1st GSA Summit
June 6-7, 2018

Addressing Uncertainty in GSP Development

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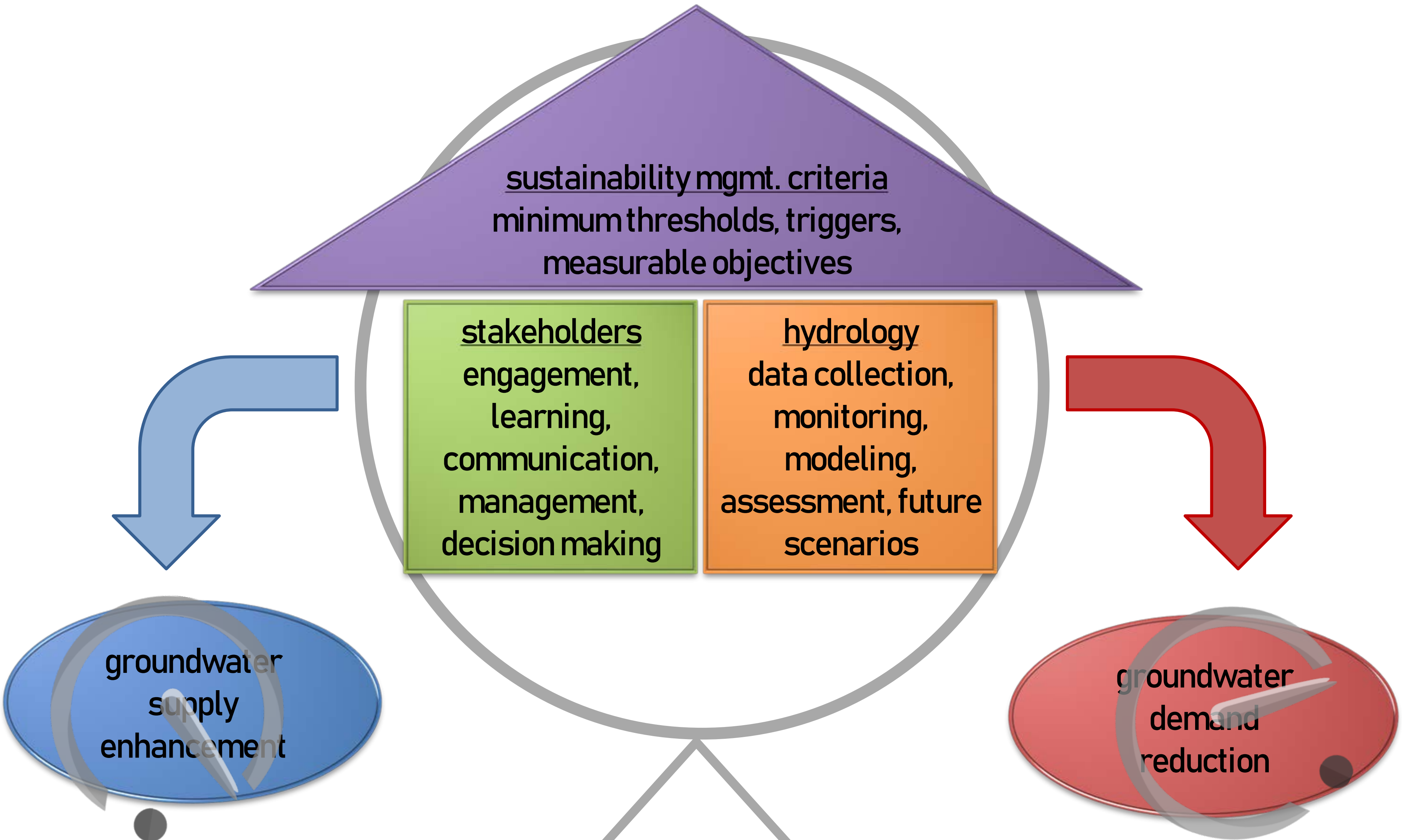
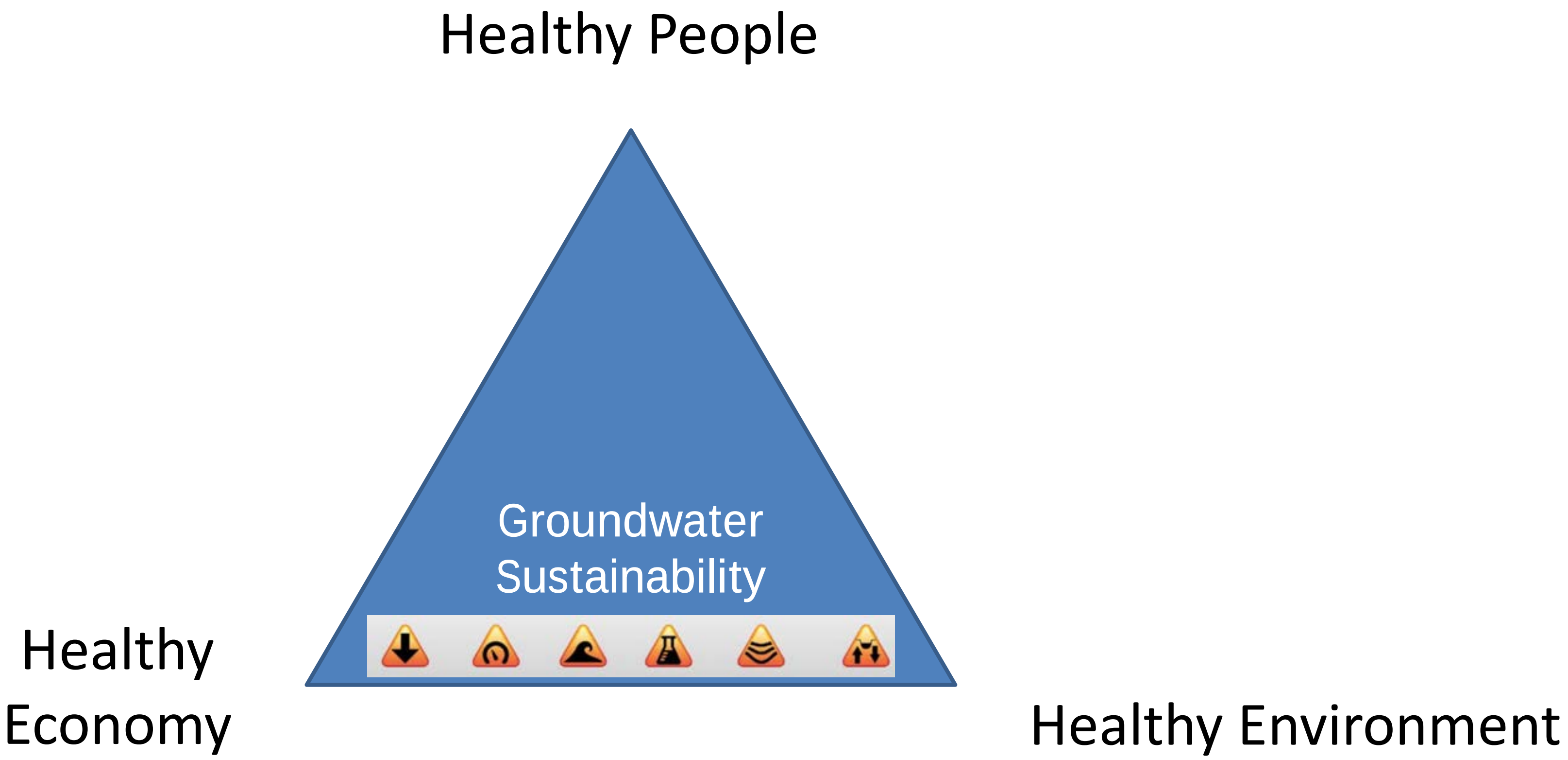
The Key Elements of Groundwater Sustainability Plans



Developing a GSP – An Optimization Problem

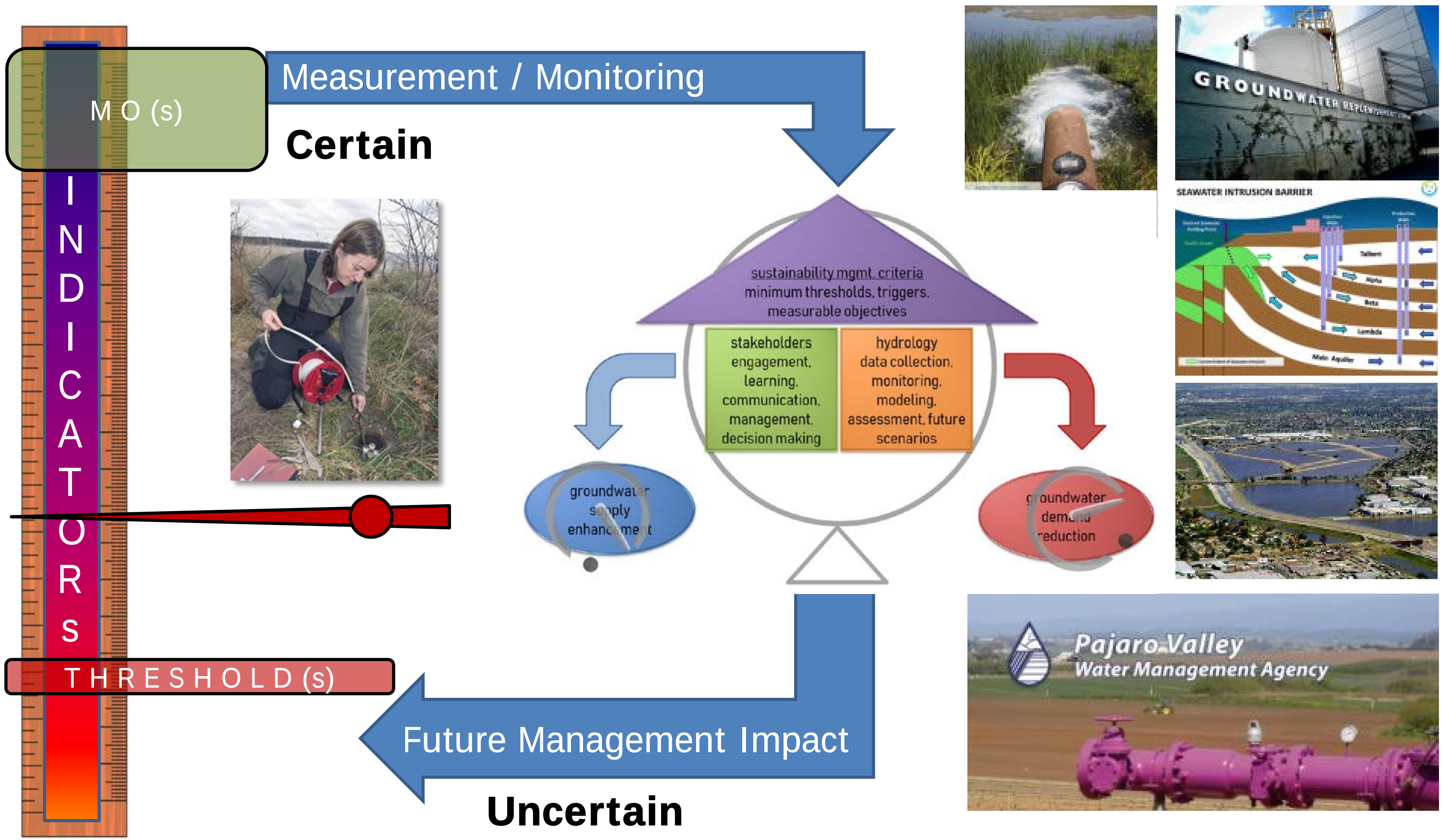


Adopted from: Marylou Shockley, CSU Monterey Bay

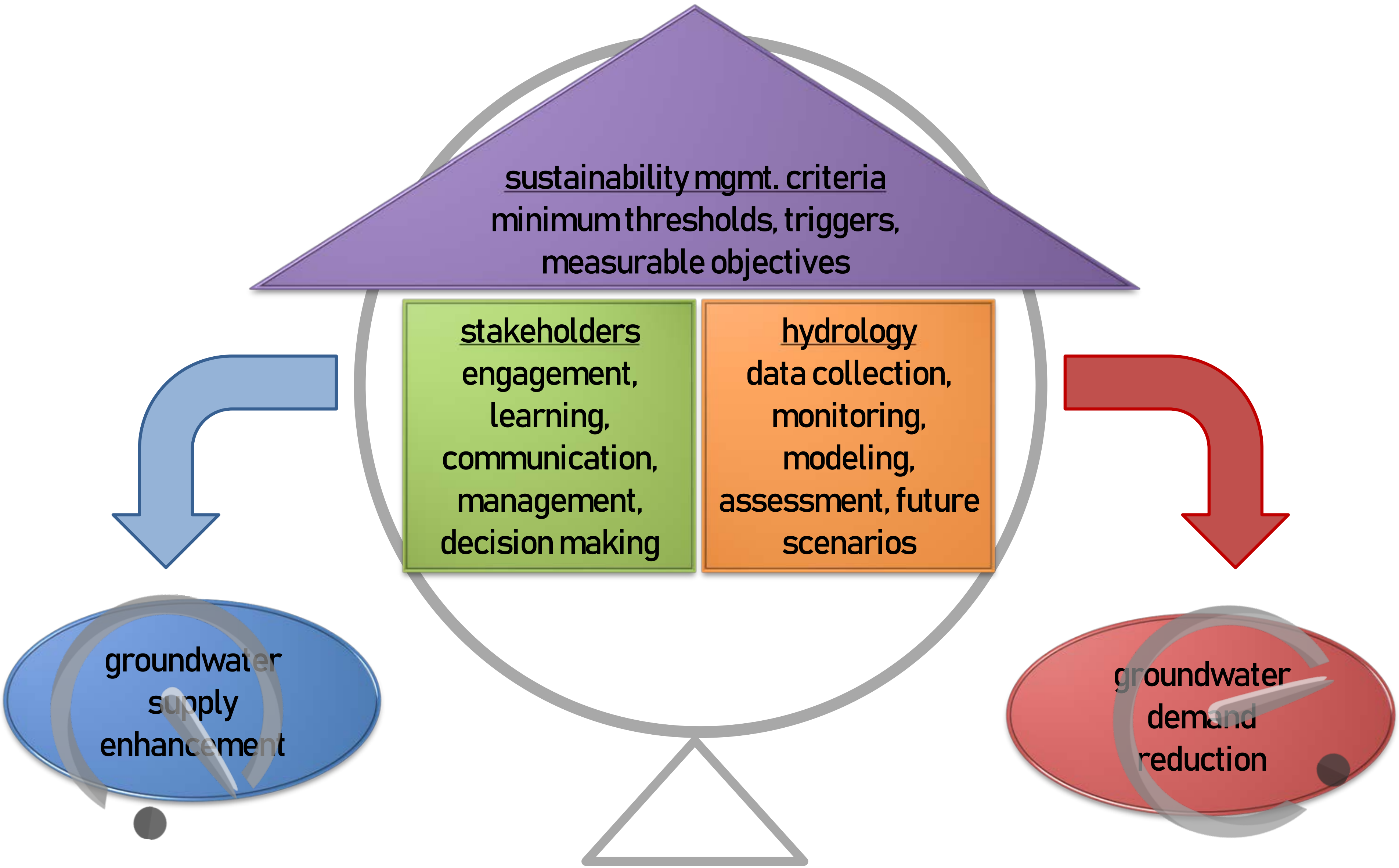
Combating Uncertainty: Adaptive Management

