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A Modified SWAT Model for Evaluation of Prior Appropriation Water Rights

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Outline

- **Motivation** – Why Water Rights?
- **Objectives** – Scope of this Study
- **Methodology** – Modifications in SWAT model
- **Results & Discussions** – Testing via Application to Umatilla River Basin, OR
- **Conclusions and Future Work** – Insights Gained
- **Acknowledgements**

Motivation

- West of the Mississippi River, Water Rights Allocations are based on Prior Appropriations Doctrine
  - During droughts and water shortages, senior water rights are last to be shut off.

- Need to prevent excessive groundwater declines (e.g., *Critical GW Areas*) are resulting in restrictions to further appropriations of groundwater rights and need for local adaptation.

- However, most water rights holders in the regional food-energy-water sectors desire autonomy and are prone to siloed decision making – i.e., formulate their adaptation plans based exclusively on their respective farm/sector.

- This research is aiming to improve water management approach that allows <u>coordination of water rights planning across a river basin</u>.

Motivation

- SWAT has been used in multiple studies to incorporate the influence of water rights based decisions. For example,
  - Wei et al. (2018) included water rights by assigning irrigation water based on historical canal diversion records.
  - Noa-Yarasca et al. (2023) included instream water rights to include water use constraints in a modified SWAT model used for simulating water temperatures.
- While the current SWAT model enables of water withdrawals via water rights, it is not set up to simulate the effects of **water rights priorities** in a region making, thereby limiting applications involving the water rights allocations in the West.
- Additionally,
  - Many times, historical records of diversions are not available and the only records are water rights allocations
  - HRUs could be using water from multiple sources and diversion locations.

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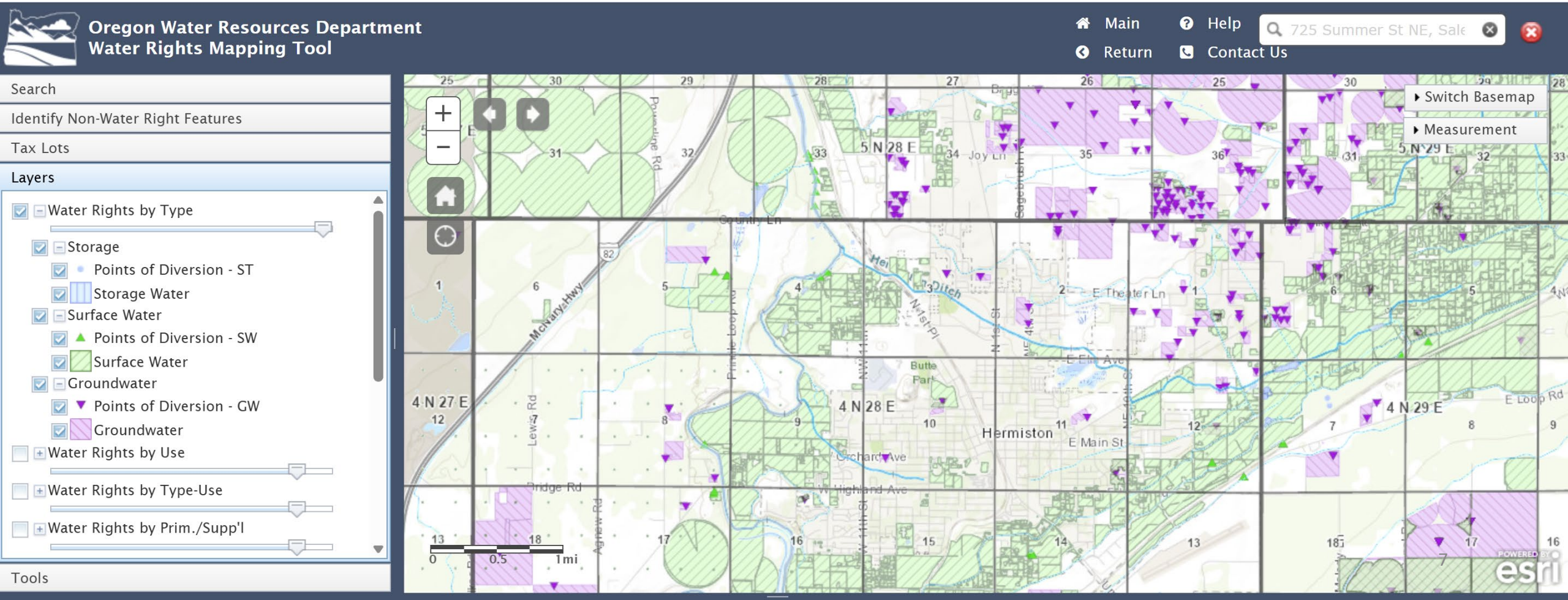
Objective of this Study

1. Improve the representation of water rights priorities in the Western USA, specifically irrigation water rights and instream water rights that play an important role in agriculture water management, in the SWAT model
2. Using the modified SWAT model, evaluate effect of water rights allocation scenarios on priority based water withdrawals, to address groundwater declines in the watershed.

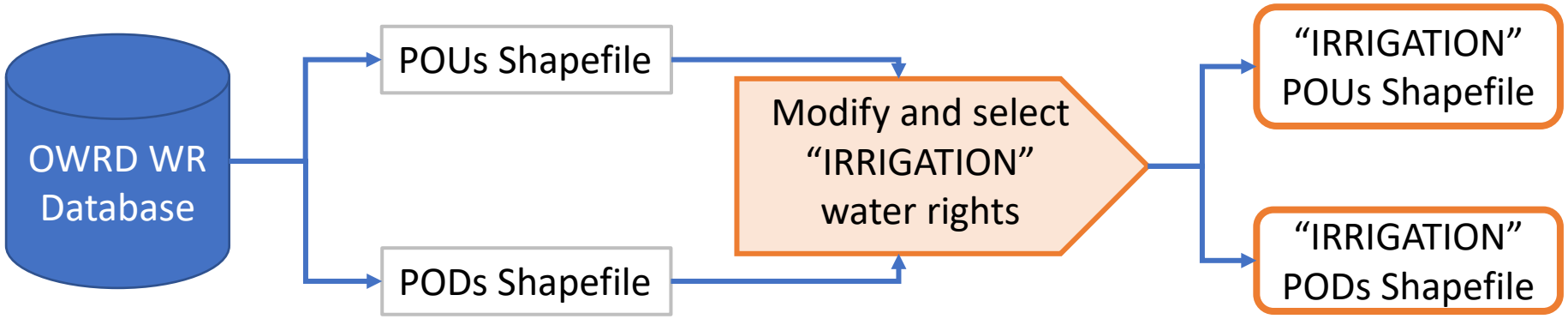
Methodology

Water Rights Data –Oregon as a Case Study

- Oregon Water Resources Department (OWRD) Water Rights Information System (WRIS)



Approach: Integration of water rights data in SWAT Model



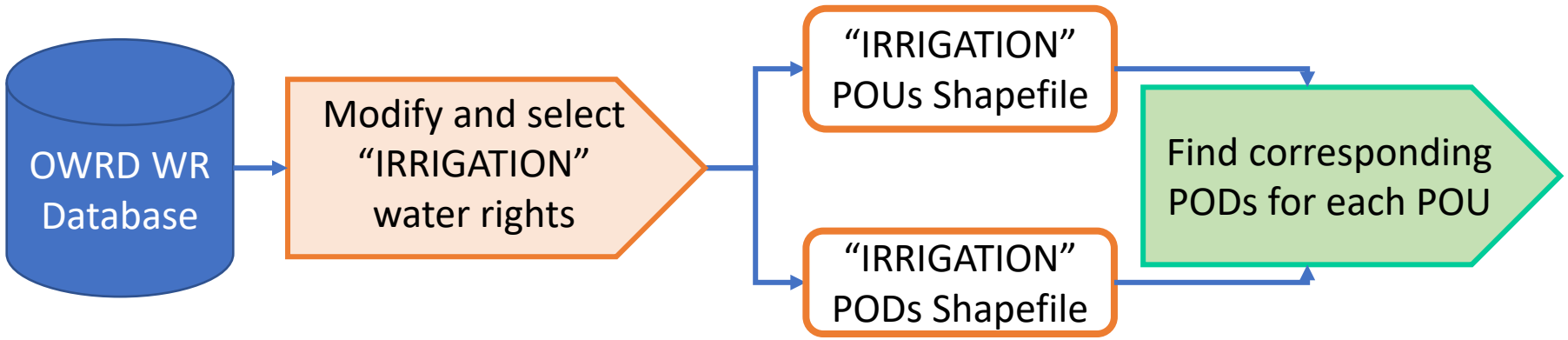
Modify and select "IRRIGATION" POUs

- Assigned "IRRIGATION" use code for POUs with a use code of:
  - "SUPPLEMENTAL IRRIGATION"
  - "IRRIGATION, LIVESTOCK AND DOMESTIC"
- Remove duplicate records and spatially merged corresponding POU's polygons

Modify and select "IRRIGATION" PODs

- Assigned "IRRIGATION" use code for PODs with a use code of:
  - "PRIMARY AND SUPPLEMENTAL IRRIGATION"
  - "IRRIGATION AND DOMESTIC"

Approach: Integration of water rights data in SWAT Model



Find corresponding POD(s) for each POU

- Match record ID, use codes, and water source
- Used to calculate total available volume per water source.
  - Total volume (TV) for POU from ***water source i***: $TV_{POU\_i} = \sum_{j=1}^{\#\ of\ PODs} (wris\_acres) * duty_j$

- Assumptions:
  - Duty (maximum volume that can be extracted) of 3 acre-ft was assumed for PODs with missing duty.
  - Earliest pumping start date and last pumping end date were used when multiple PODs had different pumping periods.

