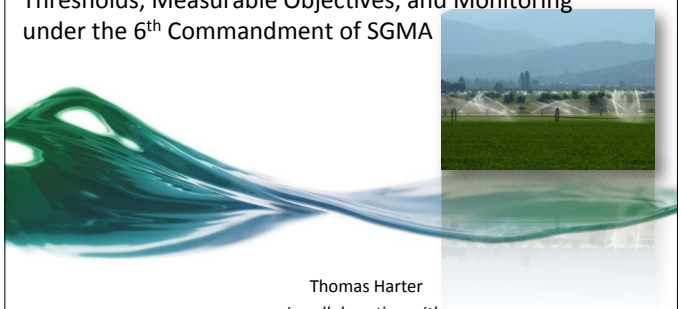
"Though Shall Not Deplete Surface Water" –

Thresholds, Measurable Objectives, and Monitoring under the 6th Commandment of SGMA



Thomas Harter
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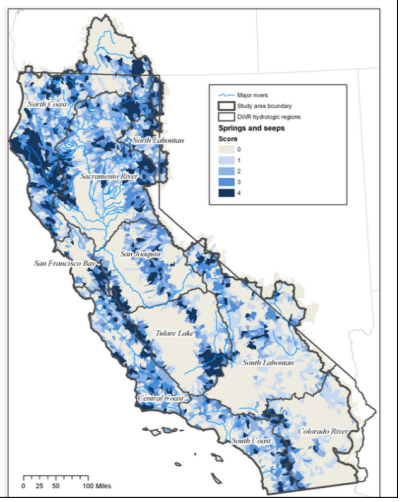
UNIVERSITY OF CALIFORNIA

1. Groundwater, Surface Water, and Ecosystems: Connections

Groundwater Dependent Ecosystems:

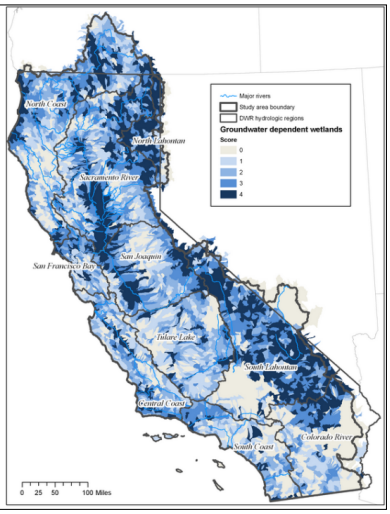
Springs and Seeps



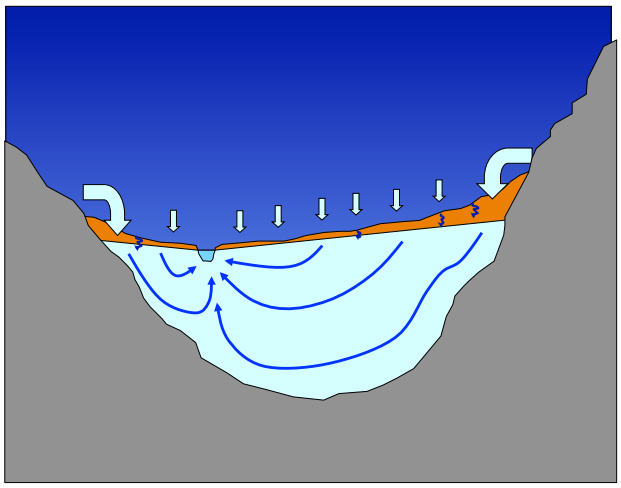
Howard and Merrifield, 2010, PlosONE, DOI: 10.1371/journal.pone.0011249

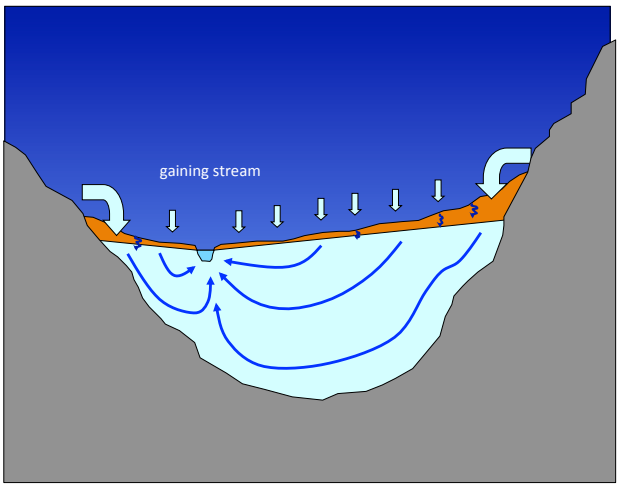
Groundwater Dependent Ecosystems:

Wetlands & Groundwater Dependent Vegetation

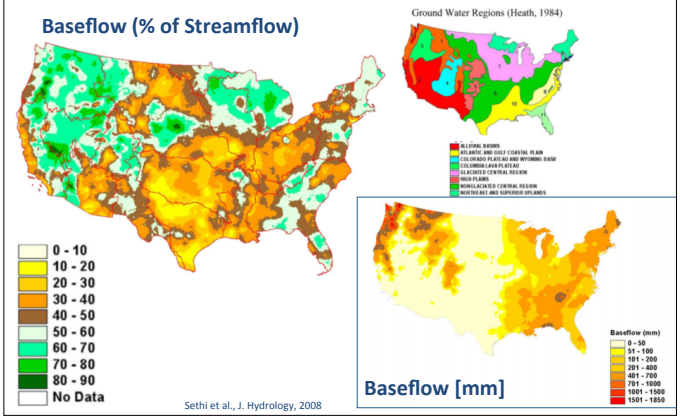


Howard and Merrifield, 2010, PlosONE, DOI: 10.1371/journal.pone.0011249

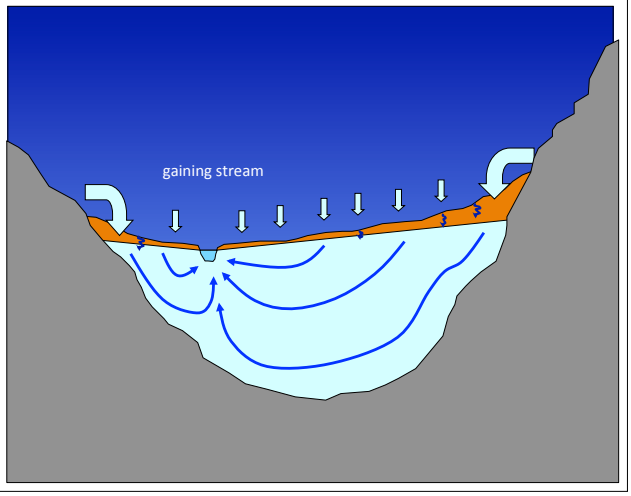


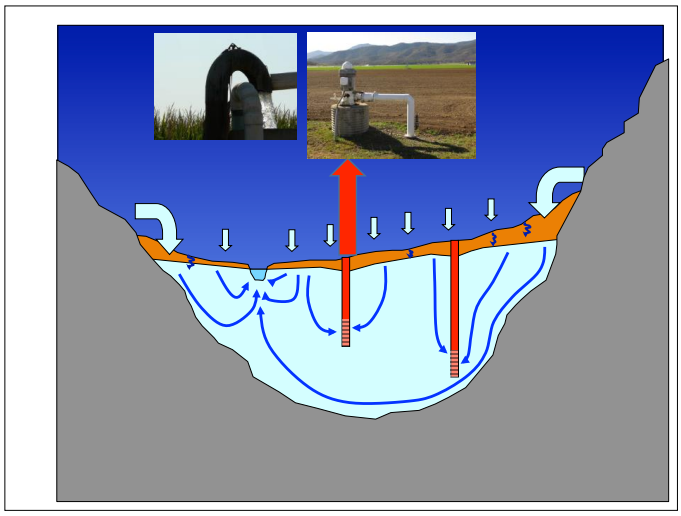


Groundwater Contribution to Streamflow: Baseflow

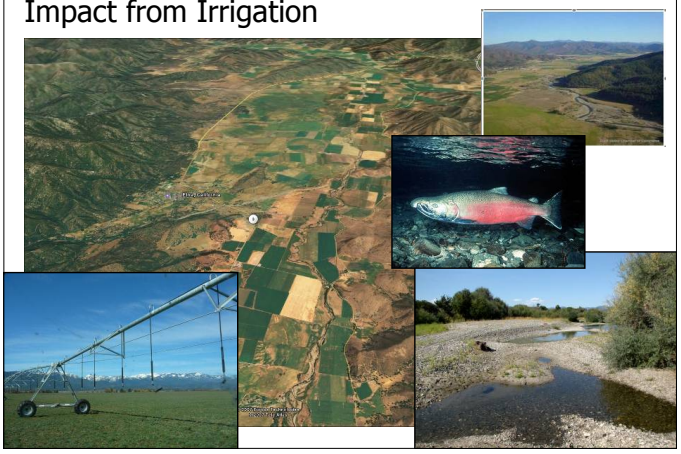


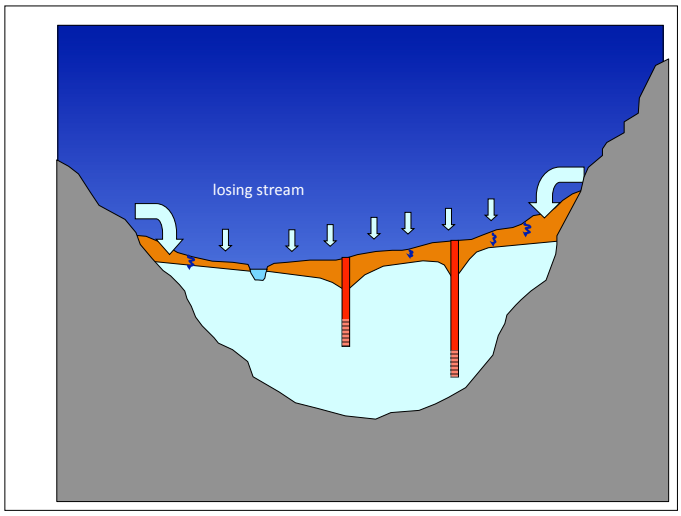
Sethi et al., J. Hydrology, 2008

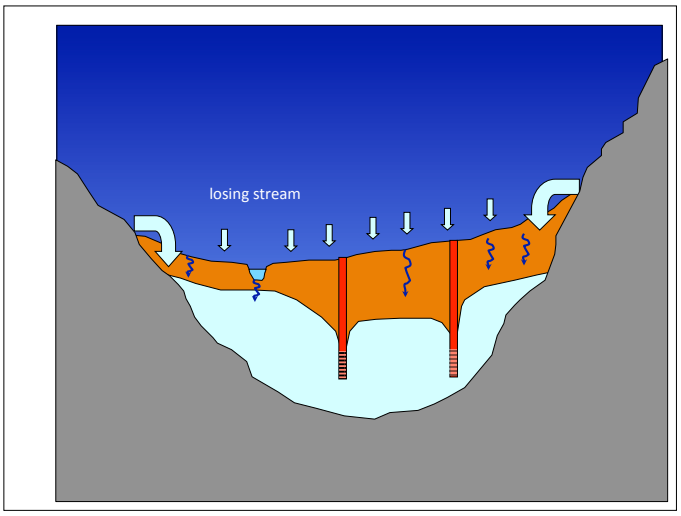


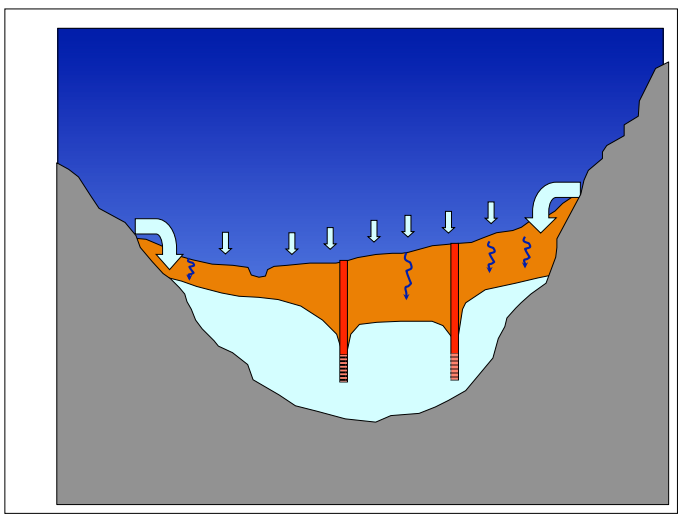


Groundwater Dependent Ecosystem: Impact from Irrigation



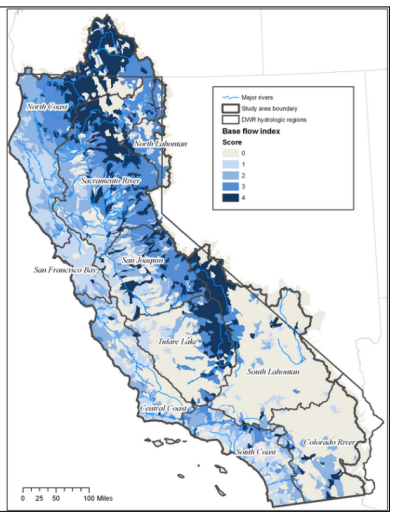






Groundwater Dependent Ecosystems:

Baseflow



Howard and Merrifield, 2010, PlosONE, DOI: 10.1371/journal.pone.0011249

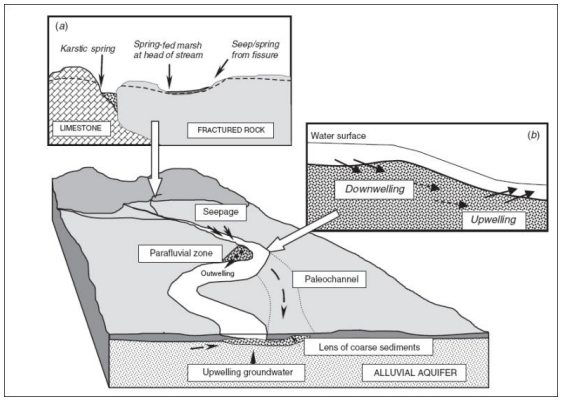
Groundwater Dependent Ecosystems: Flow Contributions

Hydrologic Region	Total Demand (acre feet)	Demand met by Groundwater (acre feet)	Demand met by Groundwater (%)
Central Coast	1,263	1,045	83
Colorado River	4,467	337	8
North Coast	1,063	263	25
North Lahontan	568	157	28
Sacramento River	8,720	2,672	31
San Francisco Bay	1,353	68	5
San Joaquin River	7,361	2,195	30
South Coast	5,124	1,177	23
South Lahontan	480	239	50
Tulare Lake	10,556	4,340	41

doi:10.1371/journal.pone.0011249.t001

Howard and Merrifield, 2010, PlosONE,
DOI: 10.1371/journal.pone.0011249

Groundwater – Surface Water Interconnection: Locally Complex Structure and Dynamics

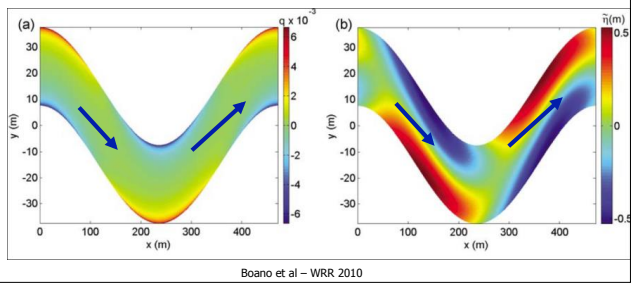


Boulton and Hancock, Austral J Botany, 2006

Meandering Stream Effects: Locally Varying Losses / Gains

Surface Water - Groundwater:
Stream Loss (red) / Gain (blue)

Deviation from Flat Streambed



Boano et al – WRR 2010

2. The SGMA Context

SGMA's 6th Commandment: Definitions

10721. DEFINITIONS

(u) **"Sustainable groundwater management" means** the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon **without causing undesirable results.**

(w) "Undesirable result" means one or more of the following effects caused by groundwater conditions occurring throughout the basin:
(6) Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water

10735. DEFINITIONS
(d) "Significant depletions of interconnected surface waters" means **reductions in flow or levels of surface water that is hydrologically connected to the basin such that the reduced surface water flow or levels have a significant and unreasonable adverse impact on beneficial uses of the surface water.**

SGMA's 6th Commandment: Definitions

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BENEFICIAL USES:
- Instream flow
- Vegetation
- Animal life

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SGMA's 6th Commandment: Plan Elements

10727.2. REQUIRED PLAN ELEMENTS. A groundwater sustainability plan shall include all of the following:

(d) Components relating to the following, as applicable to the basin:
(2) The **monitoring and management** of […] **changes in surface flow and surface water quality that directly affect groundwater levels or quality or are caused by groundwater extraction** in the basin

(e) A summary of the type of monitoring sites, type of measurements, and the frequency of monitoring for each location **monitoring […] streamflow**. […]

10727.4. ADDITIONAL PLAN ELEMENTS. In addition to the requirements of Section 10727.2, a groundwater sustainability plan **shall include, where appropriate** and in collaboration with the appropriate local agencies, all of the following:

(l) **Impacts on groundwater dependent ecosystems.**

SGMA's 6th Commandment: Basin Prioritization

10933. […] PRIORITIZATION OF BASINS BY THE DEPARTMENT
(b) The **department shall prioritize groundwater basins and subbasins** for the purpose of implementing this section. In prioritizing the basins and subbasins, the department shall, to the extent data are available, consider all of the following
[…]
(8) Any other information determined to be relevant by the department, including **adverse impacts on local habitat and local streamflows**.

SGMA's 6th Commandment: Pre-existing Conditions

10727.2. REQUIRED PLAN ELEMENTS A groundwater sustainability plan shall include all of the following:

(b)(4) The plan **may, but is not required to, address undesirable results that occurred before, and have not been corrected by, January 1, 2015**. Notwithstanding paragraphs (1) to (3), inclusive, a groundwater sustainability agency has discretion as to whether to set measurable objectives and the timeframes for achieving any objectives for undesirable results that occurred before, and have not been corrected by, January 1, 2015.

SGMA's 6th Commandment: Pre-existing Conditions

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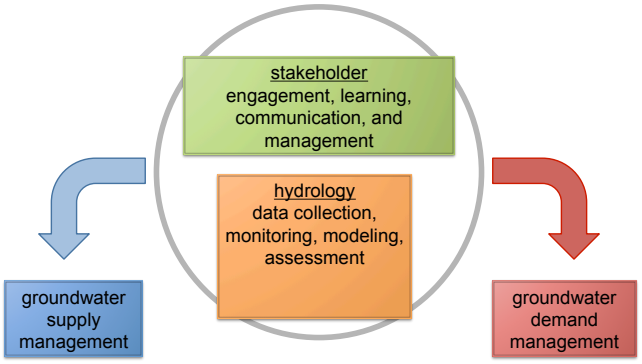
Role of:

- (federal) Clean Water Act, 1972 – temperature TMDL
- Public trust doctrine: Environmental Law Foundation v. SWRCB, Superior Court, County of Sacramento

??? !!

