Groundwater Modeling and Management: Recharge, Storage, and Local Opportunities

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Groundwater Enrichment Session
Water Supply Advisory Committee
and City of Santa Cruz
Louden Nelson Community Center
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The Recharge Initiative
Replenish • Recover • Restore
www.rechargeinitiative.org

Groundwater, Aquifers, and Basins

Groundwater: subsurface water that occurs below the water table within geologic formations that are saturated (pore spaces filled).

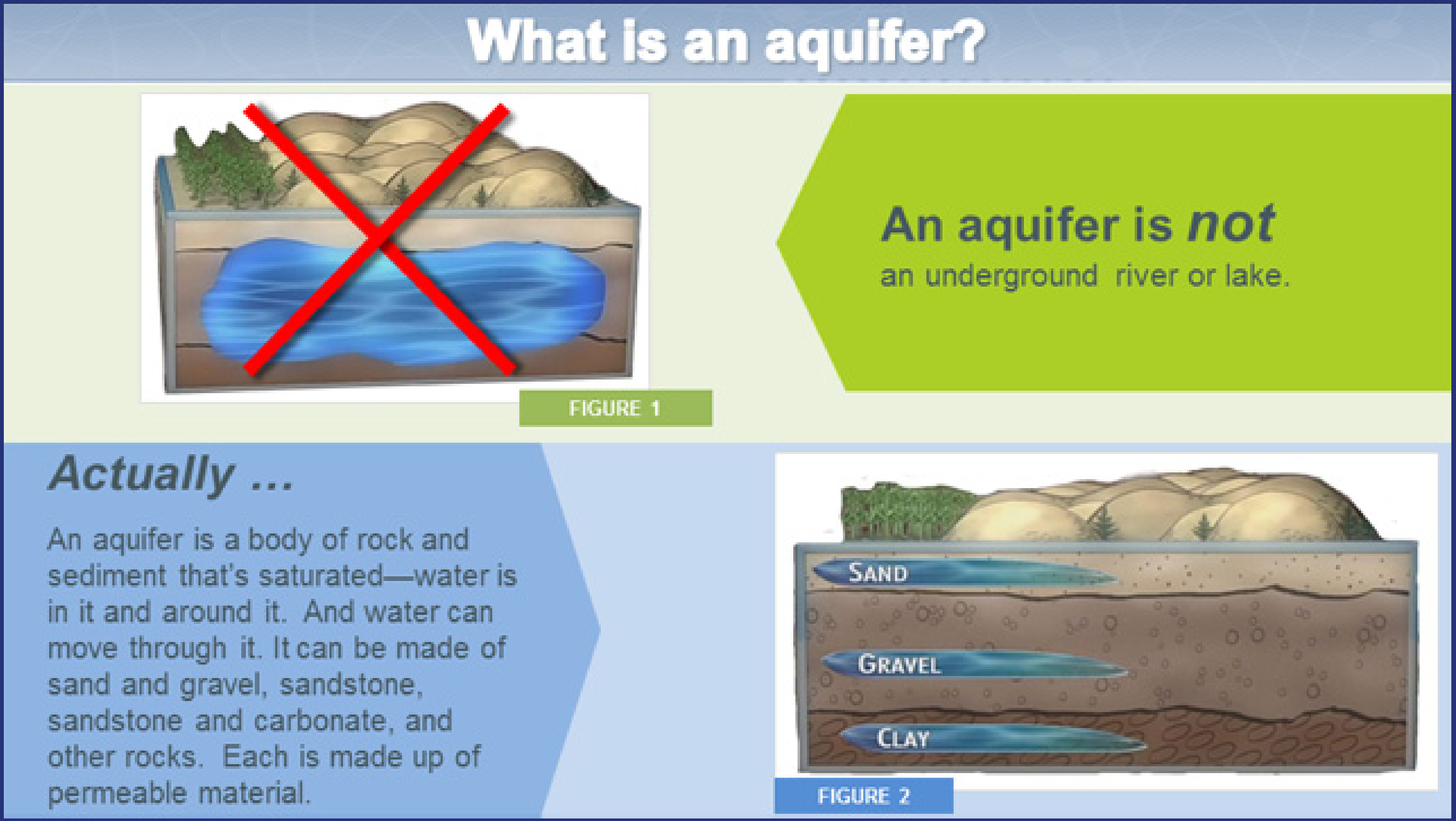
- does not include soil water (important for plants and microbes)
- most groundwater occupies pore spaces between grains or within cracks in rock (almost never = underground rivers)

Aquifer: a geological unit that can both <u>store</u> and <u>transmit</u> water in usable quantities.

Groundwater basin: an area underlain by aquifers, the limits of which are <u>barriers</u> and <u>flow divides</u>

- the aquifer(s) may comprise a complex, three-dimensional region, denoted on maps in two dimensions
- may be delimited on the basis of political or legal boundaries

Imagining Groundwater



- Conditions and aquifer extent often cryptic
- Water rarely stays in place, tends to flow

Image source: science.kqed.org

Types of Aquifers and Wells

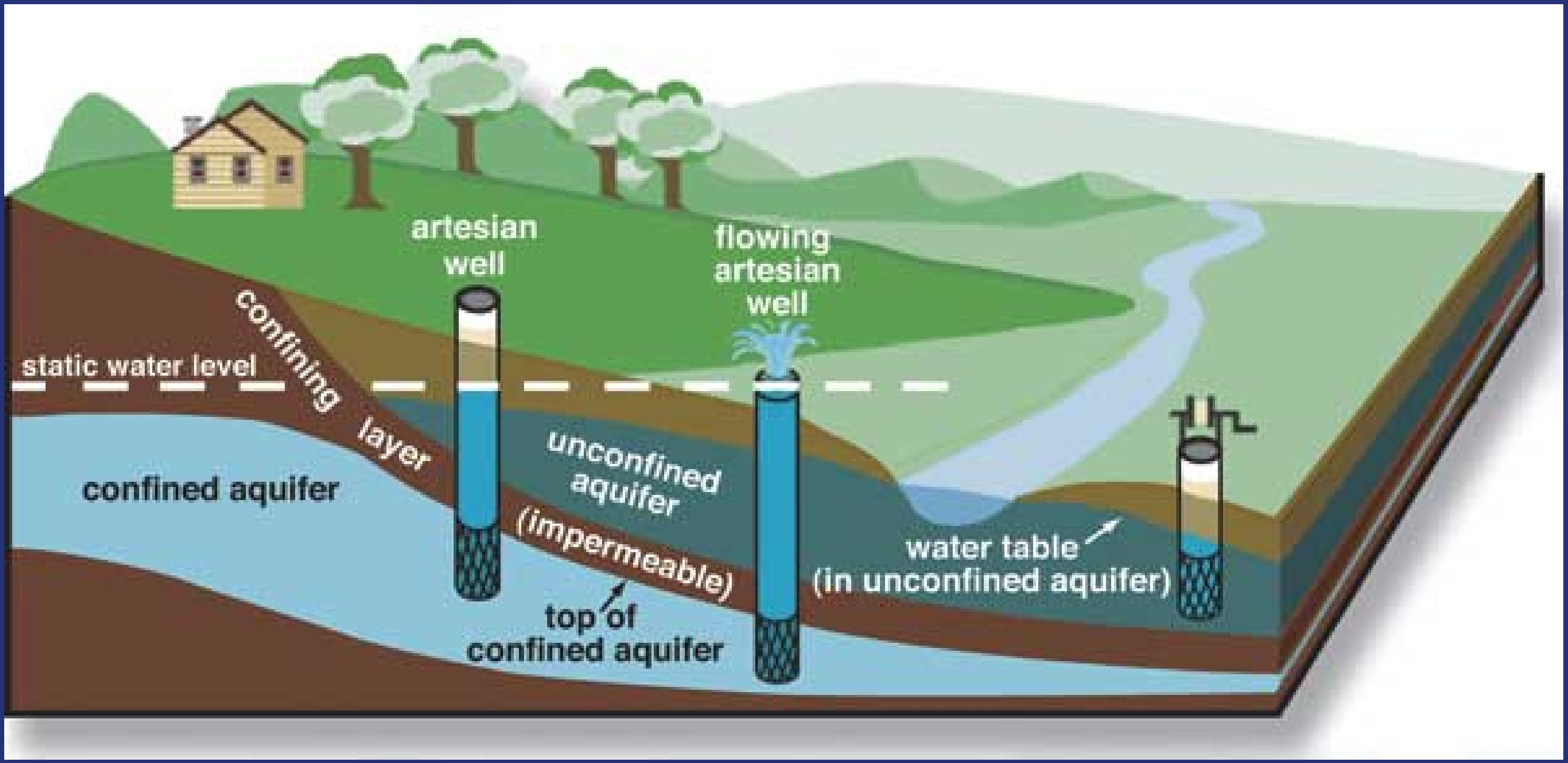
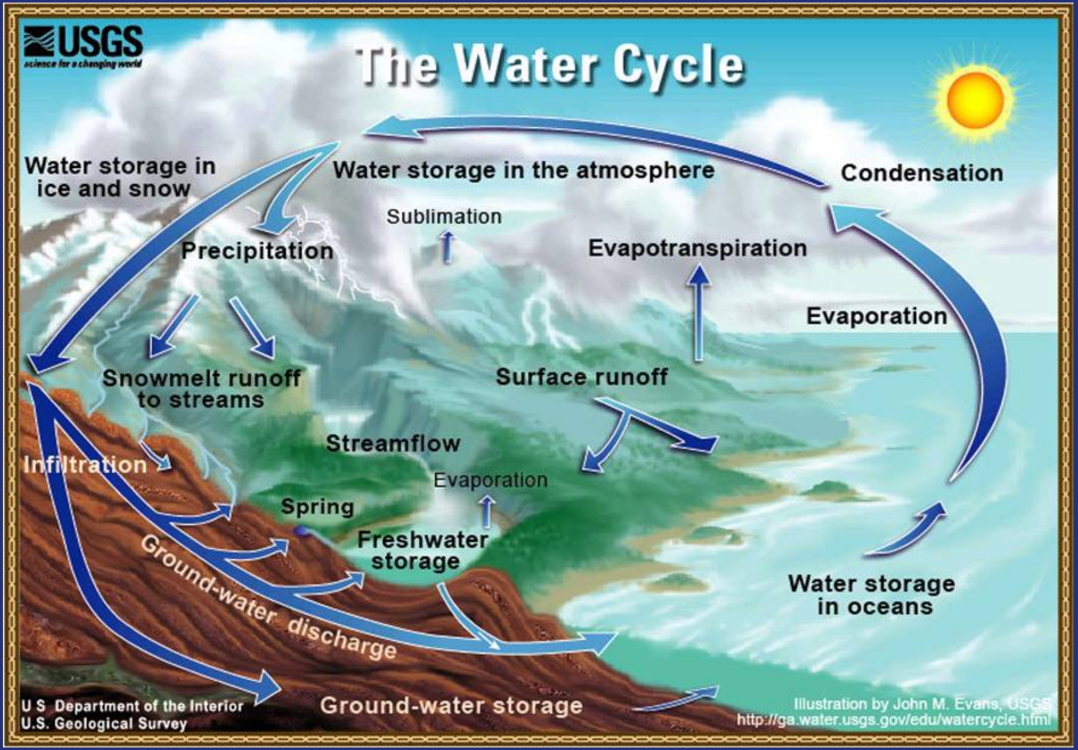


