ONE WATER

Conjunctive Water Management for Sustainability of Water Supplies

Randall T. Hanson President/Hydrologist
One-Water Hydrologic, LLC, San Diego, California, USA
http://www.one-waterhydrologic.com/
(RandyTHanson@gmail.com)

WRRC Water Webinar Series
Arizona Water Resources Research Center

THE GROUNDWATER PROJECT

November 18, 2025

One Water

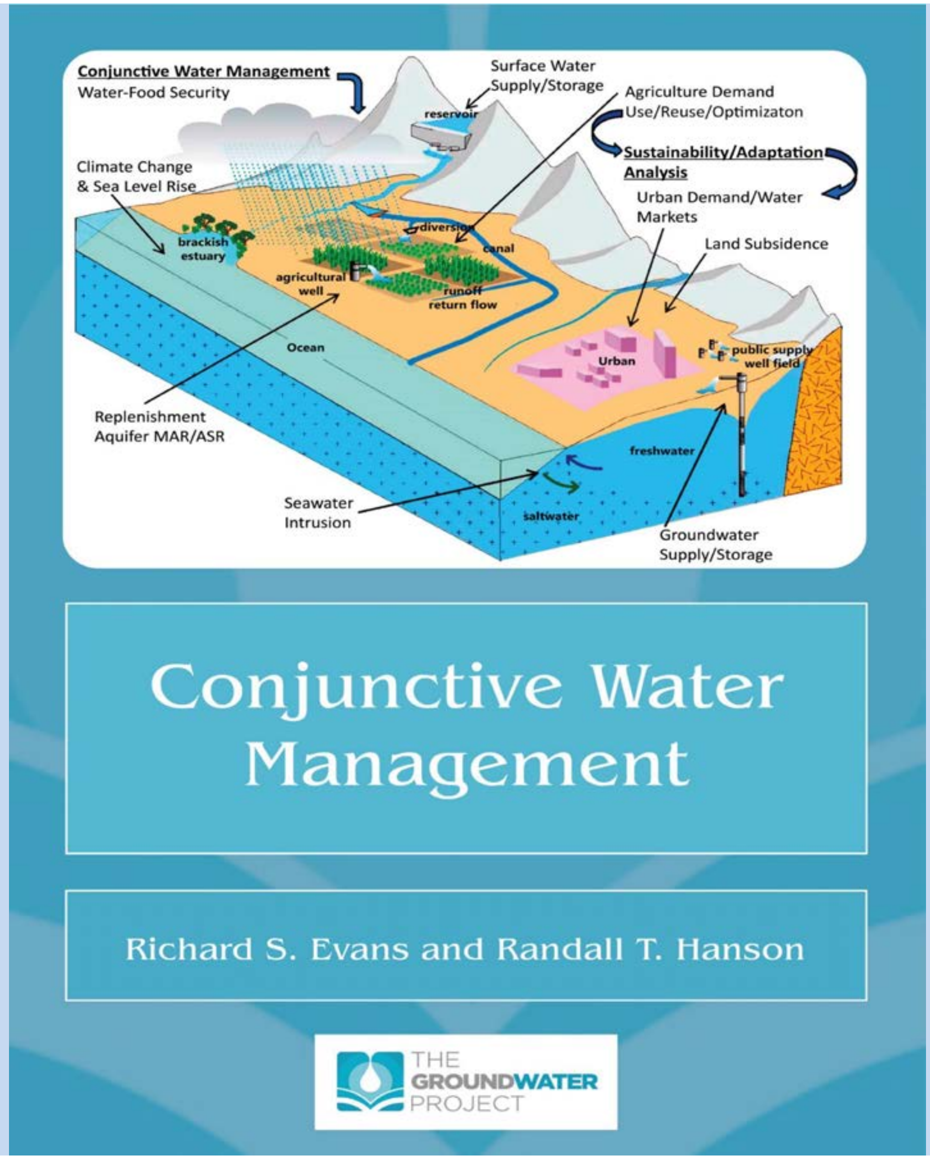
TODAY'S TALK

- *WHAT IS CONJUNCTIVE WATER MANAGEMENT?*
- FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT
- TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER
- Informal and Formal Systems
- HIGHLY VERSUS POORLY CONNECTED SYSTEMS
- BENEFITS OF CWM
- THE ROLE OF MANAGED AQUIFER RECHARGE
- ANALYSIS AND MODELING APPROACHES FOR CWM
- CWM DEVELOPMENT OPTIONS
- CWM CONCLUSIONS

One Water

Conjunctive Water Management →

Conjunctive Water Management (CWM):
The integral resource management of consumptive use from all water sources for all uses providing a diverse portfolio that facilitates reliable mechanisms for adaptation, mitigation, replenishment, and sustainability within a supply-and-demand framework for human and environmental needs and is connected to other potential drivers of supply and demand including land use, population, industry, climate, and transboundary governance.



John Cherry's Groundwater Project
(Evans & Hanson, 2025)

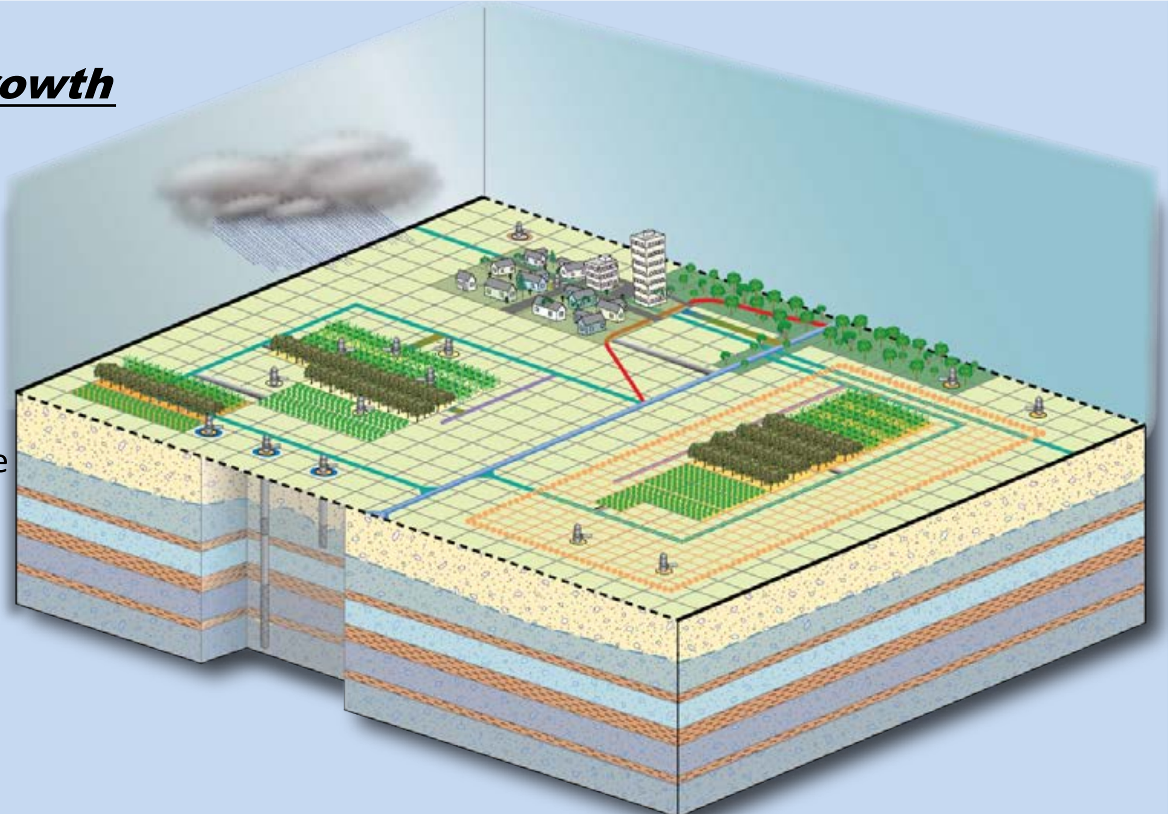
One Water

Aligning Management/Governance Framework with Climate Cycles & Growth

1) **Annual-Interannaul**:
   Operations: Urban, Industry, & Agricultural Supply & Climate Variability
2) **Internannual-Decadal:**
   Operations/Development/Governance & Climate Variability/Change
3) **Multi-Decadal**:
   Build infrastructure for Development/Climate Change
4) **Multi-Century**:
   Sustainability, Mitigation, & Adaptation

Supply Drivers: Direct Use, Reuse, Imports, Climate, MAR, FloodMAR, & DeSal

Demand Drivers: Population Growth, Land & Industry Development, Climate Variability/Change & Exports

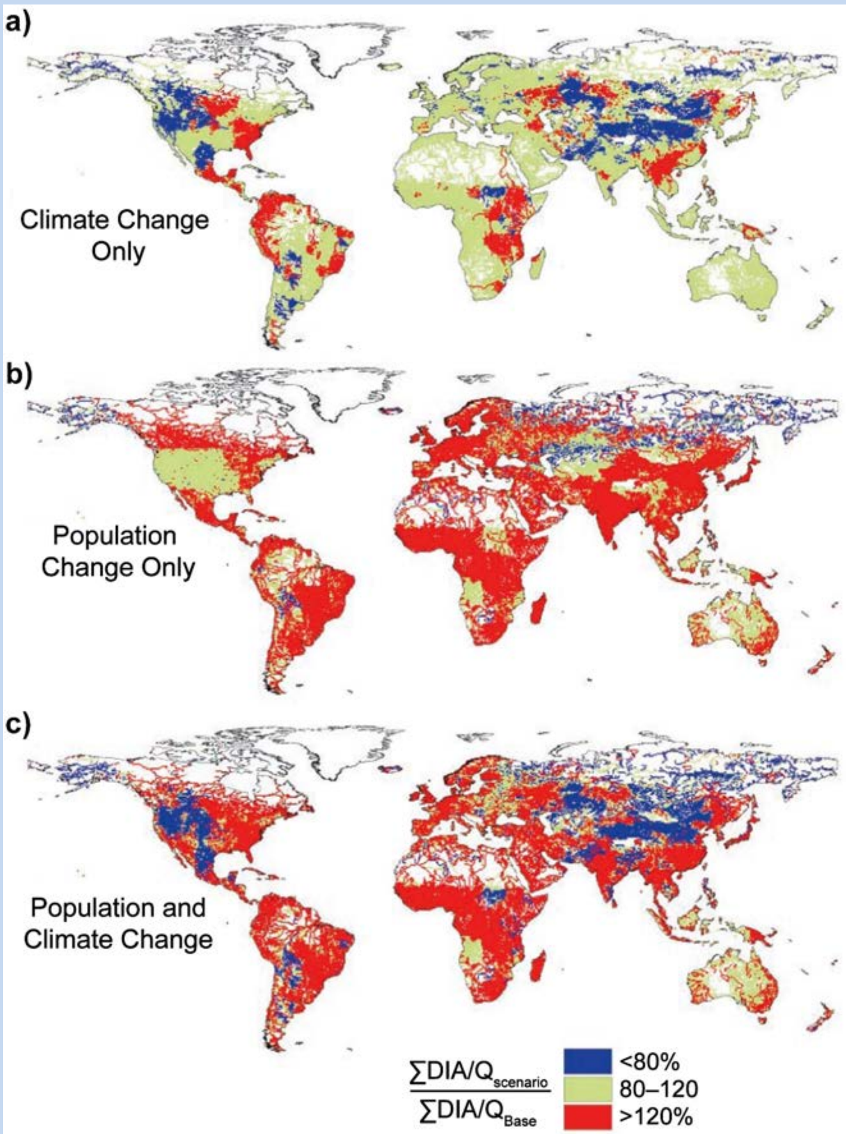


Conjunctive Use:

Combined use of precipitation, surface water, recycled, imported, saline waters, and groundwater to optimize the use and quality of all water resources throughout the watershed and connected aquifer systems for human and environmental uses that promote sustainability. (Evans and Hanson, 2025)

One Water

***One-Water Conjunctive-Use Modeling**: All The Water ➔ All The Time ➔ Everywhere*



Stress Drivers on Water Reuse from Climate Change & Population/Economic Development

Maps of the change in water reuse index (∑DIA/Q) predicted by the CGCM1/WBM model configuration under

(a) Scenario 1 (climate change alone),

(b) (Scenario 2 (population and economic development only), and

(c) Scenario 3 (both effects). Changes in the ratio of scenario specific ∑DIA/Q (∑DIA/Q-Scenario) relative to contemporary (∑DIA/Q-Base)

Conjunctive use & conjunctive water management (CWM) must be developed in formal systems in the context of sustainability that manages and acknowledges the limits and variability of the resources and other related stresses.

(Vorosmarty et al., 2010)

One Water

TODAY'S TALK

- WHAT IS CONJUNCTIVE WATER MANAGEMENT?
- *FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT*
- TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER
- INFORMAL AND FORMAL SYSTEMS
- HIGHLY VERSUS POORLY CONNECTED SYSTEMS
- BENEFITS OF CWM
- THE ROLE OF MANAGED AQUIFER RECHARGE
- ANALYSIS AND MODELING APPROACHES FOR CWM
- CWM DEVELOPMENT OPTIONS
- CWM CONCLUSIONS

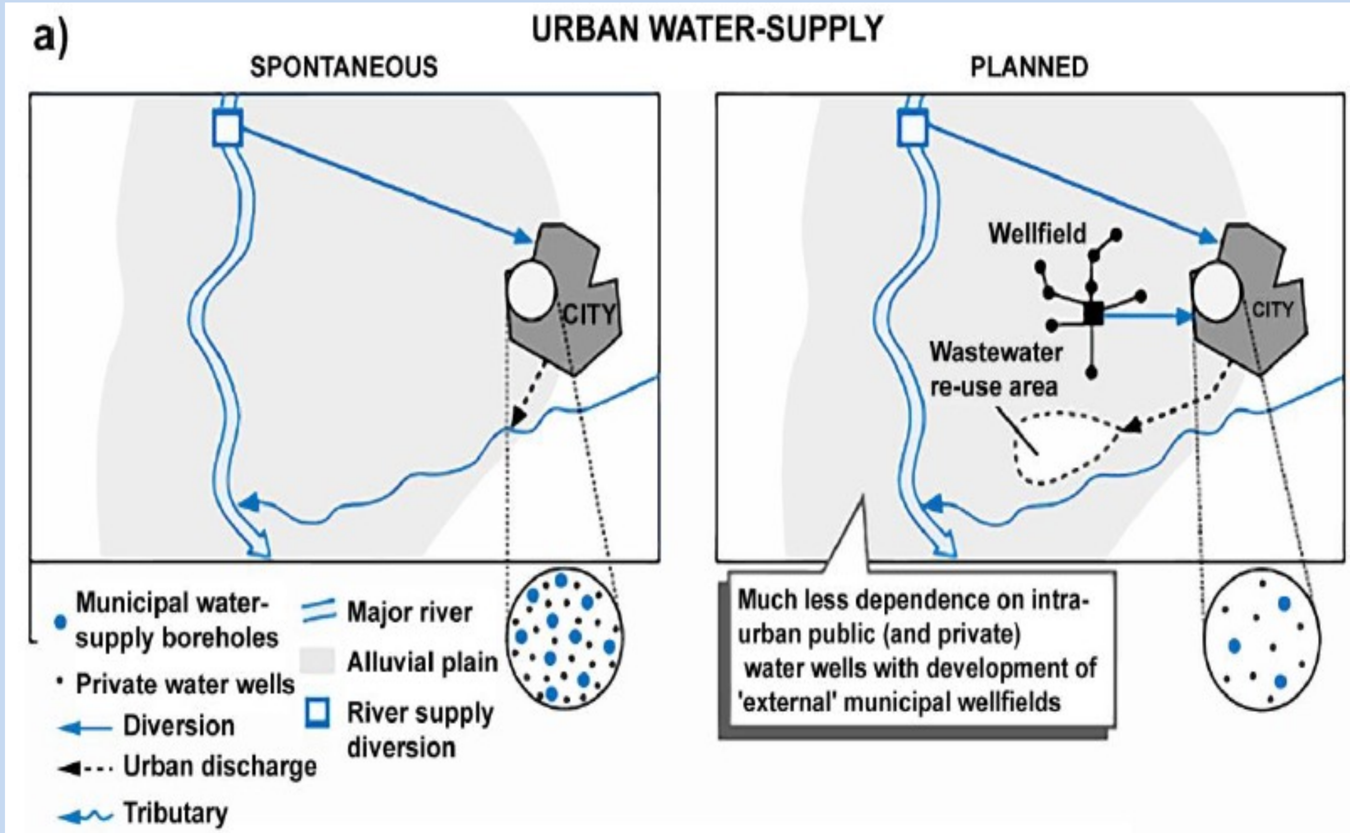
One Water

CWM Settings: Urban Supply

<u>Schemes for urban-water supply</u>:

Contrast between spontaneous (informal/unplanned) & planned (formal) CWM at the local watershed scale, the fundamental unit of supply & demand in most settings. Unplanned urban supply case have intensive local groundwater use that is often added later, causing local interference & reducing available water resources from surface-water capture & groundwater storage.

