History of Modeling Tools:
LSPC Watershed Modeling

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CWEMF
CALIFORNIA Water & Environmental Modeling Forum

PARADIGM
ENVIRONMENTAL

Presentation Overview

- Model Development for Watershed Management
- Model Development Cycle
- Model Configuration
  - Meteorological Data
  - Source Characterization
  - Drainage Area Boundaries
  - Hydrological Response Units
- Process Representation, Calibration, Validation
- Critical Conditions and Management Objectives
- Modeling Management Scenarios
- Questions

Model Development for Watershed Management

Cloud-Based

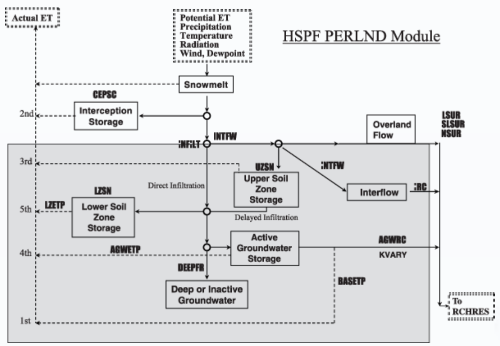
Improved Numerical Models · *GIS Integration* · *Increased Computational Speed and Storage Capacity* · *RAAs* · *Adaptive Management*

- **1959-1966**: Stanford Watershed Model
- **1971**: SWMM 1
- **1972**: EPA Clean Water Act
- **1980**: HSPF Released
- **1988**: SWMM 4
- **1992**: EPA Establishes TMDL Procedures
- **1996-98**: BASINS 1.0 – 2.0
- **2000**: MDAS (LSPC 1.0); BMP/LID Module (PGC)
- **2001**: BASINS 3.0
- **2003**: EPA TMDL Toolbox (LSPC 2.0)
- **2004**: SWMM5
- **2009**: SUSTAIN 1.0; LSPC 3.0 – 4.0
- **2010**: Los Angeles County WMMS
- **2011**: SUSTAIN 1.1
- **2013**: San Diego WQIPs; BASINS 4.0
- **2014**: SUSTAIN 1.2
- **2015**: LSPC 5.0; Los Angeles EWMPs
- **2017**: San Mateo County GI Plans
- **2018 - 2024**: LSPC 6.0; SUSTAIN 2.0; WMMS 2.0; Auckland FWMT; King County WQBE; Environmental Flows

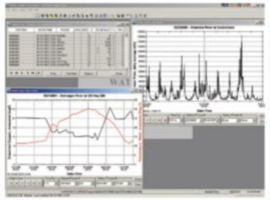
Demand for numerical forecasting models

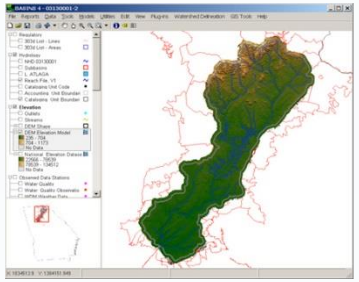
Integrated Hydrology + Water Quality Models

HSPF

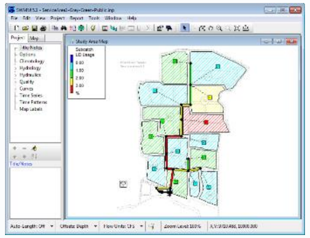


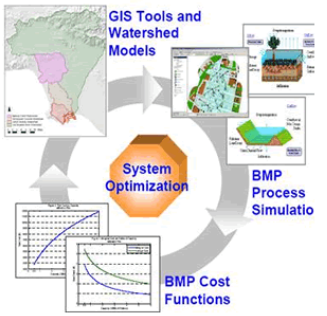
Demand for Tools: Support TMDL Implementation





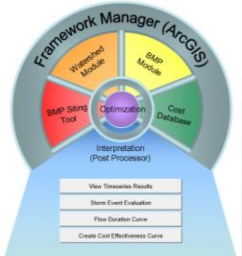
SUSTAIN Development Begins

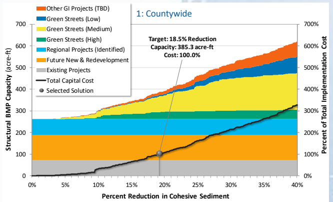


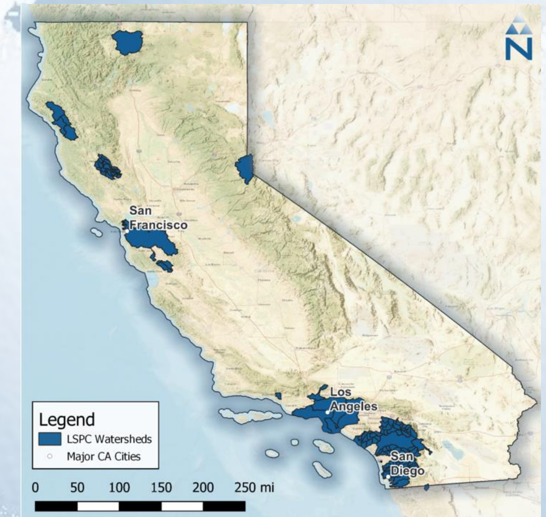


Cost-Benefit Optimization at the Watershed Scale

SUSTAIN







The Sweet Spot

Simple

Complex

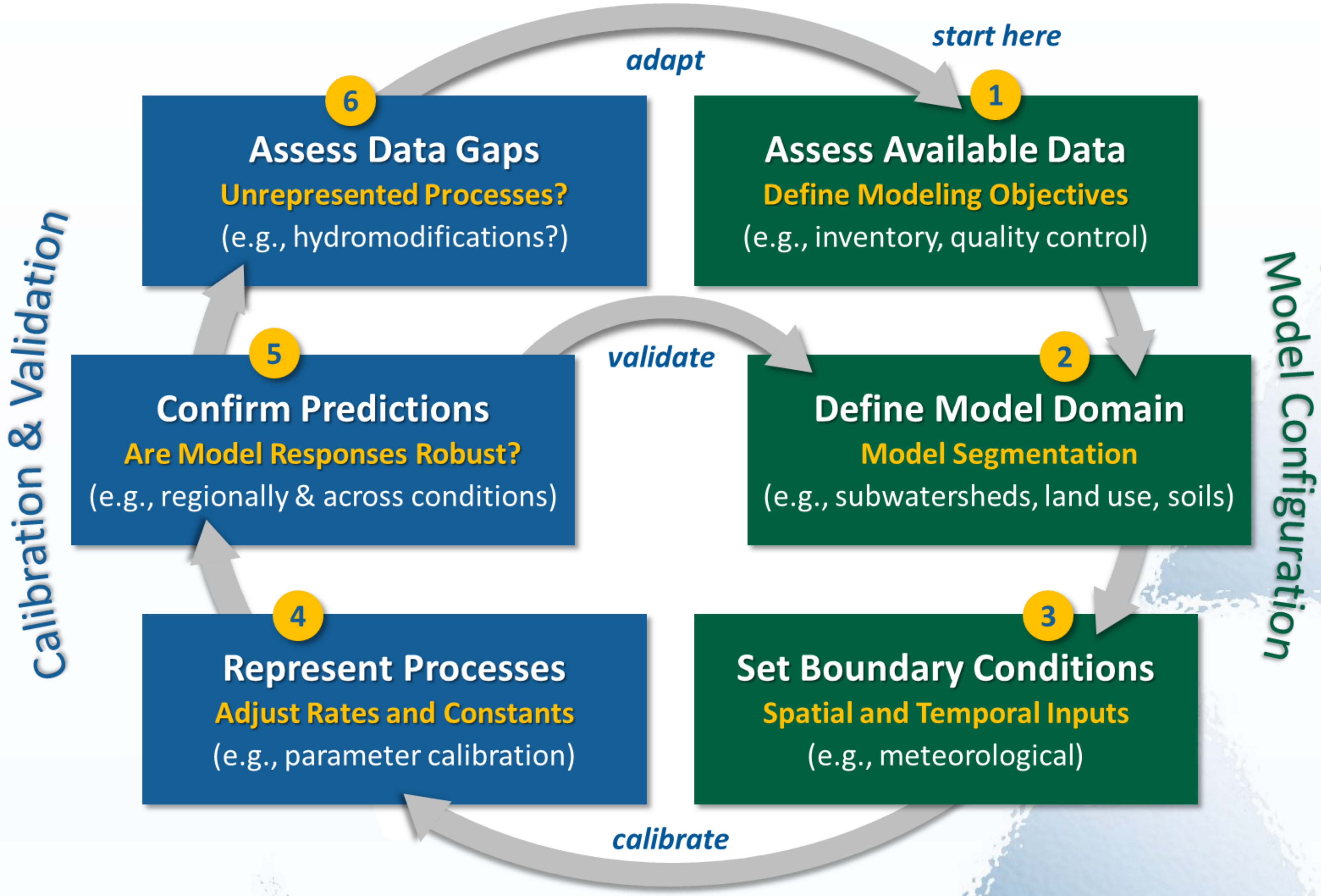
LSPC

Empirical
Coarse Spatial Resolution
Water/Load Budget
Computationally Simple

Precision Improves with:

- Higher Resolution Spatial Data
- Higher Resolution Meteorological Data
- Better Computational Resources

Deterministic
Spatially Explicit / Grid-Based
Continuous Simulation
Computationally Intensive



start here
adapt
6
Assess Data Gaps
Unrepresented Processes?
(e.g., hydromodifications?)
1
Assess Available Data
Define Modeling Objectives
(e.g., inventory, quality control)
validate
5
Confirm Predictions
Are Model Responses Robust?
(e.g., regionally & across conditions)
2
Define Model Domain
Model Segmentation
(e.g., subwatersheds, land use, soils)
4
Represent Processes
Adjust Rates and Constants
(e.g., parameter calibration)
3
Set Boundary Conditions
Spatial and Temporal Inputs
(e.g., meteorological)
calibrate
Calibration & Validation
Model Configuration

Baseline Model / Current State

Model Calibration

Weather Data

Ensure quantity + quality of spatial/temporal coverage of forcing data that drive catchment hydrology.

Focus: Weather Data

Land Hydrology

Identify influential land use features and factors. Define parameter groups. Check base flow, runoff, seasonal.

Focus: Upstream Flow Gages

Stream Transport

Include special hydraulic features of stream routing network (i.e. point sources, reservoirs, diversions).

Focus: Downstream Flow Gages

Water Quality

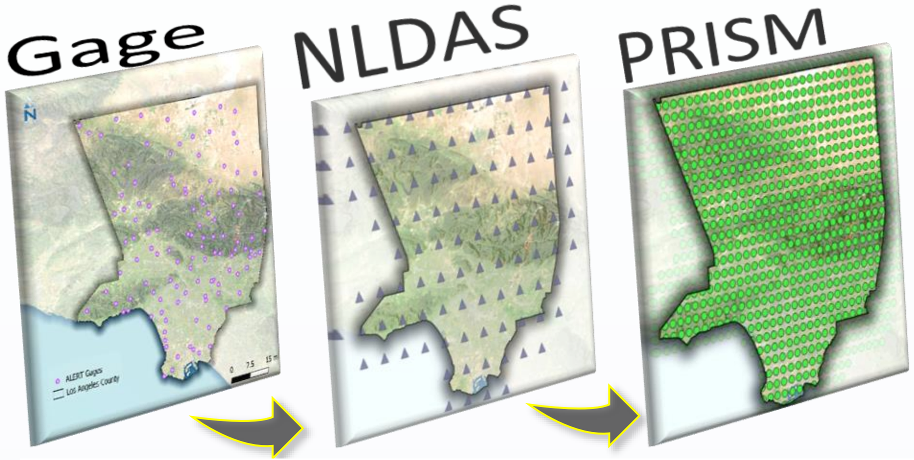
1. **Sediment**
2. **Assoc. Contaminants**
3. **Other Contaminants**
4. **Fate and Transport**

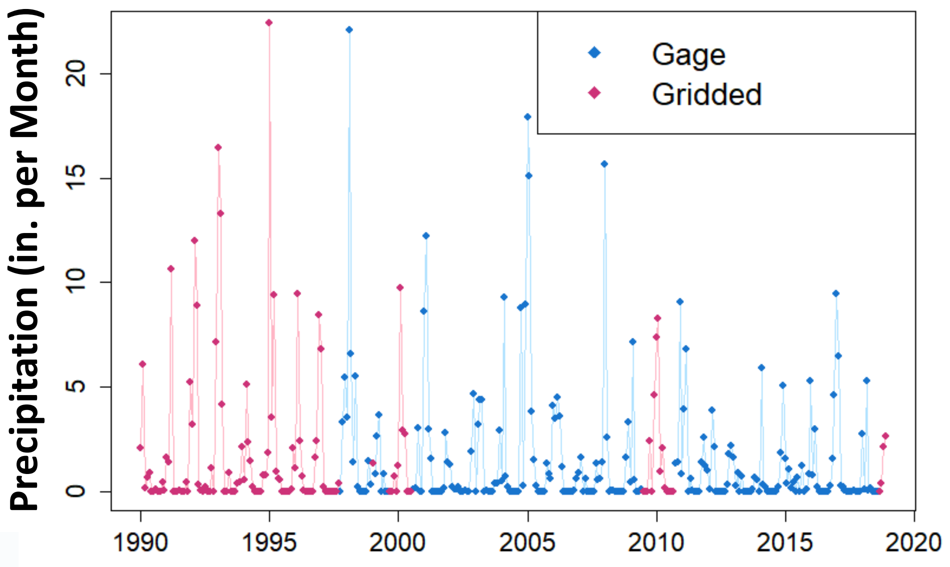
Instream Monitoring Gages

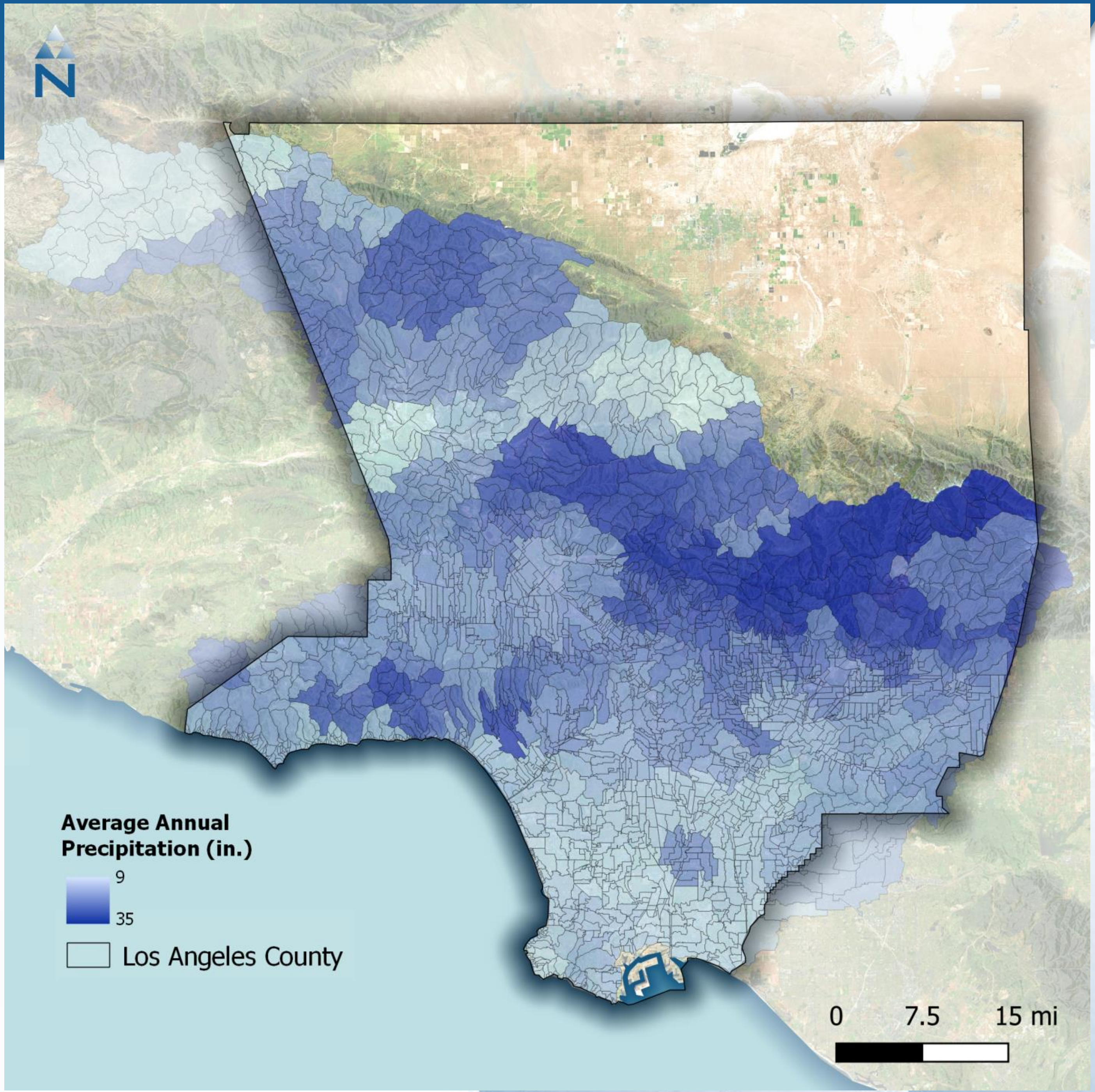
Parallel Objective: *Minimise Uncertainty Propagation*

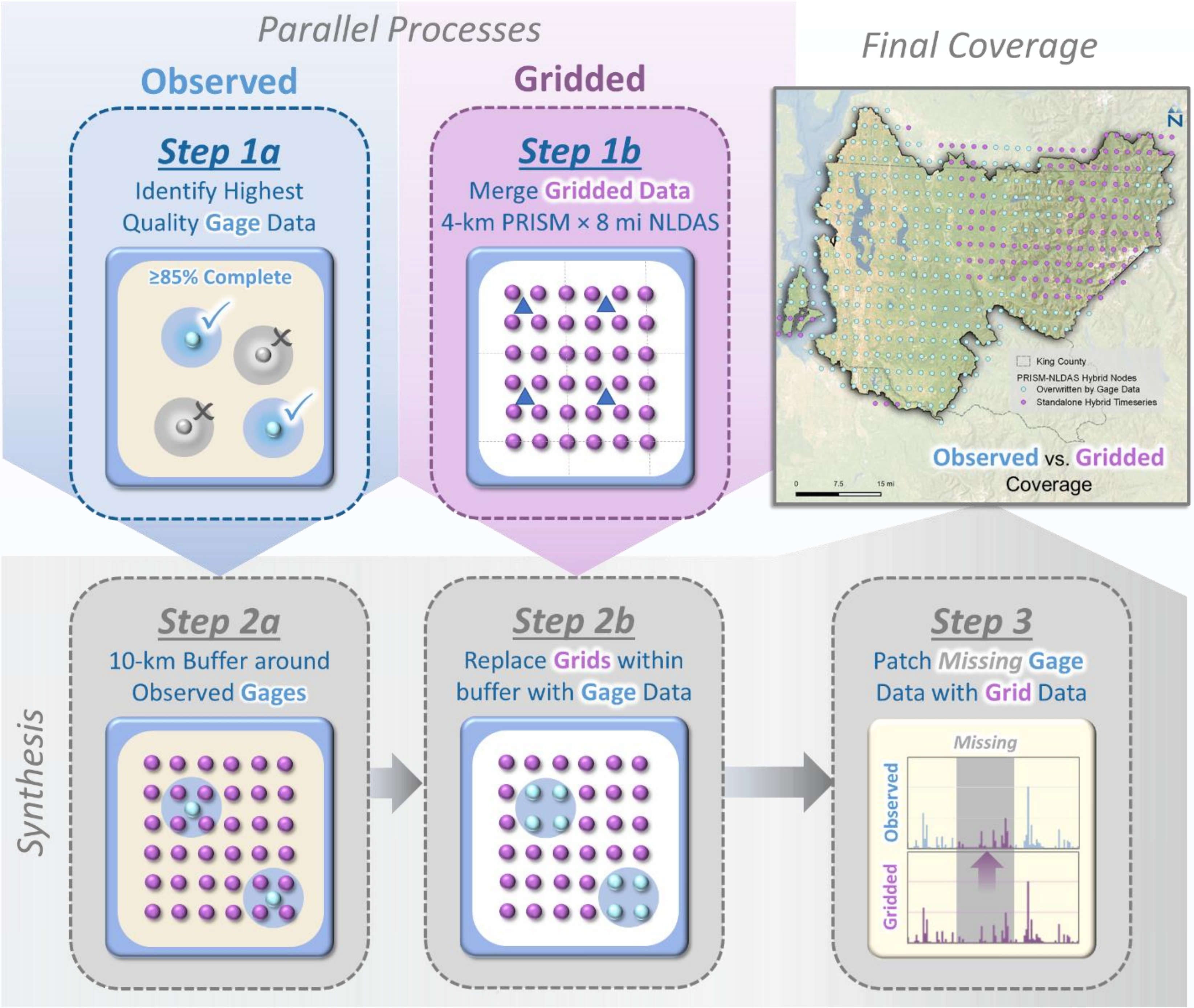
Model Configuration

Meteorological Conditions









- "Hybrid" Approach
  - **Quality-controlled observed data**
  - **Leverage gridded data to patch spatial and temporal gaps in the observed record**
- Scale drives LOE associated with this effort

