Geology of Ground Water and Aquifer Management

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California Water Action Plan (CWAP) January 2014

"...water recycling, expanded storage and serious groundwater management must all be part of the mix. It is a tall order. But it is what we must do to get through this drought and prepare for the next." _ Gov. Edmund Brown



CWAP, 2014

6. EXPAND WATER STORAGE CAPACITY AND IMPROVE GROUNDWATER MANAGEMENT

"...we need to expand our state's storage capacity, whether surface or groundwater, whether big or small." CWAP

"The administration will take steps, including sponsoring legislation, if necessary, to define local and regional responsibilities and to give local and regional agencies the authority to manage groundwater sustainably..." CWAP



The Sustainable Groundwater Act AB1739, SB1168, SB1319 – passed August 2014

- "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.
- Decision makers in local government and water districts will need to understand groundwater management issues.



Groundwater can be confusing. Take for example land subsidence.

Subsidence 1925-1977. But!





From Borchers and Carpenter, 2014.

<u>Land Subsidence from Groundwater</u>

Use in California

LETTER

doi:10.1038/nature13275

Uplift and seismicity driven by groundwater depletion in central California

Colin B. Amos¹, Pascal Audet², William C. Hammond³, Roland Bürgmann^{4,5}, Ingrid A. Johanson⁴ & Geoffrey Blewitt³

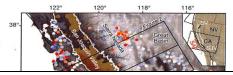
Groundwater use in California's San Joaquin Valley exceeds replenishment of the aquifer, leading to substantial diminution of this resource1-4 and rapid subsidence of the valley floor5. The volume of groundwater lost over the past century and a half also represents a substantial reduction in mass and a large-scale unburdening of the lithosphere, with significant but unexplored potential impacts on crustal deformation and seismicity. Here we use vertical global positioning system measurements to show that a broad zone of rock uplift of up to 1-3 mm per year surrounds the southern San Joaquin Valley. The observed uplift matches well with predicted flexure from a simple elastic model of current rates of water-storage loss, most of which is caused by groundwater depletion3. The height of the adjacent central Coast Ranges and the Sierra Nevada is strongly seasonal and peaks during the dry late summer and autumn, out of phase with uplift of the valley floor during wetter months. Our results suggest that long-term and late-summer flexural uplift of the Coast Ranges reduce the effective normal stress resolved on the San Andreas Fault. This process brings the fault closer to failure, thereby providing a viable mechanism for observed seasonality in microseismicity at Parkfield⁶ and potentially affecting long-term seismicity rates for fault systems adjacent to the valley. We also infer that the observed contemporary uplift of the southern Sierra Nevada previously attributed to tectonic or mantle-derived forces7-10 is partly a consequence of human-caused groundwater depletion.

Hydrospheric mass changes exert direct influence over lithospheric deformation. Both seasonal and long-term changes to ice, snow or water loads may induce displacements of the Earth's surfaceit-15 and can create stress perturbations that modulate activity on seismogenic faults¹⁶⁻¹⁹. A volume of groundwater approaching approximately 160 km² in California's Central Valley has been lost through pumping, irrigation and evapo-

transpiration over the past 150 years or so^{3,4}. Historical and modern

Continuous GPS networks spanning the southwestern USA provide a high-resolution framework for analysing crustal motion in three dimensions (Fig. 1). Longer available records and recently improved processing techniques enable determination of reliable GPS vertical velocities with a precision 32 of less than a millimetre per year, ited to the Earth system's centre of mass to within 0.5 mm yr $^{-1}$ (refs 24 and 25). GPS station data were processed to create individual time series of vertical position and were then fitted with an empirical model including epoch position, velocity, and the amplitude and phase of annual and semiannual harmonic components (to model seasonal effects). This analysis includes only stations with at least two-and-a-half years of data and vertical rate uncertainties of ≤ 1.0 mm yr $^{-1}$ (566 stations). Details of the GPS analysis and processing techniques are included in the Methods.

Figure 1 shows the distribution of vertical GPS rates across central California and east of the Sierra Nevada into the Great Basin. Long-term rates exclude GPS stations located within the San Joaquin Valley ground-water basin that display comparatively large signals owing to their position on soft sediment. These stations are affected by compaction-driven subsidence through loss of pore water⁵, poro-elastic deformation related to groundwater level fluctuations⁵⁶, local irrigation and other processes unrelated to solid earth motion.