Wikipedia

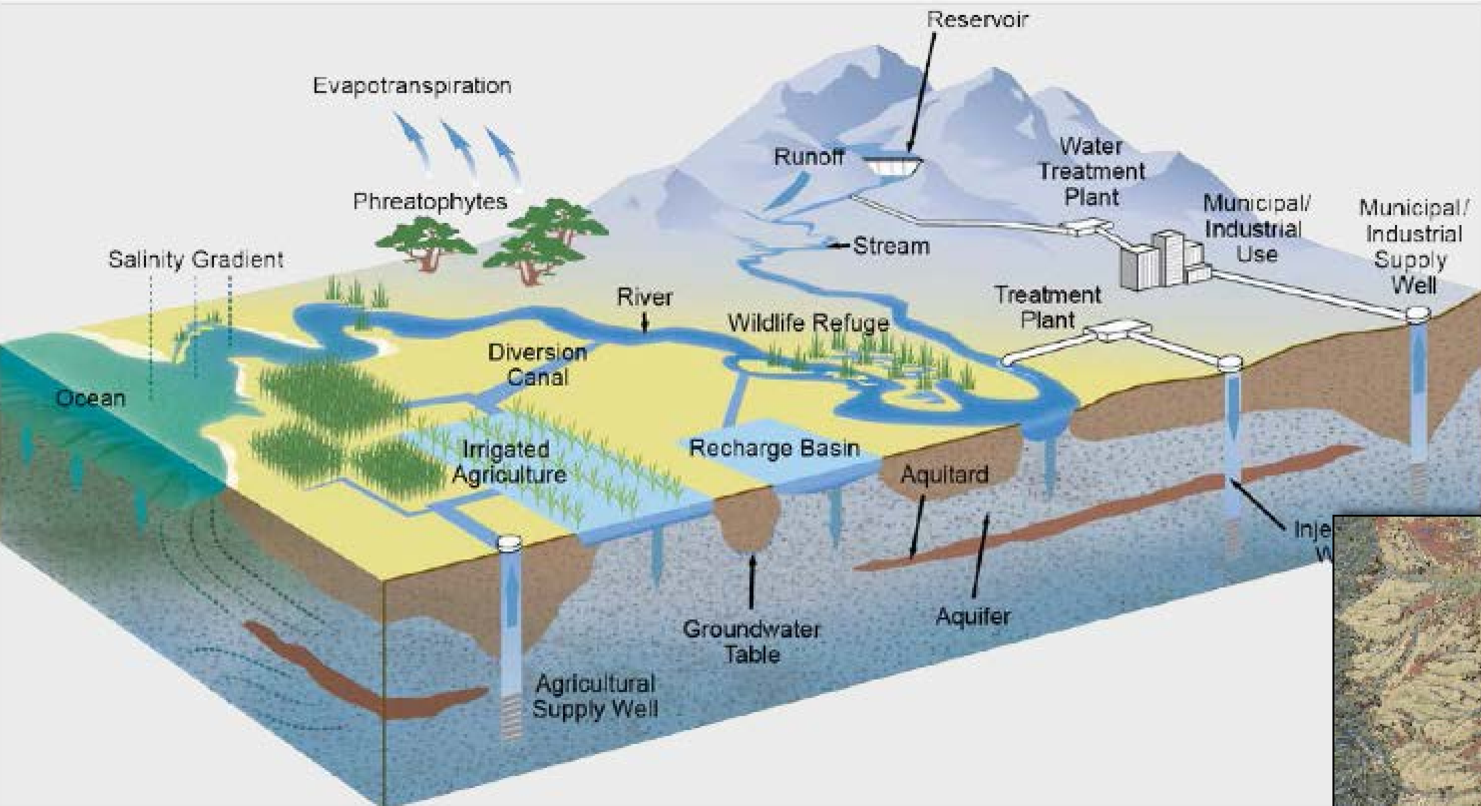
Performance Measures and GSP Implementation

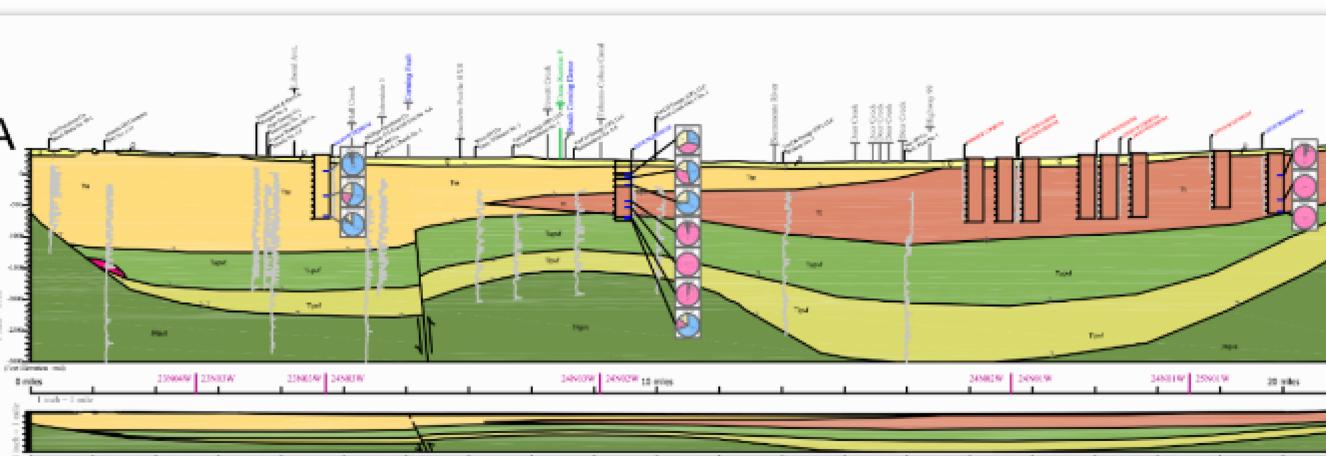


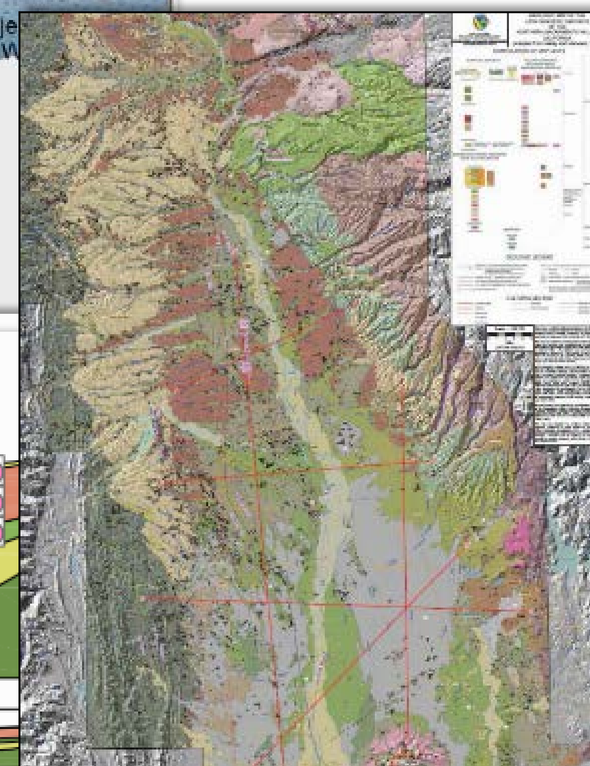
The GSA world of uncertainty



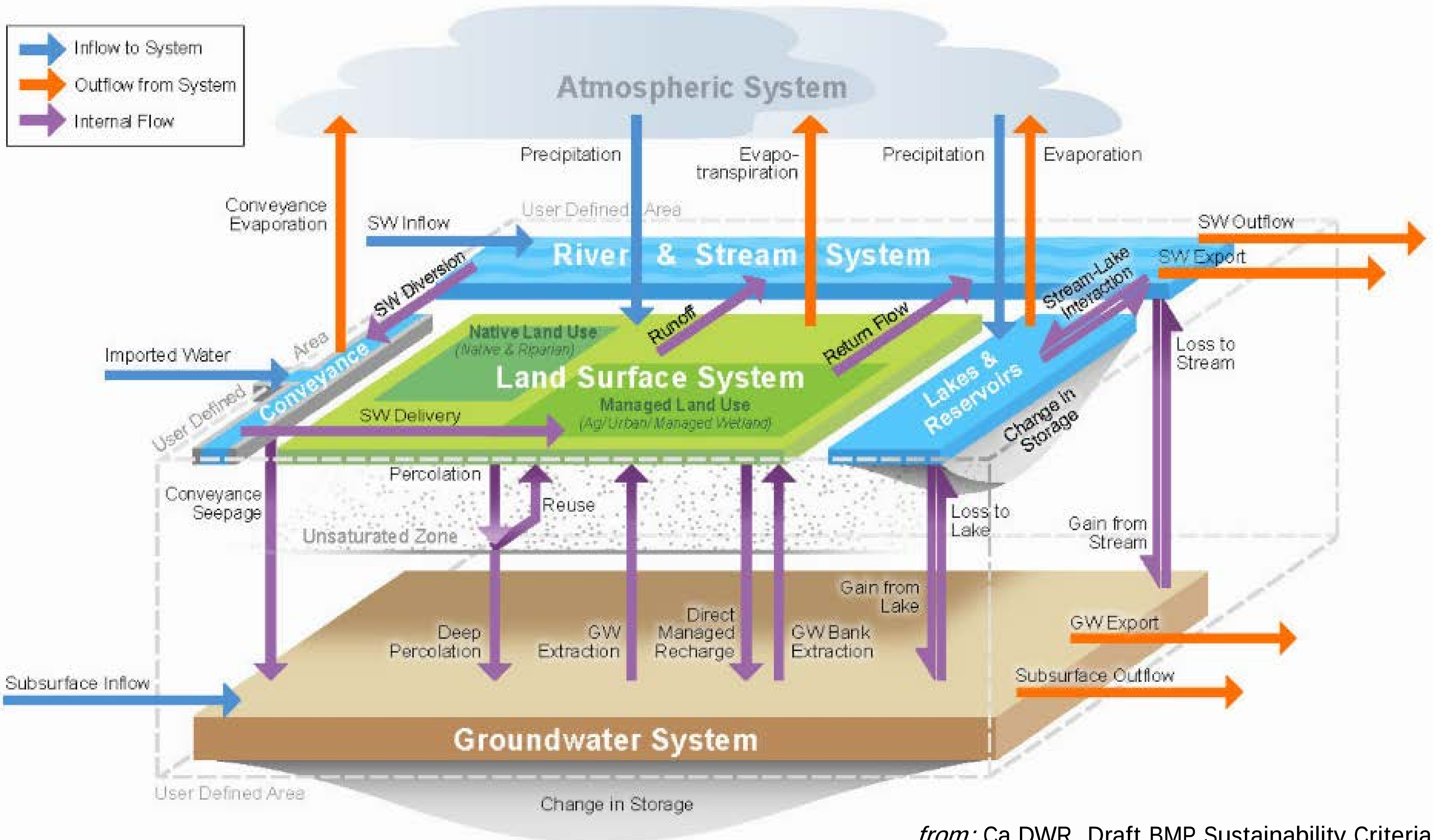
Uncertainty: Hydrologic Conceptual Models