Approach: Integration of water rights data in SWAT Model

OWRD WR Database

Modify and select "IRRIGATION" water rights

Find corresponding PODs for each POU

Spatial dictionary of WRs

Approximate POUs with missing polygons

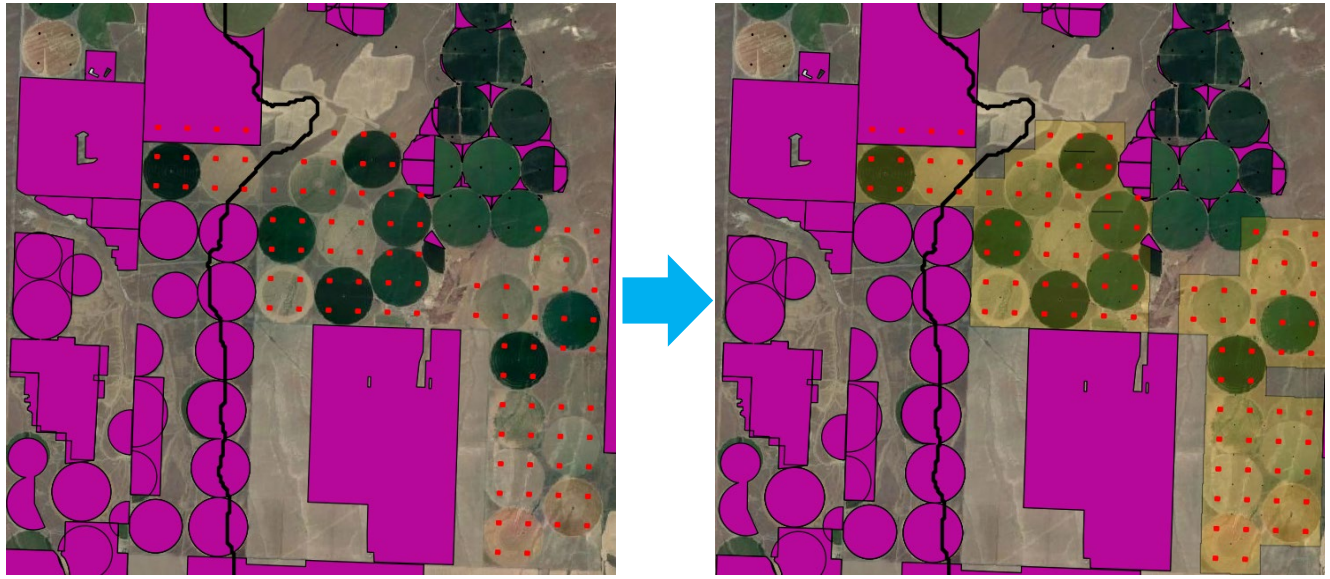
Original POUs

POU with missing polygon

Approximated POU

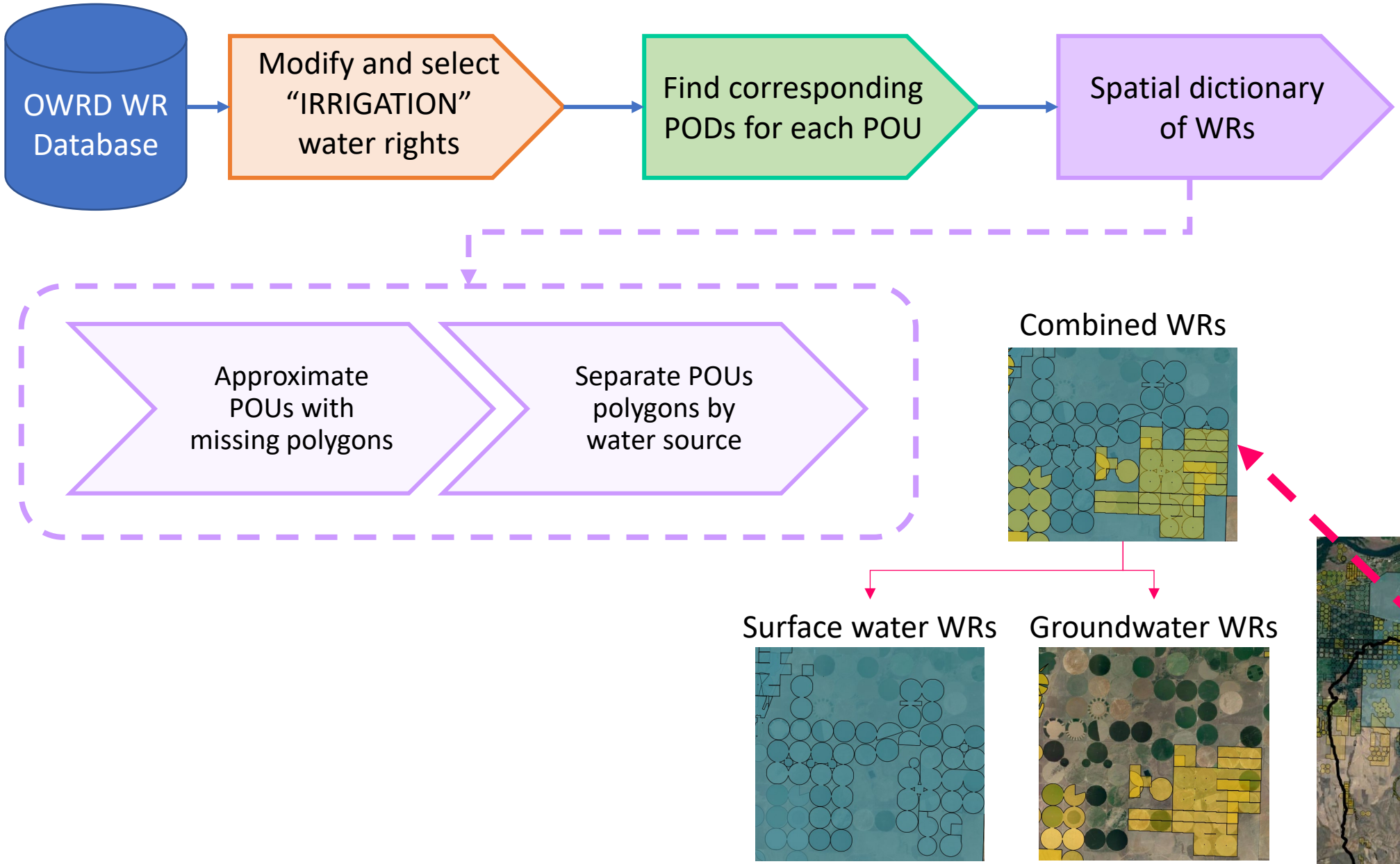
Original POUs

Modified POUs

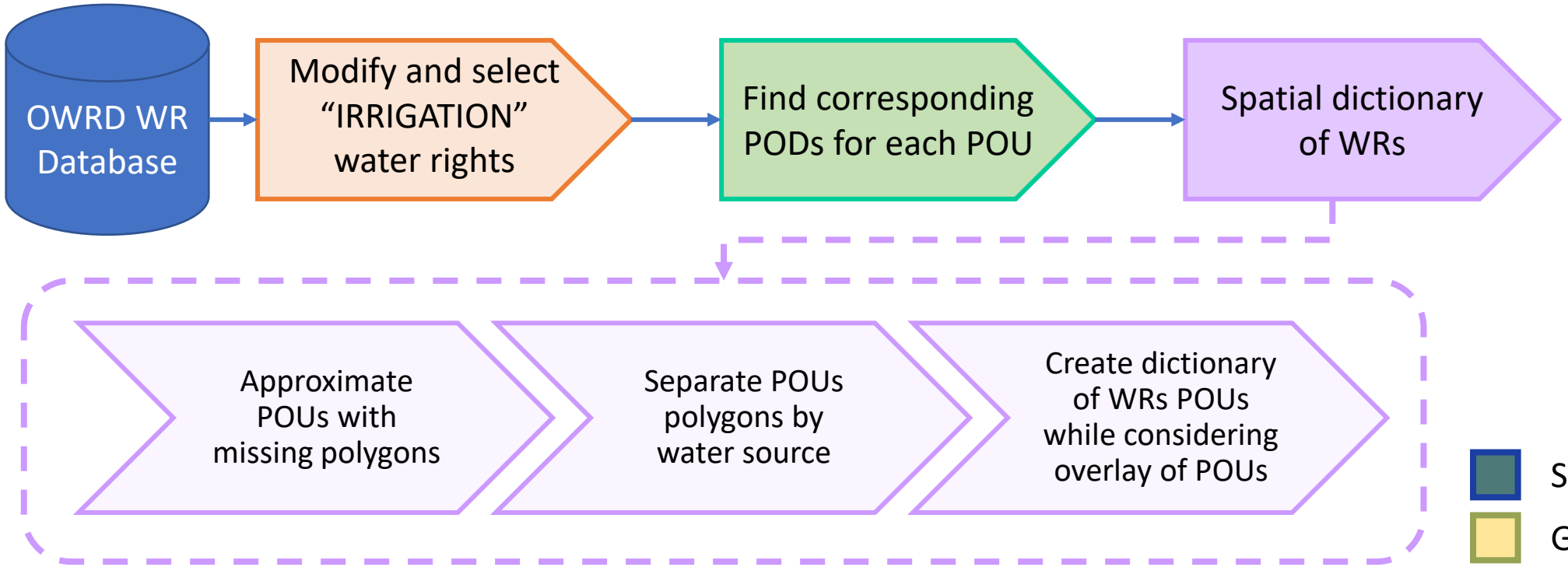


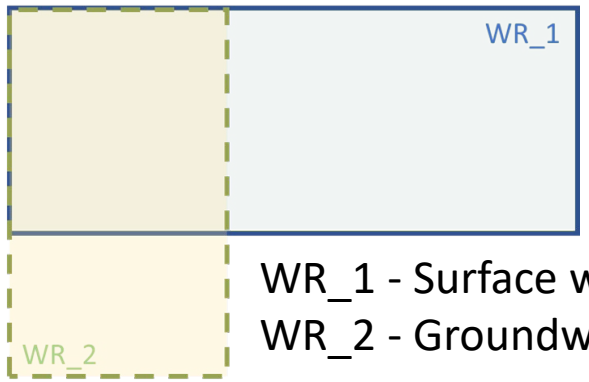
*Assumption: "Dots" represent center of Public Land Survey Quarter-Quarter