Image source: Water Education Foundation

Groundwater as Part of a Larger Cycle



Groundwater is:

- a critical reservoir
- in motion
- a buffer against drought
- subject to overuse
- important to surface flows
- sustainable *(SGMA, 2014)*

Groundwater <u>recharge</u> is:

- largest form of inflow to most aquifers
- a process that can be enhanced through established practices
- influenced by surface water conditions (quantity and quality)
- critical for long-term water security and sustainability
- difficult to measure directly!

Image source: USGS

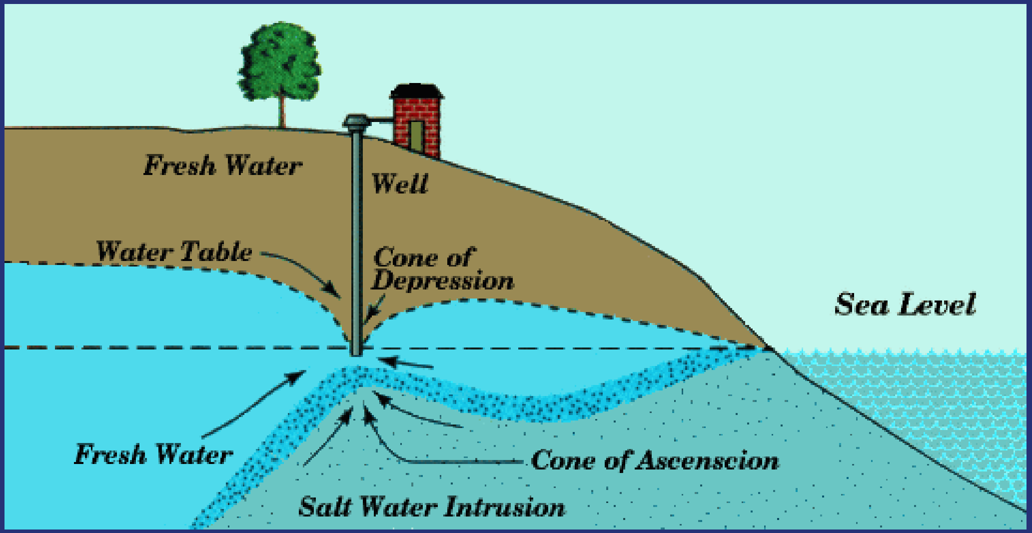
More Jargon: Yield, Overdraft

Sustainable yield: the amount of water that can be pumped from an aquifer *over the long term* without causing *unacceptable* harm.

- "*unacceptable*" is someone's definition (physical, economic, political, legal, social, biological, perhaps even hydrologic)
- "*long term*" also depends on perspective
- is *related* to recharge but not the same as recharge
- a.k.a., "safe yield," "basin yield," etc.

Groundwater overdraft: a condition within a groundwater basin in which the amount of water pumped over the long term exceeds the sustainable yield of the basin.

Groundwater overdraft can lead to numerous undesirable conditions and processes

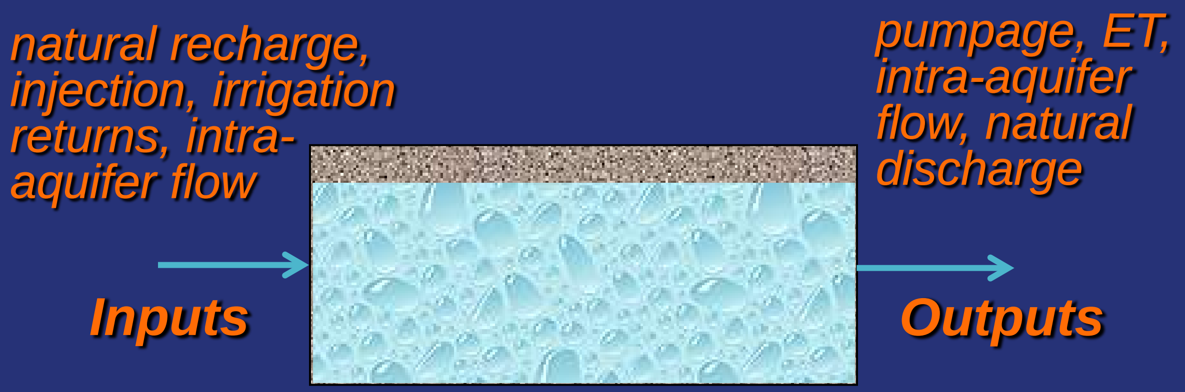


Overdraft can cause:

- seawater intrusion
- subsidence
- permanent loss of storage
- loss of stream or wetland flow
- development of dry gaps
- damage to riparian habitat
- lowering of water quality

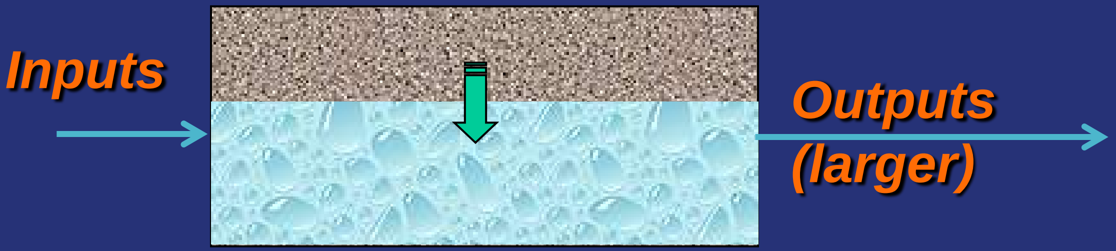
Sustainable yield is <u>not</u> the same as recharge

Initial conditions



- *When sum of inputs is balanced by some of outputs, <u>storage remains constant</u>*
- *Storage is indicated by water levels in the basin – can be high or low at steady state*