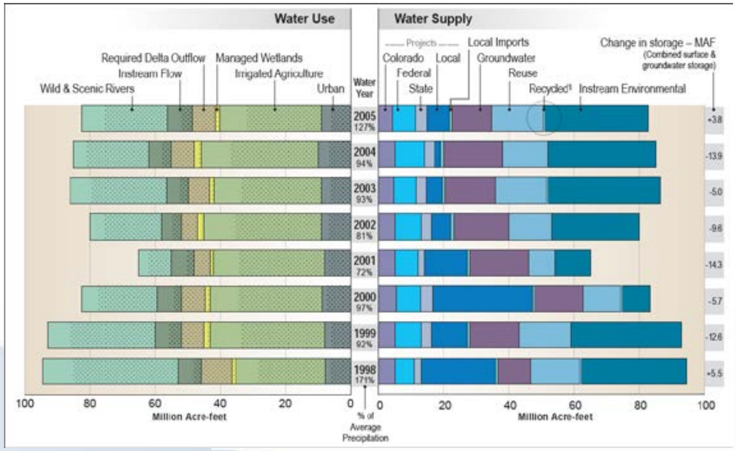


Uncertainty: Water Budget

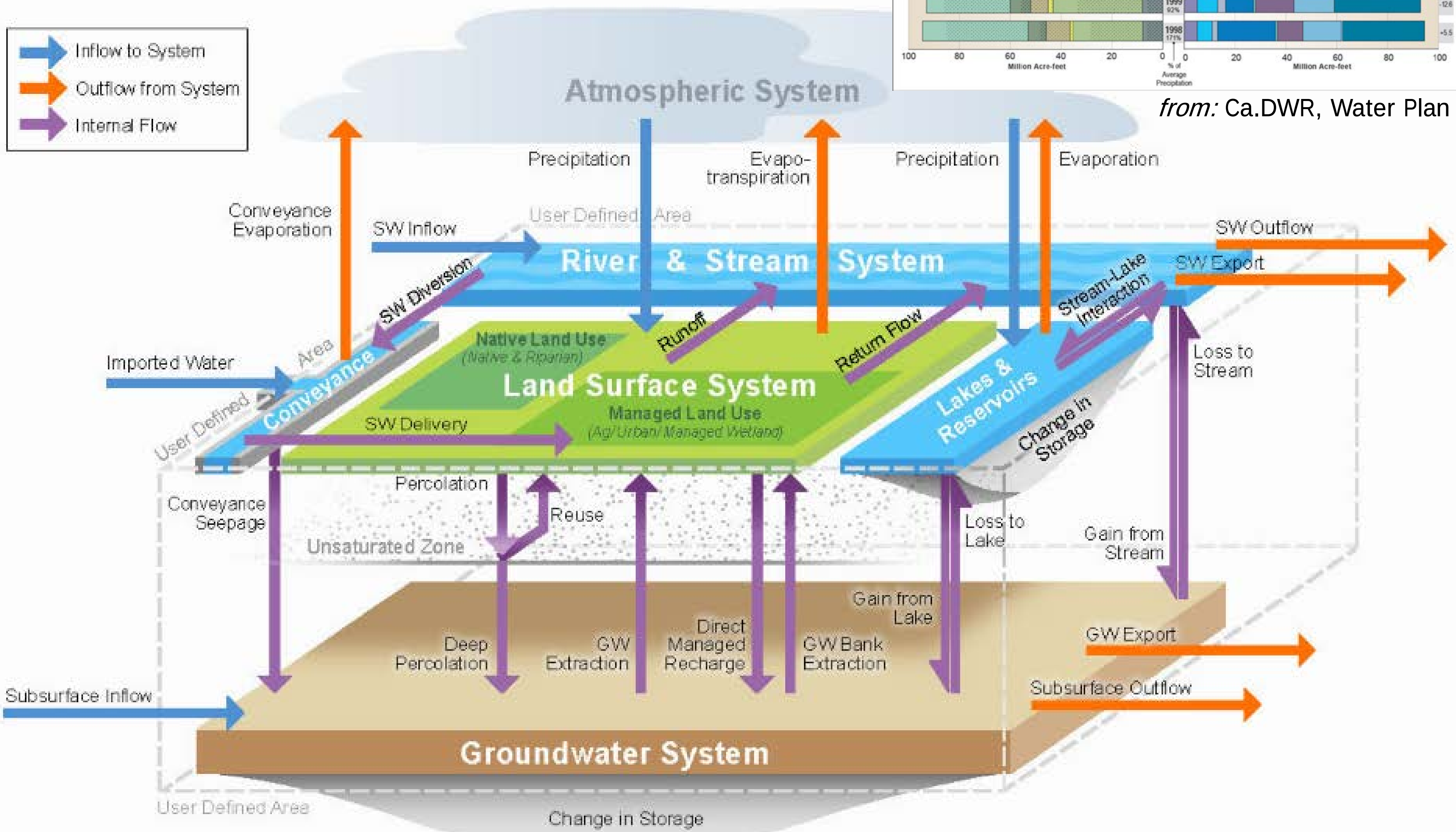


from: Ca.DWR, Draft BMP Sustainability Criteria

Uncertainty: Water Budget

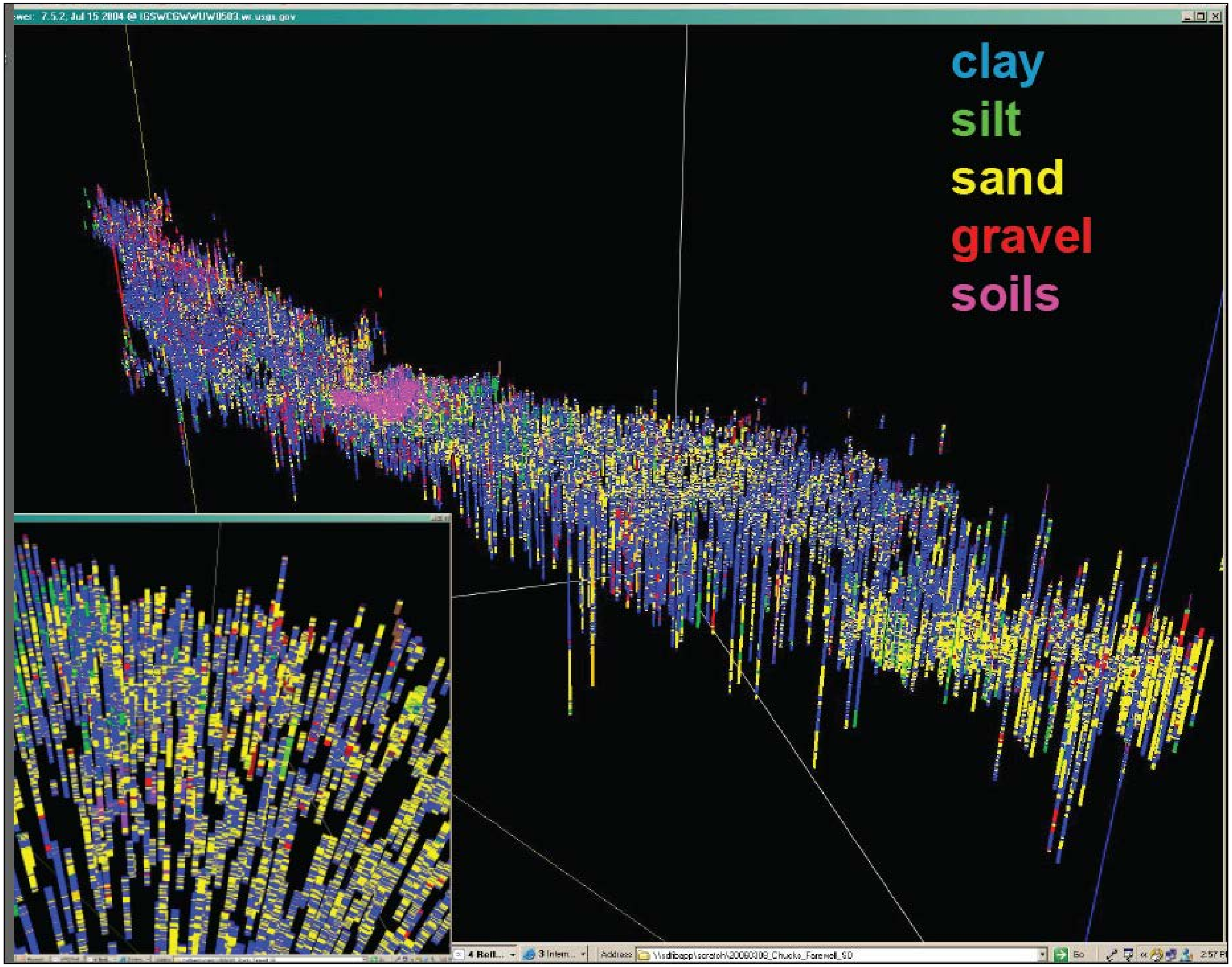


from: Ca.DWR, Water Plan



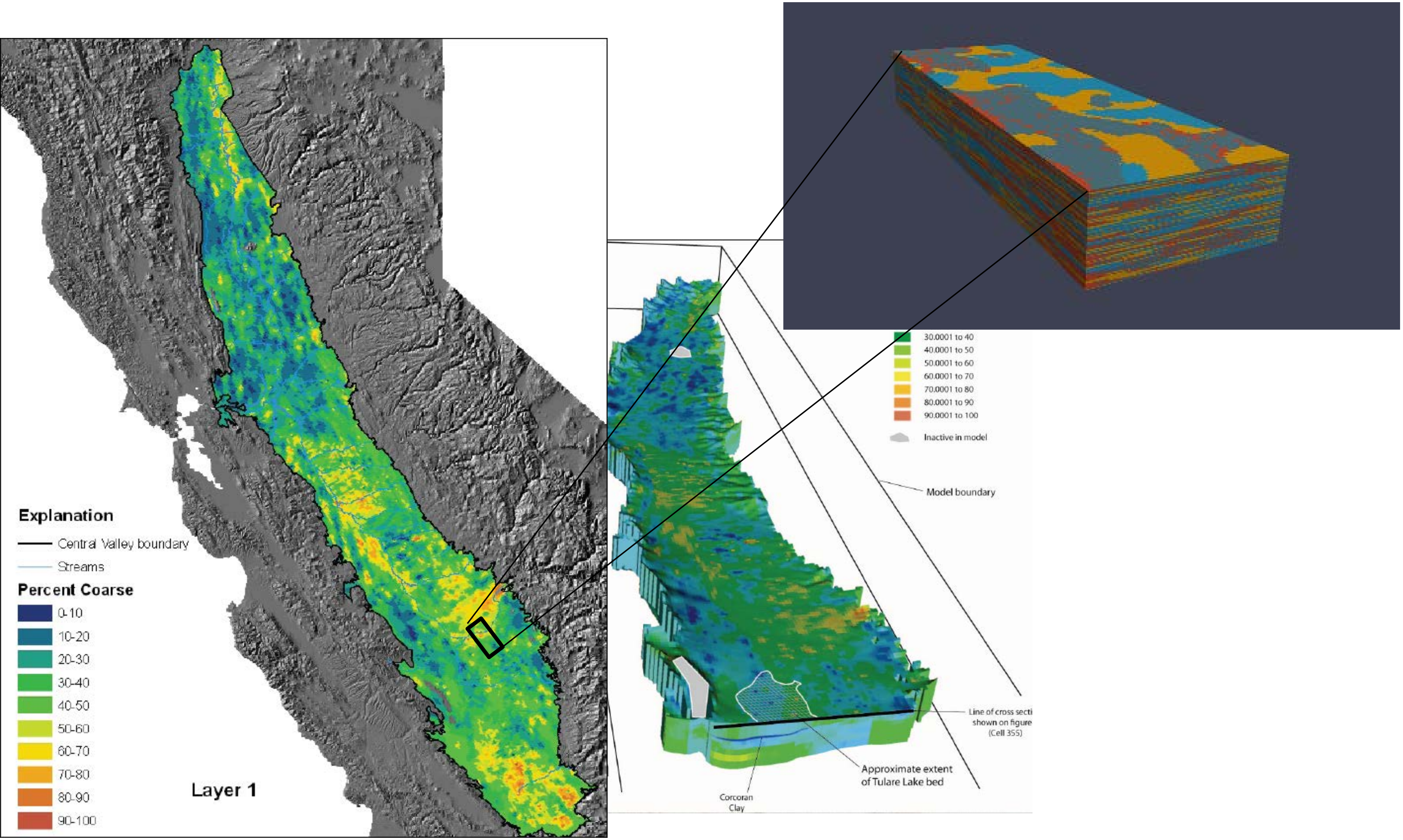
from: Ca.DWR, Draft BMP Sustainability Criteria

Uncertainty: Groundwater Model Parameters



- Hydraulic conductivity
- Specific yield
- Elastic storage
- Inelastic storage
- Pre-consolidation head

Uncertainty: Groundwater Model Parameters



Faunt et al., USGS Professional Paper 1766, 2009

CERTAINTY: Principles of Groundwater Flow

- **Mass balance**:

  Inflow - Outflow = Change in Storage

- Conservation of Momentum:

  Darcy's Law: Flux = Hydraulic Conductivity x Hydraulic Gradient

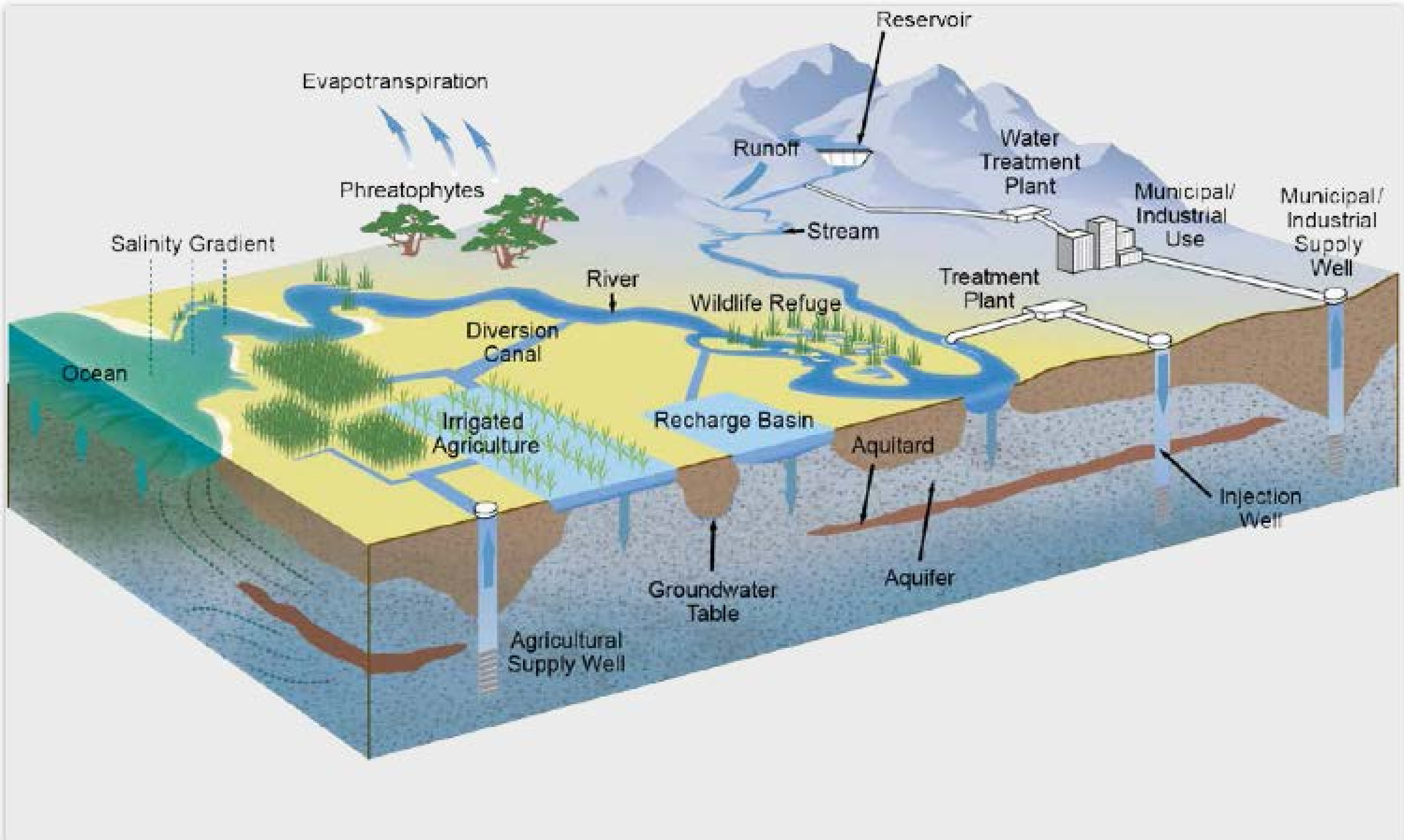
- Conservation of Momentum AND Mass Balance

  => groundwater flow equation:

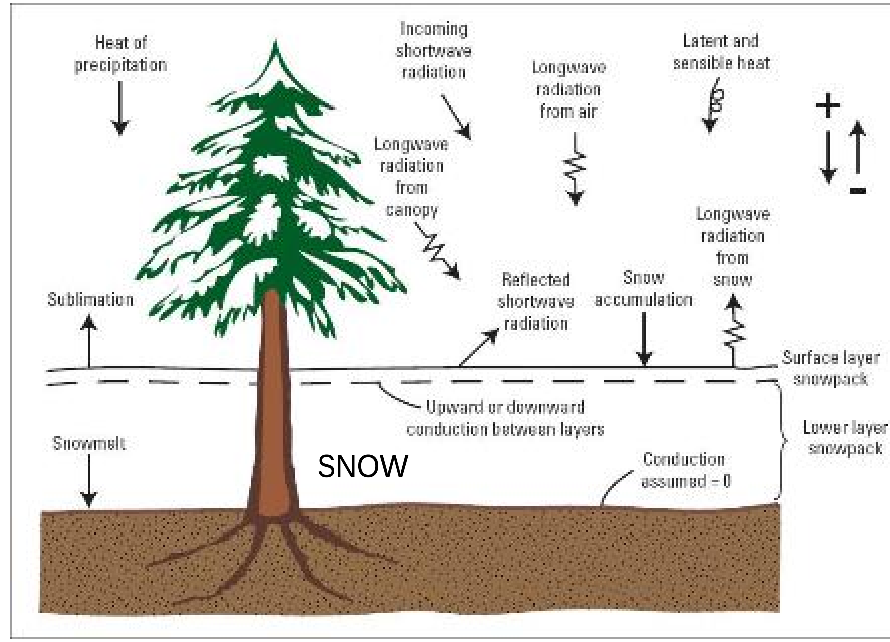
$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

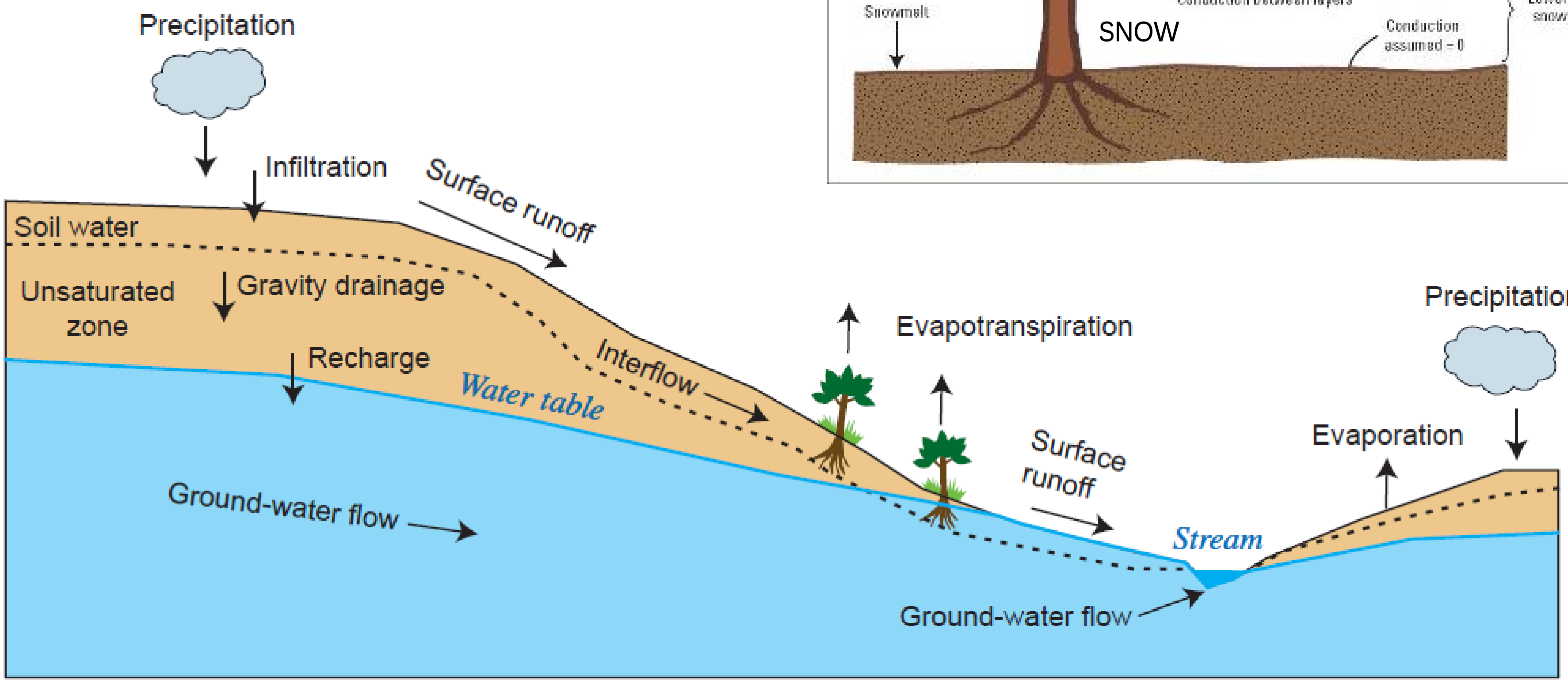
subject to initial conditions and boundary conditions