3. Groundwater-Surface Water Connections in a GSP

Getting There: GSAs plan & implement GSPs

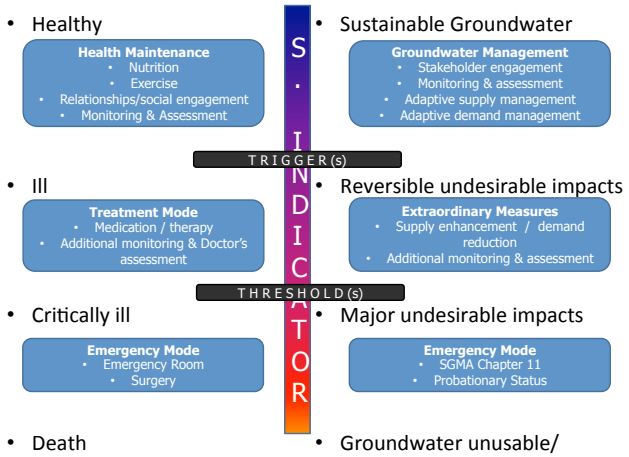


Measure of Groundwater Sustainability: Sustainability Indicators

California Department of Water Resources, 2016

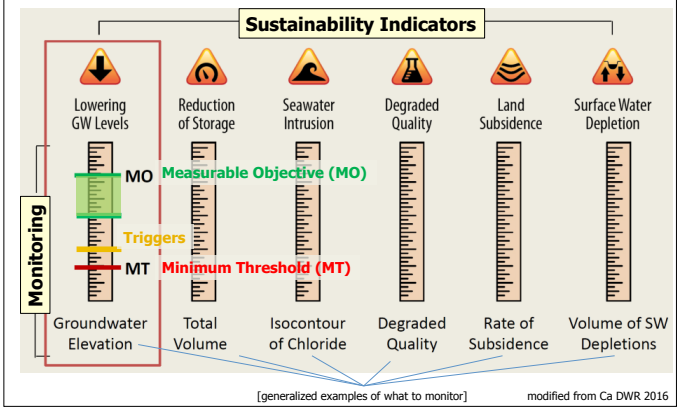
Goal of the GSP:

→ maintain sustainability indicators in good status



Thomas Harter, Univ. of California, 2016

GSP: Monitoring and Managing Sustainability



[generalized examples of what to monitor] modified from Ca DWR 2016

GSP Content – 2. Basin Setting

GSP Regs § 354.16. Groundwater Conditions

- Description of current and historical groundwater conditions
  - Including data from January 1, 2015, to current conditions:
  - .....
  - Identification of interconnected surface water systems
    - Quantity and timing of depletions
      - Data available from the Department
      - Best available information
  - Identification of groundwater dependent ecosystems within the basin
    - Data available from the Department
    - Best available information

§ 351. Definitions
(m) "Groundwater dependent ecosystem" refers to ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface.
(o) "Interconnected surface water" refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.

GSP Content – 2. Basin Setting

GSP Regs § 354.16. Groundwater Conditions

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  - .....
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    - Quantity and timing of depletions
      - Data available from the Department
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  - Identification of groundwater dependent ecosystems within the basin
    - Data available from the Department
    - Best available information

Potential GDE map (statewide)
- based on vegetation and ecosystem mapping
- joint effort by DWR, DFG, and TNC
- due later in 2016

GSP Content – 3. Sustainable Management Criteria

GSP Regs. § 354.28. Minimum Thresholds

- Establish minimum thresholds that quantify groundwater conditions for each applicable sustainability indicator at each monitoring site
  - Information and criteria used
  - Supporting information provided in the basin setting
  - Data or models as appropriate
  - Qualified by uncertainty in the understanding of the basin setting
- Relationship between the minimum thresholds for each sustainability indicator
- Criteria used to avoid causing undesirable results in adjacent basins
- Impact on interests of beneficial uses and users of groundwater or land uses and property interests.
- Relationship to state, federal, or local standards relate to the relevant sustainability indicator.

GSP Content – 3. Sustainable Management Criteria

GSP Regs. § 354.28. Minimum Thresholds

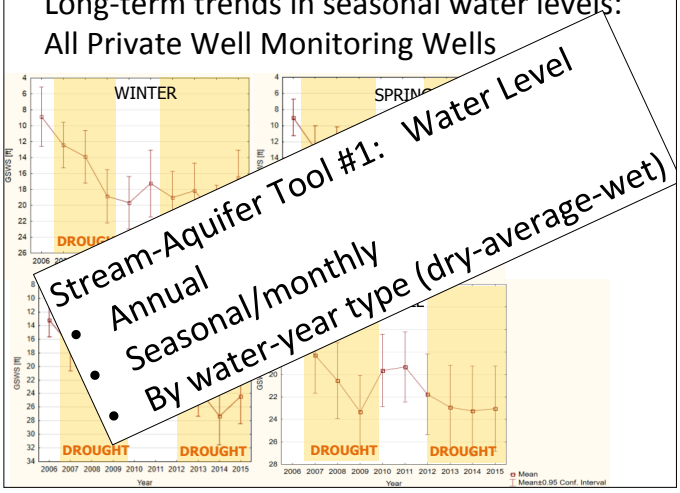
- Minimum threshold for depletions of interconnected surface water: expressed as a rate or volume of surface water depletions caused by groundwater use
- Supported by the following information:
  - The location, quantity, and timing of depletions of interconnected surface water.
  - Groundwater and surface water model description
    - Numerical model
    - Equally effective method, tool, or analytical model
- Alternative threshold: a representative minimum threshold for groundwater elevation

GSP Content – 4. Monitoring Networks

GSP Regs § 354.34. Monitoring Network

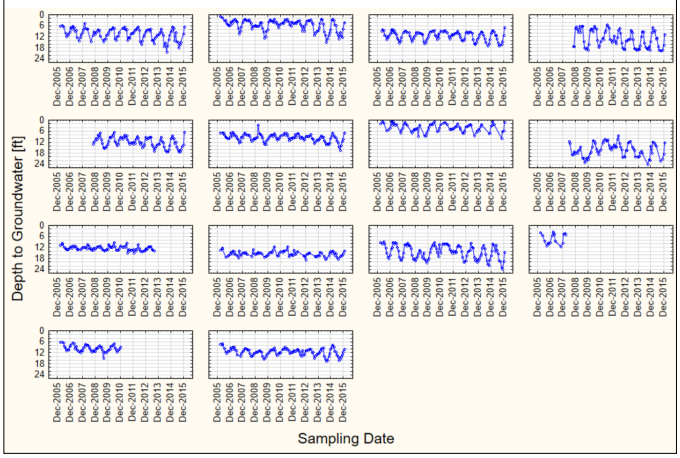
- Monitor surface water and groundwater, where interconnected surface water conditions exist
- Characterize the spatial and temporal exchanges between surface water and groundwater
- Calibrate and apply the tools and methods necessary to calculate depletions of surface water caused by groundwater extractions
- The monitoring network shall be able to characterize the following:
  - Flow conditions
    - Surface water discharge
    - Surface water head
    - Baseflow contribution.
  - Ephemeral / intermittent flowing streams
    - Approximate date and location when/where flows cease
  - Temporal dynamics due to variations in stream discharge and regional groundwater extraction.
  - Other factors to identify adverse impacts on beneficial uses of surface water.