Modified conditions

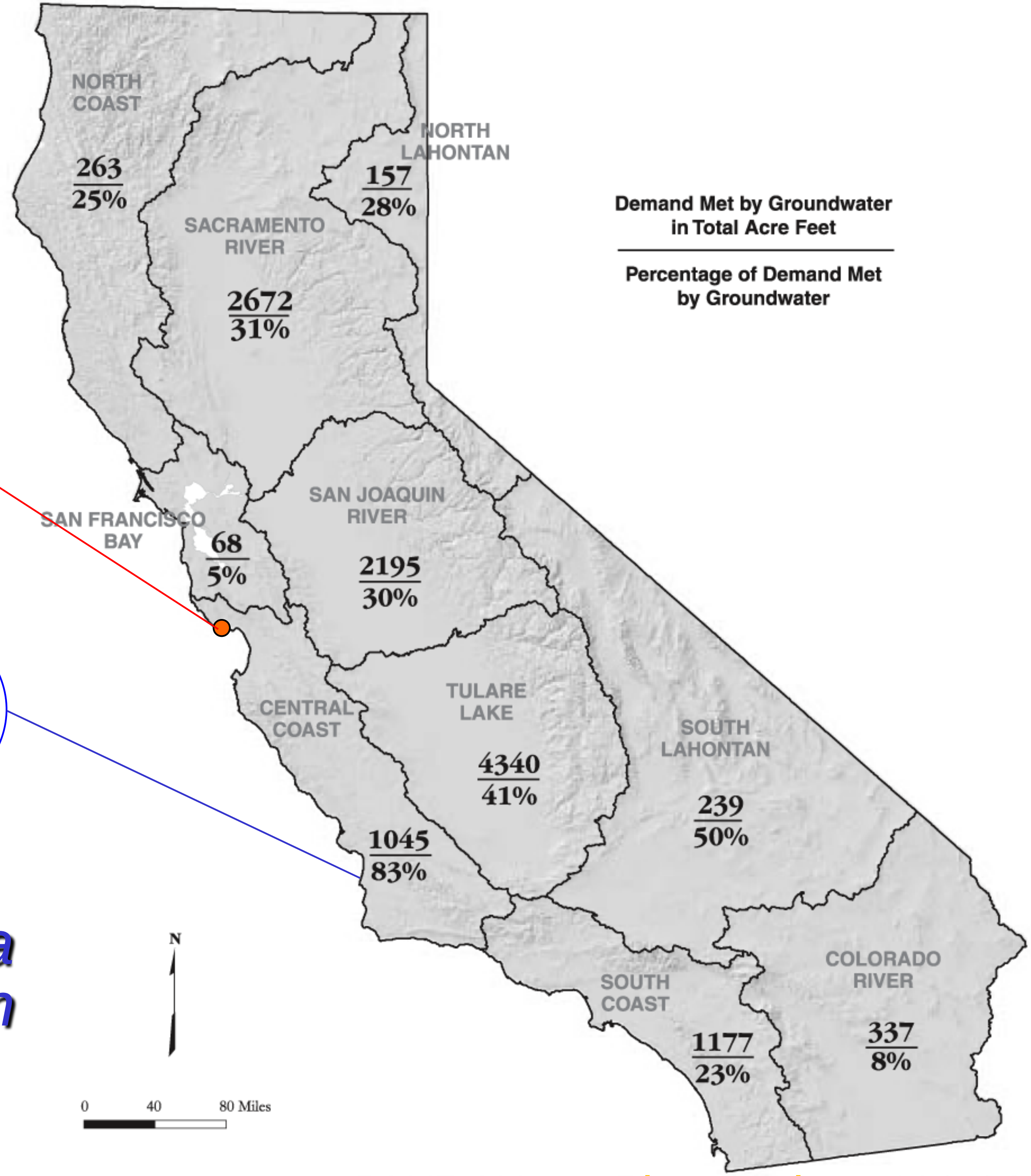


- *When outputs > inputs, storage decreases*
- *Lowering amount in storage can have a feedback on inputs and outputs*
- *Outputs do not get to "choose" the source of their inputs*

Sustainability requires consideration of both flows and storage

Central Coast: heavily reliant on groundwater

You are here



GW = 83% of demand

Simultaneously a challenge and an opportunity for our region

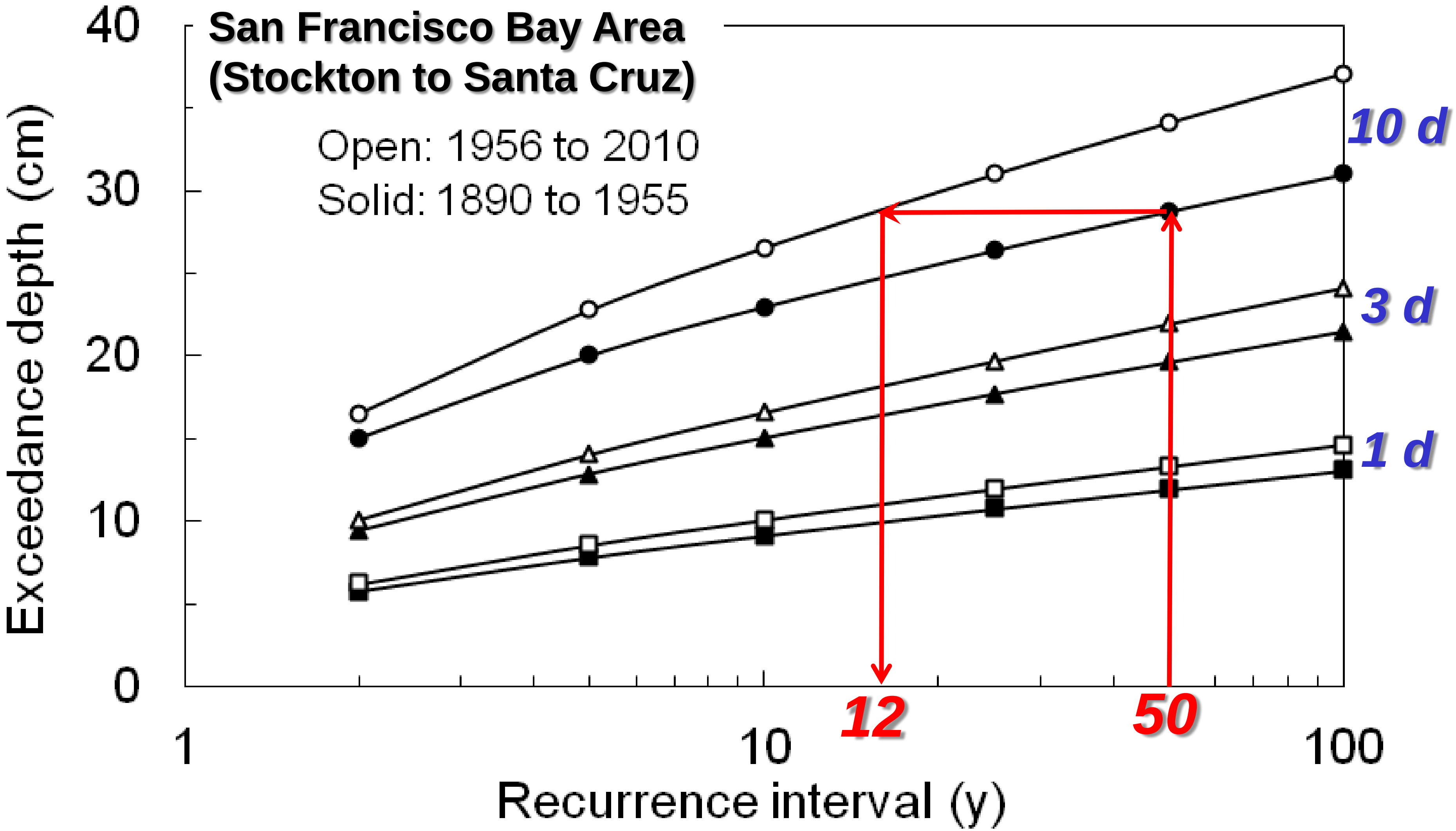
DWR Water Plan Update 160-98

Central Coast: Virtually "off the grid" in terms of large-scale water transfers

You are here

Central Coast hydrologic region

Storm intensity has increased in last 120 years, with largest storms changing most



Changes in storm intensity are greater than changes in annual precipitation

modified from Russo et al. (2013)

Implications for Resource Management

Increasing storm intensity tends to mean:

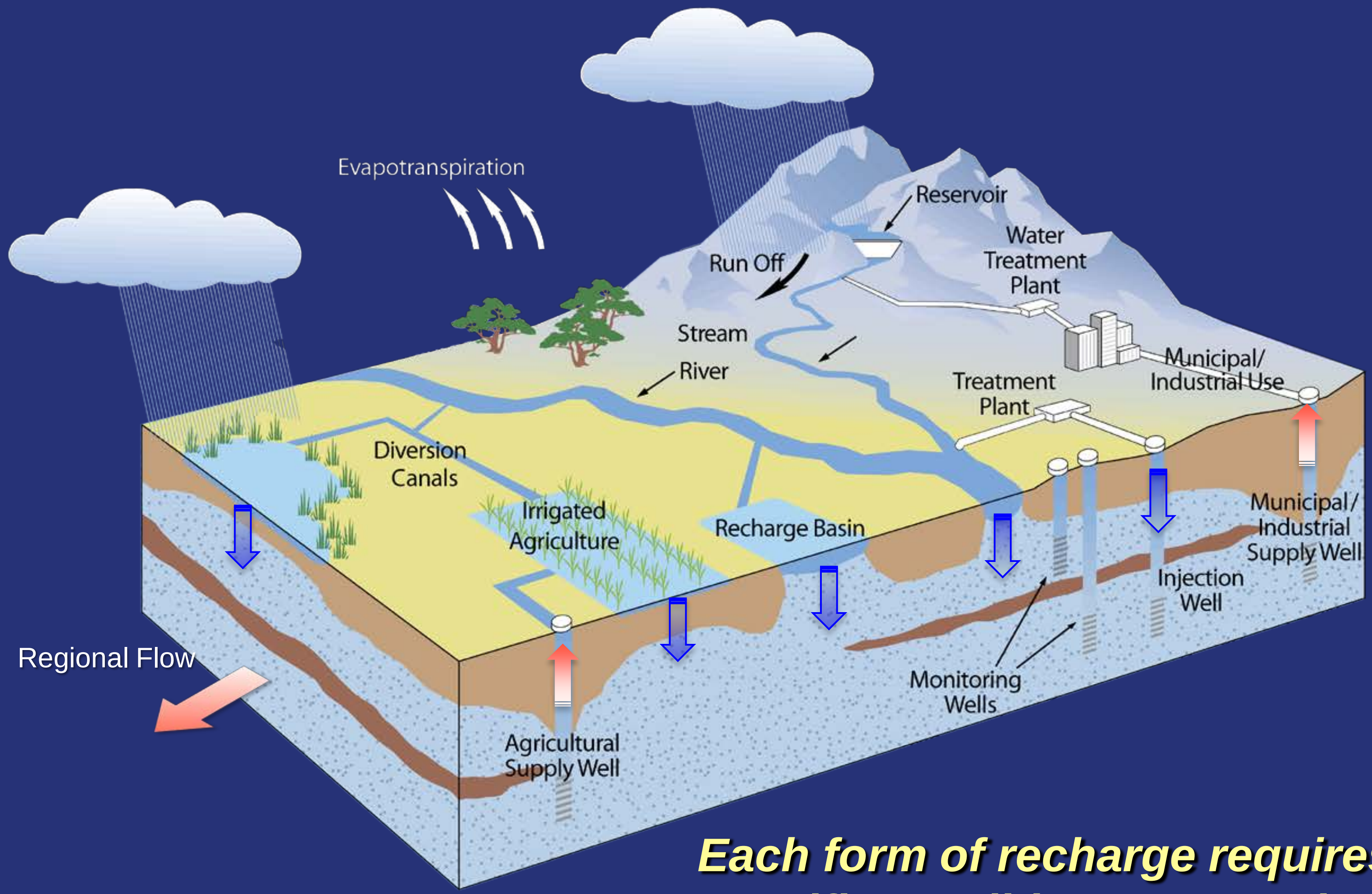
- *a large fraction of runoff (versus infiltration)*

