Managed Aquifer Recharge

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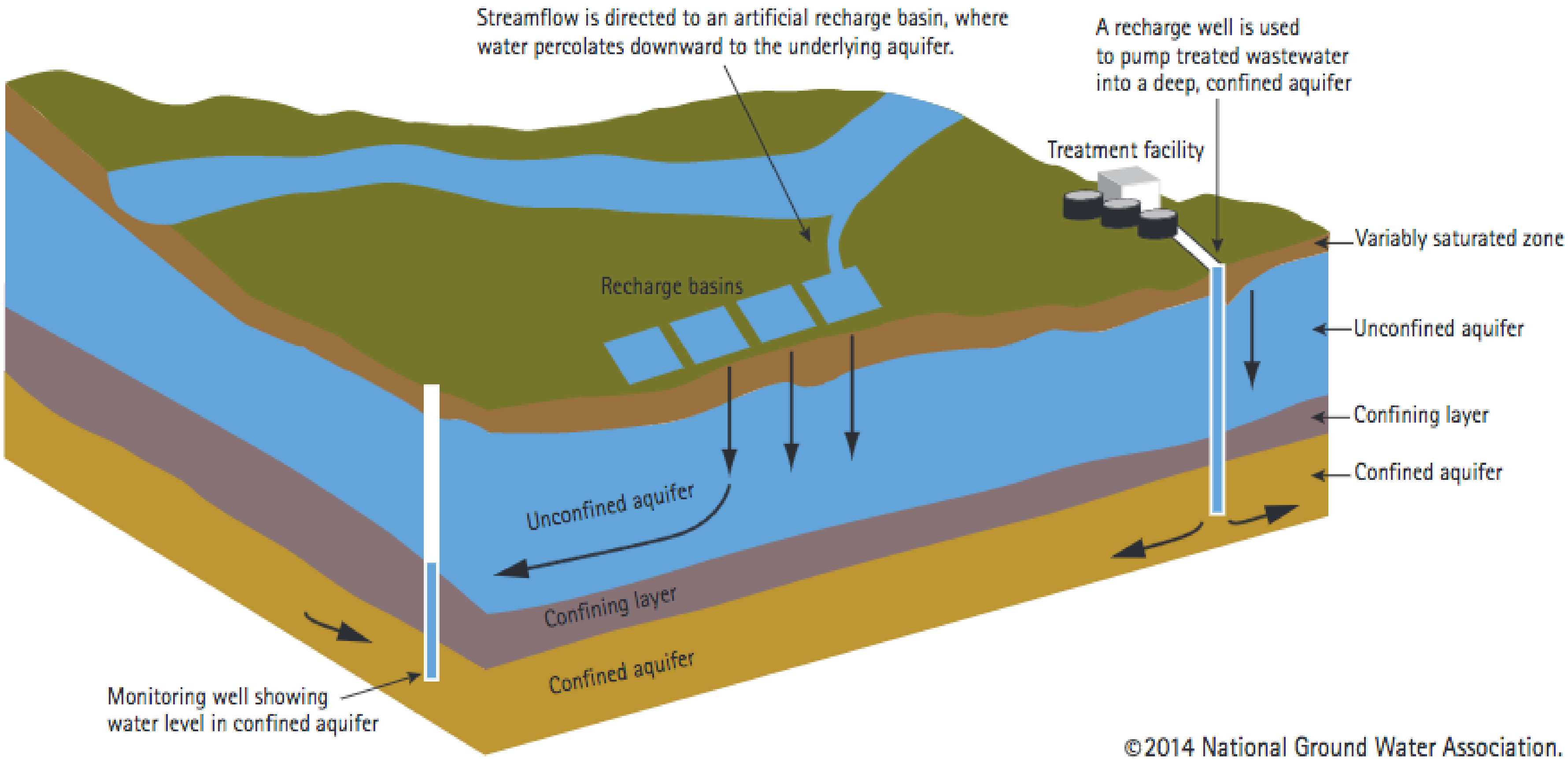


Drought Summit – December 9, 2016

Irrigation Association & National Ground Water Association

Presentation Overview

- **Managed Aquifer Recharge Terminology**
- **MAR Concepts**
- **MAR Purposes**
- **Types of MAR**
- **MAR Design Needs**
- **MAR Examples**
- **MAR and Agriculture**

Natural Recharge

- Natural groundwater recharge is the predominant source of groundwater replenishment in almost all gw basins
- Typically unmanaged and SLOW
- Water percolates into aquifers from a variety of surface water sources including precipitation, streams, rivers, lakes, surface water conveyance facilities
- Natural recharge also may occur from horizontal subsurface inflow from one part of a groundwater basin to another
- Natural recharge requires no dedicated infrastructure or land

MAR Terminology

- MAR is the purposeful recharge of water to aquifers for subsequent recovery or environmental benefit
- Source water – the water being recharged
- Receiving water – groundwater receiving the recharge
- Distributed recharge – low impact development
- Centralized – large scale projects