Approach: Integration of water rights data in SWAT Model

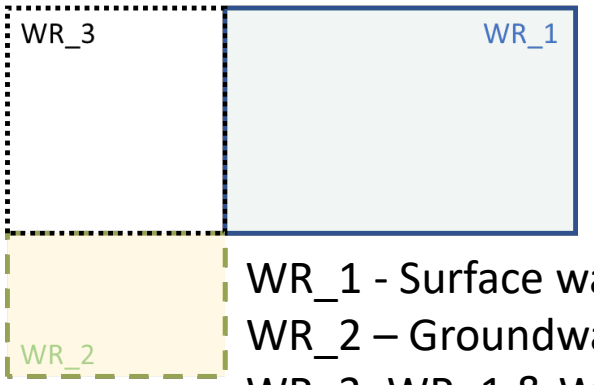


Approach: Integration of water rights data in SWAT Model





WR_1 - Surface water
WR_2 - Groundwater

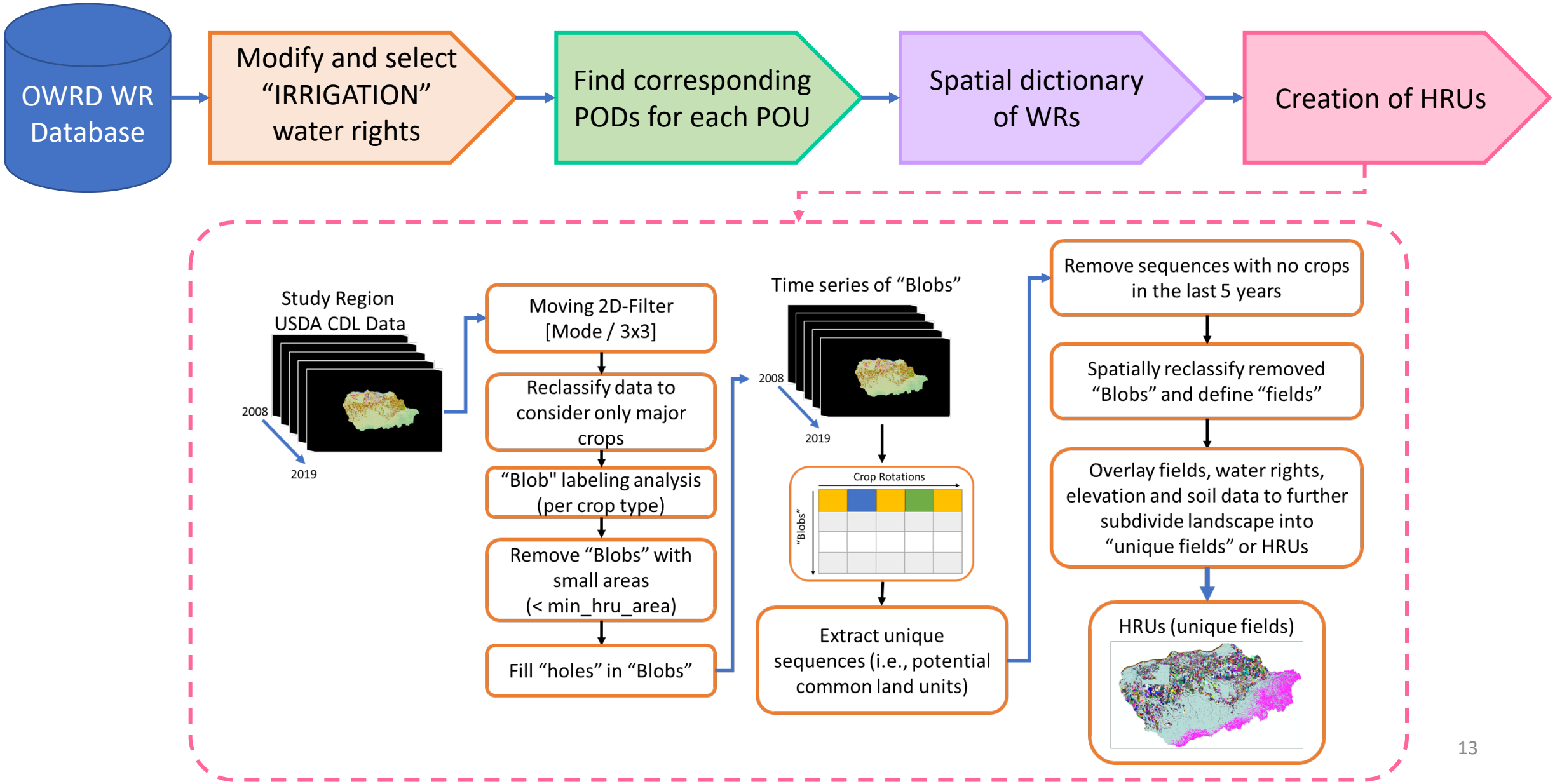


WR_1 - Surface water
WR_2 – Groundwater
WR_3: WR_1 & WR_2

Surface water POUs

Groundwater POUs

Approach: Integration of water rights data in SWAT Model



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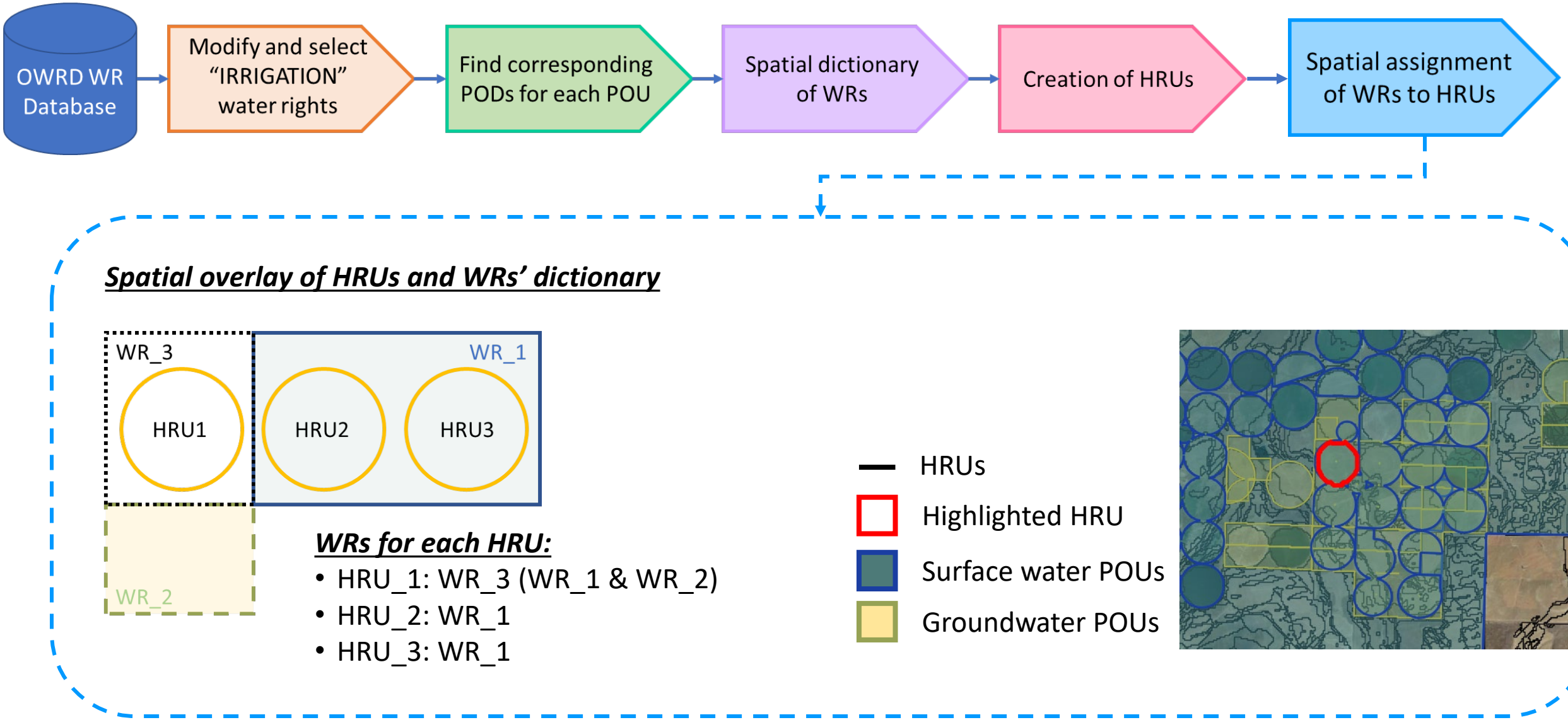


Water Rights, HRUs & Irrigation Decisions

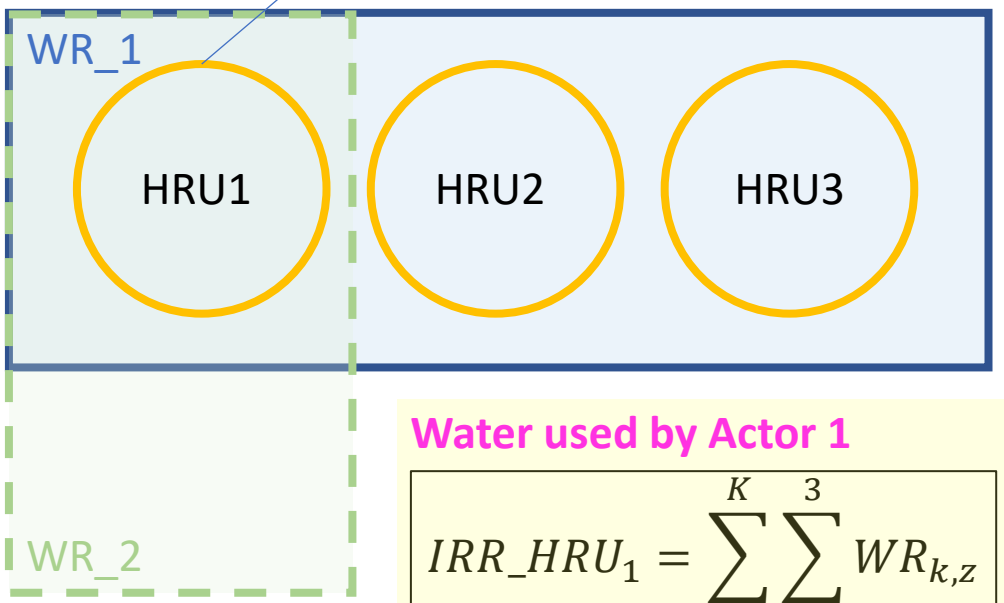
- **HRUs = Unit of Land where Irrigation Decisions are made**
  - Water rights can now be used by multiple hydrologic response units (HRUs)
  - We consider the HRUs with both GW and SW rights and/or multiple GW/SW water rights
  - Use of multiple WRs in an HRU was prioritized by:
    1. Length of pumping period