Long-term trends in seasonal water levels: All Private Well Monitoring Wells



Stream-Aquifer Tool #1: Water Level
- Annual
- Seasonal/monthly
- By water-year type (dry-average-wet)

Depth to Groundwater: Valley Floor



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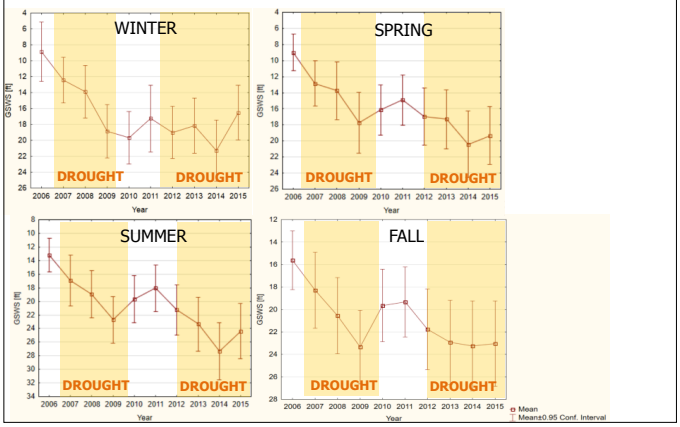
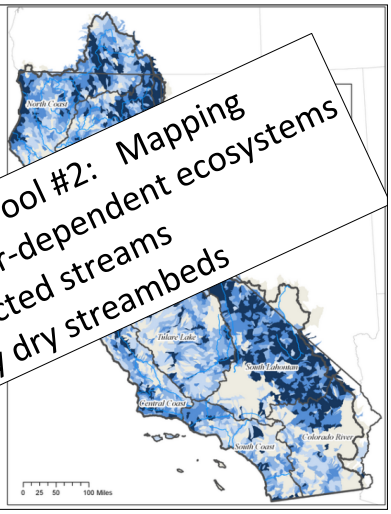


Groundwater Dependent Ecosystems:

Wetlands & Groundwater Dependent Vegetation

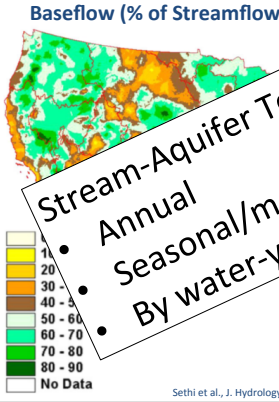


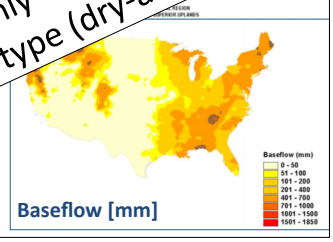
Stream-Aquifer Tool #2: Mapping
- Groundwater-dependent ecosystems
- Interconnected streams
- Seasonally dry streambeds

Howard and Merrifield, 2010, PlosONE, DOI: 10.1371/journal.pone.0011249

Groundwater Contribution to Streamflow: Baseflow

Baseflow (% of Streamflow)





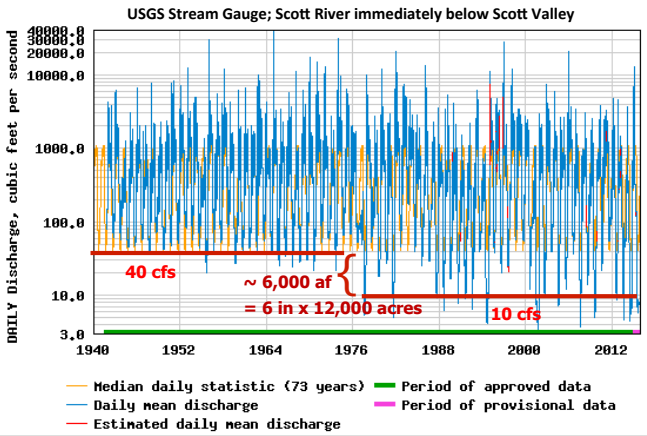
Baseflow [mm]

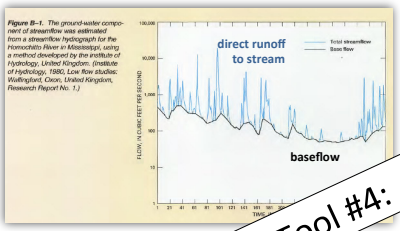
Sethi et al., J. Hydrology, 2008

Stream-Aquifer Tool #3: Water Balance

- Annual
- Seasonal/monthly
- By water-year type (dry-average-wet)

EXTENDED IRRIGATION SEASON: MORE SUMMER CROP WATER USE



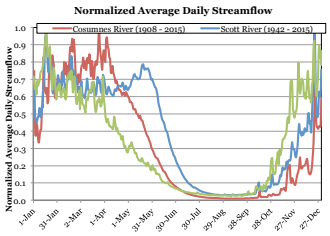


Groundwater discharge sustains streams.

This flow is call... ...eflow, or the gr... co... ...mflow

Stream-Aquifer Tool #4: Hydrograph

Source: Natural Heritage Land Trust

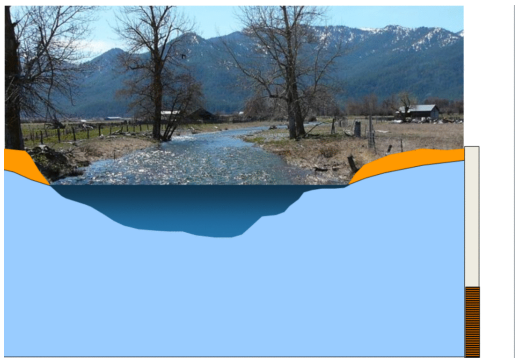


Courtesy: Ken Bradbury, Univ Wisconsin Extension

How can we model this behavior?

Stream-Aquifer Tool #5: Analytical Stream Depletion Function

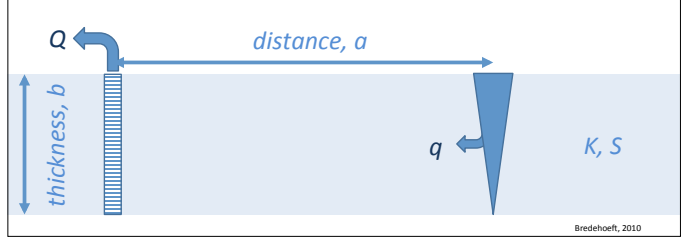
Delayed Impact of Pumping on Stream Depletion



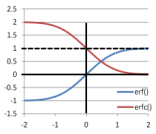
Relative Stream Depletion from Well Pumping (or: Relative Stream Repletion from Intentional Recharge)

$$q/Q = \mathrm{erfc}(\sqrt{SDF/4t})$$

Infinite, confined, uniform aquifer, fully penetrated by the stream.