HRU Representation

Land Cover

LARIAC 2019

CAMS 2019

×

Land Use

LA County Assessor 2019

×

Soils Group

USDA SSURGO 2019

×

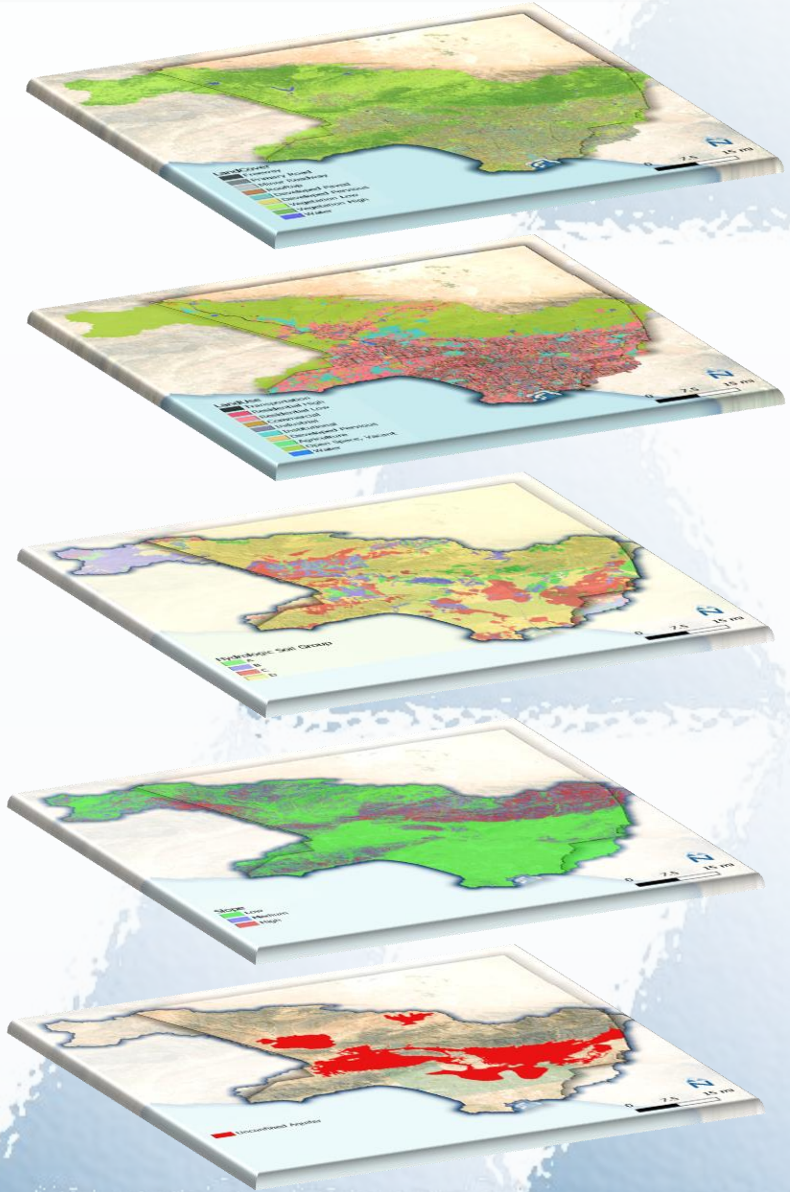
Slope

USGS

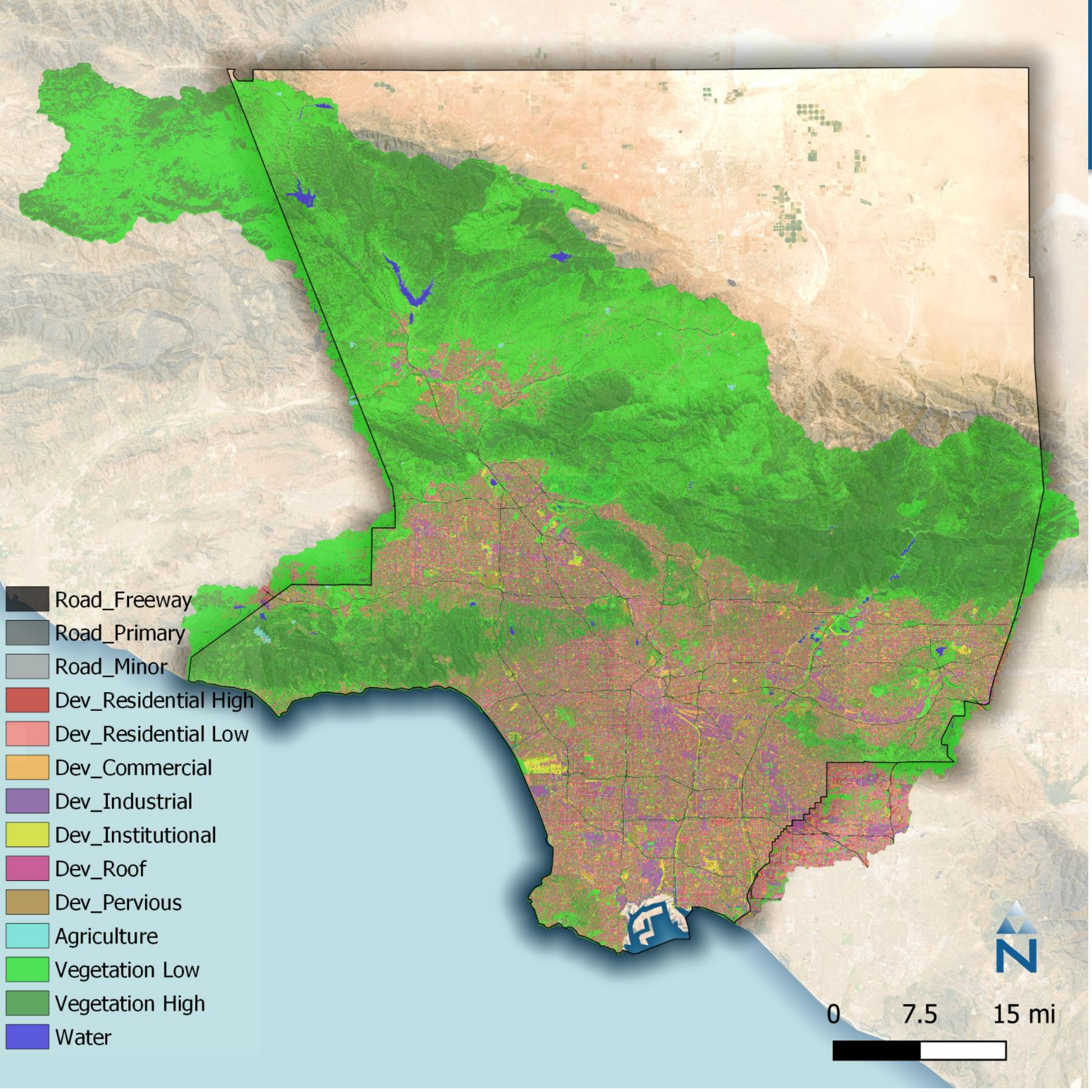
×

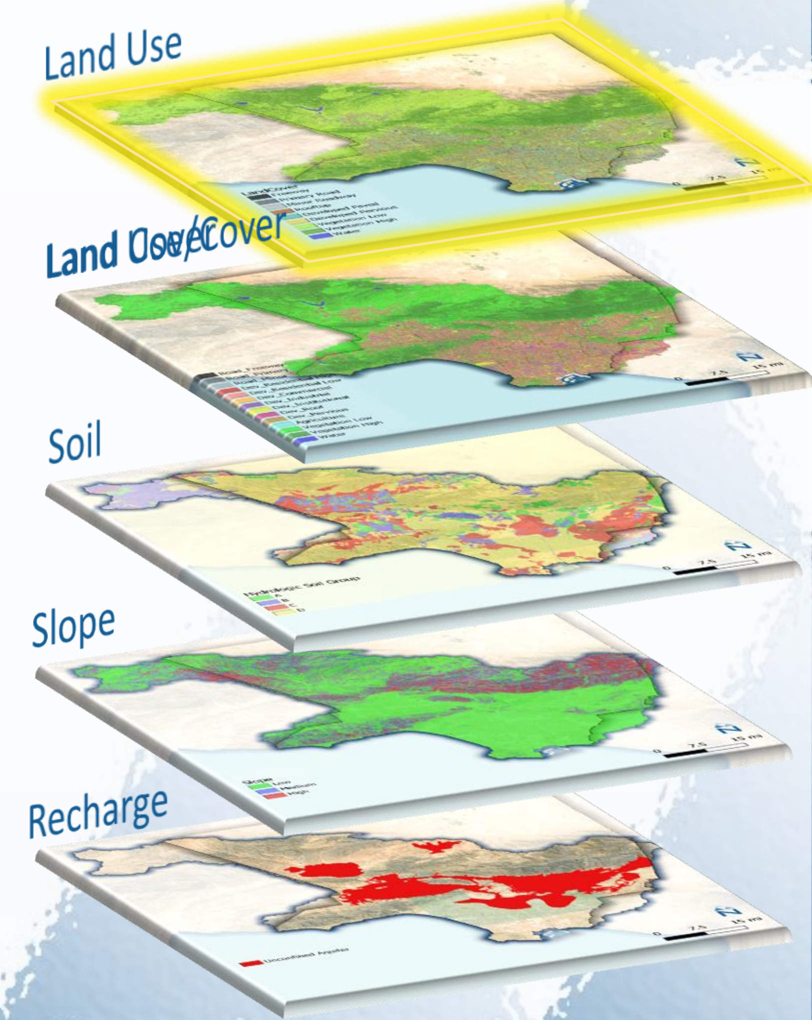
Recharge

LACDPW 2019

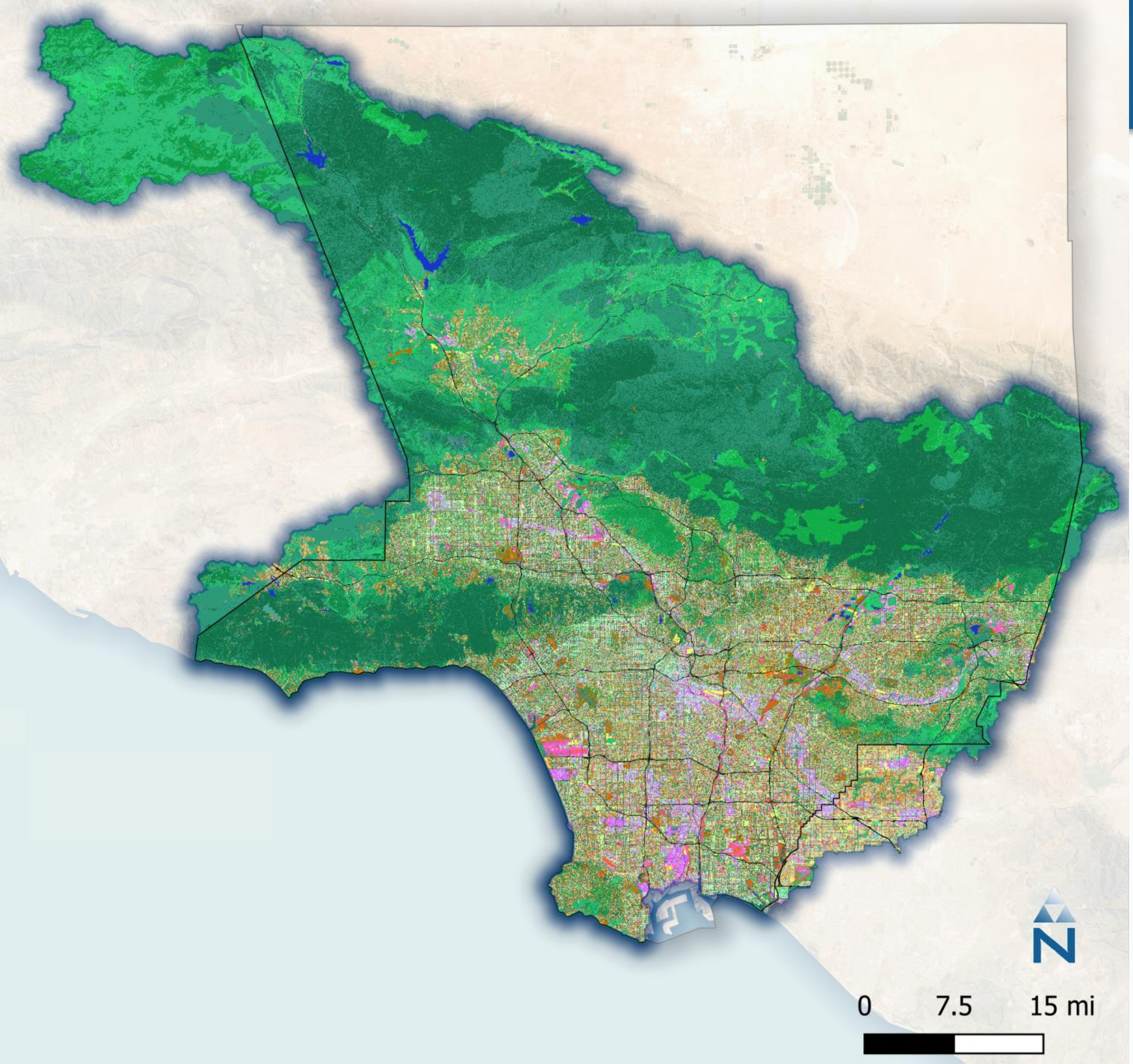


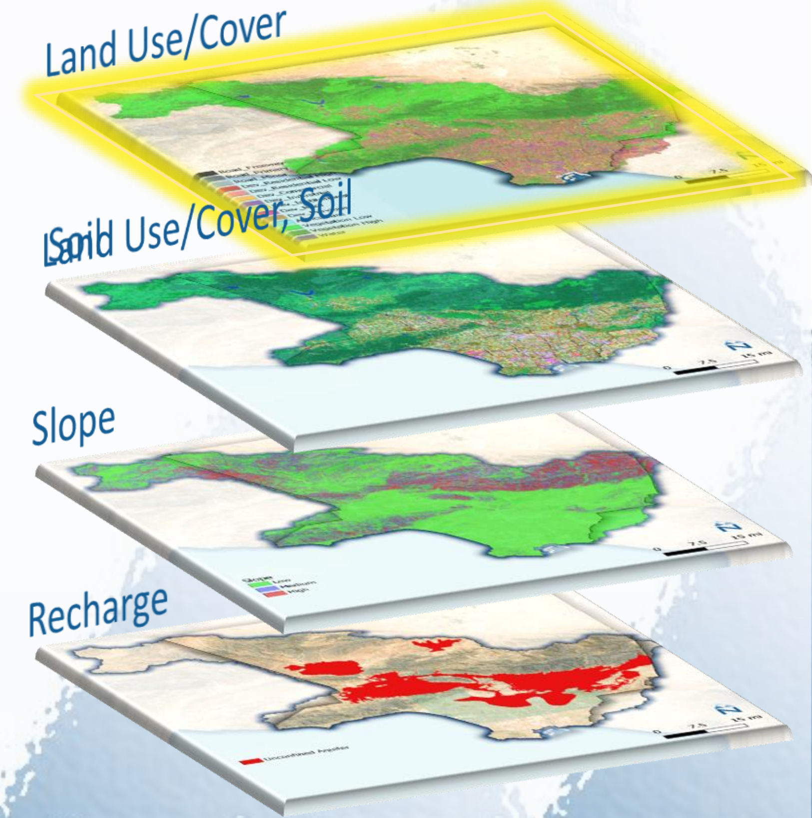
Land Use/Cover



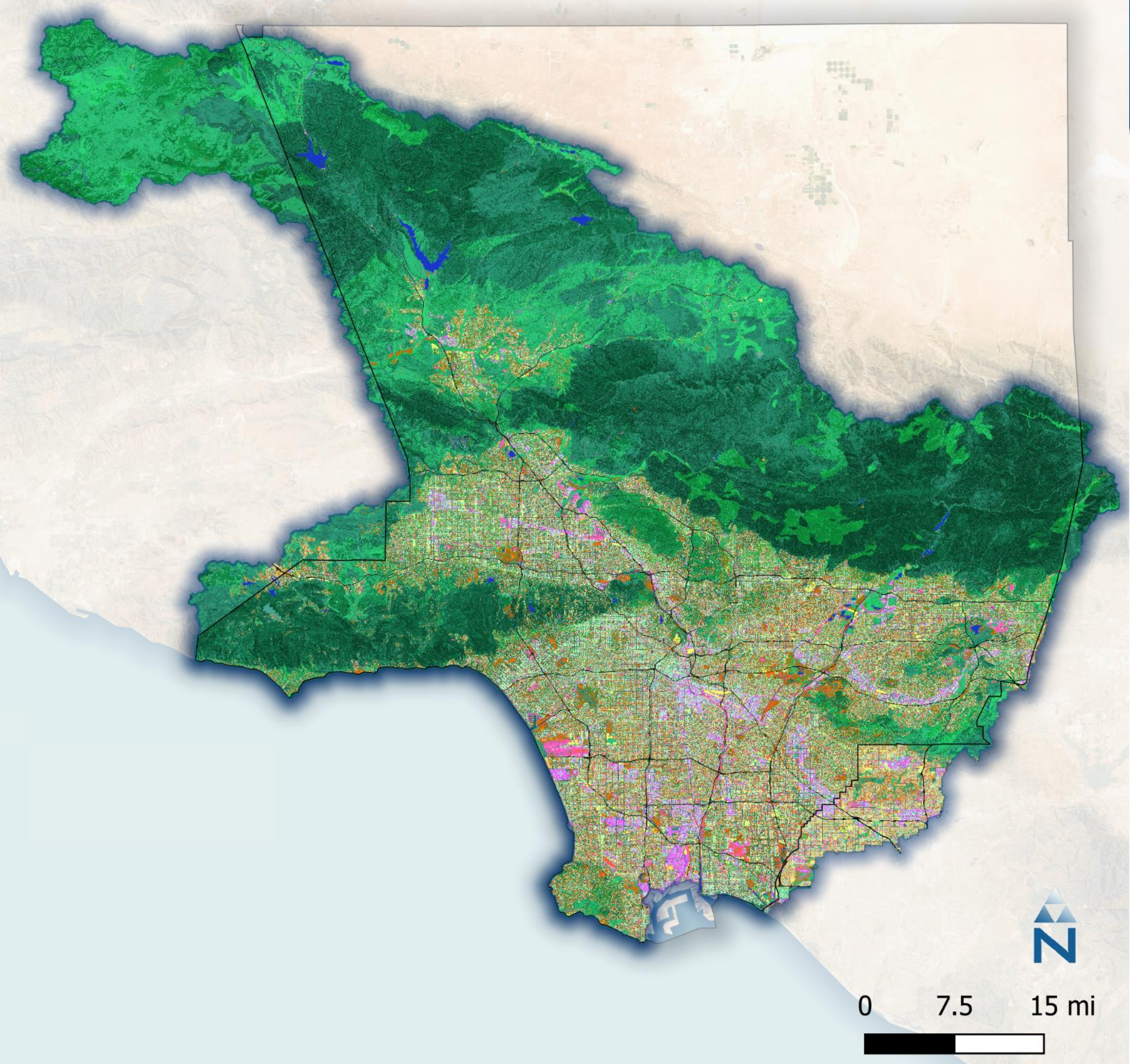


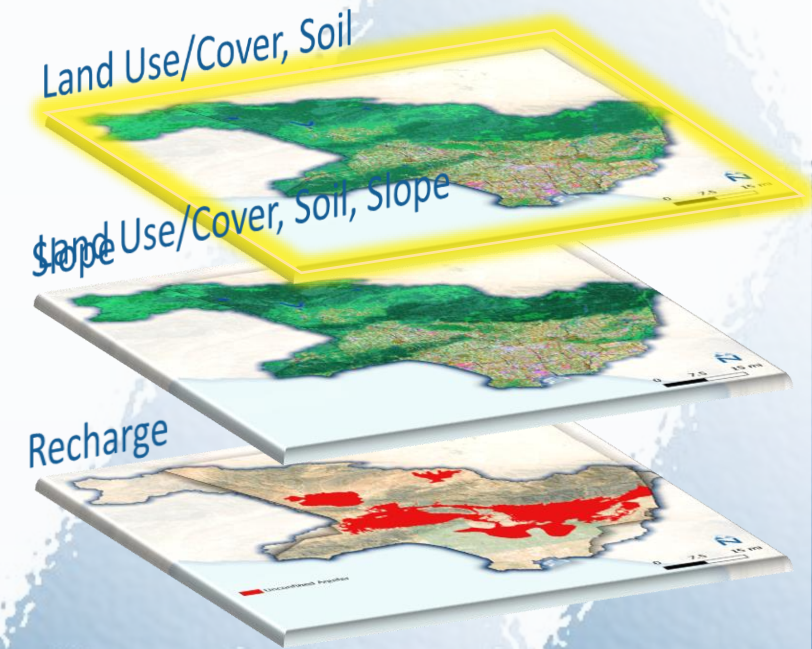
Land Use/Cover, Soil



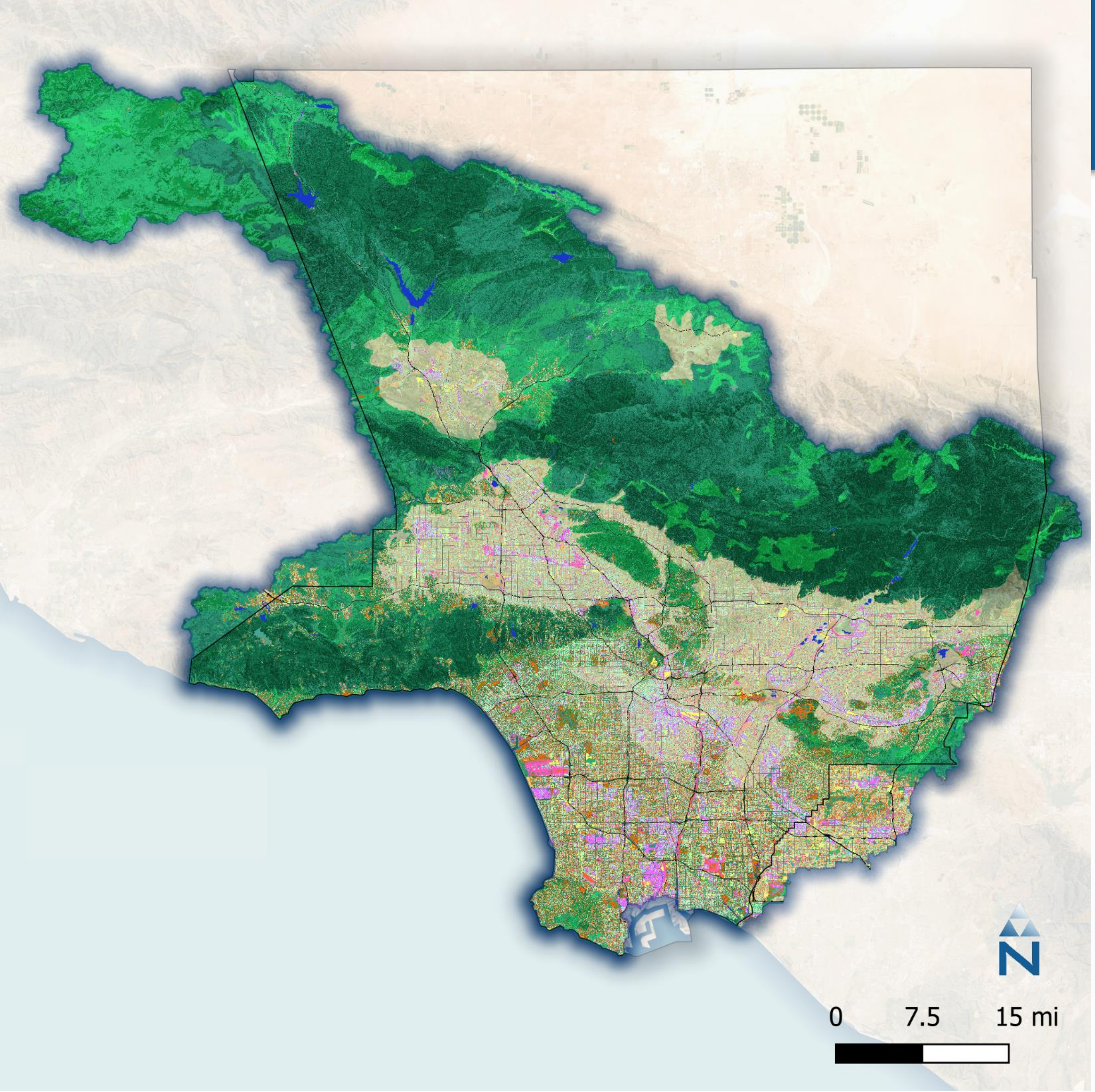


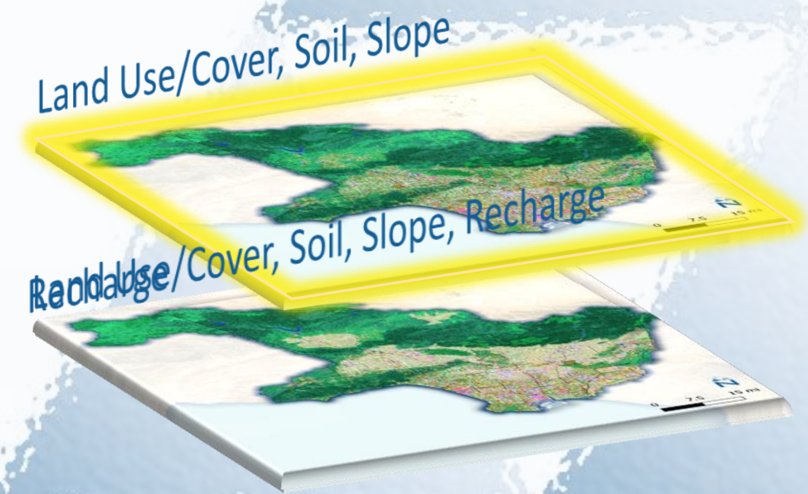
Land Use/Cover, Soil, Slope





Land Use/Cover, Soil, Slope, Recharge





Land Use/Cover, Soil, Slope, Recharge

Regional Watershed

Hydrologic Response Units

- Road_Freeway
- Road_Primary
- Road_Minor
- Dev_Res_High
- Dev_Res_Low
- Dev_Commercial
- Dev_Industrial
- Dev_Institutional
- Dev_Roof
- Dev_Pervious-A-Low
- Dev_Pervious-A-Med
- Dev_Pervious-B-Low
- Dev_Pervious-B-Med
- Dev_Pervious-C-Low
- Dev_Pervious-C-Med
- Dev_Pervious-D-Low
- Dev_Pervious-D-Med
- Veg_High-A-Med
- Veg_High-A-High
- Veg_High-B-Med
- Veg_High-B-High
- Veg_High-C-Med
- Veg_High-C-High
- Veg_High-D-Med
- Veg_High-D-High
- Veg_Low-A-Med
- Veg_Low-A-High
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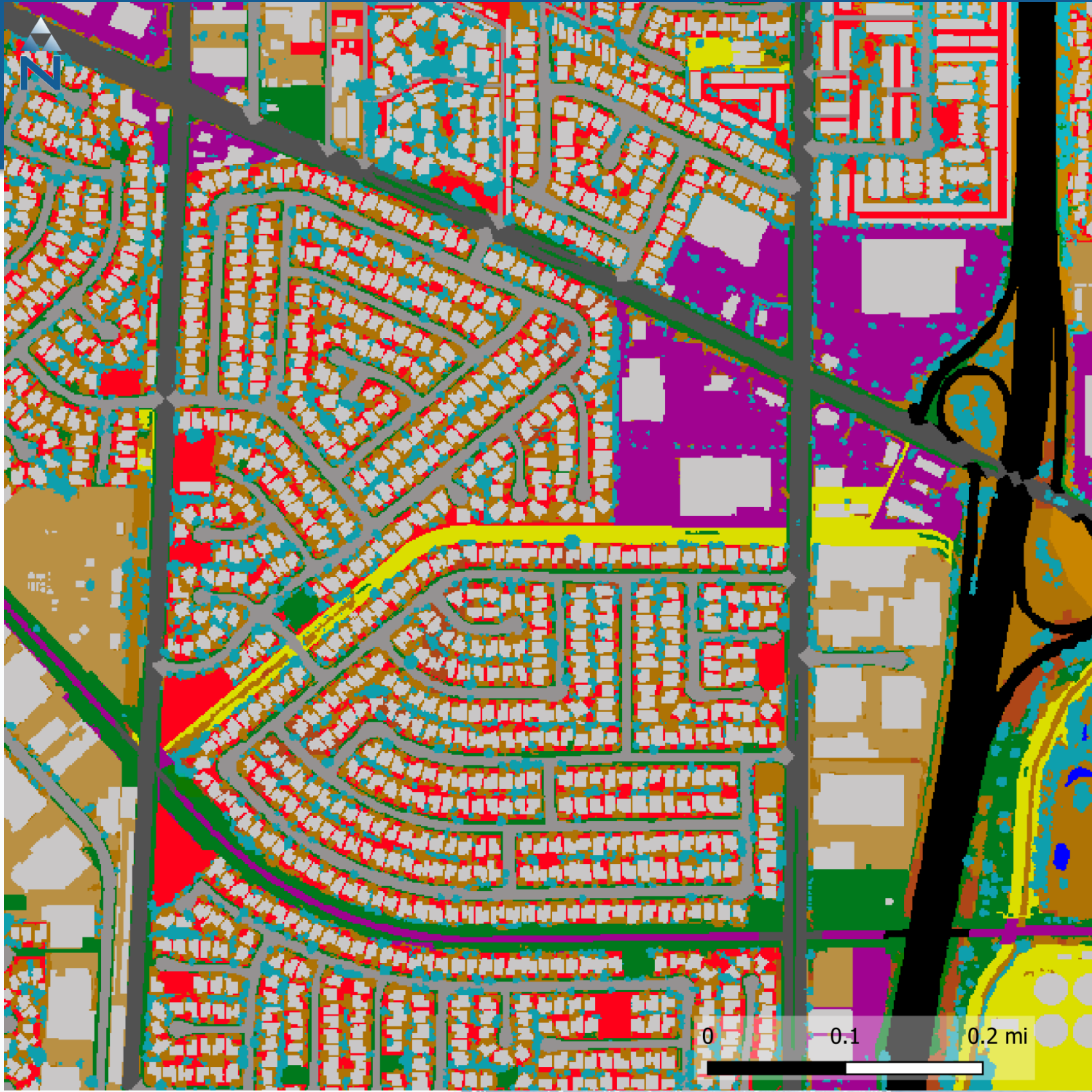
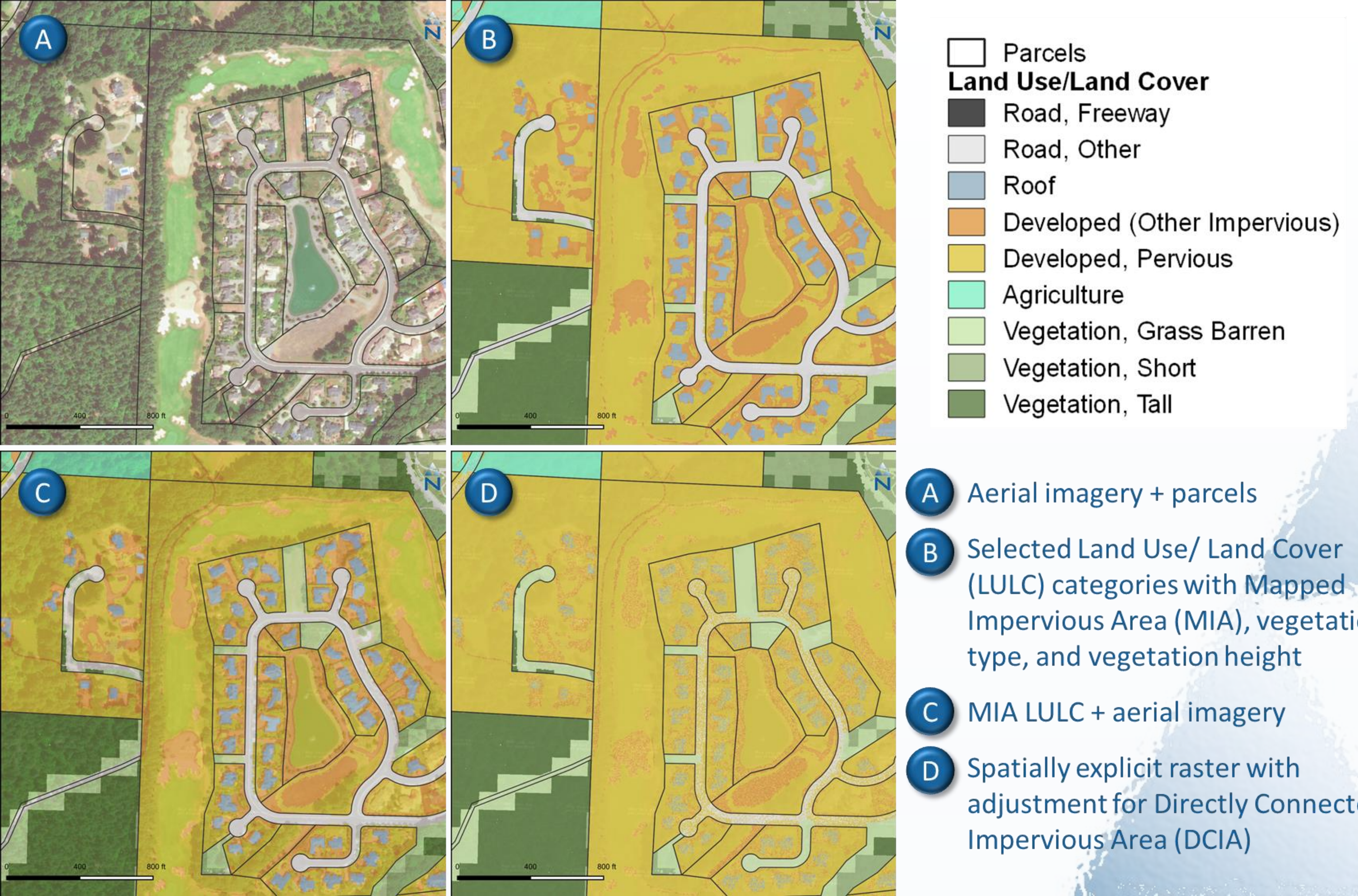
- Veg_Low-D-Med
- Veg_Low-D-High





A Aerial imagery + parcels

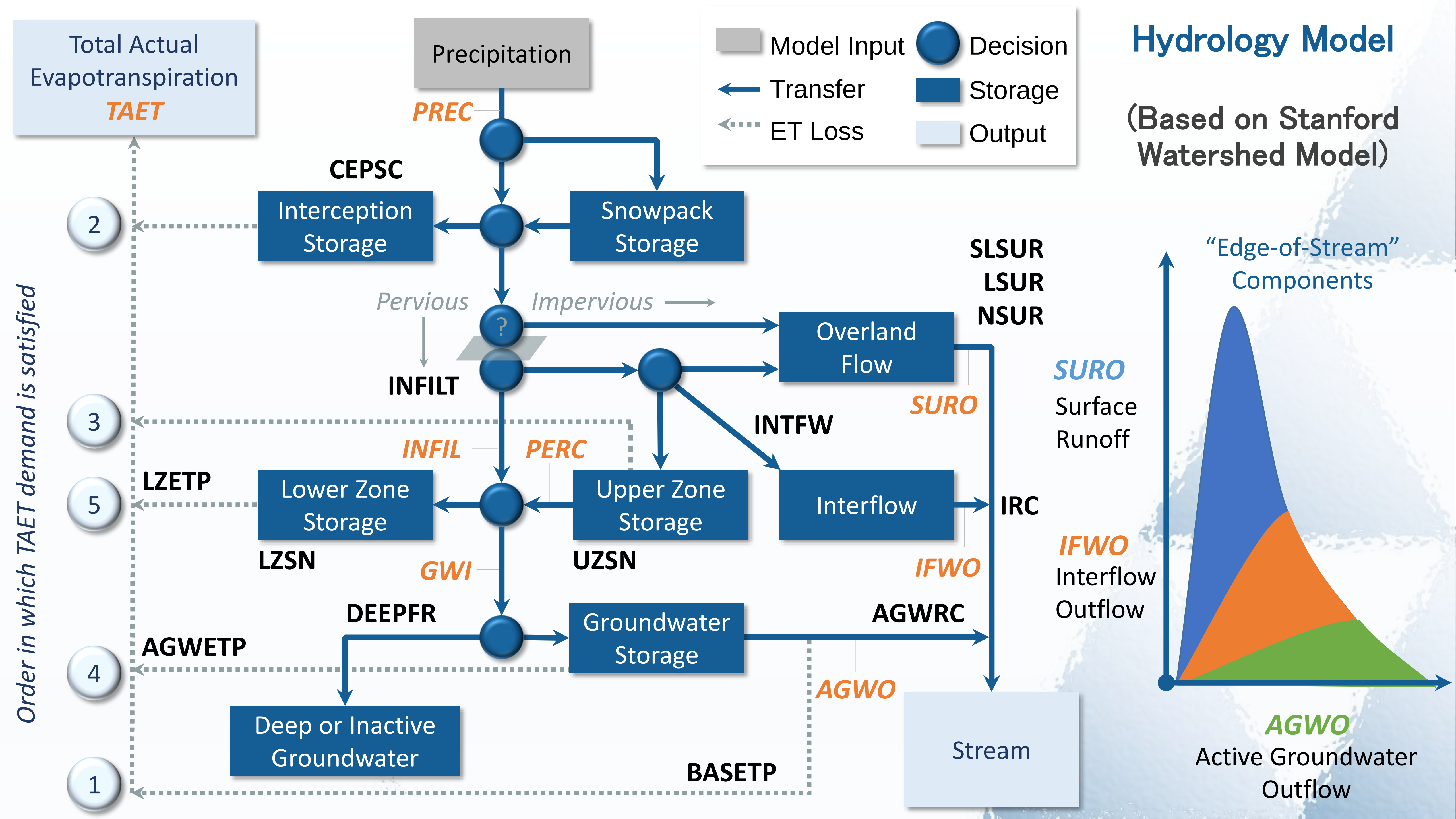
B Selected Land Use/ Land Cover (LULC) categories with Mapped Impervious Area (MIA), vegetation type, and vegetation height

C MIA LULC + aerial imagery

D Spatially explicit raster with adjustment for Directly Connected Impervious Area (DCIA)

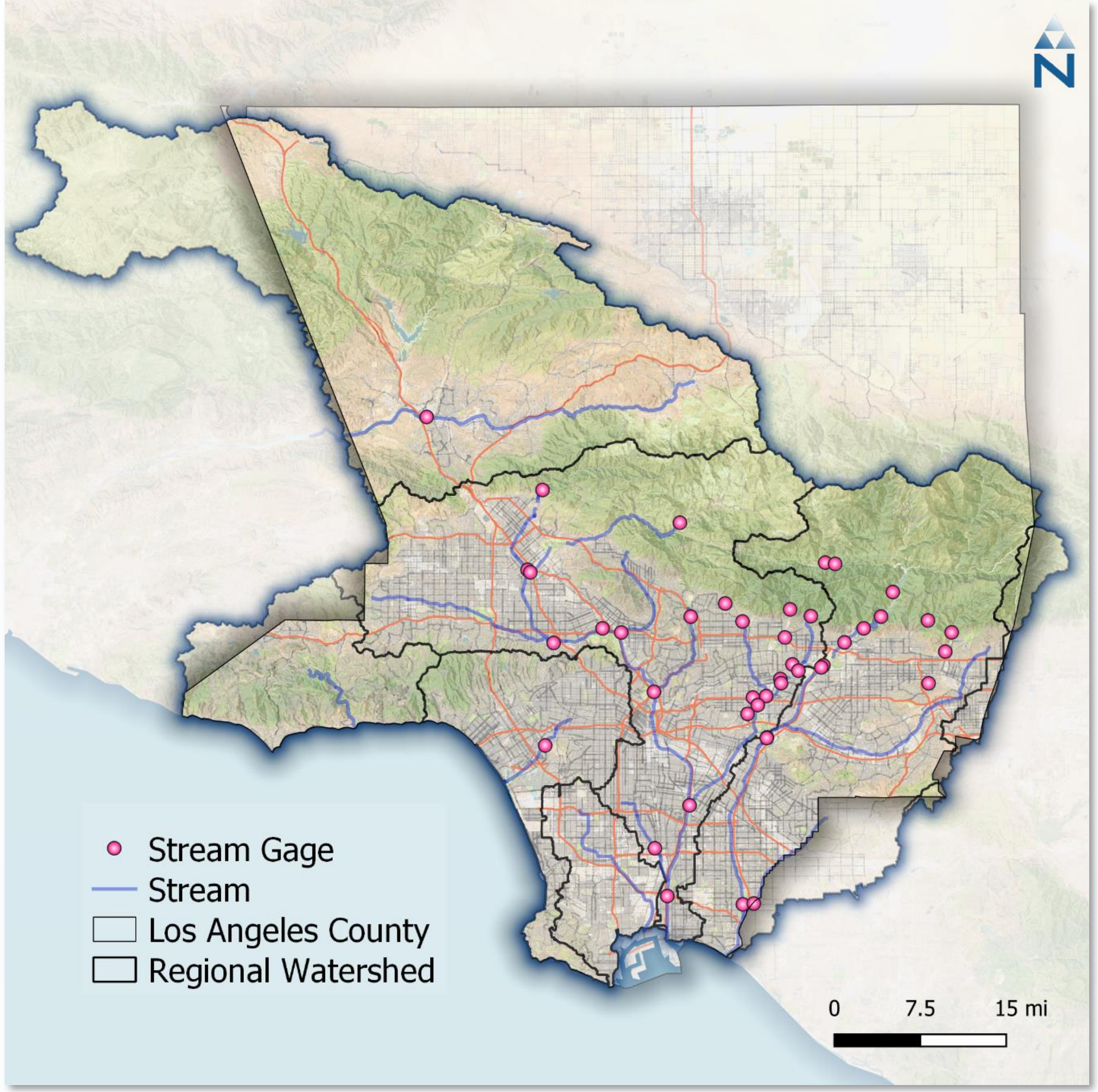
Process Representation, Calibration, and Validation