Planned CWM can also use external wellfields that increase available total water resource. But use cannot exceed rate of groundwater replenishment. Requires reuse, recycling, & artificial recharge too.



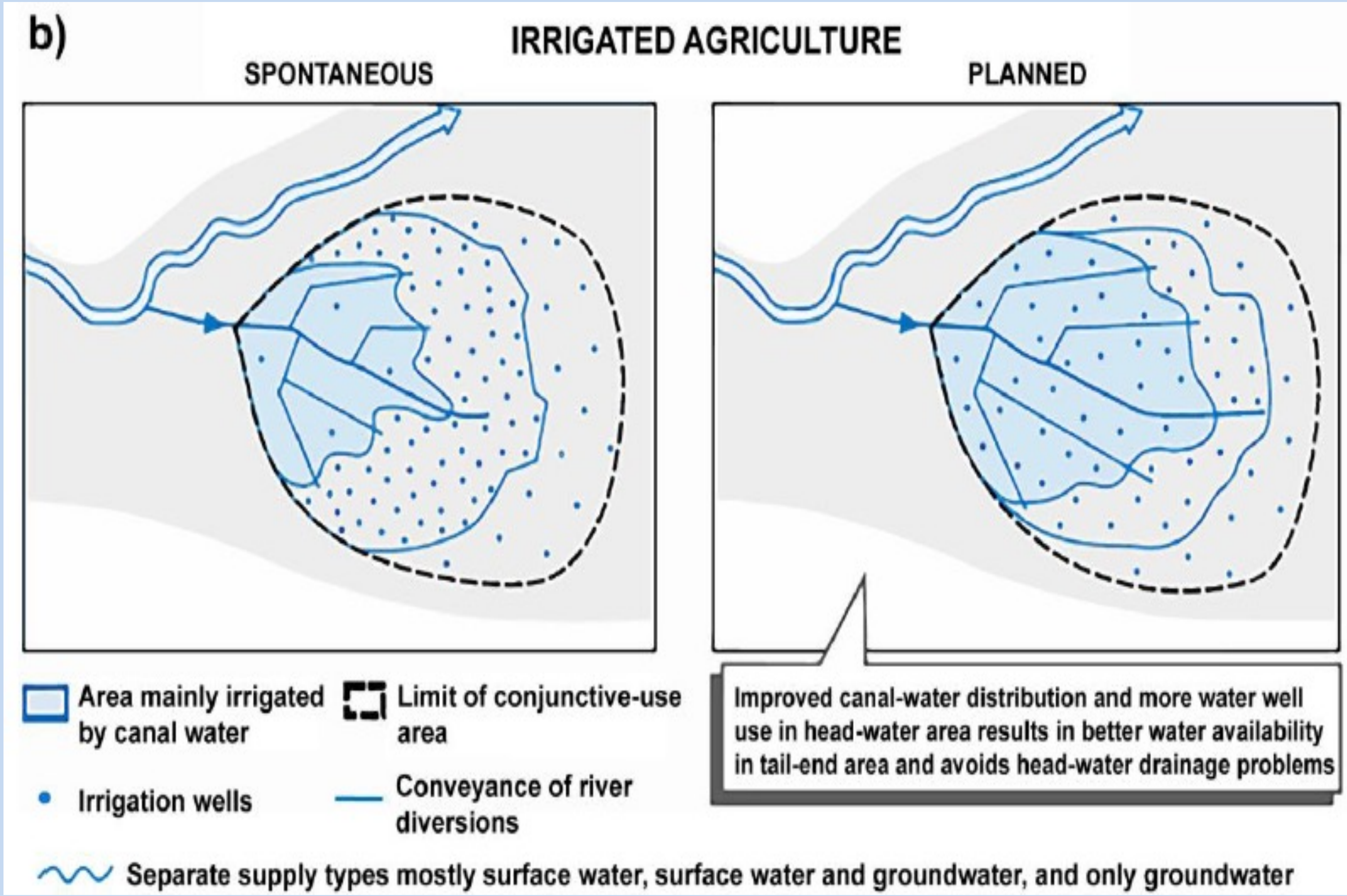
One Water

Schemes for Irrigated-agriculture supply: Planned CWM has improved canal water distribution network and more widely spaced groundwater use ➔ Greater water availability & flexibility with less environmental impact.

Effective CWM also contingent on:

- Limits to land-use development
- Conversion to permanent crops such as orchards, nuts, & vineyards are hardening demand over decades
- Climate Variability/Climate Change & related drought restrictions of supply.
- CWM framework require supply-and-demand analysis at regional scale downstream from the planned system, including transboundary obligations plus reuse, recycle, & replenishment.

CWM Settings: Agriculture



One Water

TODAY'S TALK

- WHAT IS CONJUNCTIVE WATER MANAGEMENT?
- FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT
- *TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER*
- INFORMAL AND FORMAL SYSTEMS
- HIGHLY VERSUS POORLY CONNECTED SYSTEMS
- BENEFITS OF CWM
- THE ROLE OF MANAGED AQUIFER RECHARGE
- ANALYSIS AND MODELING APPROACHES FOR CWM
- CWM DEVELOPMENT OPTIONS
- CWM CONCLUSIONS

One Water

What innovations are needed in the agri-food system to achieve food sovereignty?

Formal Systems➔ Smart Valleys➔ Monitoring + Operations + Modeling+ Analysis

One Water

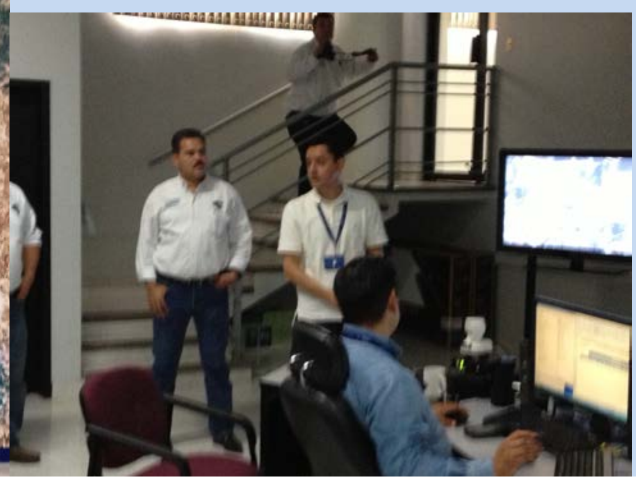
Hierarchy-Workflow SCADA+"Self-Updating Models" = SMART VALLEYS

Smart Farms, Houses, & Factories → ***Smart Agriculture, Cities, Industry, & Reservoirs***

(Land/Satellite/Drone Data Systems) ← **Smart Watersheds** ← **Smart Valleys**

Data Network Example: Distrito De Riego Del Rio Yaqui, Sonora, Mexico → 530 Pozos, Presas, Suelo, Climatico, etc.

← **Mexico's Wheat Basket**



Climate/Boundary Conditions

Water Infrastructure/ Governance

Land Use and Plant Water Demands

One-Water Model
Self-Updating
Inputs/Observations

One Water

California's (USA) Sustainable Groundwater Management Act (SGMA), enacted in 2014

Sets limits on conjunctive use and includes the following six criteria as deleterious effects that must be prevented, managed, and mitigated to insure sustainability over five-year periods of assessment

1. Groundwater-level declines,
2. Groundwater-storage reductions,
3. Seawater intrusion,
4. Water-quality degradation,
5. Land subsidence, and
6. Depletions of interconnected surface water and groundwater (gw–sw).

<u>(But Not Impairment from Adjacent Development/Use)</u>

More Physical & Regulatory issues:

- Climate change/variability including drought contingencies;
- Changing/expanding land use & agricultural demands (plus hardening of demand);
- Fish-passage streamflows & stage requirements (US National Marine Fisheries Service (NMFS));
- Habitat maintenance including Groundwater-Dependent Ecosystems (GDEs);
- Alternate water sources (runoff, reuse/recycle, imported, & desalination);
- Supply Management (Water Reuse/Recycle & Aquifer-Storage-and-Recovery (ASRs)/FloodMar);
- Demand Management as land-use, crop-type, and saline-water irrigation restrictions;
- Water-quality Requirements (US Environmental Protection Agency (US-EPA) and California Environmental Protection Agency (Cal-EPA));
- Transboundary impairment of groundwater or surface water resources (Treaties).

TODAY'S TALK

- **WHAT IS CONJUNCTIVE WATER MANAGEMENT?**
- **FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT**
- **TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER**
- ***INFORMAL AND FORMAL SYSTEMS***
- **HIGHLY VERSUS POORLY CONNECTED SYSTEMS**
- **BENEFITS OF CWM**
- **THE ROLE OF MANAGED AQUIFER RECHARGE**
- **ANALYSIS AND MODELING APPROACHES FOR CWM**
- **CWM DEVELOPMENT OPTIONS**
- **CWM CONCLUSIONS**

One Water

Informal System Issues

Informal conjunctive use of surface water and groundwater resources most commonly occurs where canal-based irrigation systems (Foster et al., 2010) are:

- Inadequately maintained & unable to sustain design flows throughout the system;
- Poorly administered, allowing unauthorized or excessive diversions;
- Overstretched capacity of surface water availability for dry-season diversion;
- Tied to rigid canal water delivery schedules & unable to respond to crop needs or drought conditions.

Conjunctive use of surface-water & groundwater sources within Informal Systems reflects a "*legacy of history*." However, many Indigenous cultures have administered these water distribution systems for centuries, with some still in use today. Yet some of the most elaborate systems, such as Mayan ones, were also prone to supply-and-demand failures, owing to overexploitation combined with climate variability (Fagan, 2008); there are other examples of the decline of Indigenous groups related to multi-century climate variability (Renteria et al., 2022). Foster and van Steenbergen (2011) report informal (spontaneous) conjunctive groundwater and surface water use in Indian, Pakistani, Moroccan, and Argentinean irrigation-canal surface-water systems, which have largely arisen due to inadequate surface-water supply to meet irrigation demand. This situation does not only occur in developing countries—it is also an inherent problem wherever canal-based irrigation is practiced and where there are challenges in terms of the reliability and quality of the water supply. These examples also exemplify the unplanned expansion of demand that, combined with climate variability, commonly drives the supply shortages from related additional land-use development in agricultural regions.

One Water

TODAY'S TALK

- **WHAT IS CONJUNCTIVE WATER MANAGEMENT?**
- **FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT**
- **TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER**
- **INFORMAL AND FORMAL SYSTEMS**
- ***HIGHLY VERSUS POORLY CONNECTED SYSTEMS***
- **BENEFITS OF CWM**
- **THE ROLE OF MANAGED AQUIFER RECHARGE**
- **ANALYSIS AND MODELING APPROACHES FOR CWM**
- **CWM DEVELOPMENT OPTIONS**
- **CWM CONCLUSIONS**

One Water

Wellbore Flow in Multi-Aquifer Wells part of Conjunctive Use ➔ Vertical-flow connections

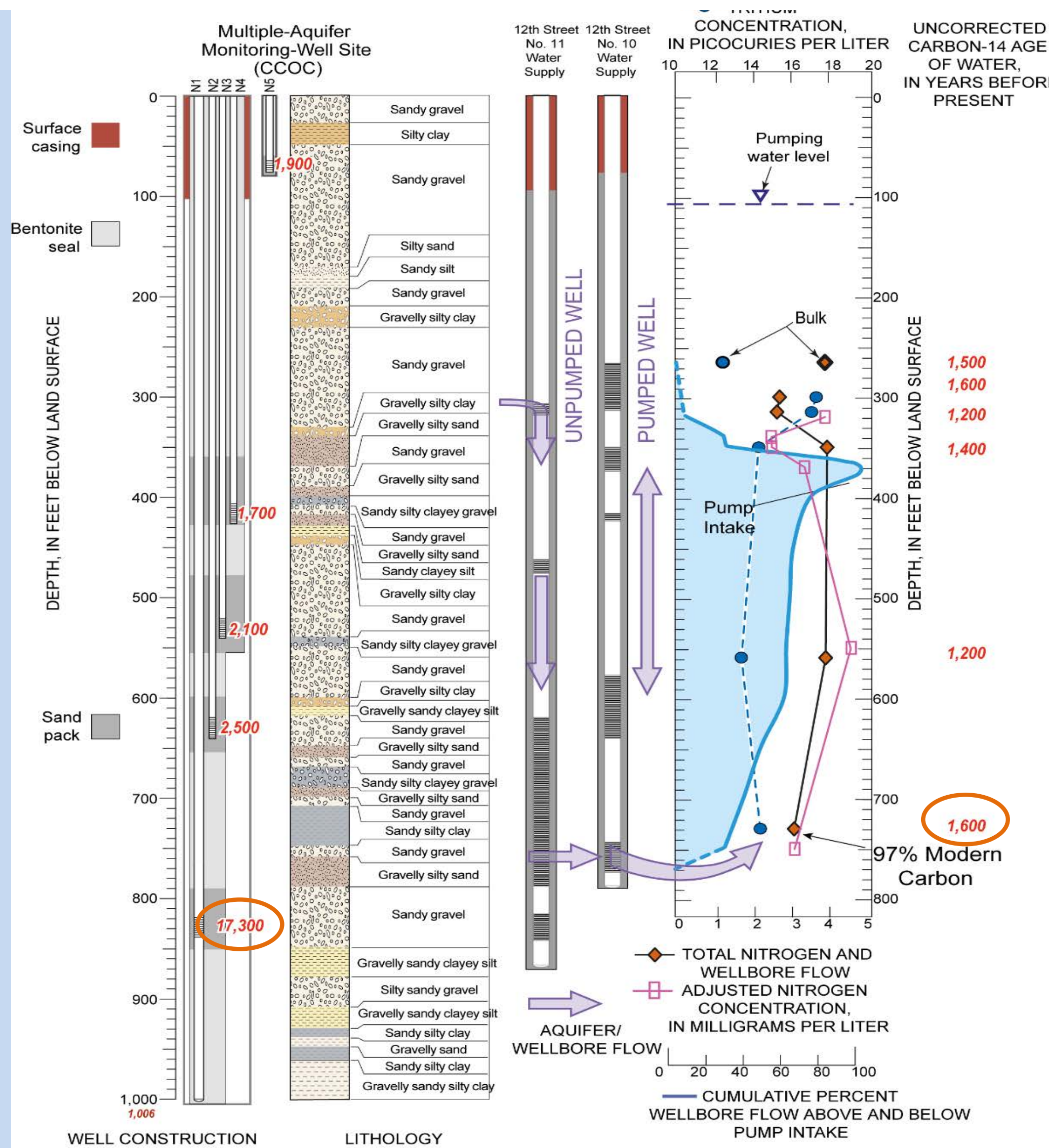
Distribution of wellbore flow in the 12th Street No. 10 water-supply well, & relation between adjacent water supply wells in well field and the CCOC multiple well monitoring site, Santa Clara Valley, California (Figure 10; Hanson, 2015).

Numbers in red ➔ uncorrected C-14 ages before present for water at that depth & purple arrows show directions of wellbore flow in pumped + nearby unpumped supply wells.

