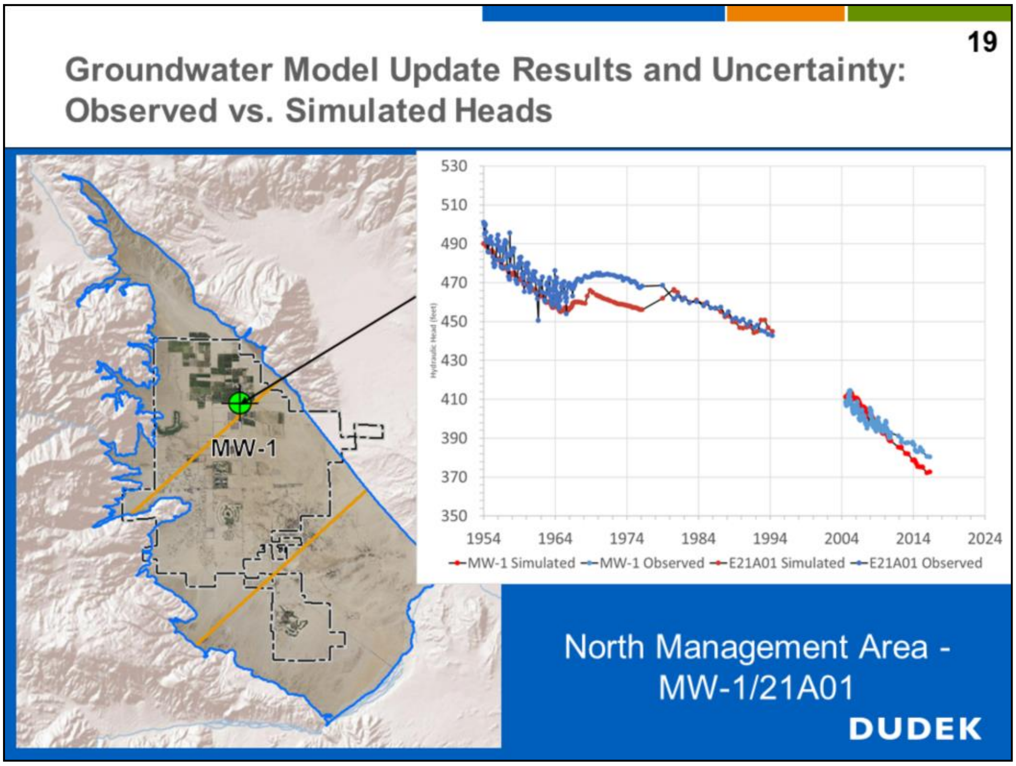
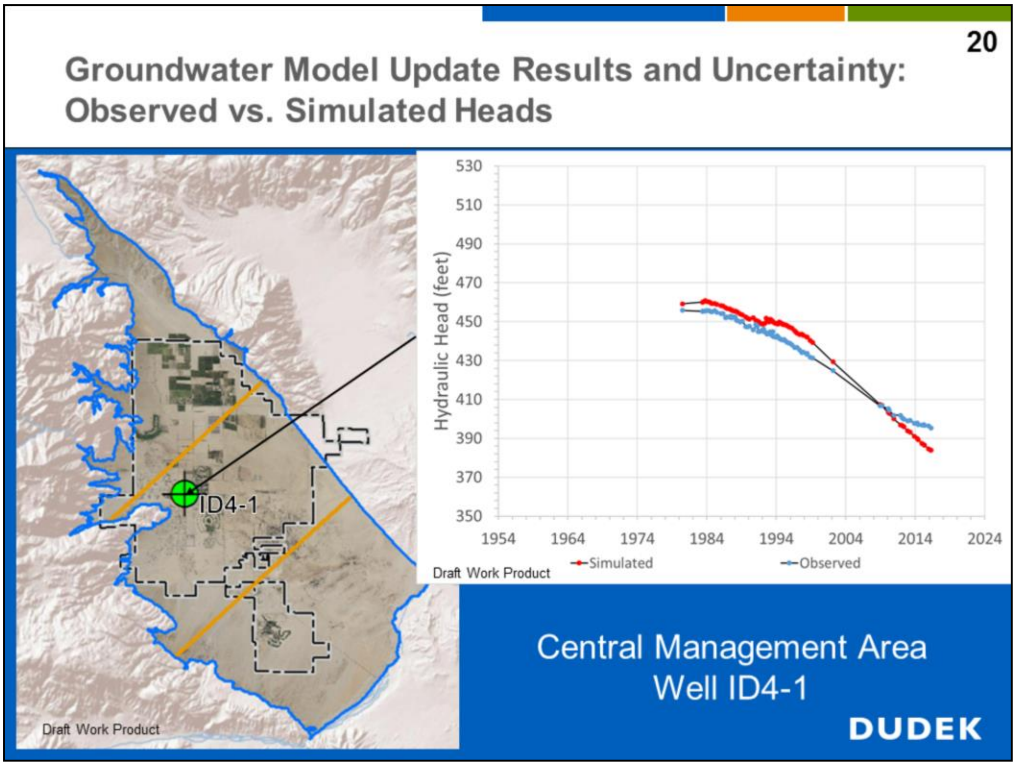
The hydrogeologic conceptual model (HCM) provides the framework for the development of water budgets, analytical and numerical models, and monitoring networks. Additionally, the HCM serves as a tool for stakeholder outreach and communication, and assists with the identification of data gaps. A HCM differs from a mathematical (analytical or numerical) model in that it does not compute specific quantities of water flowing through or moving into or out of a basin, but rather provides a general understanding of the physical setting, characteristics, and processes that govern groundwater occurrence and movement within the basin. The graphic presents the HCM developed for the Plan Area, which depicts basin boundaries, stratigraphy, land use, and a conceptual depiction of inflows and outflows from the Borrego Springs Subbasin. The HCM has been updated with current groundwater level data, climate data, land use data, stream flow data, extraction data and septic system return flows.