    2. Start pumping date
    3. Priority date
    4. Surface water over Groundwater

- Agricultural operations are still done at the HRU level
  - Assumption: Farmers ("real actors") will know which parcels of land they control, and therefore how to adjust the agricultural operations.

Decision variables (Actor level)

IRR_HRU_1 – *irrigation amount*

$Crop_j\_HRU_1$ – *crop ID*



Water used by Actor 1

$$IRR\_HRU_1 = \sum_{k=1}^{K} \sum_{z}^{3} WR_{k,z}$$

$$IRR\_HRU_1 \leq WR_1 + WR_2$$
$$IRR\_HRU_1 + IRR\_HRU_2 + IRR\_HRU_3 \leq WR_1$$

IRR_HRU_i – *volume of water used for irrigation at* HRU_i

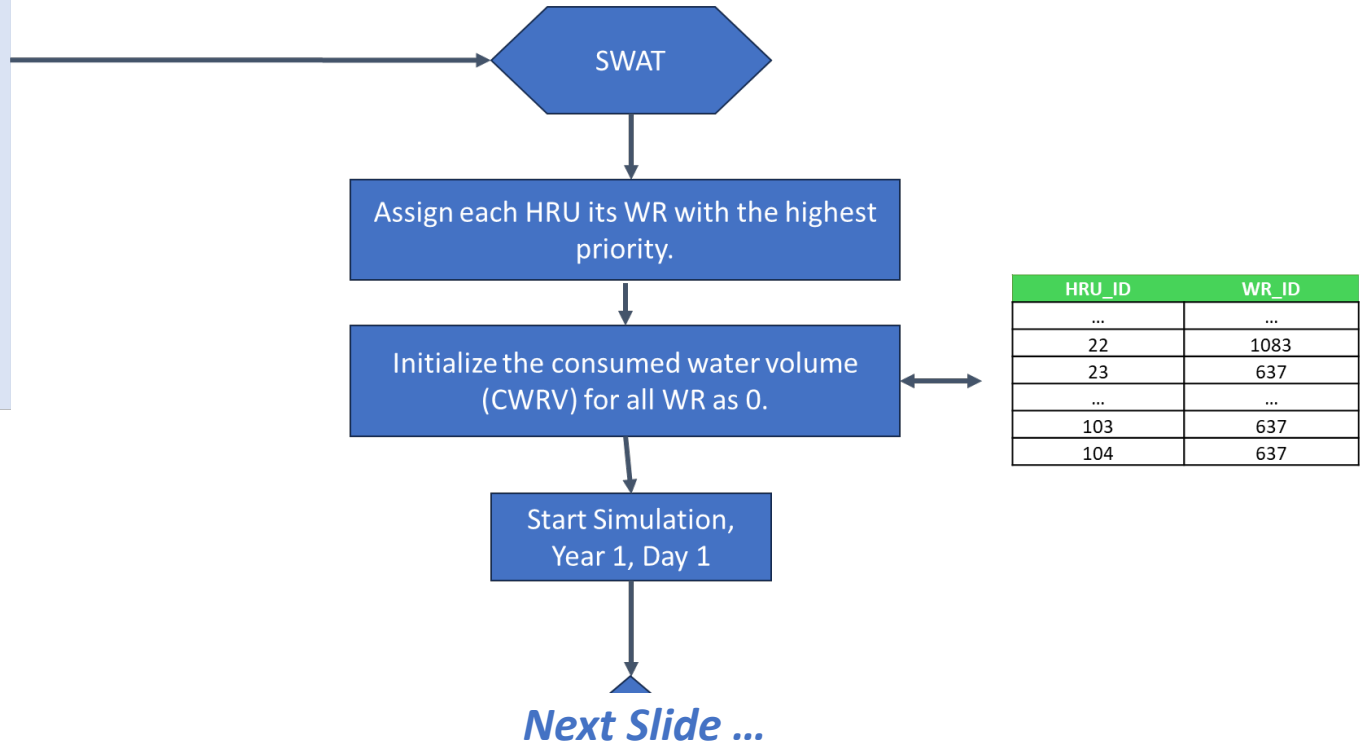
Input HRU and WR Data

wrdata.dat

YEAR_ID	WR_ID	WR_SOURCE_ID	WR_VOL	WR_START_PUMPING	WR_END_PUMPING
1	1	1	70	1	365
1	2	1	53	1	365
1	3	1	158	1	365
1	4	1	268	60	304
…	…	…	…	…	…
1	637	4	751	60	304
…	…	…	…	…	…
1	1083	3	52	60	304
…	…	…	…	…	…

