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Free and Open Source Software Tools for Water Resource Management
EU HORIZON 2020 Project

European Commission

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Open Workshop
Fostering inclusive and sustainable economic growth, employment and decent work (SDG#8) through ICT job creation tools for ensuring water security (SDG#6)

September 30th 2016

UNESCO – Room IX

7 Place de Fontenoy - 75007 Paris

Conjunctive-Use Analysis for Better Water Management with the One-Water Hydrologic Flow Model, MODFLOW-OWHM (“One Water”)

Randall T. Hanson and Scott E. Boyce
(U.S. Geological Survey, USA)

EIP Water Online Market Place
Matchmaking for water Innovation
MAR Solutions - Managed Aquifer Recharge Strategies and Actions (AG128)

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Taken from: http://stories.undp.org/cultivating-change-in-papua/photos/2990072

One Water

Today’s Talk

- ***Conjunctive Use Issues***
- ***Conjunctive Use Modeling Framework → One Water***
- **Why Use Integrated Hydrologic Modeling (IHM)?**
  Uses and Issues → Model Analysis
- **Conjunctive-Use Example → Transboundary Aquifers of the Rio Grande/Rio Bravo**
- **New Features → Version 2**

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What Do HYDROLOGIC MODELS Provide?

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Traditional Uses (Resource Assessment):

- Understanding of Regional Flow Systems
- Complete Assembly of Hydrologic-Budget Components
- Systematic Analysis of All Hydrologic Components

New Uses (Scientific Exploration ➔ Engineering Tool)

- Linkage between Databases, Monitoring Networks, Model Input Requirements, and Decision Makers (Self-Updating Models)
- Assist with Operations Analysis and Decision Making
- Analysis of Relations between Hydrosphere and others
- Flexibility for testing Policies, Projects, Remediation, & Adaptation/Sustainability (Structural and non-Structural)
- Vehicle for mediation between transboundary neighbors
- Systematic estimate of Uncertainty and Sensitivity
- Vehicle for Communication, Understanding & Water Markets

Our Goal and Philosophy for Resource Simulation and Analysis ➔ **ONE WATER !**
All the water, All the time, Everywhere in the simulated Hydrosphere

One Water

Sustainability: Development and use of water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences.

Conjunctive Use: Joint use and management of surface-water and groundwater resources to maximize reliable supply and minimize damage to the quantity or quality of the resource. (also includes natural sources precipitation/runoff)

Adaptation: Modification of use, movement, and storage of water to promote sustainability of water, food, and energy security that is physically, economically, politically, and socially feasible.

Connectivity: Ability to connect all relevant processes to each other, connect to other models & types of models to extend linkages to other higher-order processes, water trades/markets, etc. ➔ ***Feedback & Secondary Effects***!!

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Simulation of Conjunctive Use with Regional Aquifer Models are Needed to Fully Understand the Complex Relations Between Climate, Land/Water Use, & Surface/Subsurface Flows

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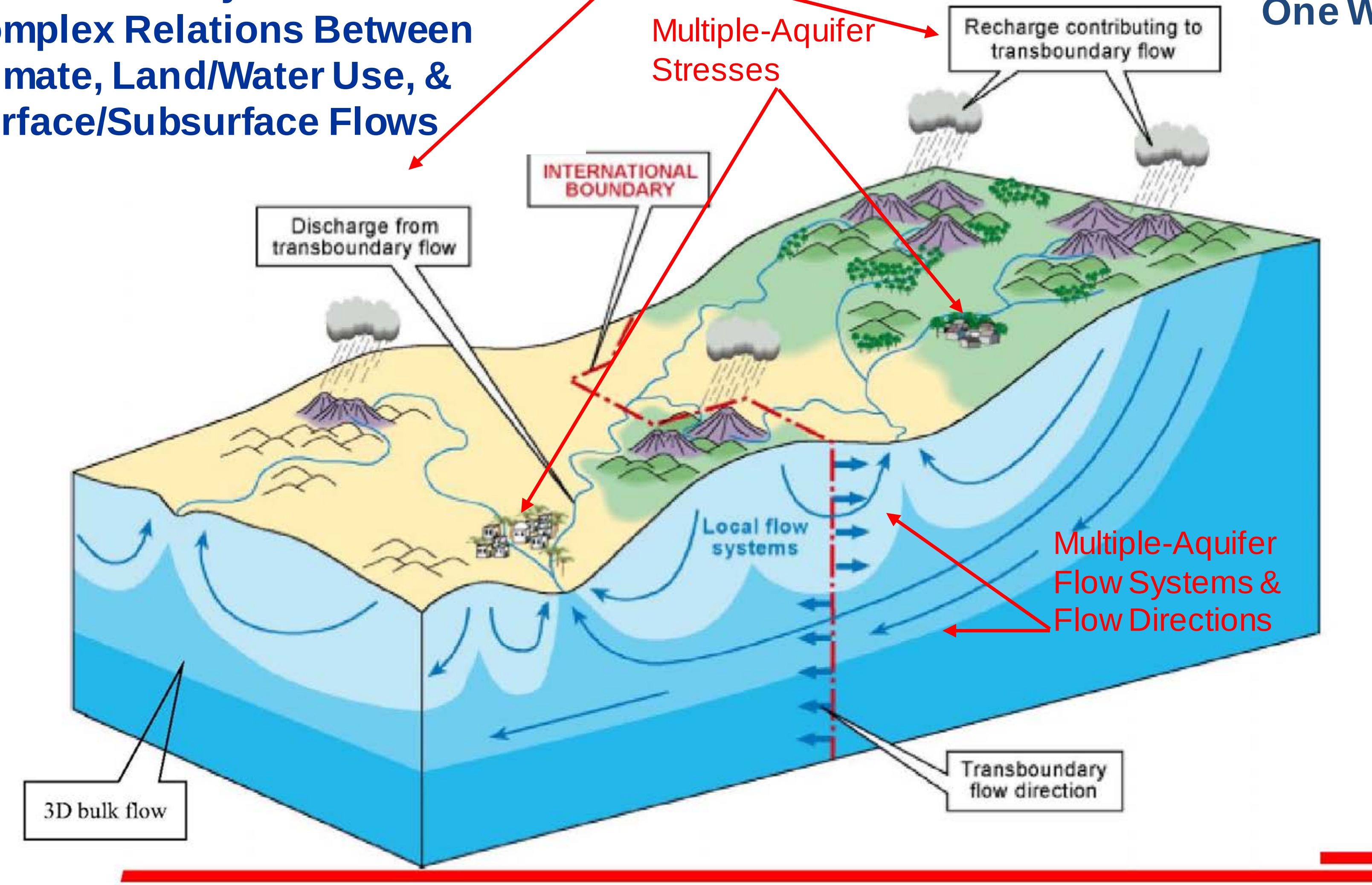

Poland-April '02

Resource Development and Management of Regional Aquifer Systems

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Sustainability of Resources is subject to changing Demands and Supplies that are integrated through Conjunctive Use ➔ ***FLOWS PAY THE BILLS!***

Demand ➔ Development
Supply ➔ Replenishment & Storage

New Demands & Supplies that are coupled➔ Water Reuse, MAR, ASR, Captured Runoff, Irrigation/Leaky-Urban Artificial Recharge

Water-Resource Management & Conjunctive Use are also subject to:

- **Social Constraints/Governance** – Water Rights, Conservation, Land-Use Planning
- **Economic Constraints** – Water Markets, Industrial/Urban/Agriculture/Tourism
- **Water Quality** – Natural & Anthropogenic Contamination
- **Land-Use Conversion** – Agriculture to Urban or Habitat Mitigation
- **Ecological Requirements** – Surface Flows and Land, GDE's
- **Climate Change & Variability** – Droughts/Wet periods, More Extreme Events, Longer Growing Periods, Increased Minimum Temperatures

How can One-Water provide insight to Conjunctive Use?

UNESCO is helping to develop better water security (SDG#6) where water scarcity in many countries is from inadequate human and institutional capacities at different levels, rather than to the scarcity of freshwater resources

In most settings of overexploitation there are:

4 Big Problems ➔ Governance/Conflict, Unchecked Growth, Use of Resources Faster than Replenishment, & Secondary Effects

Conjunctive Use takes on new meaning in developed settings where there are new components to the use and movement of water including:

- **Artificial Recharge from inefficient irrigation**
- **Recharge of deep aquifers through Wellbore flow**
- **Water Reuse & MAR/ASR**
- **Capturing Runoff**
- **Deformation-Dependent Flows (Land Subsidence)**

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Conjunctive Use Embedded into Sustainabiltiyout West!!

In the Wild Wild West of California we now have new Groundwater Law ➔ ***Sustainable Groundwater Management Act of 2014***

State Policy and Local Government Coordination

• Establishes that it is the policy of the state that groundwater resources be managed sustainably for long-term water supply reliability and multiple economic, social, or environmental benefits for current and future beneficial uses. Section 1. (a) of SB 1168

• Requires a city or county planning agency, before adopting or substantially amending a general plan, to review and consider groundwater sustainability plans. Government Code Section 65352.5

Core Provisions:

Groundwater Sustainability Agency (GSA) Formation ➔ Local Authority (Bottom up Management)
Tools for GSAs ➔ Local Management, Measure Pumpage, Studies, Regulations, Taxation
Groundwater Sustainability Plans (GSP) ➔ Inventory, Describe, Budgets, Plan, Monitor
DWR Evaluation and Assessment ➔ Conforms with SGMA, Effects others, Budgets Good
Probationary Status ➔ No GSA or GSP, No Undesirable Results
State Board Intervention/Interim Plans ➔ State takes over if locals don't comply
Protections for Areas under Sustainable Management ➔ Subregional Compliance, State Fees
Water Rights ➔ Protect existing SW/GW rights greatest extent possible consistent with SGMA
Application to Adjudicated Basins ➔ Dispensations for existing settlements
Tribal Lands ➔ Some authority consistent with Federal Laws

How can One-Water provide insight to Conjunctive Use?

Sustainable Groundwater Management Act

Subject to 6 Undesirable Results (Secondary Effects) of Overdrafted Basin:

1) **Groundwater-level declines.**
2) **Groundwater-storage reductions.**
3) **Seawater intrusion.**
4) **Water-quality degradation.**
5) **Land subsidence.**
6) **Interconnected surface-water depletions.**

They also affect their ability to achieve sustainability +/- Mitigation/Adaptation, and potentially affect neighboring regions with separate Groundwater Sustainability Programs

How can One-Water provide insight to Conjunctive Use?

Water Smart -- U.S. Bureau of Reclamation

Partner with appropriate non-Federal participants to conduct basin studies to analyze the impacts of climate change and develop adaptation strategies to meet future water supply and demand imbalances in river basins in the 17 Western United States.

1) **Develop Study Metrics**
2) **Characterize Climate Change and Related effects (ex. Sea Level Rise)**
3) **Develop Study Scenarios**
4) **Develop Modeling Tools and Inputs**
5) **Evaluate Water Supplies, Demands, and Operations (No Action)**
6) **Develop Adaptation and Mitigation Strategies (Local Stakeholders)**
7) **Evaluate Adaptation and Mitigation Strategies**
8) **Prepare Basin Study Report**

5 Climate Scenarios * 3 Adaptation Scenarios * # No. of local Models

One Water

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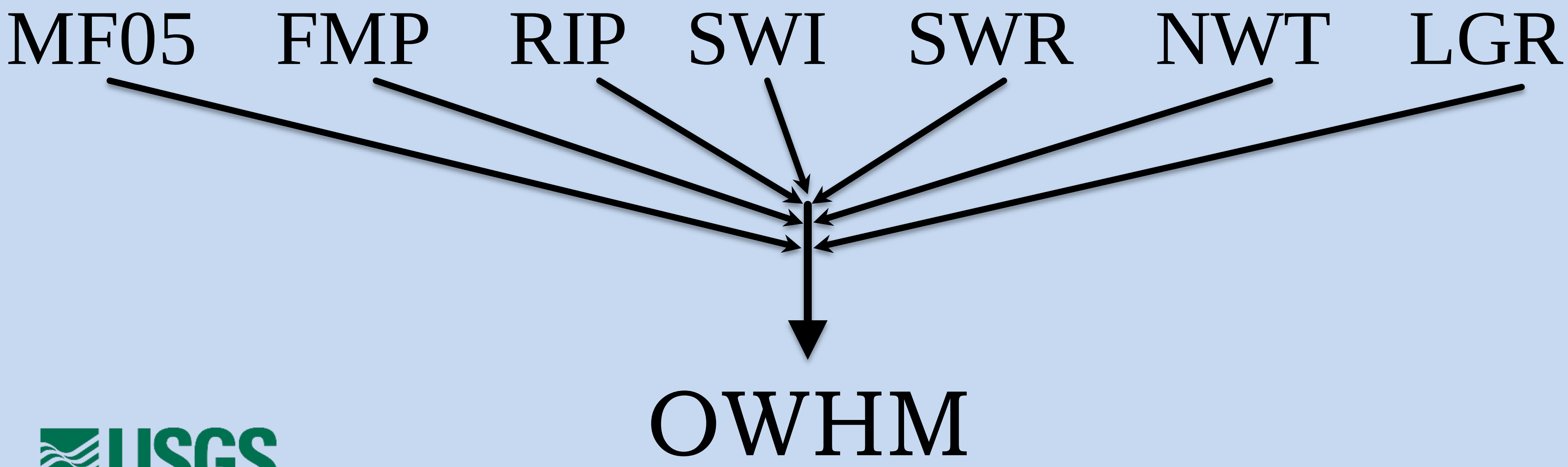
MODFLOW-OWHM
One-Water
One-Water Hydrologic Flow Model

- The One-Water Hydrologic Flow Model, MF-OWHM, is an ***<u>enhanced</u>*** fusion of multiple MF versions to serve as a new integrated hydrologic flow modeling software.