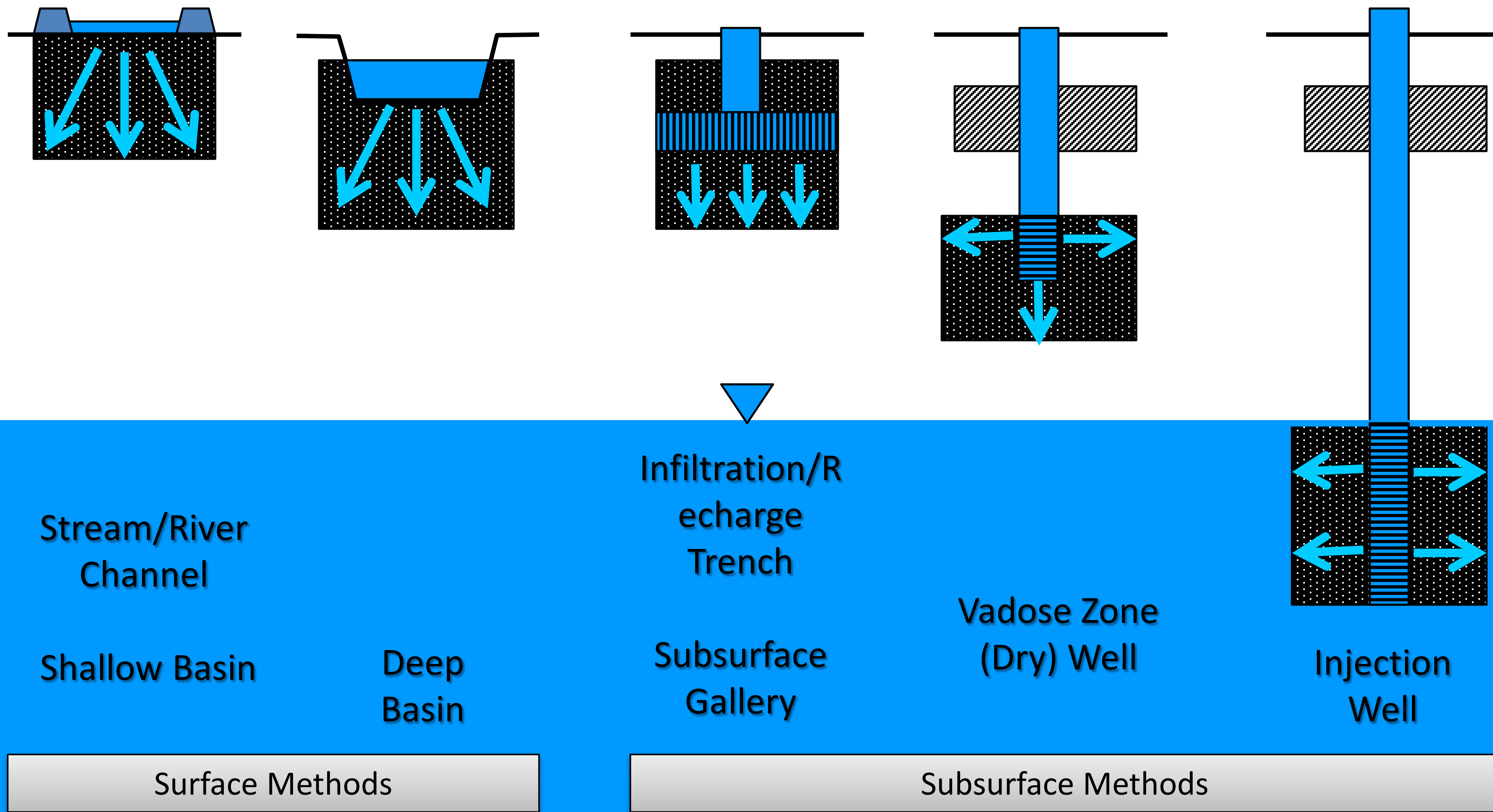
MAR Purpose

- Buffer for droughts
- Groundwater replenishment
- Storm water capture
- Soil/Aquifer treatment
- Sustain in-stream flows
- Seawater intrusion
- Land surface subsidence
- Groundwater banking

Groundwater Banking

- Groundwater banking is a management strategy that stores surface water in aquifers for future withdrawal
- It expands managed water storage capacity, which typically consists mainly of surface water reservoirs
- Groundwater banking is achieved through the intentional application of surface water
- Applied to constructed percolation basins, through injection wells, or through joint management of rivers and groundwater to effect riverbed infiltration into underlying aquifers

Multiple Ways to Get Water into the Subsurface



Purpose and Local Conditions Guide MAR Design Decisions

- Local, Site-Specific Conditions
  - Soil
  - Hydrogeology
  - Topography
  - Water availability and quality
  - Land availability and cost

MAR facility design is typically site-specific and customized to local conditions.

A Planner/Designer Needs a Large MAR Knowledge Database

- MAR purpose
- Local conditions
- Knowledge of various types of MAR facilities and how they work
  - Advantages/Issues
  - Economic/Operational Sustainability
- Experiences elsewhere and how they can be adapted to local conditions

Stream/River Channels

Advantages

- Utilize existing hydrologic feature
- Channels usually contain permeable sediments
- Reduced clogging due to continuously moving water
- Enhanced habitat
- Community benefits

Issues

- Channel armoring/reduced percolation rates (d/s of Dams)
- Conducting maintenance during nesting season (March-Sept.)
- Potential nuisance: algae, mosquitoes, midge, odor
- Public acceptance

Shallow Basins

Advantages

- Minimal storage
- Gravity drained
- Quick turn-around
- Single-use facility
- Soil/Aquifer treatment
- Infiltration through bottom
  - $K_h >> K_z$