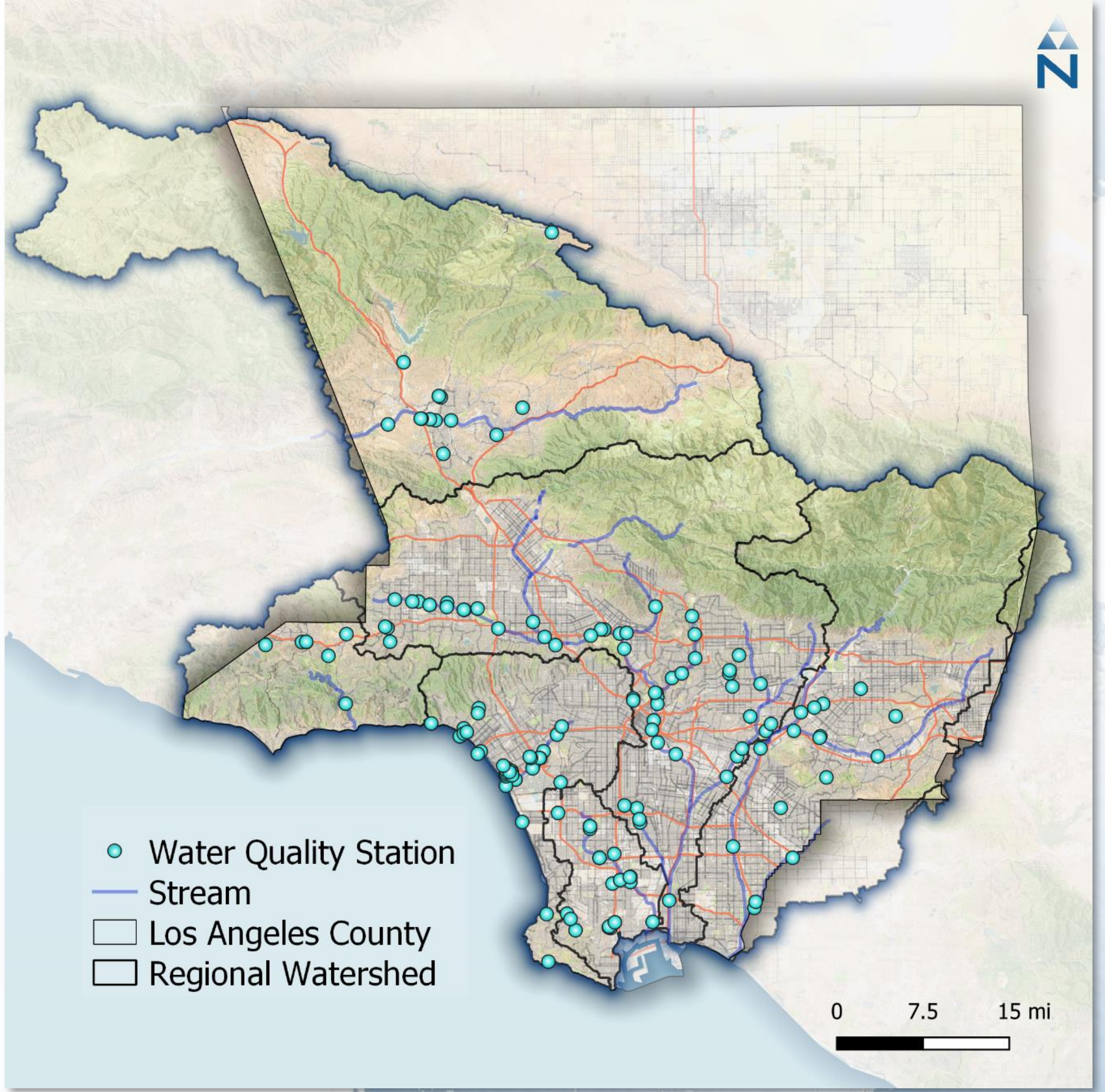
PARADIGM ENVIRONMENTAL



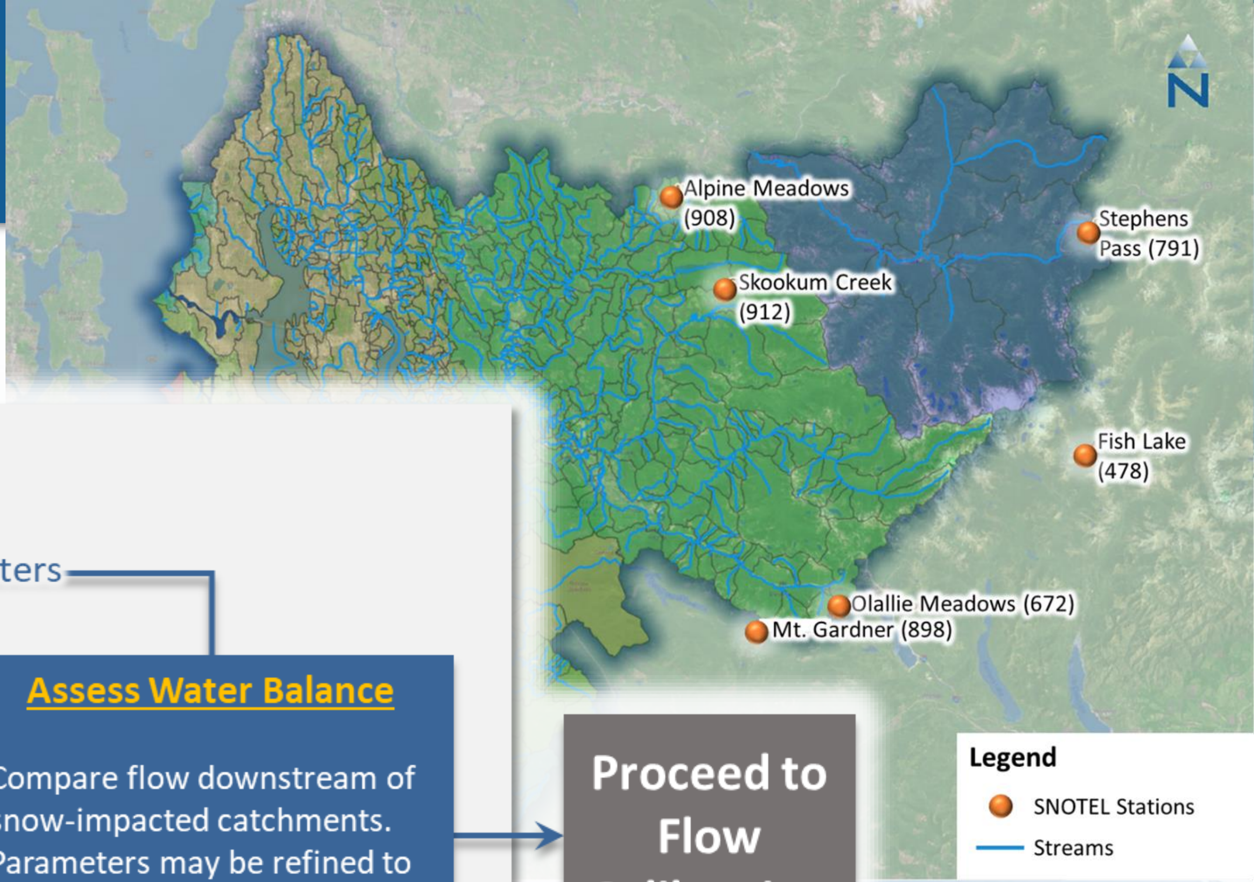
Hydrology Model
(Based on Stanford Watershed Model)
Model Input
Decision
Transfer
Storage
ET Loss
Output
Total Actual Evapotranspiration
TAET
Precipitation
PREC
CEPSC
Interception Storage
Snowpack Storage
Pervious
Impervious
Overland Flow
SLSUR
LSUR
NSUR
INFILT
INTFW
SURO
INFIL
PERC
Lower Zone Storage
Upper Zone Storage
Interflow
IRC
LZETP
LZSN
UZSN
GWI
IFWO
DEEPFR
Groundwater Storage
AGWRC
AGWETP
AGWO
Deep or Inactive Groundwater
Stream
BASETP
Order in which TAET demand is satisfied
2
3
5
4
1
"Edge-of-Stream" Components
SURO
Surface Runoff
IFWO
Interflow Outflow
AGWO
Active Groundwater Outflow

Model Calibration





Snow Calibration (as applicable)



Snow Calibration

Refine Parameters

Unit-Area Calibration

Simulate snowpack accumulation and melting for unit-area models. Calibrate snow parameters to match observed SNOTEL data.

Focus: Snow Telemetry (SNOTEL)

Basinwide Extrapolation

Extrapolate parameters to all catchments. ELDAT drives a lapse rate to adjust NLDAS temperature uniquely for each catchment.

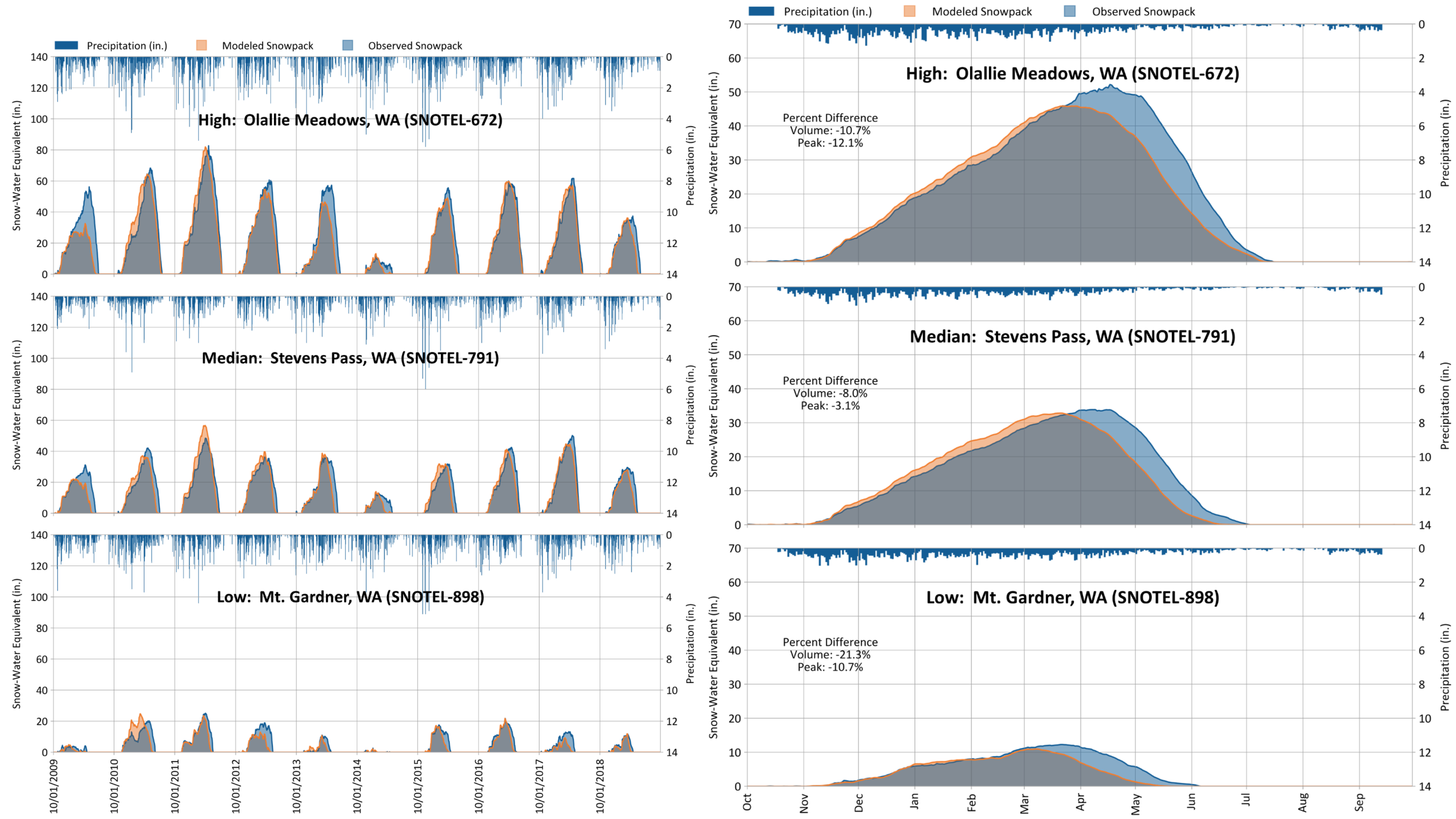
Focus: NLDAS/PRISM ELDAT MELEV

Assess Water Balance

Compare flow downstream of snow-impacted catchments. Parameters may be refined to improve water balance and overall model fit.

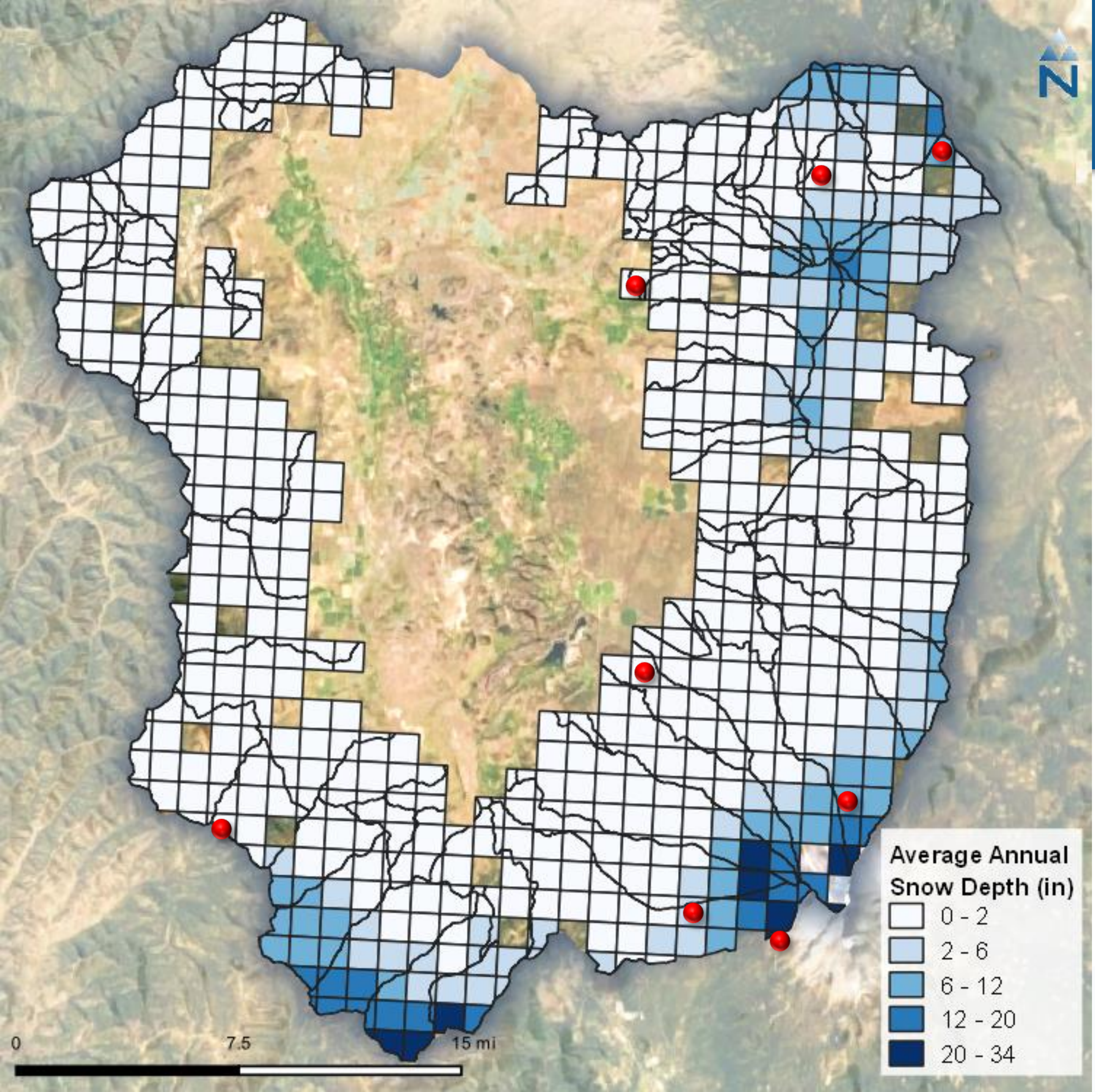
Focus: Downstream Flow Gages

Proceed to Flow Calibration

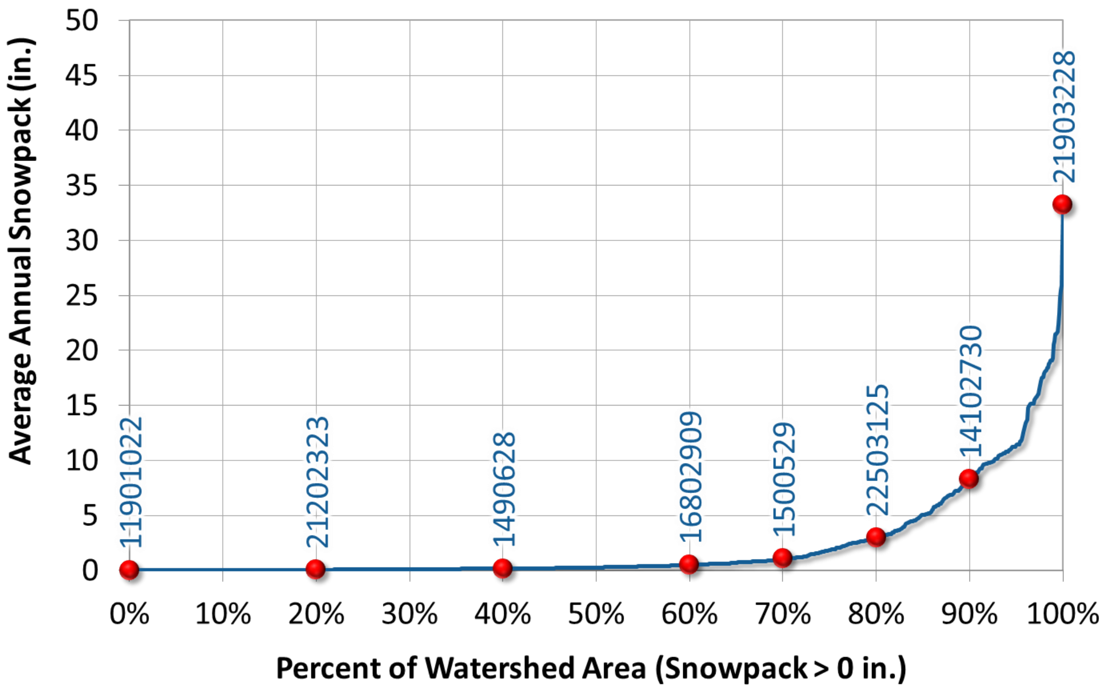


Precipitation (in.)
Modeled Snowpack
Observed Snowpack
High: Olallie Meadows, WA (SNOTEL-672)
Median: Stevens Pass, WA (SNOTEL-791)
Low: Mt. Gardner, WA (SNOTEL-898)
Snow-Water Equivalent (in.)
Precipitation (in.)
10/01/2009
10/01/2010
10/01/2011
10/01/2012
10/01/2013
10/01/2014
10/01/2015
10/01/2016
10/01/2017
10/01/2018
Percent Difference
Volume: -10.7%
Peak: -12.1%
Percent Difference
Volume: -8.0%
Peak: -3.1%
Percent Difference
Volume: -21.3%
Peak: -10.7%
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

Spatial Validation

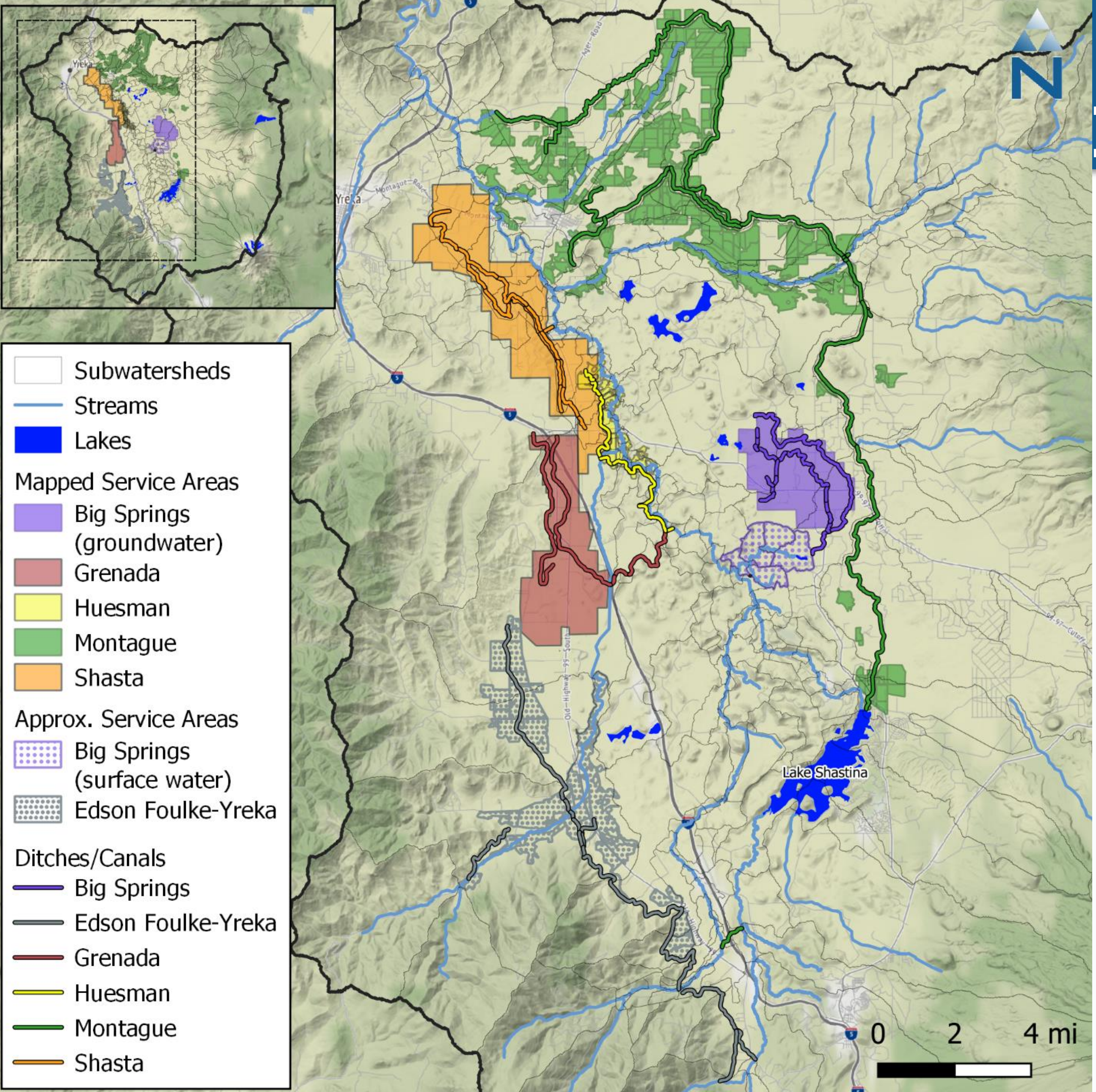


- UCSB Snow Model



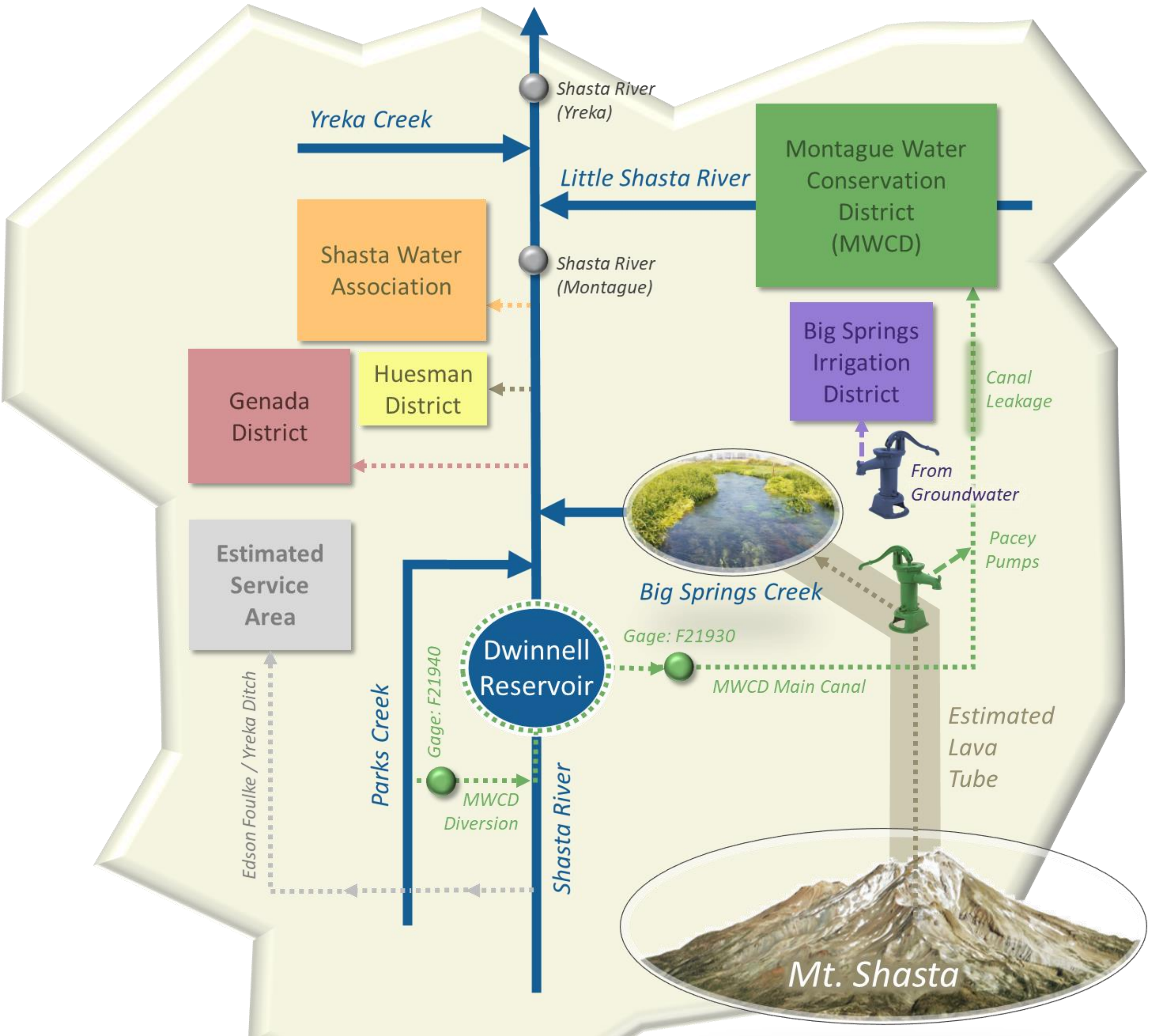
● Selected Locations

Irrigation Districts



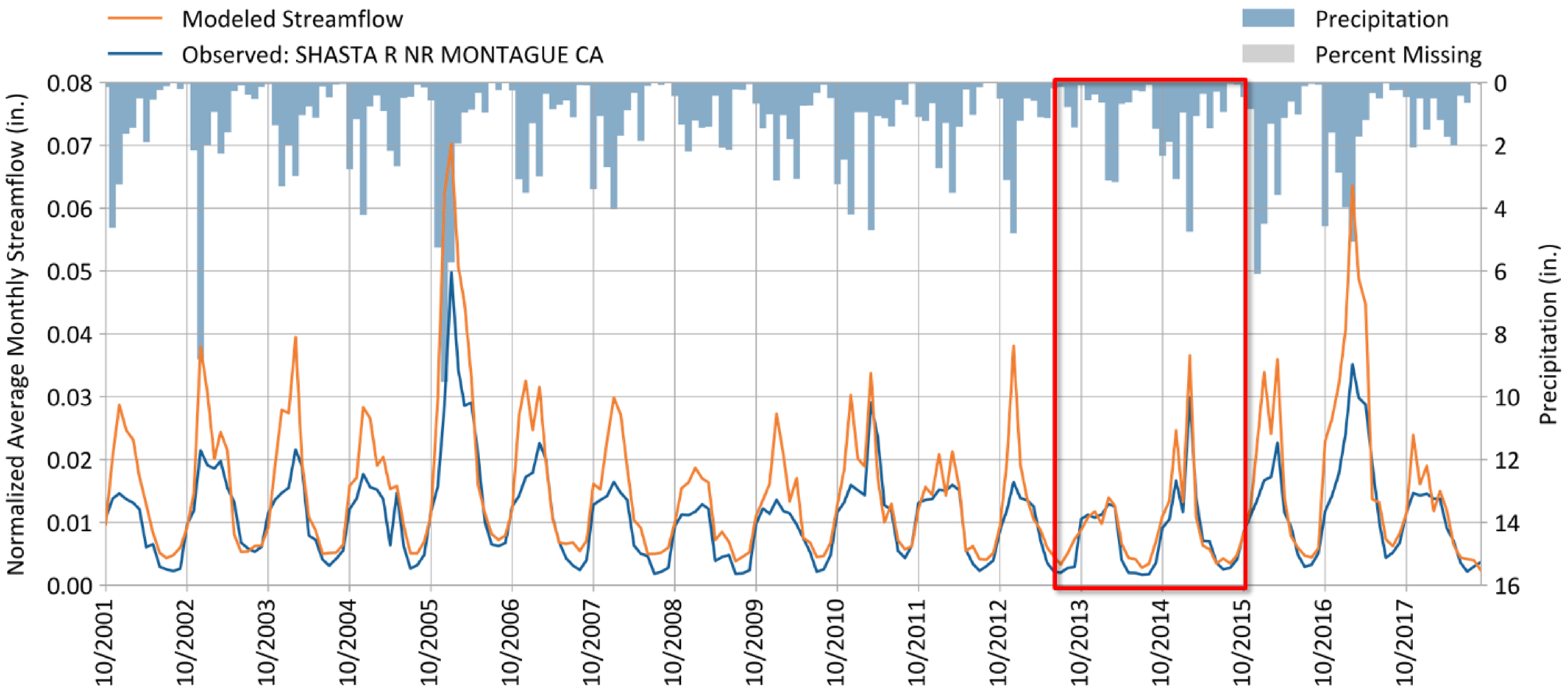
- Service Areas, Ditches, Canals
  - Big Springs
  - Grenada
  - Heusman
  - Montague
  - Shasta
  - Edson Foulke/Yreka Ditch
- Lakes and streams
- Points of diversion

Irrigation Districts



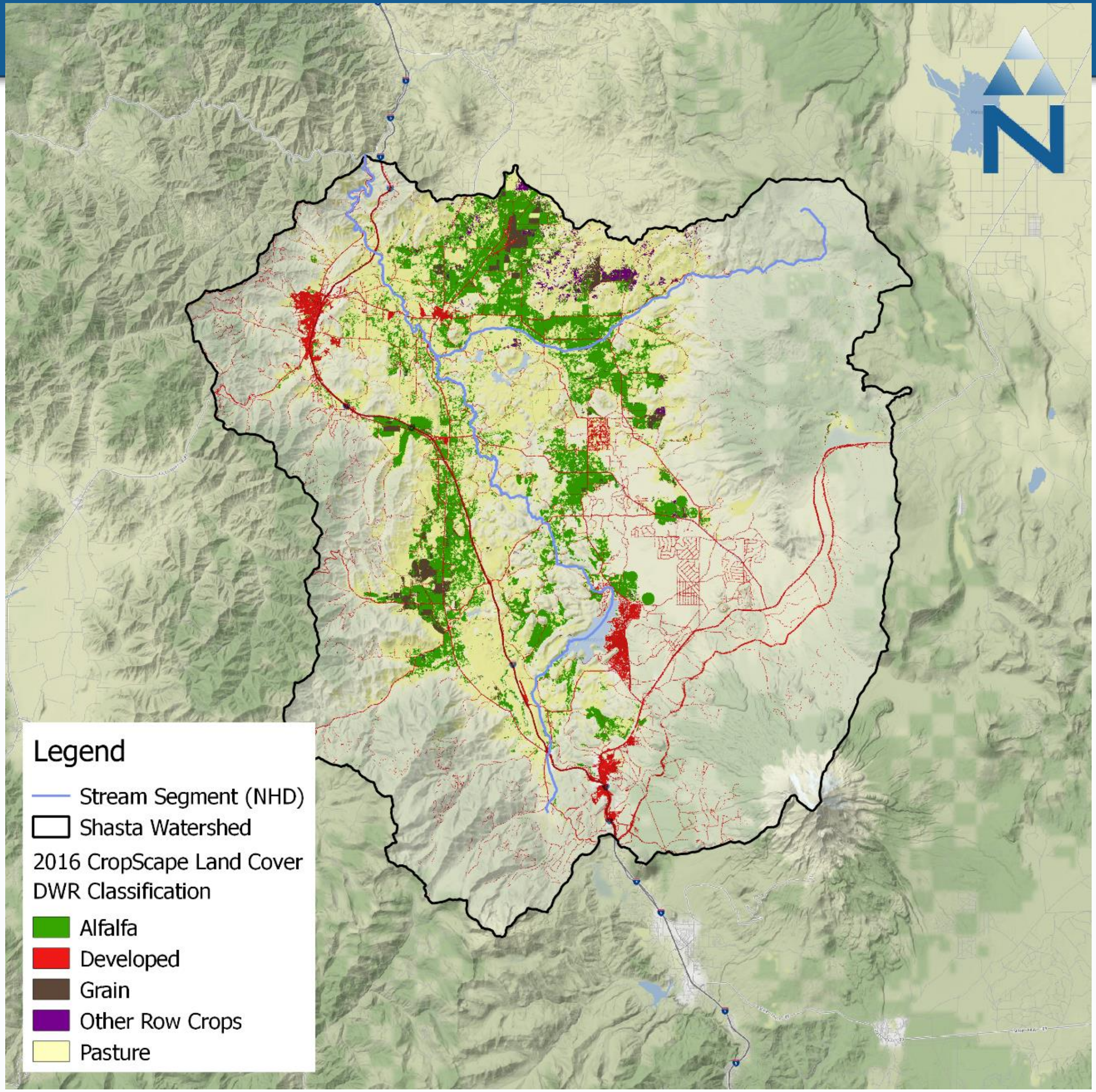
Schematic shows **major** water features and consumptive uses. All other withdrawals, diversions, and return flows occur at the place of use.