→ ***less groundwater recharge***

Other impacts:

- *more rapid peak discharge (more frequent flooding)*
- *more erosion and export of sediment*
- *infrastructure not designed for current and future conditions*

Many forms of groundwater recharge (natural, managed)



Each form of recharge requires specific conditions, properties, design, operations –

"all recharge is local"

Many forms of groundwater recharge (natural, managed)

Groundwater recharge

- ***Natural*** **recharge**
  - Regional (precipitation)
  - Streambed
  - Irrigation
- ***Managed*** **recharge**
  - Well recharge
    - *Confined aquifer wells*
    - *Water table wells*
    - *Vadose zone wells*
    - *Single purpose (injection) or dual purpose (ASR)*
  - Surface recharge (*MAR*)
    - *Stream bank filtration*
    - *Spreading basin/trench*

- *In lieu recharge* (substitute another source)
- *conjunctive use* (co-manage surface water and groundwater supplies)

Different Scales of Managed Recharge

Low-impact development (LID)

Regional spreading grounds

Different Scales of Managed Recharge

Low-impact development (LID)

1-10 af/yr per site

Regional spreading grounds

10^4-10^5 af/yr per site

Stormwater as a Source for MAR

Low-impact development (LID)

1-10 af/yr per site

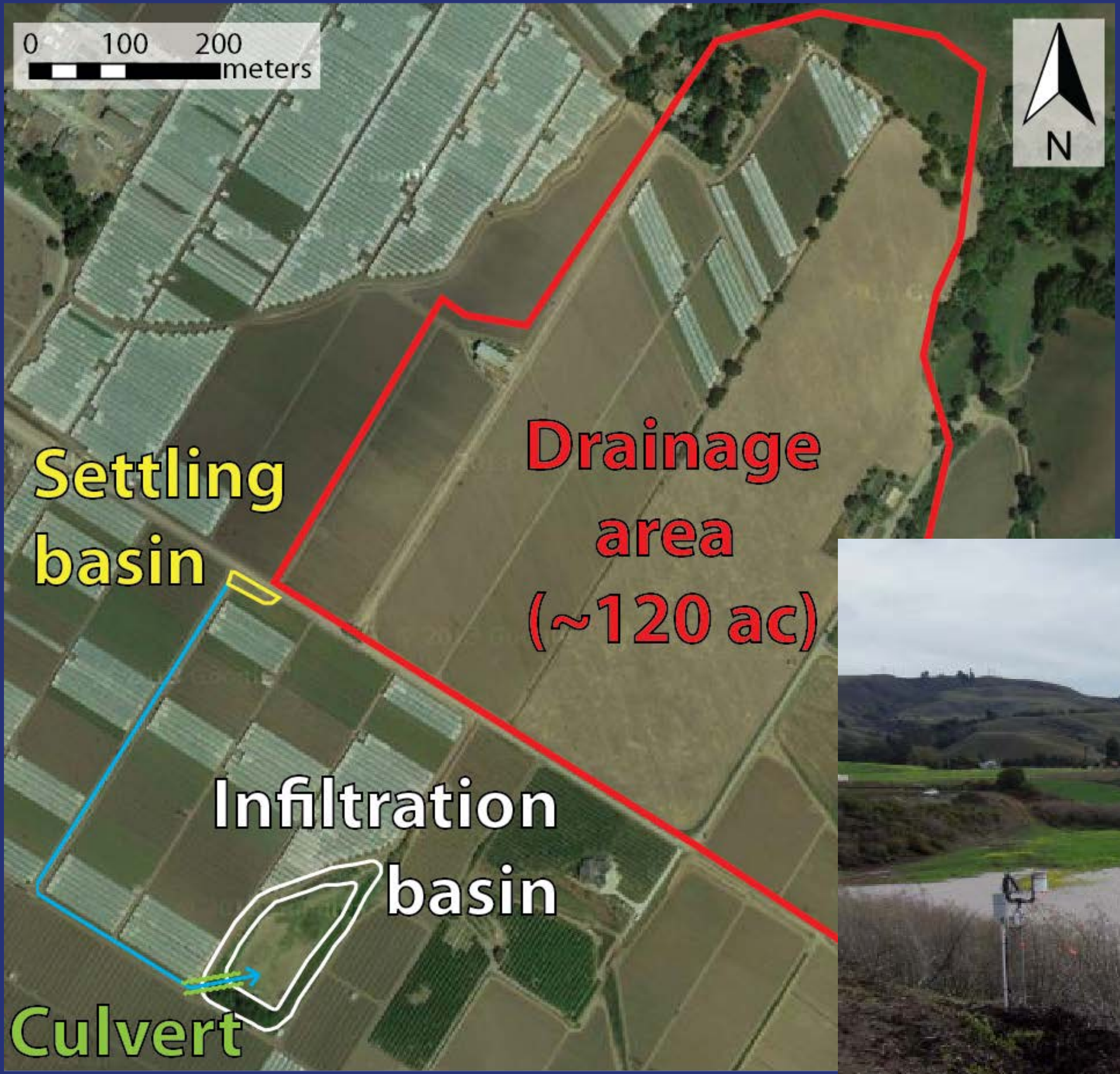
Distributed Stormwater Collection → MAR (DSC-MAR)

10^2-10^3 af/yr per site

Regional spreading grounds

10^4-10^5 af/yr per site

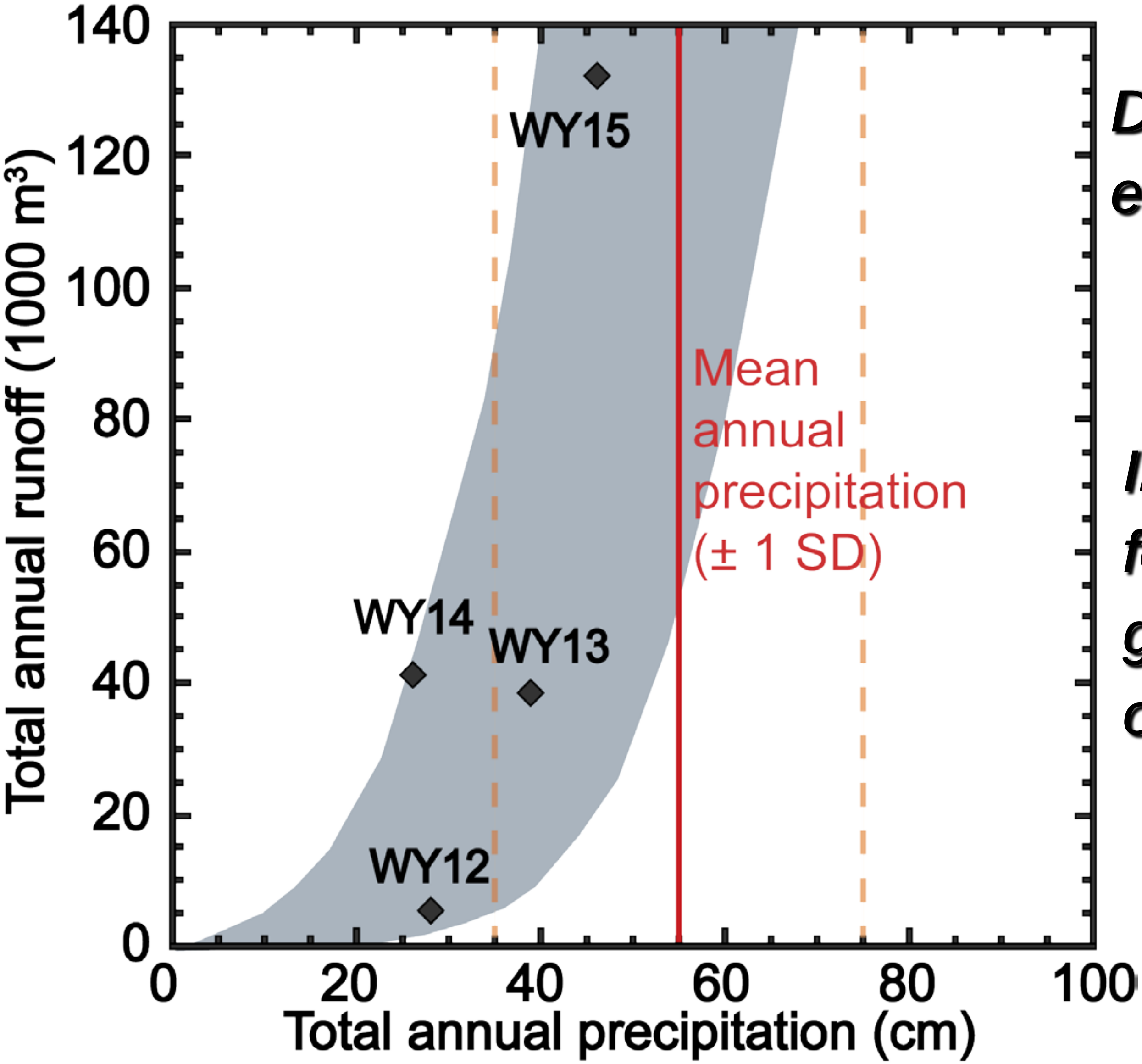
Stormwater as a Source for MAR: Field Example