hruwr.dat

HRU_ID	WR_ID	WR_SOURCE_ID	PRIORITY
…	…	…	…
22	1083	3	1
23	637	4	1
23	1083	3	2
…	…	…	…
103	637	4	1
104	637	4	1



HRU_ID	WR_ID
…	…
22	1083
23	637
…	…
103	637
104	637

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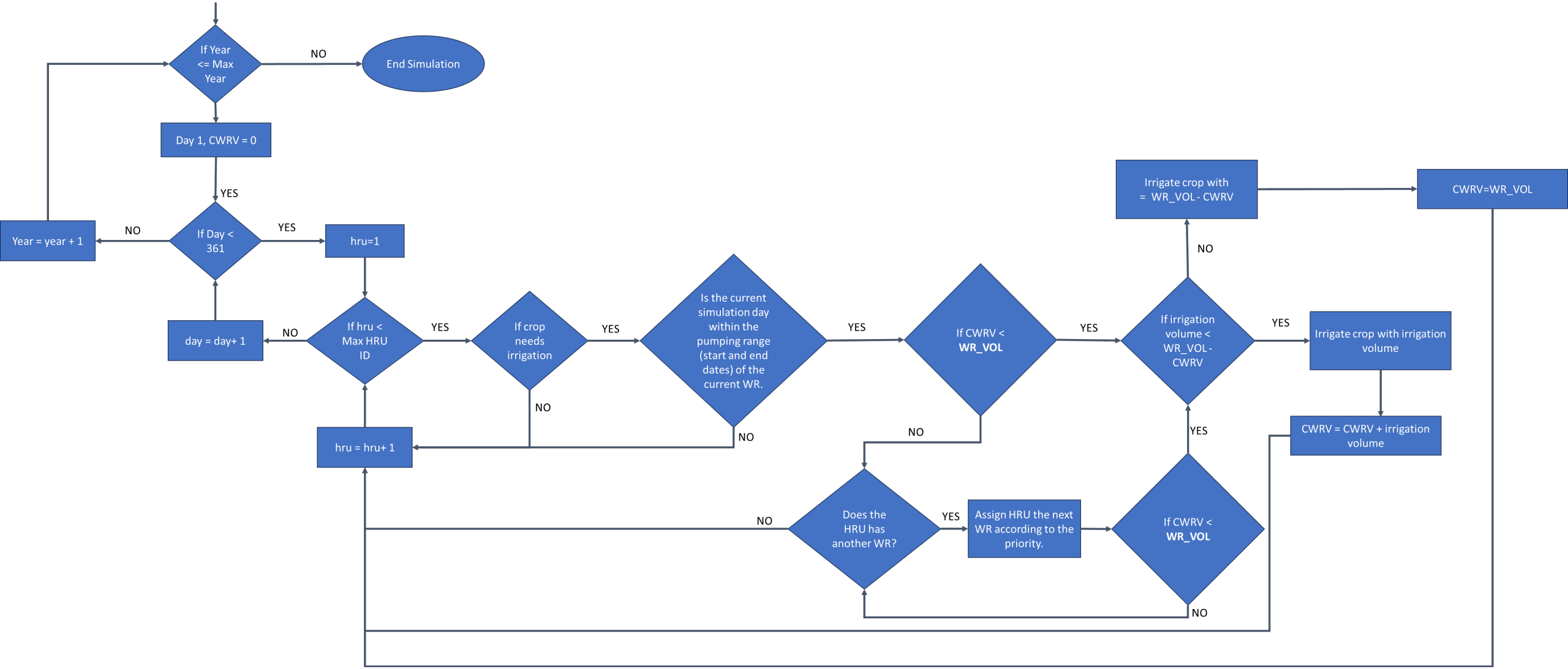
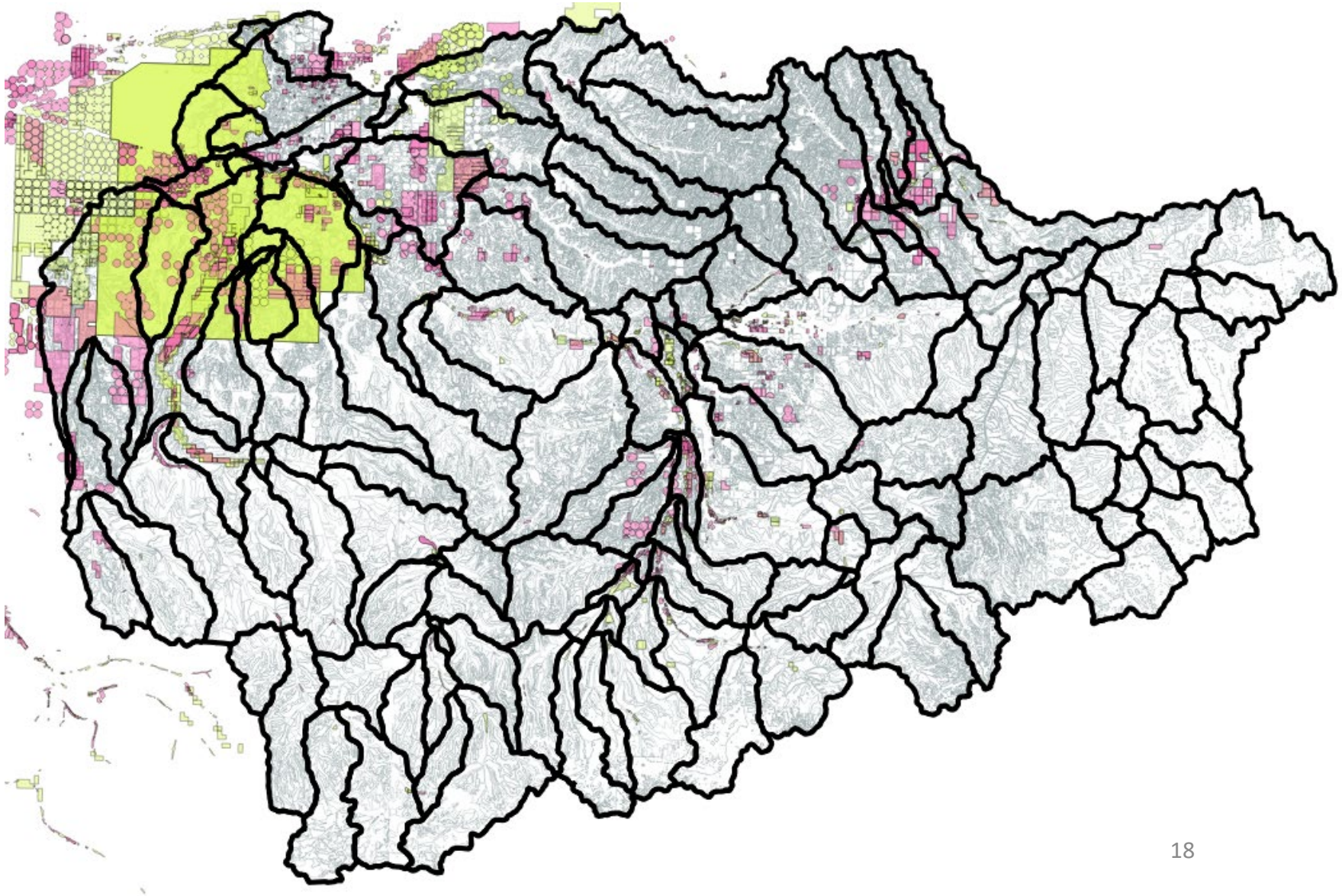


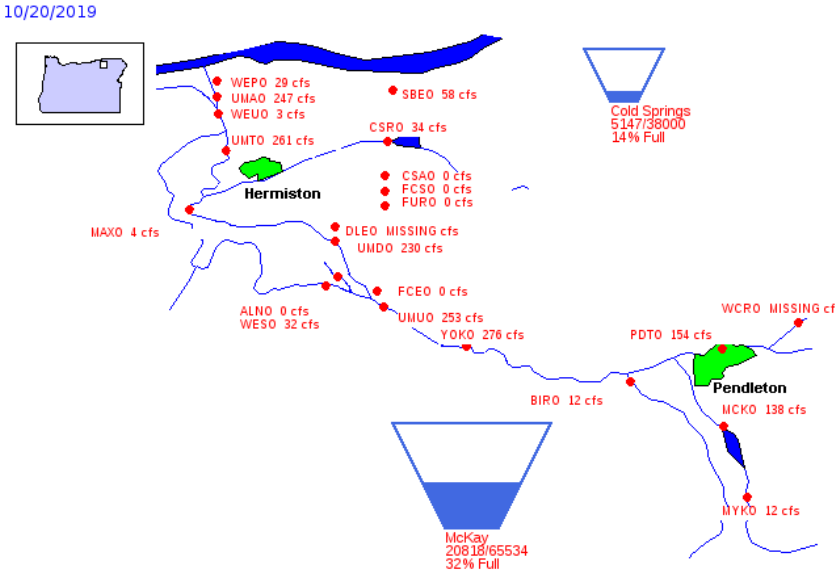
Water Rights and HRUs: Umatilla Model

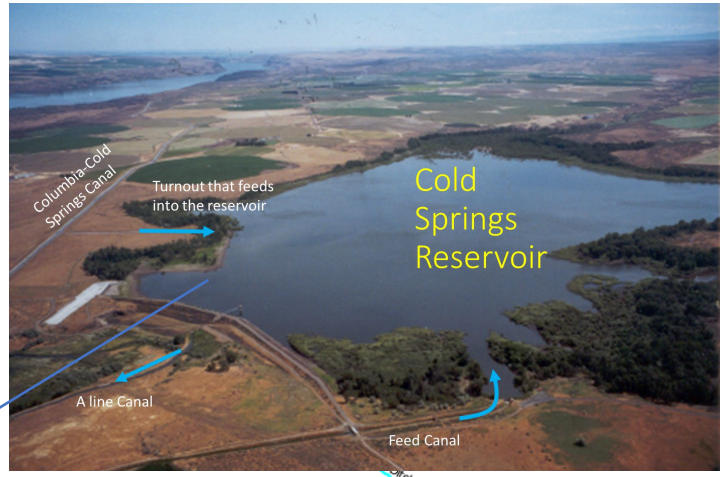
- Water rights: 1,805
- Sub-basins: 147
- HRUs: 11,346