Uncertainty: Modeling Boundary Conditions & Integrated Hydrologic Modeling

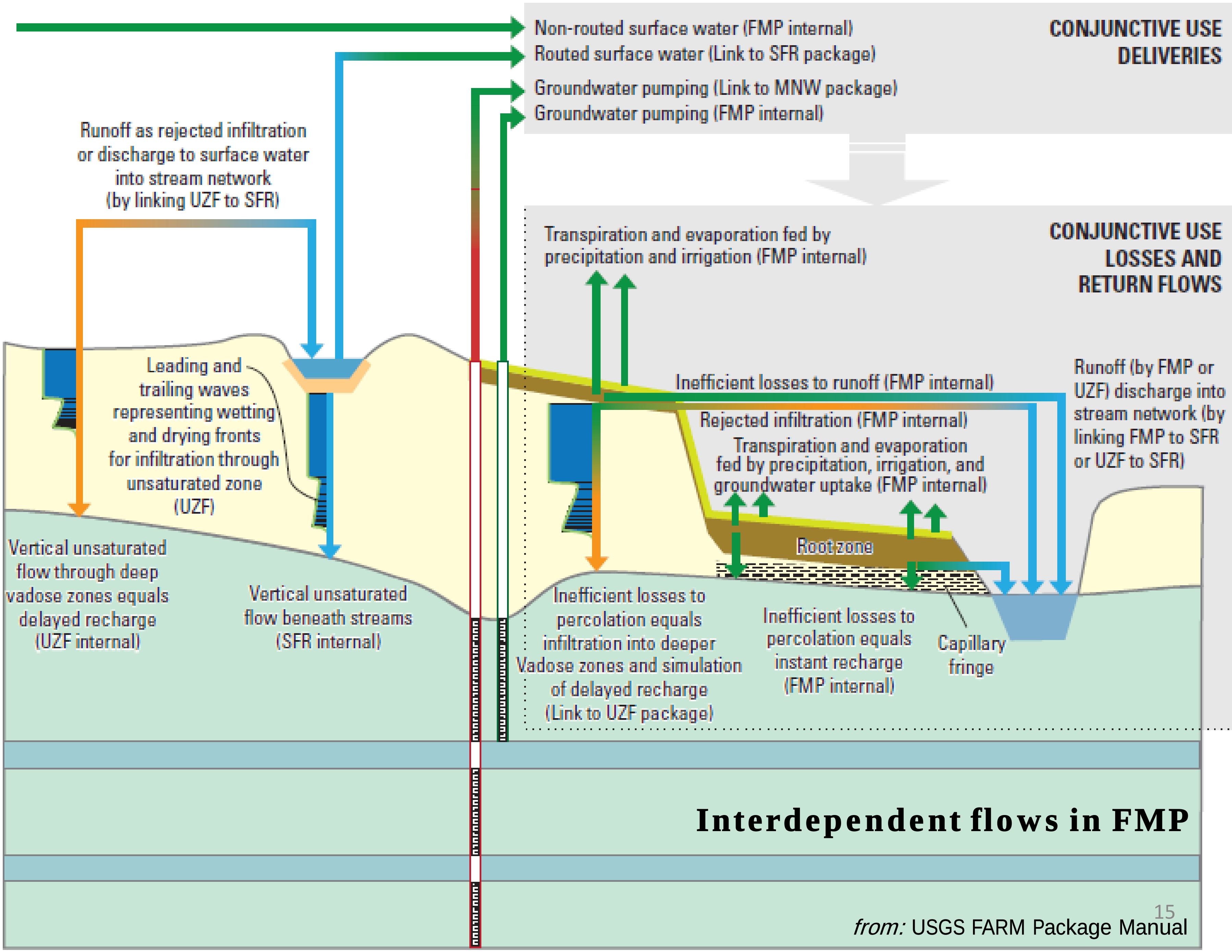


Uncertainty: Modeling Boundary Conditions





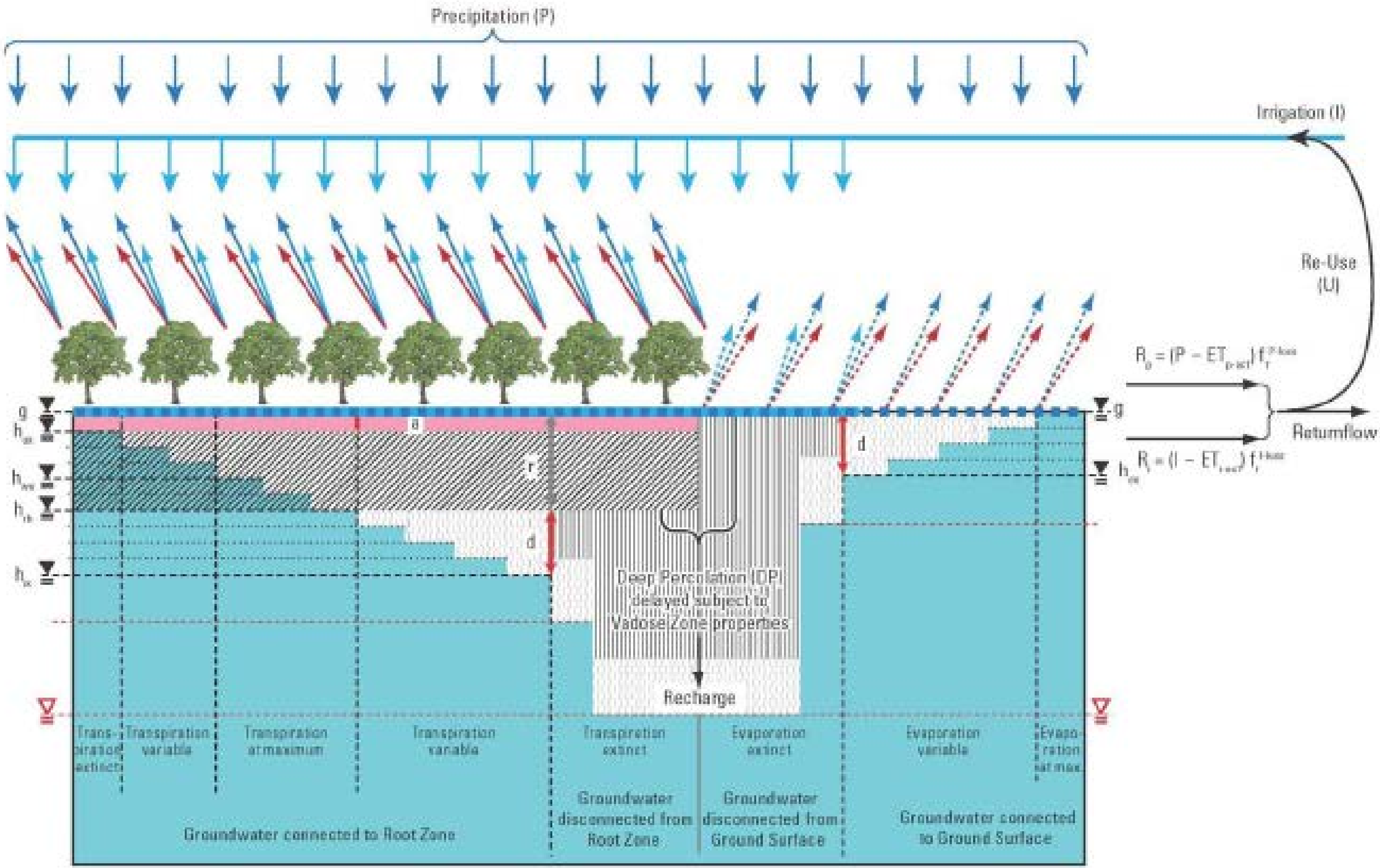
from: USGS GSFLOW Manual



Interdependent flows in FMP

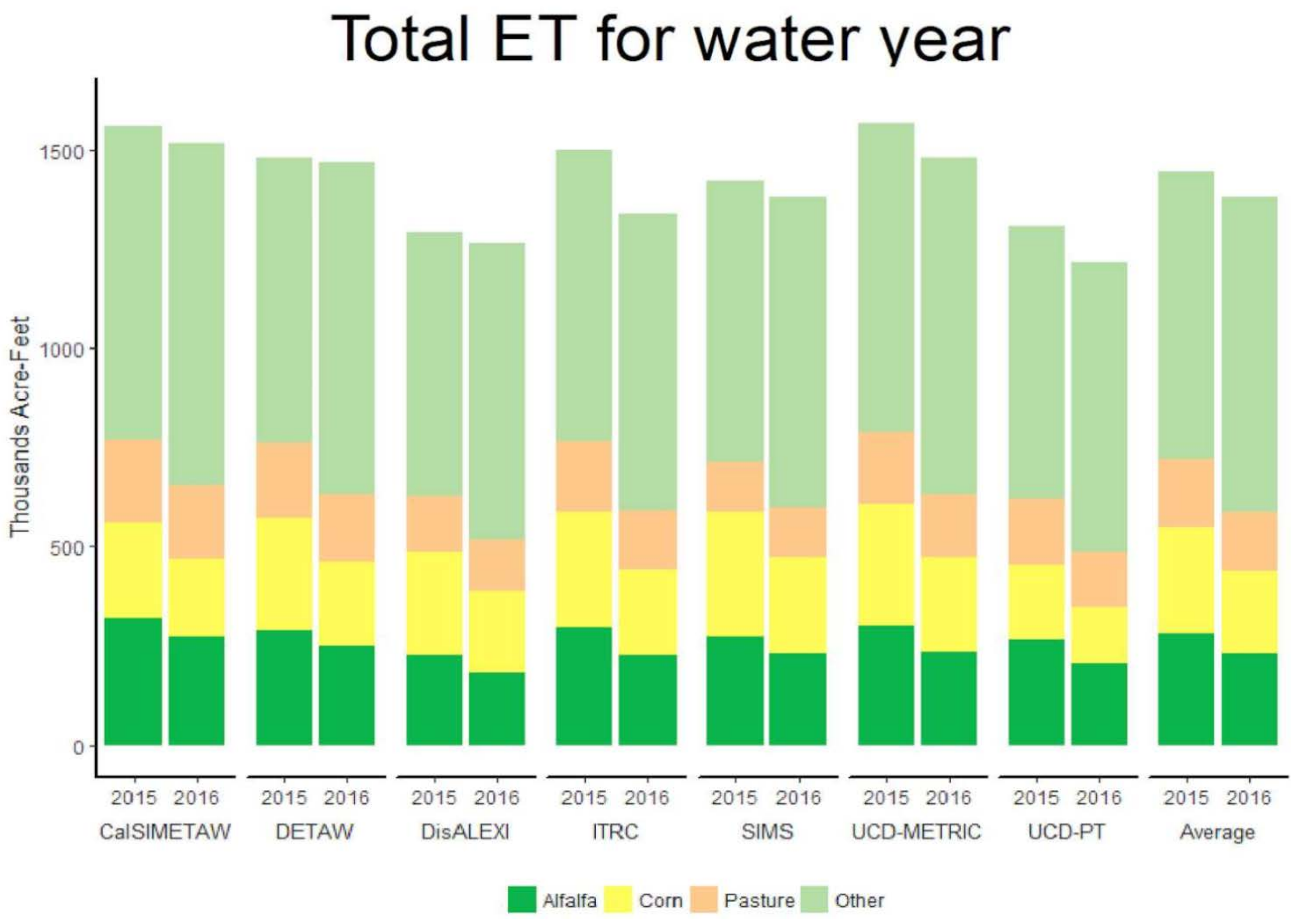
from: USGS FARM Package Manual

Uncertainty: Modeling Boundary Conditions



from: USGS FARM Package Manual

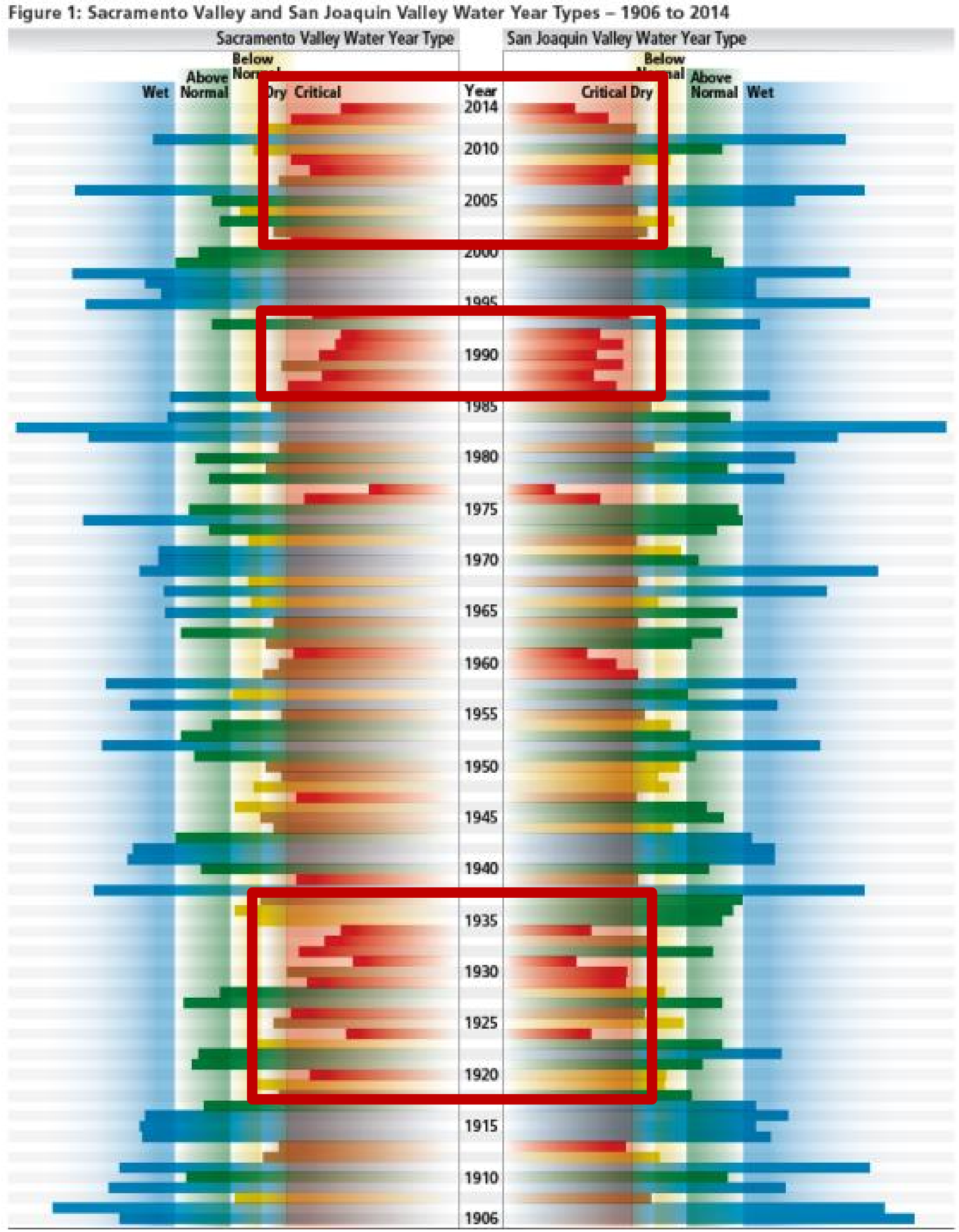
Uncertainty: Data for Modeling Boundary Conditions



Model Comparison of ET Estimates in the Sacramento-San Joaquin Delta (Center for Watershed Sciences, UC Davis, 2018)
https://californiawaterblog.com/2018/04/23/modeling-measuring-and-comparing-crop-evapotranspiration-in-the-delta/