DSC-MAR

S. Beganskas, A. Fisher

Stormwater as a Source for MAR: Field Example

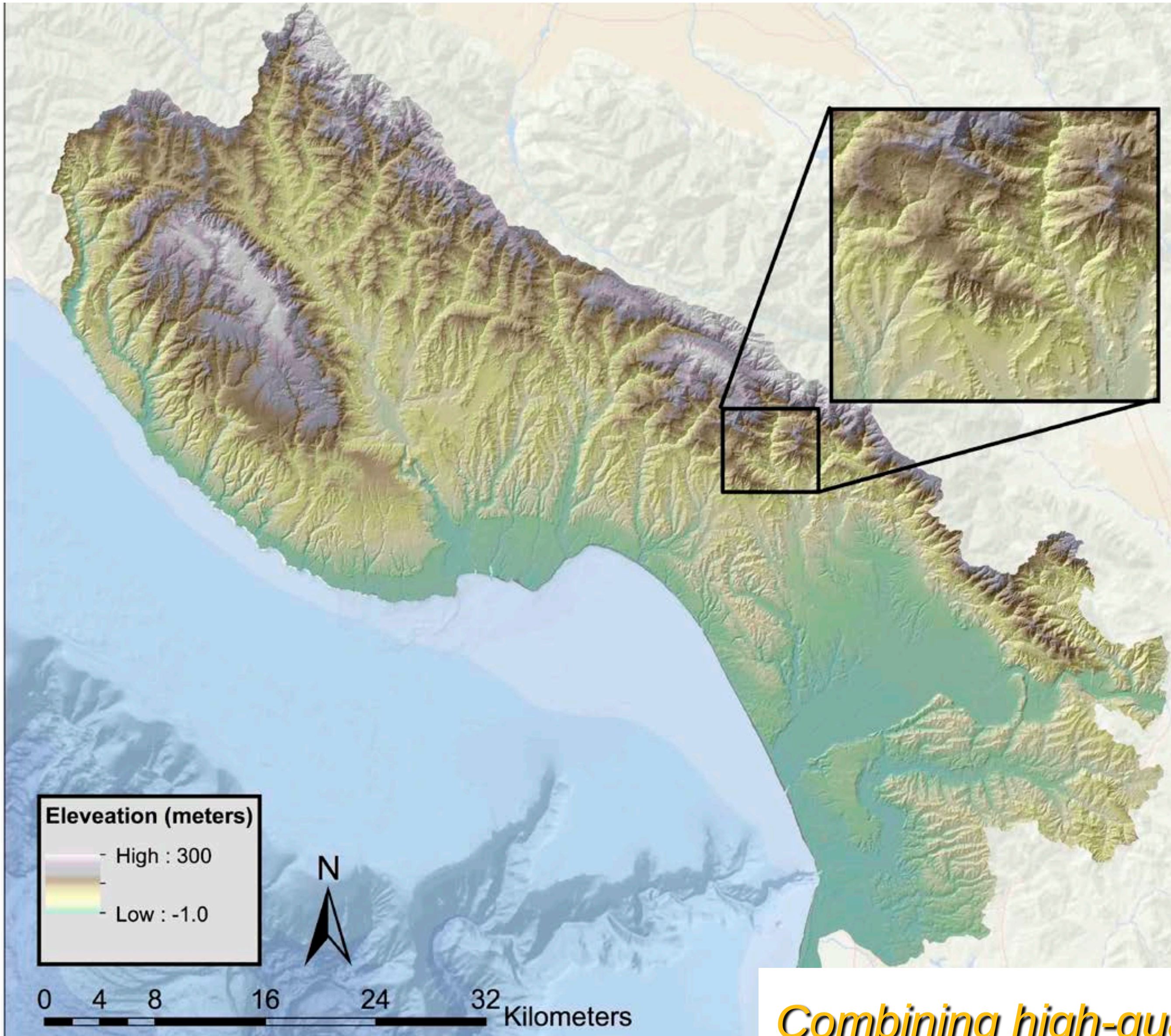


DSC-MAR can work, even during a drought

In WY15, most rain fell in a single week, generated > 100 af of runoff/infiltration!

S. Beganskas, A. Fisher

Where to Place DSC-MAR Projects?

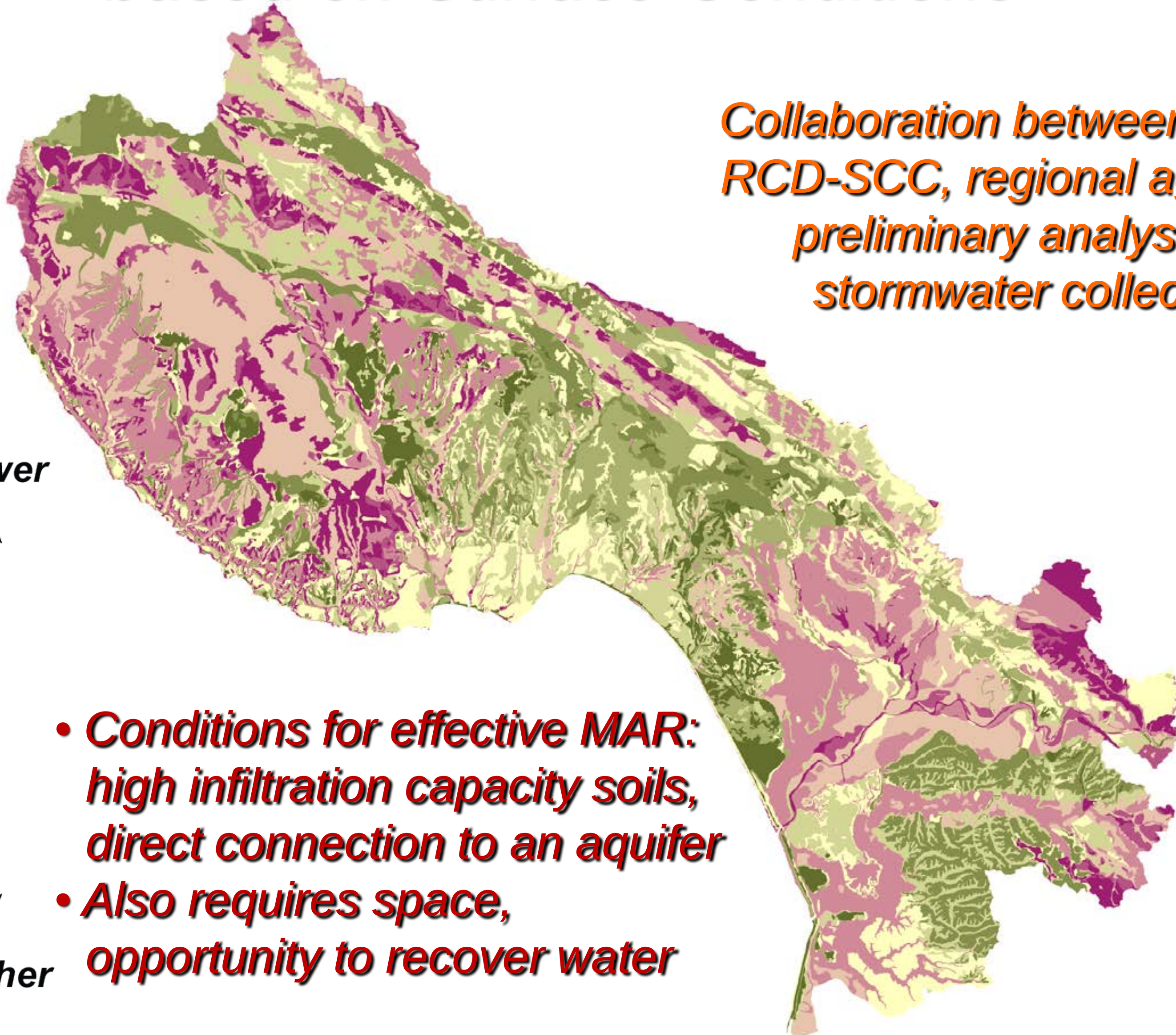


Combining high-quality data from many sources....

