Safe Yield of Aquifers

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The program:

- **1: Groundwater in the semi-arid West: the role of pronounced <u>climatic variability</u>;**
- **2: The safe yield of aquifer: an important yet elusive concept;**
- **3: Methods and example.**

The safe yield

- **"safe yield (= perennial yield = basin yield) The maximum quantity of water that can be continuously withdrawn from a groundwater basin without adverse effect".**

  CDWR **Bulletin** 118, 2003

The estimate is made over a <u>representative</u> period

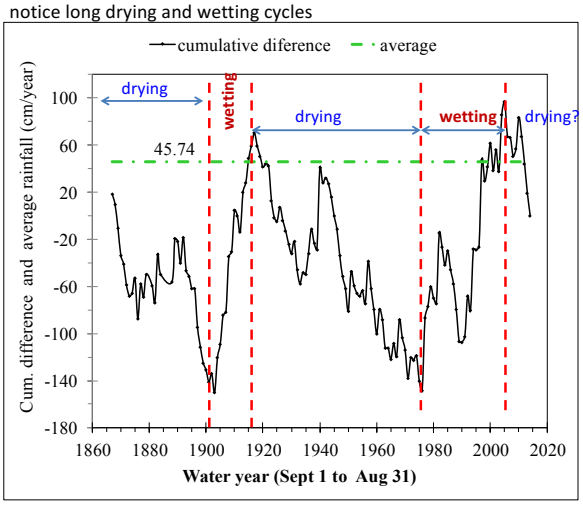
Why the safe yield?

- **The adjudication of groundwater rights commonly revolves about the safe yield;**
- **It is central to groundwater management as a baseline for groundwater extraction;**
- **The theory behind the safe yield is far from settled.**

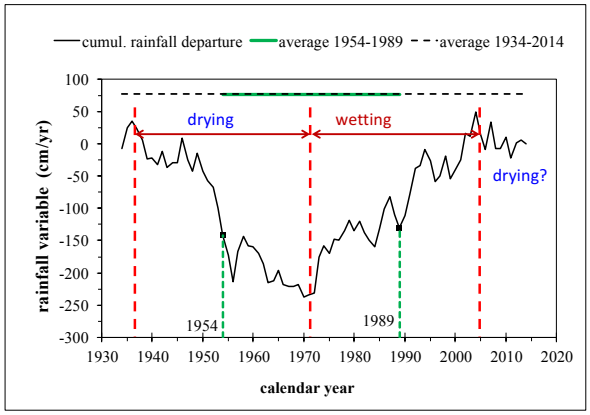
Representative climatic period

- must reflect long-term average hydrologic conditions;
- must include at least one period of overall wet conditions and at least one of overall dry conditions relative to average annual conditions;
- have an average precipitation that is close to the average precipitation for the entire period of record;
- the beginning of the representative period must be an interval of relatively dry conditions to preclude large initial aquifer storage that could anomalously reduce recharge

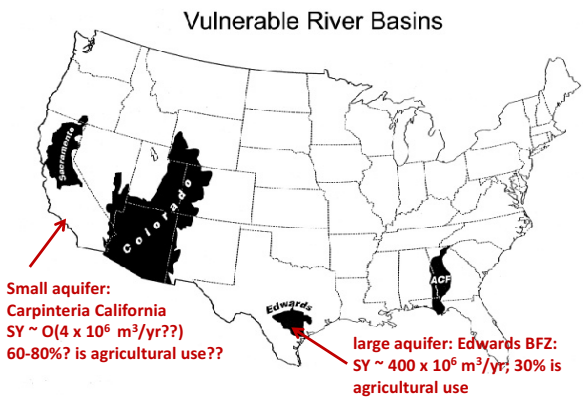
Representative period Carpinteria GWB: large inter-annual variability of precip./recha
notice long drying and wetting cycles



Representative period Edwards: 1954-989. Notice long drying-wetting cycles and large interannual variability of precip. / recharge



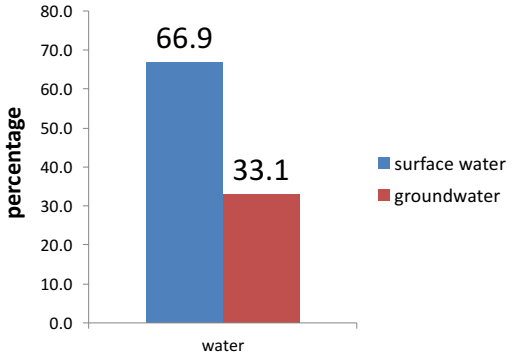
Two aquifers with ag service: different sizes



Small aquifer:
Carpinteria California
SY ~ O(4 x 10^6 m^3/yr??)
60-80%? is agricultural use??