Framework and Concepts of One Water (MF-OWHM)

One Water

- Water can stay within the model for as long as possible
  - Traditional MODFLOW would have water disappear, such as a DRN
- Fully Coupled ➔ Groundwater (GW) ↔ Surface Water (SW)
  ⇕ ⇕
  Landscape (LS) ↔ Climate(C)
- All water sources have a direct "relationship" between source, location, and type of use
- Provides infrastructure for physically-based supply-and-demand that allows meaningful analysis of conjunctive use and sustainability/adaptation
- Provides Multiple Water Budgets for Groundwater, Surface water, Landscape, & Climate

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Water Systems are Coupled

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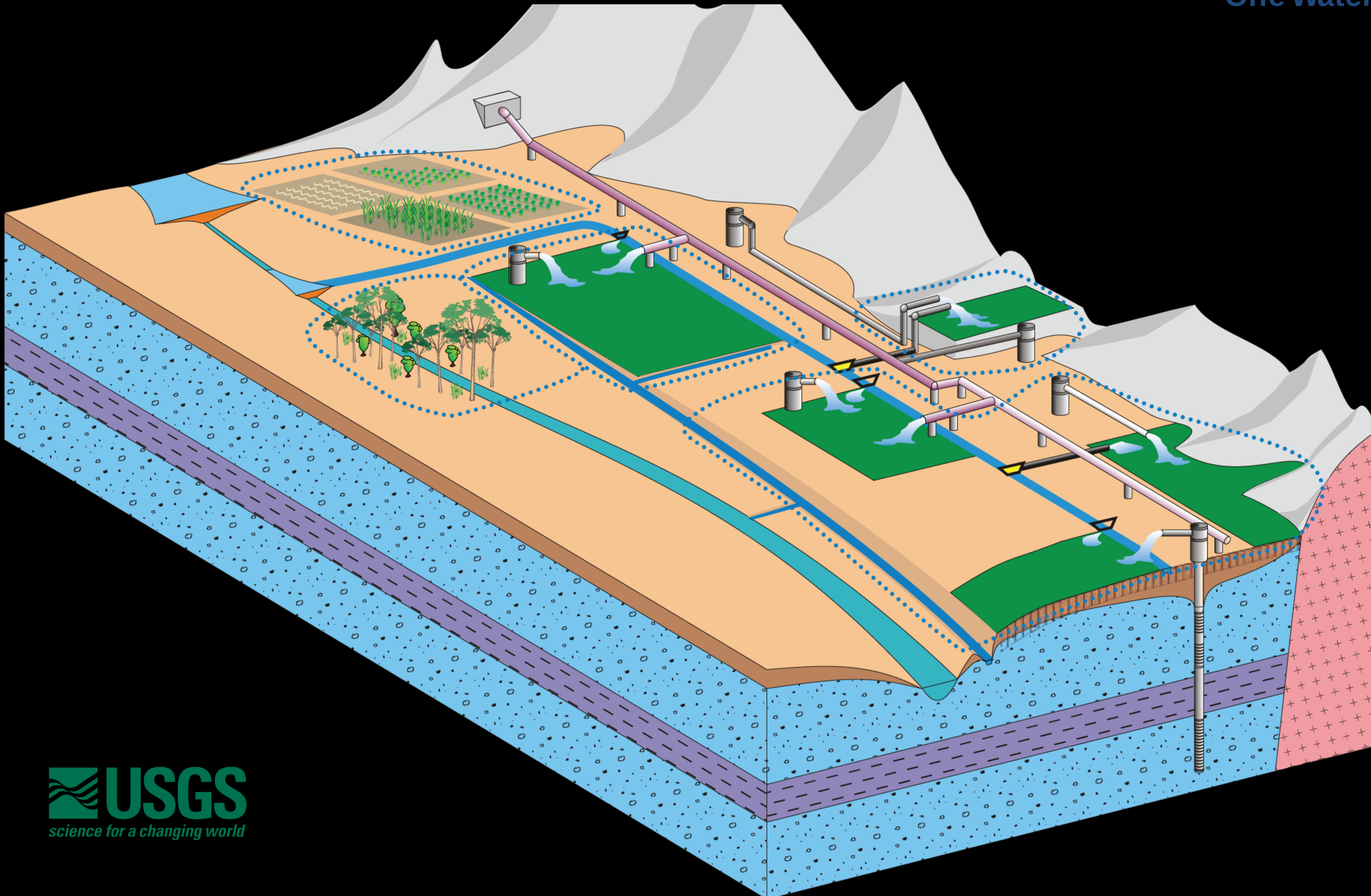
- The interaction between different waters makes a more complete simulation of conjunctive use
- This provides better understanding of a water systems and how to manage it subject to changing climate and humanity.
- Simulation is more than connections of buckets that dump into each other.
  - Simulation of conveyance is important!
  - Systems reach a Rate Limit before a Volume Limit
  - Need to reconcile Paper Water versus Wet Water

Modeling a Complex World More Completely



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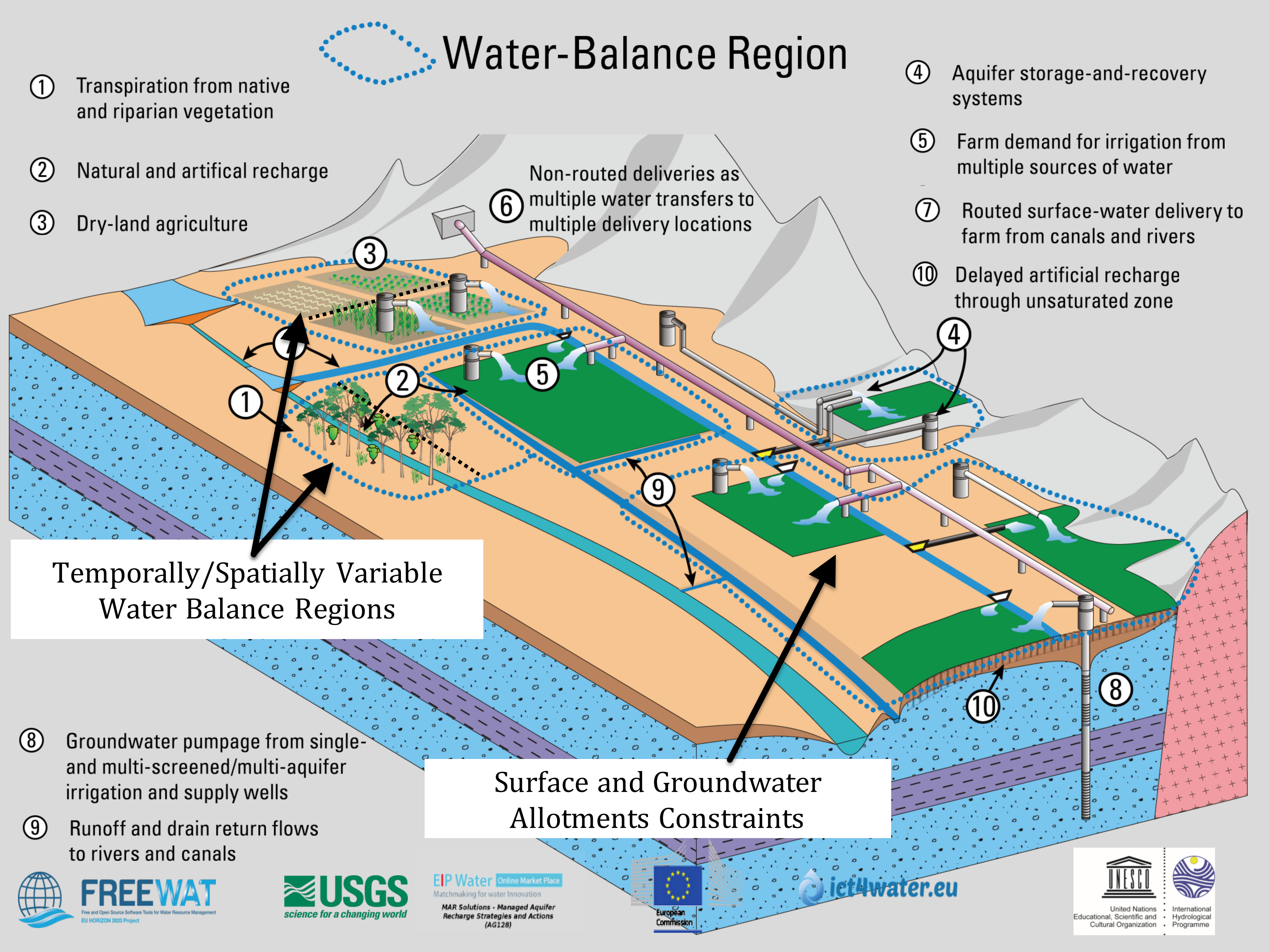
Water-Balance Region
① Transpiration from native and riparian vegetation
② Natural and artifical recharge
③ Dry-land agriculture
④ Aquifer storage-and-recovery systems
⑤ Farm demand for irrigation from multiple sources of water
⑥ Non-routed deliveries as multiple water transfers to multiple delivery locations
⑦ Routed surface-water delivery to farm from canals and rivers
⑩ Delayed artificial recharge through unsaturated zone
⑧ Groundwater pumpage from single- and multi-screened/multi-aquifer irrigation and supply wells
⑨ Runoff and drain return flows to rivers and canals
Temporally/Spatially Variable Water Balance Regions
Surface and Groundwater Allotments Constraints
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One Water with the Farm Process

SUMMARY OF FEATURES AND ADVANTAGES

One Water

MODEL FEATURES MADE EASY

- Estimates Irrigation Demand
- Estimates Surface-Water Deliveries & Return Flows
- Estimates Agricultural Ground-water Pumpage
- Estimates Net/Artificial Recharge & Natural Recharge/Runoff
- Estimates all Components for ET, Runoff, and Deep Percolation
- Complete Linkage to Ground-water and Surface-water Flow

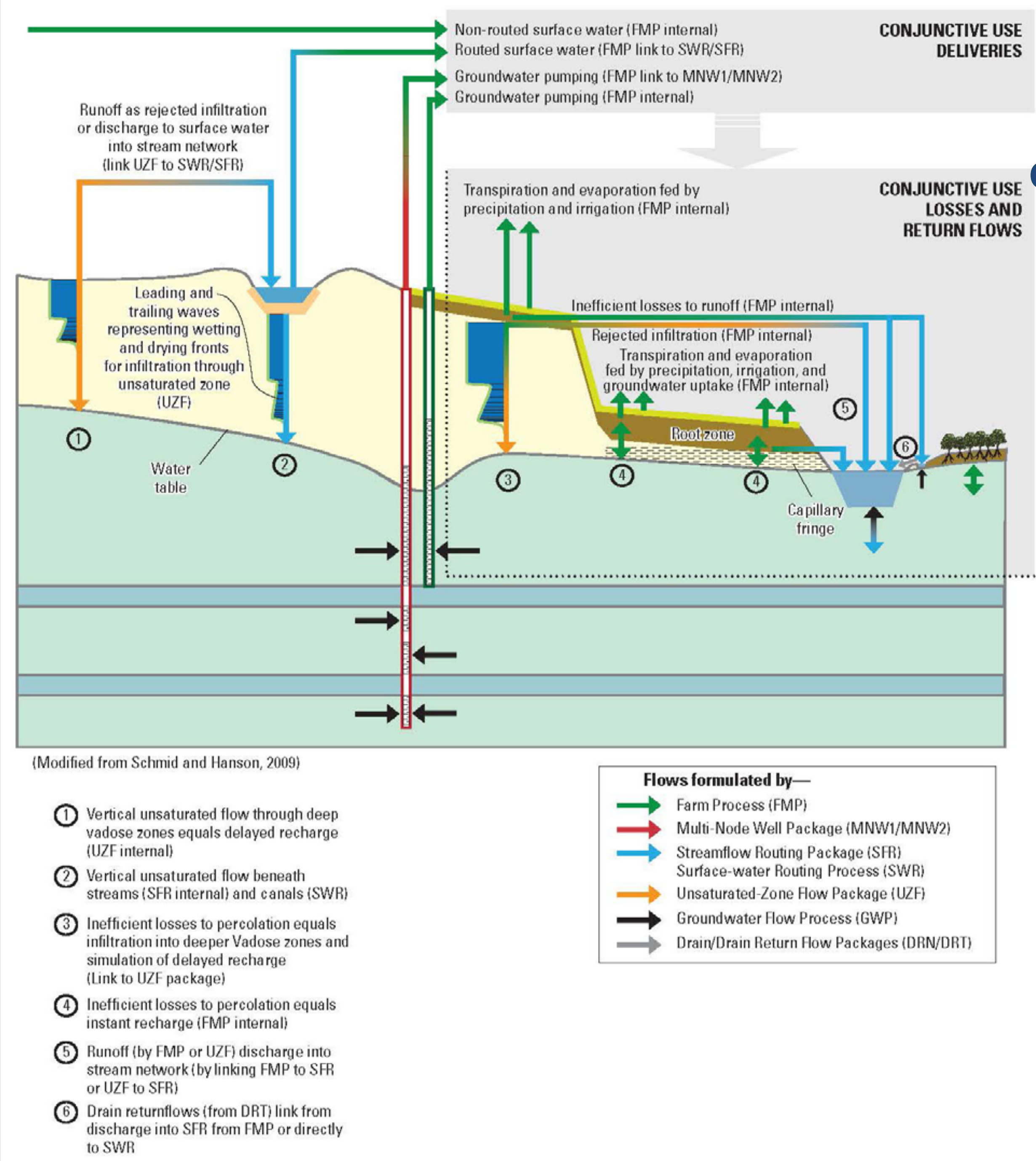
ADVANTAGES FOR MODELERS

- No need for indirect estimates of Pumpage, Recharge, ET, Runoff, or Surface-water deliveries
- Uses Natural Data → Easy to Update Model ➔ SELF-UPDATING MODELS!!
- Saves time and money for constructing, operating, and updating models
- Facilitates Operational, Forecasting, Adaptation, & Sustainability Simulations