Wellbore Flow enhances vertical flow:

- ***Deep-aquifer recharge,***
- ***Streamflow recharge,***
- ***Reduces land subsidence***

One Water

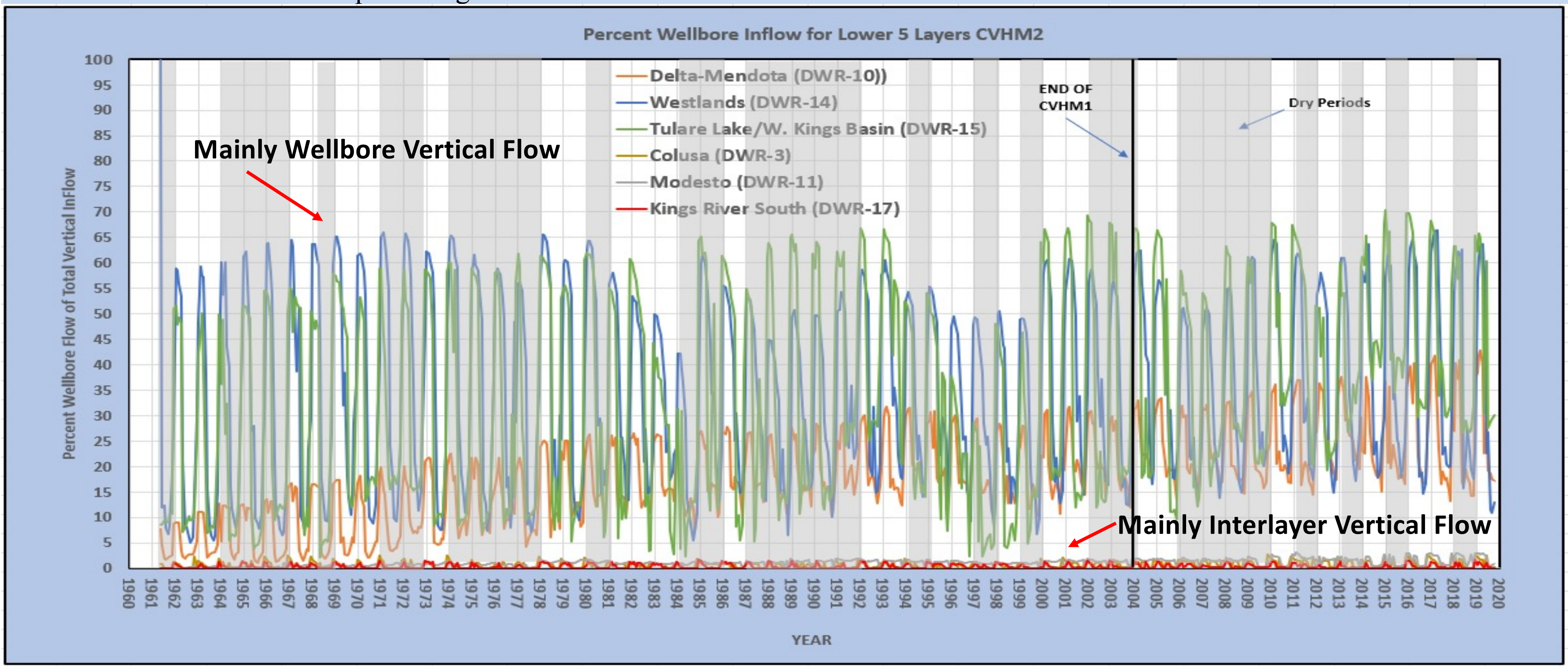


Wellbore Flow in Multi-Aquifer Wells is part of Conjunctive Use through vertical connections

Model layers combined into three groups of layers for vertical flow analyses as:

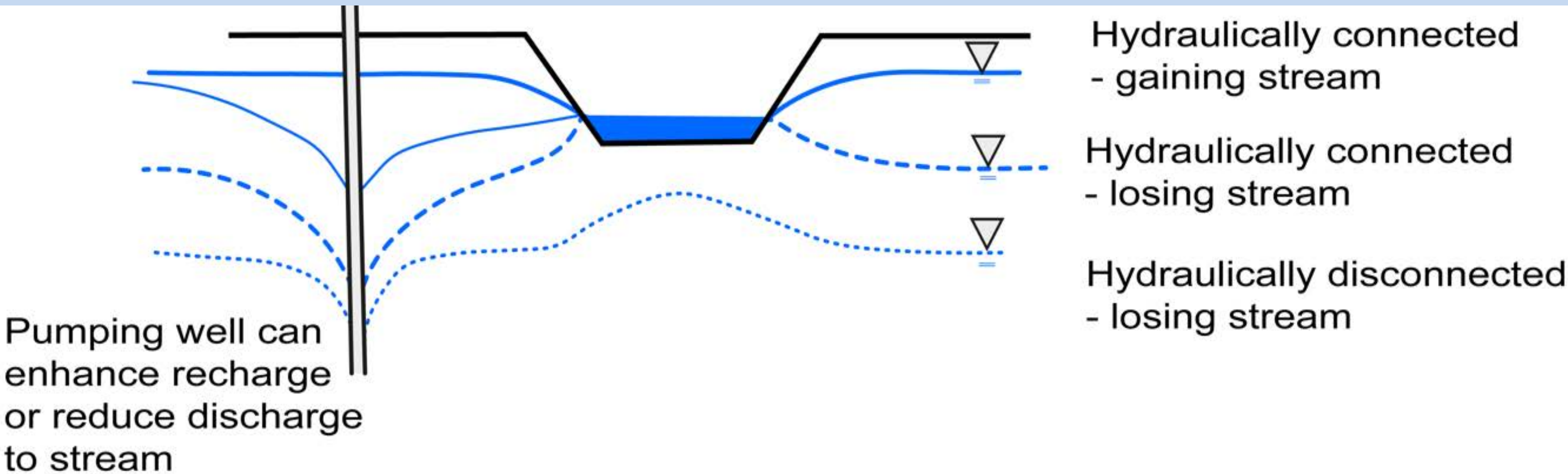
Model	Upper Aquifer System	Cocoran-Clay equivalent	Lower Aquifer System
CVHM1	(1-3)	(4 & 5)	(6-10)
CVHM2	(1-5)	(6-8)	(9-13)

Selected time series of the percentage of downward flow from simulated wellbore flow for CVHM2.



Types of Aquifer & GW-SW Connectivity Settings

The World Bank Group (2023a, 2023b) summarized economic accessibility, resource availability, & buffering capacity of groundwater systems for 4 general aquifer-systems types :
(1) local shallow,
(2) major alluvial with individual access possible,
(3) complex, and
(4) karstic.
Both of the latter three aquifer-systems types require institutional involvement.



Types of Aquifer & GW-SW Connectivity Settings - Continued

World Bank analysis underlines considerations of highly versus poorly connected systems includes:

- Layering in alluvial systems plus nature of fracture & secondary permeability in bedrock and karst aquifer systems
- Utility of groundwater systems as buffers for various human and environmental uses in the context of climate change as nature's insurance, helping to protect food security, reduce poverty, and boost resilient economic growth.
- Connectivity between surface-water and groundwater systems & related vertical distribution of well screens relative to layering or other forms of permeability will largely control the extent of interchange flow within connected systems.
- Hydraulic connectivity depends on degree of connection between the two resources & time lag for extraction from one resource to affect the other. A highly connected system has a relatively short time lag for transmission of impacts: in the order of days or weeks.
- ***All surface-water and groundwater systems are connected*** & it is just a matter of time for impacts to be felt across the connection.

One Water

Typical characteristics of relative response of groundwater and surface-water supply systems

Characteristic	Groundwater	Surface water
Response time to flow events	Slow	Quick
Time lag between supply-and-demand components	Long	Short
Size of storage	Large	Small
Security of supply	High	Low
Spatial management scale	Diffuse	Generally linear
Flexibility of supply	Very flexible in localized regions	Not flexible without more infrastructure
Adaptability to progressive increase in demand or sources of supply	Usually very adaptable	Not usually adaptable
Time to recover from a depleted resource	Years to decades	Months to years
Time to recover from seawater Intrusion	Decades to never	Years to never
Time to recover from land subsidence	Never	Never
Time to recover from quality degradation	Decades to never	Months to years
Response to Drought, Climate Cycles, and Climate Change	Years to Centuries	Months to Decades

One Water

TODAY'S TALK

- WHAT IS CONJUNCTIVE WATER MANAGEMENT?
- FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT
- TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER
- INFORMAL AND FORMAL SYSTEMS
- HIGHLY VERSUS POORLY CONNECTED SYSTEMS
- *BENEFITS OF CWM*
- THE ROLE OF MANAGED AQUIFER RECHARGE
- ANALYSIS AND MODELING APPROACHES FOR CWM
- CWM DEVELOPMENT OPTIONS
- CWM CONCLUSIONS

One Water

Benefits of Using All Water Together → CWM

One Water

Where groundwater and surface water are used conjunctively in various parts of the world, informal (spontaneous) use still commonly prevails. Foster and van Steenbergen (2011) emphasize that informal (spontaneous) conjunctive use of shallow aquifers in irrigation systems is driven by the capacity for groundwater to buffer growth in land use combined with variability of surface water availability enabling:

- Greater water-supply security;
- Secure existing crops & permit new crop types to be established;
- Better timing for irrigation, plus extension of cropping season;
- Larger water yield possible using more sources;
- Reduced environmental impact;
- Avoid excessive surface-water or groundwater depletion.

Another benefit of CWM in many settings where supply and demand of conjunctive use requires the active management of GDEs is globally summarized by Rohde and others (2017), who demonstrated how many locations have included management of GDEs as part of their sustainable groundwater policies. Managing and protecting GDEs has been highly developed in Australia and includes risk assessment. Similarly, protection of GDEs in California is also tied to protection of endangered species and maintaining fish passage and habitat, as well as sediment transport, flood protection, and river/runoff recharge infrastructure.

TODAY'S TALK

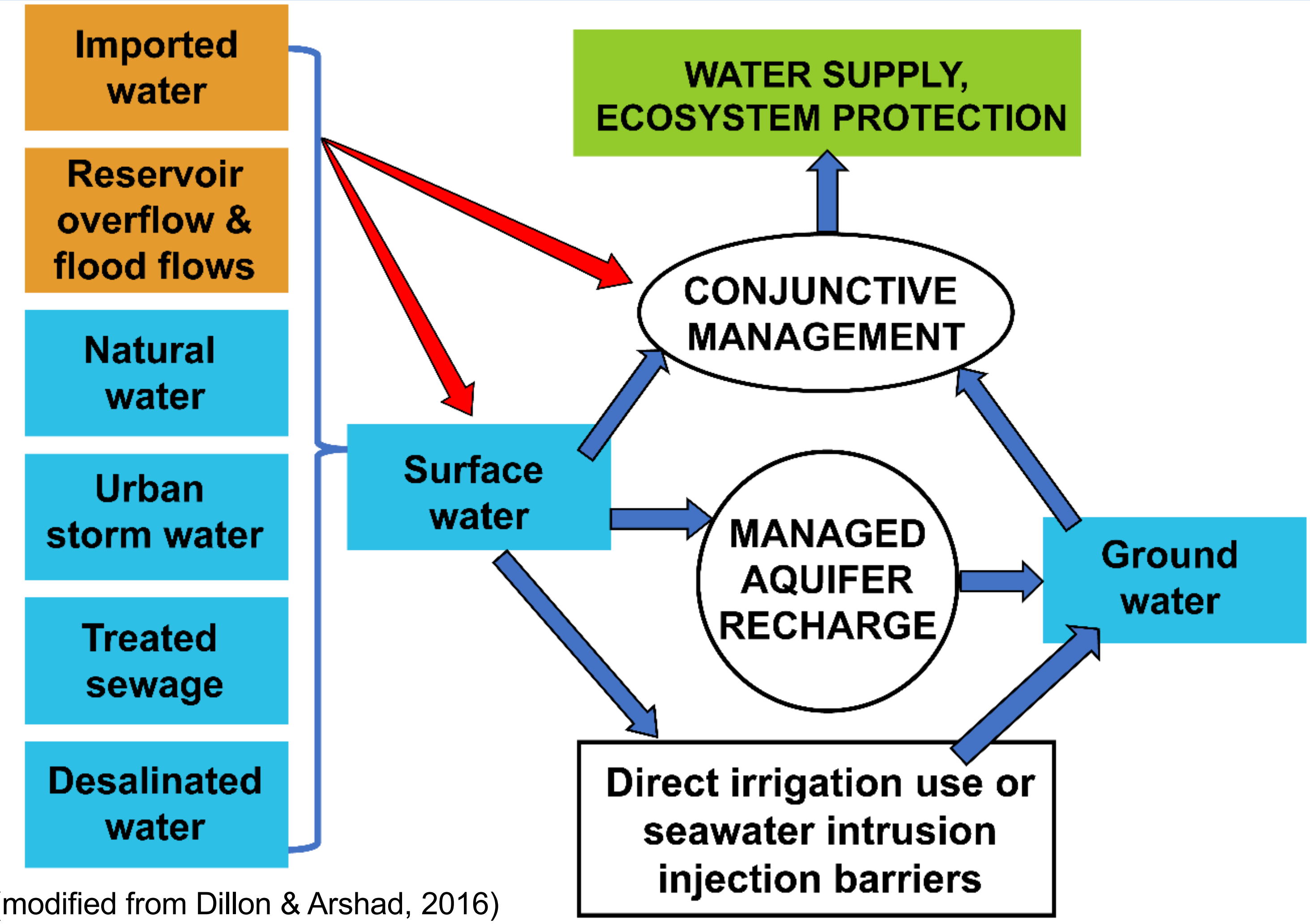
- WHAT IS CONJUNCTIVE WATER MANAGEMENT?
- FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT
- TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER
- INFORMAL AND FORMAL SYSTEMS
- HIGHLY VERSUS POORLY CONNECTED SYSTEMS
- BENEFITS OF CWM
- *THE ROLE OF MANAGED AQUIFER RECHARGE*
- ANALYSIS AND MODELING APPROACHES FOR CWM
- CWM DEVELOPMENT OPTIONS
- CWM CONCLUSIONS

One Water

Managed Aquifer Recharge (MAR), ASR, & FloodMAR

Role of MAR in CWM.
Amount of recharge economically or technically achievable is generally less than the annual groundwater deficit. A combination of demand management & recharge enhancement is essential to restore a groundwater system to equilibrium (Dillon et al., 2009b).
Most effective mechanism is direct use of these captured, recycled, or imported waters with the additional benefits:

- Multi-aquifer wells add groundwater recharge to deeper aquifers
- Reduced power consumption.