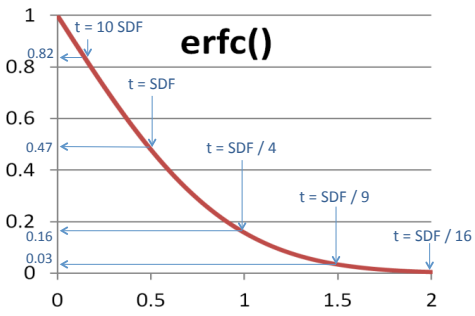
Bredehoeft, 2010



How does this equation work?

$$q/Q = \mathrm{erfc}(\sqrt{SDF/4t})$$

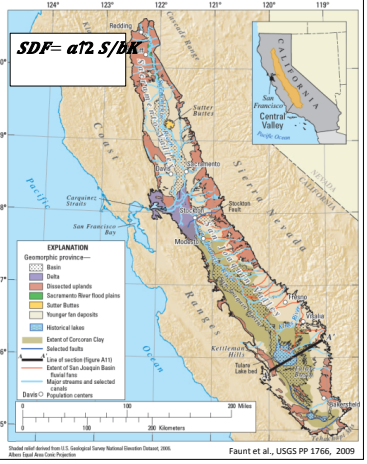
$$SDF = a\tau^2 S/bK$$



SDF: Back-of-the-Envelope Application to the Sacramento Valley

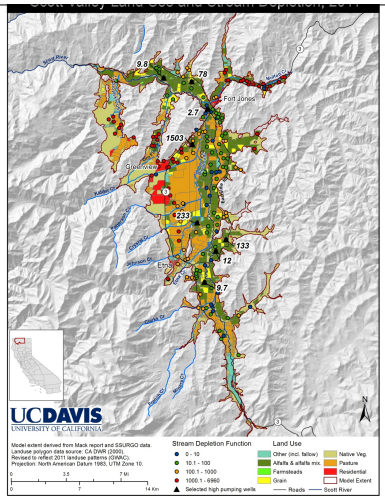
- Largest distance, a, of wells from Sac. River: ~20 miles
- Effective K: 50 ft/d
- Effective (semi-confined) storage, S: 0.01
- Effective thickness: ~100 ft

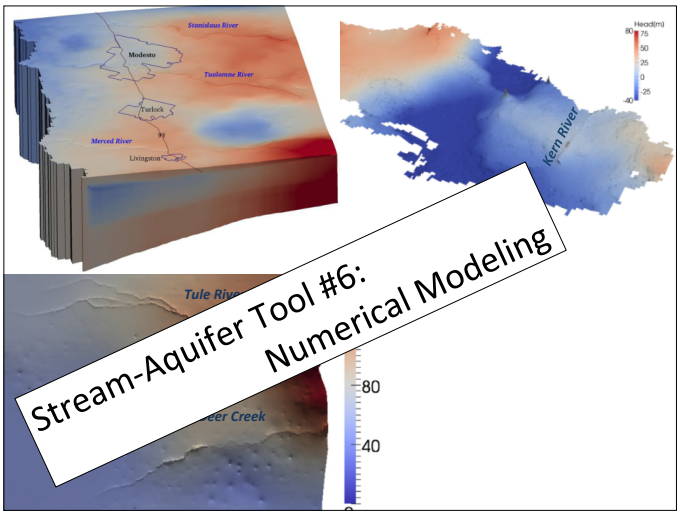
⇒SDF = decades to centuries

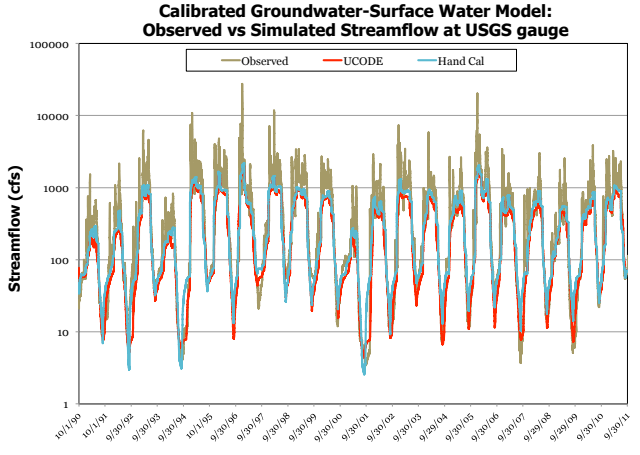


Stream Depletion Function
(Simple Analytical Model)

SDF in units of [days]

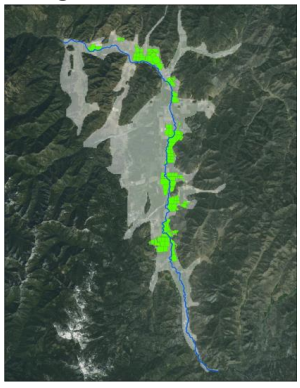


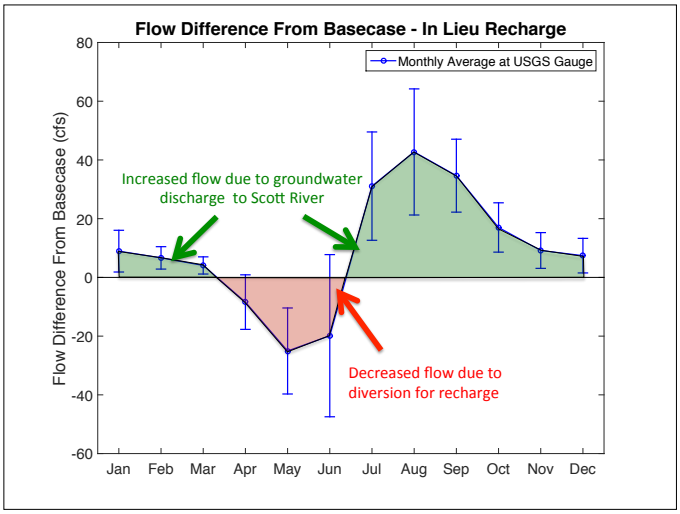




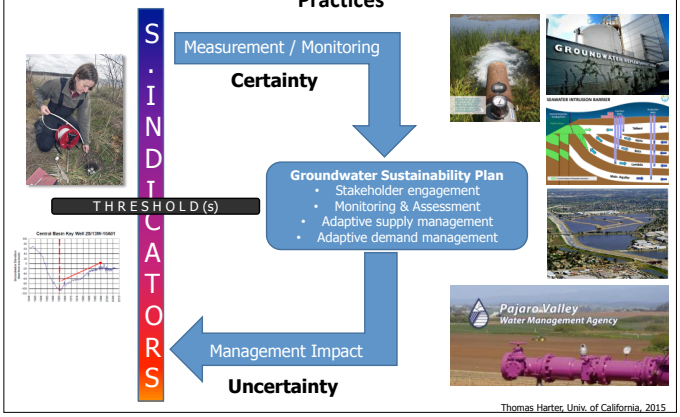
Managing the GW-SW Interface:
Example - In Lieu Recharge Scenario