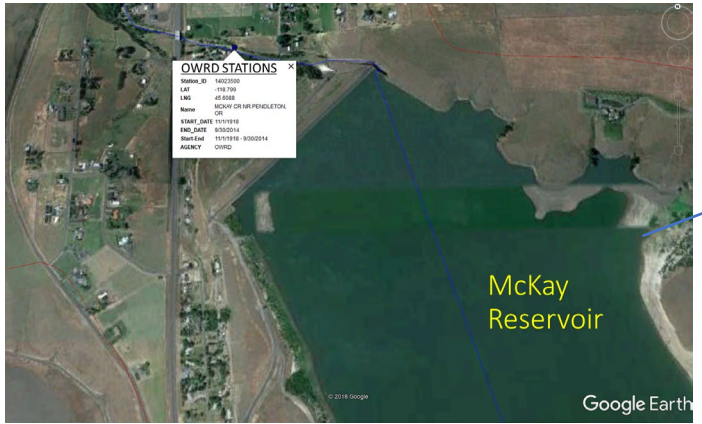


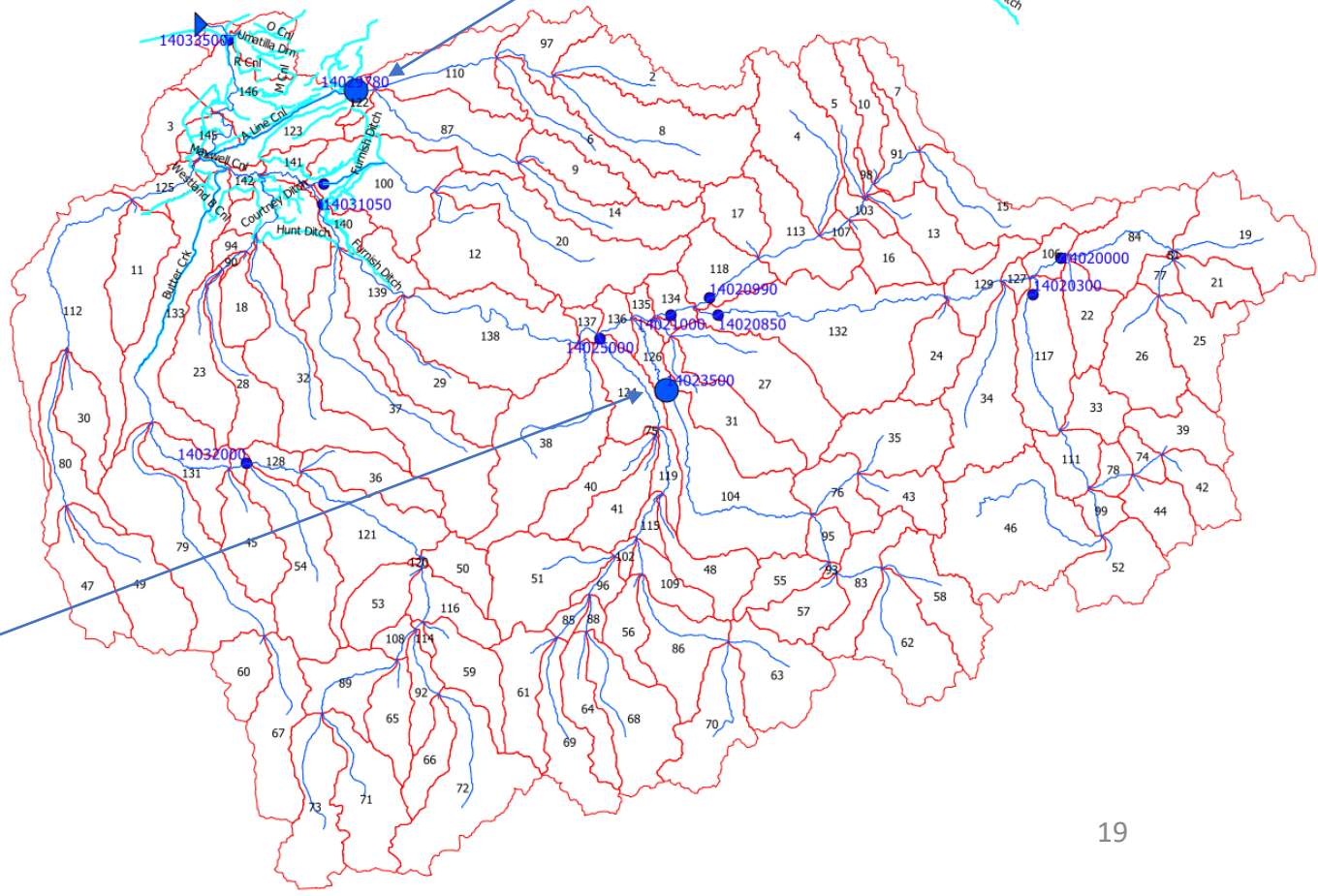
SWAT Model Inputs: Reservoirs, Diversions & Stream Gages

Bureau of Reclamation, Pacific Northwest Region
Umatilla River Basin Storage and Flow Diagram
https://www.usbr.gov/pn/hydromet/umatilla/umatea.html

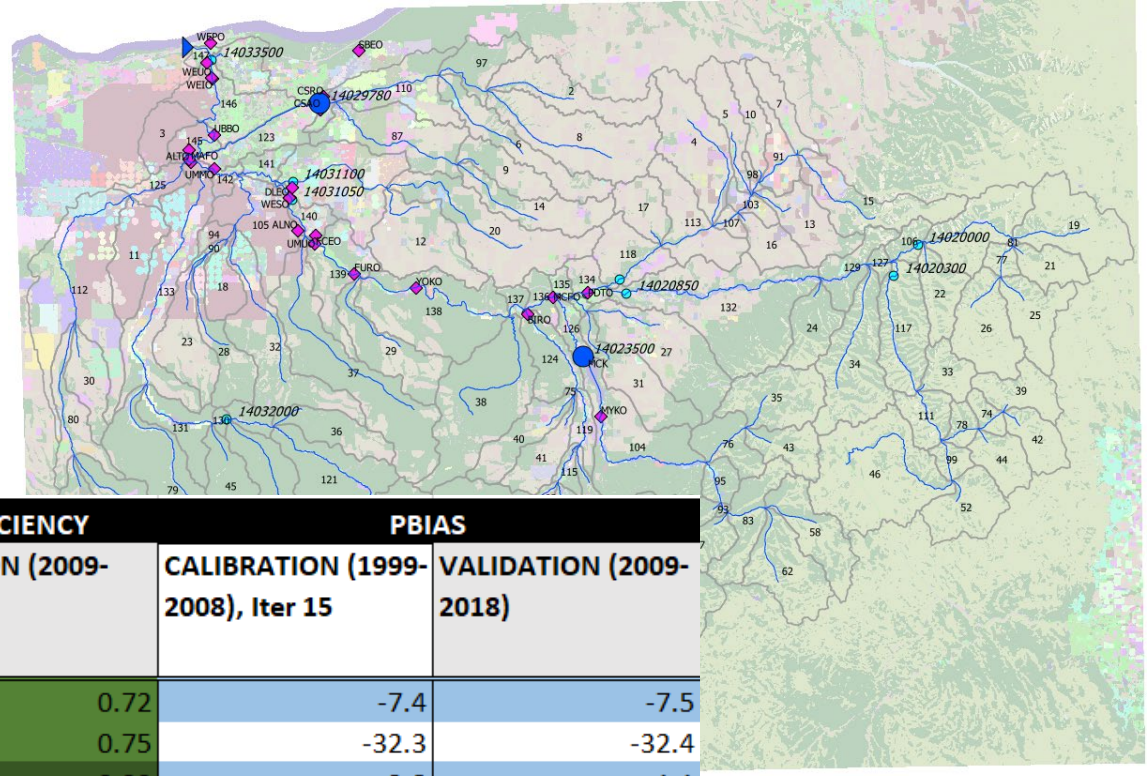








Calibration & Validation Results (Streamflows and Reservoir Storage)