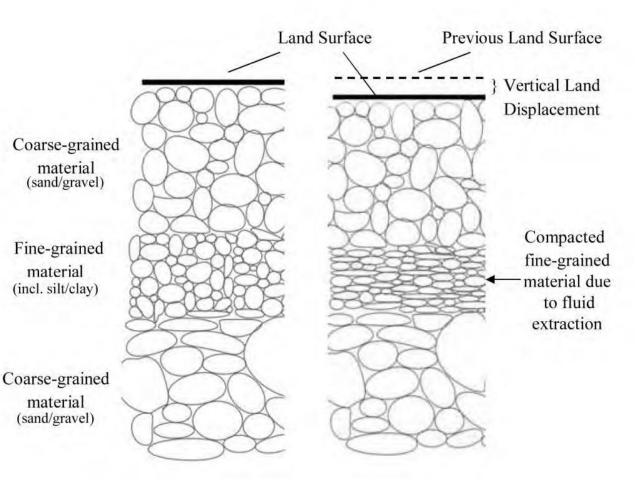
Subsidence or Uplift? Which is it?



Subsidence



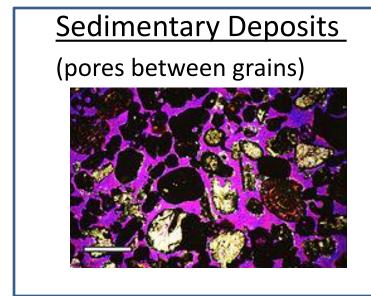
Casing of an abandoned gas well protrudes more than 46 cm (1.5 ft) higher than when it was painted 2 years earlier. (CWF, 2014)

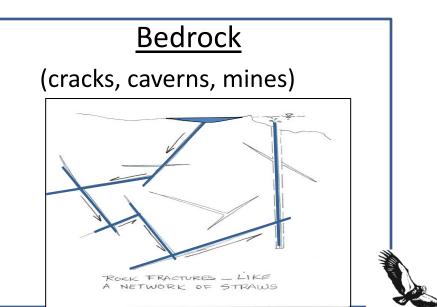


• Groundwater is from precipitation in the watershed.

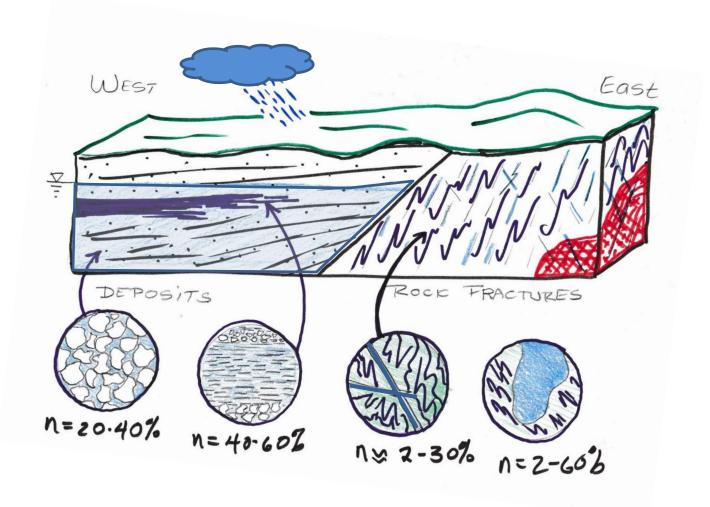
There are no underground rivers from unlimited distant sources. There is only water stored in soil over thousands of years.

Groundwater fills rock voids



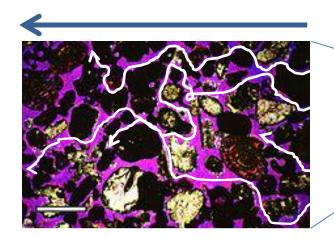


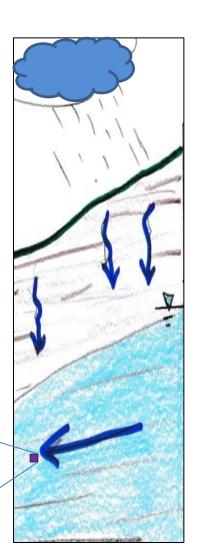
• Groundwater fills openings in deposits and rocks.