- Use surface water instead of groundwater when available on selected fields
  - ~5,900 acres
- Apply additional irrigation prior to start of growing season on selected fields
  - 33% increase
- Delays portion of groundwater pumping until later in the summer





Models Useful to Define Relationship between **Measurable Objectives (MO)** and **Management Practices**



Thomas Harter, Univ. of California, 2015

Conclusion

- GDE/GW-SW Connection most important in Central/Northern California GSAs
- Historic data: lack tributary flow, near-stream water level dynamics
  - Start searching for and archiving historic data on streamflow, tributary flow, ephemeral conditions
  - Continue/expand operation of stream gages, water level monitoring
- Look for DWR to provide statewide maps for identifying:
  - Interconnected surface water systems
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- Key Tools:
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  - Water budget / baseline conditions will be an important framework for identifying groundwater-surface water fluxes
  - Statistical analysis of climate, streamflow, snow-pack, precipitation, vegetation data => identify impacts of climate change, (upland) vegetation changes
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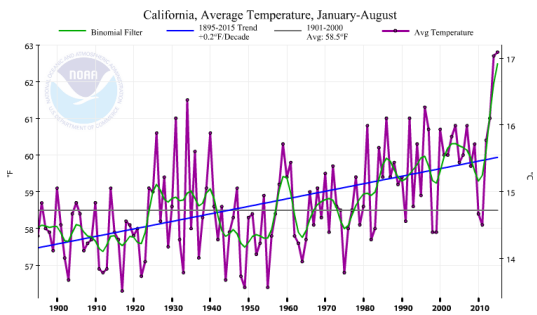
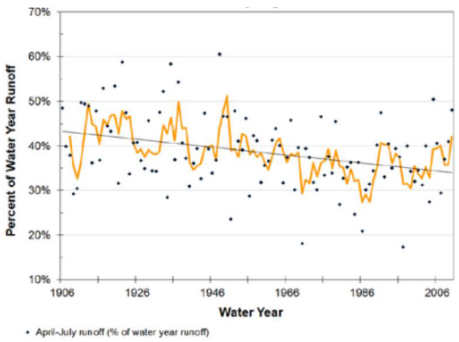
4. Some Additional Challenges

Sorting Out
Climate Impact & Vegetation Changes vs. Pumping Impact

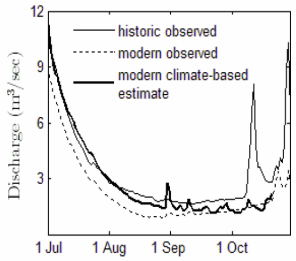


Decrease in April-July Streamflow in the Sacramento River Watershed



Climate Contribution to
Reduced Scott River Summer Streamflow:

Study 1 – statistical analysis of neighboring non-farming watersheds



Conclusion:

61% due to irrigated farming (mostly July-Aug)

39% due to climate change (all of Sep-Oct)

Kirk and Naman, 2008

Climate Contribution to
Reduced Scott River Summer Streamflow:

Study 2 – statistical analysis of September flow vs preceding snowpack and precipitation

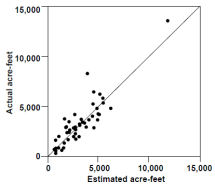
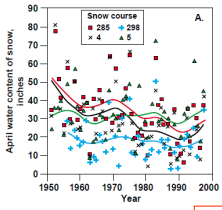


Fig. 3. Actual and estimated total September flow, acre-feet, from 1951 through 1998 (n = 48). Estimated by total September acre-feet = (2.5
+ 1.18˙ sum of previous 12 months precipitation
+ 8.6˙ precipitation in August
- 6.7˙ precipitation in July
+ .48˙ April water content at course 285
+ .25˙ April water content at course 5)²
(P = .0001, R^2 = .78)



Conclusion:

80% of reduction due to climate change (September flows)

Drake et al., 2000

Conclusion

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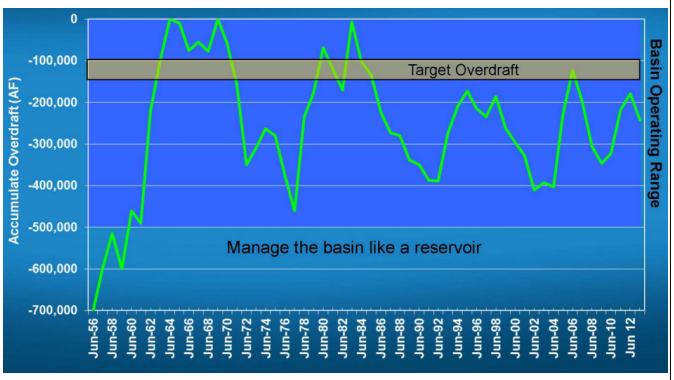
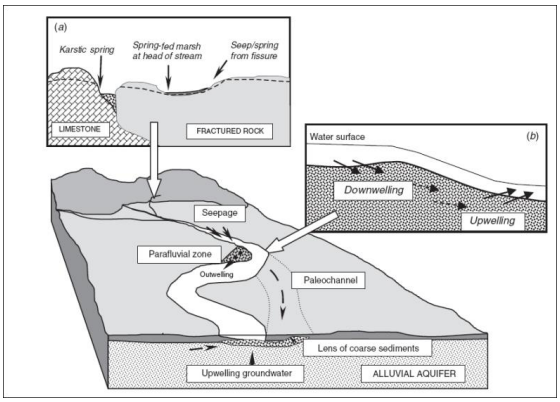
In Summary: Storage