- Service Areas, Ditches, Canals
  - Big Springs
  - Grenada
  - Heusman
  - Montague
  - Shasta
  - Edson Foulke/Yreka Ditch
- Lakes and streams
- Points of diversion

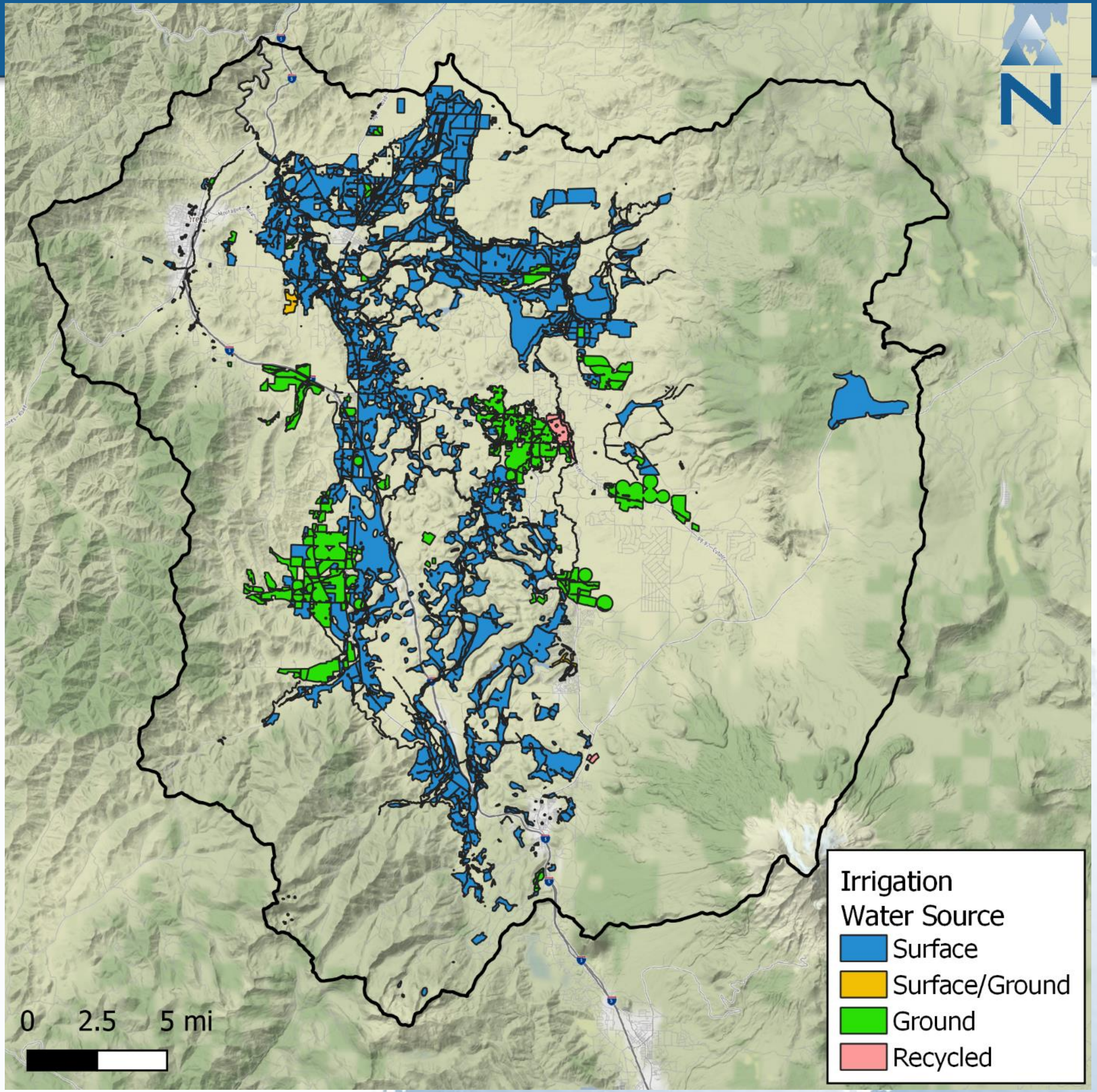


Modeled vs. Observed Streamflow at Montague, CA ***Before*** Linkage to MODFLOW

Grazing, Pasture, Crops

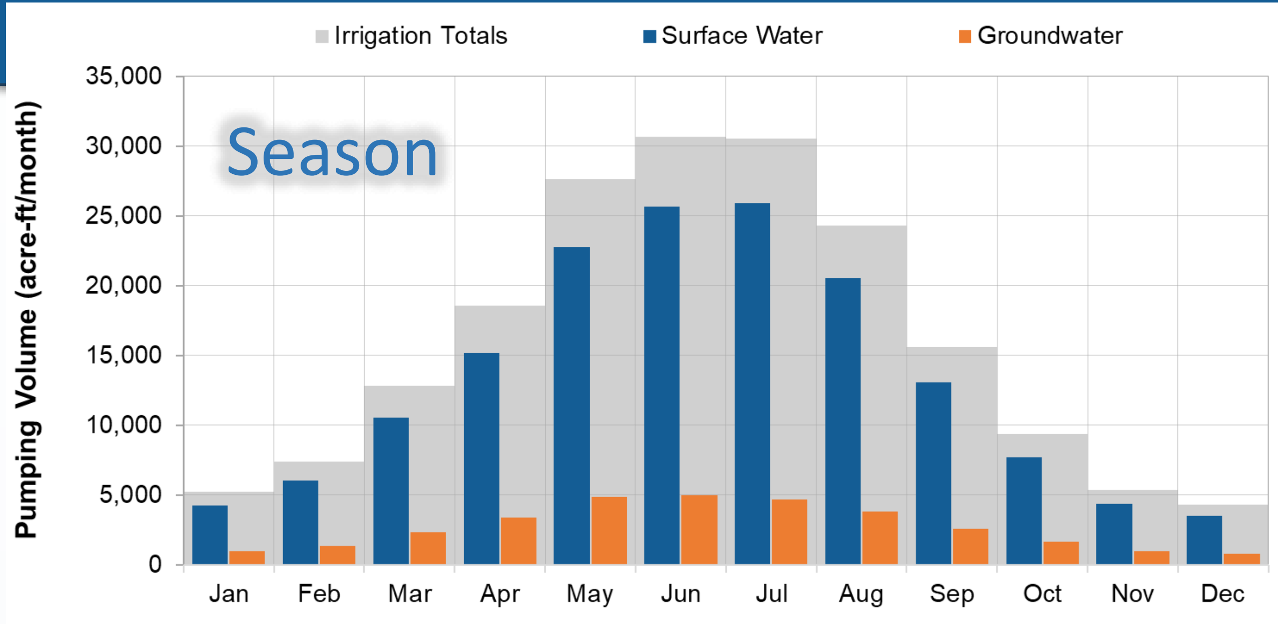


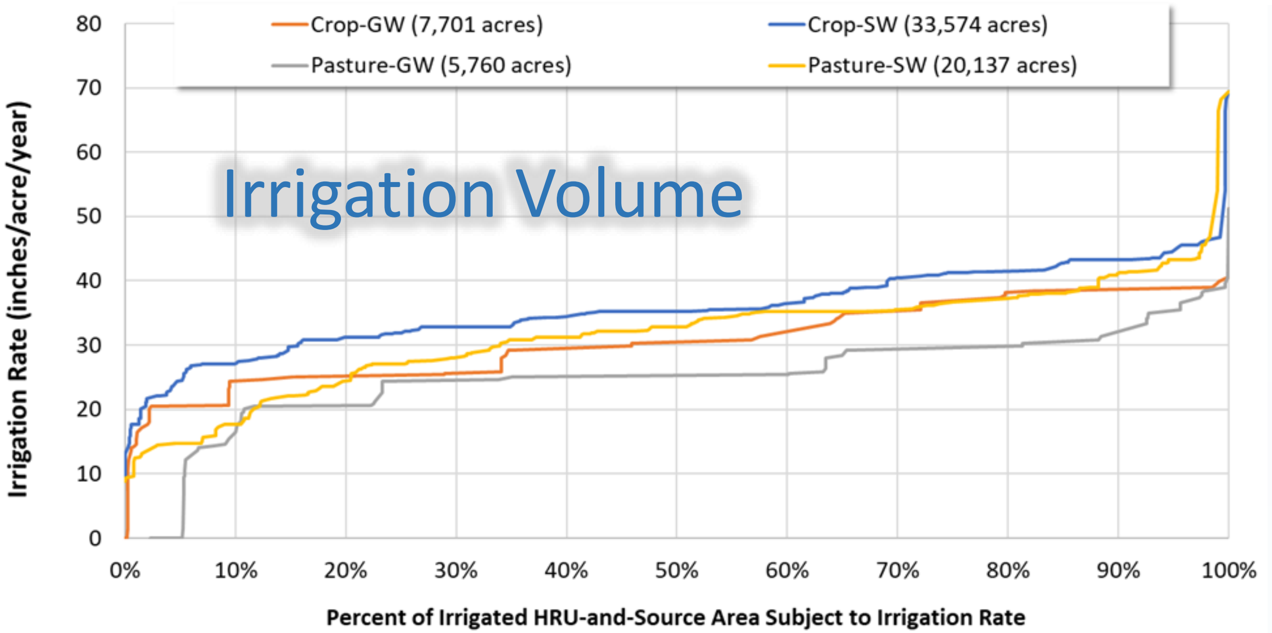
Irrigation Area/Water Source

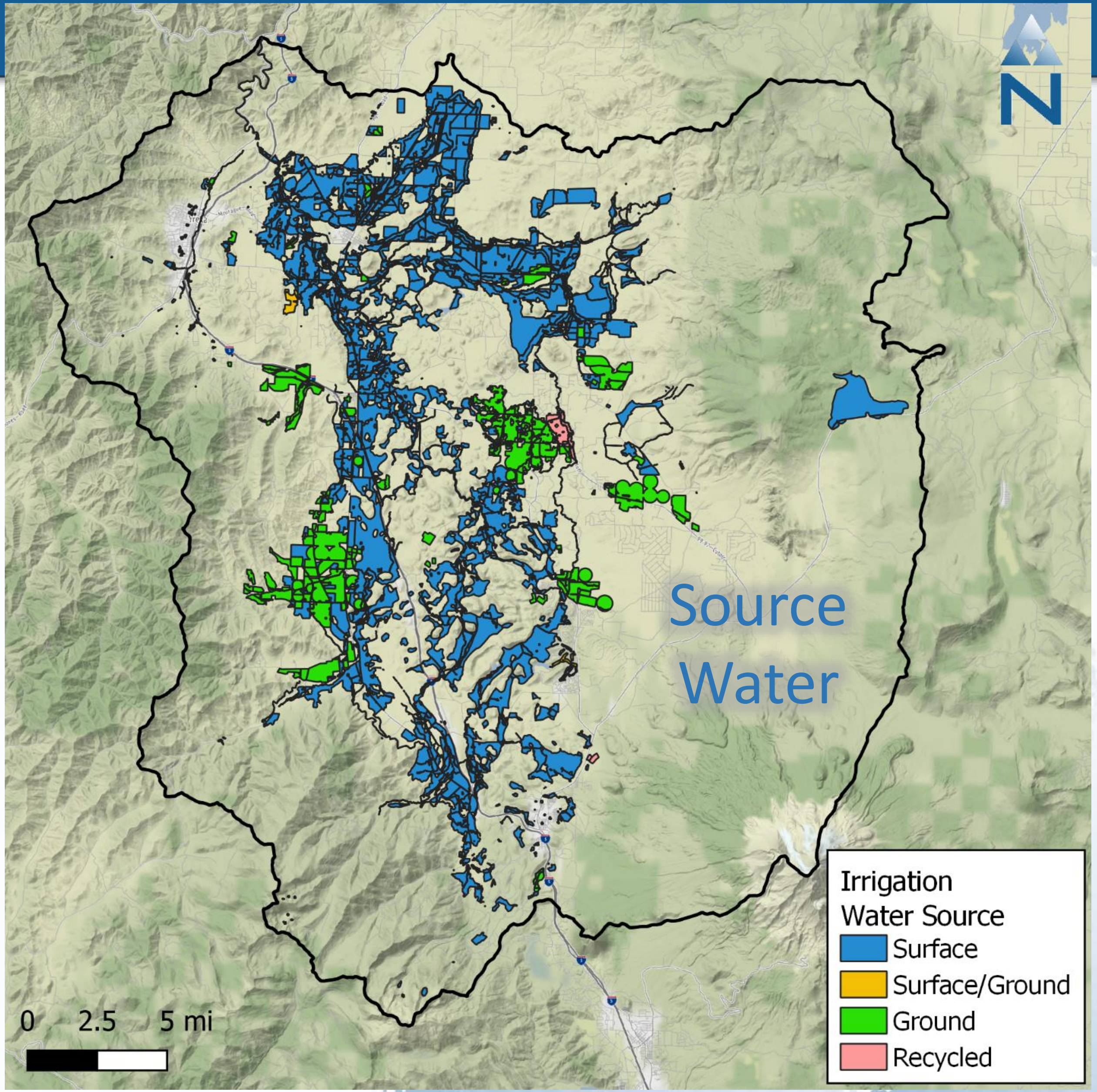


Spatiotemporal Variation

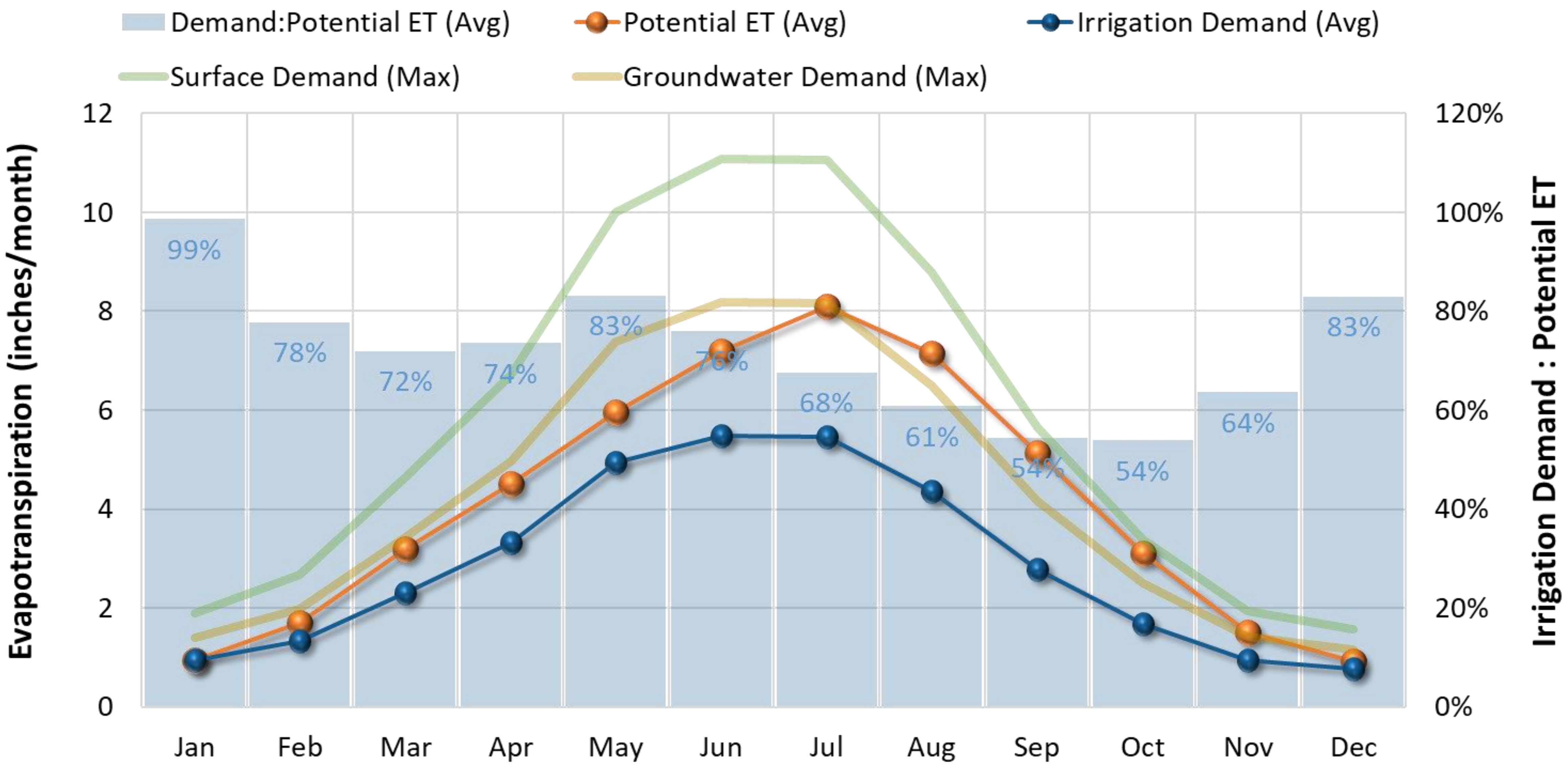
Irrigation Area/Water Source

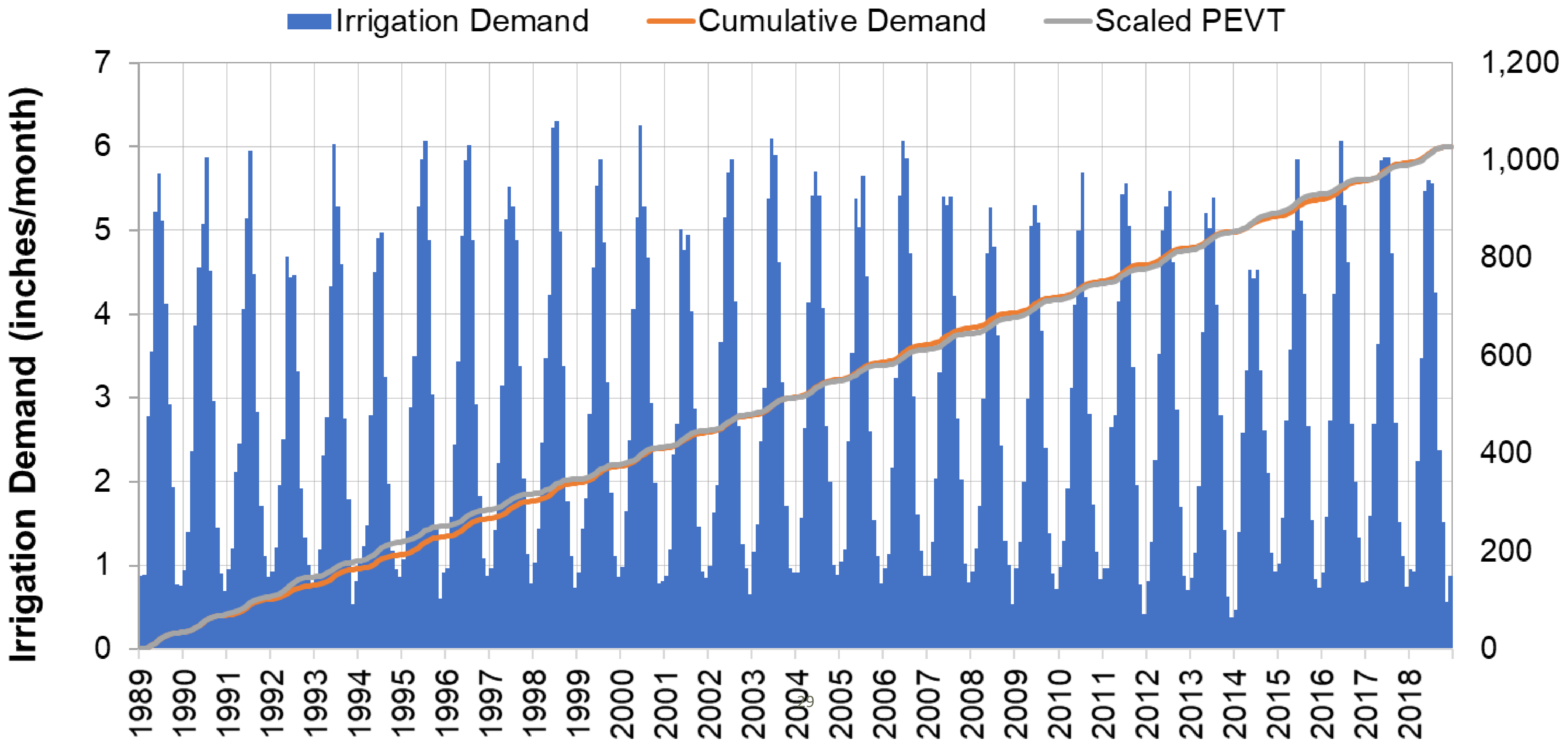






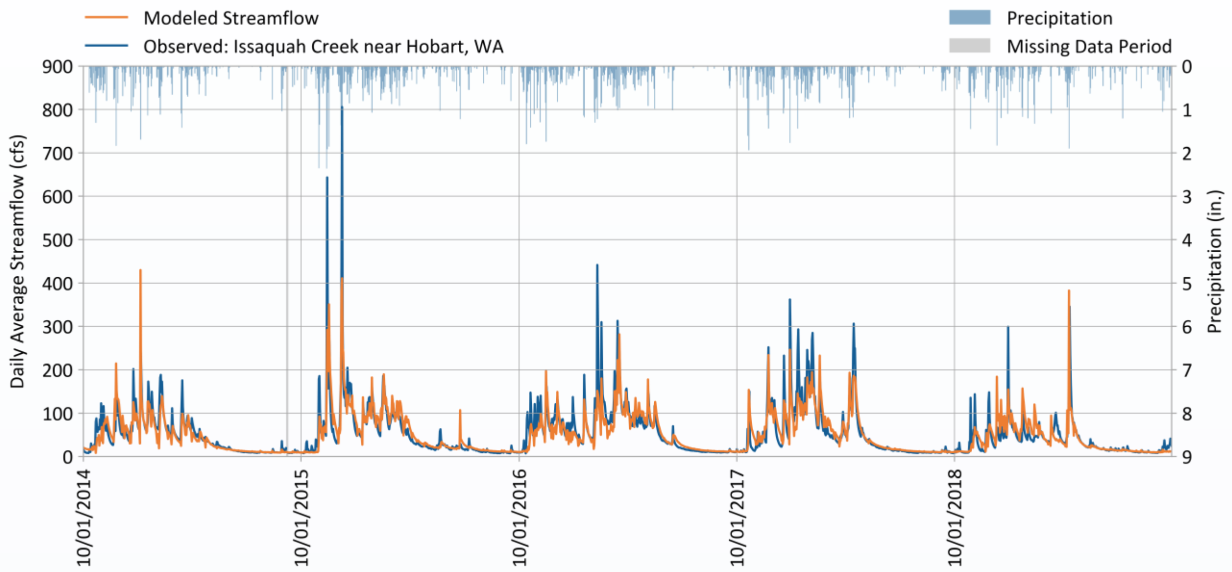
1. Find maximum demand per acre by source type
2. Vary irrigated/non-irrigated acres to match demand by subwatershed



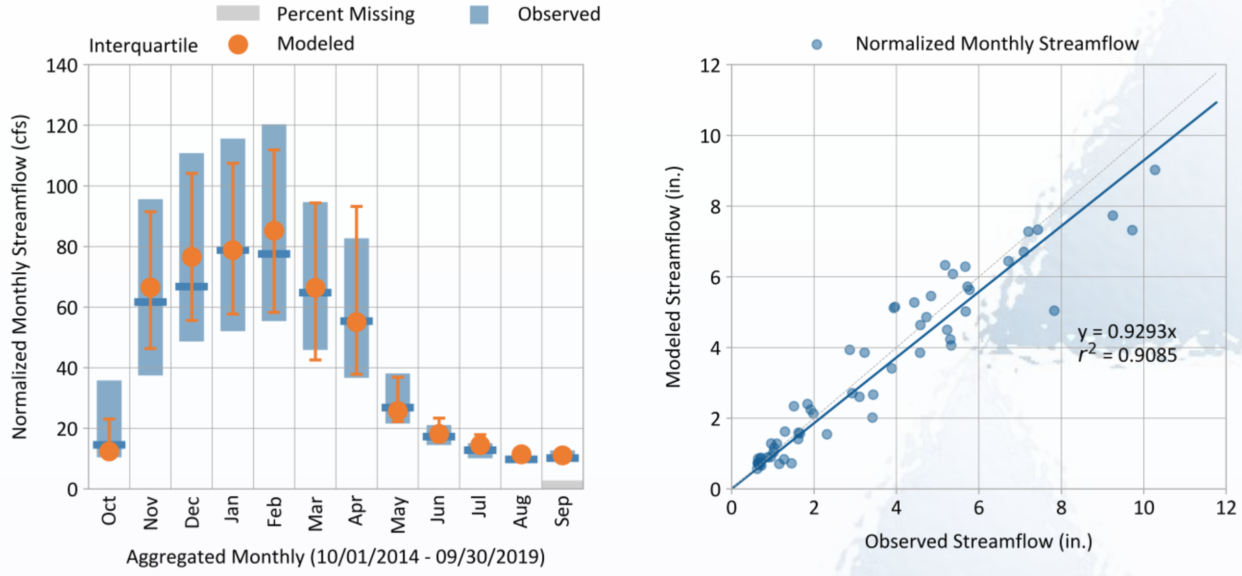


Irrigation Demand
Cumulative Demand
Scaled PEVT
Irrigation Demand (inches/month)
Cumulative Demand (inches)
0
1
2
3
4
5
6
7
0
200
400
600
800
1,000
1,200
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