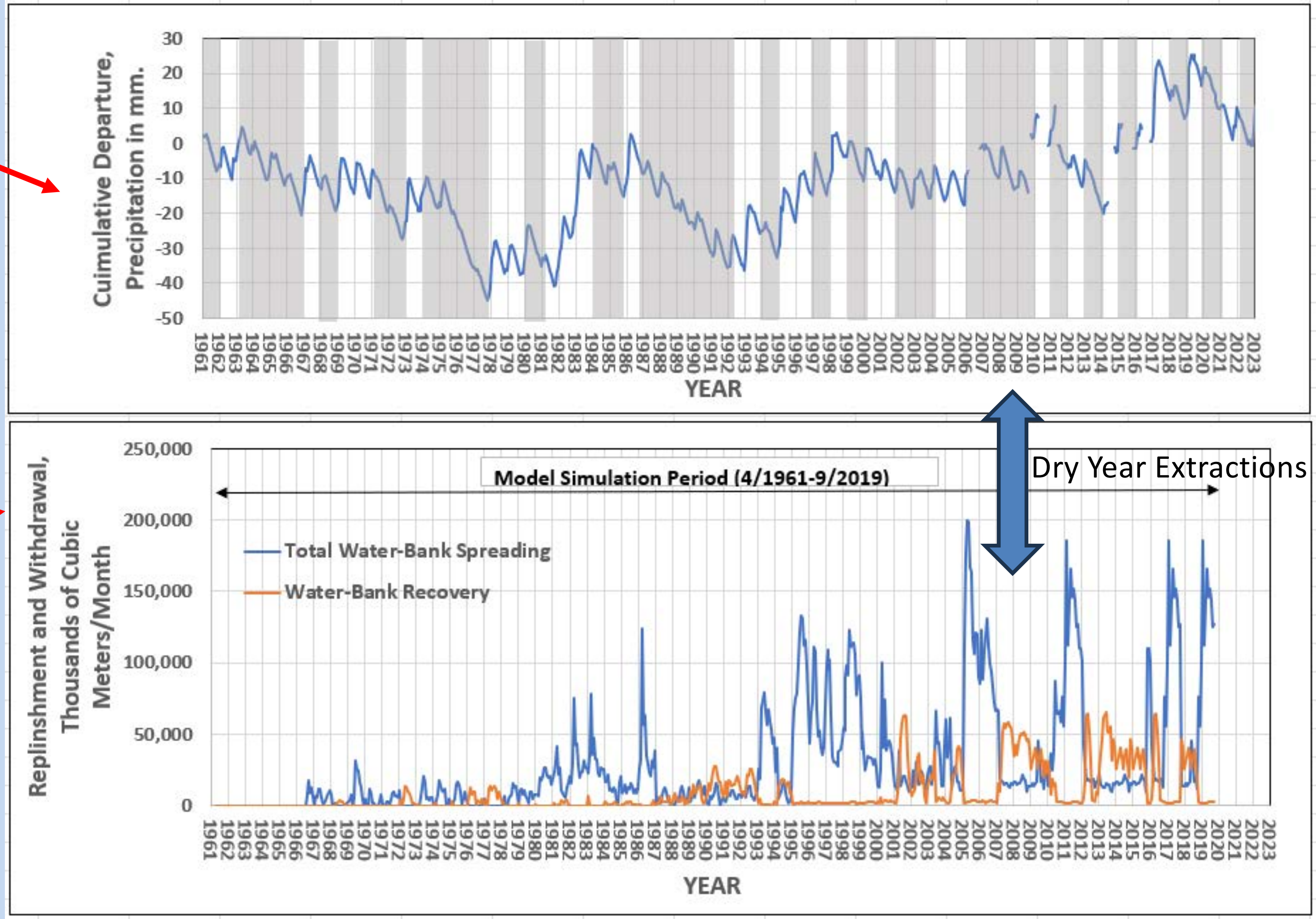


(modified from Dillon & Arshad, 2016)

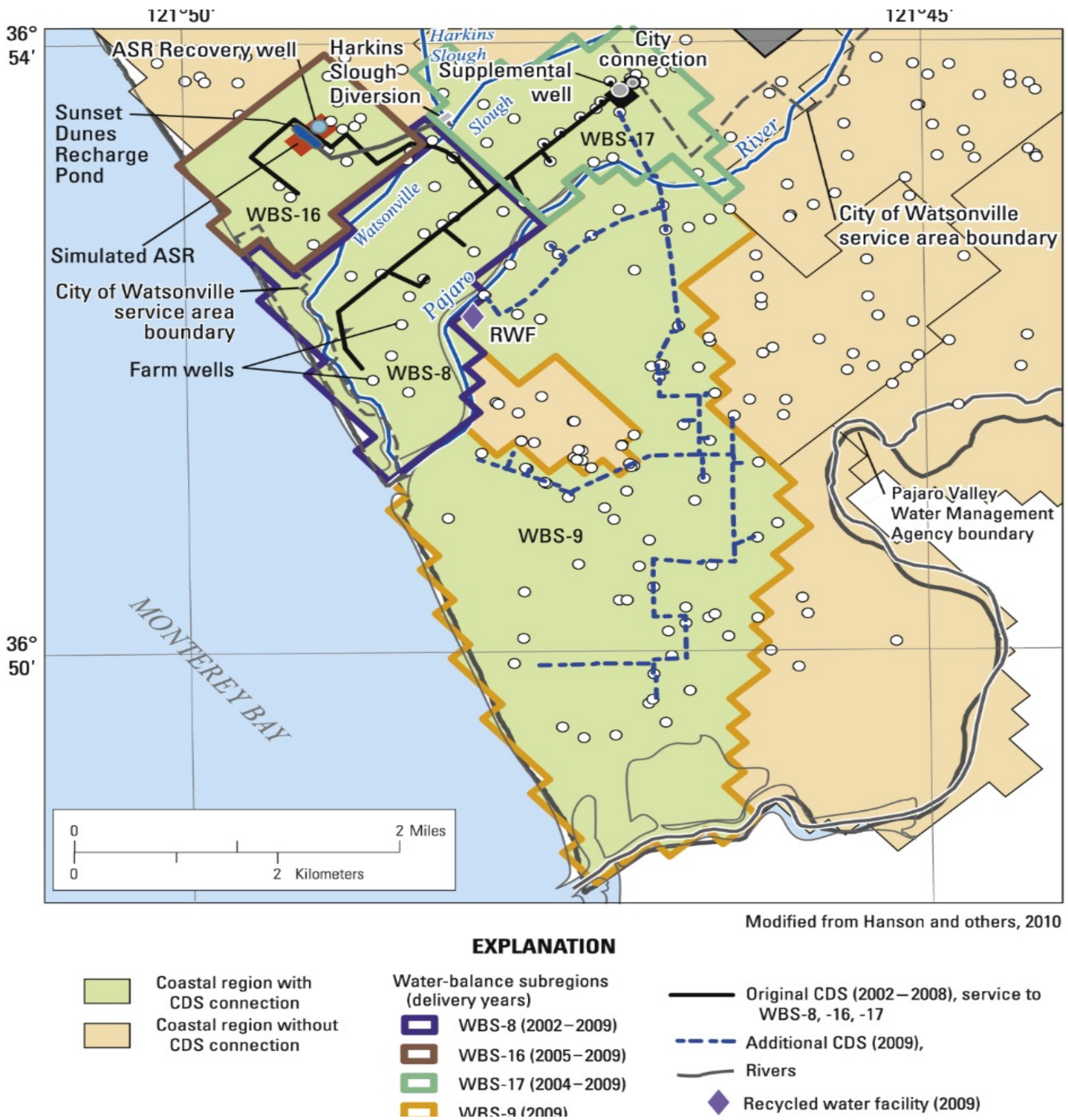
Example of Water Banking & Recovery in the Central Valley, California

Comparison of climate variability with water-banking spreading and recovery for the Central Valley, California, USA. Grey regions in cumulative departure precipitation graph indicate drier climate periods of precipitation (USGS, 2022; CDEC, 2023).

Total water banking & water-bank groundwater recovery relative to climate variability for the Central Valley, California, USA (Faunt et al., 2024).



One Water



Subsidies and incentives: Are we rewarding the wrong production practices?

Pajaro Valley Water – Monterey Bay, CA

(1) Pumping Tax ➔ O&M Management Costs

(2) Recharge Credit ➔ Capture runoff for recharge

(3) Alternative Supplies ➔ Replace Coastal Pumpage (Coastal Distribution System) (No Coastal Pumpage/Irrigation at Night)

(4) Tile Drain Waters ➔ Not Captured

This is Strawberry production in Pajaro Valley by Driscoll Farms & others.

In contrast, Driscoll & others are using ~80 RO Desalination units at wells to treat groundwater contaminated with seawater intrusion instead of preventing seawater intrusion in San Quintin, Baja, Mexico.

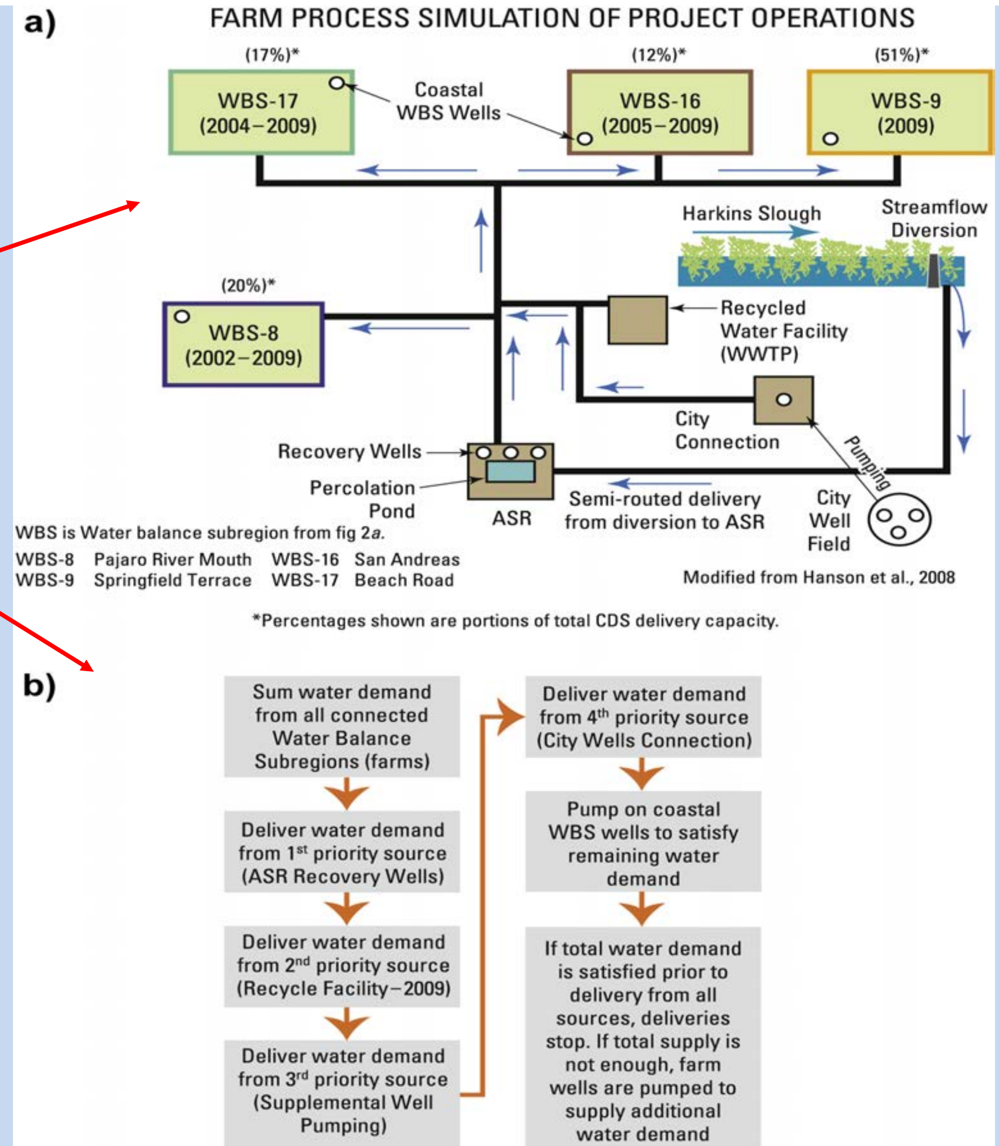
(modified from Hanson et al., 2014b)

One Water

Example of CWM Operations & Model Simulation in the Pajaro Valley, California

a) Structure of local water deliveries (ASR + Recycle + City Wells) ➔ Reduce Coastal Pumping,

b) Modeling hierarchy of simulated operation of the aquifer-storage-and-recovery (ASR) system and Coastal Distribution System (CDS) water deliveries to the regions serviced by the CDS, Pajaro Valley, California, USA (modified from Hanson et al., 2014b)



CWM Sustainability Framework & Goals

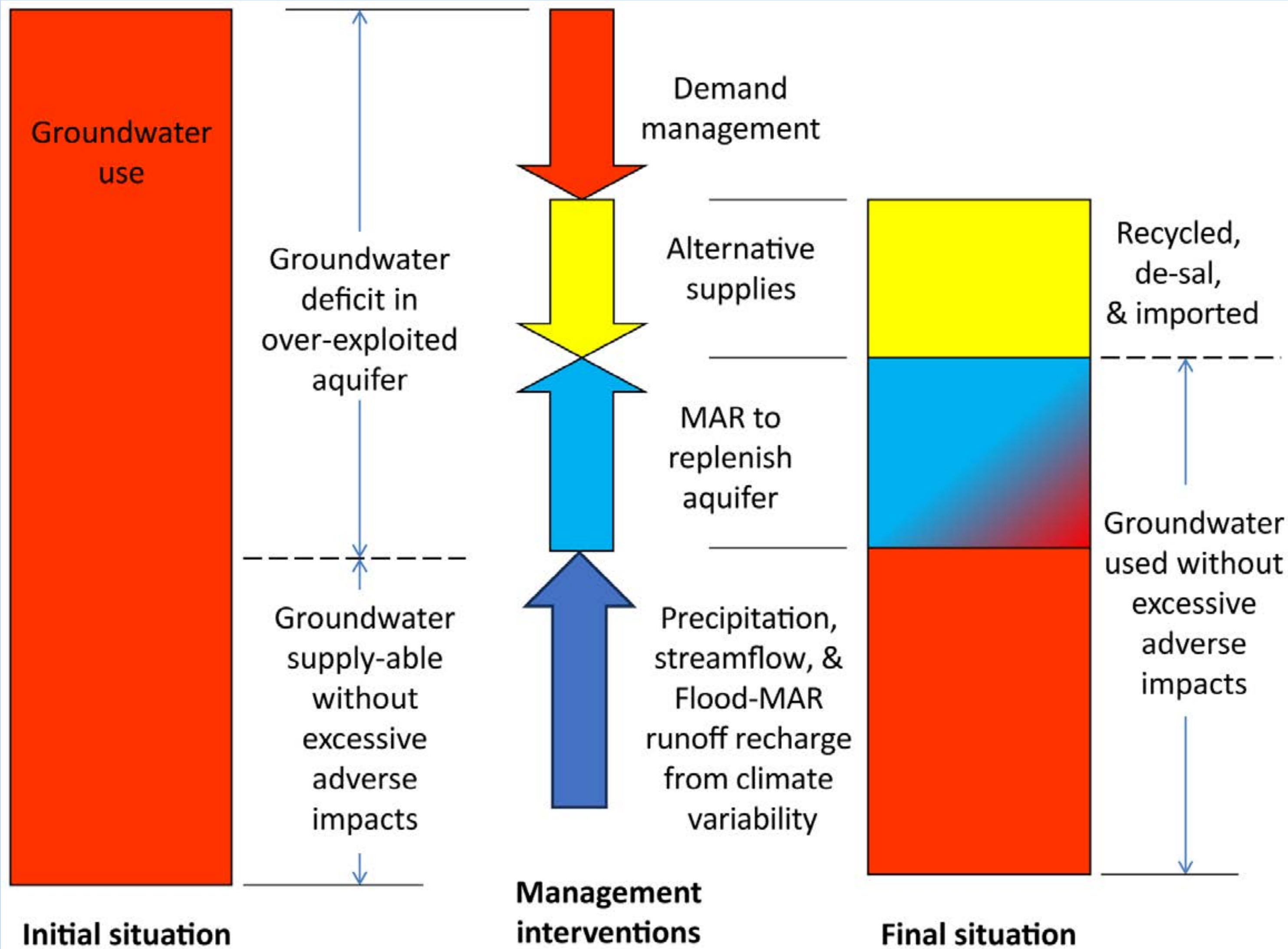
Bring aquifer back to dynamic nonequilibrium with reduced changes:

(1) Reduce extraction (demand management),
(2) Add supply sources,
(3) Both,

Using groundwater replenishment, or alternative supplies (conjunctive use)

Reduce land use or other demand drivers.
(modified from Dillon et al., 2012)

One Water



Field layout of the experimental sites at a) Plant Sciences Field Facility, Davis, CA. Davis site, a randomized complete block design consisting of seven treatments with three replicates was implemented. The table above summarizes the treatments for the Davis site. C is the control. Letters H and L stand for high and low water amounts of 4 ft and 6 ft, respectively, which are combined with letters J, F, and M to indicate the month in which the winter recharge was performed (i.e., January, February, March); and b) Scott Valley, in Siskiyou County, California (Dahlke et al., 2017, 2018).