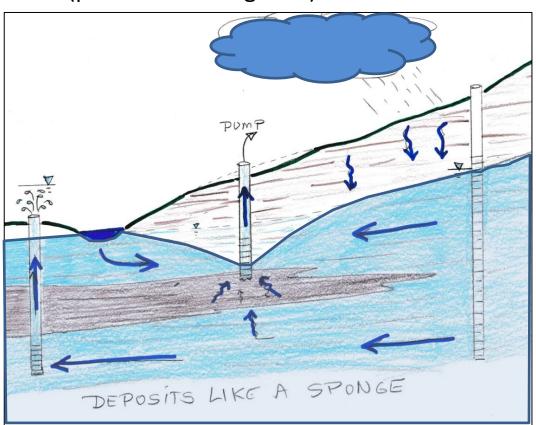
- Recharge is slow: "2,200 to 13,400 years before present in Eastern San Joaquin Groundwater Sub-basin" USGS, OFR 2012-1049.
- Flow is tortuous: linear velocity of water particles in a silty-sand aquifer <1 to <200 ft/year.



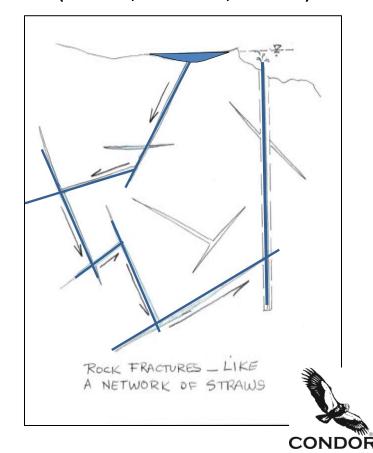


 Groundwater is pushed (or sucked) through openings by hydraulic pressure gradients.

Sedimentary Deposits (pores between grains)

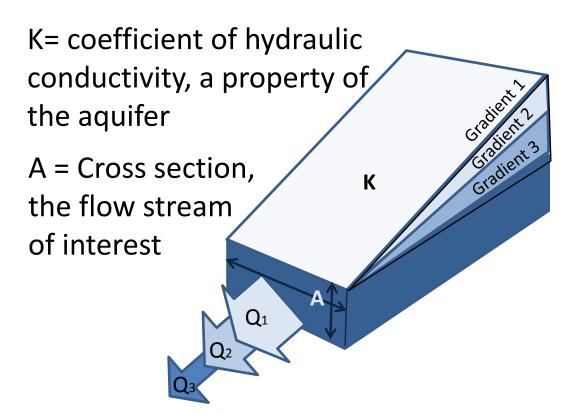


Bedrock (cracks, caverns, mines)



Hydrogeology Basics Q = -KA i

Flowrate = Conductivity x cross section x gradient How much water flows through the land?



i = Gradient, the dropin head pressure alonga flow path that drivesflow

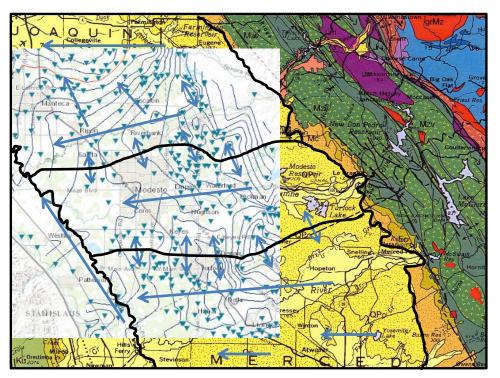
Aquifers are managed by controlling gradients with artificial recharge and wells

Declining gradients reduce flow

Geology Controls Aquifer Geometry, Storage and Transmissivity

Groundwater Basins are underground reservoirs.

They initially mirror surface watersheds with dimples and pimples under wells and recharge centers.



Deposits from rivers, beaches, dunes, lakes and seas form wedge-shaped layers in this area with different storage and Transmissivity.

Foothill bedrock forms aquifer boundaries and hosts fracture pathways.

Low storage and Transmissivity, small glacial basins.

Aquifer Storage and Recovery

• Buckets of recoverable storage anywhere? Not.