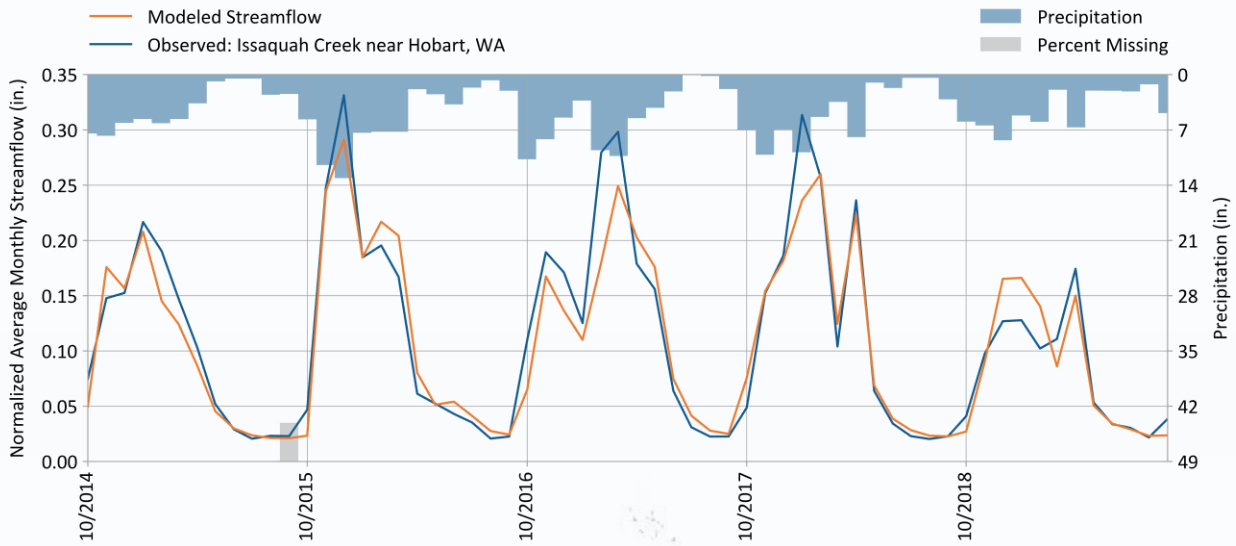
Daily Average



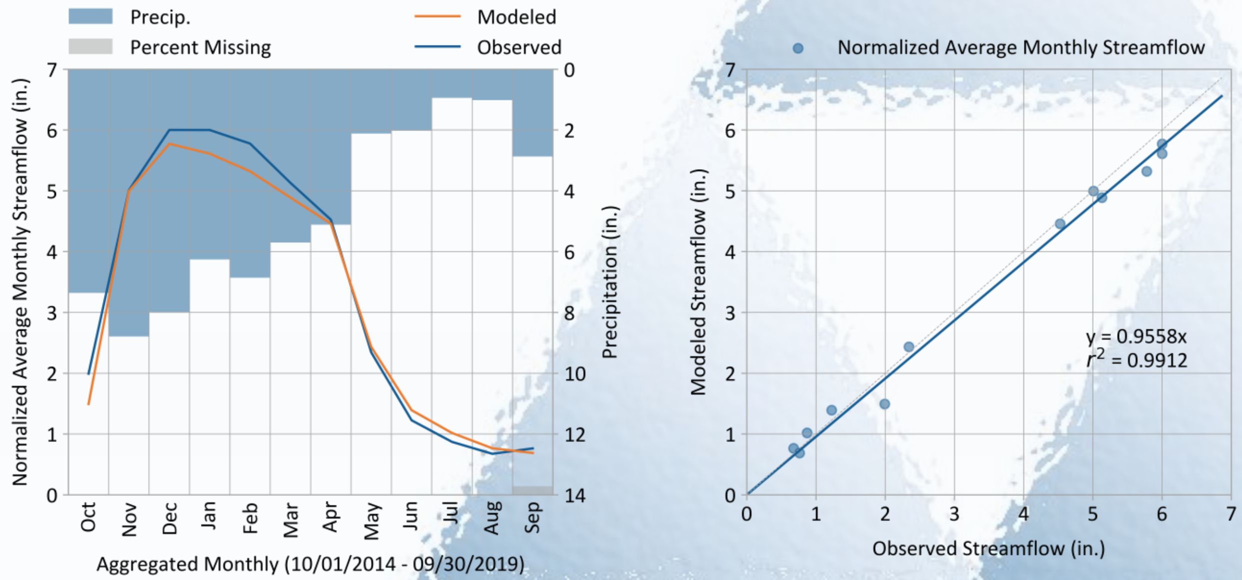
Monthly Interquartile Variability



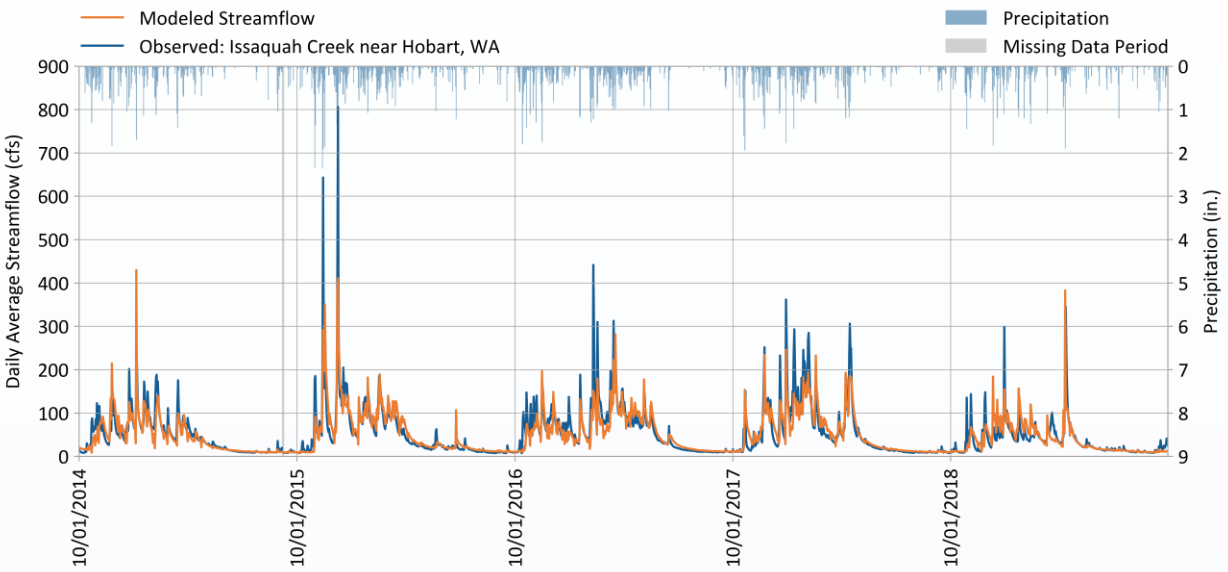
Monthly Average



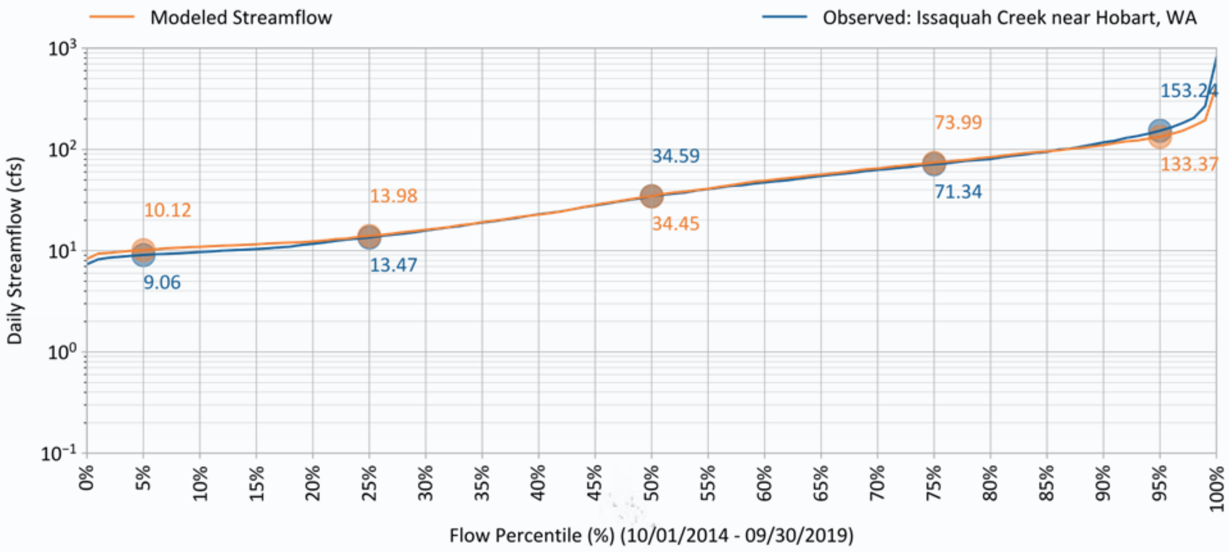
Annualized Monthly



Daily Average



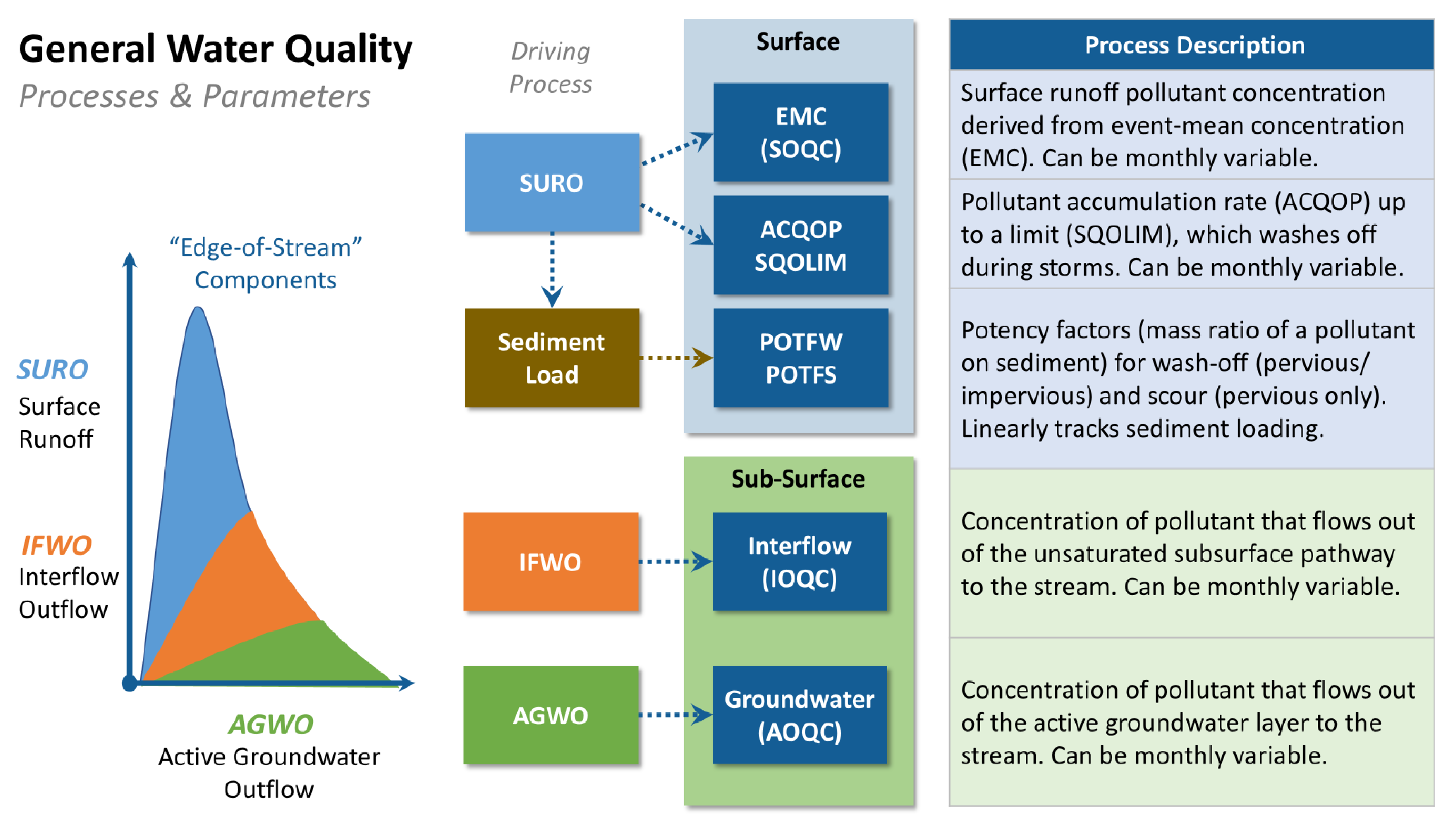
Flow Duration

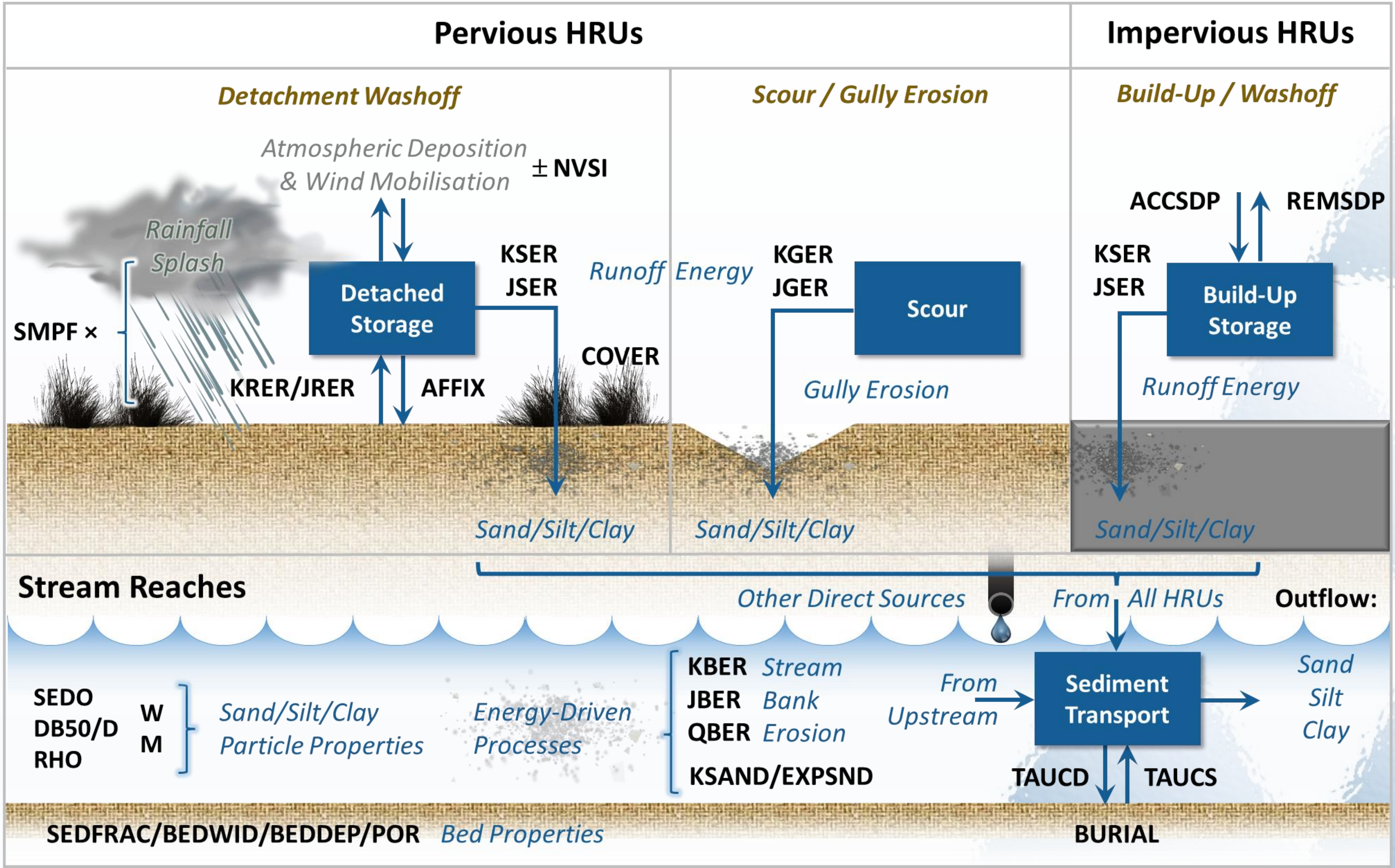


Calibration Statistics

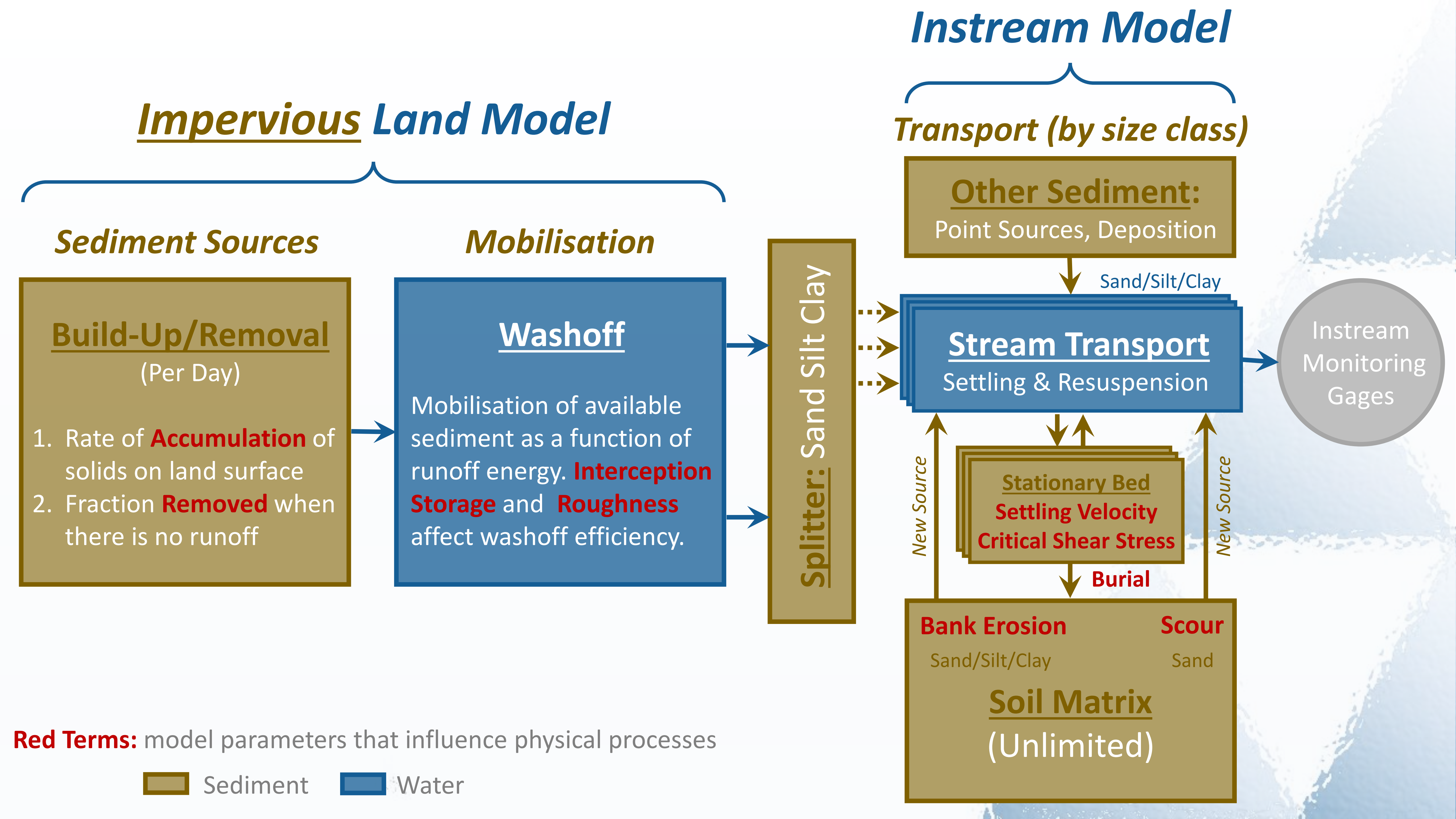
Calibration Metrics: 10/01/2014 - 09/30/2019		All Seasons	Winter	Spring	Summer	Fall
PBIAS	All Conditions	3.7%	6.4%	-2.4%	-7.0%	5.7%
	Highest 10% of Daily Flow Rates	22.4%	21.7%	19.0%	N/A	24.4%
	Lowest 50% of Daily Flow Rates	-14.7%	-18.2%	-9.6%	-9.1%	-36.3%
	Days Categorized as Storm Flow	20.4%	20.3%	8.4%	6.4%	26.9%
	Days Categorized as Baseflow	-8.8%	-3.3%	-7.7%	-14.1%	-17.3%
r-Squared		0.76	0.61	0.78	0.23	0.69
Nash Sutcliffe Efficiency (E)		0.75	0.6	0.78	0.12	0.68

Qualitative assessment (see Table 2-5 for criteria): Very Good | Good | Fair | Poor

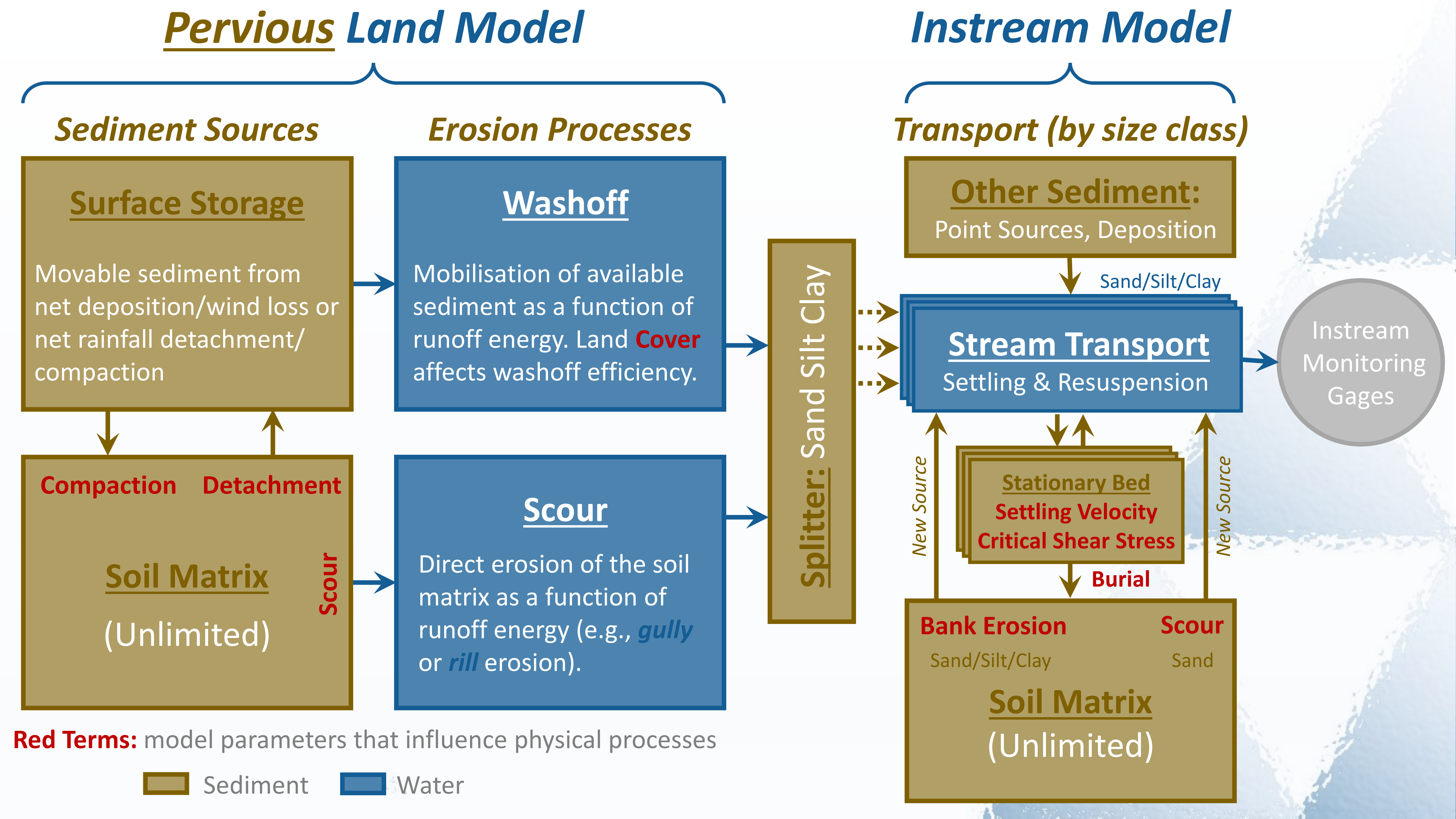

General Water Quality
Processes & Parameters
Driving Process
Surface
Sub-Surface
"Edge-of-Stream" Components
SURO
Surface Runoff
IFWO
Interflow Outflow
AGWO
Active Groundwater Outflow
SURO
Sediment Load
IFWO
AGWO
EMC (SOQC)
ACQOP SQOLIM
POTFW POTFS
Interflow (IOQC)
Groundwater (AOQC)
Process Description
Surface runoff pollutant concentration derived from event-mean concentration (EMC). Can be monthly variable.
Pollutant accumulation rate (ACQOP) up to a limit (SQOLIM), which washes off during storms. Can be monthly variable.
Potency factors (mass ratio of a pollutant on sediment) for wash-off (pervious/ impervious) and scour (pervious only). Linearly tracks sediment loading.
Concentration of pollutant that flows out of the unsaturated subsurface pathway to the stream. Can be monthly variable.
Concentration of pollutant that flows out of the active groundwater layer to the stream. Can be monthly variable.



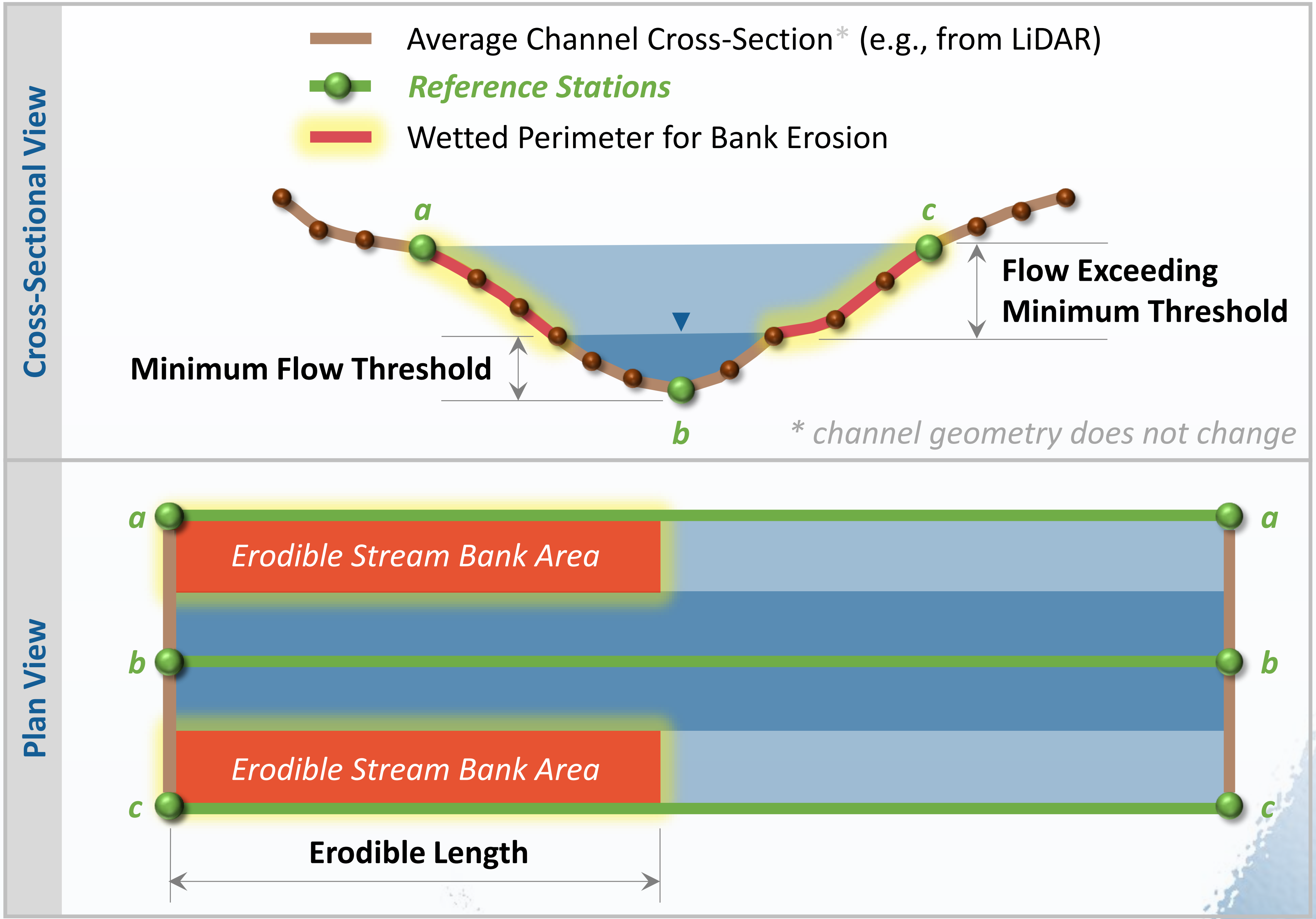
Pervious HRUs
Impervious HRUs
Detachment Washoff
Scour / Gully Erosion
Build-Up / Washoff
Atmospheric Deposition
& Wind Mobilisation
± NVSI
Rainfall
Splash
SMPF ×
Detached Storage
KSER
JSER
Runoff Energy
KRER/JRER
AFFIX
COVER
Sand/Silt/Clay
KGER
JGER
Scour
Gully Erosion
Sand/Silt/Clay
ACCSDP
REMSDP
KSER
JSER
Build-Up Storage
Runoff Energy
Sand/Silt/Clay
Stream Reaches
Other Direct Sources
From All HRUs
Outflow:
SEDO
DB50/D
RHO
W
M
Sand/Silt/Clay
Particle Properties
Energy-Driven
Processes
KBER Stream
JBER Bank
QBER Erosion
KSAND/EXPSND
From
Upstream
Sediment Transport
Sand
Silt
Clay
TAUCD
TAUCS
SEDFRAC/BEDWID/BEDDEP/POR Bed Properties
BURIAL



Instream Model
Transport (by size class)
Impervious Land Model
Sediment Sources
Mobilisation
Build-Up/Removal
(Per Day)
1. Rate of Accumulation of solids on land surface
2. Fraction Removed when there is no runoff
Washoff
Mobilisation of available sediment as a function of runoff energy. Interception Storage and Roughness affect washoff efficiency.
Splitter: Sand Silt Clay
Other Sediment:
Point Sources, Deposition
Sand/Silt/Clay
Stream Transport
Settling & Resuspension
Instream Monitoring Gages
Stationary Bed
Settling Velocity
Critical Shear Stress
New Source
New Source
Burial
Bank Erosion
Sand/Silt/Clay
Scour
Sand
Soil Matrix
(Unlimited)
Red Terms: model parameters that influence physical processes
Sediment
Water


Pervious Land Model
Instream Model
Sediment Sources
Erosion Processes
Transport (by size class)
Surface Storage
Movable sediment from net deposition/wind loss or net rainfall detachment/ compaction
Washoff
Mobilisation of available sediment as a function of runoff energy. Land Cover affects washoff efficiency.
Splitter: Sand Silt Clay
Other Sediment:
Point Sources, Deposition
Sand/Silt/Clay
Stream Transport
Settling & Resuspension
Instream Monitoring Gages
Compaction
Detachment
Soil Matrix
(Unlimited)
Scour
Scour
Direct erosion of the soil matrix as a function of runoff energy (e.g., gully or rill erosion).
New Source
Stationary Bed
Settling Velocity
Critical Shear Stress
New Source
Burial
Bank Erosion
Scour
Sand/Silt/Clay
Sand
Soil Matrix
(Unlimited)
Red Terms: model parameters that influence physical processes
Sediment
Water

LSPC Bank Erosion Module (Erodible Area)



Initial Parameter Values:

Minimum Flow Threshold = 0

Erodible Length = Full Reach Length

Erodible Stream Bank Area = Wetted Perimeter × Length

LSPC Bank Erosion Module (Specific Yield)

HSPF/LSPC Scour (Gully/Rill)

$$SCRSD = DELT60 \times KGER \times \left(\frac{SURO}{DELT60}\right)^{JGER}$$

$SCRSD$ = Scour Sediment Yield [Mass/Area/Time]
$SURO$ = Surface Runoff Outflow [Vol/Time]
$DELT60$ = Hours per Timestep [unitless]
$KGER$ = Coefficient, Matrix Soil Scour [unitless]
$JGER$ = Exponent, Matrix Soil Scour [unitless]

Homogeneous: driven by unit-area runoff

Bank Erosion Module

$$BERSD = DELT60 \times KBER \times \left(\frac{UARO}{DELT60}\right)^{JBER}$$

$$UARO = \frac{Cumulative\ Flow}{Cumulative\ Drainage\ Area}$$

$BERSD$ = Bank Erosion Sediment Yield [Mass/Area/Time]
$UARO$ = Unit-Area Runoff Outflow [unitless]
$KBER$ = Coefficient, Matrix Soil Scour [unitless]
$JBER$ = Exponent, Matrix Soil Scour [unitless]

UARO captures the cumulative impact of upstream drainage area characteristics

Homogeneous: driven by normalized flow only

Critical Conditions and Management Scenarios

Integrated Modeling Approach

Weather Data

Ensure quantity + quality of spatial/temporal coverage of forcing data to drive watershed hydrology.

Land Hydrology

Represent evaporation losses, runoff, interflow, and groundwater inflow from land—simulated on an *hourly* basis.

Stream Routing

Route land-based flows, net groundwater flows. Represent surface withdrawals, diversions and hydromodifications.