Conjunctive-Use Simulated with Fully Coupled Groundwater-Surface Water-Landscape-Climate Linkages of MF-OWHM

- Head-dependent flow
- Flow-dependent flow
- Deformation-dependent flow

Embedded in a Physically-Based Supply-and-Demand Framework of Demand-Driven and Supply Constrained Use and Movement of Water



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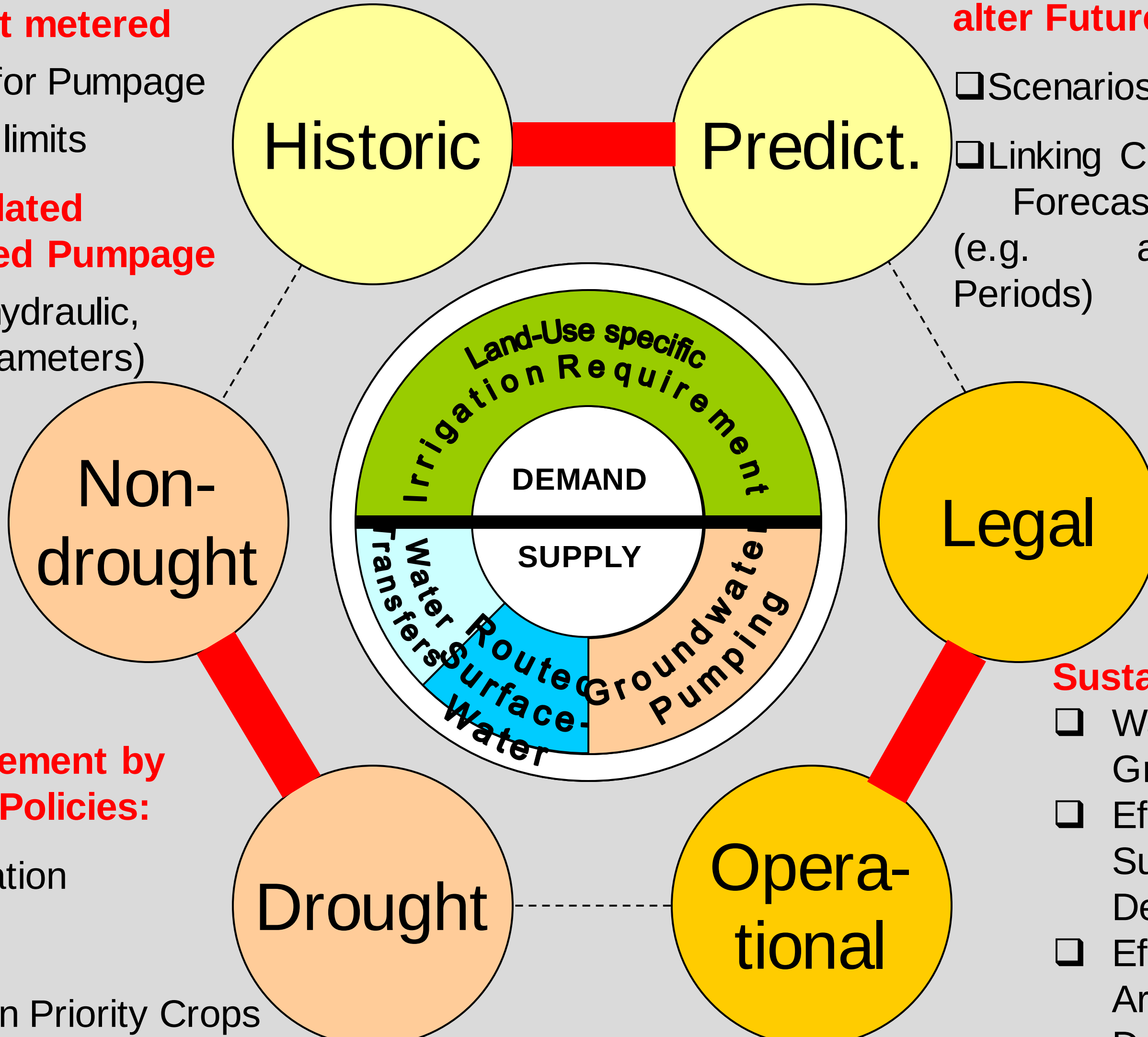
Main FMP Uses in One Water ➔ Why do we need a "Farm Process?"

Model-Implicit Estimation of Historic Well Pumpage if not metered

- ❑Adjudication asks for Pumpage
- ❑Define abstraction limits

Calibration of Simulated Pumpage by metered Pumpage

(estimate unknown hydraulic, land-use, & farm parameters)



Conjunctive Management by Drought Response Policies:

- ❑ Acreage Optimization
- ❑ Deficit Irrigation
- ❑ Water-Stacking on Priority Crops

Predict response to conditions that alter Future Supply & Demand

- ❑Scenarios: changing SW/GW allot
- ❑Linking Climate Change with FMP Forecast of Supply & Demand (e.g. ahead of Droughts, Wet Periods)

Surface-Water Rights Appropriations

- ❑ Individual "Farms";
- ❑ Irrigation Districts;
- ❑ Transboundary Set.

Sustainable Management:

- ❑ Water Allocations Prior to Growing Season;
- ❑ Effects of Water-Transfers on Sufficiency or Recovery of Depleted Aquifers;
- ❑ Effects of Natural and Artificial Recharge on Depleted Aquifers.

Potential Issues Capable of Model Simulation & Analysis

(1) **Development/Availability**

(a) Adequacy of Agricultural Pumpage ➔
Shortages in water supply = Increased groundwater pumping capacity?

(b) Wellfield development ➔ Additional wells? Where?

(c) Role of Groundwater Supplies, Managed Aquifer Recharge, & ASR Projects

(d) Regional Water Budgets ➔ Characterization of all Water Resources
(Model + Ground/Satellite-based Monitoring Networks)

(2) **Conjunctive Use/Transboundary Relations/Compact Issues**

(a) Operating Agreements Reservoir Allocations to Districts, States, and Nations,

(b) Wellfield Capture of Streamflow Analysis for Operating Agreement

(c) Negotiations with Transboundary neighbors over land & groundwater developments

(d) Canal-Water management ➔ Delivery, MAR/ASR, & Reuse

(d) Storm water management & capture/use ➔ MAR/ASR & Reuse

(e) Reuse ➔ Recycling Reclaimed water for Irrigation/Landscape/Industrial

(f) Pulsed Reservoir Releases ➔ Better river conveyance

(g) Salinity Management ➔ Irrigation & Species Conservation Habitat, Saline GW intrusion, &
Salinity Management Plan

(3) **Sustainability/Secondary Effects** (Water-Food Security)

(a) Primary ➔ Best Management Practices (Conjunctive-Use & Optimization Analysis),
Adaptation (Structural and non-Structural), Sustainability

(b) **Secondary** ➔ Salinity, Land Subsidence, Climate Change/Variability, &
Land-Use Changes Natural/Ag ➔ Urban, Urban Exports, Habitat (Riparian, GDEs)

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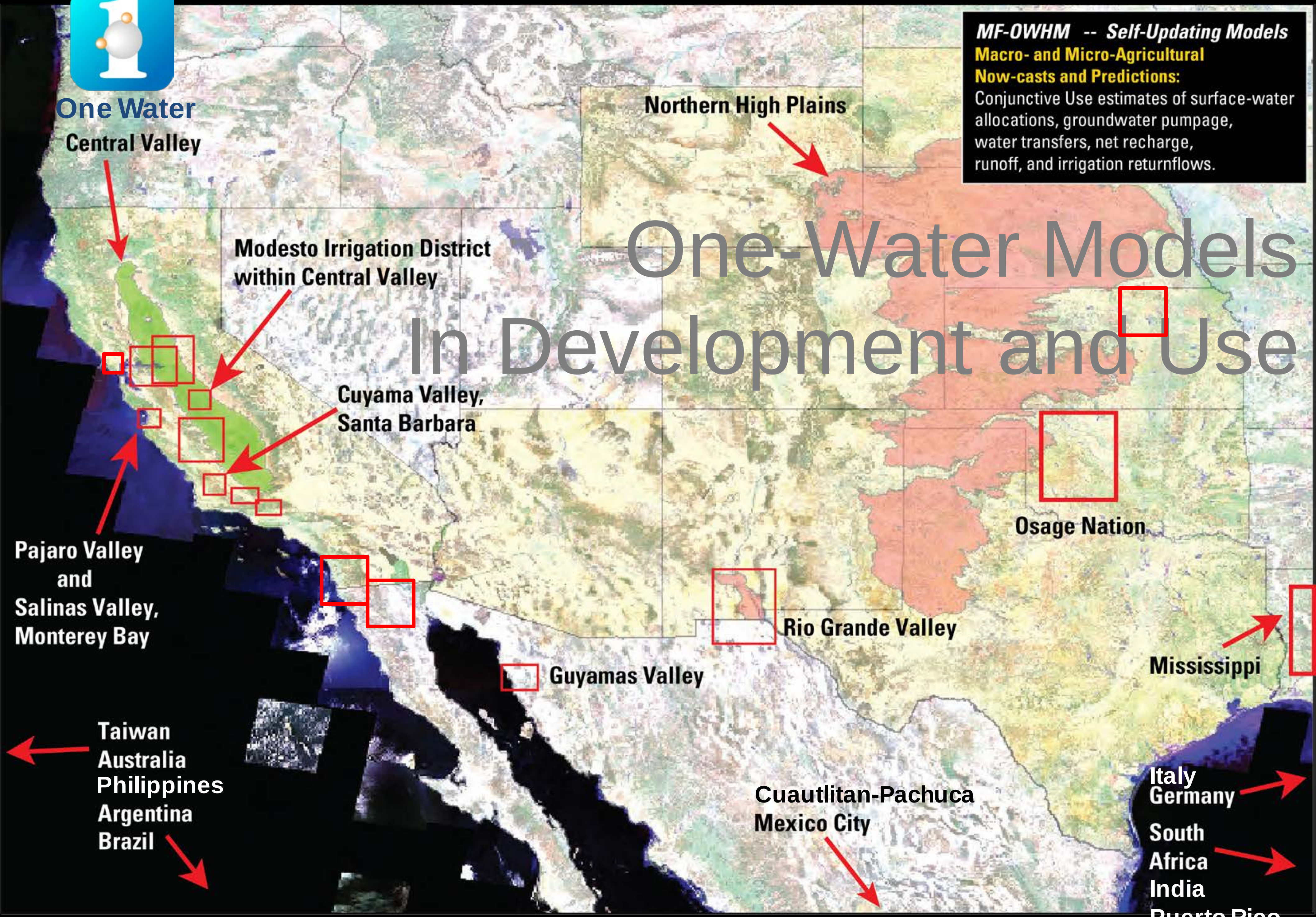
San Joaquin River Restoration Project

Seepage in vineyard on right bank of San Joaquin River during high flows (4/13/2011)

One-Water Models In Development and Use



One-Water Model Construction

1) **Develop Landscape Features** ➔ Water-Balance Subregions, Crop/Land-Use Categories
2) **Develop Surface-Water Networks** ➔ Network, Inflow and diversion points, & Network attributes, Reservoirs, Lakes, Canals, Drains, etc.
3) **Geologic/aquifer framework** ➔ Extent, Layering, parameters and facies subregions for calibration
4) **Observations** ➔ GW, SW, LandScape, Climate

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Typical Problem Design

Workflow Process

Identify Major Questions the study will analyze and answer for historical/future time

Determine Extent of Model Region (Watershed/Basin/ Subregions?)

Determine Water-Balance Subregions & Super Groups (SubWatersheds, /Farms/Political or Jusidictional subregions?)

Determine Land-Use & Crop Groups (Individual Crops, or Types of Land-Use subregions?)