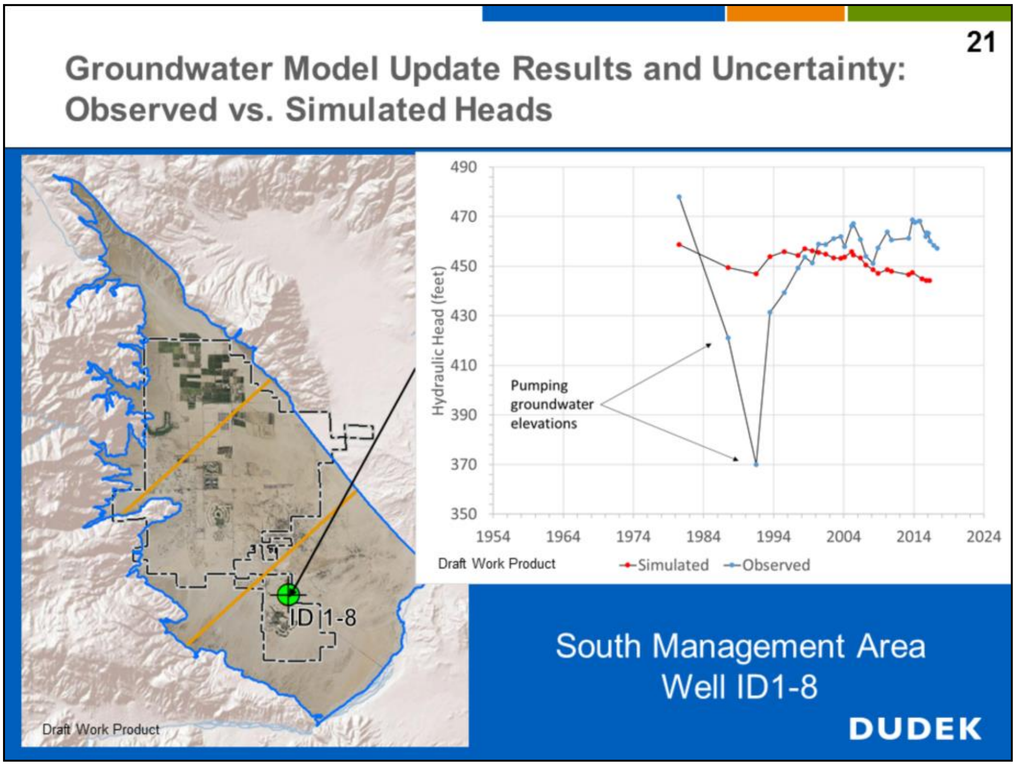
The water budget for the basin provides an accounting and assessment of the average annual volume of groundwater and surface water entering and leaving the basin. It includes information on the historical and current water budget conditions, as well as the change in the volume of water stored. The water budget provides detail sufficient to build local understanding of how historical changes to supply, demand, hydrology, population, land use, and climatic conditions have affected the applicable sustainability indicators in the basin. This information is used to predict how these same variables may affect or guide future management actions. Building a coordinated understanding of the interrelationship between changing water budget components and aquifer response will allow the GSA to effectively identify future management actions and projects most likely to achieve and maintain the sustainability goal for the basin. Annual change in storage estimated using the USGS groundwater numerical model, and is shown in the above figure. For the period of model simulation, including the model update (1945 through 2016), the annual change in storage ranged from a decrease in storage of approximately 18,000 AF in 2006 to an increase in storage of approximately 18,100 AF in 1978 (wet year). On average, the Subbasin lost approximately 7,300 AFY from storage for the period between 1945 and 2016. When considering the average over the last 10 years only, the average loss increases to 13,137 AFY. Refinement to the water budget will occur during GSP implementation based on actual metered data and other inflow/outflow components. For instance, the maximum pumping in the numerical model is 20,000 AFY in 2007, which is less than the current estimated baseline pumping allocation of 22,044 AFY.