Aim

Nash Sutcliffe Efficiency ≥ 0.5

PBIAS ≤ ± 25%

			NASH SUTCLIFFE EFFICIENCY		PBIAS	
	STATE VARIABLES	LOCATIONS	CALIBRATION (1999-2008), Iter 15	VALIDATION (2009-2018)	CALIBRATION (1999-2008), Iter 15	VALIDATION (2009-2018)
Calibration Process (East Region)	FLOW_IN_106	14020000	0.72	0.72	-7.4	-7.5
	FLOW_OUT_104 (McKay in)	MYKO	0.72	0.75	-32.3	-32.4
	RES_FLOW_OUT_2_104 (McKay OUT)	MCKO	0.98	0.99	2.8	1.1
	FLOW_OUT_117	14020300	0.72	0.67	-21.3	-26.5
	FLOW_OUT_118	14020990	0.65	0.61	-2.6	-34.8
	FLOW_OUT_124	14025000	0.61	0.71	-48	-32.7
	FLOW_OUT_132	14020850	0.76	0.74	-9.8	-16.6
	FLOW_OUT_134	14021000	0.74	0.72	-17.2	-25
Calibration Process (West Region)	FLOW_IN_130	14032000	0.47	0.42	-18.3	29.1
	FLOW_IN_123 (CS OUT)	14029780	0.98	0.99	4.11	2.33
	FLOW_OUT_140	14031050	0.63	0.77	-23	-24.6
	FLOW_OUT_146	14033500	0.55	0.74	-29.5	-23.8
	RES_VOL_1_122 (CS)	CS STARG	0.85	0.75	12.13	-7.97
	RES_VOL_2_104 (McKay)	MCKAY STARG	0.56	0.48	10.8	-3.5

Results and Discussions

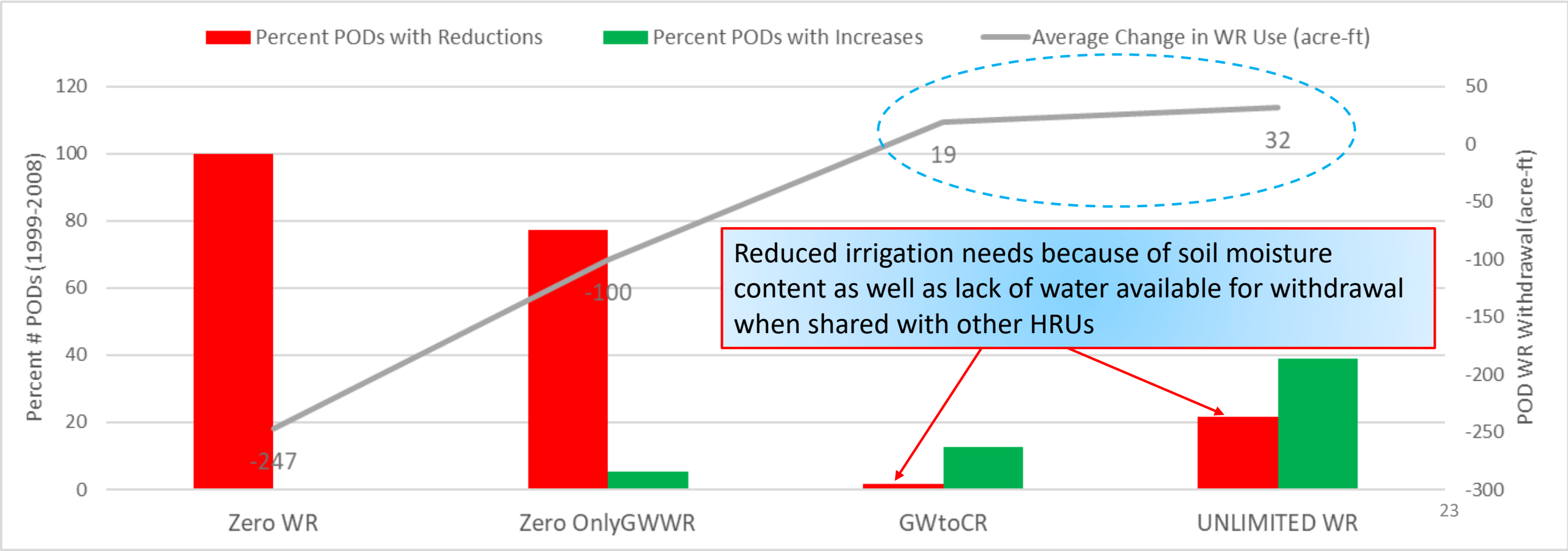
Water Allocation Scenarios Tested

1. **Baseline:** Current Allocations of Irrigation Water Rights
2. **Zero WR:** Zero allocation of surface water and groundwater water rights used for irrigation (i.e., “shut off all WR”)
3. **Unlimited WR:** No constraining limits to water volumes of existing surface water and groundwater water rights used for irrigation
4. **Zero OnlyGWWR:** Zero allocation of groundwater water rights for irrigation (i.e., “shut off only GWWR”)
5. **GWtoCR:** Source of all groundwater water rights replaced with an external source (specifically, the main Columbia River downstream of the outlet of Umatilla river basin).

Effect on POD Water Withdrawals (WRS_USE.OUT)

In comparison to Baseline (i.e., current) Water Right withdrawals, over a ten year period (1999-2008)

1. **ZeroWR** have most number of WR diversions affected by reductions, as expected
2. While **UmlimitedWR** has the highest number of water rights that experienced increases in withdrawals, the average increase in the amount water rights volumes (acre-ft) of **UmlimitedWR** was only slightly higher than that of **GWtoCR**.



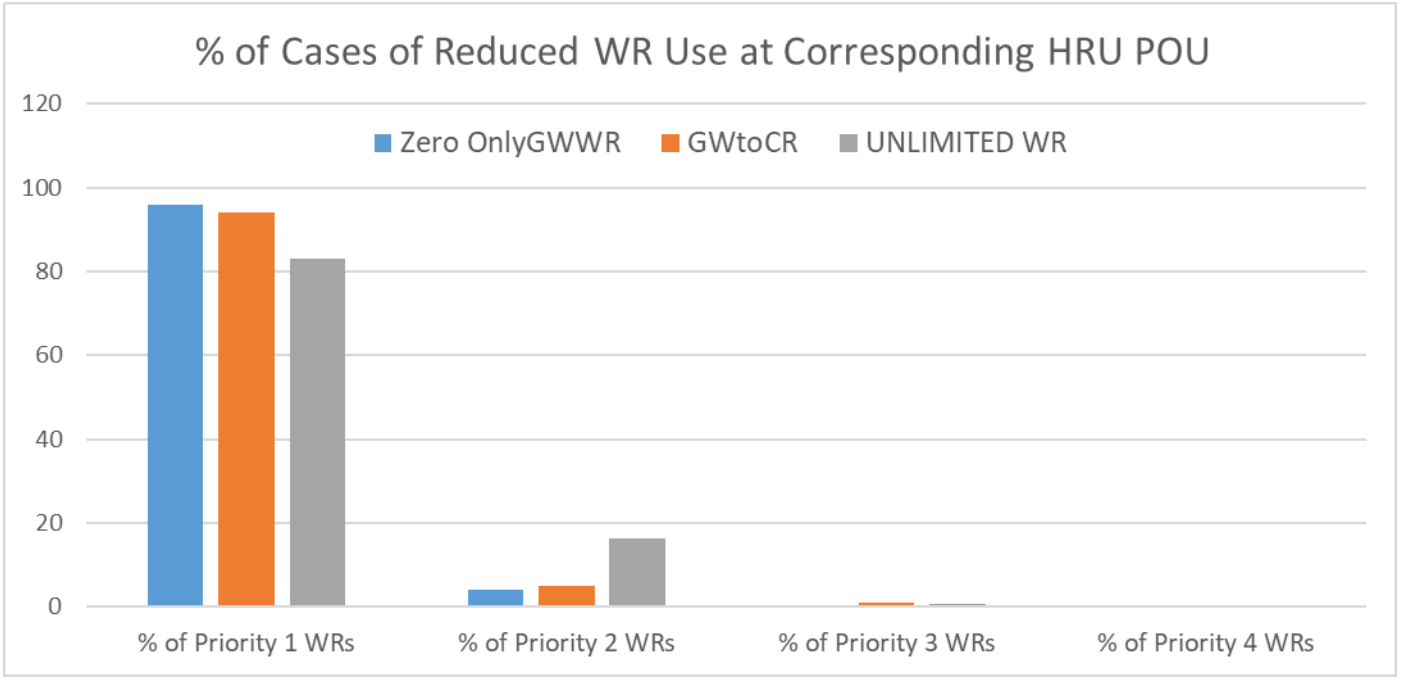
Effect on Water Use at HRU POU (HRU_WRT.OUT)