MAR = Managed Aquifer Recharge

Suitability for Managed Aquifer Recharge based on Surface Conditions

Collaboration between UCSC, RCD-SCC, regional agencies: preliminary analysis for stormwater collection



- *Conditions for effective MAR: high infiltration capacity soils, direct connection to an aquifer*
- *Also requires space, opportunity to recover water*

R. Harmon, S. Beganskas, E. Teo, A. Fisher, S. Lozano

Data from USDA, NOAA, USGS, etc.

Groundwater Provides and Receives "Hydrologic System Services (HSS)"

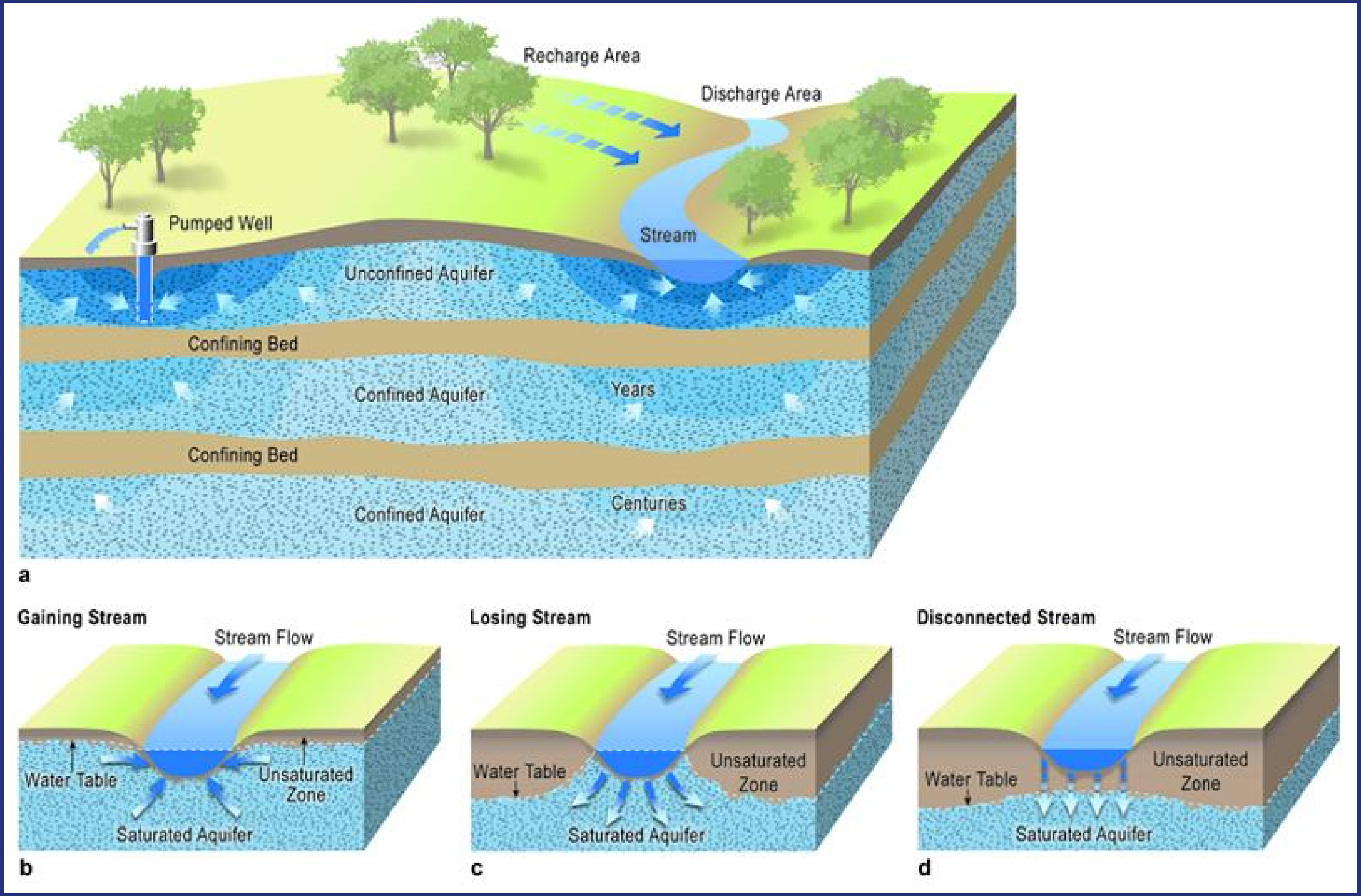
Concept of Ecosystem Services (ESS) is Well Established:

- Used to quantify economic and/or social benefit of ecosystems
- Values are assessed based on impacts mainly to human societies
- *Ex: coastal wetlands mitigate hurricane damage, levees prevent/limit flooding, catchments provide water to cities, etc.*

Hydrologic System Services (HSS) can include ESS, also include benefits to/from other hydrologic processes and conditions

- *Ex: restoring floods to benefit creation of sand bars in the Colorado River*
- *Ex: increasing groundwater levels can increase baseflow (water leaves storage)*
- *Ex: enhancing recharge in coastal basins can increase storage and flows to the ocean (helps to mitigate seawater intrusion)*

Groundwater Provides and Receives "Hydrologic System Services (HSS)"



- *Not all HSS result in a greater water supply – but the flows themselves provide benefits*
- *Groundwater often remains in motion – return from "banking" often <100%!*

Some advantages of enhancing groundwater storage

- *may be considerable space available (particularly if overdrafting)*
- *less evaporative loss than surface storage*
- *potential to improve water quality in impacted aquifers*
- *can be less surface impact from infrastructure development*
- *can use less energy for storage and conveyance*
- *uses limited surface storage multiple times*
- *can be cheaper than concentrated surface storage and conveyance*
- *can respond to irregular supply, changing climate conditions*
- *allows for conjunctive use, banking (increases flexibility)*
- *can be combined with LID, stormwater retention, other goals*
- *can improve aquatic habitat, especially if natural channels are used*
- *can reduce seawater intrusion, other impacts from overdraft*
- *local solution to a local problem (can be politically viable)*

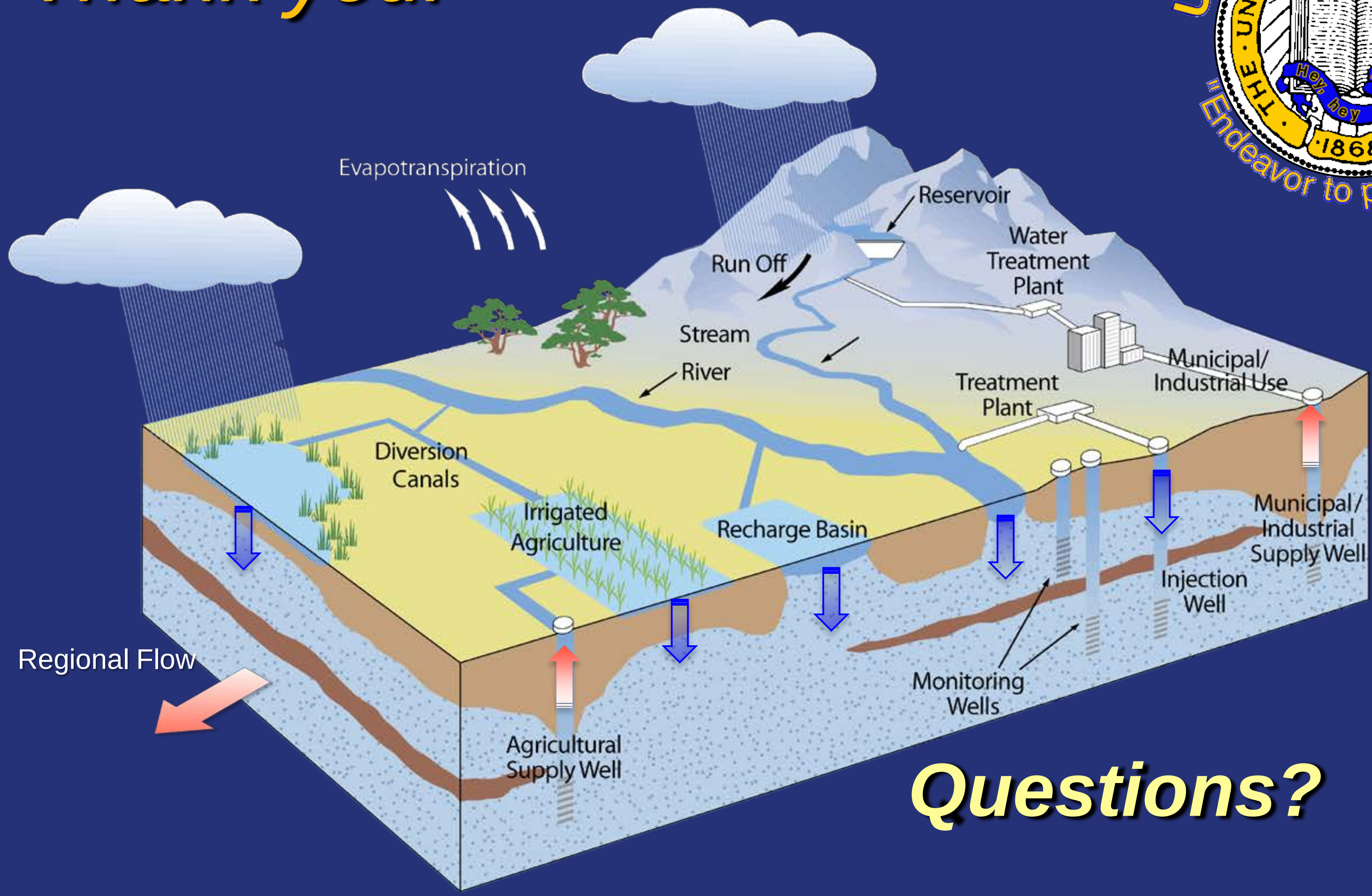
Some challenges for enhancing groundwater storage