Build hydrologic Model Grid in GIS as polygon shape file for the area of interest

Build Geologic Model Grid in GIS as polygon shape file for the area of interest

Identify Sources of water and relate them to sources of demand for water

Design sources of water:
Surface-Water
Groundwater
Non-Routed Deliveries

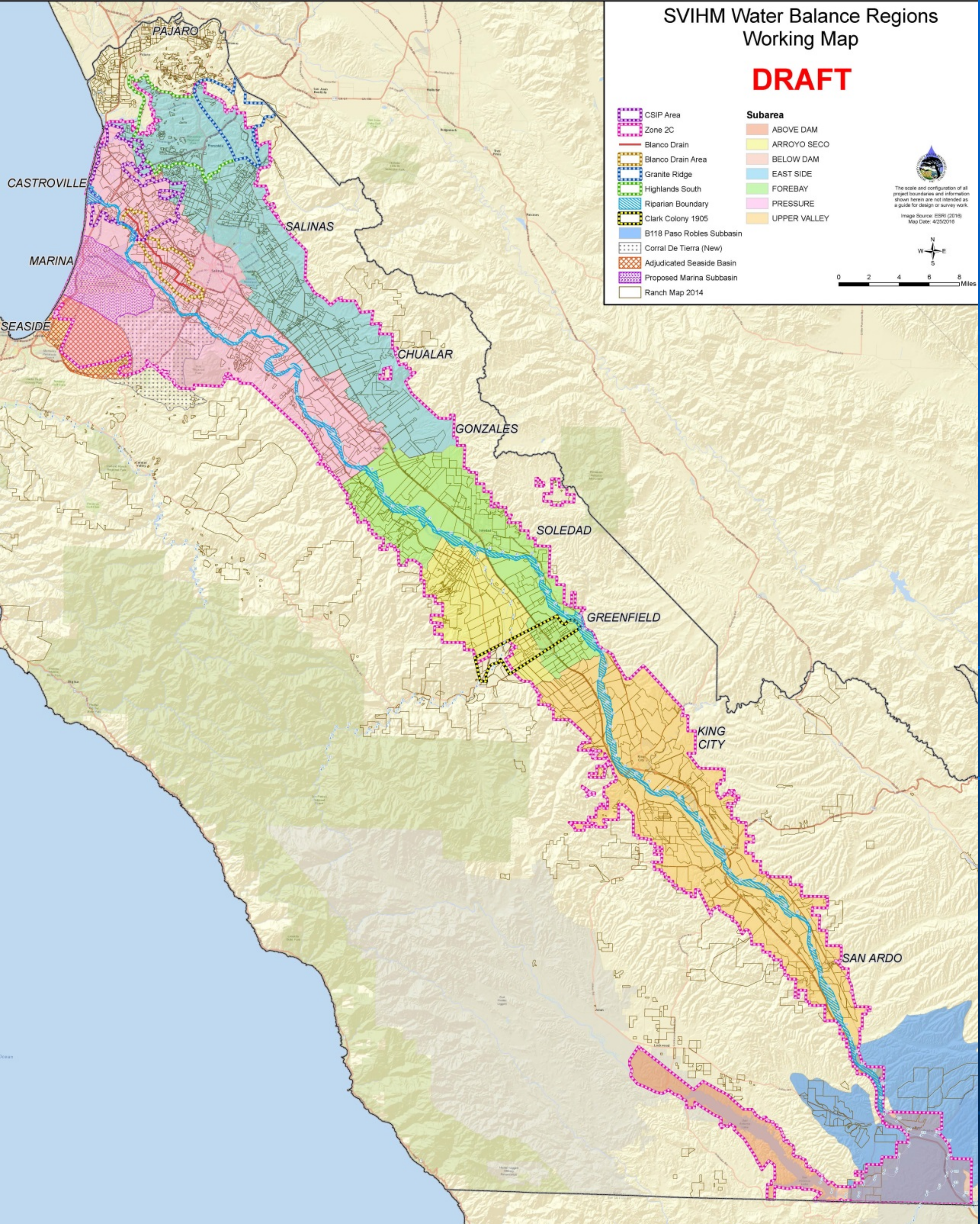
Estimate Climate
Crop and Farming Attributes

Estimate Layers tops/bottoms and hydraulic properties of aquifers

Develop Surface-water Networks and Wells with attributes in GIS/spreadsheets

Develop Observations of surface flows, gw heads, etc.

Develop Parameter Estimation Input and Control



Salinas Valley Jurisdictional Units for Water-Budget Analysis and Sustainable Groundwater Management Act (SGMA) compliance

$7 Billion/Year in Agriculture (America's Salad Bowl)

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30 SVIHM Water-Balance Accounting Units

(1) Riparian Corridor (Monterey and SLO Counties) ➔ *Preserved Fish and Plant Habitat Salinas River*
(2) CSIP Area ➔ *Recycled Water Irrigation Region*
(3) Coastal Urban areas (Salinas, Castroville, Marina, parts of Monterey, Del Rey Oaks) ➔ *Urban Demand*
(4) Inland Urban areas (Chualar, Gonzales, Soledad, Greenfield, King City, & San Ardo) ➔ *Urban Demand*
(5) *Agriculture* ➔ Highlands South
(6) *Agriculture* ➔ Granite Ridge
(7) *Suburban* ➔ Corral De Tierra inside of Zone 2C
(8) *Agriculture* ➔ Blanco Drain Area (Not in CSIP)
(9) *Agriculture* ➔ Remainder of Zone2C – East Side
(10) *Agriculture* ➔ Remainder of Zone2C – Pressure NE of Salinas River
(11) *Agriculture* ➔ Remainder of Zone2C – Pressure SW of Salinas River
(12) *Agriculture* ➔ Remainder of Zone 2C – Forebay NE side of Salinas River
(13) *Agriculture* ➔ Remainder of Zone 2C – Forebay SW side of Salinas River
(14) *Agriculture* ➔ Remainder of Zone 2C – Arroyo Secco
(15) *Agriculture/SW Delivery* ➔ Clark Colony 1905 (non-urban)
(16) *Agriculture* ➔ Zone 2C -- Upper Valley NE subregion East of Salinas R & Northeast of King City
(17) *Agriculture* ➔ Zone 2C -- Upper Valley NW subregion West of Salinas R & West of King City
(18) *Agriculture* ➔ Zone 2C -- Upper Valley SE subregion East of Salinas R & East of King City
(19) *Agriculture* ➔ Zone 2C -- Upper Valley SW subregion West of Salinas R & West of King City
(20) *Agriculture* ➔ Zone 2C – Below Dam
(21) *Native* ➔ Westside Regions Active outside Zone 2C boundary in Monterey County for Inland Southwest of Arroyo Seco and Clark Colony Region
(22) *New Agriculture* ➔ Hames Valley – Monterey County
(23) NE Quarries ➔ *Mining*
(24) *Native* ➔ Boundary of Model outside of Zone 2C on the Northeast side of the remainder of the East Side, Granite Ridge, and Highlands South subregions
(25) *Native* ➔ Southwest side Region Active outside of Coastal Pressure subegion Zone 2C boundary in Monterey County
(26) *Native* ➔ Boundary of Model outside of Zone 2C on the Northeast side of the remainder of the Forebay subregion
(27) *Native* ➔ Boundary of Model outside of Zone 2C on the Southwest side of the Upper Valley, Arroyo Seco, and Forebay regions, Hames Valley, and SLO active Regions
(28) *Native* ➔ Eastside Regions Active East and outside of Below Dam and Upper Valley subregions of Zone2C boundary in Monterey County
(29) *Native* ➔ Remainder of Paso Robles Basin in active model grid in SLO County (SLO Model Active Grid Extent)
(30) Offshore (gw analysis only) ➔ *Source of Seawater Intrusion*

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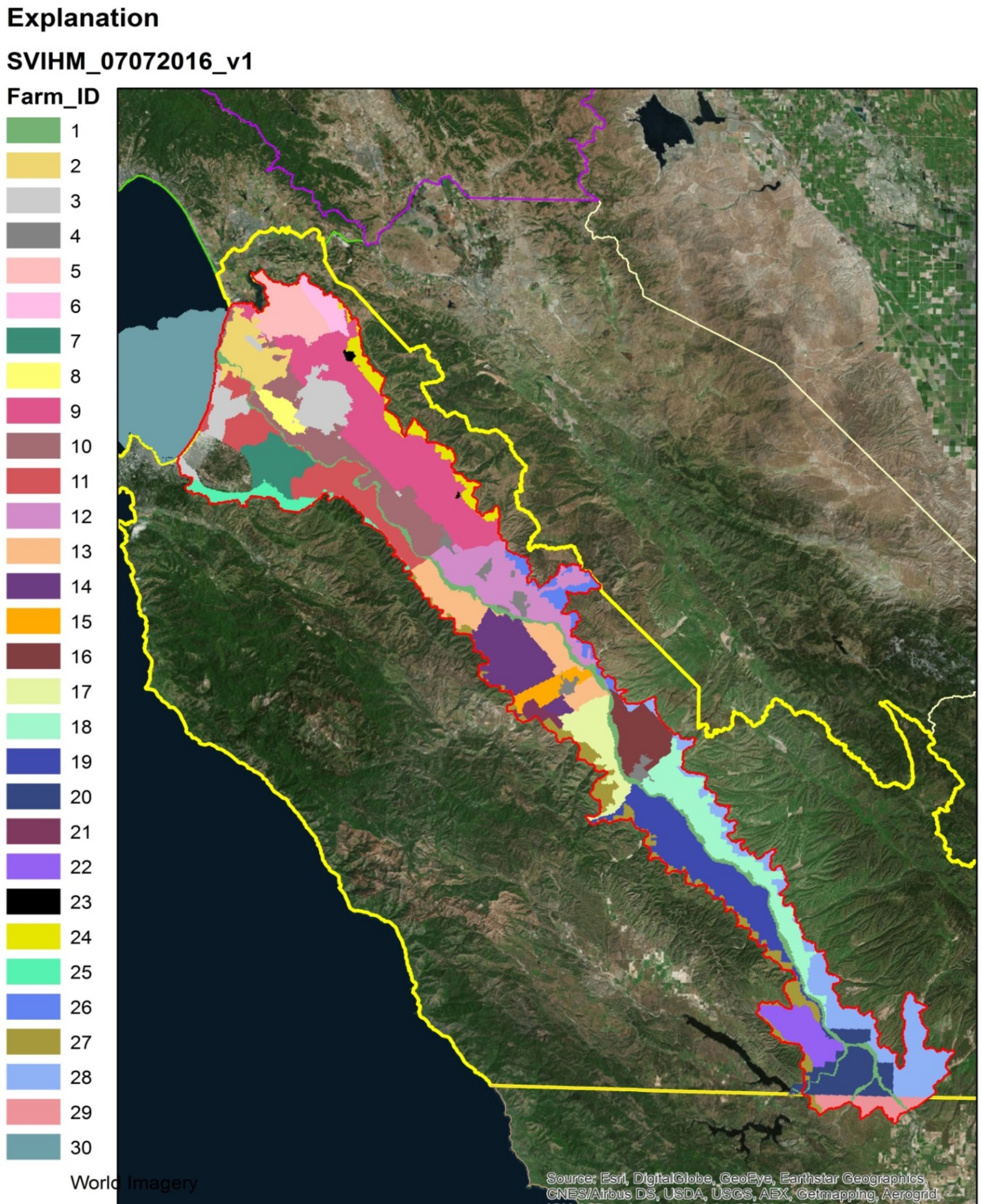

30 SVIHM Water-Balance Accounting Units

- Seaside Basin Excluded
- Coastal and Inland Urban areas grouped
- Zone 2C regions subdivided
- Additional regions added outside of Zone 2C
- Offshore region still under development

Conjunctive-Use Issues Include:

- Groundwater Pumping interference with Streamflow
- Seawater Intrusion
- Saline-water Irrigation
- Streamflow for Ag and Fish
- Aquifer Depletion
- Water Reuse

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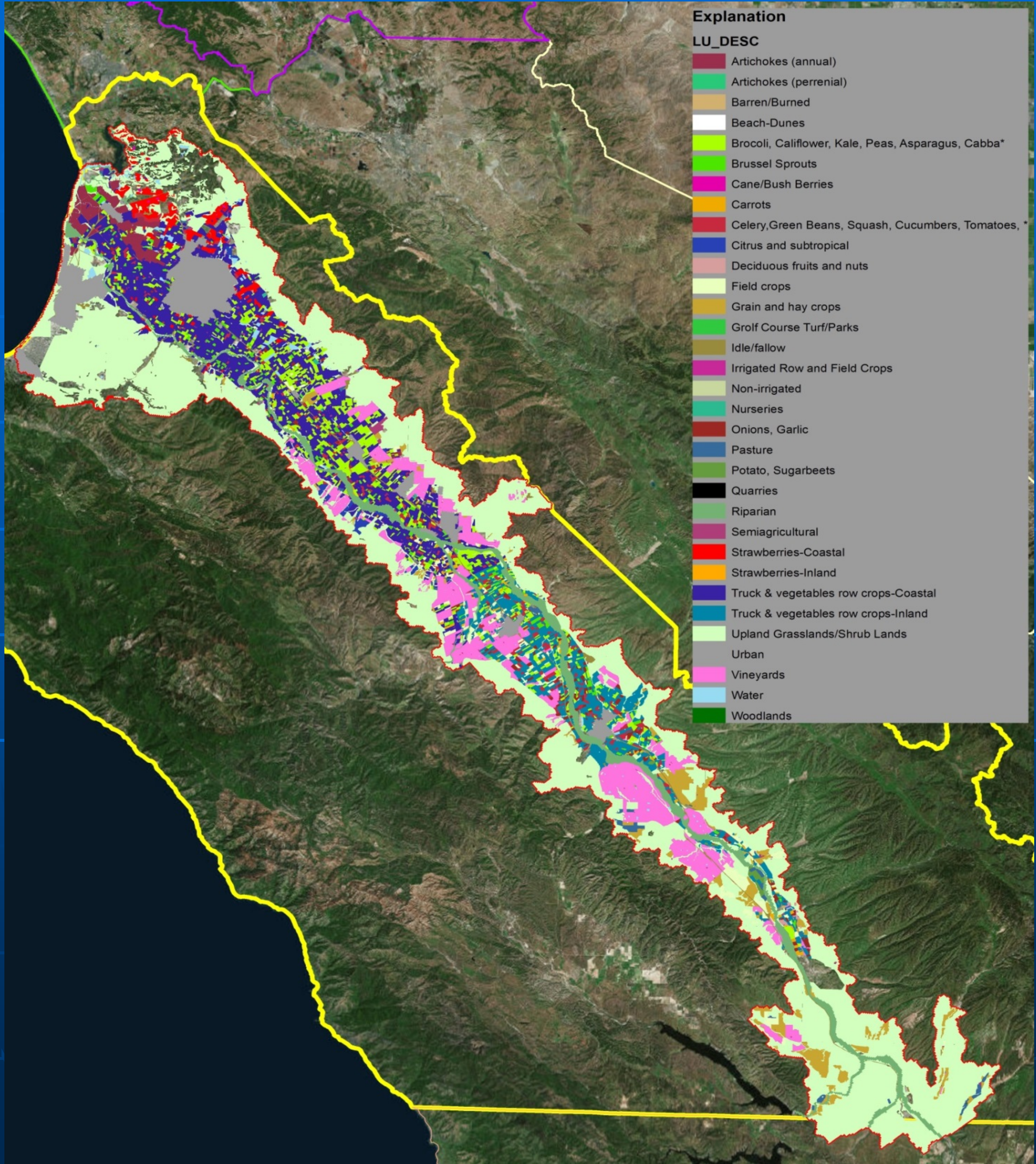
Crop/Land-Use Categories for Coastal and Inland Regions:

- Selected Individual Crops
- Selected Crops Groupings
- Coastal and Inland Groups
- Early-year/SVIGSM Groups
- Native Vegetation
- Riparian Vegetation
- Human Development

Crop_ID	Crop/Land-Use Group	Sub-Group Components
1	Truck & vegetables row crops-Coastal	Spinach, Lettuce, Pepper Spice, Endive Escarol, Cilantro, Peppers
2	Truck & vegetables row crops-Inland	Spinach, Lettuce, Pepper Spice, Endive Escarol, Cilantro, Peppers
3	Strawberries-Coastal	
4	Strawberries-Inland	
5	Brocoli, Califlower, Kale, Peas, Asparagus, Cabbage, Cole Crops-Coastal	
6	Brocoli, Califlower, Kale, Peas, Asparagus, Cabbage, Cole Crops-Inland	
7	Artichokes (annual)	
8	Artichokes (perennial)	
9	Spring Mix (Baby Crops)-Coastal	
10	Spring Mix (Baby Crops)-Inland	
11	Carrots	
12	Onions, Garlic	
13	Brussel Sprouts	
14	Potato, Sugar beets	
15	Celery, Green Beans, Squash, Cucumbers, Tomatoes, Melons- Coastal	
16	Celery, Green Beans, Squash, Cucumbers, Tomatoes, Melons - Inland	
17	Cane/Bush Berries	Blackberries and raspberries
18	Field crops	
19	Deciduous fruits and nuts	Apple, Walnuts, Stone Fruit
20	Citrus and subtropical	Lemon, Orange, Avocado, Pomegranite, Olive, Kiwi
21	Vineyards	Wine & Table Grapes
22	Pasture	Alfalfa
23	Grain and hay crops	Oats
24	Urban	
25	Rotational Crops-Coastal	
26	Rotational Crops-Inland	
27	Water	
28	Nurseries	Nursery, Outdoor Flowers, OF-Bulb, GP-Bulb
29	Cropland and pasture	Rangeland
30	Irrigated Row and Field Crops	Used for earlier Land-Use periods, less detailed maps
31	Non-irrigated	Used for earlier Land-Use periods, less detailed maps
32	Semiagricultural	Uncultivated Non-AG, Beehive, (livestock feedlots, diaries, poultry farms)
33	Idle/fallow	
34	Ag_Trees	Cristmas Trees, TMBRLND
35	Riparian	Crop/Land-Use Group Color Codes
36	Upland Grasslands/Shrub Lands	Individual
37	Woodlands	FOREST (Grouped)
38	Beach-Dunes	Native Vegetation/Undeveloped Land
39	Barren/Burned	
40	Quarries	Sand and Aggregate mining
41	Golf Course Turf/Parks	



Salinas Valley SVIHM Land Used for 3 Years (1997-1999)

➔ One of 11 Land Use Periods used to represent developed and natural Land Use for the period 1967-2014

One Water

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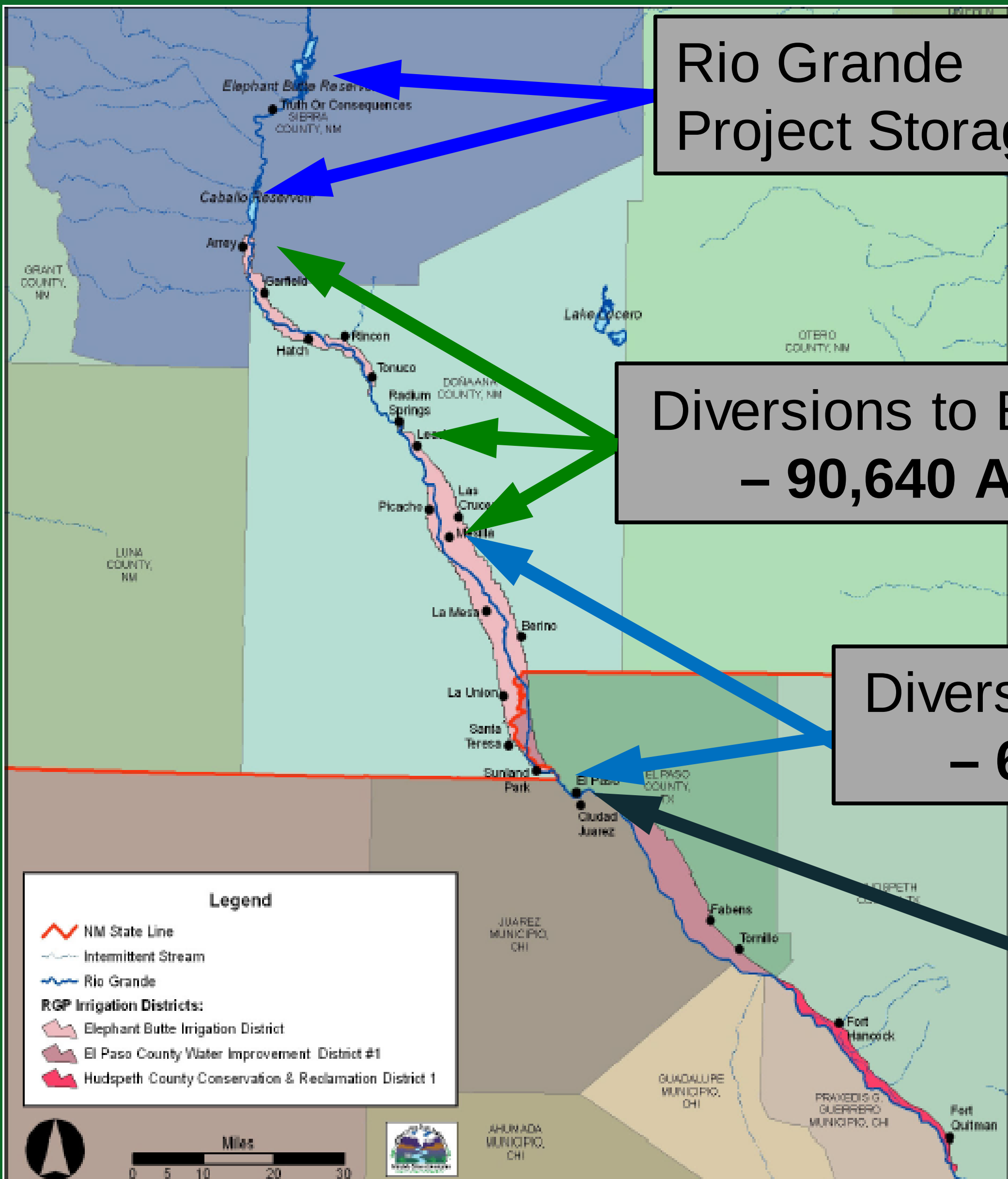
Case Study: Rio Grande

Rio Grande Project → RGTIHM



Rio Grande Project Storage

Diversions to EBID (NM)
– 90,640 Acres –

Diversions to EP#1 (TX)
– 69,010 Acres –

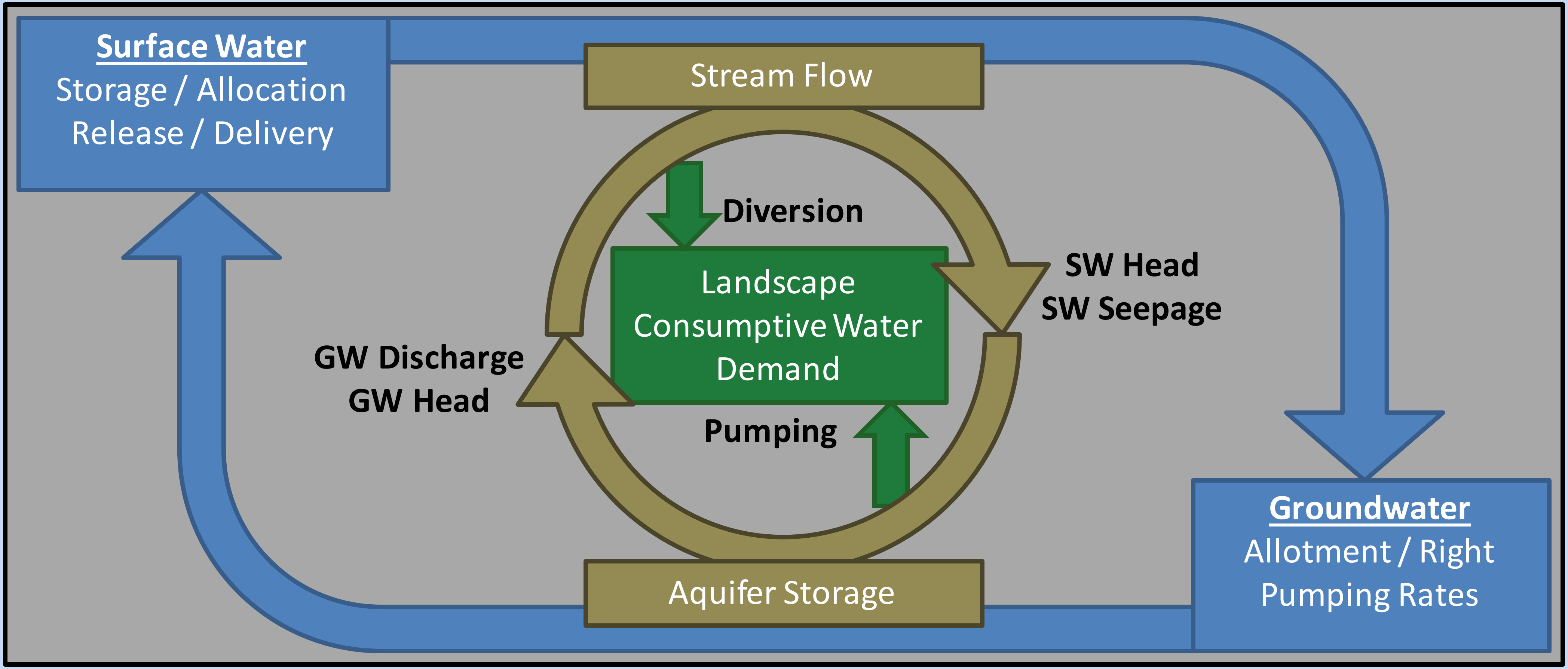
Delivery to Mexico

One Water

GW/SW Feedbacks

One Water

Bigger picture includes two-way feedbacks within Demand-Driven and Supply-Constrained Coupling



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EIP Water Online Market Place Matchmaking for water innovation

MAR Solutions - Managed Aquifer Recharge Strategies and Actions (AG128)

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Punch Line:

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- Extensive conjunctive use, feedbacks between groundwater and surface water management and use
- Long history of conflict over water allocation & accounting
- Long history of modeling, focused primarily on impacts of groundwater pumping on historical surface-water operations
- New modeling focuses on
  - Evaluate effects of groundwater pumping
  - Evaluate effects of changes in surface water operations
  - Evaluate effects of other factors - e.g., crops, on-farm efficiency

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Background: Project Operations

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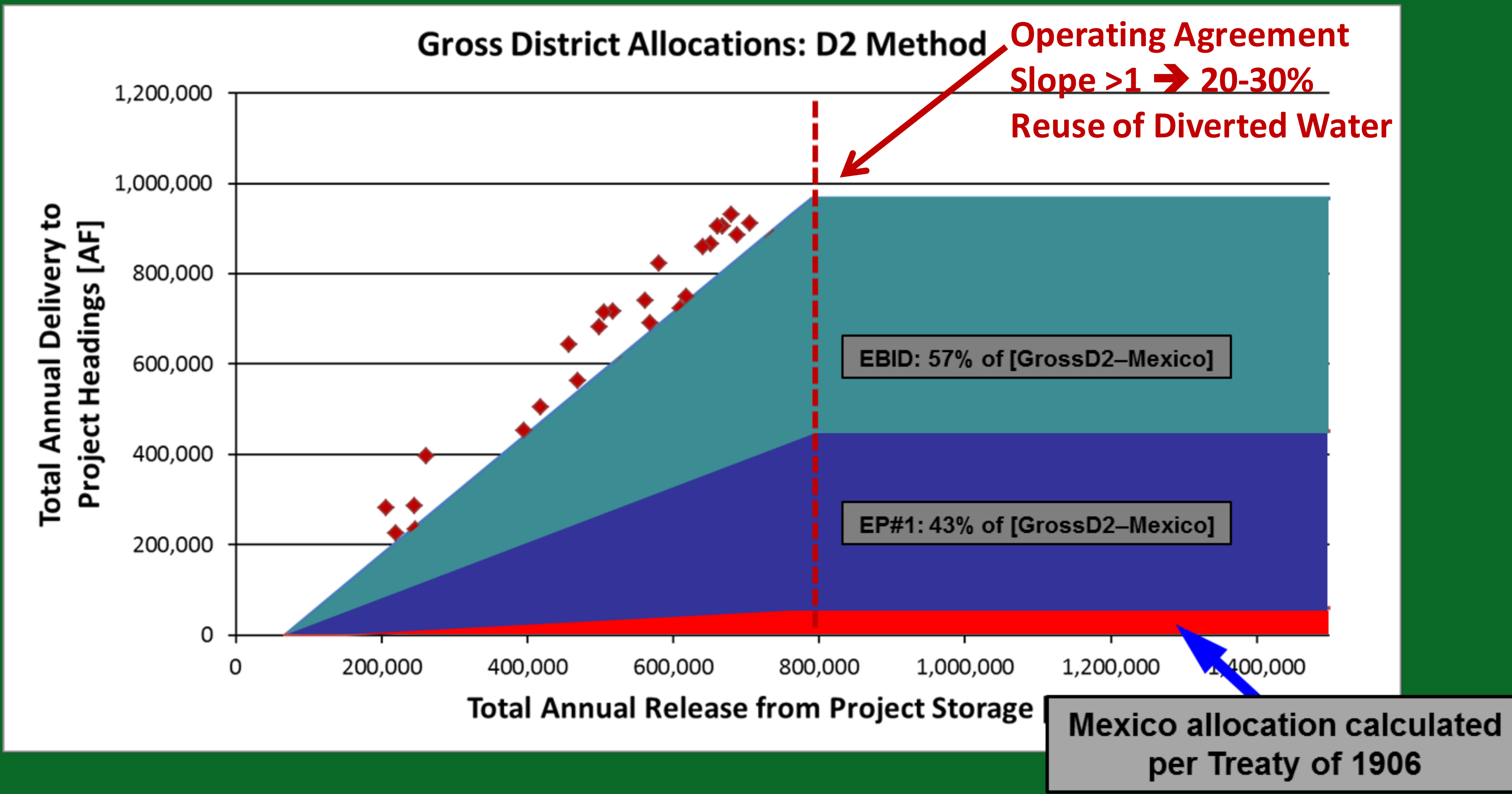
- **Project Operations – 1980-2007** (D2 Operating Agreement)