Issues

- Removal of sediment during cleanings
- Clogging due to bank erosion
- Potential nuisance: algae, mosquitoes, midge, odor
- Public acceptance

Shallow Recharge Basins are Easier to Drain and Clean

Deep Basins

Advantages

- Provide storage
- Multi-use capability
  - E.g., Flood retention basin
  - E.g., Fishing
- Soil/Aquifer treatment
- Infiltration through bottom and sides
  - $K_h >> K_z$

Issues

- Area-intensive
- Drained by pumping ($)
- Slow turn-around
- Removal of sediment during cleanings
- Clogging due to bank erosion
- Cleaning banks
- Potential nuisance: algae, mosquitoes, midge, odor
- Public acceptance/conflict with multi-use objectives

OCWD's Deep Basin Complex Covers 200 Acres

Subsurface Recharge

Advantages

- Can have smaller footprint than surface recharge
- Multiple land uses possible
  - E.g., Parks, Athletic Fields
- Can target specific aquifers
  - E.g., Seawater intrusion

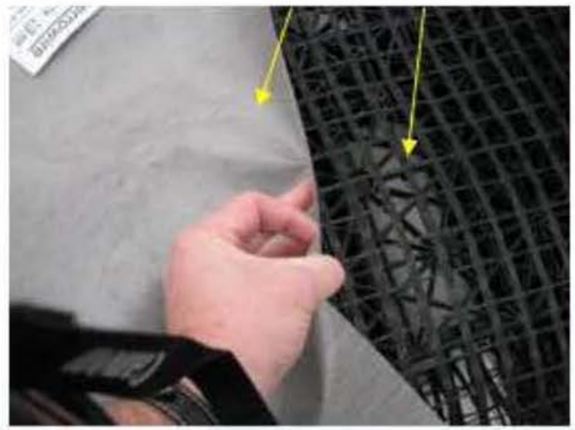
Issues

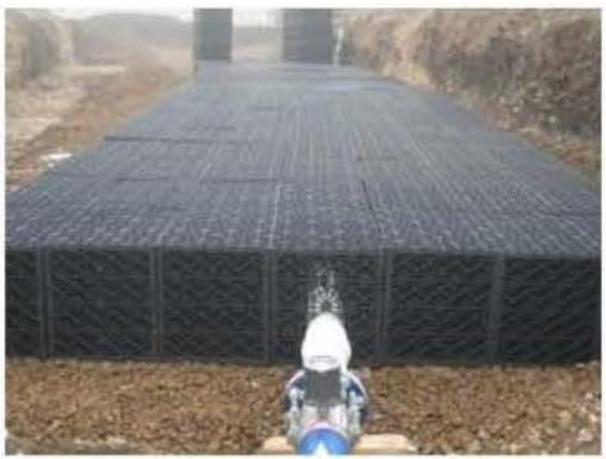
- More expensive than surface methods (minus land costs)
- Need clean water source to minimize clogging
- Geochemical compatibility
- Reduced soil/aquifer treatment

Atlantis brand rain tanks were used to test subsurface recharge in Walla Walla, WA.