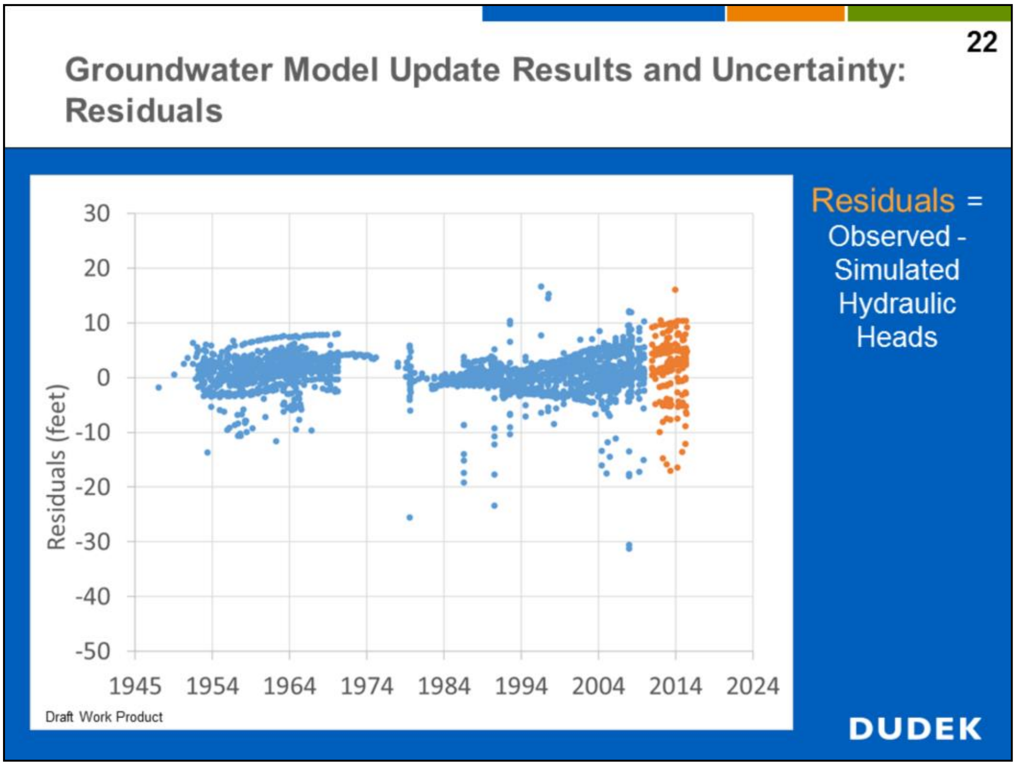
This chart shows a comparison between observed (i.e., measured) and simulated groundwater levels at well MW-1 in the North Management Area. The model simulates the general declining trend in groundwater level observed at this well.



This chart shows a comparison between observed (i.e., measured) and simulated groundwater levels at well ID4-1 in the Central Management Area. The model simulates the general declining trend in groundwater level observed at this well.