  U.S. Bureau of Reclamation Lower Rio Grande Project allocated water to districts and Mexico, delivered water to river headings



Farm Process – Coupling between Demand and Supply

Problem: Conjunctive use of groundwater and surface water results in flows affecting each other

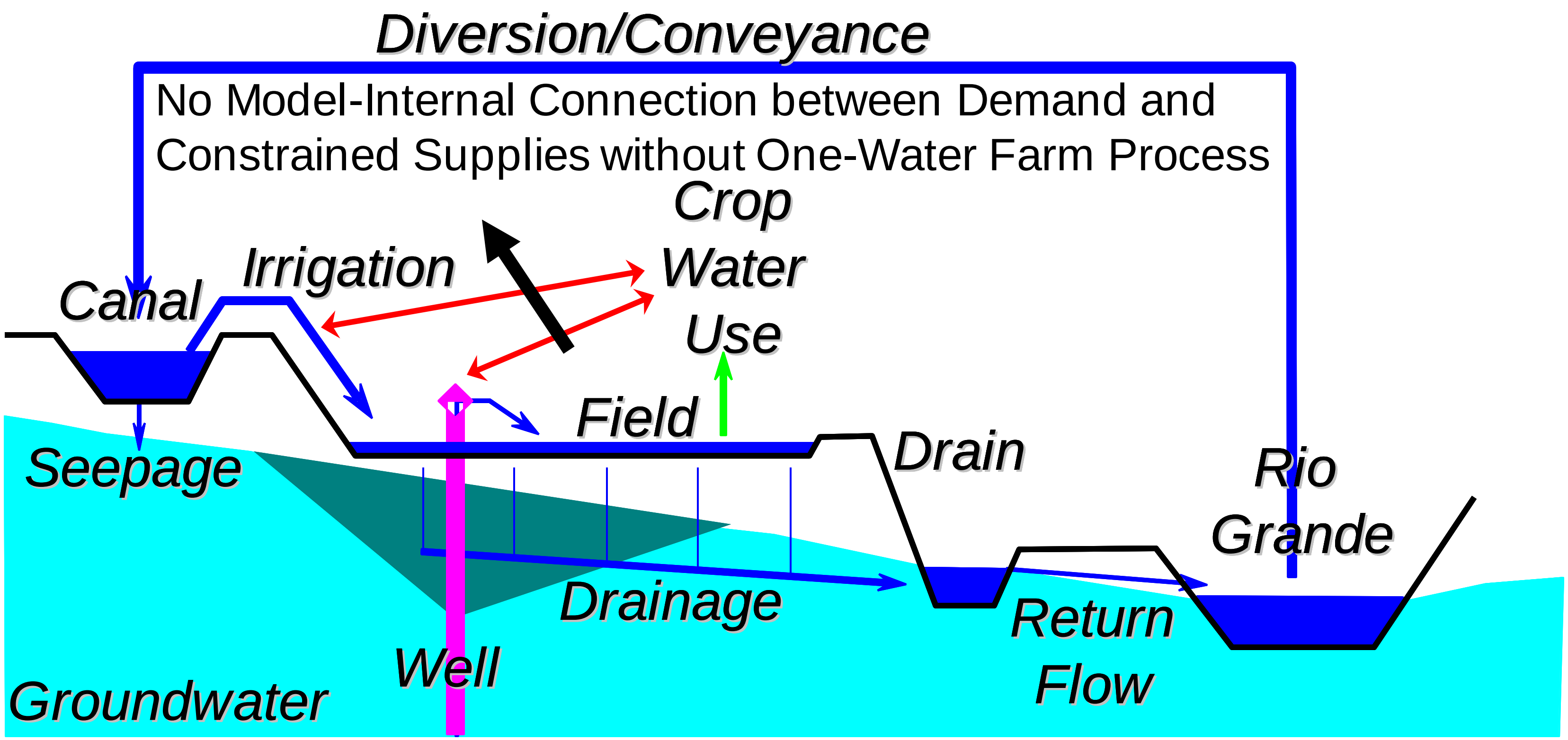


Diagram from Phil King, 2011

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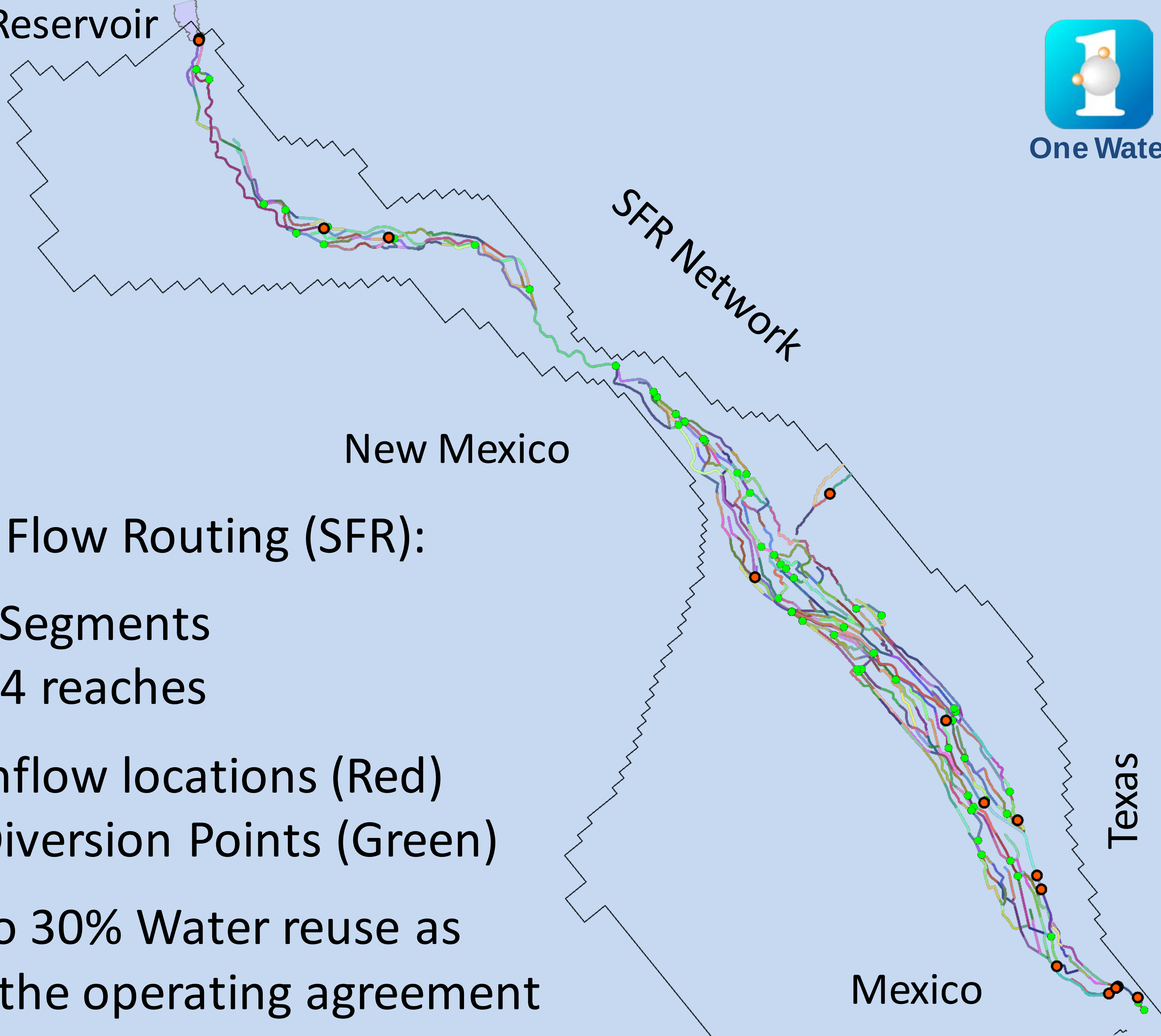


Stream Flow Routing (SFR):

- 478 Segments
- 6,344 reaches
- 16 Inflow locations (Red)
- 71 Diversion Points (Green)
- 20 to 30% Water reuse as part of the operating agreement

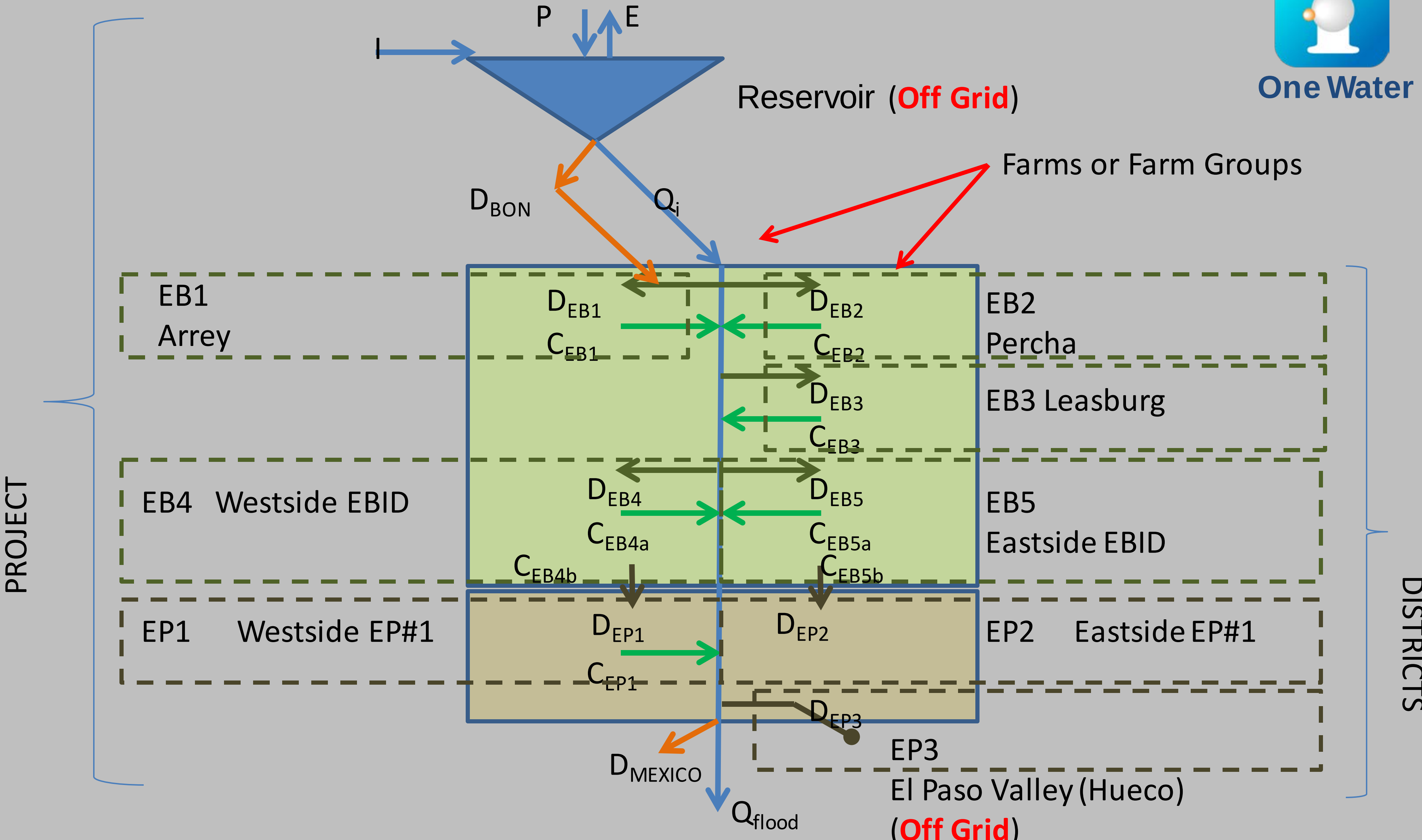
New One-Water Process/Linkage Surface-Water Operations (SWO)

One Water

- Includes a new “Layered” system of definition for water accounting units.
  - The base Demand unit is still a Farm (water accounting unit), but there are now additional units that define a broader class related to Supply (District) and Demand (Units within Districts that receive supply)
- The Reservoir is linked to SFR (**Conveyance**) and FMP (**Demand**).
  - The reservoir follows basic operation rules and has storage that changes in time (based on its inflows, losses, and releases). Tracks charges, credits, carry-over storage, and conveyance efficiencies.
- FMP calculates demand and makes a call on the reservoir for supply.
- The reservoir makes a release into a SFR network.
  - SWO then calculates the seepage losses during transit to the demand source (ie the calling water accounting unit).
- Based on the gains and losses from the SFR network SWO makes a release that will meet the demand of the water accounting unit➔ **Conveyance!!**
- If the demand is not met, either larger release from SWO or if not possible then FMP follows its normal procedure when supply cannot meet demand (including a smaller request of water from the reservoir)➔ **Feedback**!!
- **Calculates Reservoir Storage Change, Carry Over, Charges & Credits**

Example: OVERVIEW SCHEMATIC for RIO GRANDE PROJECT

One Water



SWO ➔ Layered Supply & Demand!!