Raintanks being deployed

Gallery top: filter fabric and mesh

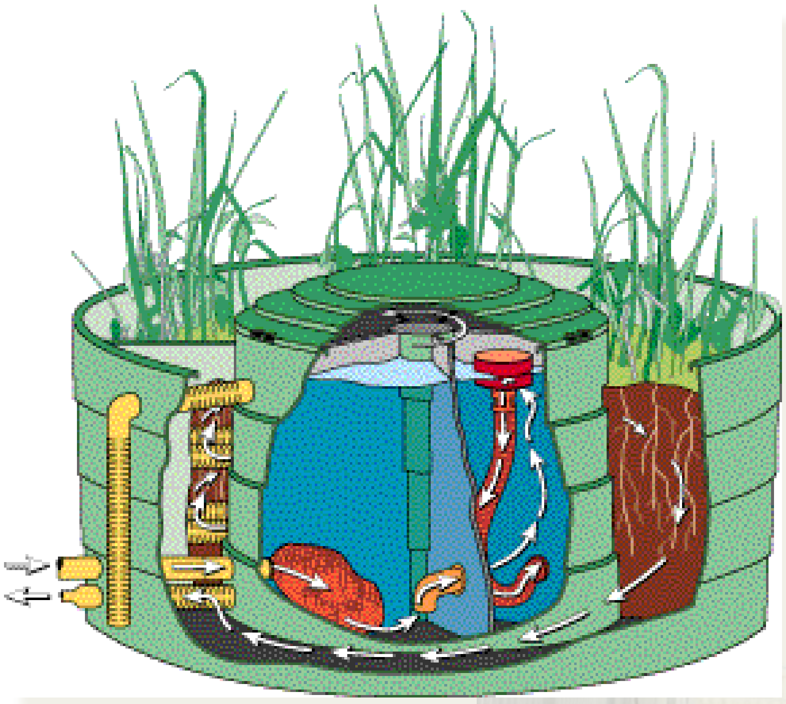




Intake: Value and metered

HBDIC Testing Site: 1000 feet^2 infiltration area

Onsite Natural Infiltration/Filtration

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All visitors must check in at Superintendent's Trailer
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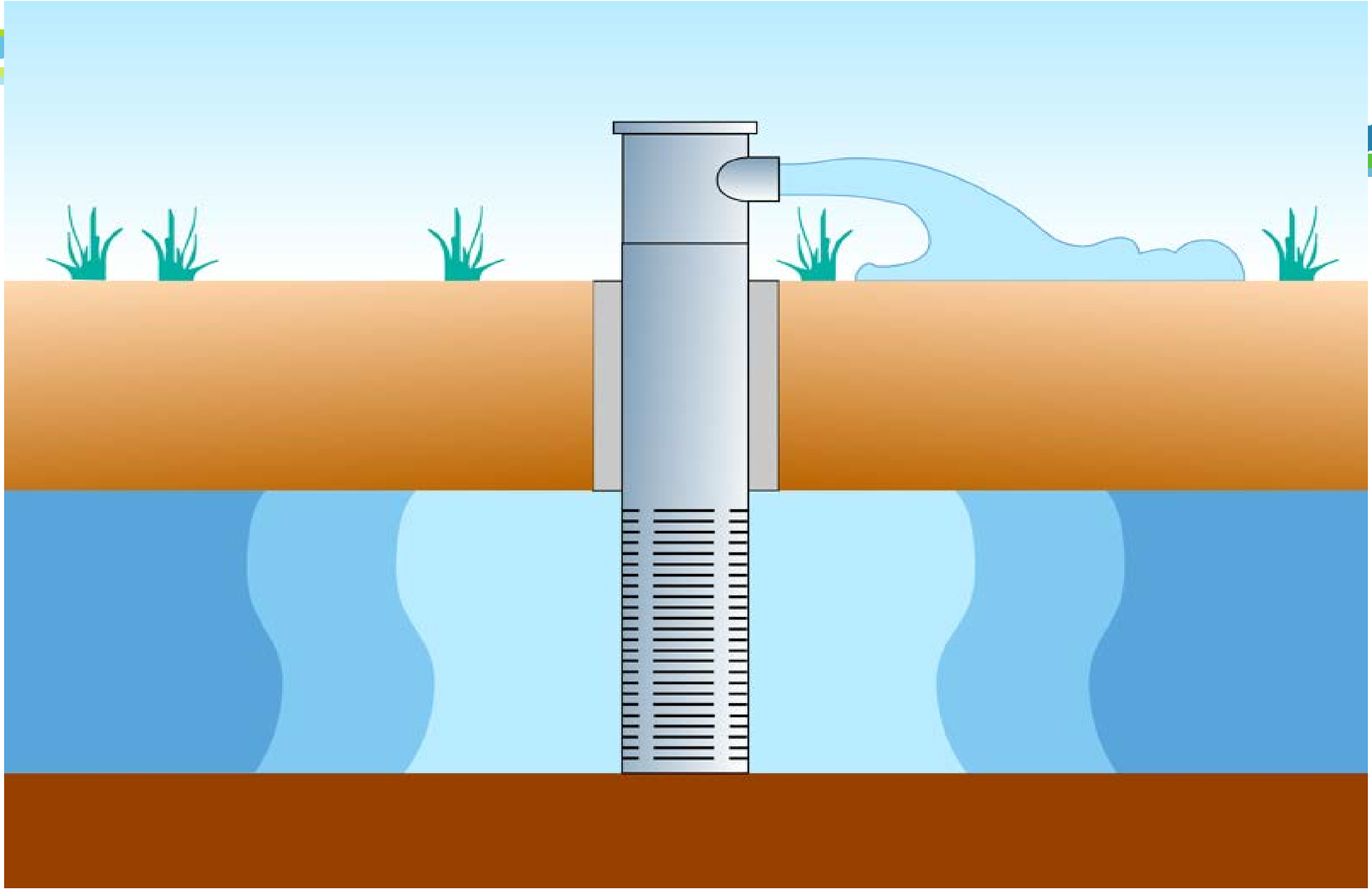
Well Recharge Options

- Injection wells
  - Single purpose wells for aquifer recharge or water disposal
- Vadose Zone ("dry") wells
  - Deep water tables
- Aquifer Storage Recovery (ASR) wells
  - Dual-purpose wells for aquifer storage and recovery
- Aquifer Storage Transfer Recovery (ASTR) wells (Australia)
  - Multiple-barrier natural treatment and storage
- Dual-Infiltration wells (Netherlands)
  - Natural treatment; no storage
- Others? (HDD wells; Freshkeeper wells)