Orange County Water District, 2014

Meandering Streams & Paleochannels

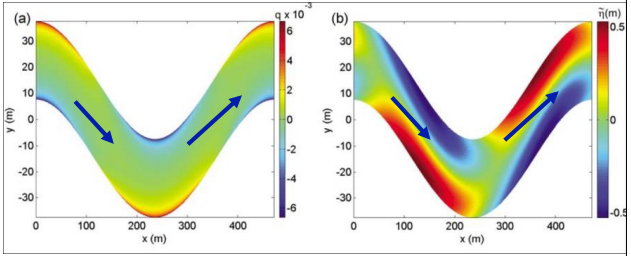


Boulton and Hancock, Austral J Botany, 2006

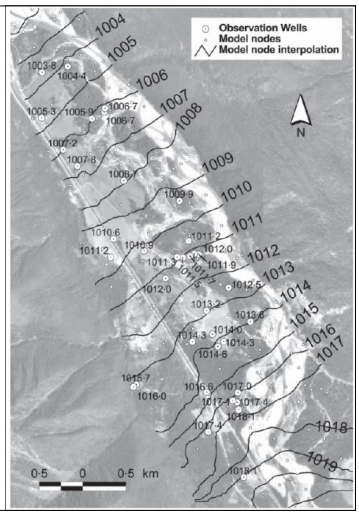
Meandering Stream Effects

Surface Water - Groundwater:
Stream Loss (red) / Gain (blue)

Deviation from Flat Streambed

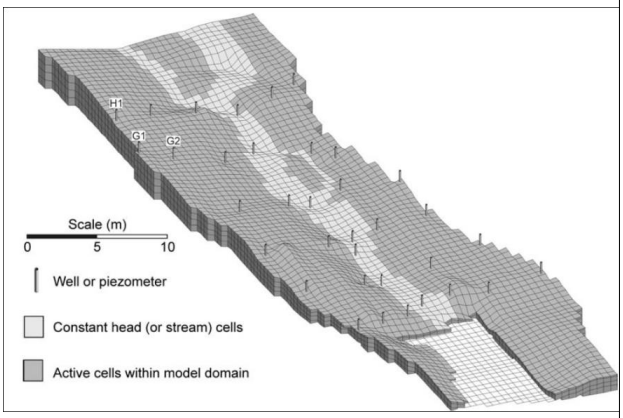


Boano et al – WRR 2010



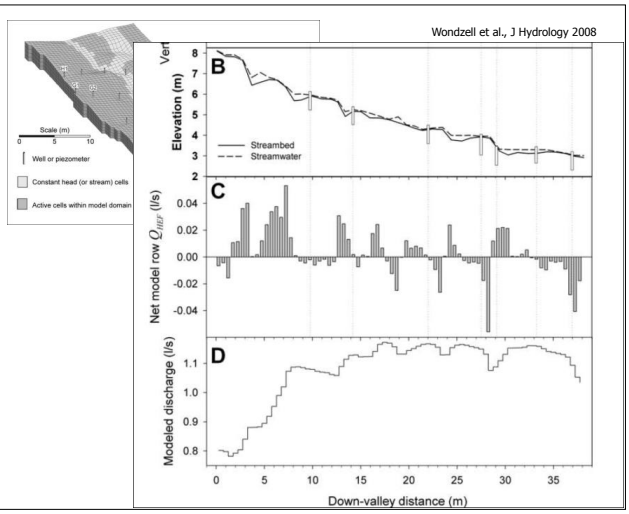
Poole et al., Earth Surface Processes 2004

Stream Geomorphology Affects GW-SW Interaction

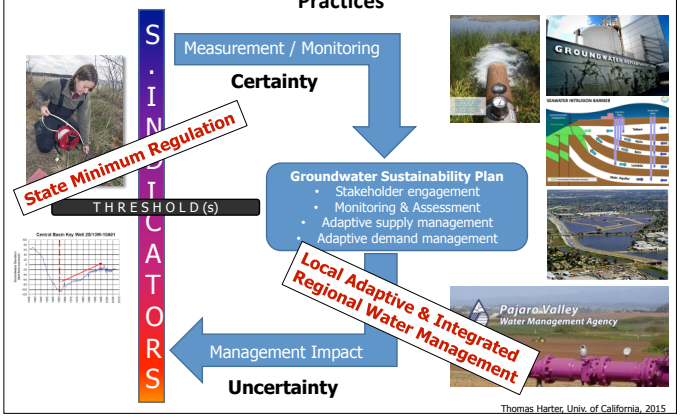


Wondzell et al., J Hydrology 2008

Wondzell et al., J Hydrology 2008



Relationship between Measurable Objectives (MO) and Management Practices



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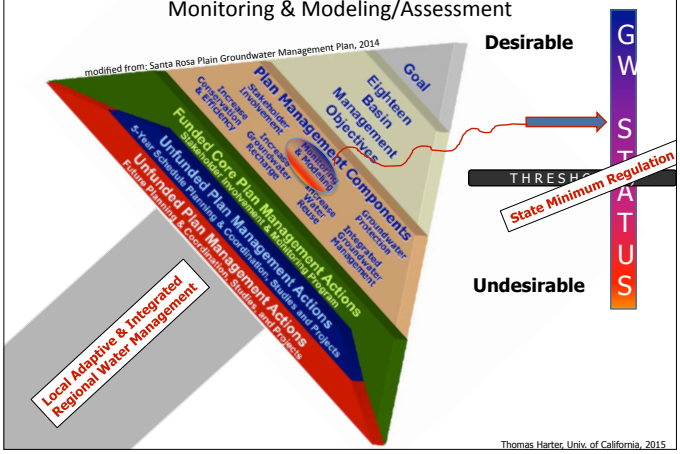
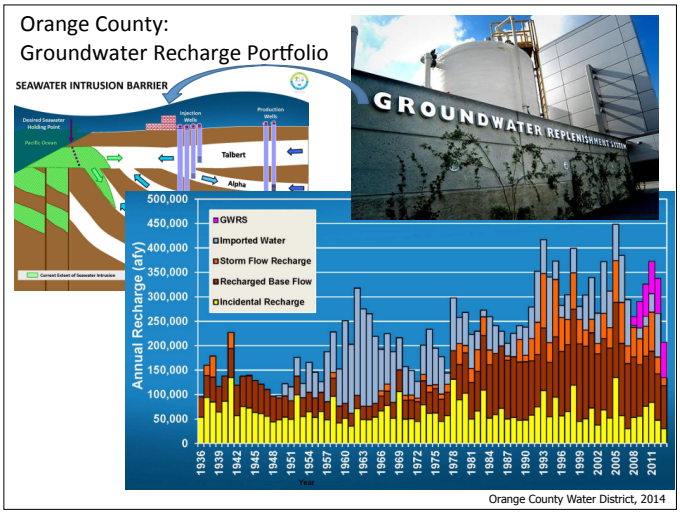
Core Link between Local Planning Effort and State Oversight: Monitoring & Modeling/Assessment



Thomas Harter, Univ. of California, 2015

Orange County: Groundwater Recharge Portfolio



Orange County Water District, 2014