This chart shows a comparison between observed (i.e., measured) and simulated groundwater levels at well ID1-8 in the South Management Area. Further refinement of the model needed in this area to simulate the groundwater level fluctuations observed when the well pumps. Refinement may include additional data from aquifer testing.

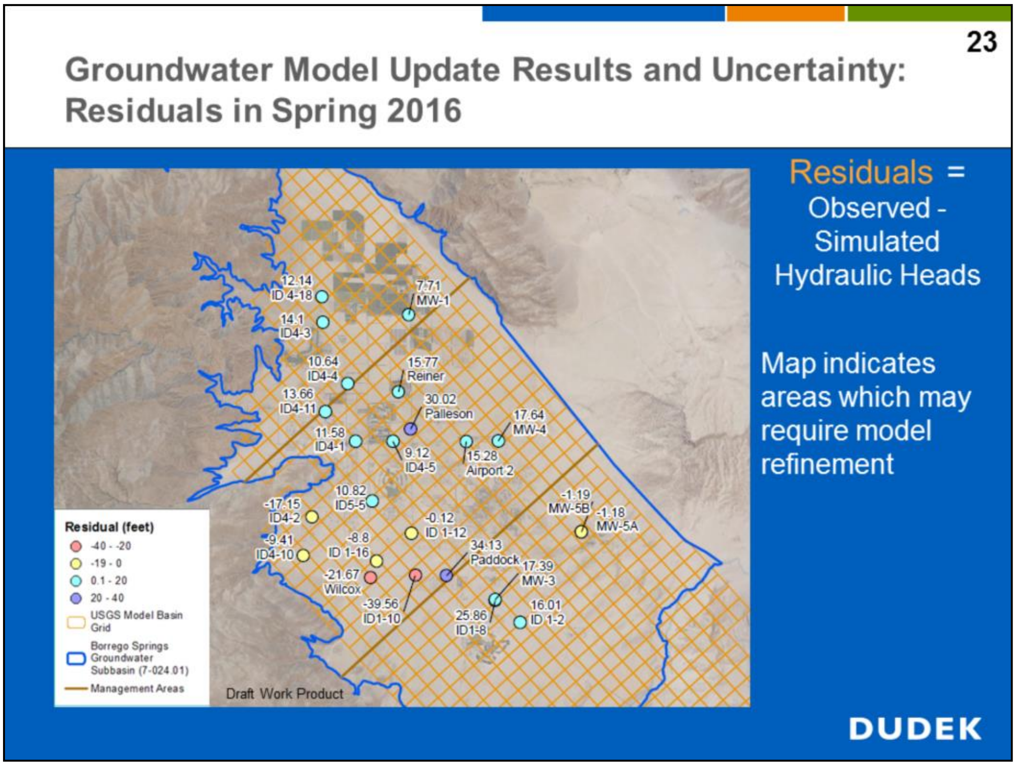


Slide comparing residual statistics. Orange shows model update and validation period from 2011 though water year 2016 (ending September 30, 2016). Positive numbers represent higher observed heads than simulated by the model, while negative numbers represent lower observed heads than simulated by the model. Overall, model does a relatively good job of simulating real world conditions.

Residuals 1945 to 2010: RMSE = 17.95 feet. Mean Residual = 2.41 feet.

Residuals 2011 to 2016: RMSE = 19.13 feet. Mean Residual = 6.62 feet.

RMSE = Root Mean Square Error



The model tends to predict lower groundwater levels than observed. In general, the model showed a slight bias towards lower modeled heads than observed heads in areas of intense pumping (i.e. the model is overestimating groundwater level decline in some areas of the aquifer). The model may overestimate groundwater level decline in the basin because it is overestimating pumping, underestimating recharge, underestimating water stored in the aquifer, or some combination of these three factors. While model calibration and validation indicated a tendency of the model to simulate lower heads than those observed in the basin, additional data is needed to determine which model inputs are responsible for this model bias.