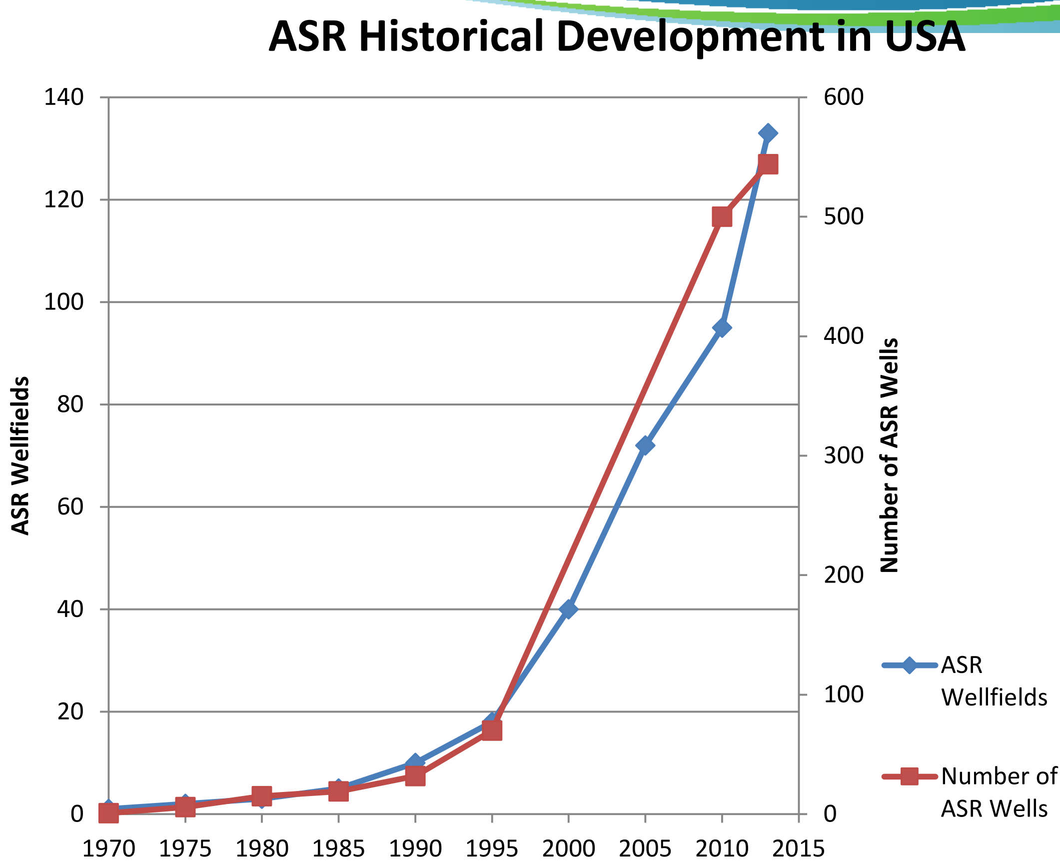
Aquifer Storage Recover: “Managed Aquifer Recharge” Through Wells



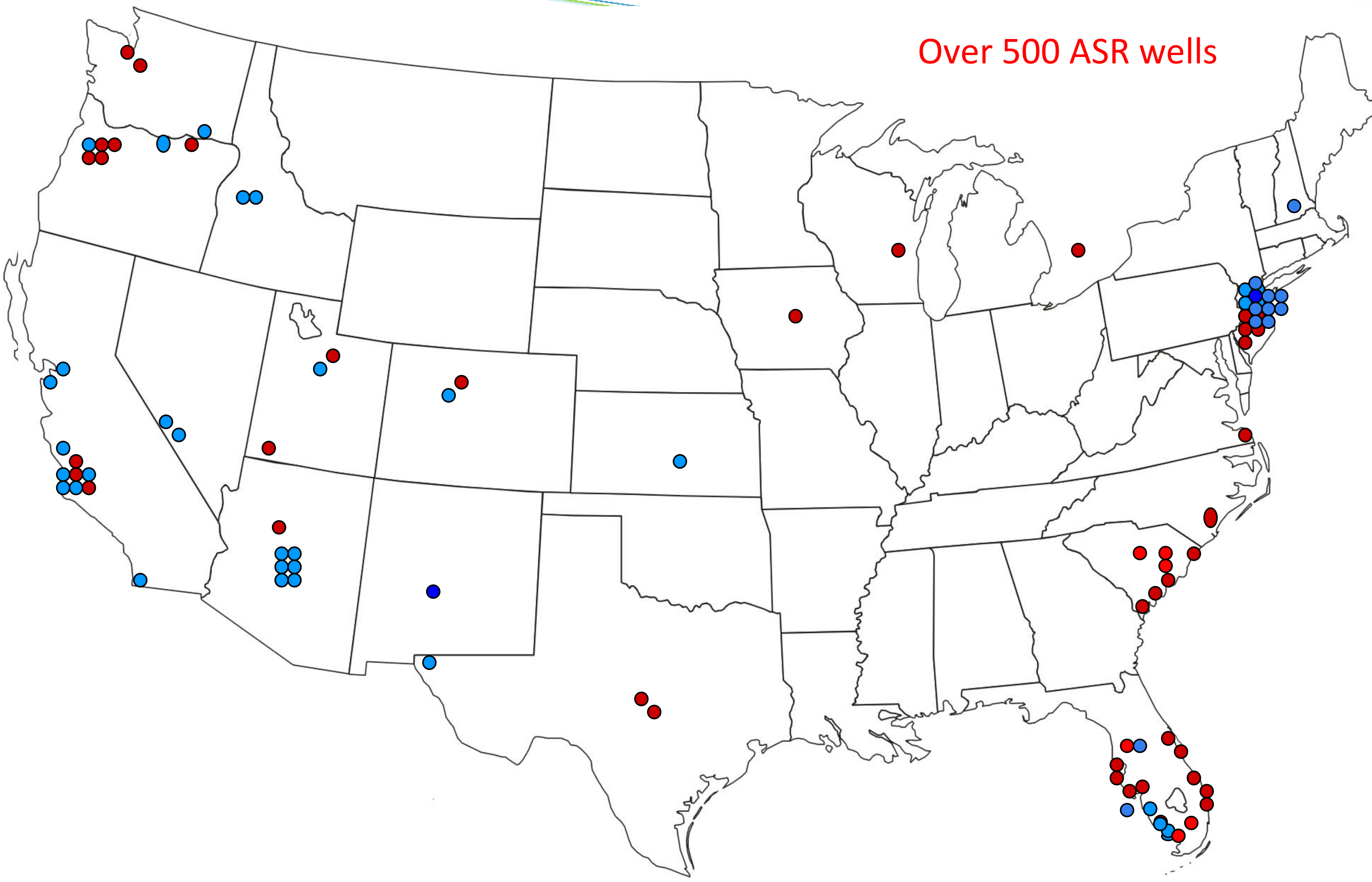
Storage of water through a well in a suitable aquifer during times when the water is available, and recovery of the stored water from the same well when needed