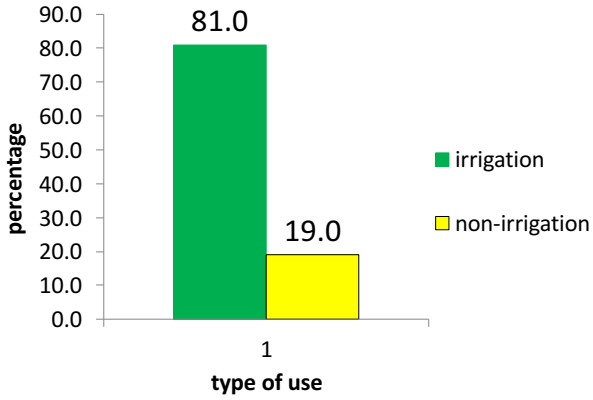
large aquifer: Edwards BFZ:
SY ~ 400 x 10^6 m^3/yr; 30% is agricultural use

population 7 of the states Colorado River Basin: ~ **58 million** (2010)

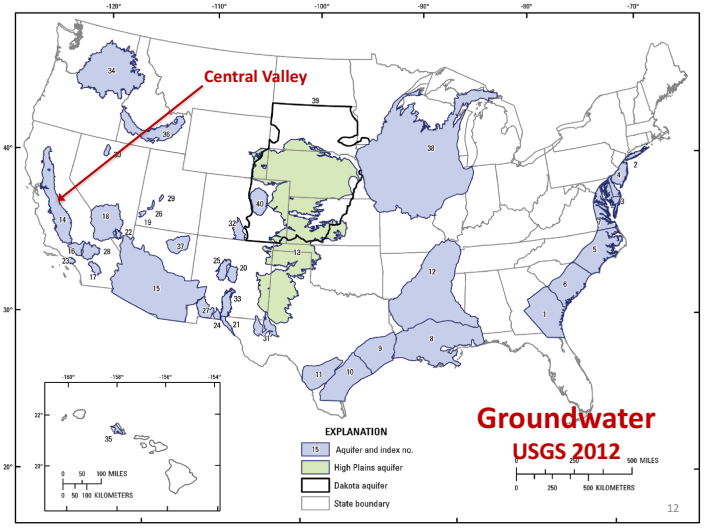


Source data USGS 2014

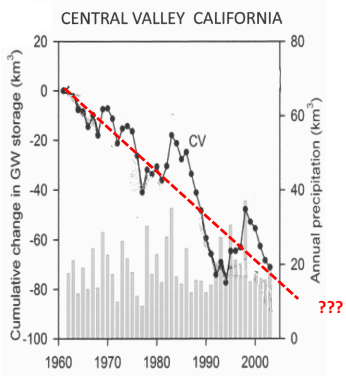
Fresh water use 7 of states Colorado River basin (year 2010)



Source data USGS 2014



OVERDRAFT : "… when the amount of water extracted exceeds the amount of ground water recharging the basin over the long term": CDWR Bulletin 118-2003