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Case Study:

Rio Grande Project

- Effects of On-Farm-Efficiency on Project operations:
  - MODFLOW-OWHM allows for fully-integrated simulation of conjunctive use at *farm scale* coupled with the Farm Process (FMP)
  - New WaterOps features allow for fully-integrated simulation of conjunctive use at *regional to basin scale*, including reservoir operations

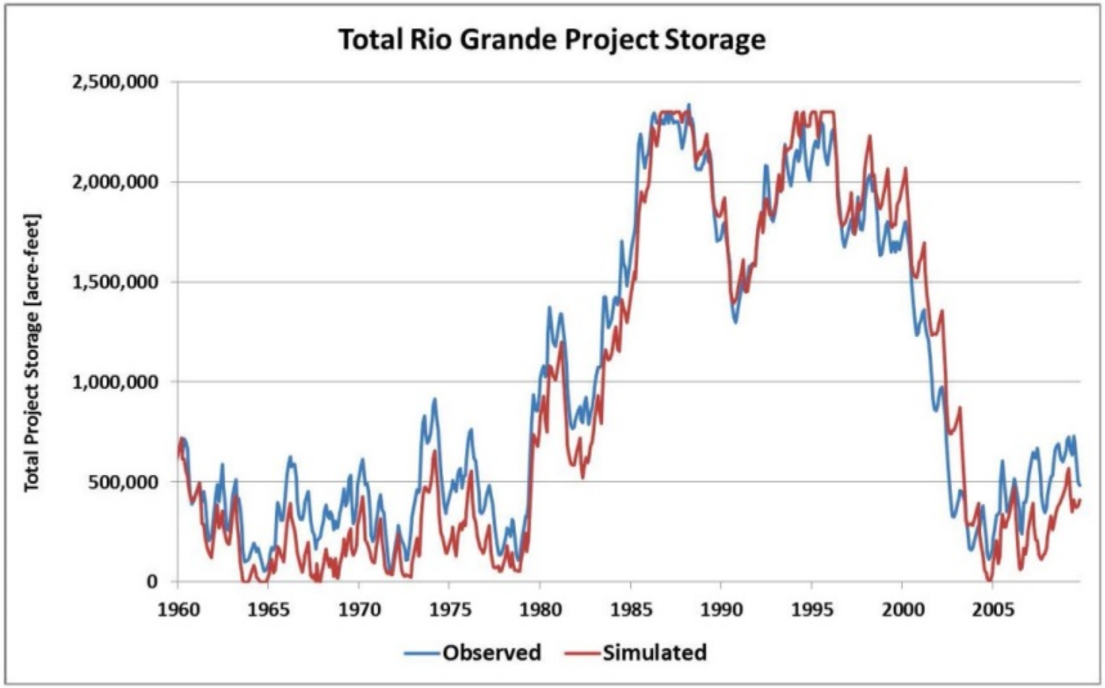

Figure 2: Observed and simulated monthly total Rio Grande Project storage in Elephant Butte and Caballo reservoirs (acre-feet) for the period 1960-2010.

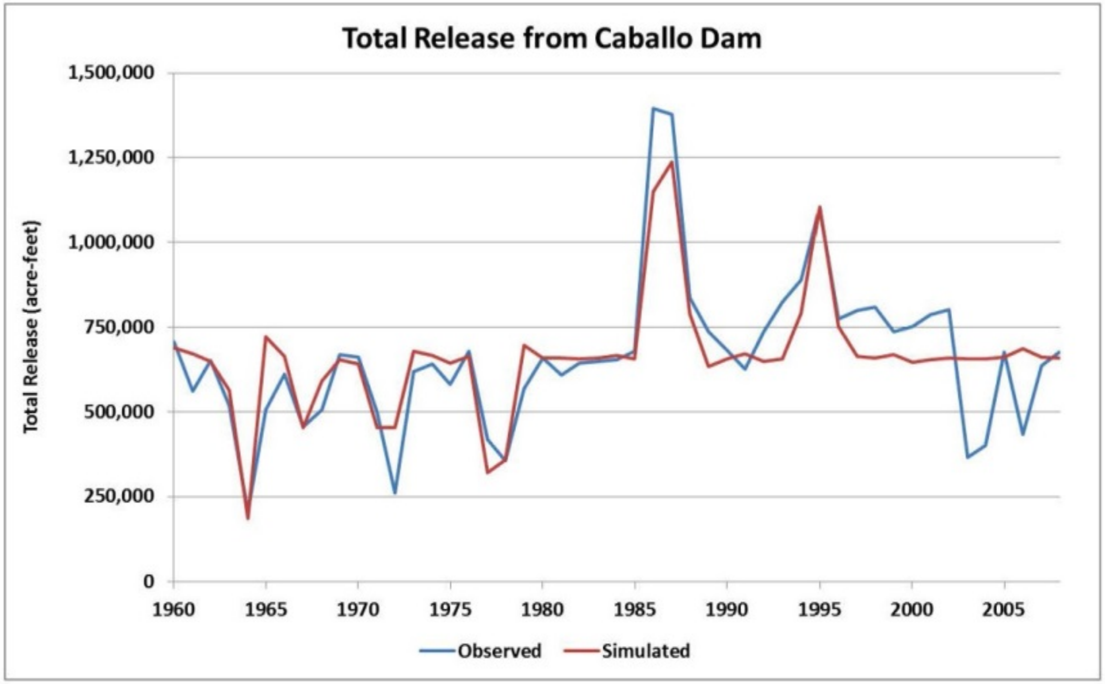

Figure 3: Observed and simulated annual release from Cabal Dam (acre-feet) for the period 1960-2010.

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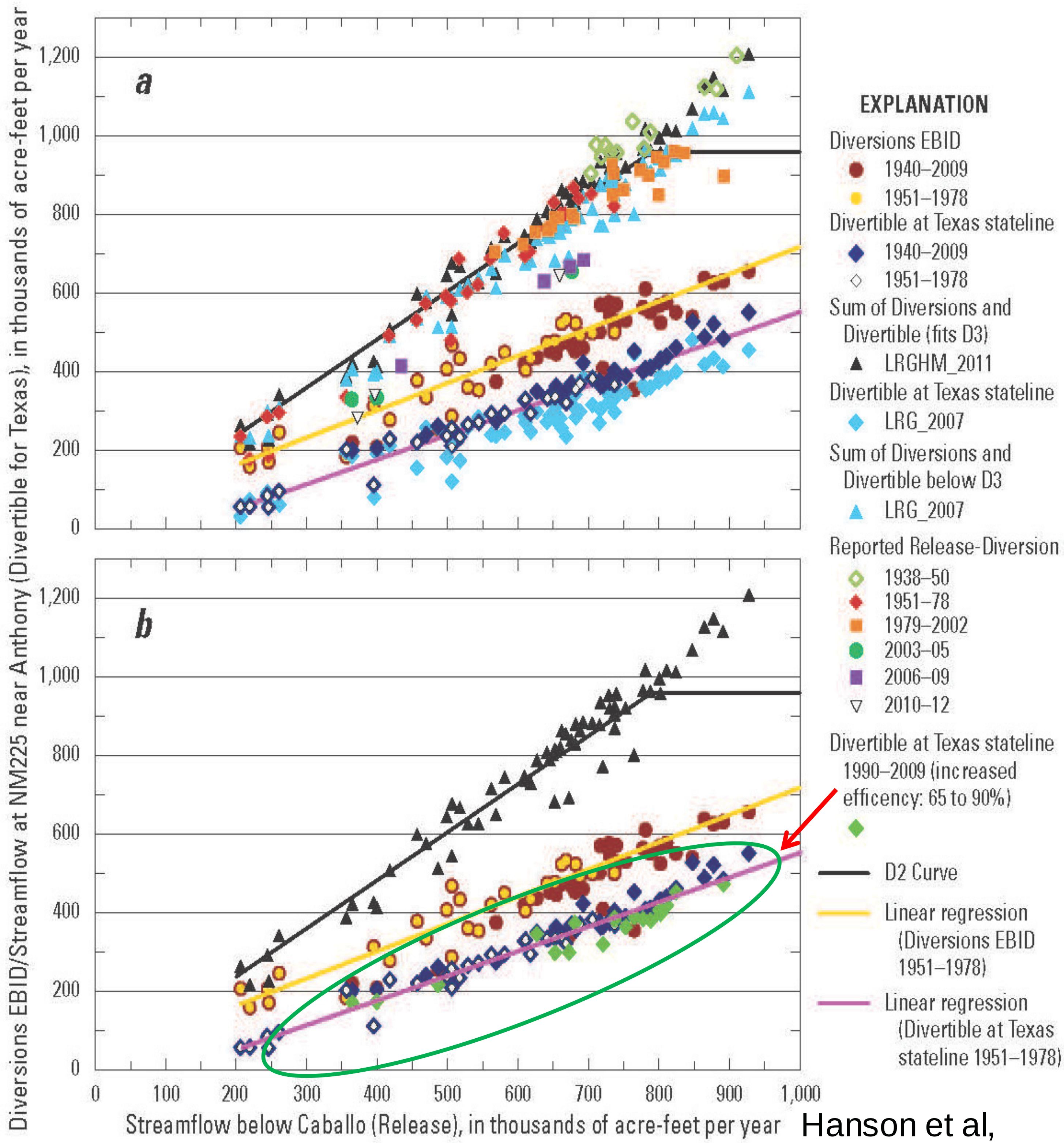
Treaties and operating agreements as well as adaptation and new projects require analysis of all water ➔ **Flow dependent flows** simulated with Integrated Hydrologic Model MF-OWHM



Hanson et al,

One Water

Today's Talk

- **Conjunctive Use Issues**
- **Conjunctive Use Modeling Framework ➔ One Water**
- **Why Use Integrated Hydrologic Modeling (IHM)?**
  Uses and Issues ➔ Model Analysis
- **Conjunctive-Use Example ➔ Transboundary Aquifers of the Rio Grande/Rio Bravo**
- ***New Features ➔ Version 2 (2017)***

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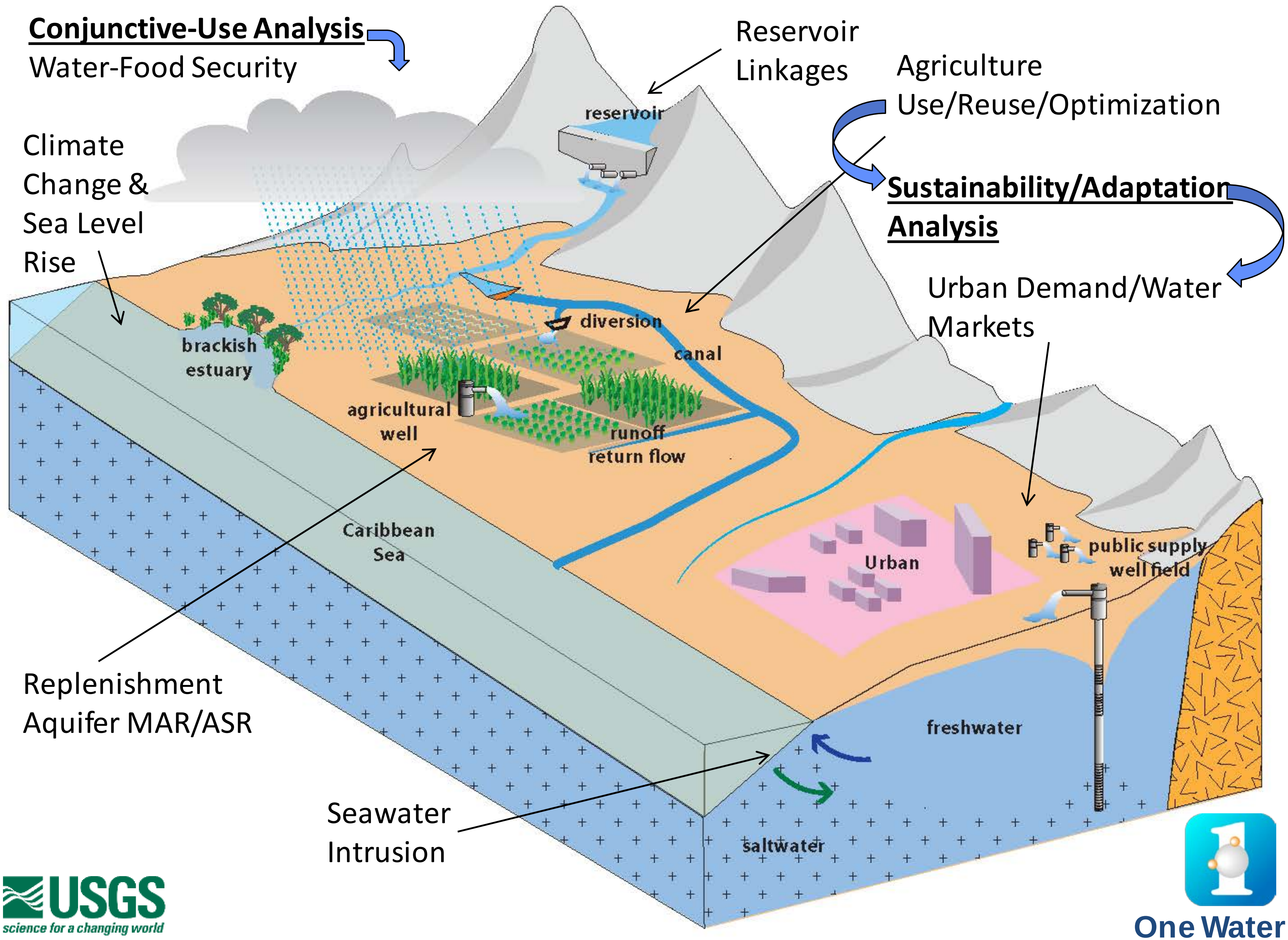
Example New One-Water Features Version 2, Puerto Rico