- *stored water can't be seen*
- *not all basins/formations are amenable to enhanced recharge*
- *managed recharge can require specialized infrastructure*
- *requires energy for construction and operation*
- *groundwater does not stay put, recovery <100% (often <<100%)*
- *managed recharge may be hard to distinguish from ambient groundwater (→ operational, legal, permit issues)*
- *for ASR, injection/recovery requires specialized engineering*
- *potential to harm water quality*
- *can lead to problems with infiltration, poor drainage*
- *water rights can limit access (surface and/or subsurface)*
- *permitting required/restrictions for use of some water sources*
- *if multi-agency: infrastructure, operational and economic ties, coop*

Take away messages

- *Groundwater is an important freshwater resource*
  - ***City of Santa Cruz currently makes limited use of groundwater***
  - ***This could change with the right kinds of project(s)***
- *Sustaining groundwater requires careful management*
- *Groundwater is increasingly stressed because of increasing demand and decreasing rates of input (recharge)*
- *Managed recharge can help to improve sustainability, need to choose projects and sites carefully – not all locations/methods will work!*
- *Improving groundwater management can benefit surface water systems (and vice versa)*

Thank you!



UCSC Hydrogeology

"Endeavor to persevere..."

Questions?

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Climate change → changes in rainfall....

Atmospheric Warming and the Amplification of Precipitation Extremes

Allan and Soden (2009), *Science*

CLIMATE CHANGE

Human influence on rainfall

Rising concentrations of anthropogenic greenhouse gases in the atmosphere may already be influencing the intensity of rainfall and increasing the risk of substantial damage from the associated flooding. SEE LETTERS P.378 & P.382

Allan (2011), *Nature*

LETTER

doi:10.1038/nature09763

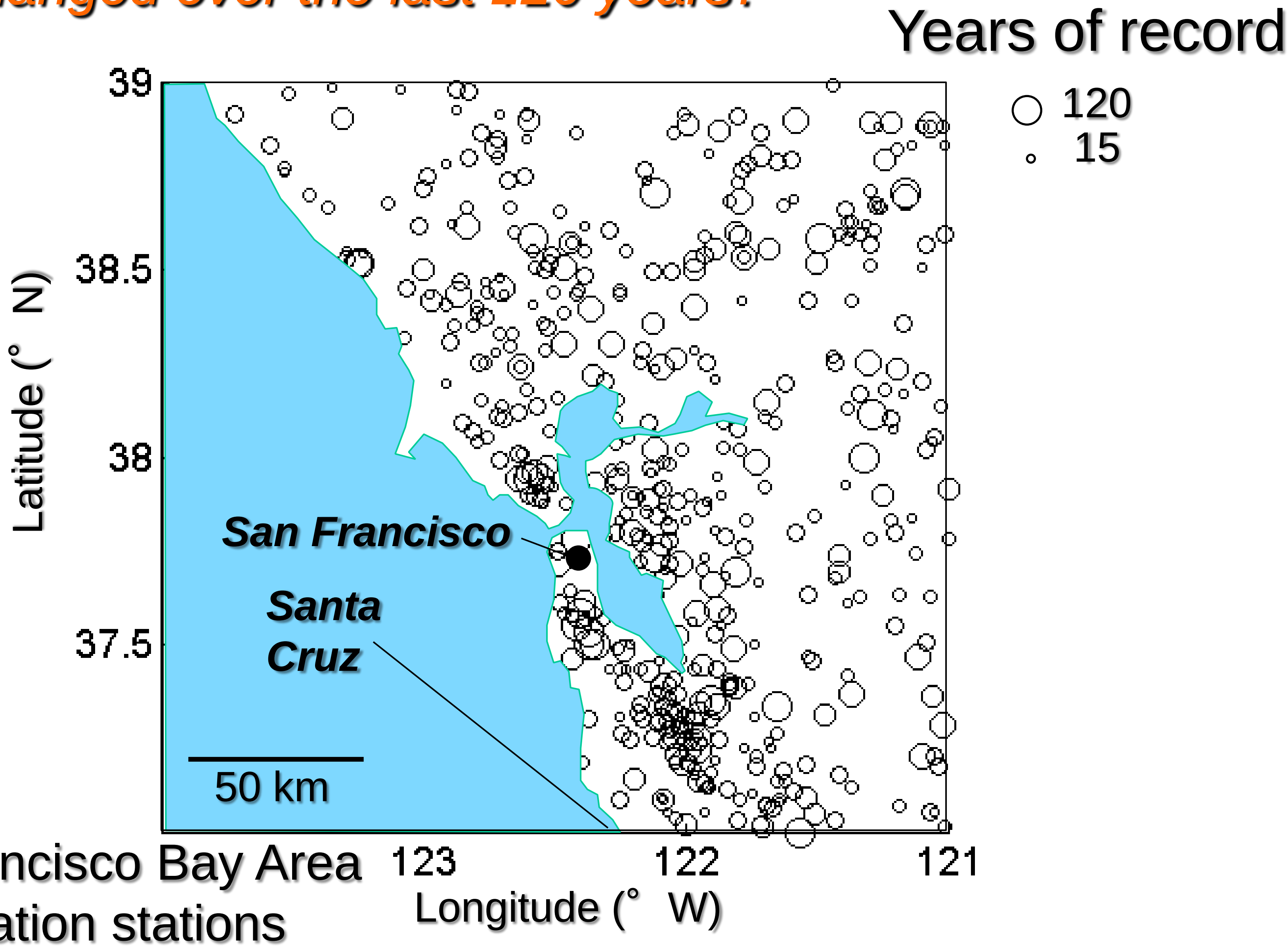
Human contribution to more-intense precipitation extremes

Min et al. (2011), *Nature*

…but climate models are challenged by regional to local variability

Fortunately, we have the observational record....

How has extreme rainfall in the SFBA changed over the last 120 years?



San Francisco Bay Area
Precipitation stations
1890–2010

modified from Russo et al. (2013)

For City of Santa Cruz

Recharge of "Santa Cruz City" aquifer

- <5% of fresh water supply comes from groundwater, and there is limited reservoir storage (Purisima aquifer is not ideal)
- Surface basins/streams unlikely to be efficient, ASR likely would be required (more complex, expensive)
- ASR would require considerable infrastructure, engineering, operations, power
- Close to ocean and SqCWD wells → low efficiency of recovery
- Supplies not assured, particularly during prolonged drought or periods of high flows in the SL River (turbidity)

For City of Santa Cruz

Cooperate for use of neighboring aquifers

- *SqCWD use mainly Purisima aquifer – most efficient if using "in lieu" recharge (water not pumped), requires reliable (offset) supply*
- *Scotts Valley and San Lorenzo Valley – sandier aquifers (SMGB) with some good connections to surface (streams, quarries, etc.)*

But…

- Legal limits on what kind(s) of water can be recharged in proximity to active domestic and municipal wells
- Studies suggest that some managed recharge in SMGB would discharge to streams (less loss with deeper injection)
- Some streams have problems with sediment load, could lead to clogging under low-flow conditions
- Recent studies favor LID, in-lieu recharge/inter-district exchange, local diversion/managed recharge

For City of Santa Cruz

All groundwater enhancement options.....