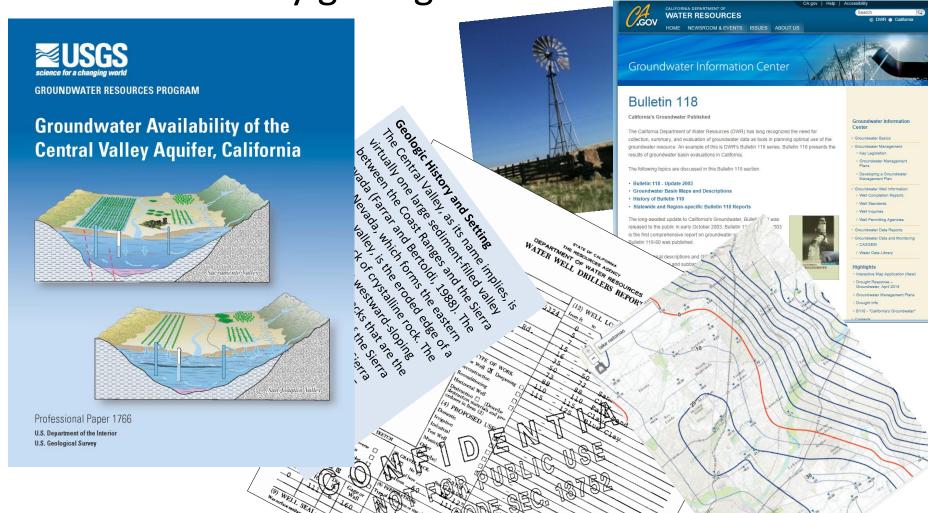
Las Posas Basin Aquifer Failure Illustrates Risks Of Underground Reservoirs

AP By Michael R. Blood and Elliot Spagat

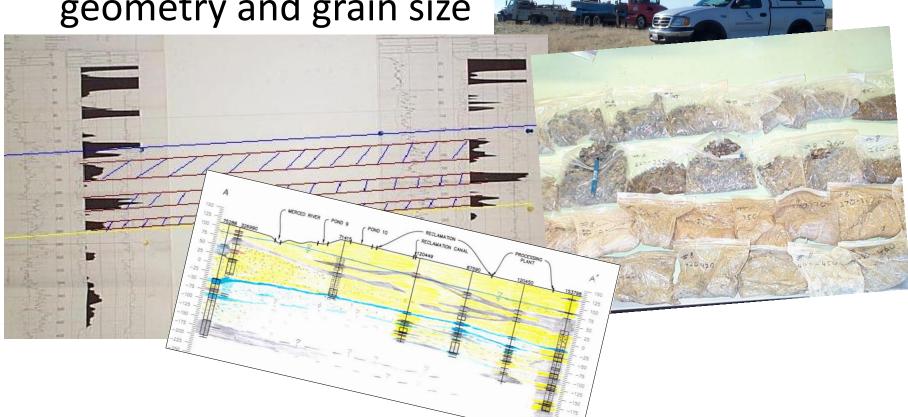


"...the venture was marred by insufficient research, poor judgment and hollow assurances — all with a hefty price tag for ratepayers. The cost, estimated in 1995 at \$47 million, has gradually tripled to about \$150 million. More than \$56 million in long-term debt remains... 'What was known about the basin wasn't the whole picture,' said Calleguas general manager Susan Mulligan. 'It doesn't work for a drought. The basin doesn't store it."