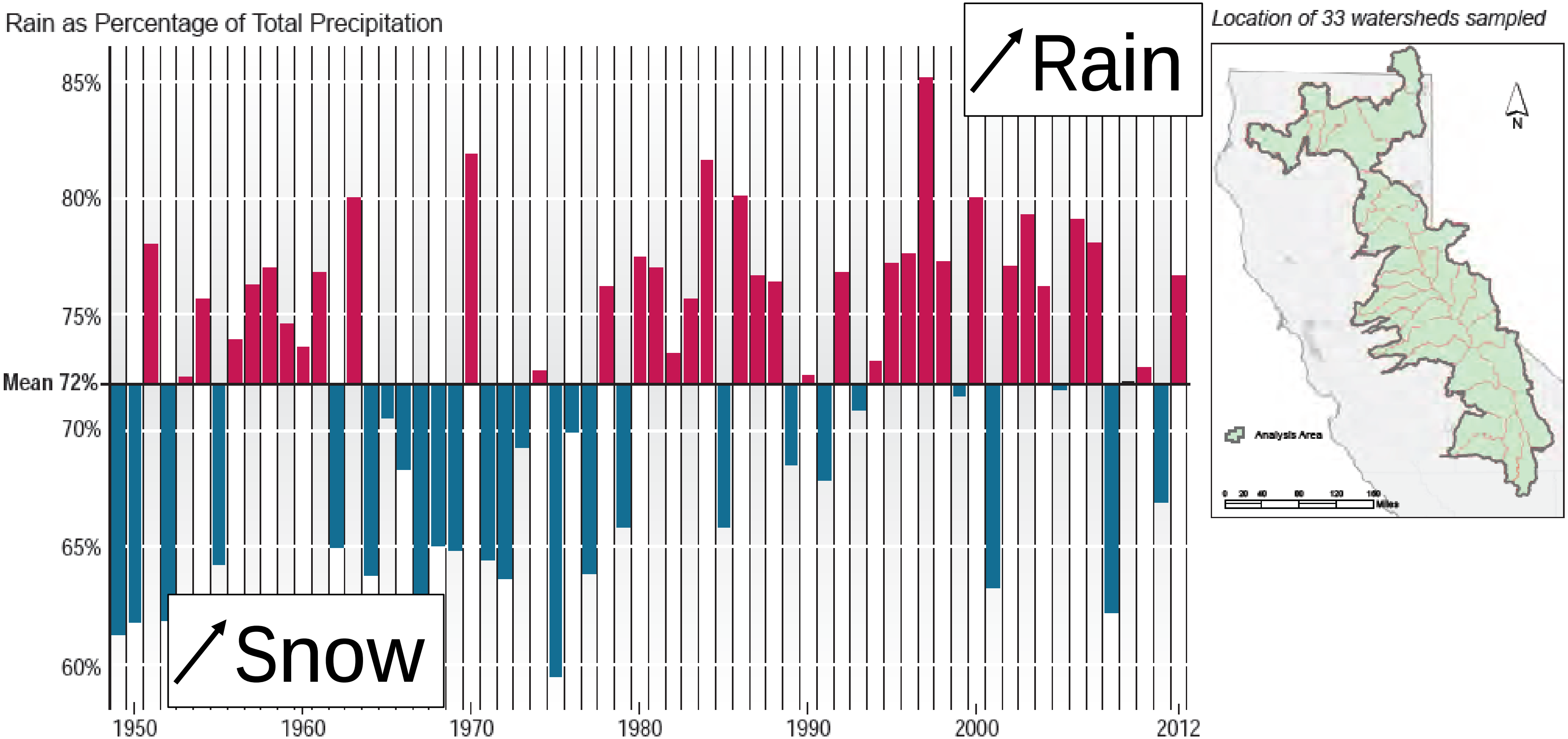
Uncertainty: Data for Modeling Boundary Conditions

Climate Variability



California Department of Water Resources;
Drought Response Update Fall 2014

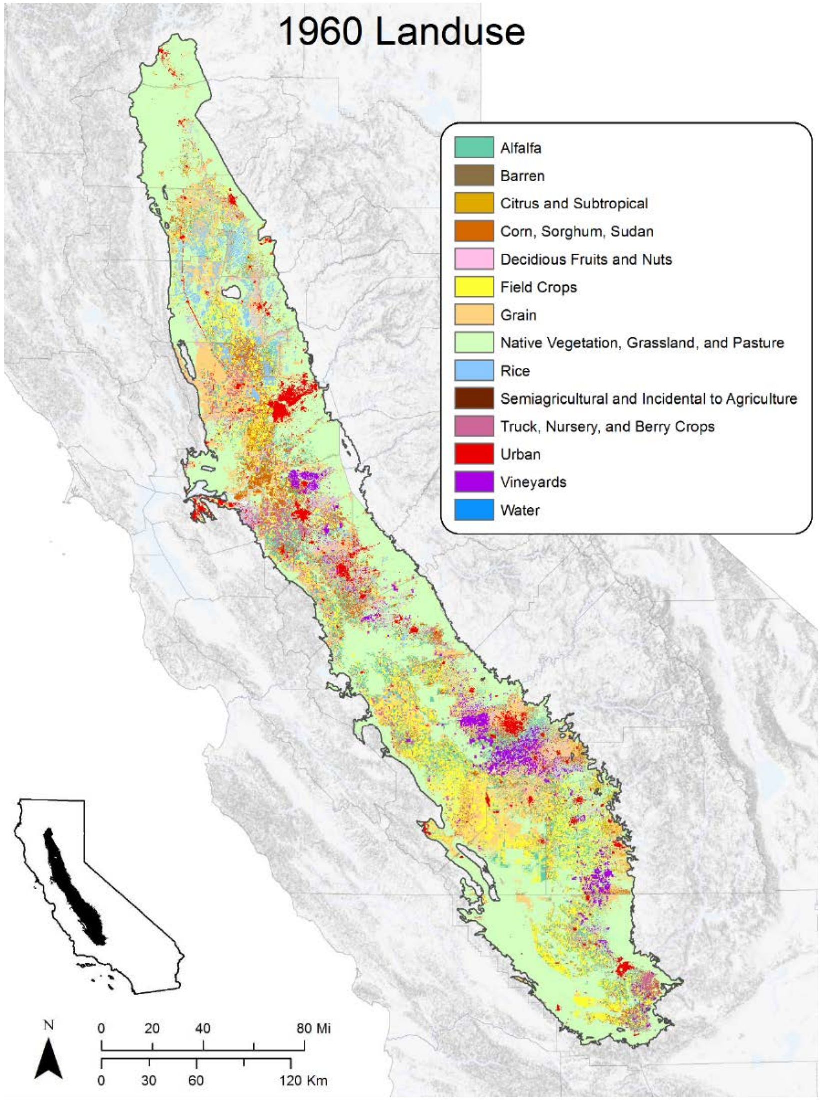
Uncertainty: Data for Modeling Boundary Conditions
Climate Change

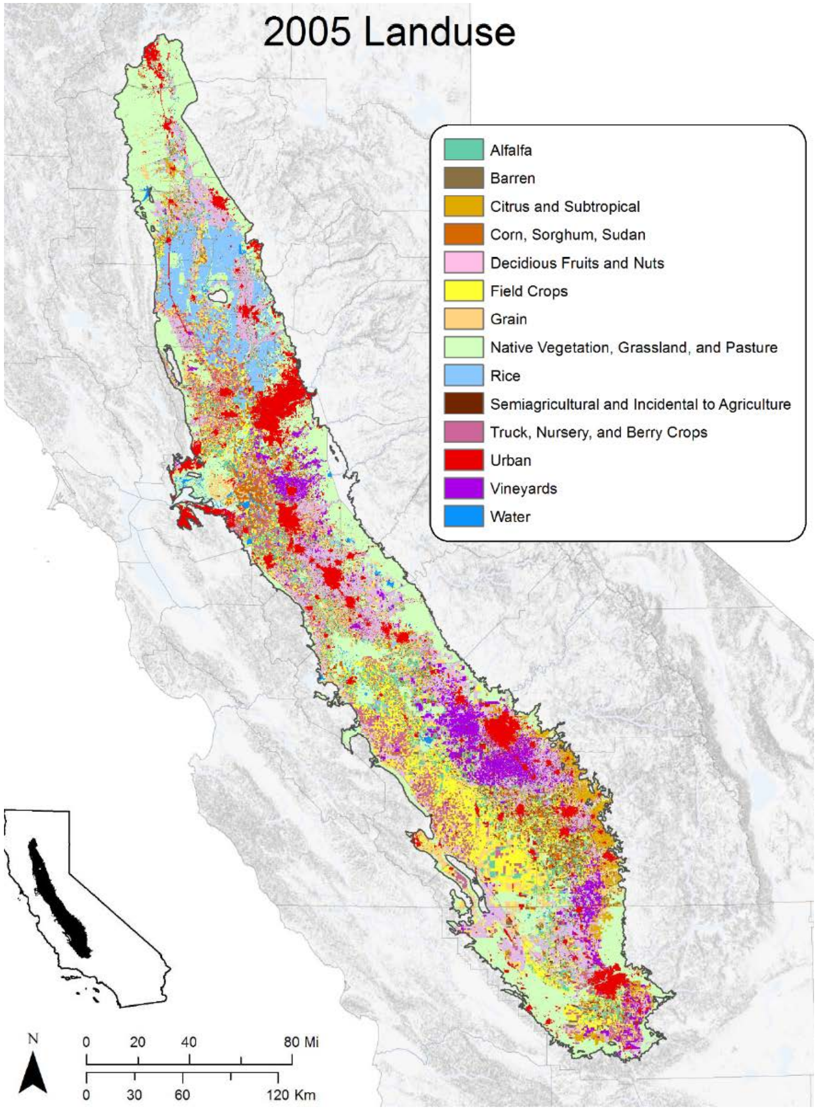


Note: Percentage of precipitation falling as rain over the 33 main water-supply watersheds of the State is shown for water years ending 1949 through 2012 (Oct. 1948-Sept. 2012), using Western Region Climate Center historic precipitation and freezing level re-analysis (http://www.wrcc.dri.edu).

Uncertainty: Data for Modeling Boundary Conditions

Landuse Change

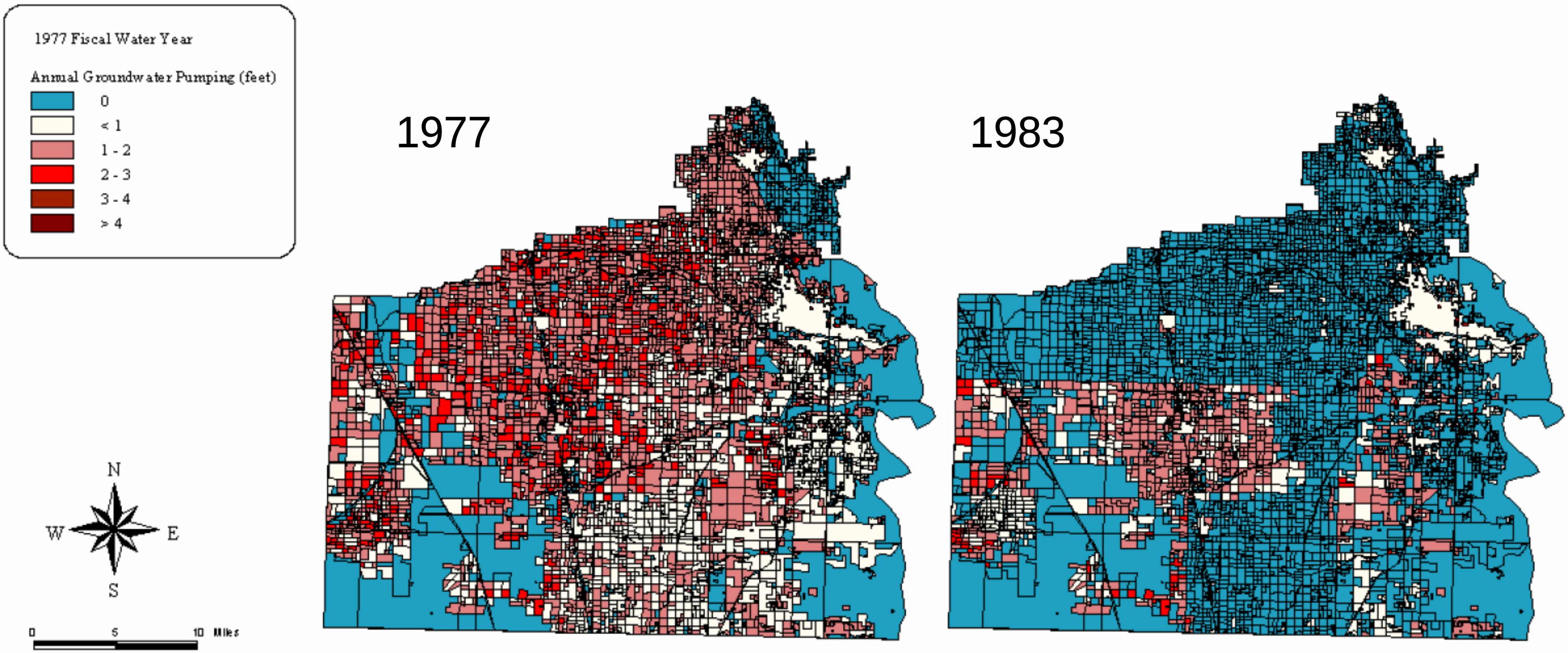




Harter et al., CDFA FREP Final Report, 2017

Uncertainty: Data for Modeling Boundary Conditions

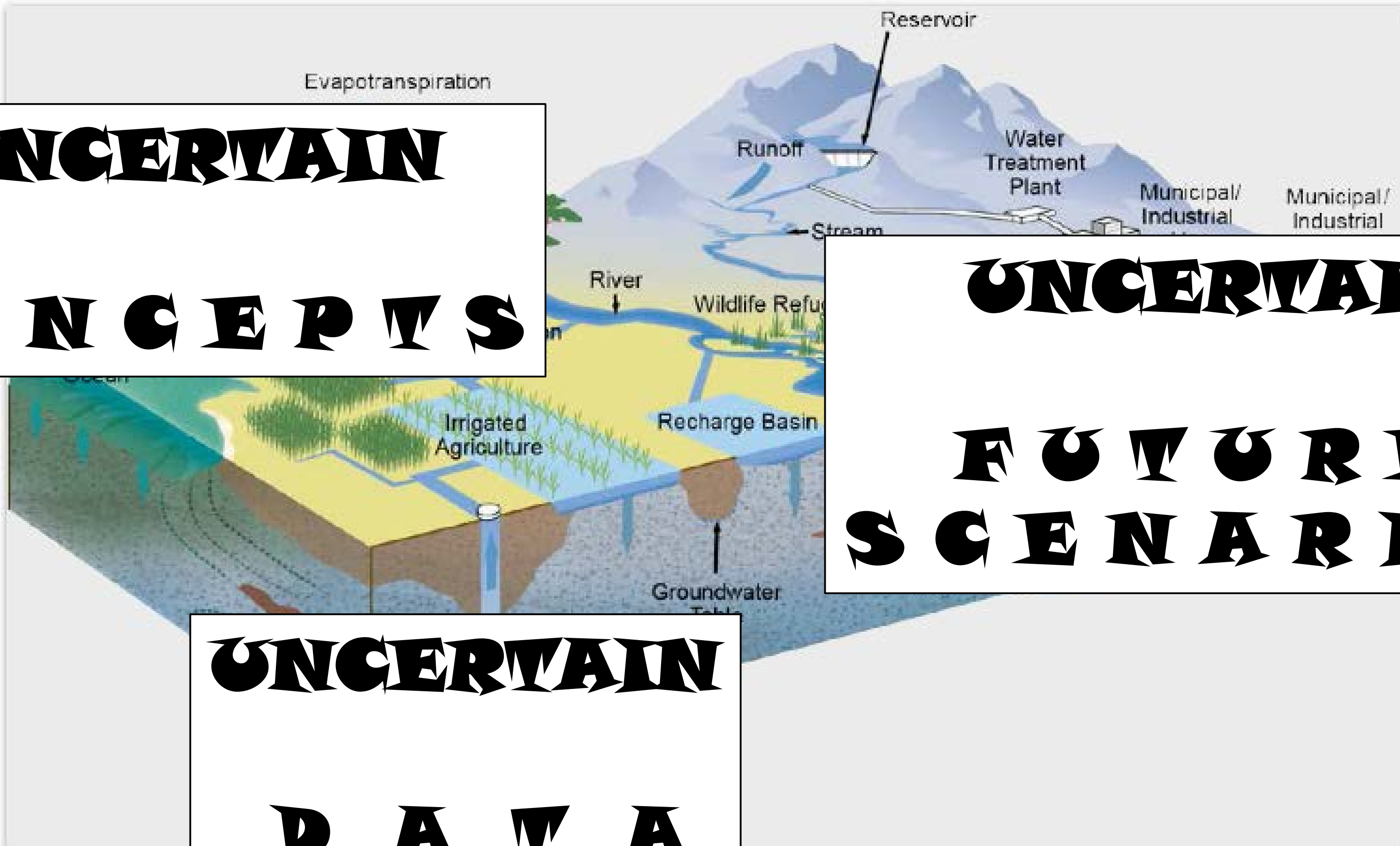
Groundwater Pumping



Ruud et al., JoH and USBR Report 2003

Uncertainty in Hydrology =

Uncertainty in the Scientific/Technical Assessment



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C O N C E P T S

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F U T U R E /
S C E N A R I O S