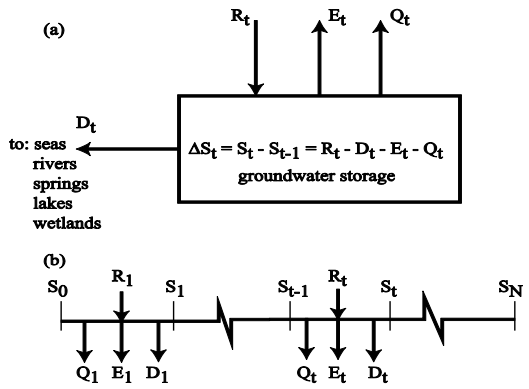


Adapted from Scanlon et al 2012

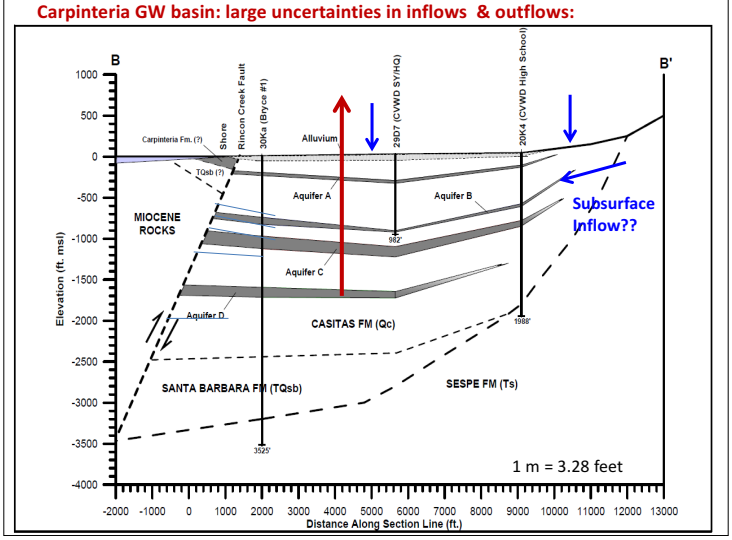
Another key definition

- Recharge: water that enters groundwater storage
- Naturally or by human action

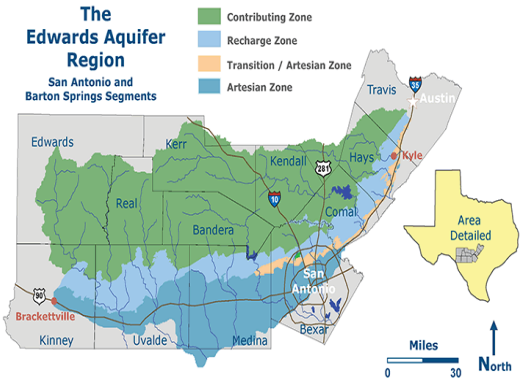
Long-term fluxes and groundwater basin balancing are needed for safe yield estimation.



Carpinteria GW basin: large uncertainties in inflows & outflows:

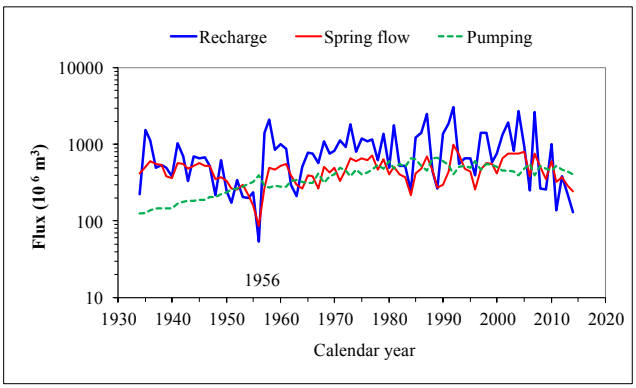


Edwards: recharge is mainly by stream seepage across recharge zone; well extraction is measured; spring discharge is measured



1 mile = 1609 meters

Edwards aquifer groundwater balance: excellent data 1934-2015



Part of the struggle over Edwards GW

- Several impacted species, among which
- fountain darter *(Etheostoma fonticola*, a fish*),*
- the Comal Springs riffle beetle *(Heterelmis comalensis),*
- the Texas wild-rice *(Zizania texana),*
- and the Texas blind salamander *(Eurycea rathbuni)*

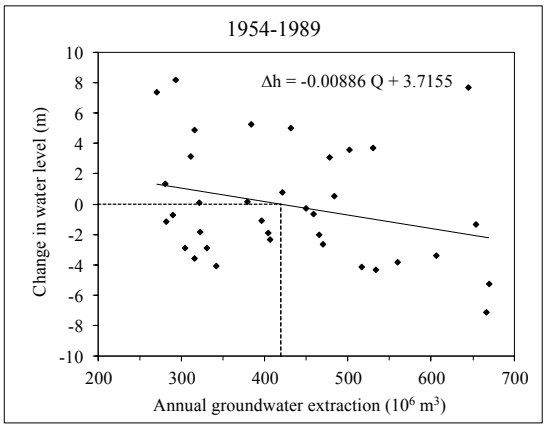
Methods to estimate safe yield (Loáiciga 2016)

- From inflow and outflow (annual average R, D, E over the **climatically representative period**)

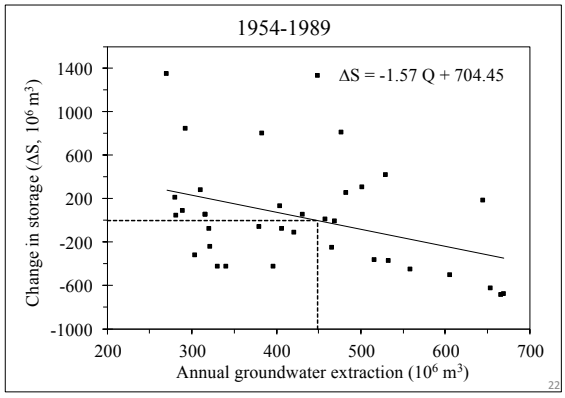
  $Q_{safe} = R - D - E$ average annual fluxes