ASR Development Has Been Rapid During the Past 35 Years

- Currently (2016) at least 500 ASR wells operating in at least 175 ASR wellfields in at least 25 states in USA
- Many other countries as well
- 28 different types of ASR applications
- Many different types of water sources for aquifer recharge
- Storage in many different types of aquifers and lithologic settings



Approximately 175 Operational ASR Wellfields in the United States (2016)



Some Key Factors to Consider for ASR

- Geochemistry
- Buffer Zone
- Target Storage Volume
- Recovery Efficiency
- Clogging, Backflushing, Redevelopment
- Cycle Testing and Stress Test

New Strategy for MAR and Agriculture

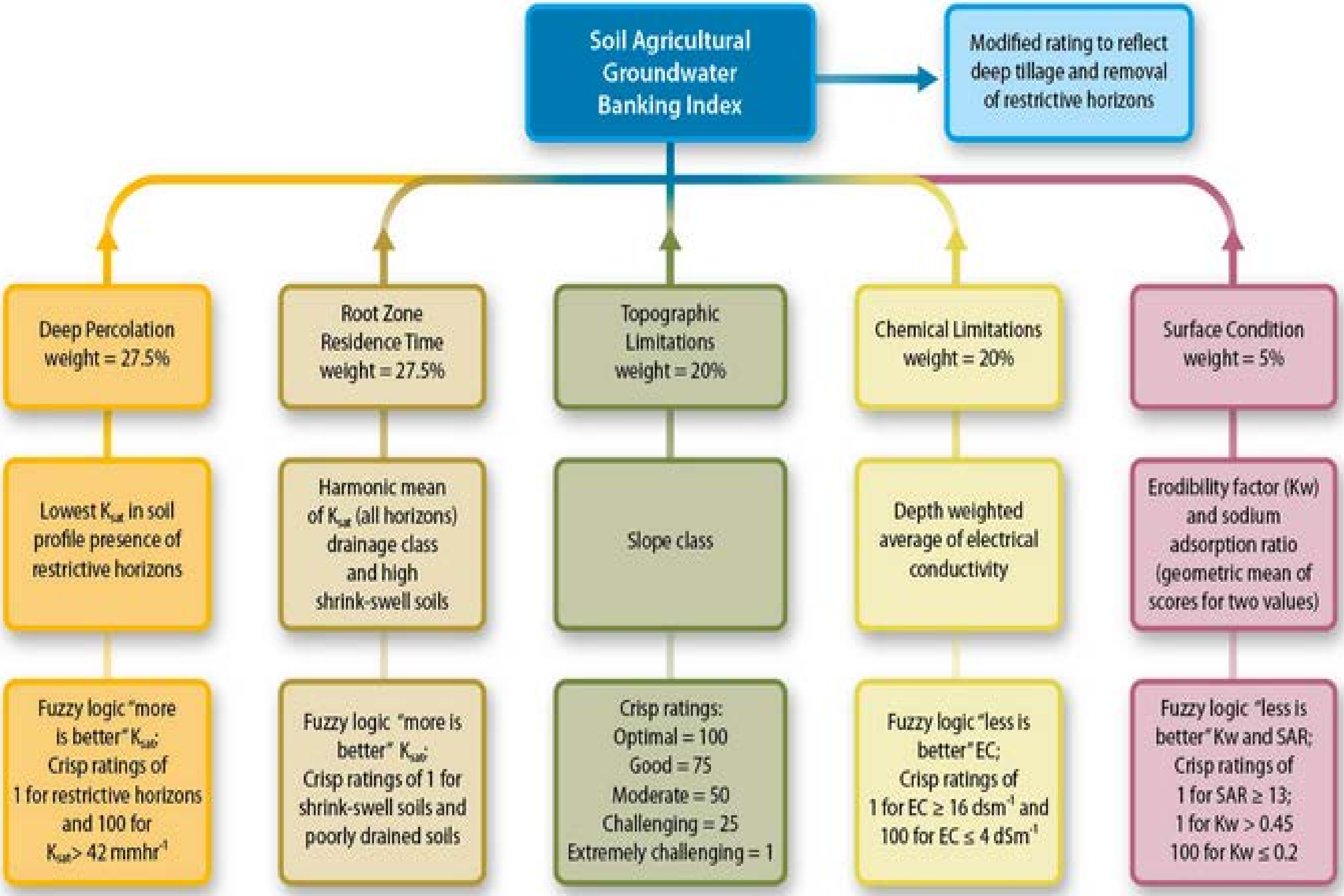
- Involves applying water to agricultural lands outside of the usual irrigation season for the specific purpose of recharging a groundwater basin
- Using agricultural lands as percolation basins has the potential to increase groundwater recharge during wet periods when surface water is available
- One potential source of water for recharge on agricultural land is river floodwaters, where surface water rights may be re-negotiated (or may not apply) for excess water
- Has potential dual benefit of withdrawing large amounts of water from a river that is at or near flood stage and reducing downstream flood risks