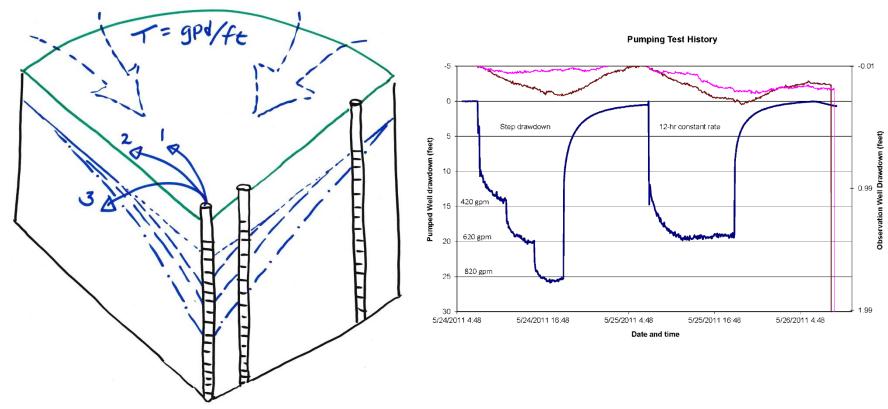
Preliminary geological research



 Drilling and geophysics for measuring aquifer geometry and grain size

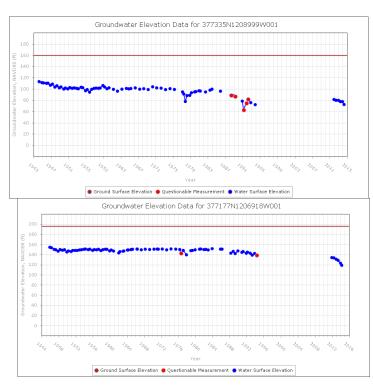


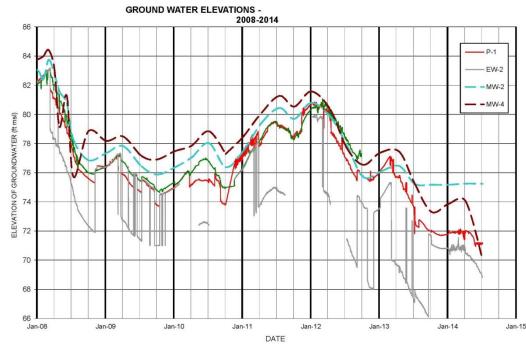
 Pumping Tests – to estimate Transmissivity and storage of aquifer, efficiency of well



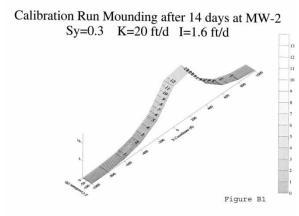
Aquifer Transmissivity in gpd/ft (linear), specific yield of well in gpm/ft (drawdown)

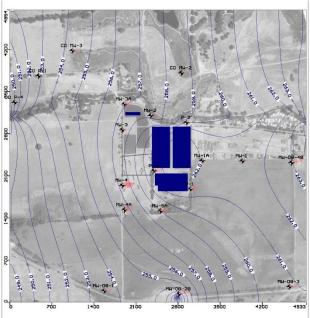
Monitoring Well Hydrographs (pressure heads)

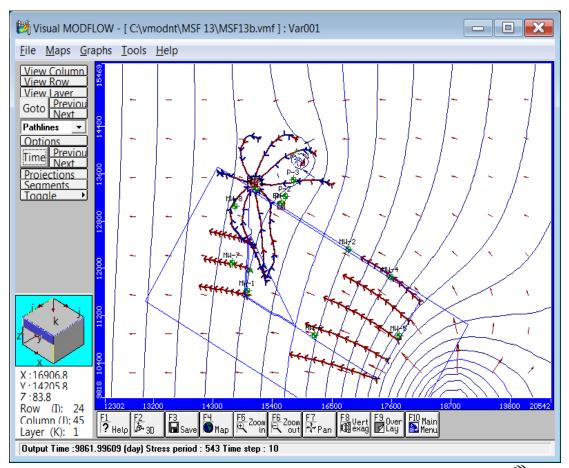




Groundwater Modeling





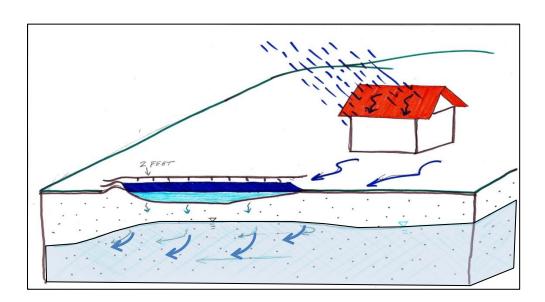




Aquifer Recharge

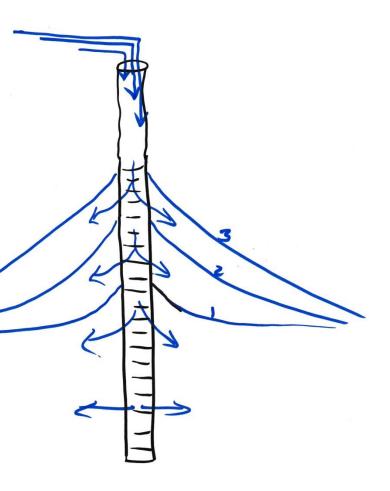
Infiltration Basins – most used technique

Groundwater mounds up under recharge sources, increasing the gradient that drives groundwater flow away from center.



Aquifer Recharge

- Injection Wells
 - Can target specific layers or zones
 - Can be reversed for recovery
 - Special designs and maintenance
 - Requires disinfection and filtration



Conclusion

- The California Water Action Plan calls for Sustainable management of groundwater basins.
- Groundwater is out of sight but is not mysterious- it's occurrence and flow are intuitive and obvious if you understand the basic principles.
- Decision makers should rely on thorough hydrogeologic characterizations to manage aquifers in their basins.
- Hydrogeologists study aquifers to understand where water is stored, how much is there, and how it flows through the land.

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