- From average annual extraction and change in groundwater storage (annual average ΔS, Q over the **climatically representative period**)
- $Q_{safe} = \Delta S + Q$ where $\Delta S = \text{sum}(S_{storat} \times \text{Area} \times \Delta h)$

Methods to estimate the safe yield continued
Δh(basinwide) vs Q [EDWARDS]
(annual values)

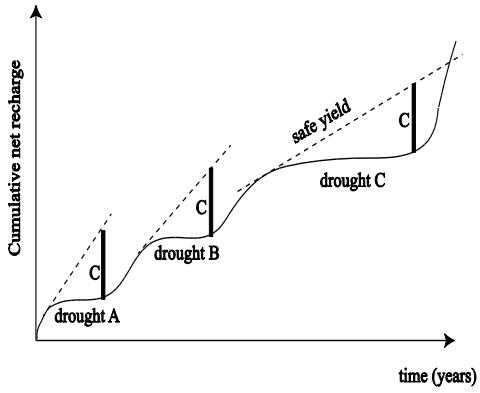


Methods to estimate the safe yield continued
ΔS vs Q where $\Delta S = \text{sum}(S_{storat} \times \text{Area} \times \Delta h)$ [EDWARDS]
(annual values)

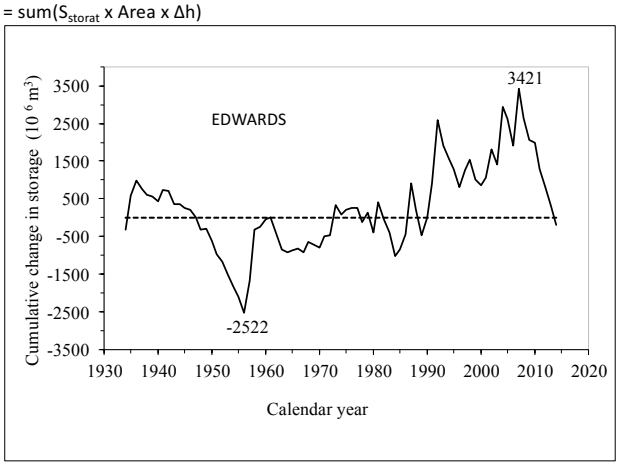


Methods to estimate the safe yield continued

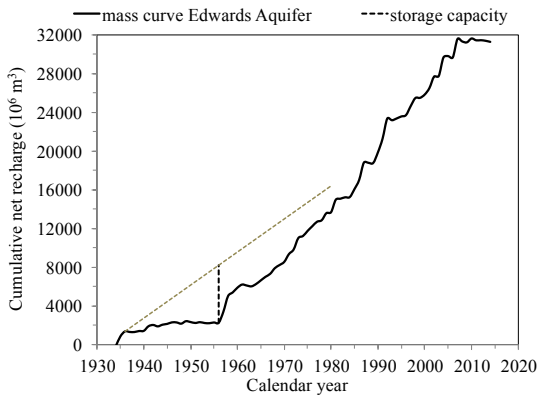
Mass-curve analysis: cumulative net recharge = sum(R-D-E)



Storage capacity (C) from cumulative change in storage: need LONG time series
This is a lower bound estimate of C, implies a relatively low Safe Yield; C ↑ 5943 MCM
Or $C = \text{sum}(S_{storat} \times \text{Area} \times \Delta h)$



MASS CURVE ANALYSIS EDWARDS



SUMMARY OF RESULTS EDWARDS AQUIFER

Method	period	Q_{safe} 10^6 m^3/yr
R – D – E (averages annual)	1954-1989	459
	1934-2014	386
Δh vs Q (annual values)	1954-1989	419
	1934-2014	327
ΔS vs Q (annual values)	1954-1989	449
	1934-2014	384
Mass curve analysis	1954-1989	Not applicable
	1934-2014	342

Final Remarks

- To manage groundwater basin sustainably one must MEASURE Q, R, D, E, h
- measure the aquifer: S_{storat}; T; Area, thickness
- It may take many decades or centuries in climatically variable regions to ascertain the safe yield
- GW management must be adaptive to climatic fluctuations