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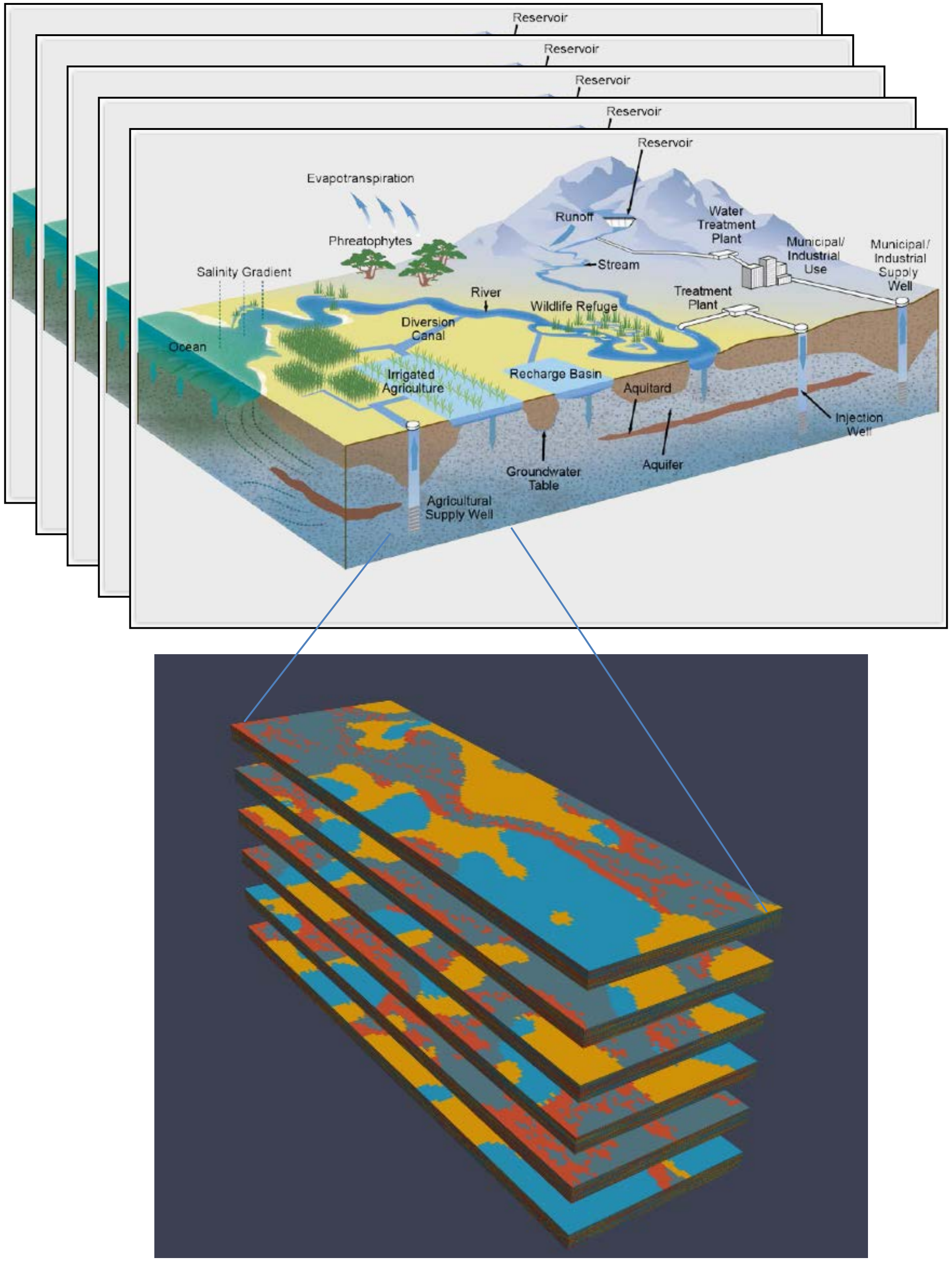
D A T A

George E. P. Box, 2011

"Essentially, all models are wrong, but some are useful."

Box, G. E. P., and Draper, N. R., (1987), *Empirical Model Building and Response Surfaces*, John Wiley & Sons, New York, NY.

Address Uncertainty in Concepts/Data/Models: Using Models



Statistical Analysis:

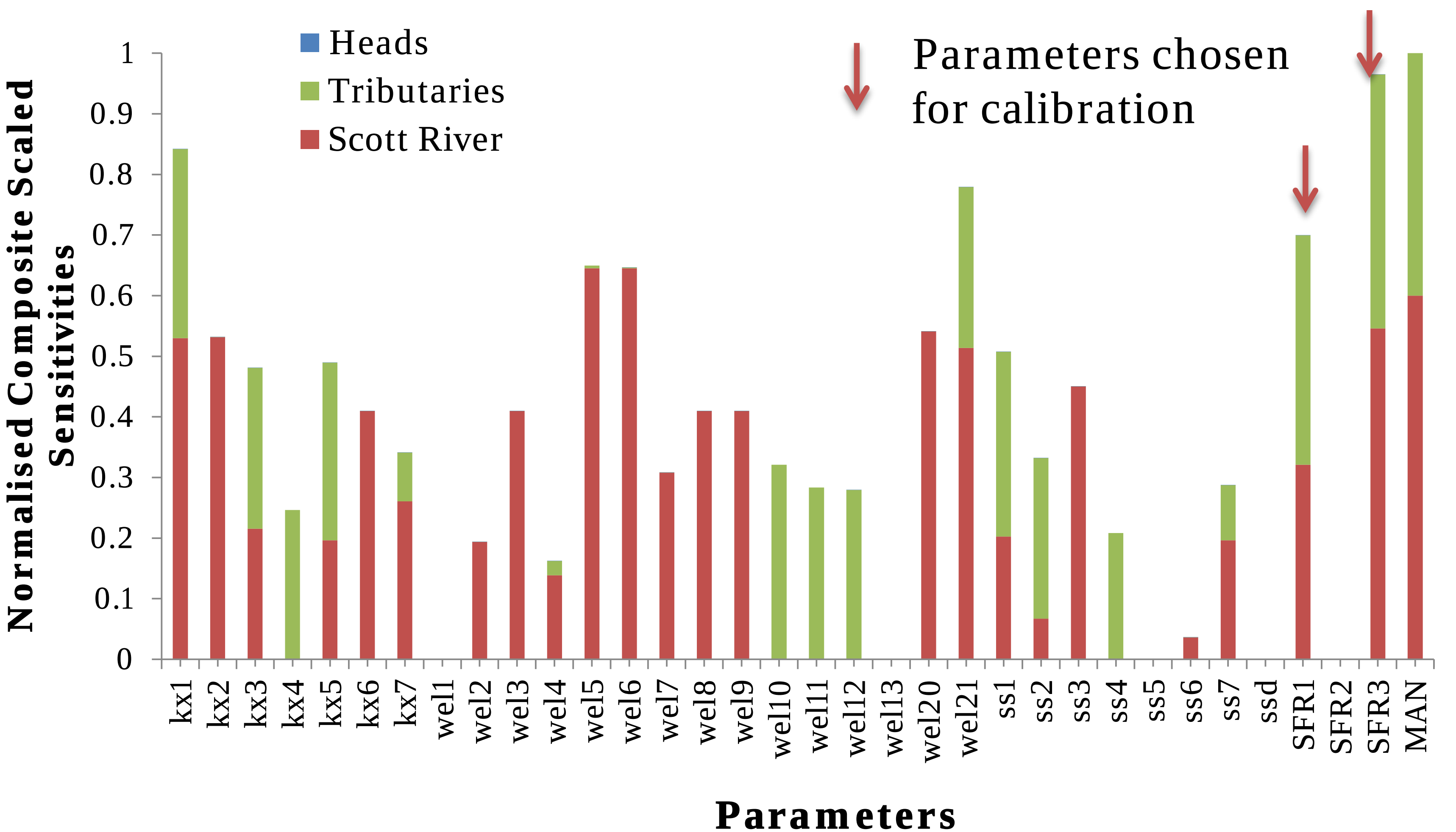
- Using sensitivity analysis / calibration tools / Monte Carlo analysis

Results:

- distribution of outcomes ⇔ uncertainty about outcome
- most likely outcome
- lower and upper bound of outcomes

How sensitive are model results to knowledge uncertainty?
=> guidelines for future measurement

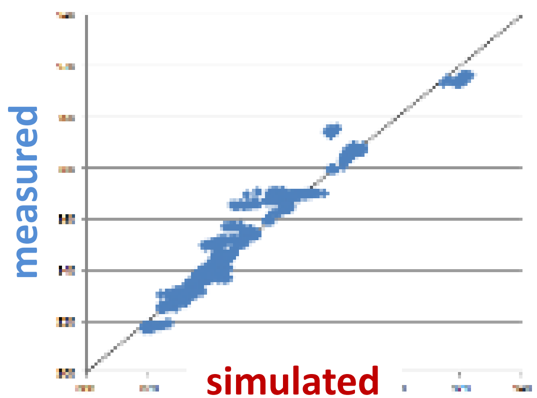
Large value identifies important parameters



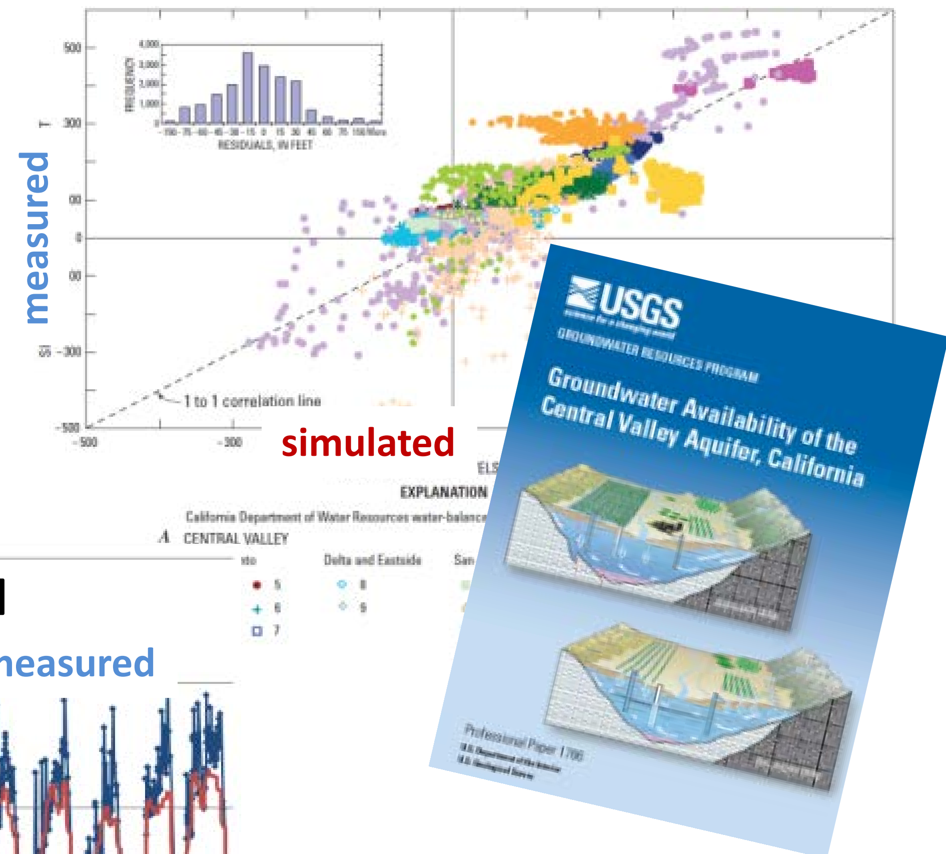
Flow observations clearly dominated the sensitivity analysis and this can results in possible problems with the future calibration

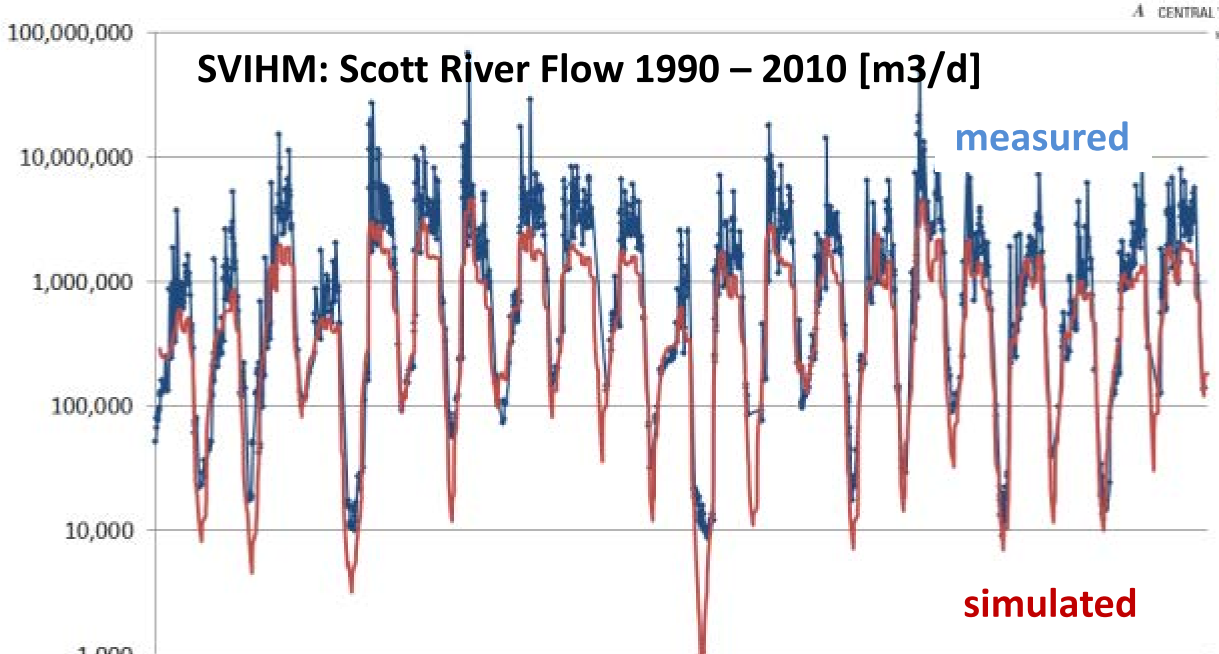
Building Confidence: Model Results vs. Observed Data