- *Require a reliable supply (± predictable?), capture/use of incidental (storm) water or a designated supply (diversion, recycled), each of which has limits, legal/economic restrictions*
- *Depend on having a good place to store the water, yet Santa Cruz has limited local space – collaborative arrangement with adjacent basin(s) would be required*

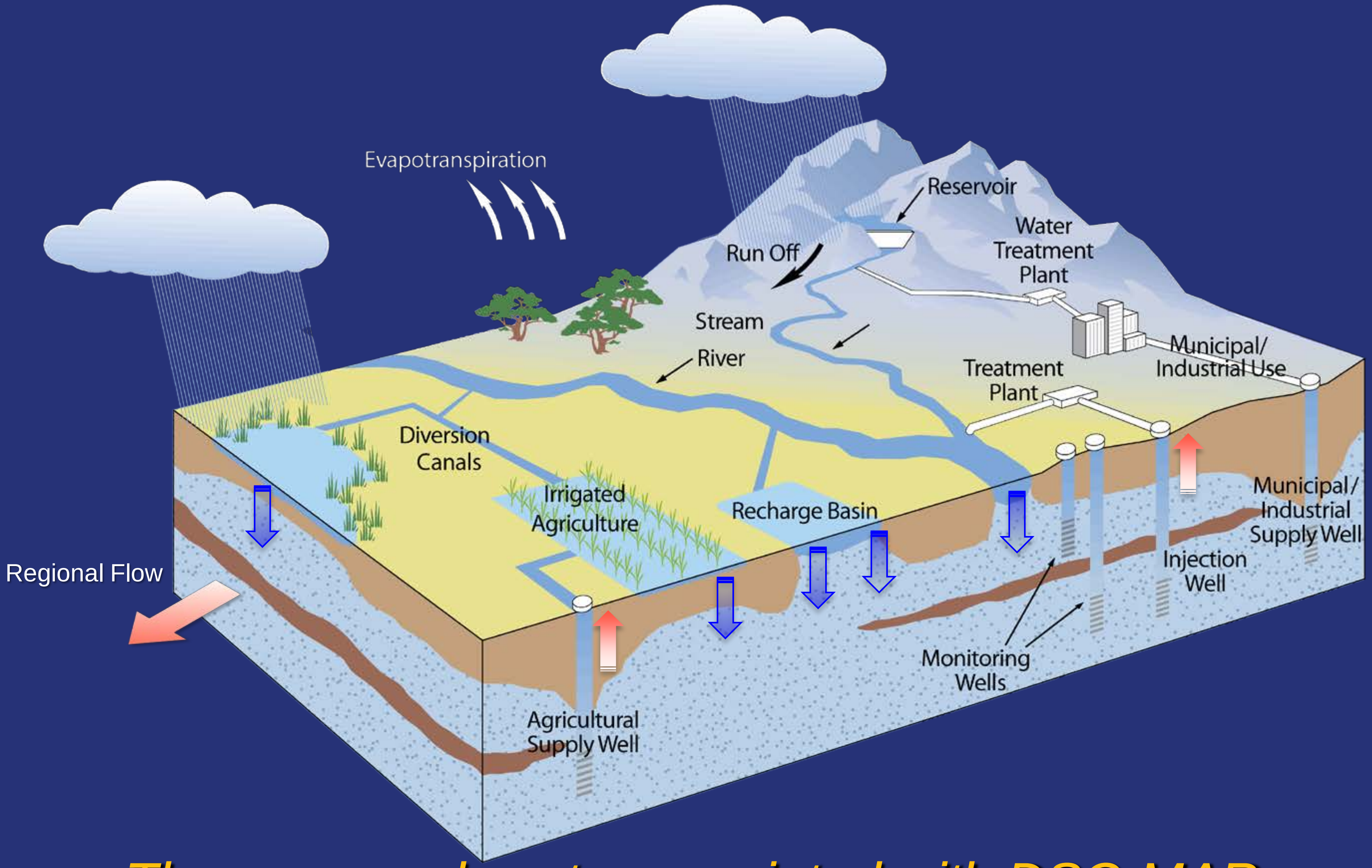
Big question:

- *How does Santa Cruz develop agreements, infrastructure, support capital and operating costs for use of non-City aquifer space?*

In any case:

- *Identify and sustain/enhance recharge areas (like losing streams), limit sediment clogging, capture stormwater, practice LID, etc.*

How can landowners/tenants be incentivized?

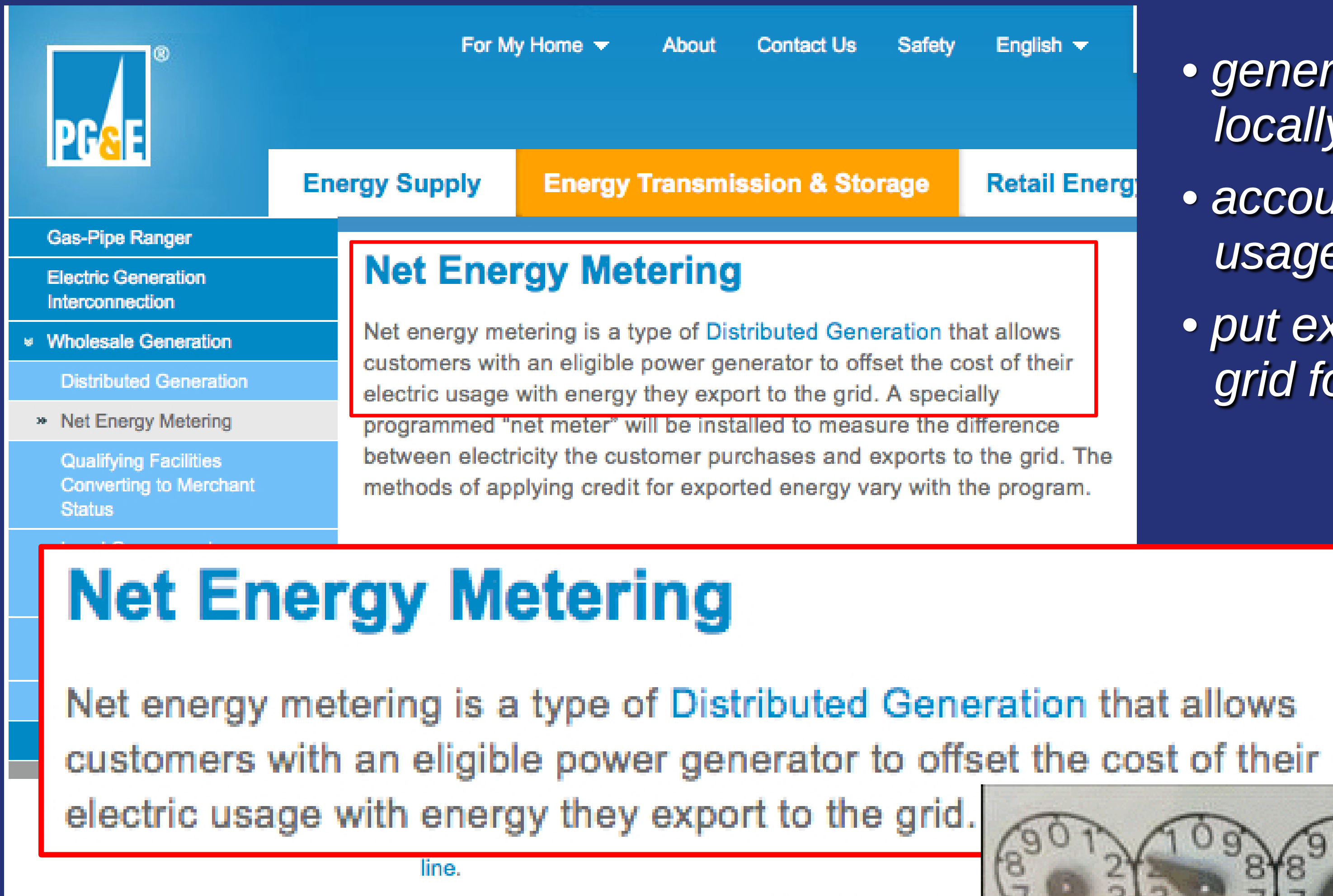


There are real costs associated with DSC-MAR: capital, operations/maintenance

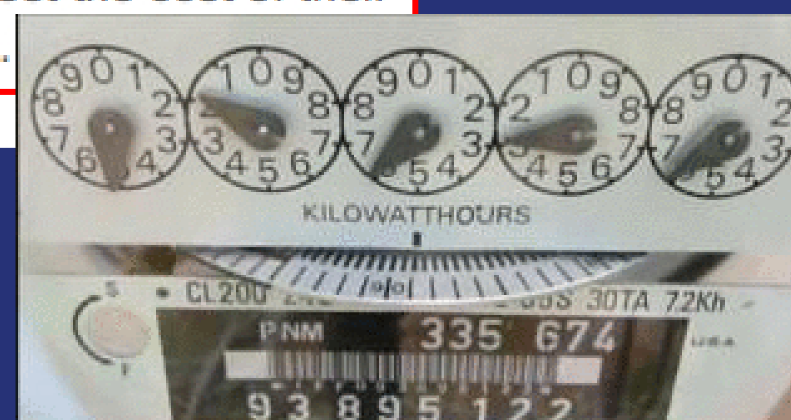
Costs to Growers/Landowners for DSC-MAR

- Land taken from production
- Maintenance of infiltration structures (basins, drywells)

There is a Workable Example: Net Energy Metering



- *generate energy locally*
- *account for net usage*
- *put excess power on grid for shared use*



- *Requires reliable measurement/accounting*
- *Reasonable formula to calculate benefits*

Thanks to collaborators, field assistance...

M. Los Huertos, S. Beganskas, T. Russo, R. Harmon,

B. Lockwood, A. Racz, C. Schmidt, E. Teo, W. Weir,

K. Young, S. Lozano, K. Camara, L. Lurie, E. Paddock

....and those providing field access, technical assistance....

PVWMA staff, D. Sampson, B. Cheney, Community Water Dialog

....and funding

NIWR

USDA

NSF

RESOURCE CONSERVATION DISTRICT OF SANTA CRUZ COUNTY

State of California Coastal Conservancy

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