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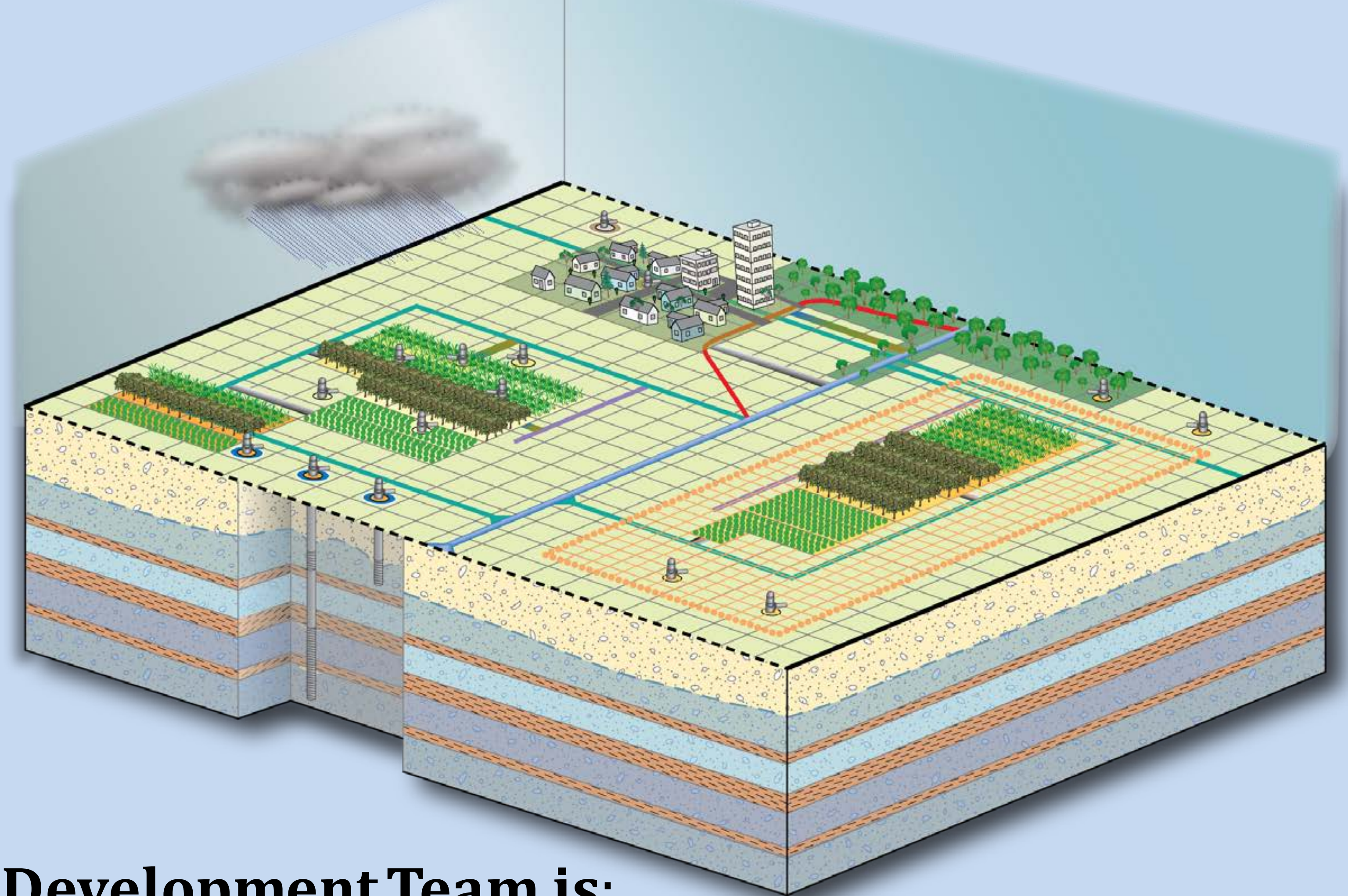

USGS - MF-OWHM Development Team is:

- **Inclusive** ➔ We encourage talking with us & give you a jump start on Conjunctive Use
- **Process & Widget Oriented** ➔ Future collaboration & incorporation of new ideas/tools
- **Building a Community** ➔ Help us Help you develop Food and Water Security
- **Invite you to Participate** ➔ Build a project & new features with us!!

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THE END - THANKS !

QUESTIONS & DISCUSSION ?

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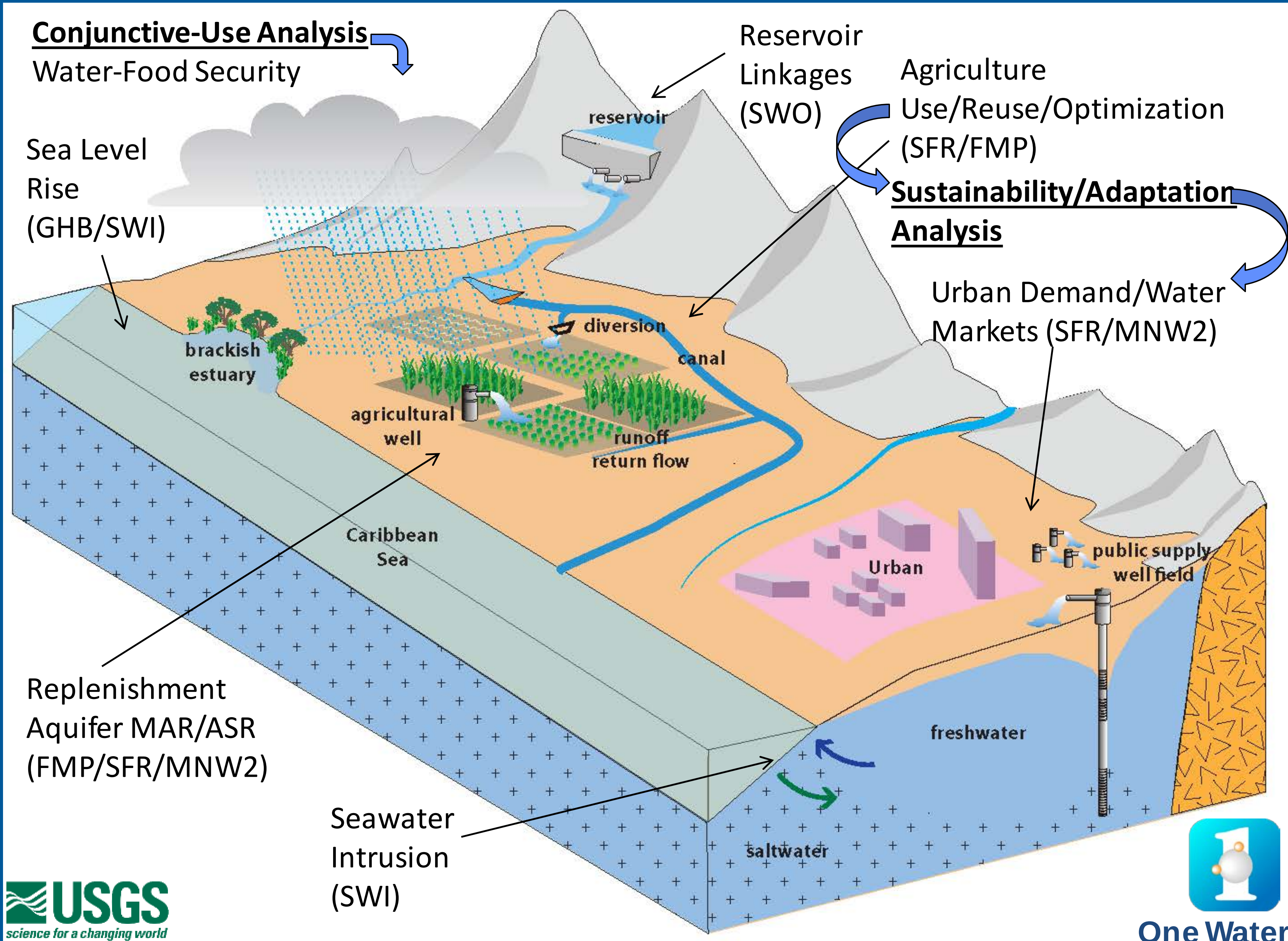
GROUND-WATER SUSTAINABILITY = STRAWBERRY FIELDS FOREVER ?

Pajaro Valley, Monterey Bay, California, USA

Example New One-Water Features Version 2, Puerto Rico



Current Features of One-Water Model (MF-OWHM) Version 1 Facilitate Conjunctive Use and Self-Updating Models

MF-OWHM Features (Version 1):

Solvers (**NWT**, PCG, **PCGN**, **GMG**, SIP, D4)➔ NWT with variable solution parameters
Surface-water (**SWR**, SFR, LAK) + Linkages to Runoff Models (BCM,VIC, PRMS), SubLink
Landscape (**FMP3**)➔ GW Allotments, Variable Farms, SubLink
Evapotranspiration (ET, ETS, **RIP-ET**, **FMP3**)➔ SubLink
Drains (DRN, **DRT** ➔ **FMP/SFR/SWR** connection for Tile Drains & Water Reuse) ➔ SubLink
Aquifers (LPF, **UPW**, HUF)
Wells (Well, FMP-well, MNW1**, MNW2** ➔ **FMP** connection)
Boundary Flows (GHB, FHB) **GHB-TabFiles**
Deformation (SUB, SUB-WT)
Seawater Intrusion (**SWI**)
Embedded Models (**LGR**)
Flow Barriers (**HFB2** ➔ variable faults/layer connections)
Unsaturated Flow (UZF, SFR, **SWR**)
Time Series (HYDMOD, SFR-Gage, **HOB**, **SWR-Obs**)

New Support Features:

Deformation Linkage (**SUBLink**) ➔ All land-surface/aquifer features
Expression Parser (**MULT2**) ➔ Build Aquifer and Subsidence Properties, Sea Levels (GHB)
MT3D Output ➔ SFR & UZF
Additional I/O for Parameter Estimation OBS ➔ Hydraulic Properties (PVAL), Actual ET (FMP)

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Many New Features of One-Water Model (MF-OWHM) Version 2 Conjunctive-Use, Sustainability/Adaptation, & Climate Change

One Water

MF-OWHM Features (Version 2):

- Surface-water (**SWR**, SFR, LAK) ➔ Additional Linkages, DRT/FMP, LineFeed Data Structures SFR
- Reservoir Operations (**SWO**) Linkage to SFR/SWR/FMP ➔ Reservoirs and Additional Demand units off Grid
- Landscape (**FMP3**) ➔ New Data Structures (in support of Self-Updating Models➔ Options & Transient-Array Reader Linkage), Varying Water Source Priorities, Salinity Water Demand, More Links, On-Farm Storage (MAR/Reuse), Multiple SRDs or RetrunFlow Locations/Farm, Separate Grid with Optional mixed Crops, External Crop-Water Yield function, Linkage for other Crop Models
- Evapotranspiration (**FMP3**) ➔ Mixed crop and array structures for Crop attributes
- Wells Well/MNW2/FMP ➔ Improved Pumpage Smoothing, LineFeed Data Structures (Self-Updating Models)
- Aquifers ➔ Enhanced Conduit Flow/Fractured Rock Flow with Transport
- Soil Package ➔ Simple (Sand Box) – Complex (Richard's Approx) & Linkage to UZF
- Deformation (SSUB) ➔ Improved and combined Subsidence Package
- Seawater Intrusion (**SWI**) ➔ Tabfiles, Linkage to Expression Parser for Time-Varying Heads/Conc.
- Embedded Models (**LGR**) ➔ Adjacent Model Linkage (Partial or Full)
- Expression Parser (**MULT2**) ➔ Linkage to FMP Crops Salinity Demand, SWI Boundary Heads
- More MT3D Output ➔ FMP, SOIL, SWI, MNW2 (?)
- Additional I/O for Parameter Estimation OBS➔ MicroGravity, HOB Dynamic Output
- Linkages for output needed for wrapper Optimization Analysis (Dakota)
- Crop Optimization Ag Mgmt/Crop Rotation➔ Dakota-FMP wrappers
- FMP Linkage to land-based & remote sensing data streams ➔ Self-Updating Models
- Sustainability Package ➔ Reduced storage depletion, subsidence, seawater intrusion, & discharge capture

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Obtaining MODFLOW-OWHM

One-Water Team ➔ Randall Hanson, Scott Boyce, Wes Henson, Ian Ferguson, Thomas Reiman, Steffen Mehl, Stanley Leake, Thomas Maddock, & Joe Hevesi

Email ➔ modflow_owhm@usgs.gov

- Official Site:
  http://water.usgs.gov/ogw/modflow-owhm/
- Unofficial Site:
  https://sourceforge.net/projects/modflow-owhm/
- Online Guide:
  http://water.usgs.gov/ogw/modflow-owhm/Guide/index.html
- Model Muse for MF-OWHM:
  http://water.usgs.gov/nrp/gwsoftware/ModelMuse/ModelMuse.html

What is a Self-Updating Model Structure ?

- Set Model Build-Run-Analysis Folder Structure
- Set scripting and Object-Oriented Flow Charts (Workflows)
- Linkages to standard Data Streams (Climate, Land Use, Streamflow, groundwater levels, sea level, subsidence, pumpage, etc.)
- New Model Input ➔ Separation of Structural Attributes from Temporal Attributes ➔ append temporal data without rebuilding model input & “Smarter” input data sets
- Temporal Attributes are on-line, client, or 3rd-party Databases managed separately ➔ linked to simple spreadsheets for model updates