Scott Valley Integrated Hydrologic Model (SVIHM): Groundwater Levels



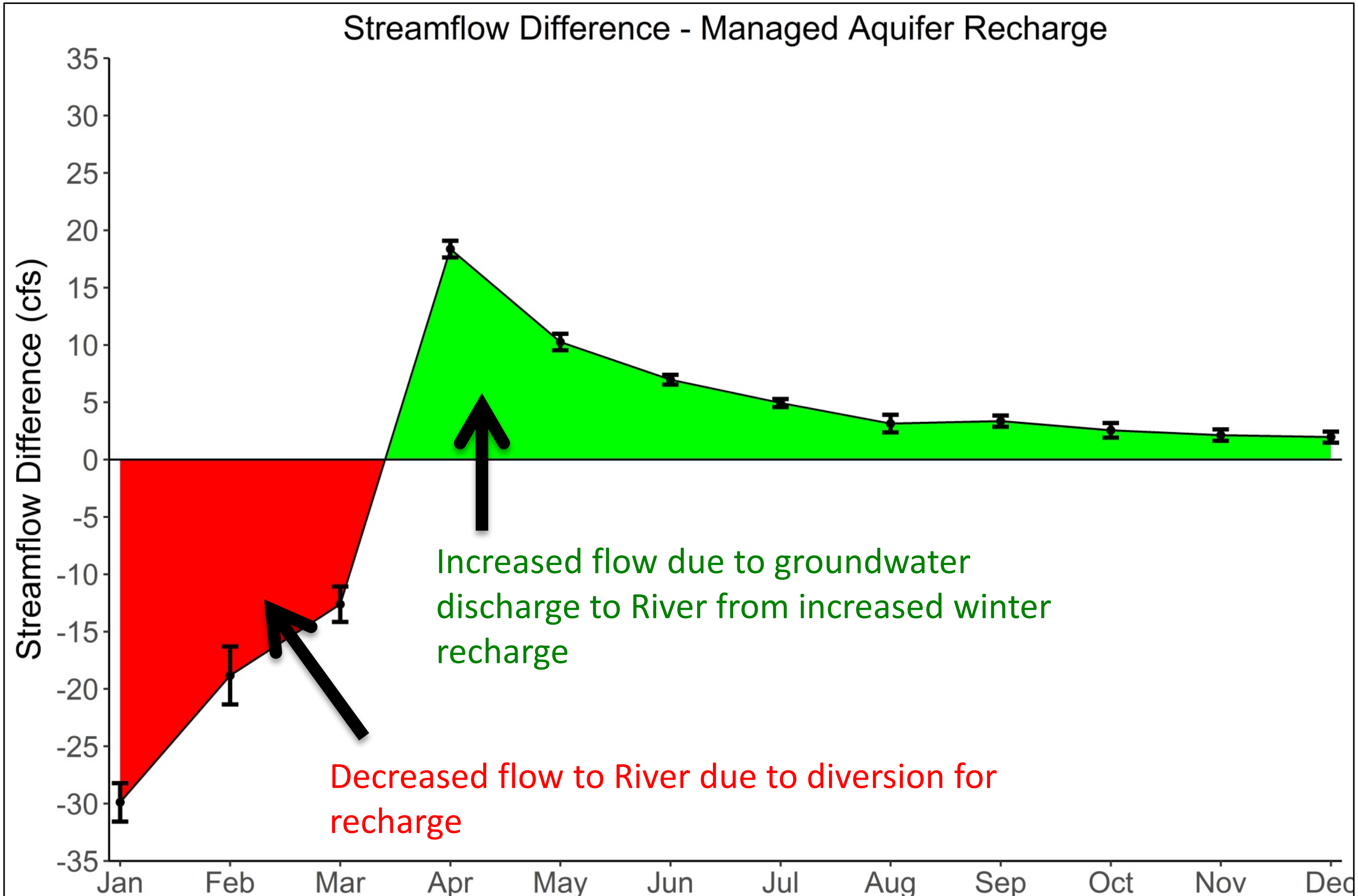
Central Valley Hydrologic Model (CVHM):



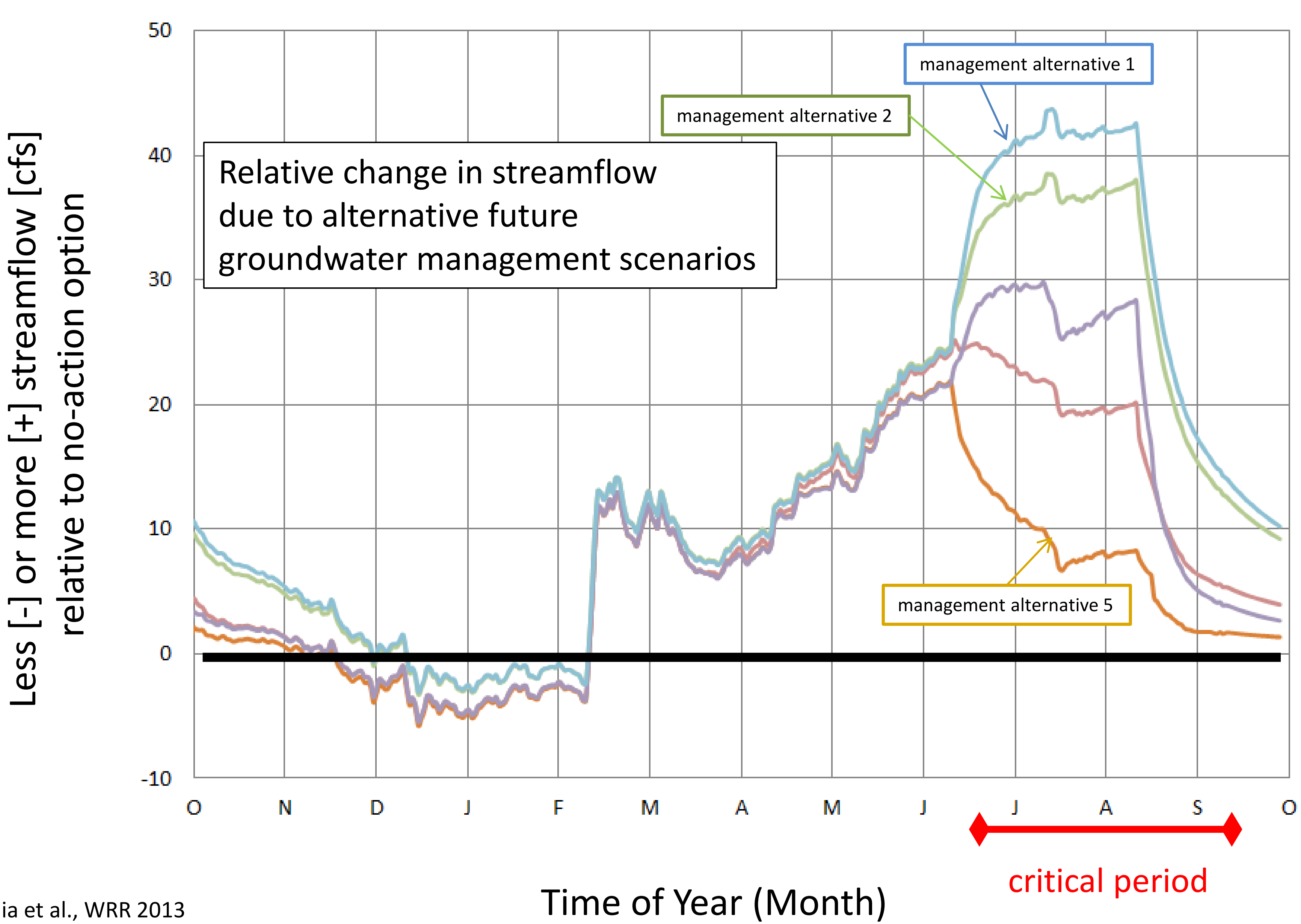


http://groundwater.ucdavis.edu/Research/ScottValley

Simulating Scenarios: Focus on the Difference to BAU

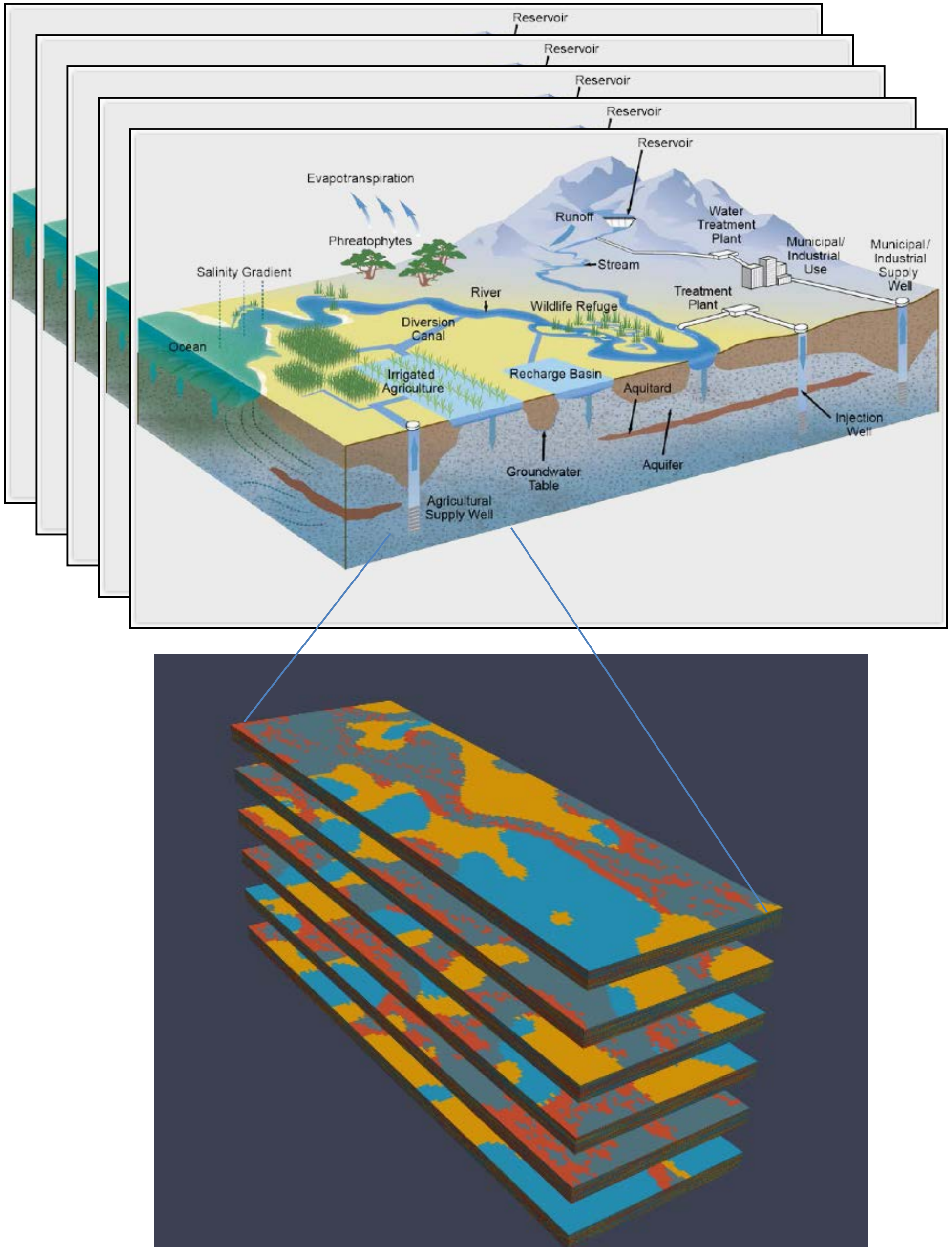


Investigate Impact of Alternative Management Practices



Foglia et al., WRR 2013

Address Uncertainty in Monitoring Needs: Using Models



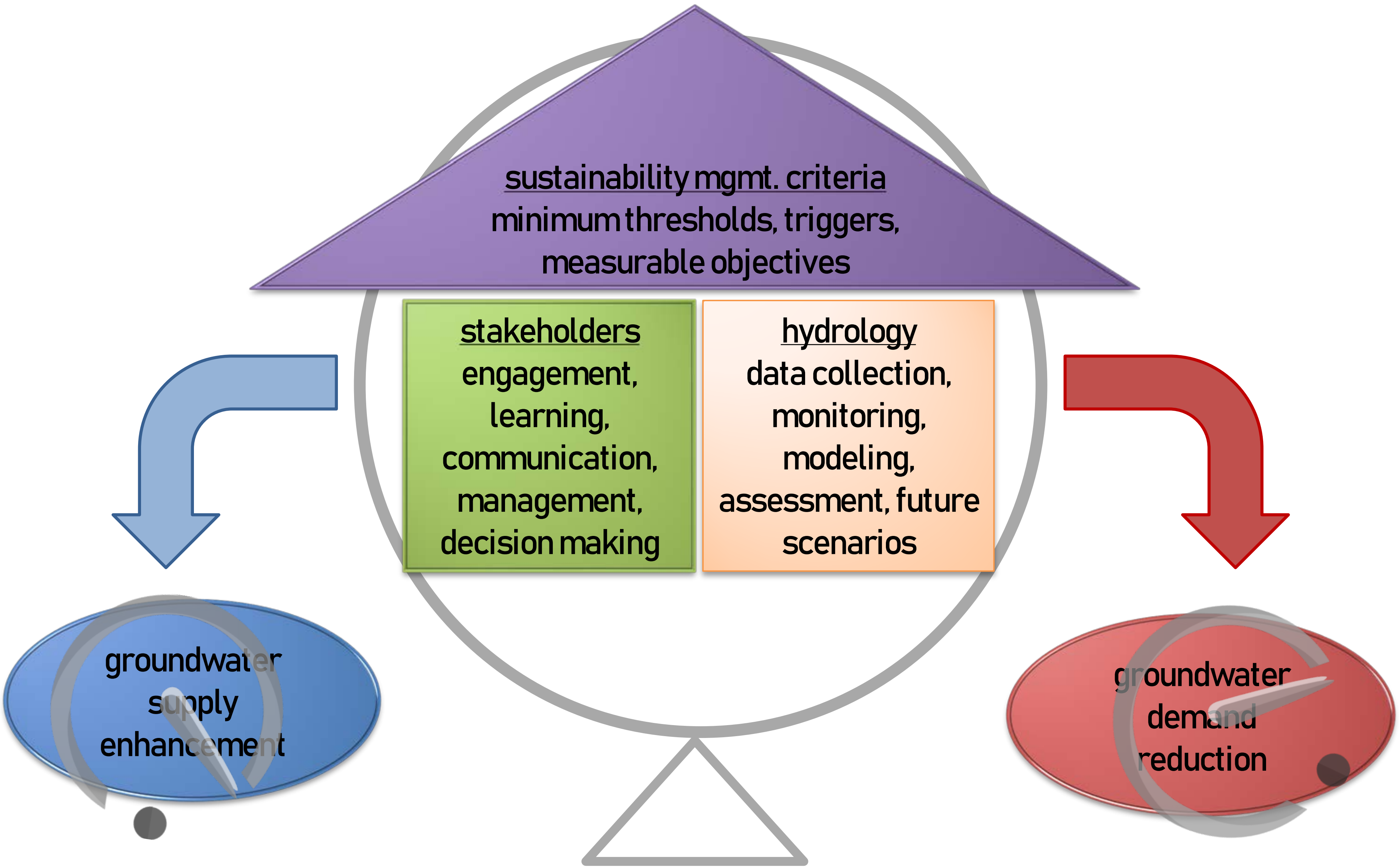
Statistical Analysis:

- Using calibration tools / sensitivity analysis

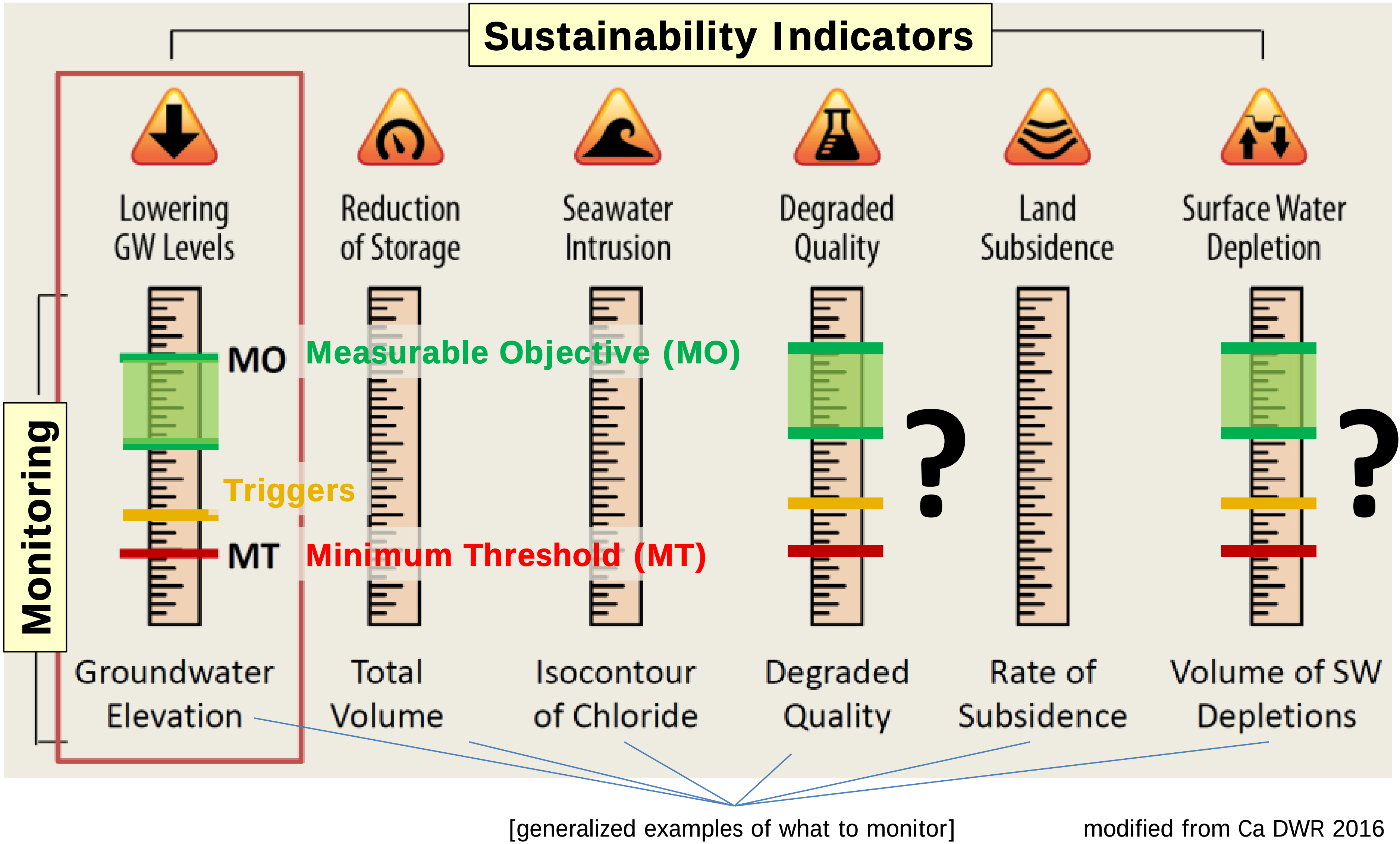
Results:

- Identify most important data to measure
- Identify most important locations and time points to measure

The GSA world of uncertainty

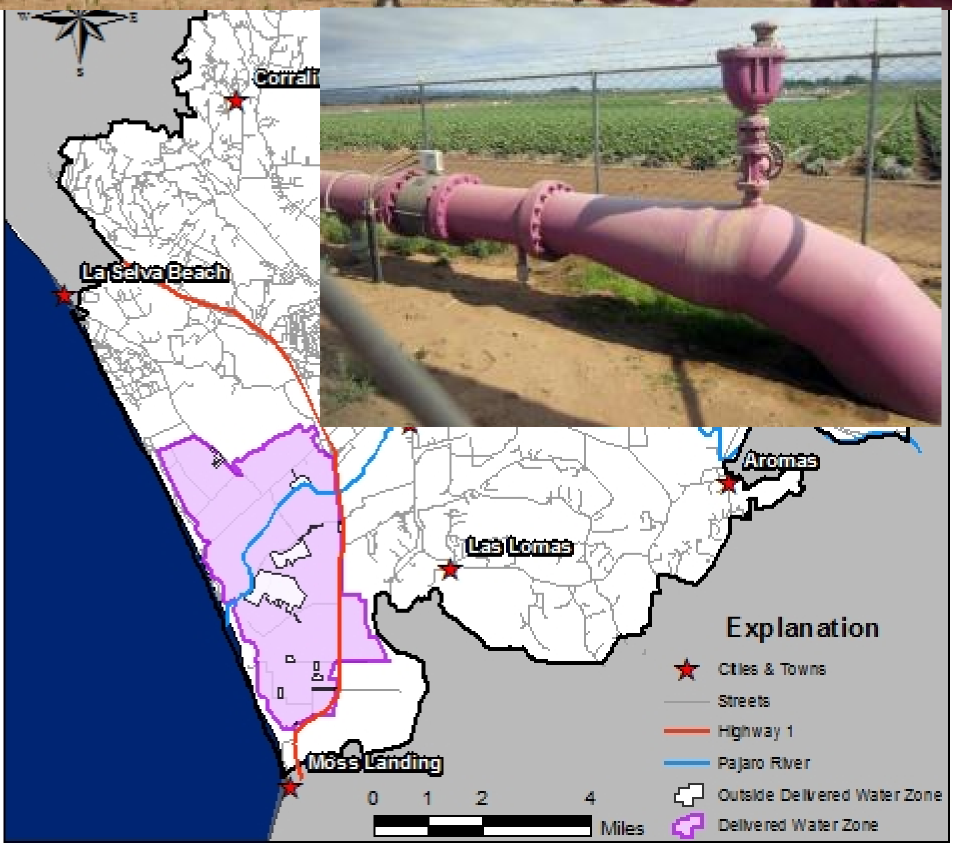


Sustainable Management Criteria: Where do we land?



modified from Ca DWR 2016

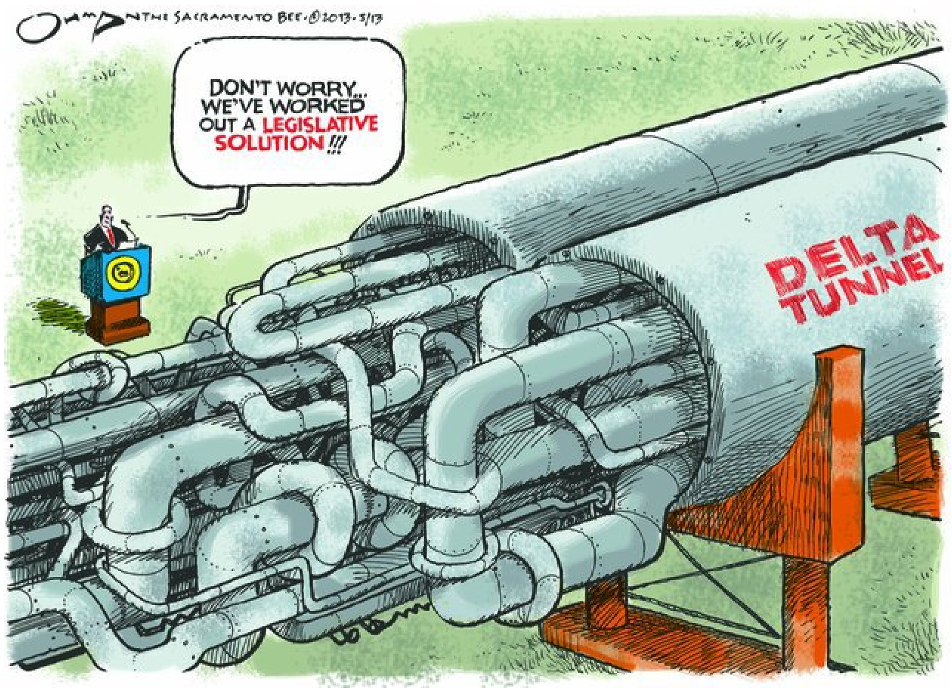
Uncertainty: Project Cost, Funding, Planning, Implementation



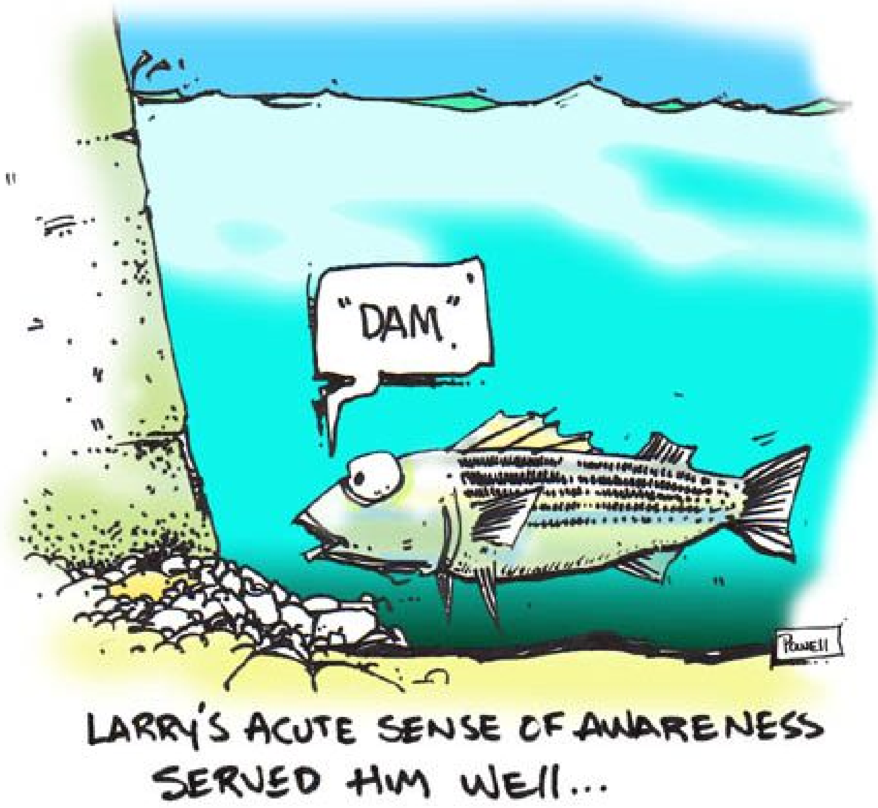
from: Ted Johnson, WRD 2013

from : George Sakkestad, Mercury News, 2015

Uncertainty: Project Cost, Funding, Planning, Implementation



from: Sacramento Bee



from: Conservation Corridor

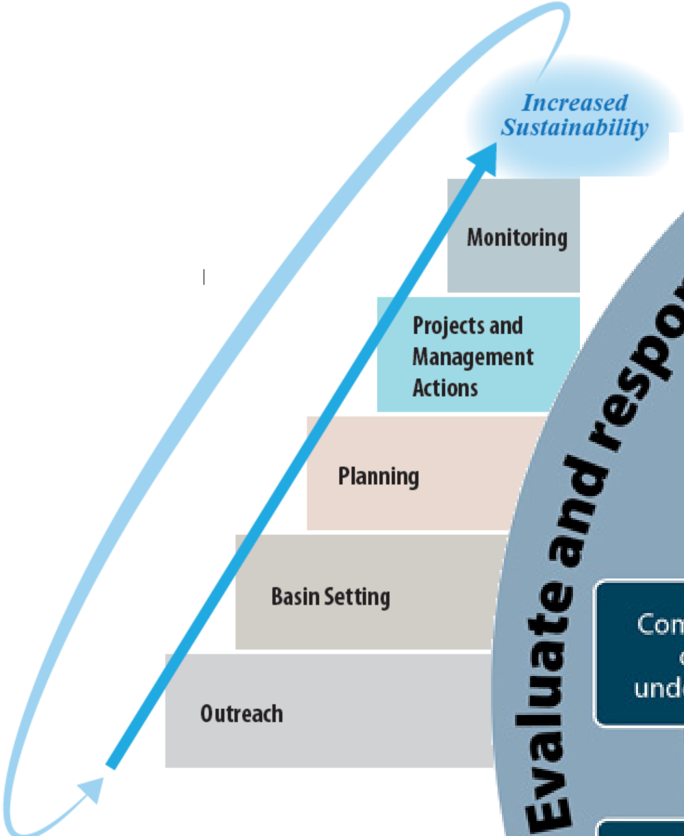
Uncertainty: Controlling Demand

Uncertainty: Governance

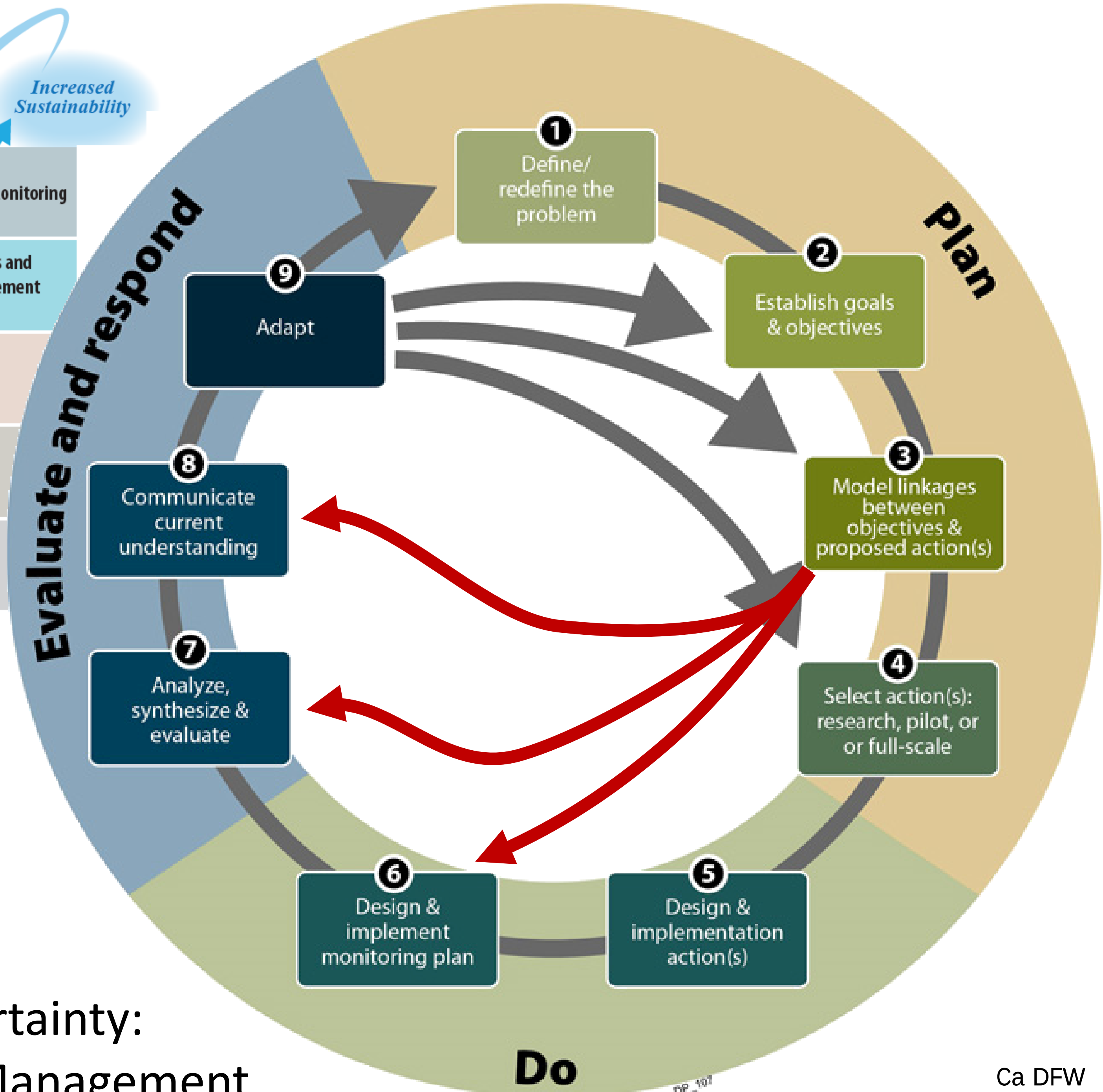
George E. P. Box, 2011

“The only way to know how a complex system will behave-after you modify it-is to modify it and see how it behaves.”

Box, G. E. P., and Draper, N. R., (1987), *Empirical Model Building and Response Surfaces*, John Wiley & Sons, New York, NY.



Ca DWR BMP Framework 2017



Ca DFW

Combating Uncertainty: Smart Adaptive Management