On-farm experiments

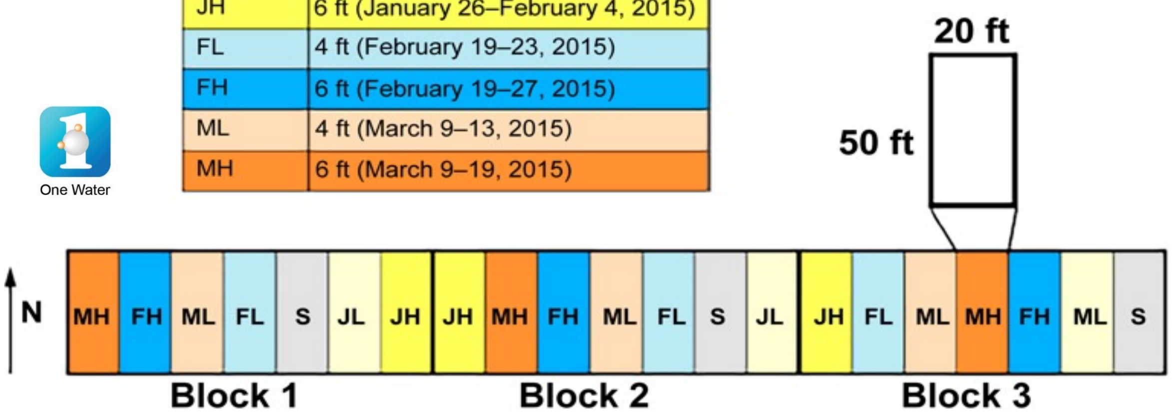
Infiltration Experiments to Evaluate FloodMAR

a) Davis, CA (Plant Sciences Research Farm)

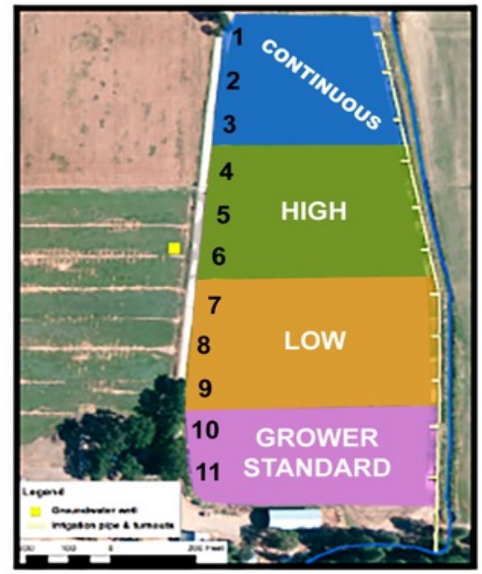
- **Block Experiment with three replicates on Yolo silty clay loam, 4-year stand**
  - Timing (Jan, Feb, March)
  - Applied water (4 ft, 6 ft)
  - Control

Treatment	Amount and Timing
S	Grower Standard, precipitation only
JL	4 ft (January 26–29, 2015)
JH	6 ft (January 26–February 4, 2015)
FL	4 ft (February 19–23, 2015)
FH	6 ft (February 19–27, 2015)
ML	4 ft (March 9–13, 2015)
MH	6 ft (March 9–19, 2015)

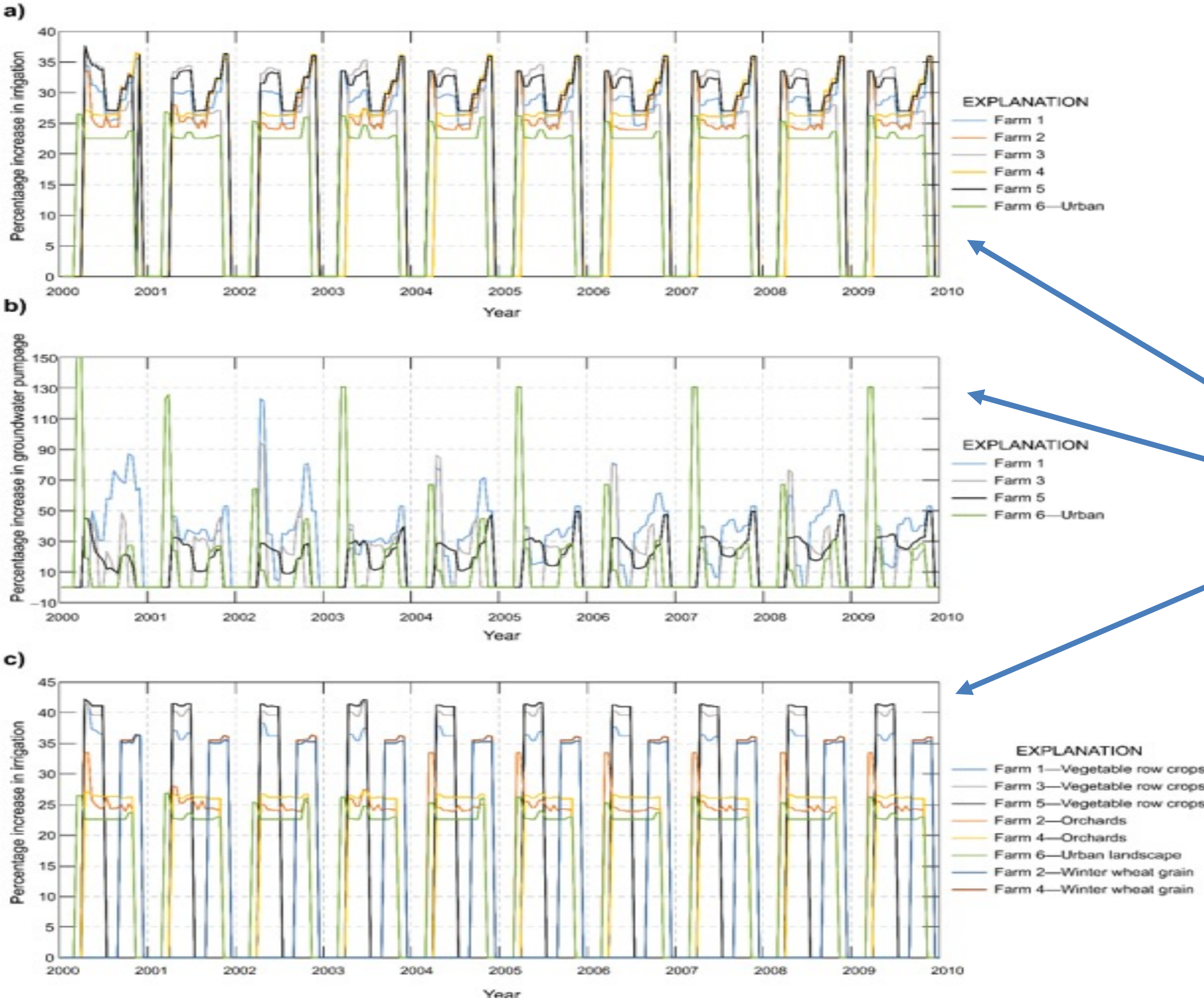
One Water



b) Scott Valley, Siskiyou County, 15 acres, 9-yr alfalfa stand



- Stoner gravelly sandy loam
- Three winter water application rates:
  - ***Continuous*** - every day
  - ***High*** – 3-5 water applications per week
  - ***Low*** – 1-3 water applications per week
  - ***Standard*** - no winter water application



Simulating Demand from Salinity Flushing

Relative increase with leaching among simulations from OWHM example model with & without the salinity demand option:

a) 22-38% more irrigation for leaching

b) 20-80% more groundwater pumpage,

c) 22-43% (vrc) & 24-34% (orchards) more irrigation for selected crops and farms

(Boyce et al., 2020)
(Evans and Hanson, 2025)

One Water

TODAY'S TALK

- **WHAT IS CONJUNCTIVE WATER MANAGEMENT?**
- **FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT**
- **TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER**
- **INFORMAL AND FORMAL SYSTEMS**
- **HIGHLY VERSUS POORLY CONNECTED SYSTEMS**
- **BENEFITS OF CWM**
- **THE ROLE OF MANAGED AQUIFER RECHARGE**
- ***ANALYSIS AND MODELING APPROACHES FOR CWM***
- **CWM DEVELOPMENT OPTIONS**
- **CWM CONCLUSIONS**

One Water

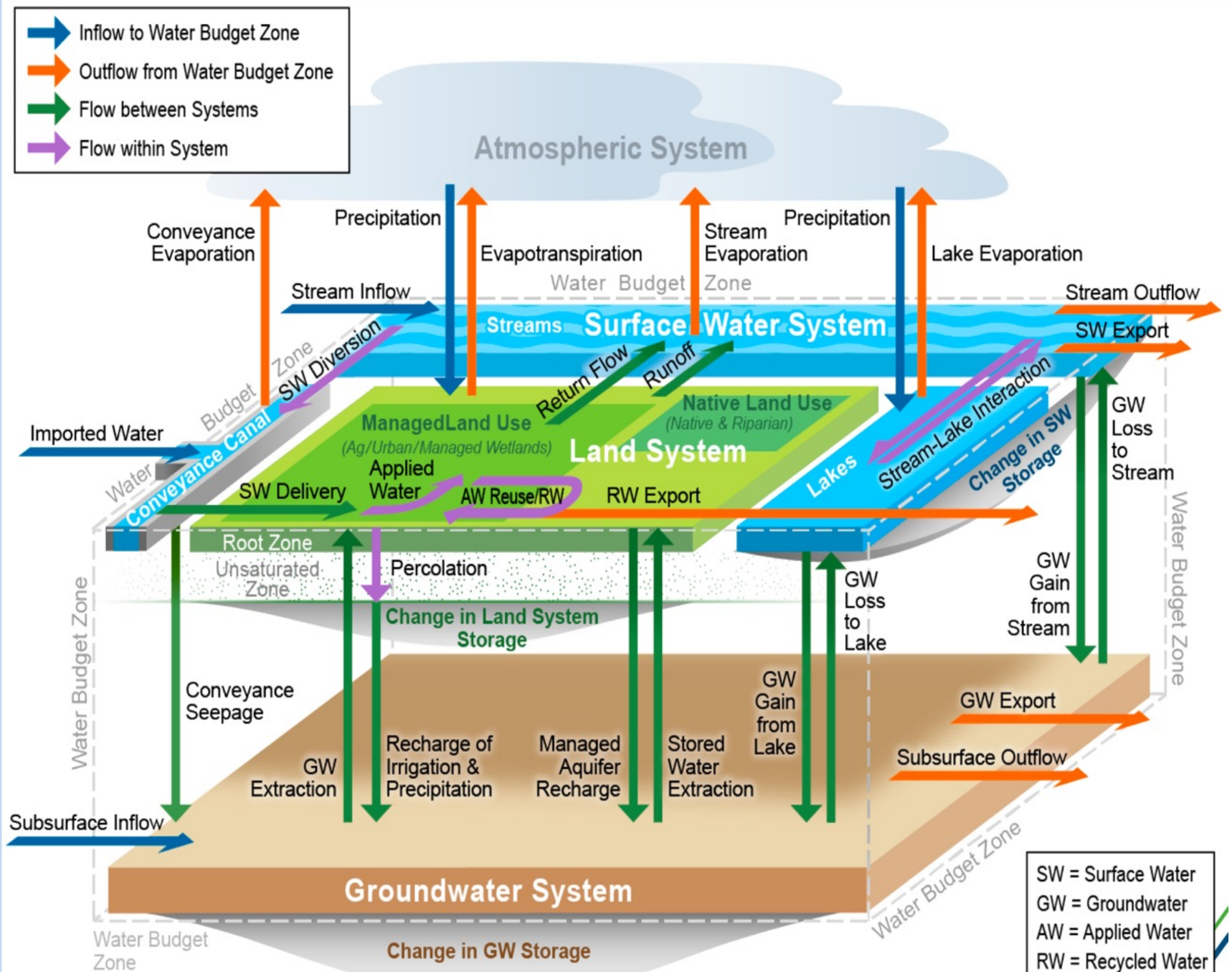
CWM Requires Multiple Hydrologic Budgets

Hydrologic-Flow Budgets ➔ CWM groundwater sustainability analysis.

4 Hydrologic-Flow Budgets estimated for Groundwater Sustainability Association multiple water budget subregions (WBS) using an IHM model:

(1) Climate
(2) Land system
(3) Surface-water
(4) Groundwater

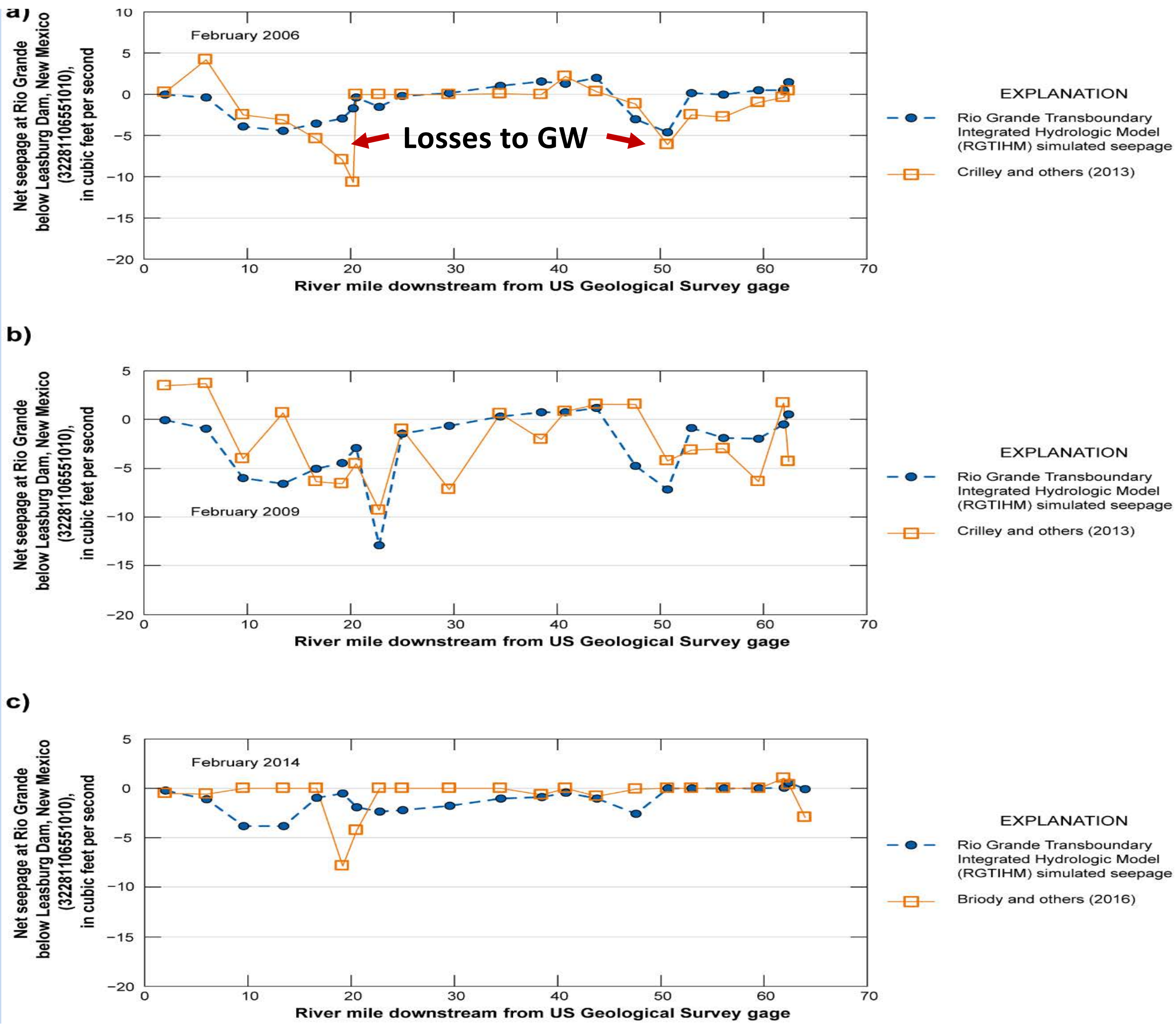
One Water



(California Department of Water Resources , 2020)

CWM ➔ Simulate & Analyze Streamflow Gains/Losses with Annual Seepage Runs, Rio Grande (Rio Bravo)

Simulated & observed streamflow hydrographs for selected Rio Grande winter-seepage estimates, where positive values represent gains, & negative values represent seepage losses, Lower Rio Grande, New Mexico (Hanson et al., 2020).