Compare: Instream Flow Gages

Compare: Weather Patterns

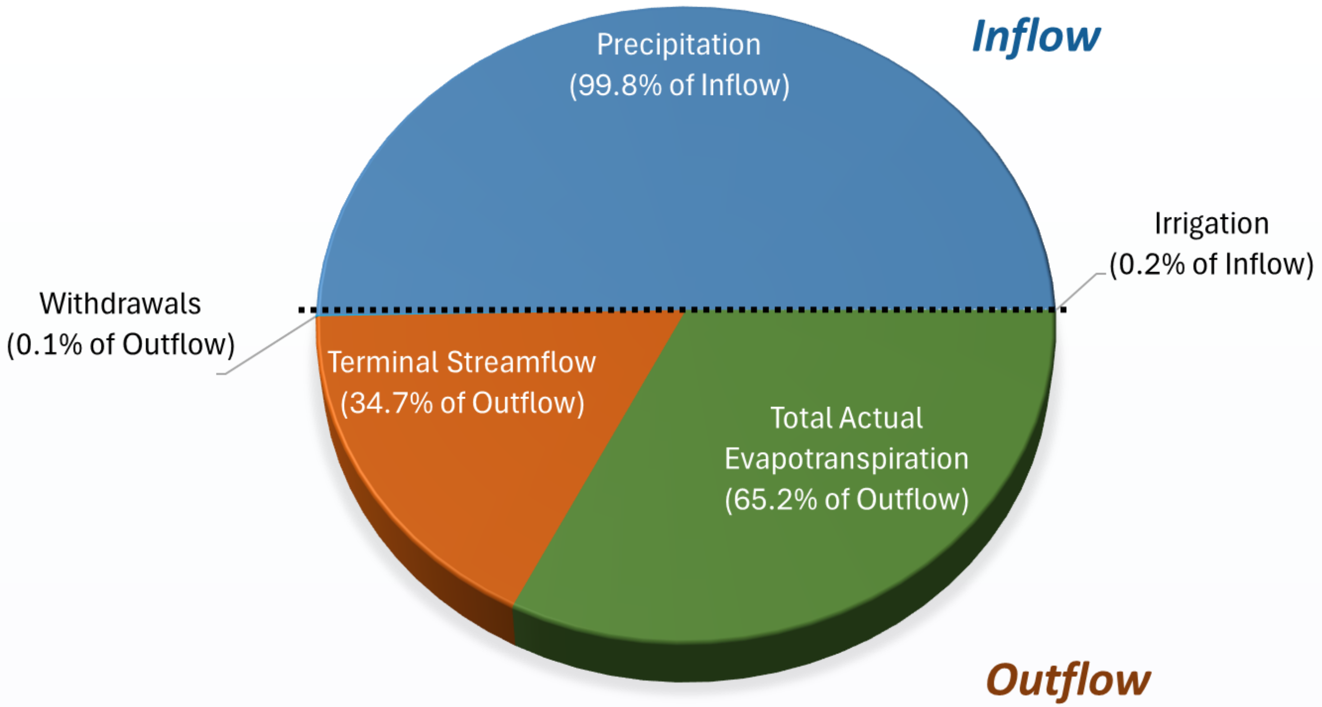
Groundwater Model

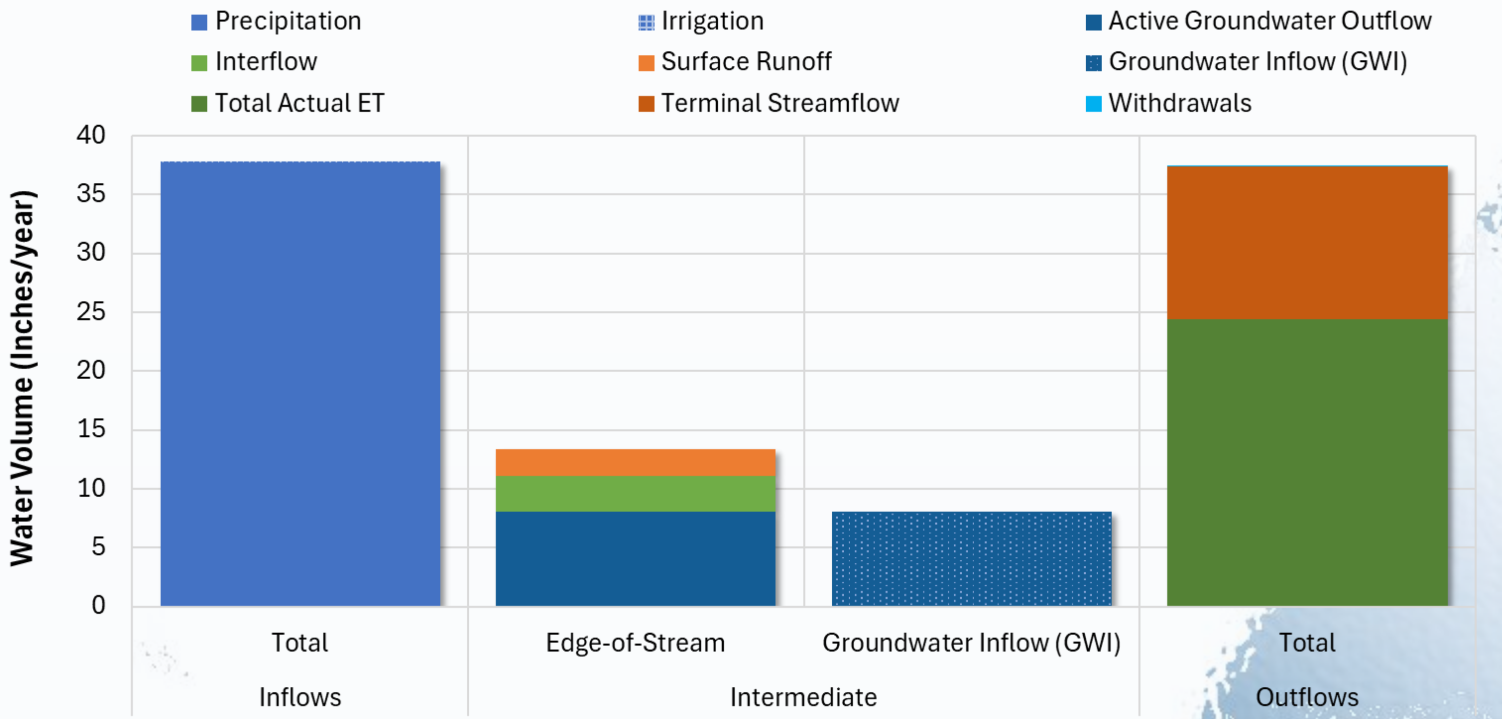
Receives groundwater inflows (aggregated to *monthly*). Incorporates consumptive groundwater pumping and transpiration losses. Outputs downscaled to *hourly*.

Compare: Groundwater Levels

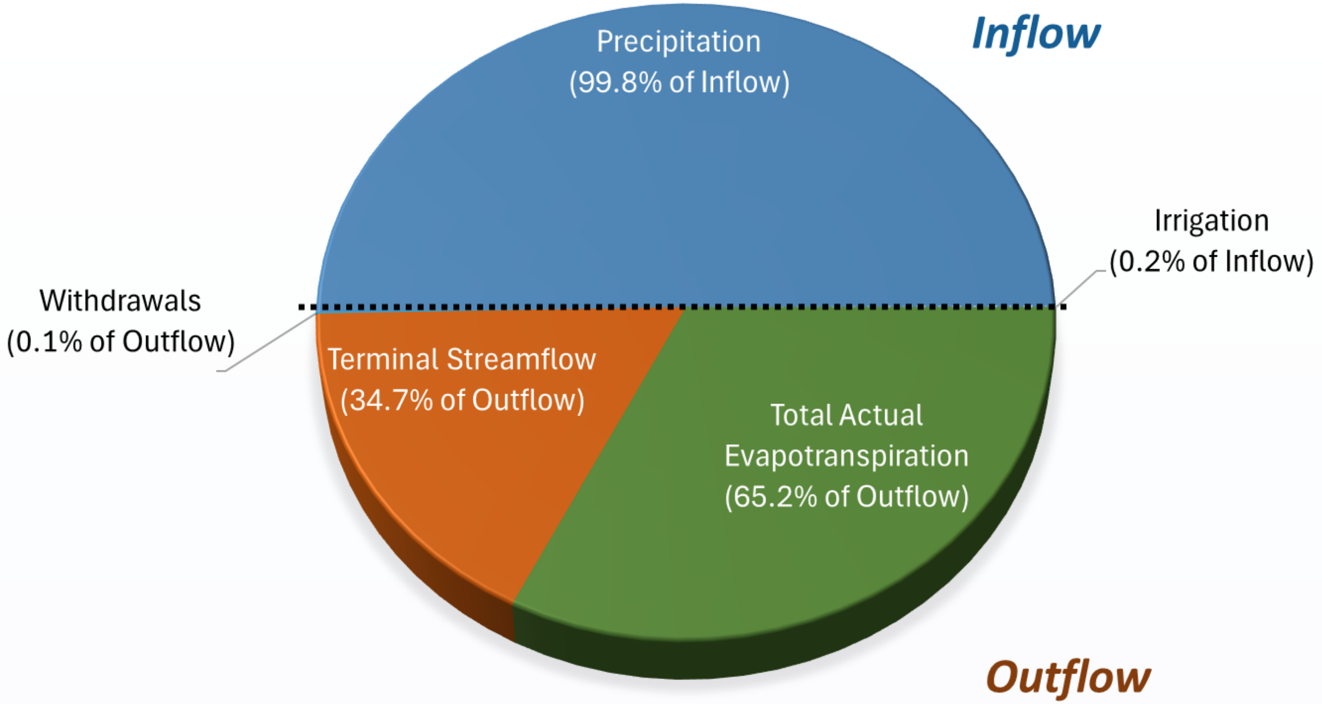
Calibration Objective: *Minimize Residual*

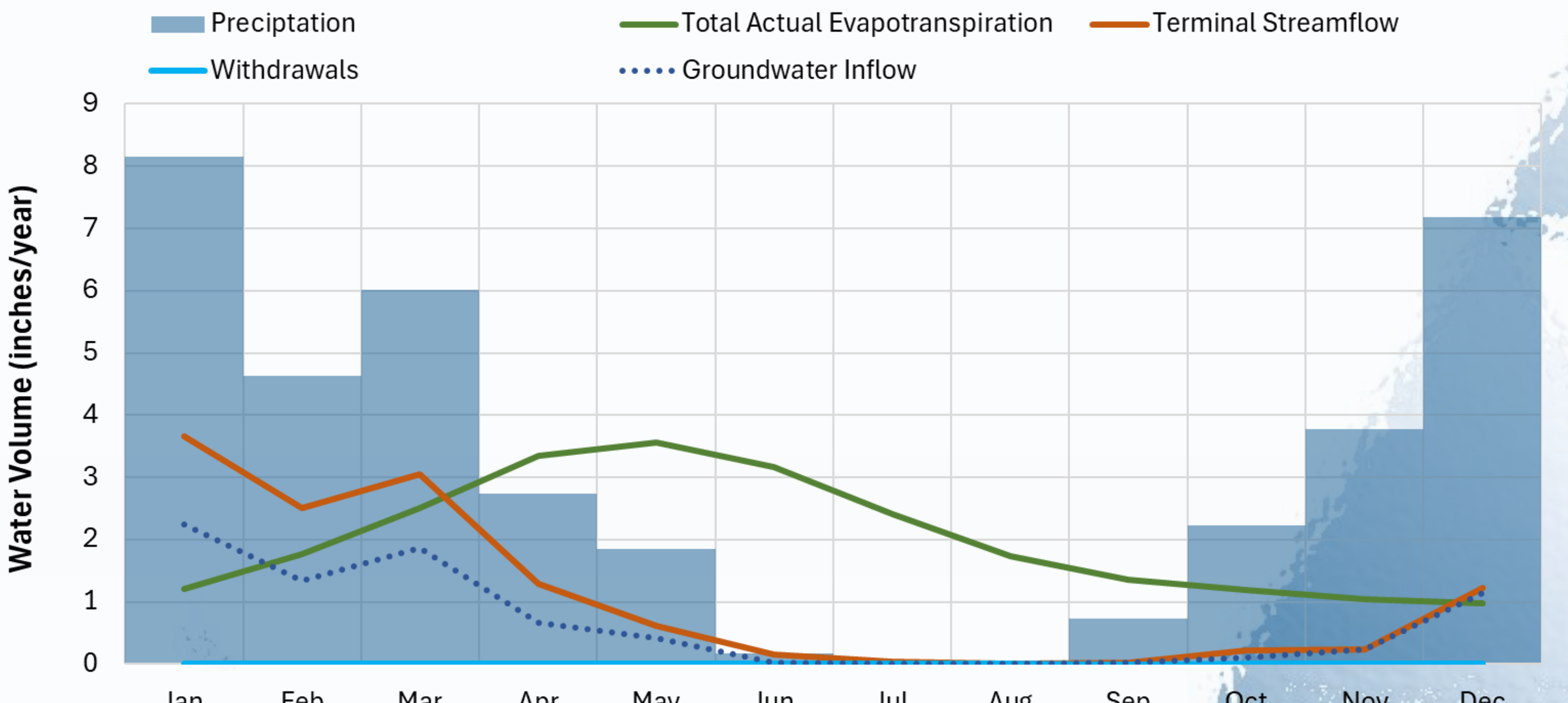
Water Budget Summaries



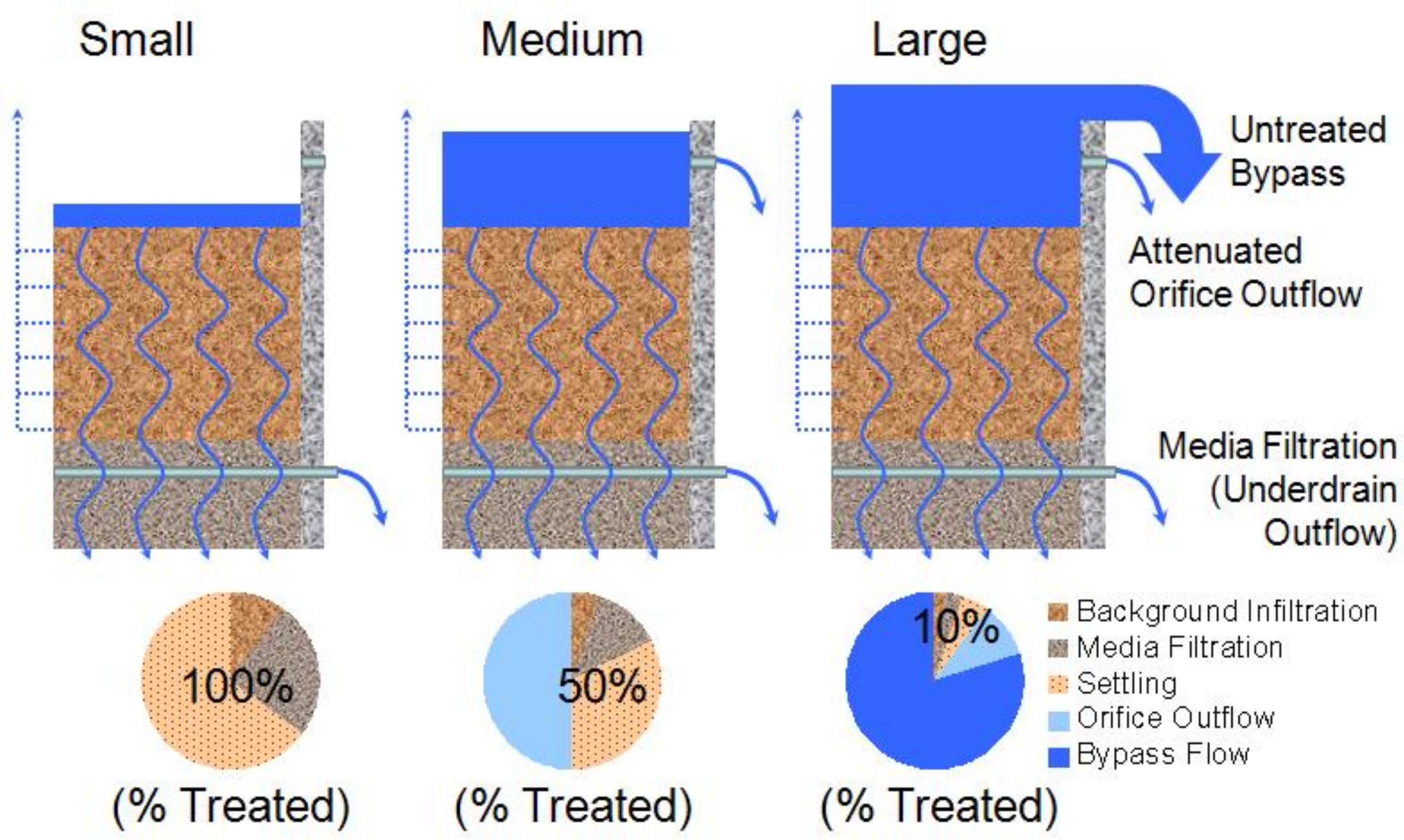


Water Budget Summaries





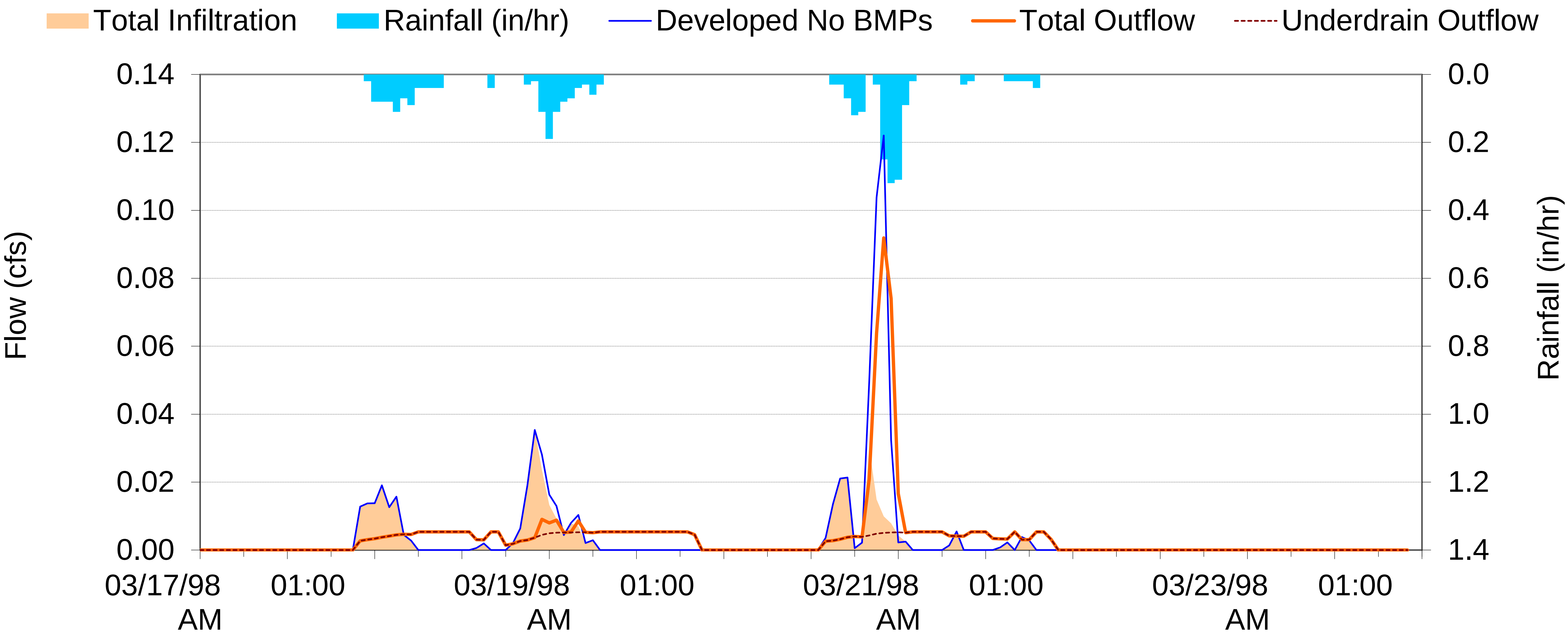
Why Continuous Simulation?



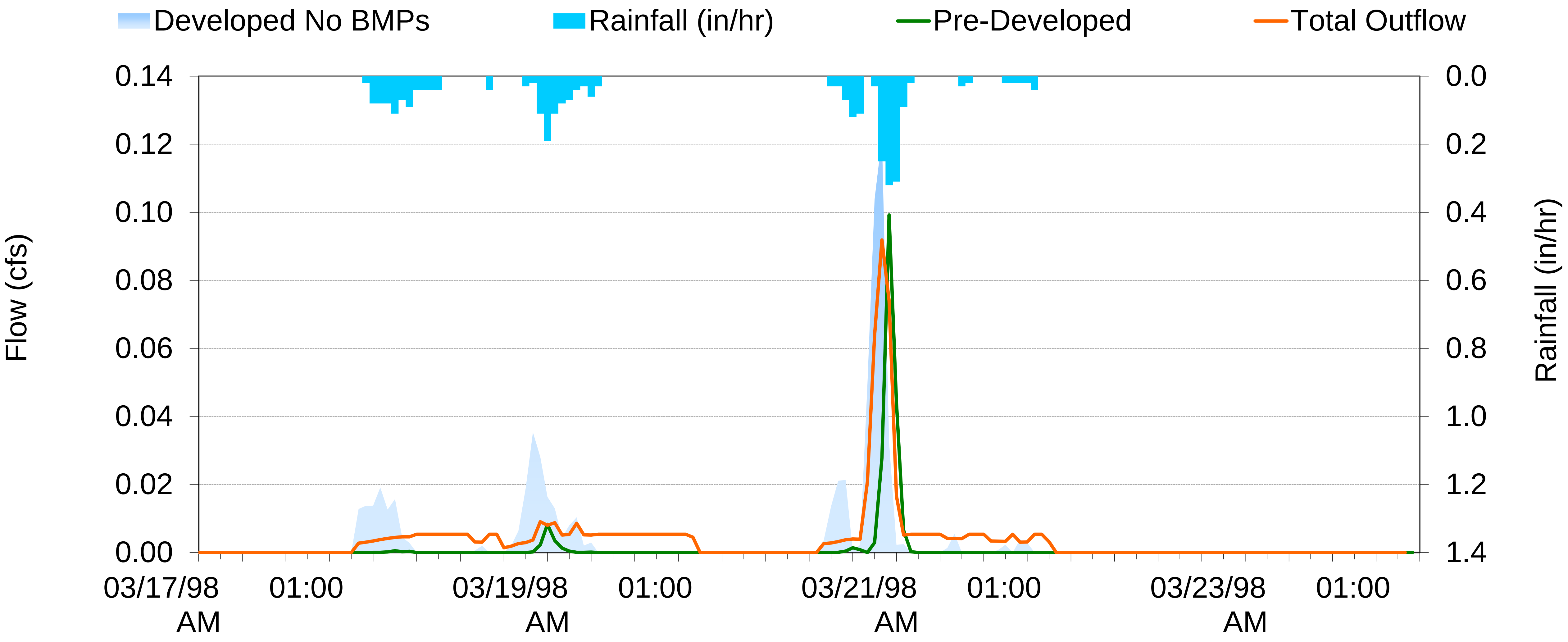
+

Comprehensive Analysis in Stormwater BMP/LID/GI Dynamics

Why Continuous Simulation?



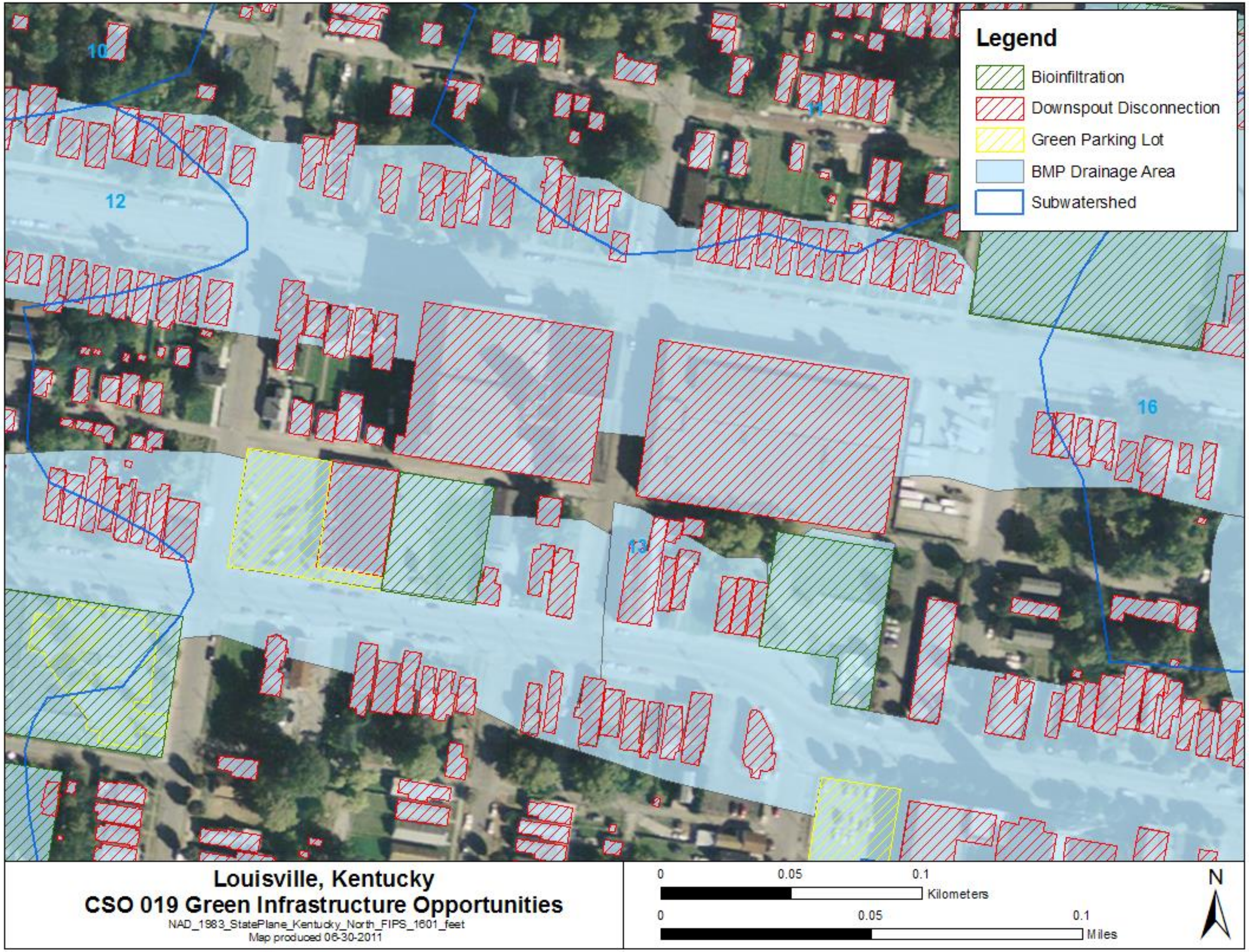
Why Continuous Simulation?



Opportunity Constraints

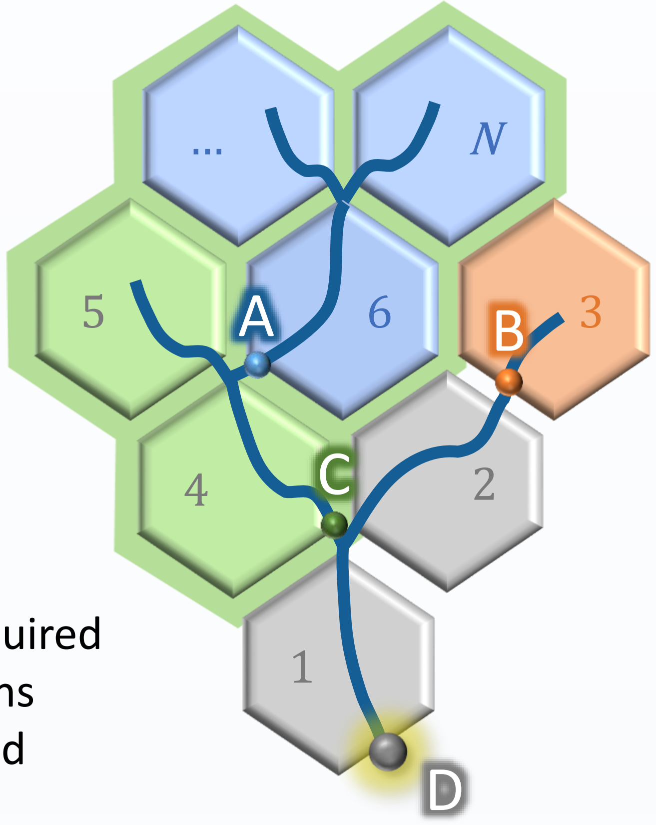
Not all area can be treated

- Where are drainage boundaries?
- How much area can be managed?
- Screening analysis is an important part of the process



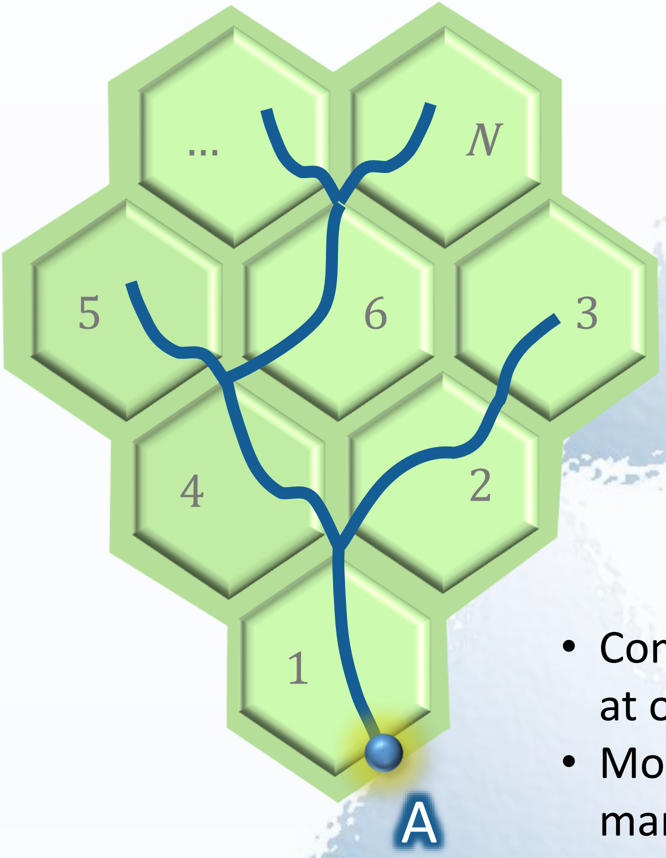
Assessment Points

Evaluate Compliance at Intermediate Outlets



- Compliance required at more locations
- More distributed management
- Higher cost

Evaluate Compliance at Downstream Outlet



- Compliance required at one location
- More targeted management
- Lower cost

BMP Menu and Parameterization

	Design Type
Distributed	Bioretention/biofiltration
	Porous Pavement
	Cistern/Rain Barrel
	Infiltration Well
	Diversion to Sewer
	Treatment Unit[1]
Regional	Infiltration Facility
	Treatment Facility, Filtration
	Treatment Facility, Sewer Diversion
	Treatment Facility, Retention/Detention
	Treatment Facility, Constructed Wetland

	Parameter	Value
	Ponding Height	12 inches[1,2]
Soil Media	Depth	36 inches[1,2]
	Infiltration rate	5 in./hr[1,2,3]
	Porosity	0.45 [4,5]
	Wilting Point	0.085 [4,5]
	Field capacity	0.19 [4,5]
Underdrain	Depth	12 inches[1]
	Void Space	0.40 (No. 57 stone)[6,7,8]
	Native Infiltration	Site Specific. See Musgrave 1955 (in./hr)

Bioretention/Biofiltration

(optional underdrain)

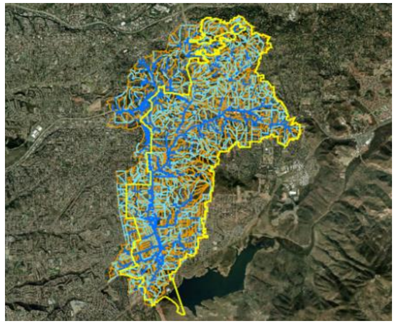
Modeling System Components

Watershed Model

Data

- Real Rainfall
- Streamflow Data
- Water Quality Data
- Soil Type
- Land Use
- Elevation
- Slopes
- Evaporation
- Infiltration

Hydrology & Water Quality

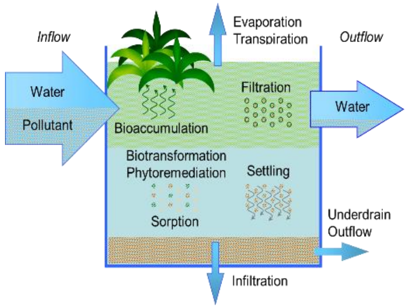


BMP Model

Data

- BMP Types
- BMP Sizing & Designs
- Locations
- Treatment Processes
- Infiltration
- Harvesting & Use
- Costs