USGS Model Sensitivity Results

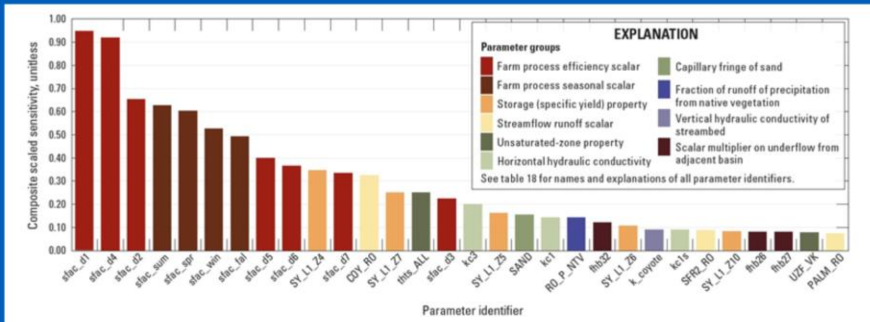


Figure 46. Most sensitive parameters for the Borrego Valley Hydrologic Model, Borrego Valley, California.

Source: USGS 2015

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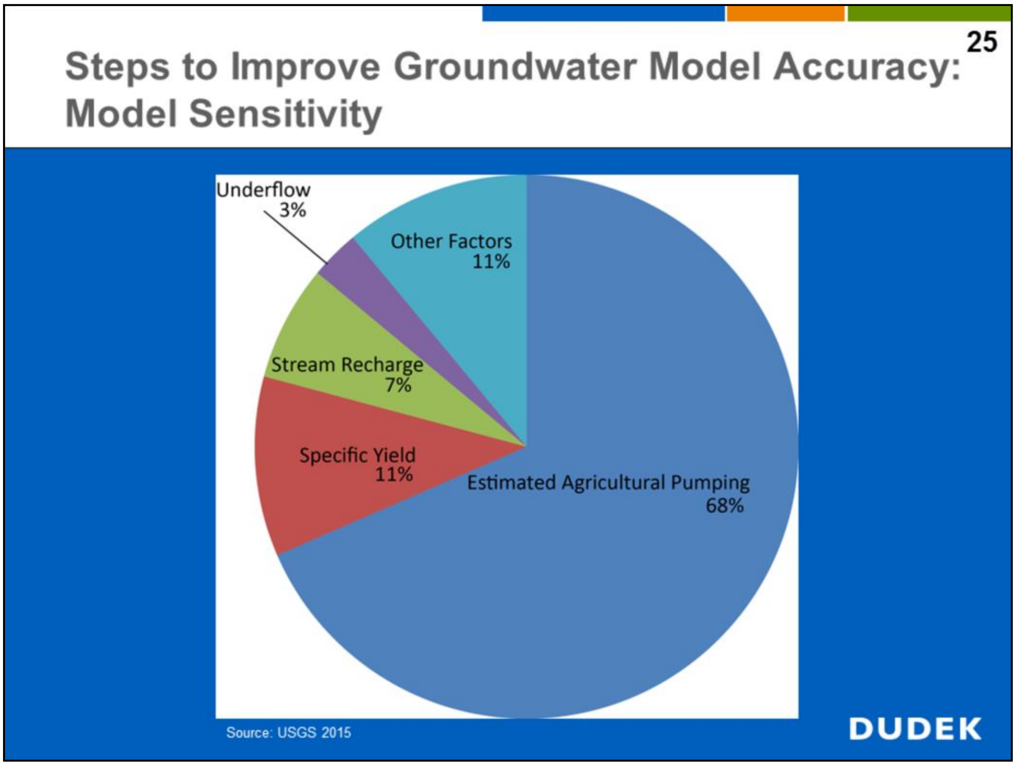
Figure showing the results of the USGS sensitivity analysis for their BVHM model calibration. The larger the bar, the more sensitive the model is to the parameter. The sensitivity analysis shows the model is most sensitive to Farm efficiency factors and farm seasonal processes (used in calculating water demand) and specific yield.



USGS analysis indicated that the model performance is most sensitive to estimated agricultural pumping (68%), specific yield (11%), stream recharge (7%), underflow (3%) and other factors (11%). Other factors include, but are not limited to, unsaturated flow, hydraulic conductivity, and capillary fringe effects.

The biggest reduction in uncertainty can be gained by using metered pumping for irrigated fields.