Types of Numerical Models

- **Simple groundwater or surface water models that treat other flows simply user-specified boundary conditions such as specified flows or head-dependent flows,**
- **Passively coupled models that use output from a companion model as input and are not subject to active coupling or any feedback between the flows in the companion model, and**
- **Fully coupled hydrologic models that are either iteratively or fully integrated solutions to the surface water and groundwater flow features.**

Passively-coupled models use a watershed (precipitation-runoff) model to provide recharge as lateral runoff and mountain-block recharge as groundwater underflow from surrounding sub-watersheds that is computed first and then used as input to an IHM. Some examples are:

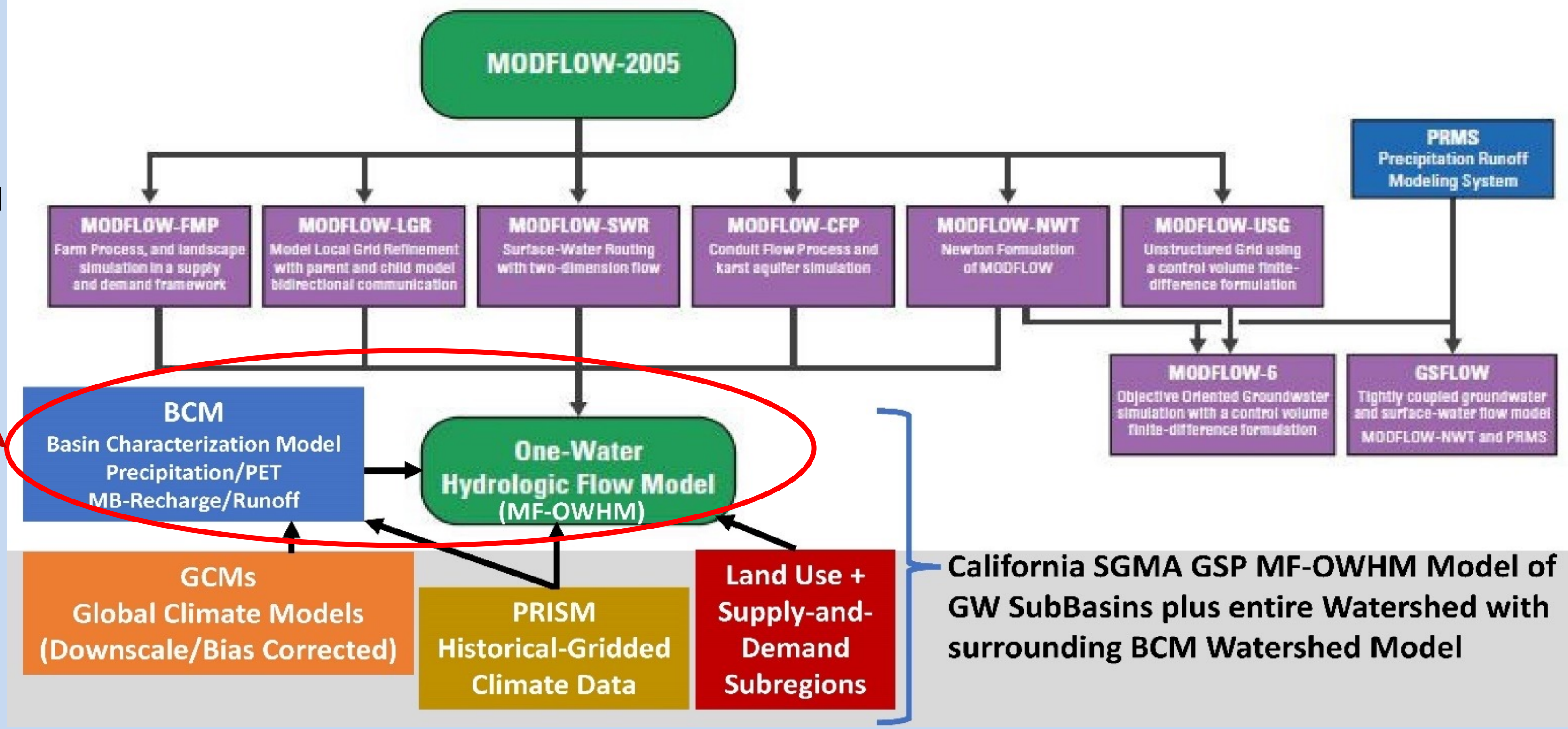
- **the Basin Characterization Model (BCM; Flint et al., 2021),**
- **the Variable Infiltration Capacity model (VIC; Liang et al., 1994, 1996; Nijssen et al., 1997),**
- **the Hydrological Simulation Program-Fortran (HSPF; Donigian et al., 1995; Donigian, 2002),**
- **the Soil-Water Balance model (SWB; Westenbroek et al., 2018), or**
- **the Precipitation Runoff Modelling System (PRMS; Markstrom et al., 2015).**

One Water

Integrated Monitoring/Modeling for CWM & Sustainability

MF-OWHM2 Conjunctive-Use Modeling Framework is Fusion/Update/Upgrades of MF-2005 Code Family

Passively Coupled Watershed Rainfall - Runoff model (BCM) + IHM model (MF-OWHM)



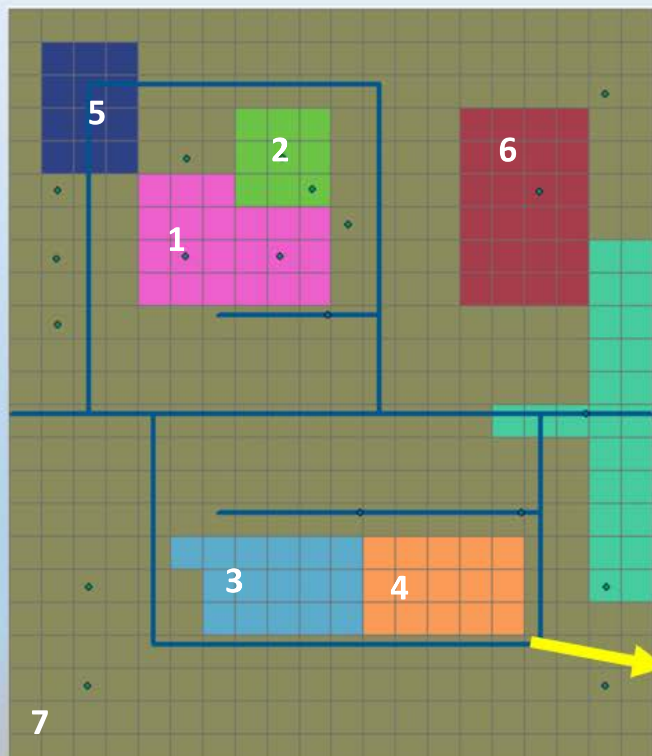
USGS Download site One-Water (Modflow-OWHM2 ver 2.3.0): https://code.usgs.gov/modflow/mf-owhm

Conjunctive-use modelling framework → Combines land use, supply-and-demand subregions, and global climate model (GCM) data into a two-model linked framework: Watershed (BCM) & Basin (IHM) models (modified from Boyce et al., 2020).

Water Use/Movement - Coupled to Land Use in Supply-and-Demand Framework

Farm Process establishes a supply and demand framework for a specified land use

A water demand is calculated for each Land Use



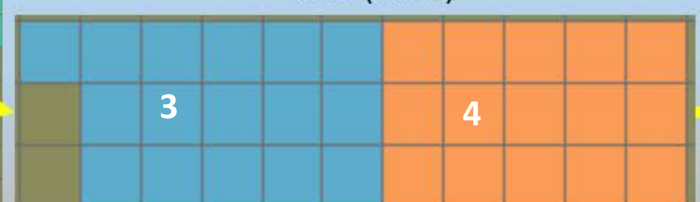
The use and movement of water is subdivided into Water Balance Subregions (WBS)

A WBS defines a group of land uses with common water supply

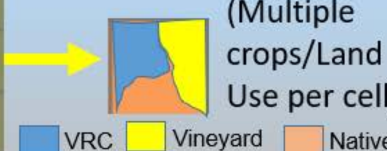
Precipitation, Wells, stream diversions, reservoir releases, non routed deliveries (pipelines, reuse) and groundwater are potential sources to meet demands

Supply and demand is accounted for on each WBS

WBS (Farm)



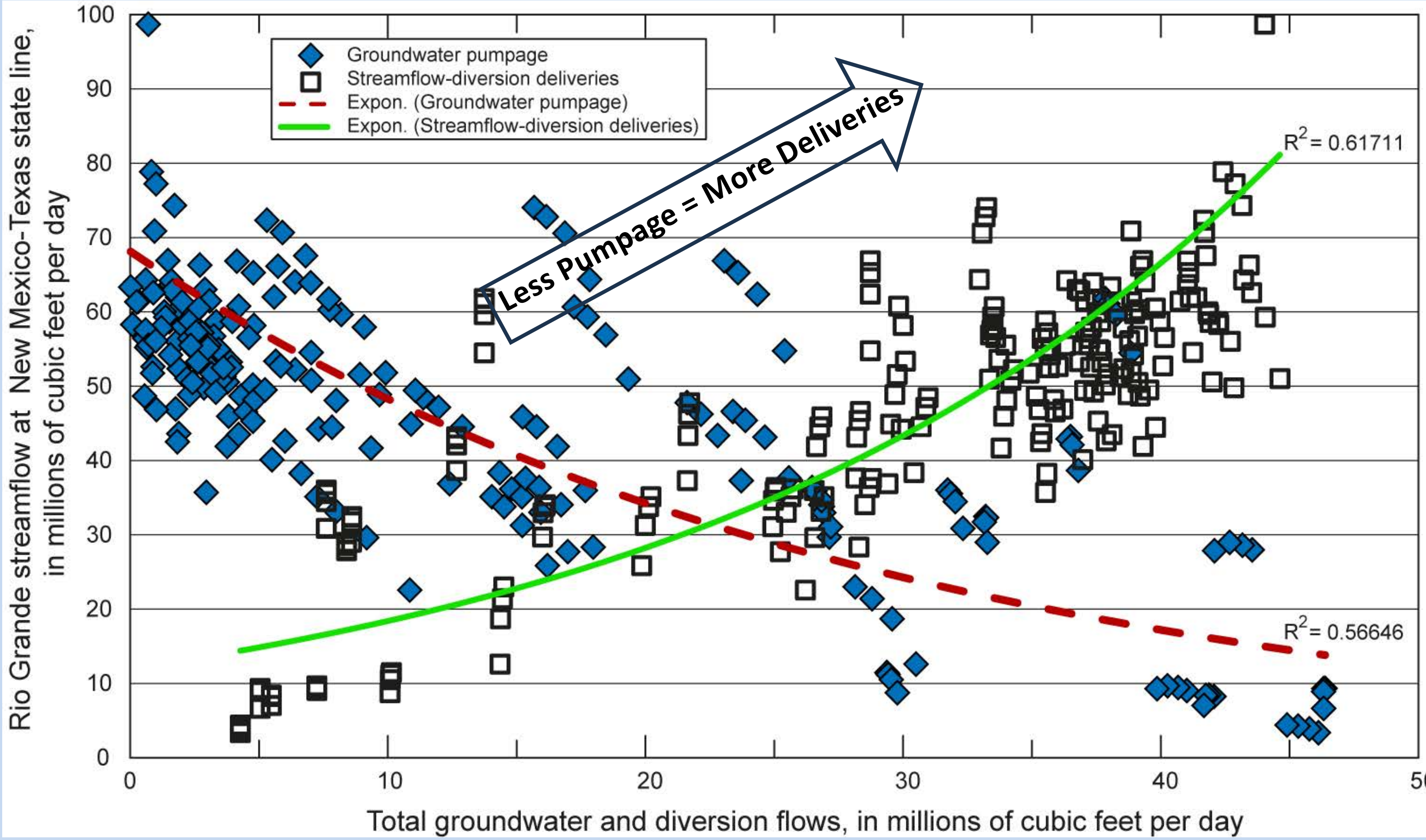
Fractional Land Use (Multiple crops/Land Use per cell)



One Water

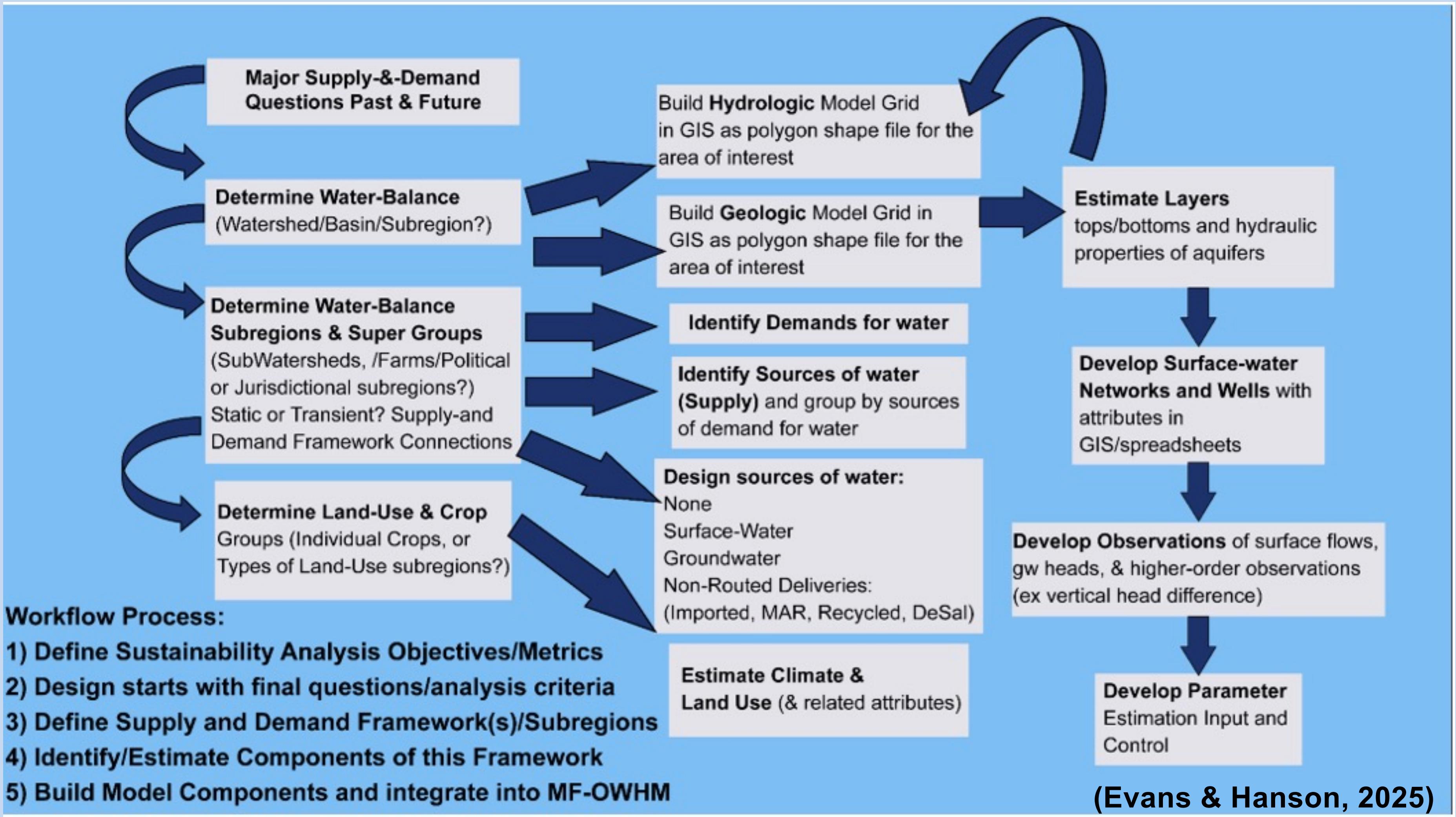
Groundwater-Surface-Water Interaction and Capture Analysis with IHM (MF-OWHM)

Lower Rio Grande Model Analysis showing impact of upstream agricultural use & pumpage on downstream streamflow & agricultural diversion deliveries. The nonlinear relation between streamflow, diversions, & pumpage demonstrates that conjunctive use requires analysis of all water use & movement with an IHM model where these processes are internally simulated & coupled.