Capture & Treatment

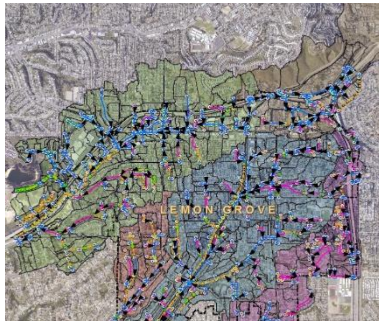


Instream Model

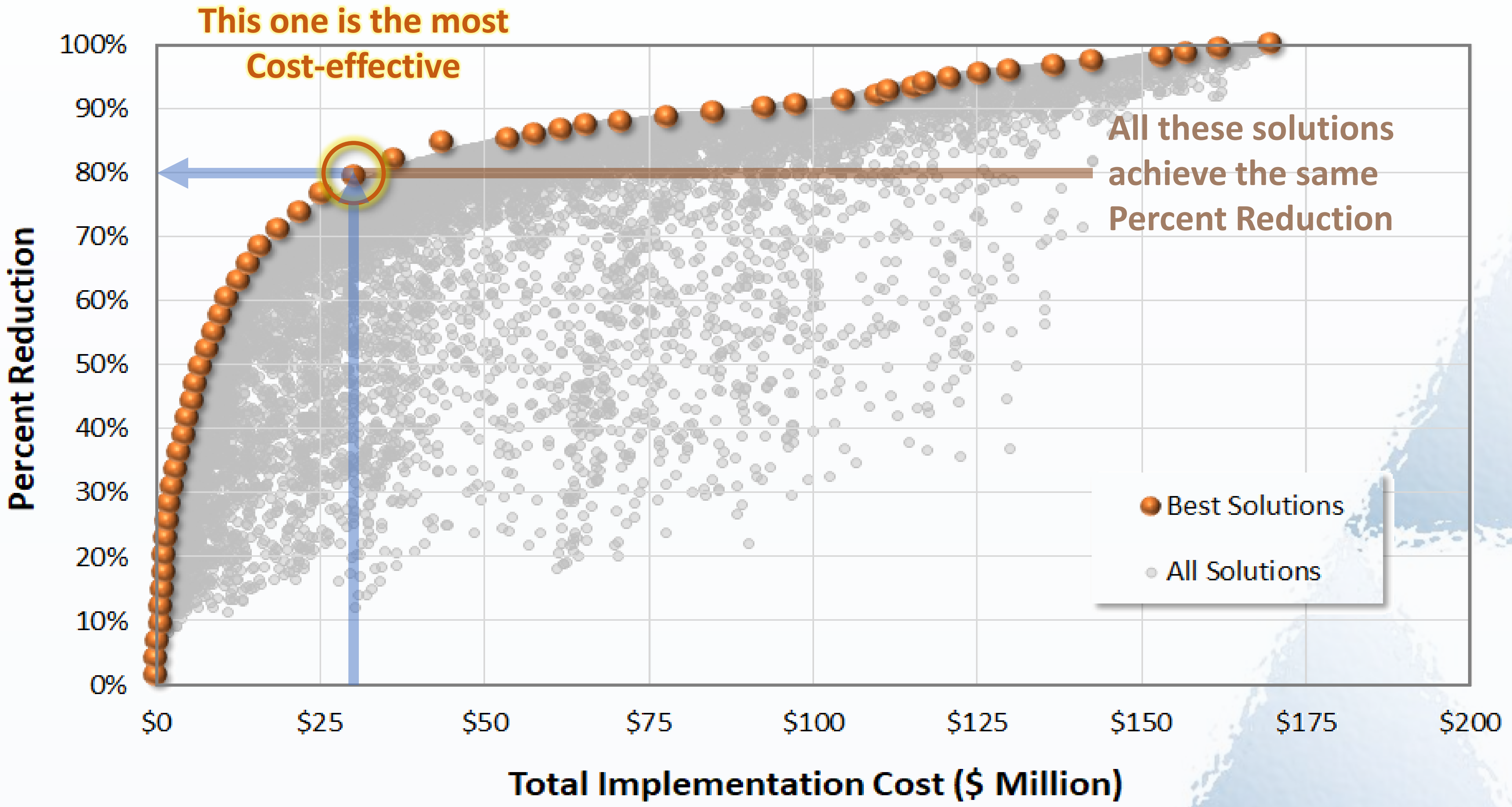
Data

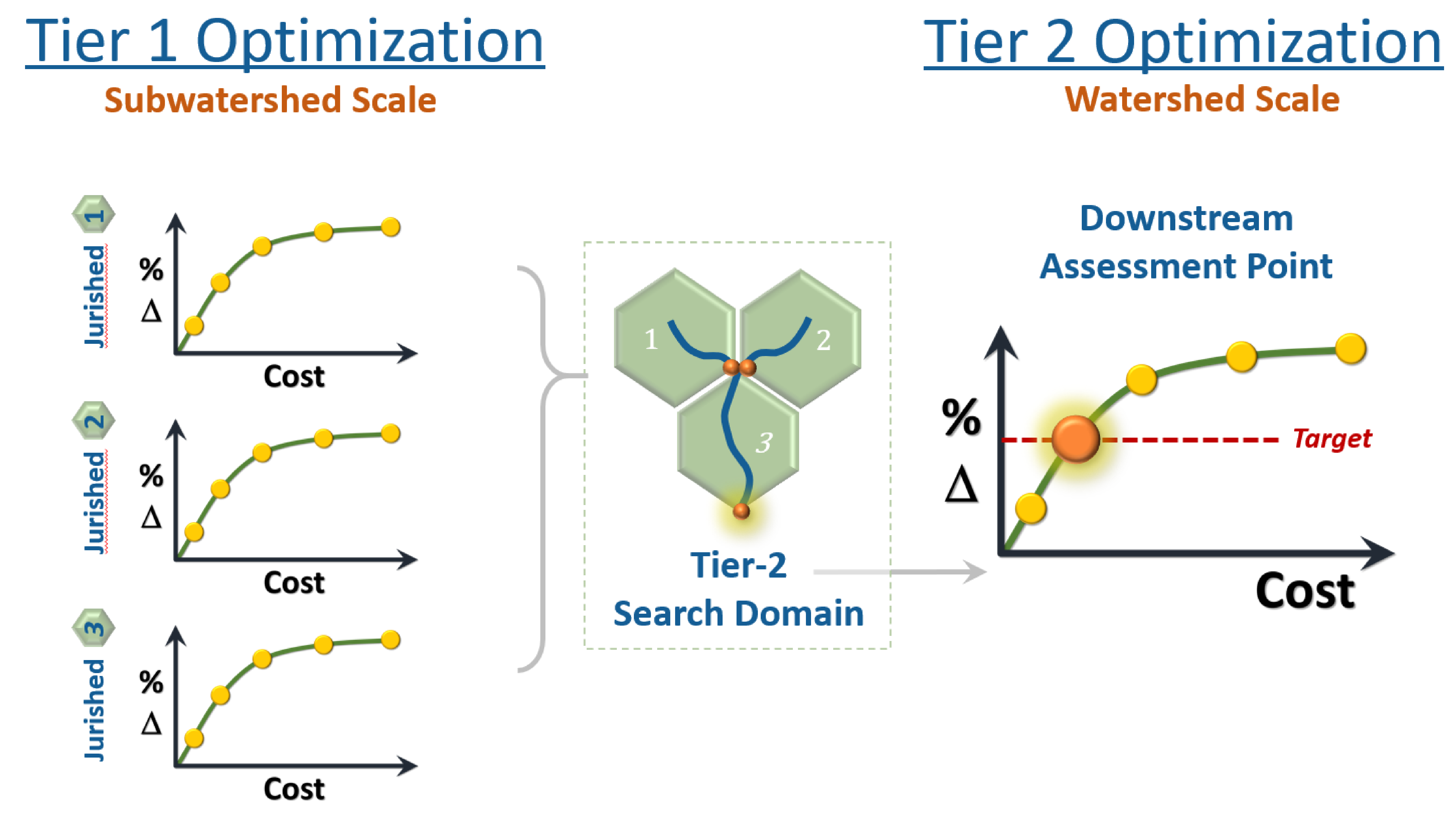
- Cross-Sections
- Streamflow Data
- Design Details
- Field Observations
- Physical Characteristics
- Elevation
- Slopes

Stormwater Conveyance



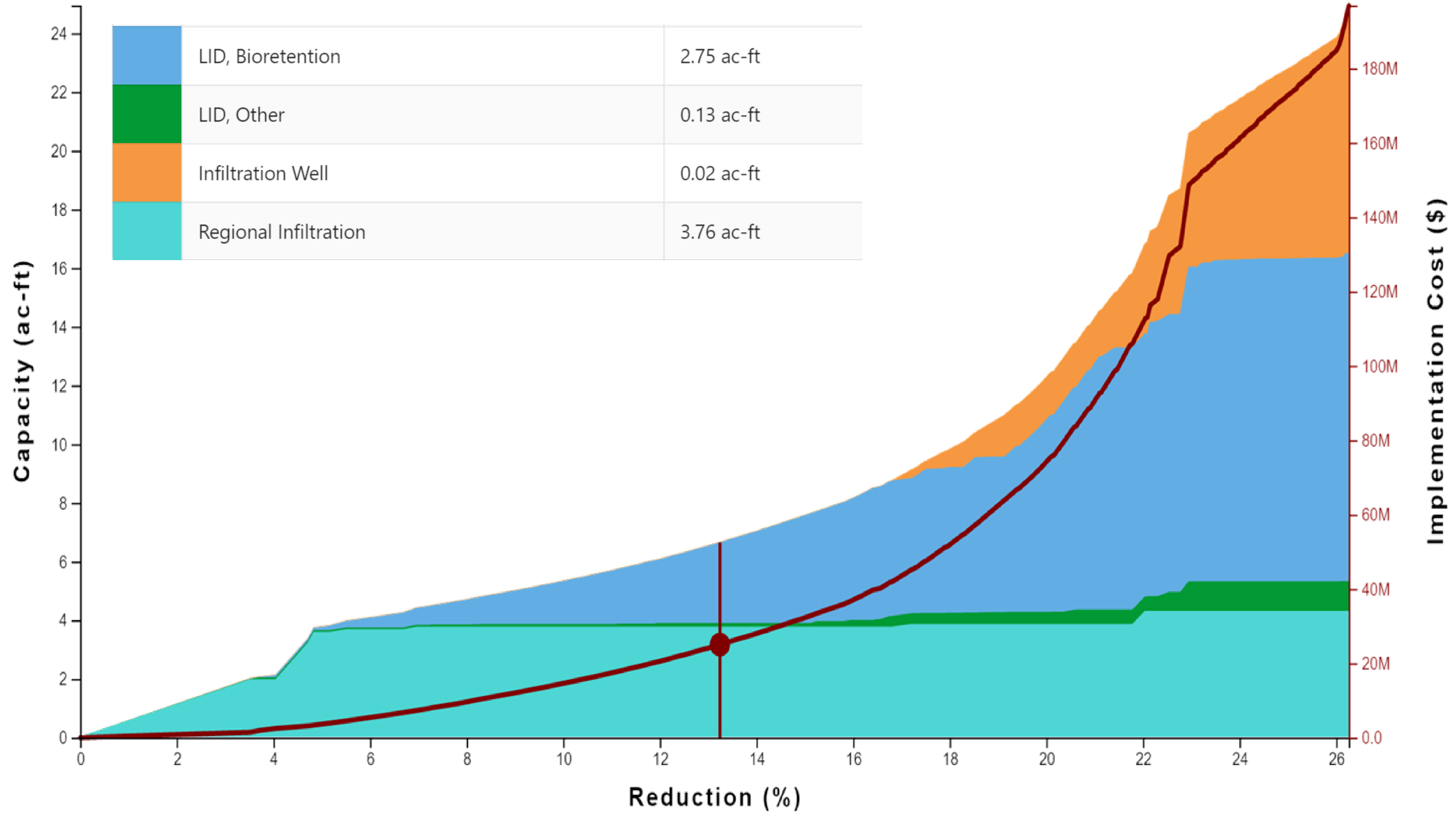
Cost-Benefit Optimization Framework





Tier 1 Optimization
Subwatershed Scale
Tier 2 Optimization
Watershed Scale
1
Jurished
% Δ
Cost
2
Jurished
% Δ
Cost
3
Jurished
% Δ
Cost
1
2
3
Tier-2
Search Domain
Downstream
Assessment Point
% Δ
Target
Cost

Optimization Utilities



Optimization Viewer

WMMS² | About | Documents, Data & Downloads | Utilities | Optimization Viewer | Links

Optimization Viewer

Welcome to the Optimization Viewer. This viewer renders watershed-scale optimization outputs from the WMMS2 Two-Tiered Utility. These optimization curves are the culmination of the WMMS2 modeling workflow; they display the cost-optimized strategies to achieve pollutant or flow reductions based on the provided BMP menu and opportunities.

Upload CRZ files from the Two-Tiered Utility to compare and contrast implementation options. The 'Generate Plan' button enables output of the detailed BMP recipe and costs for each jurished. The 'To LSPC' button outputs files to support routing of time series back to LSPC for simulating the 'post-implementation' time series that incorporates the pollutant reduction benefits of the BMPs.

Select a scenario to upload:

File Name: **Tier2Output.crz**

Click here to select a .crz file.

Add to Viewer

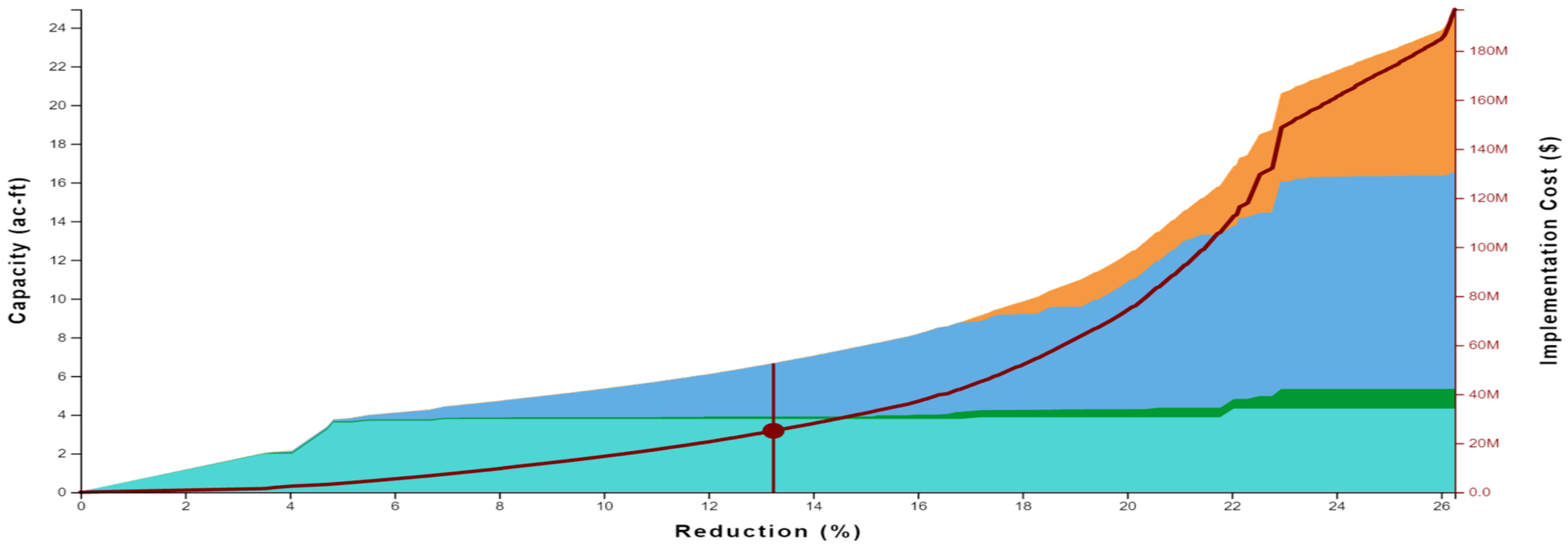
Compare Curve Slices

Optimization Target: 1 - Flow

Assessment Point: 1 - DS All

Evaluation Factor: Flow

Update



	Scenario 1 (Flow) -- Assessment Point 1 (DS All)	
●	Flow Reduction	15.94 %
—	Total Cost	$ 37 M
	Total Capacity	11.01 ac-ft
	LID, Bioretention	2.28 ac-ft
	LID, Other	0.10 ac-ft
	Infiltration Well	0.99 ac-ft
	Regional Infiltration	3.76 ac-ft
	MJR BMP	3.87 ac-ft

Generate Plan

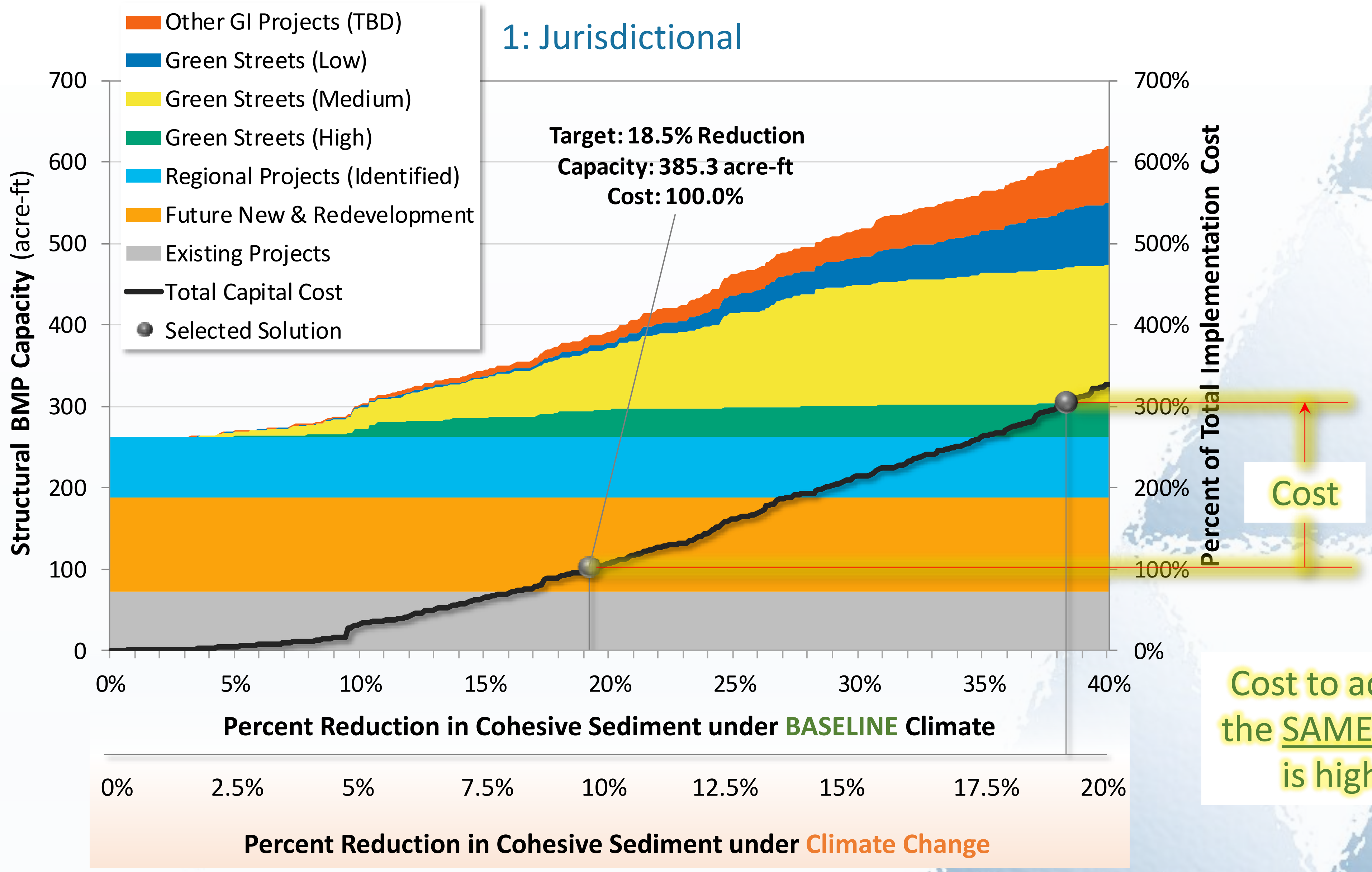
To LSPC

Optimization Viewer

Generated: 2020-04-09	**Scenario: 1**	**Assessment Point: DS All**								
Evaluation Factor: SOSED	**Target Reduction: 22.81**									
Capacity Units: ac-ft	**Footprint Units: sq-ft**									
Jurished ID	Type	Total	LID1	LID4	LID10	LID13	REG1	MJRBMP1	MJRBMP2	MJRBMP3
700549	Capacity	18.7071	8.3189	0.5795	0.3597	2.8116	4.2040	**2.4334**	0.0000	0.0000
700549	Footprint	206744.6	154201.0	9178.6	13045.3	1973.8	17953.8	**10392.2**	0.0	0.0
700549	Cost	$120,414,905.39	$76,329,493.07	$4,928,904.65	$4,631,084.87	$32,210,614.98	$2,375,282.49	**$1,769,784.31**	$0.00	$0.00
700649	Capacity	3.0455	0.0037	0.0000	0.0000	0.0000	0.0000	0.0000	**3.0418**	0.0000
700649	Footprint	13059.1	68.9	0.0	0.0	0.0	0.0	0.0	**12990.2**	0.0
700649	Cost	$2,065,410.92	$34,124.49	$0.00	$0.00	$0.00	$0.00	$0.00	**$2,116,102.94**	$0.00
700787	Capacity	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
700787	Footprint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
700787	Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
700849	Capacity	0.3738	0.0000	0.0000	0.0000	0.0179	0.0000	0.0000	0.0000	**0.3559**
700849	Footprint	1532.5	0.0	0.0	0.0	12.6	0.0	0.0	0.0	**1519.9**
700849	Cost	$1,250,917.59	$0.00	$0.00	$0.00	$205,304.15	$0.00	$0.00	$0.00	**$244,022.34**
700949	Capacity	0.4853	0.0080	0.0000	0.0014	0.0000	0.0000	0.0000	0.0000	0.4759
700949	Footprint	2231.0	148.4	0.0	50.1	0.0	0.0	0.0	0.0	2032.5
700949	Cost	$1,229,520.03	$73,439.99	$0.00	$17,788.76	$0.00	$0.00	$0.00	$0.00	$326,316.19
700983	Capacity	0.1455	0.0000	0.1010	0.0444	0.0000	0.0000	0.0000	0.0000	0.0000
700983	Footprint	3212.0	0.0	1600.2	1611.8	0.0	0.0	0.0	0.0	0.0
700983	Cost	$1,288,552.26	$0.00	$859,323.54	$572,185.83	$0.00	$0.00	$0.00	$0.00	$0.00
701049	Capacity	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
701049	Footprint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
701049	Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
701087	Capacity	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
701087	Footprint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
701087	Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
701187	Capacity	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
701187	Footprint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
701187	Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**Capacity**	**22.7572**	**8.3306**	**0.6805**	**0.4055**	**2.8295**	**4.2040**	**2.4334**	**3.0418**	**0.8318**
Total	**Footprint**	**226779.2**	**154418.3**	**10778.8**	**14707.2**	**1986.4**	**17953.8**	**10392.2**	**12990.2**	**3552.4**
Total	**Cost**	**$126,249,306.20**	**$76,437,057.55**	**$5,788,228.19**	**$5,221,059.46**	**$32,415,919.13**	**$2,375,282.49**	**$1,769,784.31**	**$2,116,102.94**	**$570,338.52**

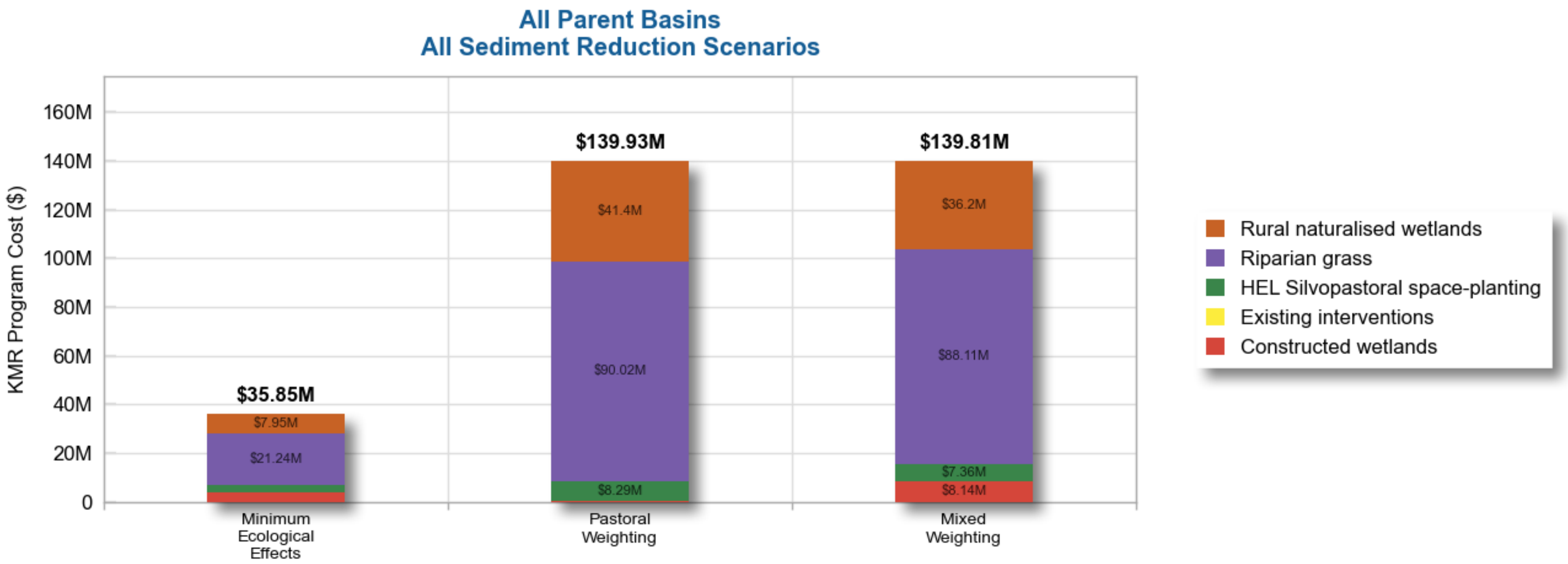
Implementation Details | Design Details | Graph

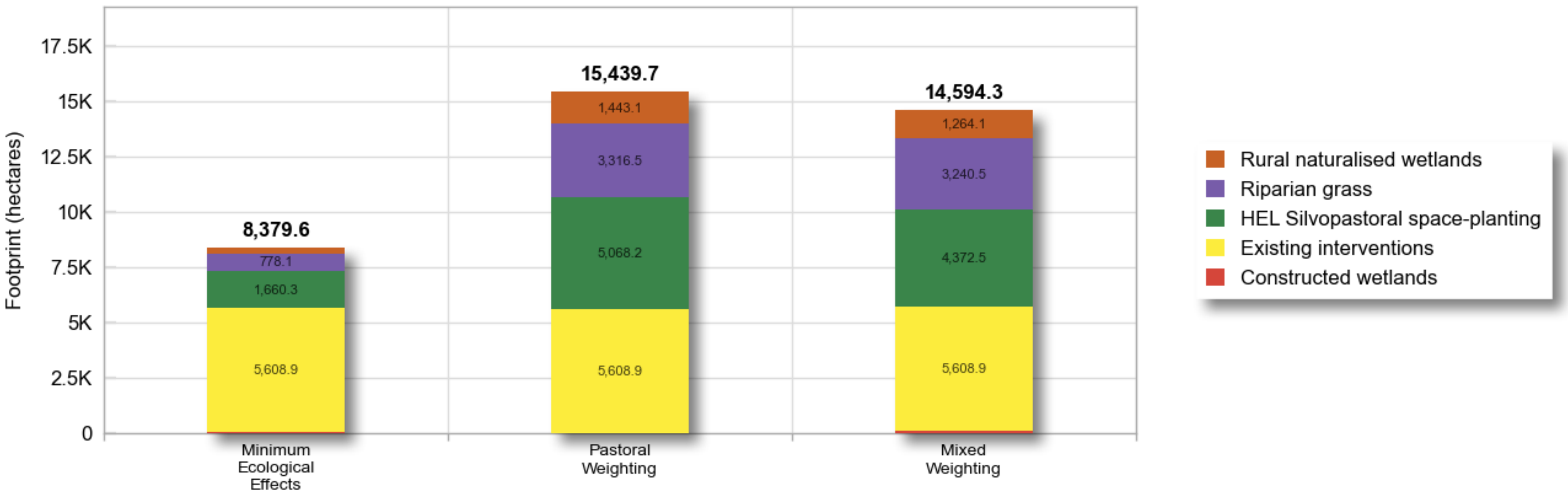
Climate Change Scenarios "Stress-Test" Current Optimized Solutions: The runs produce a new x-Axis.



Cost to achieve the SAME target is higher

Investment Strategies Example:






Questions?