New Strategy for MAR and Agriculture

- Flooding agricultural land during fallow or dormant periods has the potential to increase groundwater recharge substantially
- Using data on soils, topography and crop type, a spatially explicit index was developed on the suitability for groundwater recharge of land in all agricultural regions in California
- 3.6 million acres of agricultural land in CA was determined as having Excellent or Good potential for groundwater recharge
- The index provides preliminary guidance about the locations where groundwater recharge on agricultural land is likely to be feasible
- A variety of institutional, infrastructure and other issues must also be addressed before this practice can be implemented widely

Five Factors that Determine Feasibility of Groundwater Recharge on Agricultural Land

1) **Deep percolation:** Soils must be readily able to transmit water beyond the root zone (1.5 m, 5 ft).
2) **Root zone residence time:** The duration of saturated/near saturated conditions after water application must be acceptable for the crops grown on lands under consideration for groundwater banking throughout the entire crop root zone.
3) **Topography:** Slopes that negatively influence the even distribution of water will be more difficult to manage.
4) **Chemical limitations:** High soil salinity may result in saline leachate (poor water quality) that must be avoided to protect groundwater quality.
5) **Soil surface condition:** Certain soils may be susceptible to compaction and erosion if large volumes of water are applied. Surface horizons with high sodium are prone to crusting that may contribute to decreased surface infiltration rates.



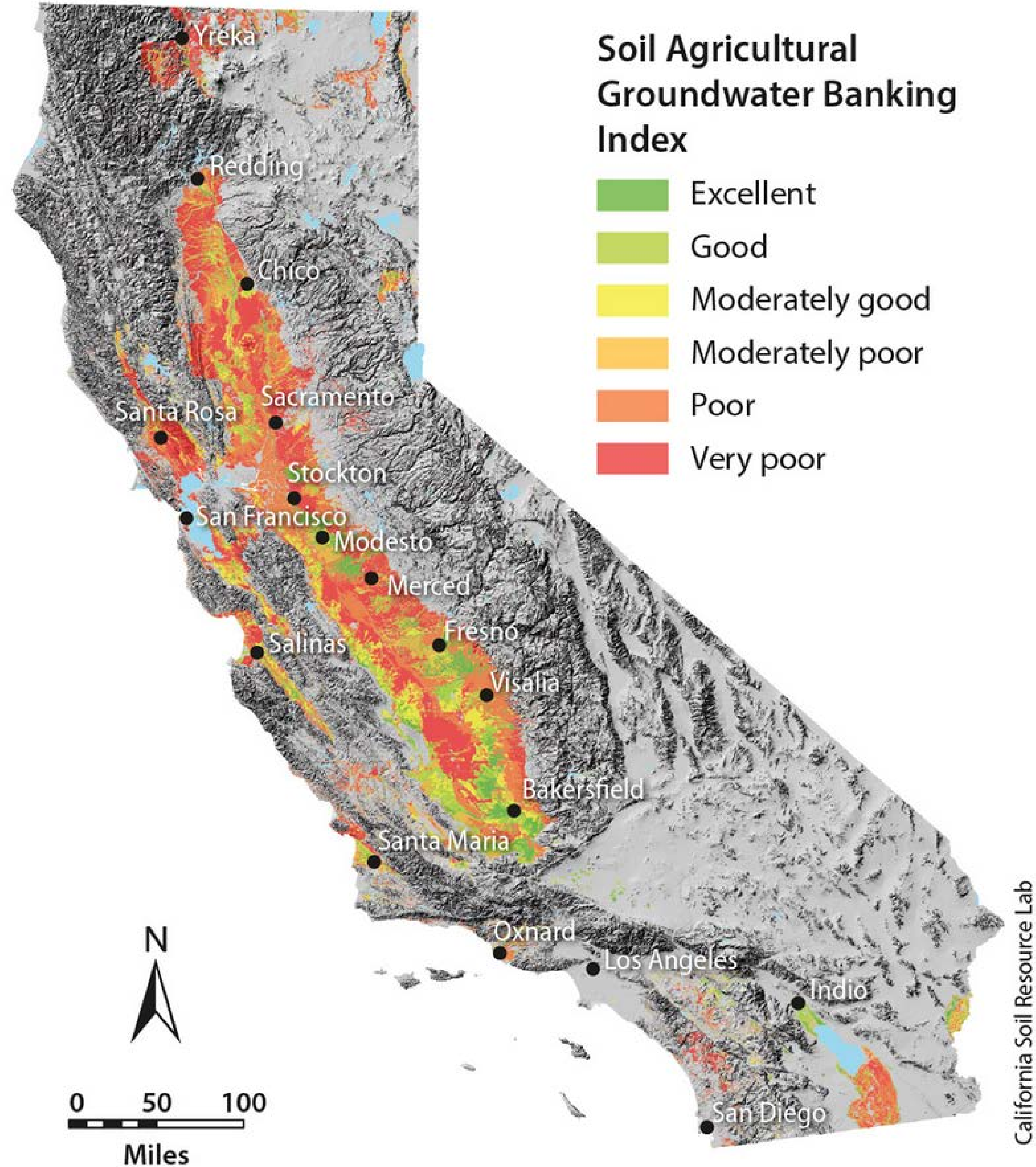
Soil Agricultural Groundwater Banking Index
Modified rating to reflect deep tillage and removal of restrictive horizons
Deep Percolation weight = 27.5%
Root Zone Residence Time weight = 27.5%
Topographic Limitations weight = 20%
Chemical Limitations weight = 20%
Surface Condition weight = 5%
Lowest K_{sat} in soil profile presence of restrictive horizons
Harmonic mean of K_{sat} (all horizons) drainage class and high shrink-swell soils
Slope class
Depth weighted average of electrical conductivity
Erodibility factor (Kw) and sodium adsorption ratio (geometric mean of scores for two values)
Fuzzy logic "more is better" K_{sat}; Crisp ratings of 1 for restrictive horizons and 100 for K_{sat} > 42 $mmhr^{-1}$
Fuzzy logic "more is better" K_{sat}; Crisp ratings of 1 for shrink-swell soils and poorly drained soils
Crisp ratings: Optimal = 100 Good = 75 Moderate = 50 Challenging = 25 Extremely challenging = 1
Fuzzy logic "less is better" EC; Crisp ratings of 1 for EC ≥ 16 dsm^{-1} and 100 for EC ≤ 4 dSm^{-1}
Fuzzy logic "less is better" Kw and SAR; Crisp ratings of 1 for SAR ≥ 13; 1 for Kw > 0.45 100 for Kw ≤ 0.2