(Hanson & Schmid, 2013)

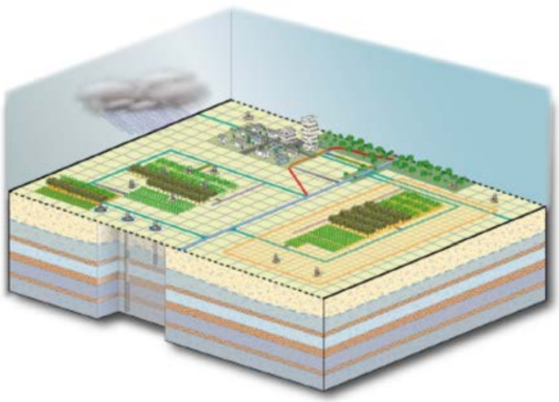
Workflow for IHM development with MF-OWHM for CWM sustainability analysis



One Water

CWM Example-Model Scenario Exercises with MF-OWHMv2 Randall T. Hanson

CWM Example-Model Scenario Exercises with MF-OWHM



One-Water Conjunctive-Use Modeling:

All The Water ➔ All The Time ➔ Everywhere

Randall T. Hanson

CWM Analysis with an Integrated Hydrologic Model (IHM)

Six scenarios address the following variations from a base case.

(1) Addition of an Urban Well ➔Effects on Streamflow and Subsidence

(2) Change Crop Type ➔ Change Winter Wheat to Vegetable Row Crops and to Orchards Effects on Water Demand

(3) Addition of Salinity Flushing ➔ Effects on Water Demand & Water Sources

(4) Adjustment of Water Demand to Equal Supply for Sustainability ➔ Effects on Reduction of Demand to Equal Supply

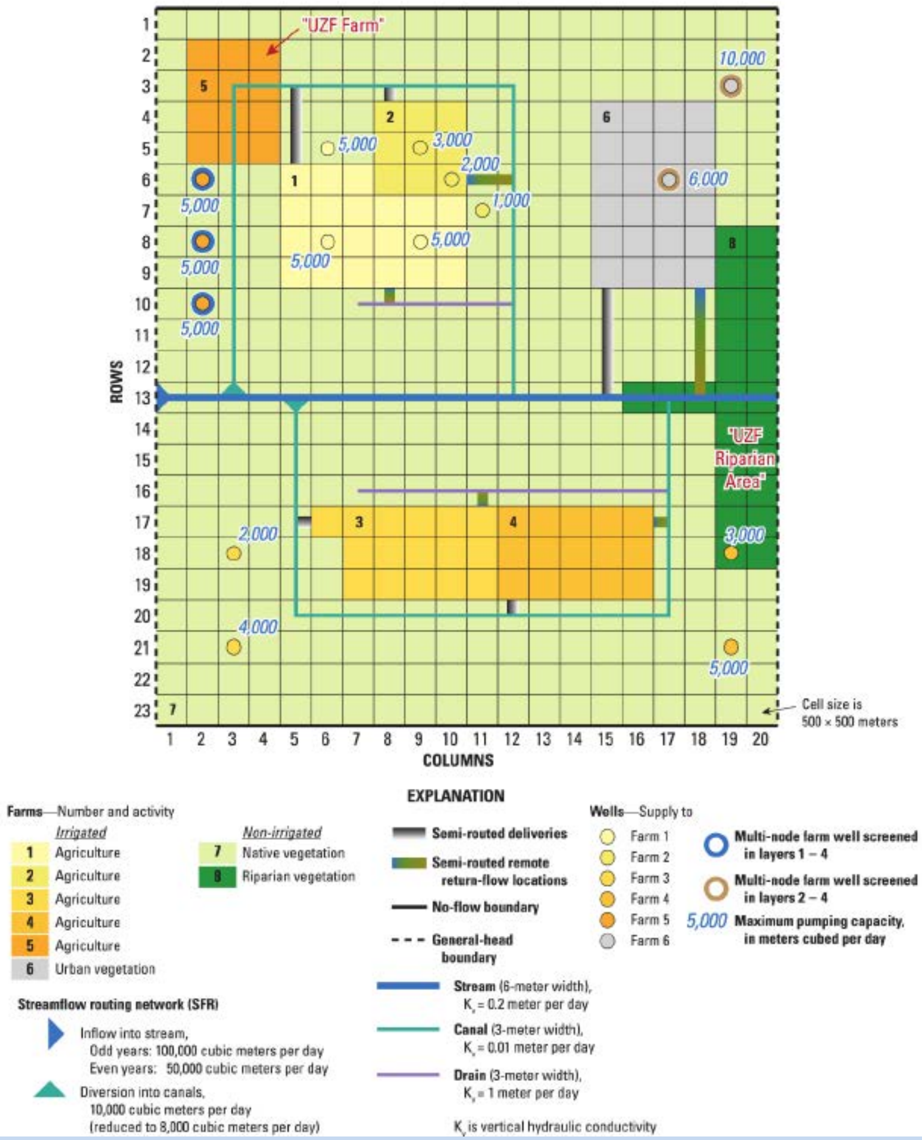
(5) Changed Water Supply and Demand due to Climate Change ➔ Effects of Warm/Dry and Cool/Wet on Water Demands

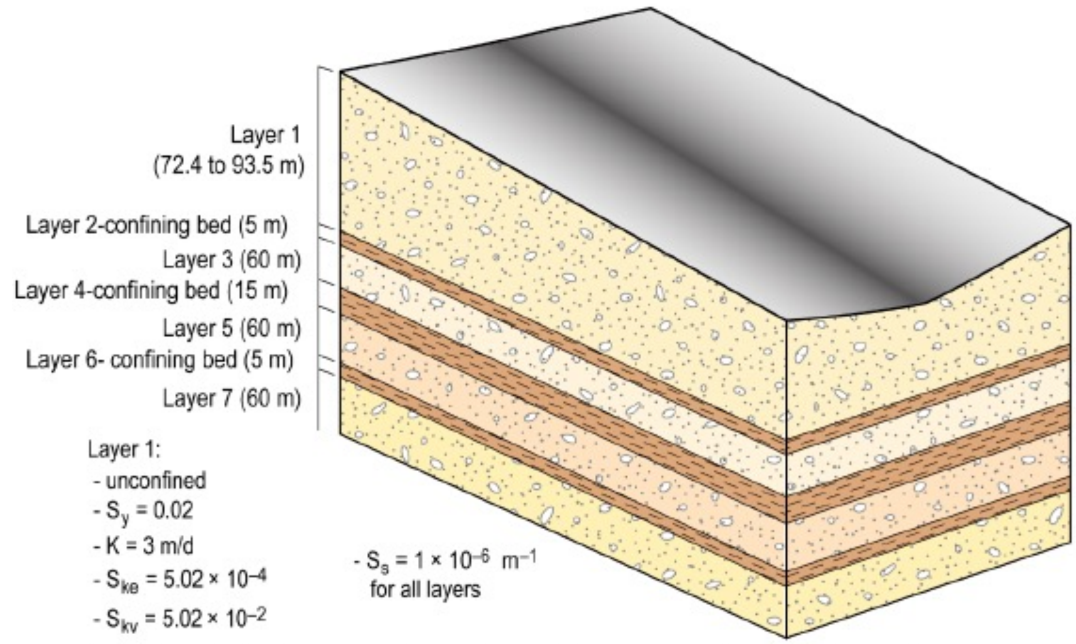
(6) Adjustment of Surface-Water Operations ➔ Effects of Reservoir Operations & Operating framework to enhance Surface-Water Deliveries

Using the USGS IHM:
Modflow-One-Water Hydrologic Model (MF-OWHM)

One Water

CWM Example Model Set Up





Layer 1:
- unconfined
- $S_y = 0.02$
- K = 3 m/d
- $S_{ke} = 5.02 \times 10^{-4}$
- $S_{kv} = 5.02 \times 10^{-2}$

- $S_s = 1 \times 10^{-6}\ m^{-1}$ for all layers

Layer 2 (confining bed at bottom of Layer 1):
- K = 0.1 m/d
- $S_{ke} = 1.5 \times 10^{-5}$
- $S_{kv} = 1.5 \times 10^{-3}$

Layer 4 (confining bed at bottom of Layer 3):
- K = 0.1 m/d
- $S_{ke} = 4.5 \times 10^{-5}$
- $S_{kv} = 4.5 \times 10^{-3}$

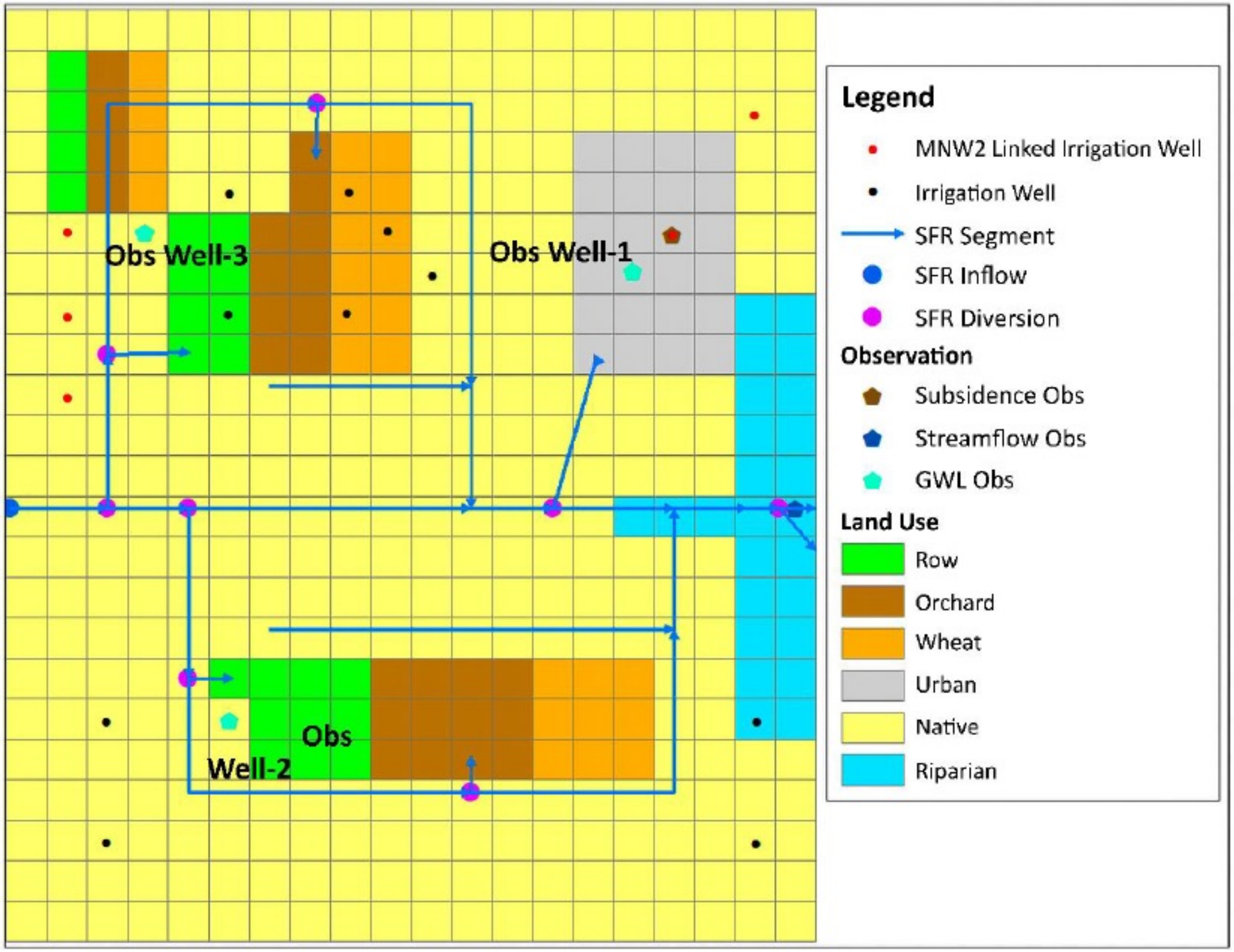
Layer 6 (confining bed at bottom of Layer 5):
- K = 0.1 m/d
- $S_{ke} = 1.5 \times 10^{-5}$
- $S_{kv} = 1.5 \times 10^{-3}$

Layer 3:
- confined
- K =2 m/d
- $S_{ke} = 3.6 \times 10^{-4}$
- $S_{kv} = 3.6 \times 10^{-2}$

Layer 5:
- confined
- K =2 m/d
- $S_{ke} = 3.6 \times 10^{-4}$
- $S_{kv} = 3.6 \times 10^{-2}$

Layer 7:
- ***confined***
- K =2 m/d
- $S_{ke} = 3.6 \times 10^{-4}$
- $S_{kv} = 3.6 \times 10^{-2}$

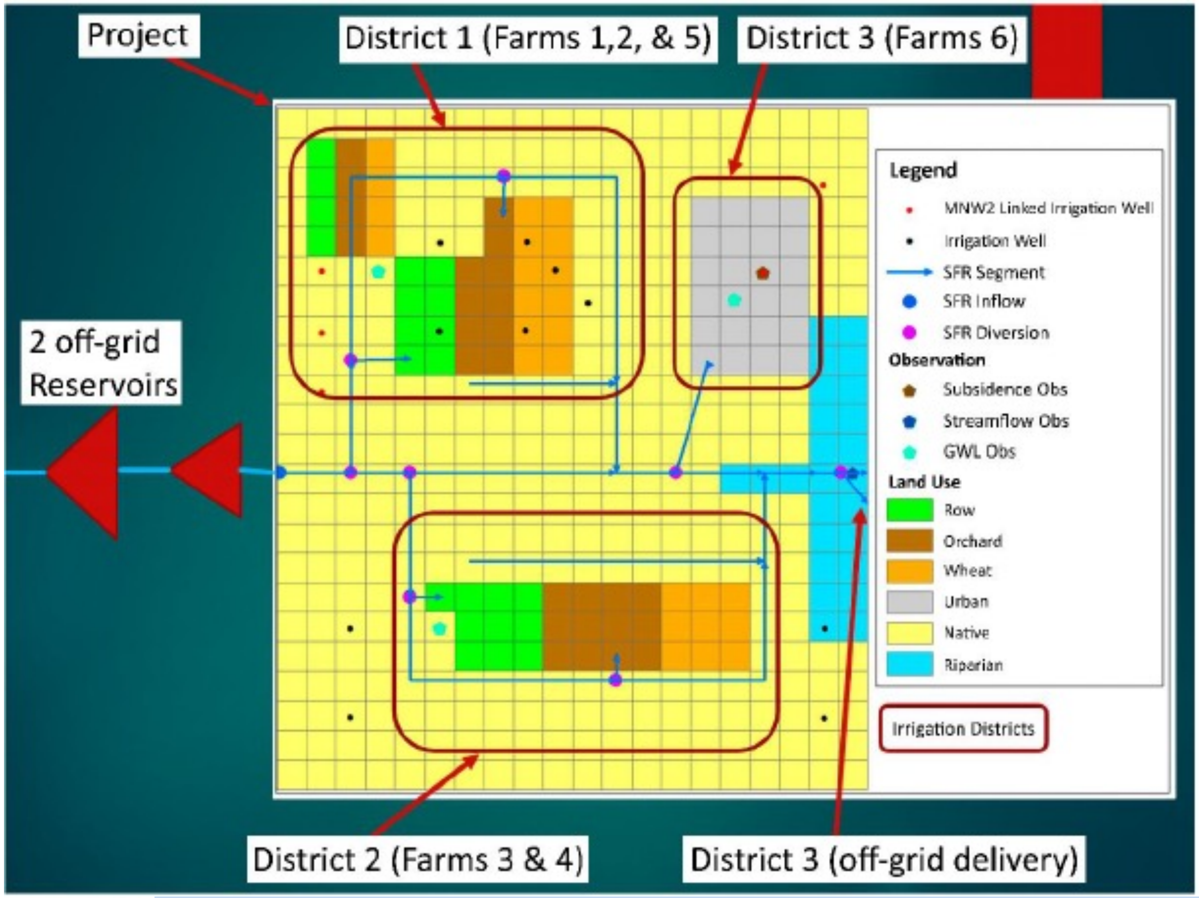
CWM Model Exercise Analysis of Sustainability