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Steps to Improve Groundwater Model Accuracy: Recommendations to Refine Model

- Dudek proposes incorporating new data to refine the numerical model and reduce uncertainty over next 5 years
- Three main areas to refine:
  - **Pumping** – Model estimates agricultural pumping using Farm Process. Metered agricultural pumping may markedly reduce uncertainty in model simulations
  - **Specific Yield** – Future aquifer tests will refine aquifer storage properties in the model
  - **Recharge** – The addition of stream gauges in distinct areas within the Basin will refine recharge estimates and reduce uncertainty

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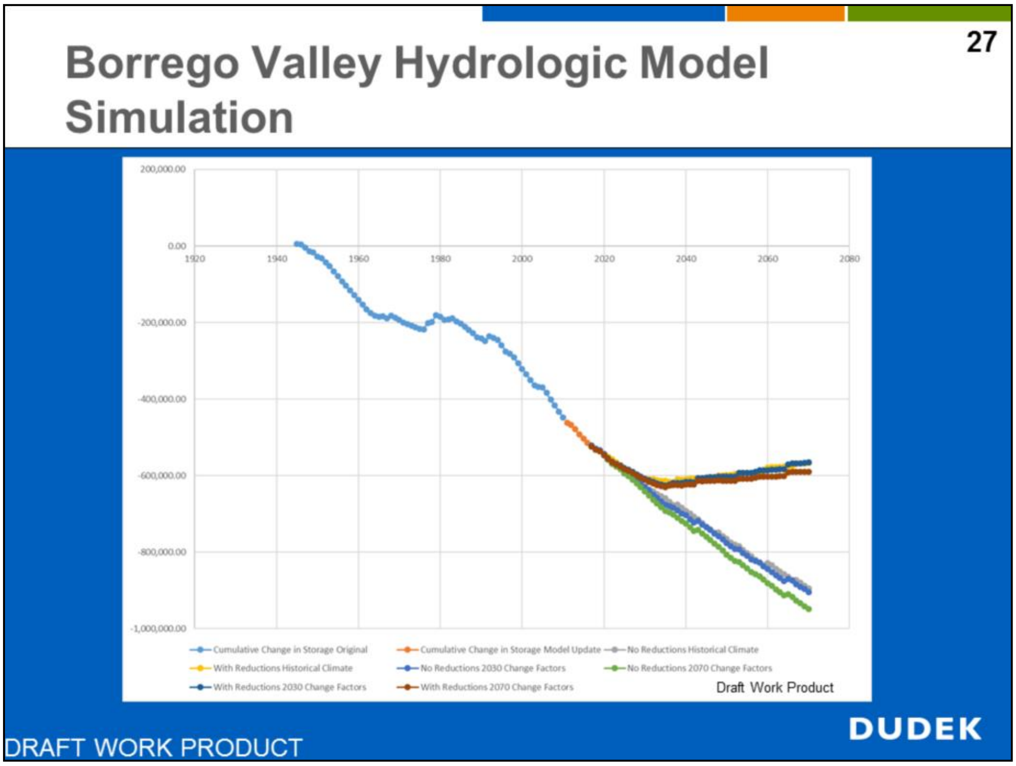
No additional notes.



Preliminary Model Runs Addressing Future Climate and Pumping Reductions: This chart shows the cumulative change in storage for the entire Borrego Basin for several model runs. The cumulative change in storage from the original USGS model run (1945 through 2010) is shown on the figure in blue and labeled as “Cumulative Change in Storage Original”. The cumulative change in storage for the model update (2011 through 2016) is shown in red and labeled “”Cumulative Change in Storage Model Update”. In addition, the model was run to address six different future scenarios. Future scenarios can be divided into two groups: 1) pumping remains the same as current levels (labeled “No Reductions”), and 2) A linear or fixed reduction in pumping from current levels to a target of 5,700 AFY between 2020 and 2040 (labeled “With Reductions”). Due to model limitations, the actual pumping from 2040 through 2070 averages approximately 5,500 AFY, 200 AFY less than the target of 5,700 AFY. Three potential climate scenarios were run for each of the scenarios: 1) Historical climate from 1960 through 2010 was repeated for the period 2020 through 2070 (labeled “Historical Climate”, 2) DWR change factors for projected climate conditions in 2030 were applied to the historical period from 1960 through 2010 following the procedures outlined in the DWR climate guidance for GSPs (labeled “2030 change factors”), and 3) DWR change factors for projected climate conditions in 2070 were applied to the historical period from 1960 through 2010 following the procedures outlined in the DWR climate guidance for GSPs (labeled “2070 change factors”). Results indicate that 5,700 AFY appears to be a reasonable target for sustainability, and that changes in climate have a small impact on storage in the basin when compared to changes in pumping and historical variability in 20-year recharge.