Almonds	Information Not Found in Literature
Vineyards (Established)	1 day, "Managing" (State of Victoria, 2011) 1-2 weeks (Terranova pilot study)
Pasture	Withstand several days (~3 days) of flooding without injury (University of Florida, 1998)
Alfalfa	Less than 3 to 4 days (University of Florida, 1998)
Pistachios	Information Not Found in Literature
Oats	Greater ability to recover from waterlogging compared to wheat and barley (Setter & Waters, 2003)
Wheat	6 days immediately after germination reduces populations to 12 - 38% of non-waterlogged plants (Setter & Waters, 2003)
Barley	10 - 15 days reduces yield by 1% to over 40% damage depending on variety (Setter & Waters, 2003)
Corn	For young corn: 4 days (with temperature less than 65 deg. F) or fewer days for warmer temperature (Nielsen, 2014)
Cotton	2 days (Thongbai, Milroy, Bange, Rapp, & Smith, 2001)
Tomatoes	2 days (University of Delaware, Cooperative Extension, 2013) One day (Terranova pilot study)

Crop	Rootstock	Tolerance to saturation before budbreak	Tolerance to saturation after budbreak	Recommended N fertilizer rate
				lbs N/ac/yr
Almonds	Peach; peach x almond hybrid	1	1	250
Almonds	Plum; peach x plum hybrid	2–3	1	250
Avocados	—	0	0	150
Cherries	—	1	0	60
Citrus	—	0	0	100
Wine grapes	—	4	2	15–30
Olives	—	?	?	<100
Pears	*P. betulaefolia*	4	4	100–150
Pears	*P. communis*	4	3	100–150
Pears	*Cydonia oblonga*	3–4	2–3	100–150
Pistachios	—	?	?	200
Plums/prunes	Peach	1	1	150
Plums/prunes	Plum; peach x plum hybrid	2–3	1	150
Pomegranate	—	?	?	100
Walnuts	—	2–3	1	200

The following scores were used to estimate vulnerability: 0 - No tolerance for standing water; 1 - tolerant of standing water up to 48 hours; 2 - tolerant of standing water up to 1 week; 3 - tolerant of standing water up to 2 weeks; 4 - tolerant of standing water > 2 weeks; ? - tolerance unknown.

Tolerance to saturated conditions is based on expert opinion and has not been supported by controlled experimentation.



Soil Agricultural Groundwater Banking Index
Excellent
Good
Moderately good
Moderately poor
Poor
Very poor
Yreka
Redding
Chico
Sacramento
Santa Rosa
Stockton
San Francisco
Modesto
Merced
Fresno
Salinas
Visalia
Bakersfield
Santa Maria
Oxnard
Los Angeles
Indio
San Diego
N
0
50
100
Miles
California Soil Resource Lab

Final Thoughts

- Managed Aquifer Recharge provides an opportunity to replenish and bank groundwater during wet seasons and wetter years
- Technology is well developed with many types and sizes of projects successfully applied globally
- New cost effective approaches using field flooding show promise and may help mitigate overdrafted areas in agricultural areas

Resources/References

- Sustainable Conservation http://suscon.org/wp-content/uploads/2016/11/Accelerated-Groundwater-Recharge-Assessment-Project.pdf
- California Water Foundation http://waterfoundation.net/wp-content/uploads/2015/09/Creating%20an%20Opportunity%20On%20Farm%20Recharge%20Final%20Full%20Report%20(00306327xA1C15).pdf
- University of California – California Agriculture http://calag.ucanr.edu/Archive/?article=ca.v069n02p75
- International Association of Hydrogeologists – Managed Aquifer Recharge Commission https://recharge.iah.org/
- ASR Systems http://www.asrsystems.ws/
- Orange County Water District www.OCWD.com Adam Hutchinsonahutchinson@ocwd.com

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