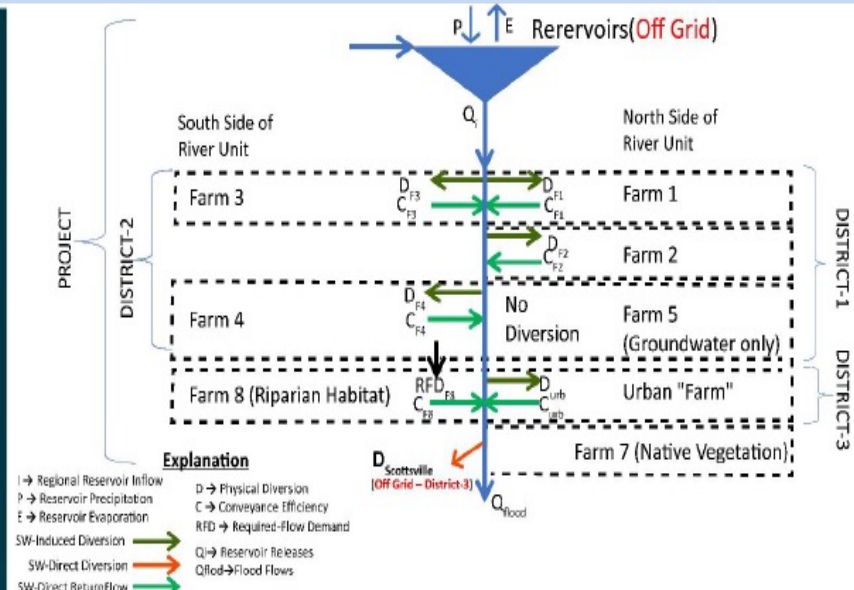


CWM Analysis includes:

(1) Groundwater & Landscape Water Flow Budget Analysis + Comparisons to Base Case Flows
(2) Groundwater & Surface-Water hydrograph Analysis
(3) Pumping Analysis
(4) Farm Supply-and Demand Flow Budget Analysis
(5) Subsidence Analysis
(6) Recharge Analysis

Reservoir Operations (SWO) only with USGS MF-OWHM





Simulation of Reservoir Operations Includes:

(1) Reservoir Storage & Releases ➔ FMP/SFR

(2) Effects on Surface-Water and Groundwater Deliveries

(3) Allocations, Carry Over, Allotments, Deliveries, District Charges & Credits

One Water

3 CWM-SWO Scenarios: (1) Base Case with SWO,

(2) SWO + Surface-Water Allotments (Constraints),

(3) SWO + Salinity Flushing

TODAY'S TALK

- WHAT IS CONJUNCTIVE WATER MANAGEMENT?
- FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT
- TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER
- INFORMAL AND FORMAL SYSTEMS
- HIGHLY VERSUS POORLY CONNECTED SYSTEMS
- BENEFITS OF CWM
- THE ROLE OF MANAGED AQUIFER RECHARGE
- ANALYSIS AND MODELING APPROACHES FOR CWM
- *CWM DEVELOPMENT OPTIONS*
- CWM CONCLUSIONS

One Water

Governance Approaches

Institutional Strengthening, Policy and Legislation, Planning, Market and Pricing Approaches, Actual Implementation, Building Knowledge and Communication

General water governance principles cover several main areas, including authority, accountability, transparency, stakeholder participation, and integration:

- **Authority** through policy & statutory powers vested in the government or delegated to an agency to administer & regulate on behalf of the government. The associated authority becomes the decision maker who must be held accountable for operationalizing policy & legislative instruments. Such an authority must be accountable for its decisions, with appropriate mechanisms in place, & supportive of natural justice by enabling appeals against decisions to be independently reviewed. Such authorities typically operate at basin scale, which raises boundary issues when, for example, river basin boundaries do not match the underlying aquifer system.
- **Transparency** is required to demystify the decision-making process, support stakeholder confidence in the management process, & provide the grounds for any appeal. Transparency also must include public outreach, monitoring, and data sharing.
- **Stakeholder participation** ensures there is ownership of the process by all, which goes a long way toward achieving planned outcomes.
- **Institutional and technical integration** is required to ensure that all aspects of water tenure are subject to a single basic water resource regime. Water is a single resource and should be managed accordingly and in concert with the other major stressors of supply and demand such as land use, population and industrial growth, and climate.

One Water

Building Knowledge and Communication

To facilitate CWM, knowledge is required in two key areas:

1. **Technical understanding** through development and sharing of networks monitoring the spatial and temporal distribution of the total consumptive available water, replenishment of water, and other sources of supply; and
2. **Support & Funding for planning** through the capability to provide future impact scenarios; the latter may be in the form of a complex numerical model of aquifer-river basin performance or, at times, simple analytical approaches.

Use of Financial and Market-based Instruments to Develop Planned CWM

Financial and market-based instruments (FMBI) are a range of financial and economic measures that can be used to encourage specific actions and trends. In the context of water resource planning, FMBI can consist of the following:

- **Direct financial incentives** (e.g., taxation reduction, subsidies to lower electricity prices, resource grants, bonds, water markets, and replenishment incentives),
- **Disincentives** (e.g., taxation increases, transmission fees, or litigation costs), or
- **Indirect trade-offs or offsets** (e.g., pollution reduction schemes or watershed climate or salt credits) and the introduction of inter-basin or regional import/export systems such as water trading.

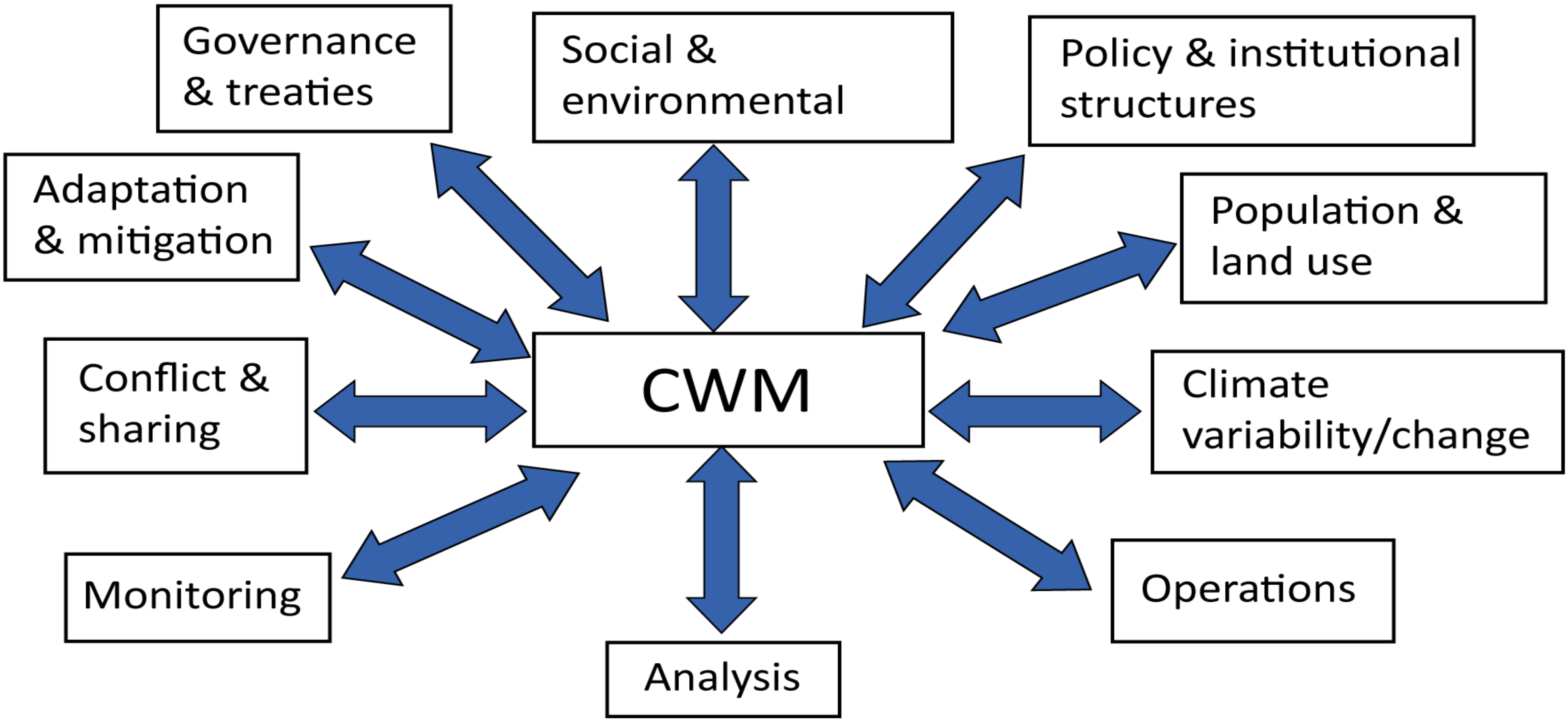
One Water

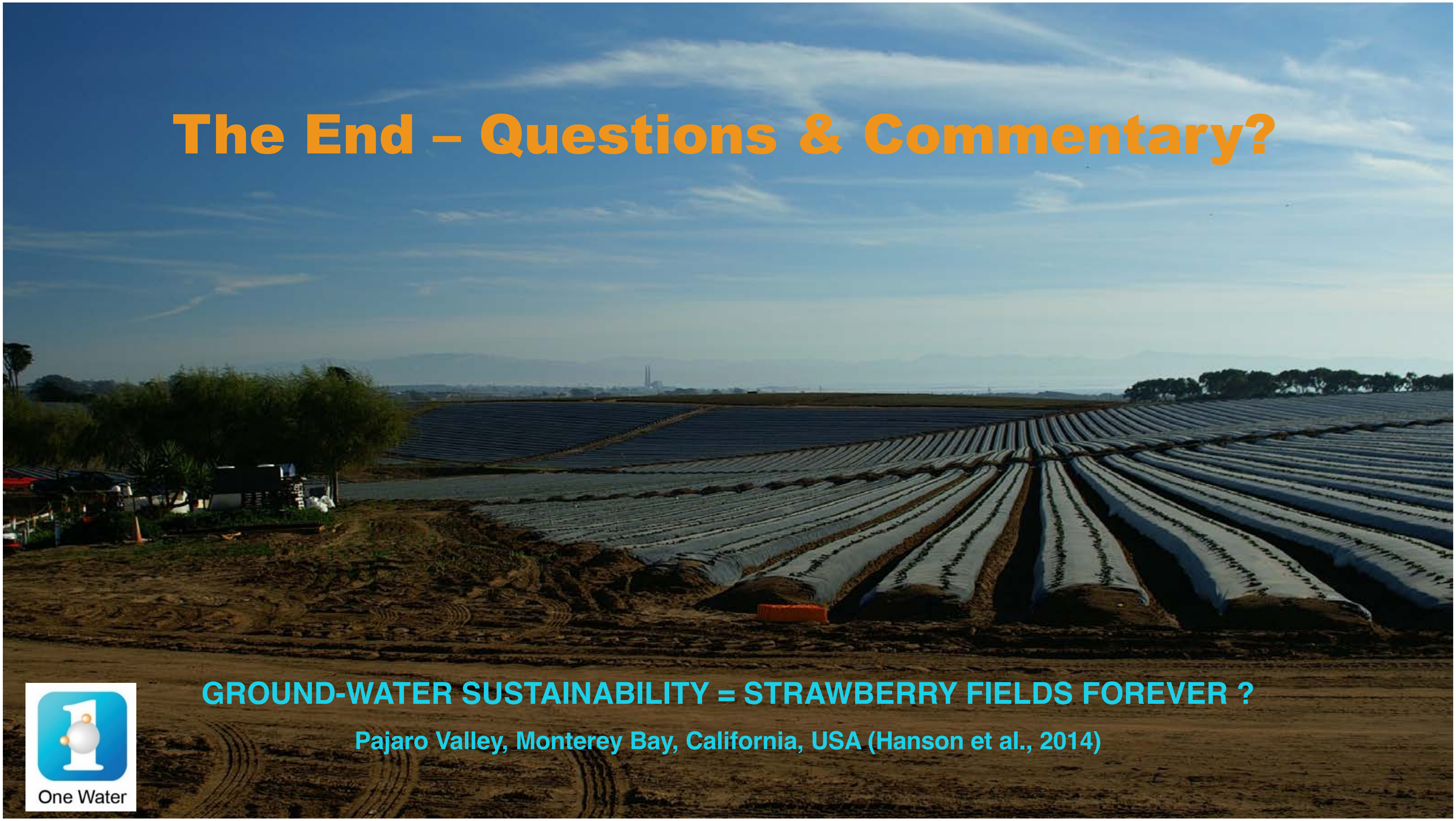
TODAY'S TALK

- WHAT IS CONJUNCTIVE WATER MANAGEMENT?
- FUNDAMENTAL CONCEPTS OF CONJUNCTIVE WATER MANAGEMENT
- TECHNICAL AND MANAGEMENT DIFFERENCES BETWEEN SURFACE WATER AND GROUNDWATER
- INFORMAL AND FORMAL SYSTEMS
- HIGHLY VERSUS POORLY CONNECTED SYSTEMS
- BENEFITS OF CWM
- THE ROLE OF MANAGED AQUIFER RECHARGE
- ANALYSIS AND MODELING APPROACHES FOR CWM
- CWM DEVELOPMENT OPTIONS
- *CWM CONCLUSIONS*

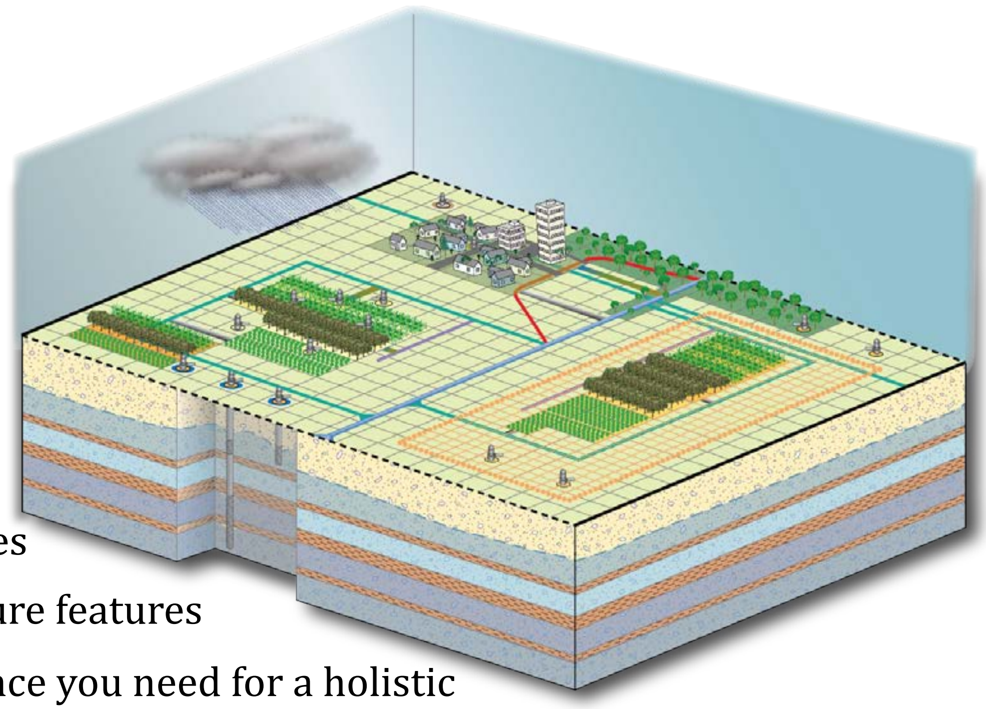
One Water

Social and Physical interfaces within a CWM supply-and-demand framework




The End – Questions & Commentary?
GROUND-WATER SUSTAINABILITY = STRAWBERRY FIELDS FOREVER ?
Pajaro Valley, Monterey Bay, California, USA (Hanson et al., 2014)
One Water

Thank You &
Let’s work together!



- Please consider our approach to Transboundary Studies
- Let’s Collaborate: New projects incorporate new & future features
- **One-Water Hydrologic** can provide the tools & guidance you need for a holistic path to sustainability for Food and Water Security

ONE WATER

One-Water Hydrologic
http://www.one-waterhydrologic.com
Email: RandyTHanson@gmail.com, Skype: rthanson