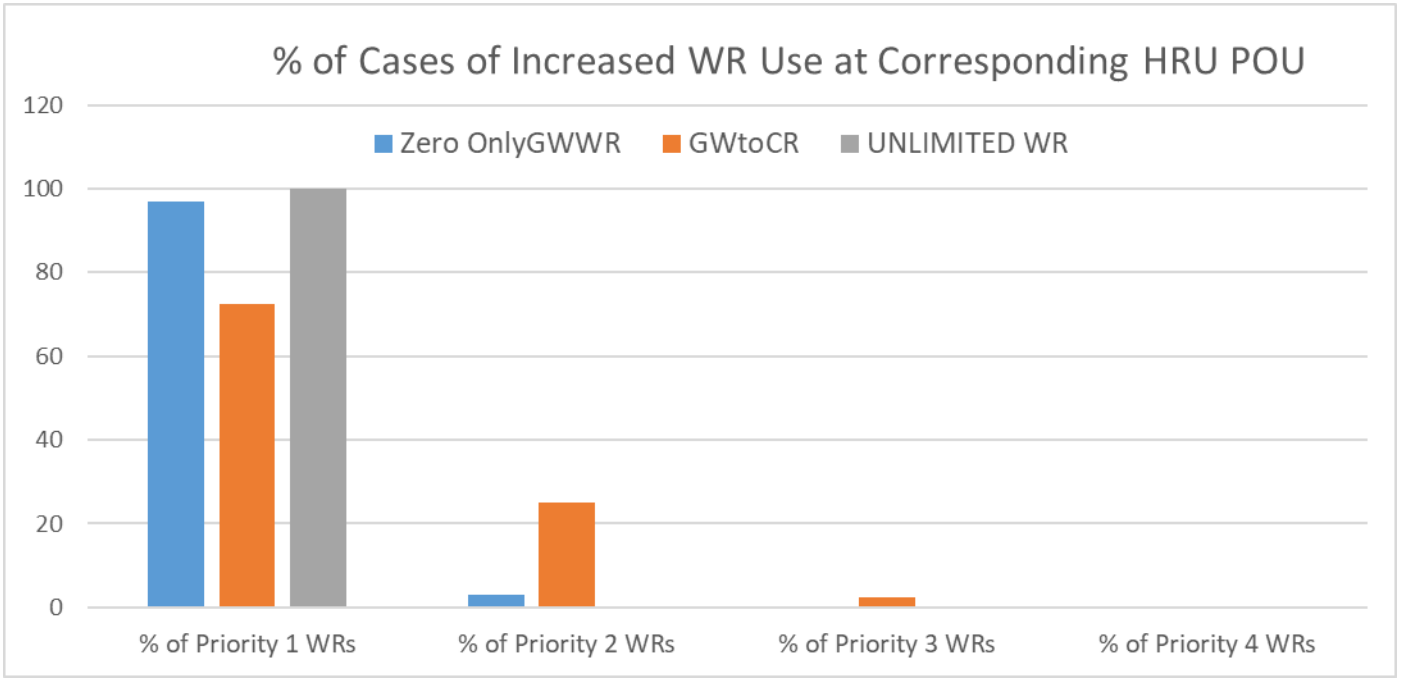
In comparison to Baseline (i.e., current) Water Right use at POU (i.e., HRU), over a ten year period (1999-2008):

1) **Ratio of # HRUs** with reductions in WR use versus increase in WR use (*excluding those with no change*)
    1) Zero_OnlyGWWR = 14:1
    2) GWtoCR = 1:4
    3) UNLIMITED WR = 1:2

2) For HRUs that had reductions in WR Use,
    1) **Zero_OnlyGWWR** scenario had the highest share of **Priority 1** WRs affected .
    2) Among **Priority 1** WRs, **UNLIMITED WR** scenario had the **lowest share of Priority 1** WRs affected and **highest share of Priority 2** WRs affected.

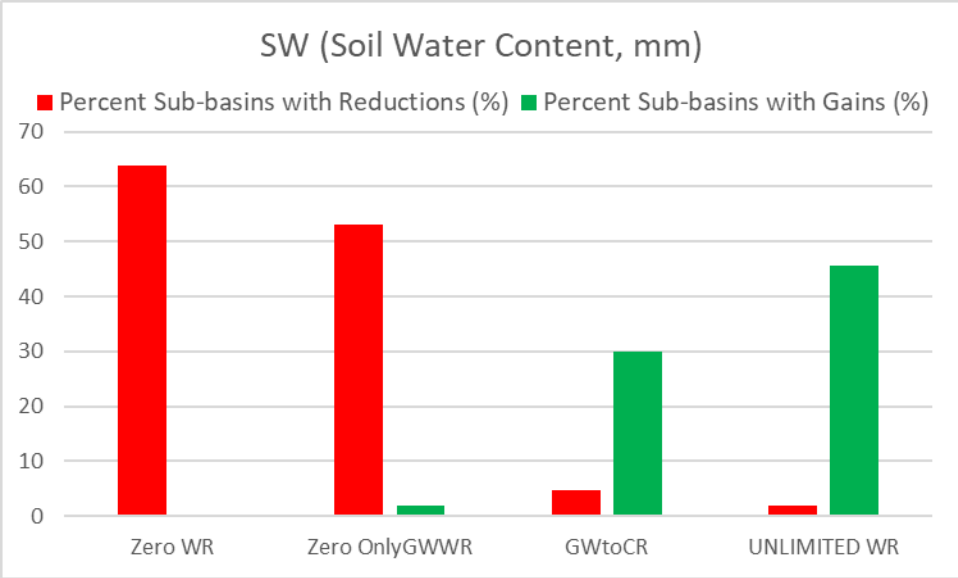
3) For HRUs that had increases in WR Use,
    1) **UNLIMITED WR** scenario had the highest numbers of **Priority 1** WRs affected .
    2) Among **Priority 1** WRs, **GWtoCR** scenario had the **lowest share of Priority 1** WRs affected and **highest share of Priority 2 and Priority 3** WRs affected.





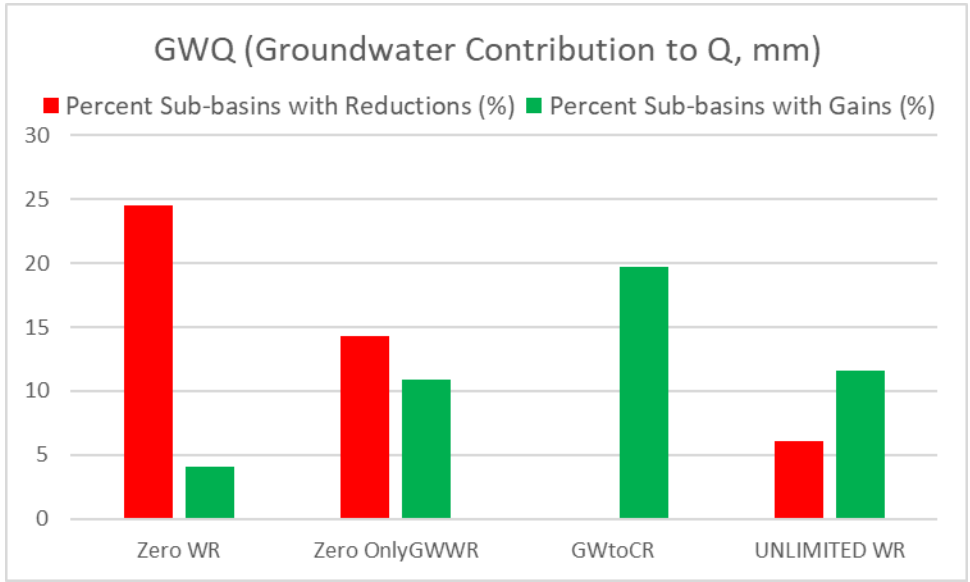
Effect on Sub-basin Water Budgets

Averages over a ten year period (1999-2008)



Shutting off WRs (**Zero WR** and **Zero OnlyGWWR**) negatively affected Soil Water Content in most sub-basins

GWtoCR and **UnlimitedWR** positively affected Soil Water Content and Water Yield in most sub-basins



GWtoCR is more effective in improving groundwater contribution to streamflows in comparison to **UNLIMITED WR** where original surface water rights are also overconsumed

Conclusions and Future Work

- Water rights allocation can increase or decrease the use of junior and senior water rights in unique ways at their place of use (i.e., at HRU).
- Interdependencies exist among water rights (sources and amounts), irrigation demand, and hydrologic processes can significantly influence the impacts of new water rights allocations in a region.
- **Future:**
  - Instead of identifying irrigation needs using HRU as a counter, use a combination of HRU IDs and WR Priority Dates to allocate water every day.
  - Add other water rights withdrawals to the code (e.g., municipal withdrawals)

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Acknowledgements

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- Students: Nicholas Giles, Sudip Gautam