EXTRA SLIDES:

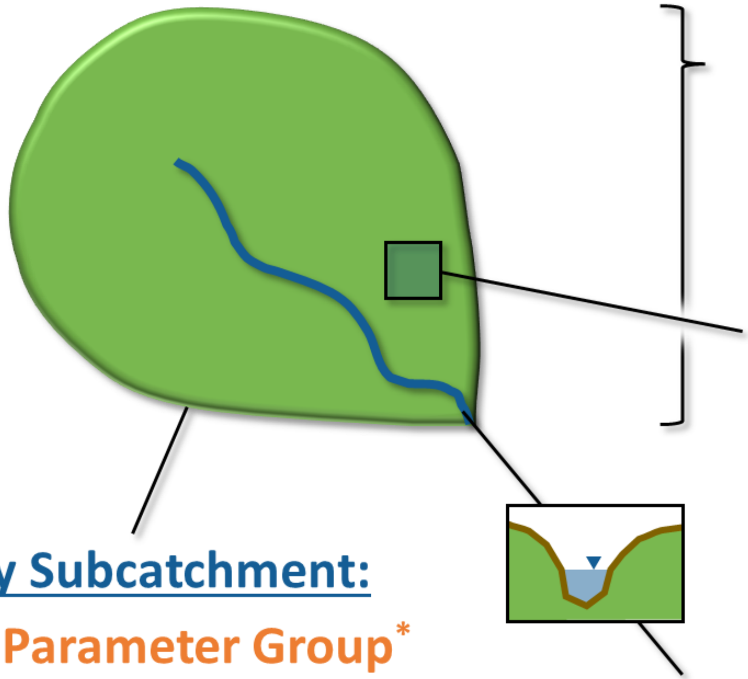
HRU Deeper Dive

PARADIGM ENVIRONMENTAL

LSPC HRU Concepts

- HRUs represent areas of similar physical characteristics attributable to core hydrological processes
  - **Primarily land cover (LC), hydrologic soil group (HSG), and slope**
  - **Secondary layers can be added to provide additional data as needed (e.g., land use, imperviousness, tree canopy, geology)**
- Goal of HRU development is a regional set of HRUs for the entire model domain
  - **Parameters adjusted globally during model calibration**

LSPC HRU Concepts



By HRU × Subcatchment (Physical):

- Slope of HRU
- Length of Overland Flow
- Imperviousness

By Individual HRU (Processes):

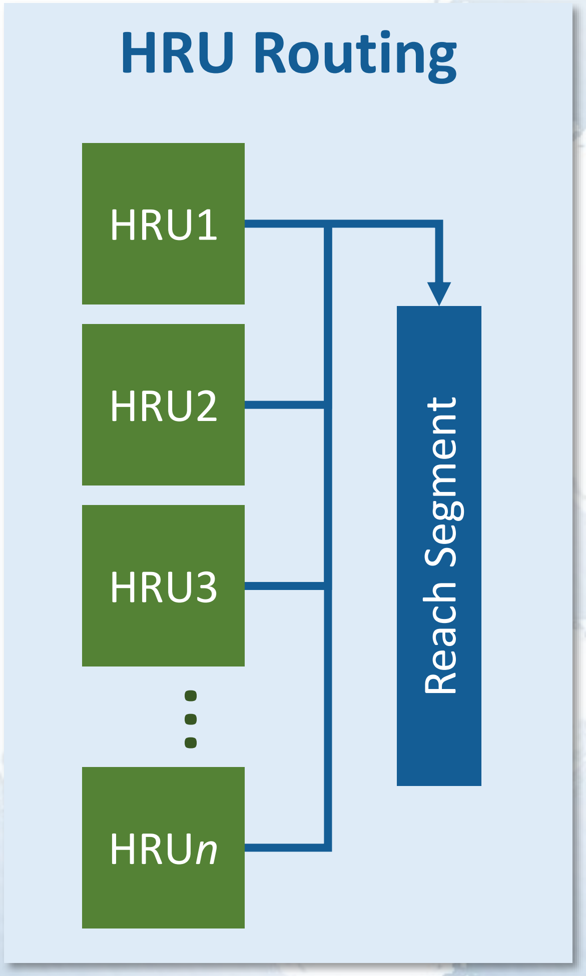
- Interception Storage Capacity
- Subsurface Storage Capacity
- All other Hydrological Parameters, Rates, and Constants

By Subcatchment:

- **Parameter Group***
- HRU Area Distribution
- Weather Data
- Average Elevation
- Reach or Lake Segment

By Reach/Lake Segment:

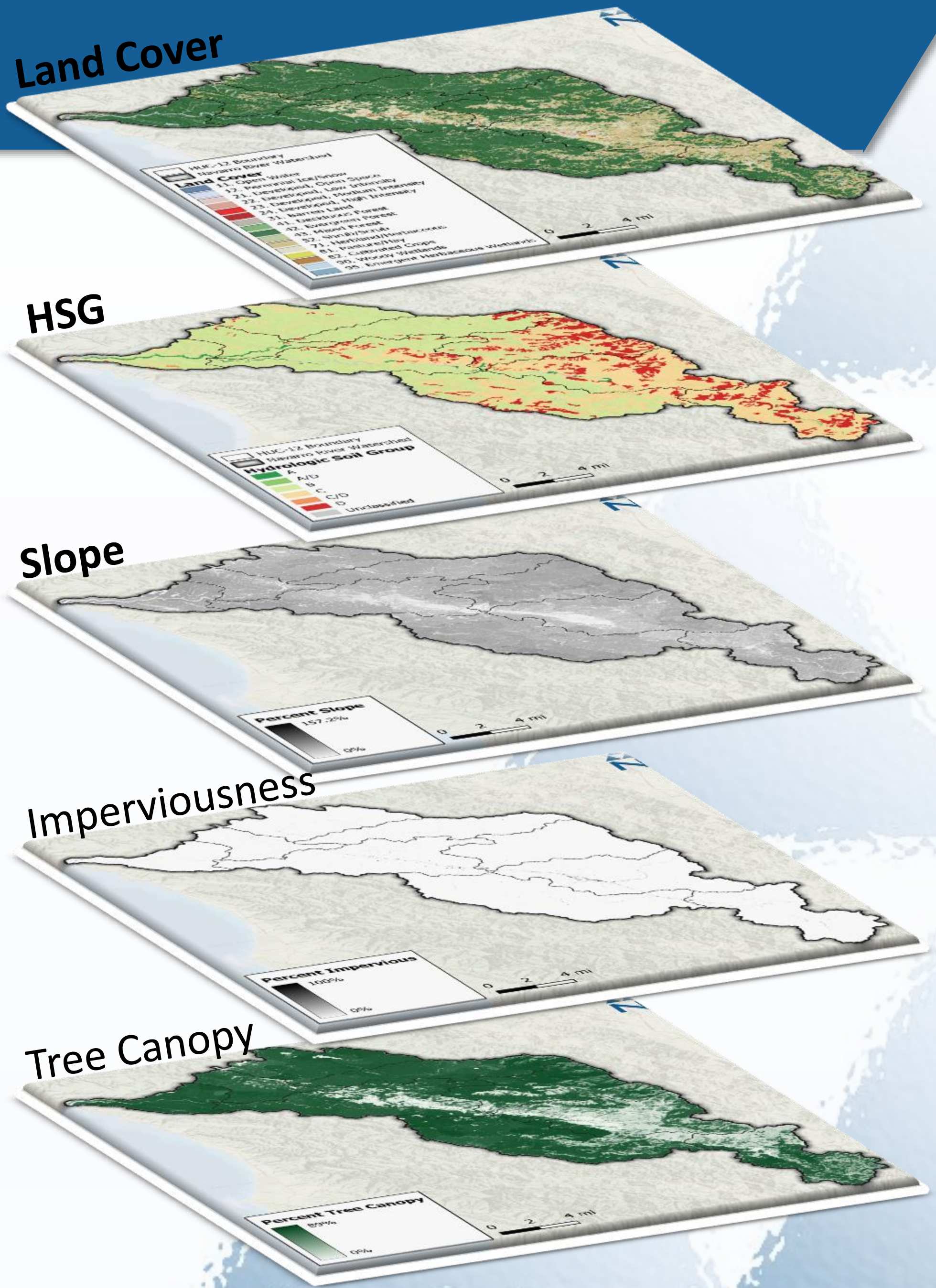
- **Reach Group ***
- Geometry
- Transport Rates and Constants



* **Parameter/Reach Groups** can be used to differentiate features with distinct characteristics.

HRU Development Process

- Convert all layers to 30-meter rasters
  - Same extent and spatial alignment
- Spatially overlay into unique combinations
- Reclassify/group raster values as appropriate
  - Developed Impervious/Developed Pervious
- Adjust connectedness of impervious surfaces
- Examine unique combinations and group into final HRUs
- Calculate distribution of HRUs by subwatershed



Land Cover

NLCD Class	Description	Model Group	Area Distribution (ac)	
			Total	%
22	Developed, Low Intensity	Developed, Low Intensity	411.21	0.20%
23	Developed, Medium Intensity	Developed, Medium Intensit	141.44	0.07%
24	Developed, High Intensity	Developed, High Intensity	24.46	0.01%
21	Developed, Open Space	Developed, Open Space	9,267.38	4.60%
31	Barren Land (Rock/Sand/Clay)	Barren	22.24	0.01%
41	Deciduous Forest	Forest	603.35	0.30%
42	Evergreen Forest	Forest	134,393.56	66.74%
43	Mixed Forest	Forest	9,203.77	4.57%
52	Shrub/Scrub	Scrub	32,938.99	16.36%
71	Grassland/Herbaceous	Grassland	12,431.38	6.17%
81	Pasture/Hay	Pasture	141.00	0.07%
82	Cultivated Crops	Agriculture	638.72	0.32%
90	Woody Wetlands	Forest	817.08	0.41%
95	Emergent Herbaceous Wetlands	Grassland	237.29	0.12%
11	Open Water	Water	96.52	0.05%
		Total (acre):	201,368	100.00%

Hydrologic Soil Groups

Raw SSURGO Data

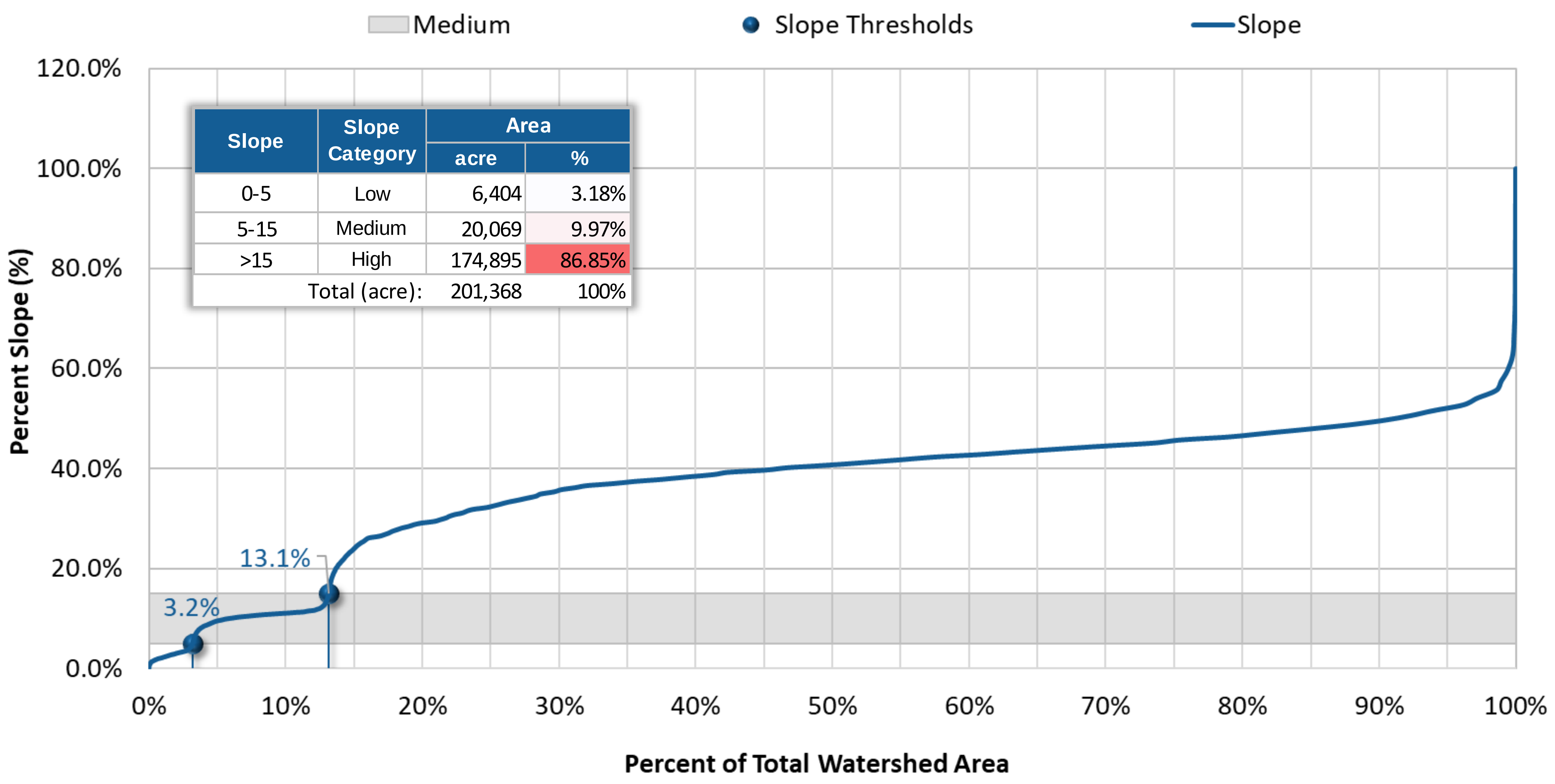
Soil Group	New Soil	Justification	Area (acre)	Area (%)
NoData	B	Dominate HSG	-	0%
C	C		72,414	36%
A/D	B	nearest primary group	135	0%
D	D		23,745	12%
B	B		101,691	50%
Unclassified	B	Dominate HSG	1,395	1%
A	A		1,580	1%
C/D	D	nearest primary group	408	0%

Reclassified

New Soil	Area	%
A	1,555	0.8%
B	103,071	51.2%
C	72,239	35.9%
D	24,097	12.0%
MIA	406	0.2%

Total (acre): 201,368 100.0%

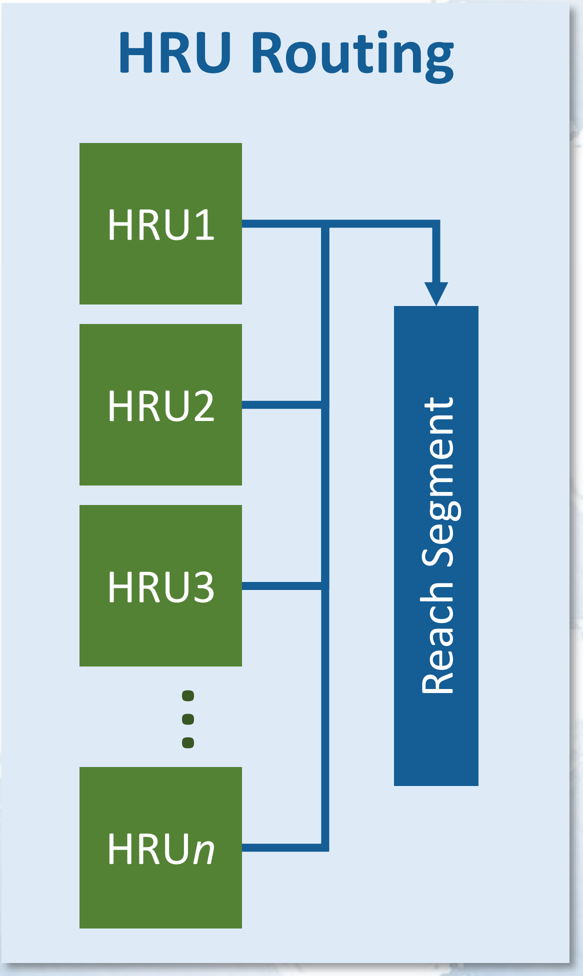
Slope



Slope	Slope Category	Area	
		acre	%
0-5	Low	6,404	3.18%
5-15	Medium	20,069	9.97%
>15	High	174,895	86.85%
	Total (acre):	201,368	100%

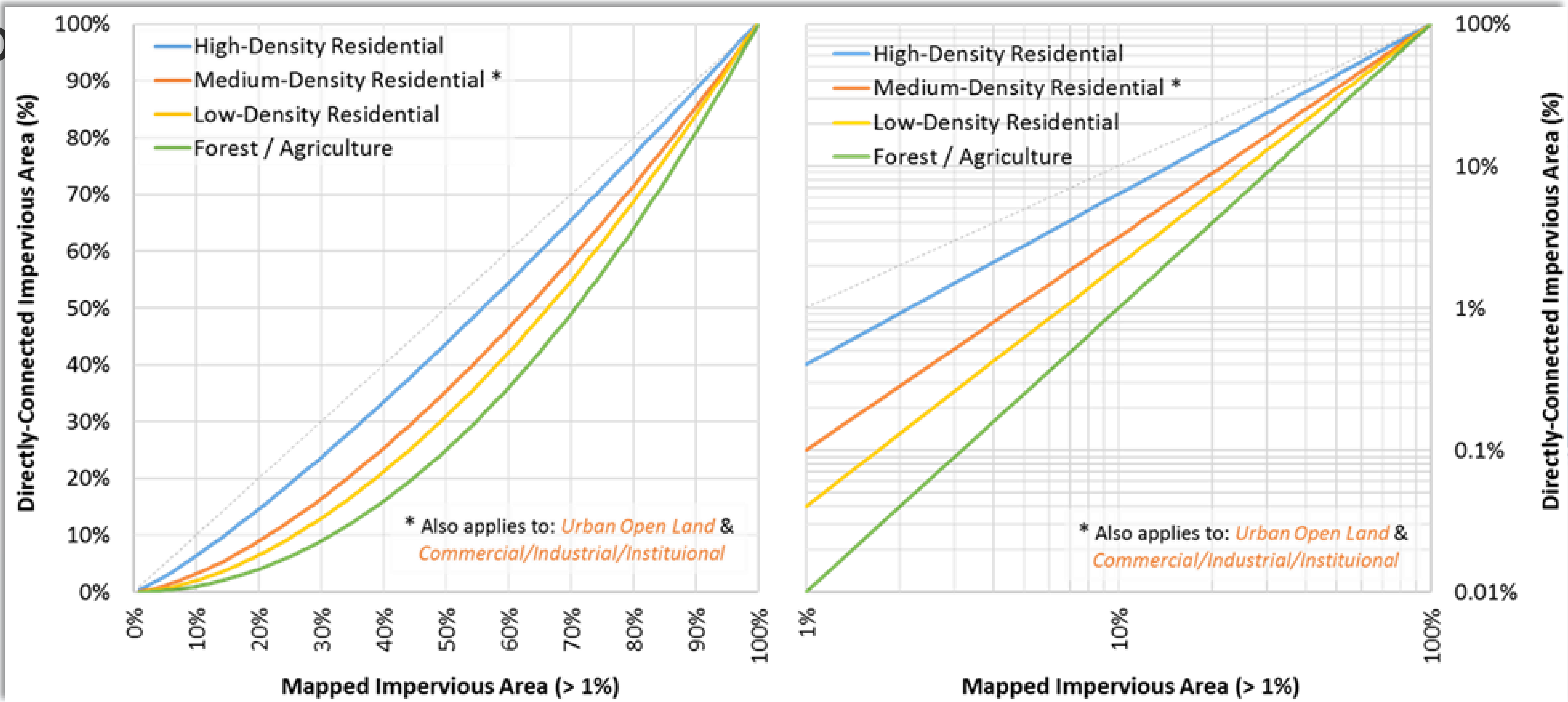
Connectedness of Impervious Surfaces

- Impervious areas that are not connected to a drainage network can flow onto pervious surfaces, infiltrate, and become part of pervious subsurface and overland flow
  - No HRU-to-HRU flow in LSPC
- Approximated in LSPC by converting a portion of impervious land to pervious land



Connectedness of Impervious Surfaces

- Sutherland Eqs. (2000): empirically derived, show
  stro
  and



Sutherland, R. C. (2000). Methods for Estimating the Effective Impervious Area of Urban Watersheds, Technical Note 58. In T. R. Scueler & H. K. Holland (Eds.), The Practice of Watershed Protection (pp. 193–195). Center for Watershed Protection.

Connectedness of Impervious Surfaces

- NLCD percentage impervious used to calculate mapped impervious area of Developed LC classes
- Sutherland Eqs. used to translate Developed Impervious to Developed Pervious

Model Group	Area (acre)	%
Developed, Low Intensity	411.21	0.204%
Developed, Medium Intensity	141.44	0.070%
Developed, High Intensity	24.46	0.012%
Developed, Open Space	9,267.38	4.602%
Barren	22.24	0.011%
Forest	145,017.76	72.016%
Scrub	32,938.99	16.358%
Grassland	12,668.67	6.291%
Pasture	141.00	0.070%
Agriculture	638.72	0.317%
Water	96.52	0.048%
Total (acre):	201,368	100.0%

Description	Equation	MIA	EIA	EIA:MIA
High Density Developed	DCIA=0.4(MIA)1.2	75%	72%	95%
Medium Density Developed	DCIA=0.1(MIA)1.5	51%	37%	73%
Low Density Developed	DCIA=0.04(MIA)1.7	27%	11%	42%
Open Space	DCIA=0.01(MIA)2.0	0%	0%	100%

Connectedness of Impervious Surfaces

- NLCD percentage impervious used to calculate mapped impervious area of Developed LC classes
- Sutherland Eqs. used to translate Developed Impervious to Developed Pervious

Model Group	Area (acre)	%
Developed, Low Intensity	411.21	0.204%
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Forest	145,017.76	72.016%
Scrub	32,938.99	16.358%
Grassland	12,668.67	6.291%
Pasture	141.00	0.070%
Agriculture	638.72	0.317%
Water	96.52	0.048%
Total (acre):	201,368	100.0%

Order	Model Group	Area (acre)	%
1	Developed, Impervious	406.36	0.202%
2	Developed, Pervious	9,438.13	4.687%
3	Barren	22.24	0.011%
4	Forest	145,017.76	72.016%
5	Scrub	32,938.99	16.358%
6	Grassland	12,668.67	6.291%
7	Pasture	141.00	0.070%
8	Agriculture	638.72	0.317%
9	Water	96.52	0.048%
	Total (acre):	201,368	100.0%

Switchboard

- Unique attribute combinations after reclassification/grouping
- Final HRU codes:
  - Land cover–Soil–Slope–Other
  - Ex.: 4110 = Forest, HSG-A, Low Slope
- Adaptable to unique watershed

Total No. of HRUs: **86**

Reclassify | Build Landuse Table

Order	LULC	PERIMP	Soil Group				Slope		
			A	B	C	D	0-5	5-15	>15
		0/1	1	2	3	4	1	2	3
1	Developed, Impervious	1	0	0	0	0	0	0	0
2	Developed, Pervious	0	1	2	3	4	1	2	3
3	Barren	0	1	2	3	4	1	2	3
4	Forest	0	1	2	3	4	1	2	3
5	Scrub	0	1	2	3	4	1	2	3
6	Grassland	0	1	2	3	4	1	2	3
7	Pasture	0	1	2	3	4	1	2	3
8	Agriculture	0	1	2	3	4	1	2	3
9	Water	0	0	0	0	0	0	0	0

Order	LULC	Percent of Area	Soil Group (% LULC Area)				Slope (% LULC Area)		
			A	B	C	D	0-5	5-15	>15
			1	2	3	4	1	2	3
1	Developed, Impervious	0.2%	6.1%	36.9%	43.0%	14.0%	32.6%	25.4%	42.0%
2	Developed, Pervious	4.7%	3.9%	51.9%	30.8%	13.5%	8.7%	23.0%	68.3%
3	Barren	0.0%	13.0%	59.0%	23.0%	5.0%	45.0%	34.0%	21.0%
4	Forest	72.0%	0.6%	63.5%	29.0%	6.9%	1.4%	6.9%	91.8%
5	Scrub	16.4%	0.2%	12.9%	59.3%	27.7%	2.3%	12.4%	85.3%
6	Grassland	6.3%	1.7%	12.4%	58.0%	28.0%	16.9%	27.5%	55.6%
7	Pasture	0.1%	7.4%	17.2%	46.2%	29.2%	79.2%	16.6%	4.3%
8	Agriculture	0.3%	4.8%	28.9%	57.5%	8.8%	55.0%	39.8%	5.2%
9	Water	0.0%	0.9%	68.4%	25.6%	5.1%	62.9%	17.7%	19.4%
	Total	100.0%	0.8%	51.3%	36.0%	12.0%	3.2%	10.0%	86.8%

EXTRA SLIDES:

TMDL Example

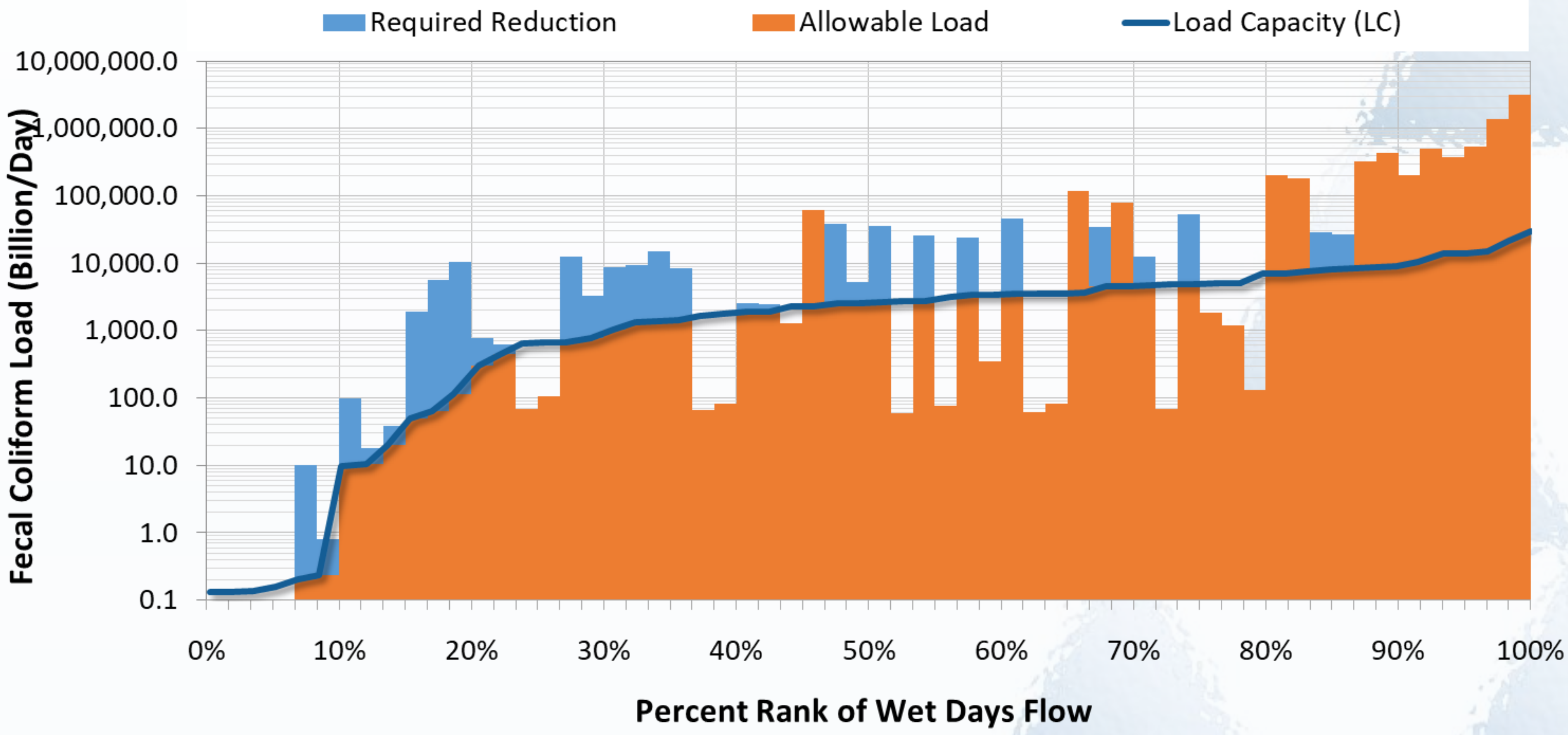
Considerations for Critical Periods

- 1993 used for critical period in TMDL
- Alternative periods considered
  - **Select water year within recent 10-year period (2012 to 2022)**
    - Average annual rainfall ("AVG WY"): 2012
    - 90th percentile annual rainfall ("90th WY"): 2017

Water Year	Annual Rainfall (in)	
2012	7.27	**AVG WY**
2013	5.49	
2014	4.87	
2015	6.91	
2016	6.82	
2017	13.16	**90th WY**
2018	4.18	
2019	13.81	
2020	12.07	
2021	3.65	
2022	5.88	

FIB (Fecal Coliform)

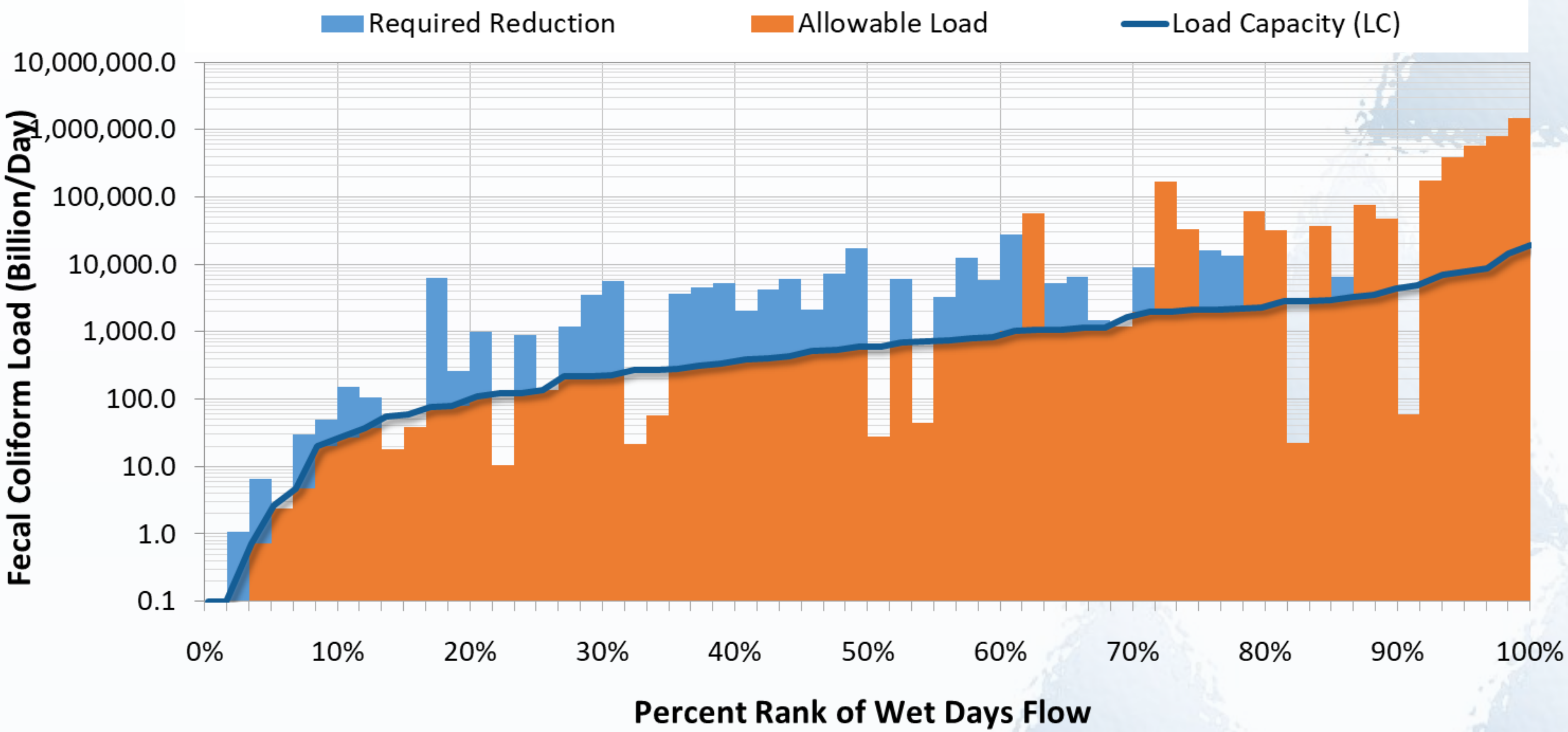
Metric	Value
Constituent	F. Coli.
Location	Fresh**
WY (TMDL)	1993
Allowable Exceedance	22%
Wet Day Load (MPN)	8.00M
Load Reduction	4.4%
Annual Runoff (ac-ft)	12,648



Wet days are sorted from low to high (daily flow volume).
Days with load under water quality standard are allowable. Orange bars (i.e., no reduction required).
Days with load over water quality standard are not allowable. Blue bars (i.e., reduction required).
Then top 22% of loading days are "allowed" by the allowable exceedance. Orange bars above "LC".
Remaining load volume is required to be reduced.

FIB (Fecal Coliform)

Metric	Value
Constituent	F. Coli.
Location	Ocean
WY (90th%)	2017
Allowable Exceedance	22%
Wet Day Load (MPN)	4.10M
Load Reduction	4.0%
Annual Runoff (ac-ft)	8,094



Wet days are sorted from low to high (daily flow volume).
Days with load under water quality standard are allowable. Orange bars (i.e., no reduction required).
Days with load over water quality standard are not allowable. Blue bars (i.e., reduction required).
Then top 22% of loading days are “allowed” by the allowable exceedance. Orange bars above “LC”.
Remaining load volume is required to be reduced.

FIB Summary

Water Year	Annual Runoff (ac-ft)	Period of Analysis	Rainfall (in)
1993	12,663	Bacteria I TMDL water year	18.7
2012	2,027	Average water year (2012-2022)	7.3
2017	8,094	90^{th} percentile water year (2012-2022)	13.2

FIB Summary

- w/ 22% allowable exceedance

Water Year	Annual Runoff (ac-ft)	Load Reduction		Volume Managed (ac-ft)	
		Enterococcus	Fecal Coliform	Enterococcus	Fecal Coliform
1993	12,663	5.3%	4.4%	2,964	2,642
2012	2,027	36.7%	33.5%	961	794
2017	8,094	5.0%	4.0%	1,672	1,517

Conclusion: Enterococcus is the “limiting” FIB. If reduction for enterococcus is achieved, fecal coliform is also achieved.

FIB Summary

- w/ 22% allowable exceedance

Water Year	Annual Runoff (ac-ft)	Volume Managed (Qty of Petco Parks)		Volume Managed (ac-ft)	
		Enterococcus	Fecal Coliform	Enterococcus	Fecal Coliform
1993	12,663	2.9	2.6	2,964	2,642
2012	2,027	0.9	0.8	961	794
2017	8,094	1.6	1.5	1,672	1,517

Conclusion: Enterococcus is the “limiting” FIB. If reduction for enterococcus is achieved, fecal coliform is also achieved.