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# Understanding the Impact of Agriculture on Water Quality in Oregon



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UNIVERSITY

Agricultural  
Experiment Station

**OSU** Extension  
Service

# Impact of Agriculture on Water Quality in Oregon and the Pacific Northwest



# Pesticide Use and Water Quality – A Big Concern?

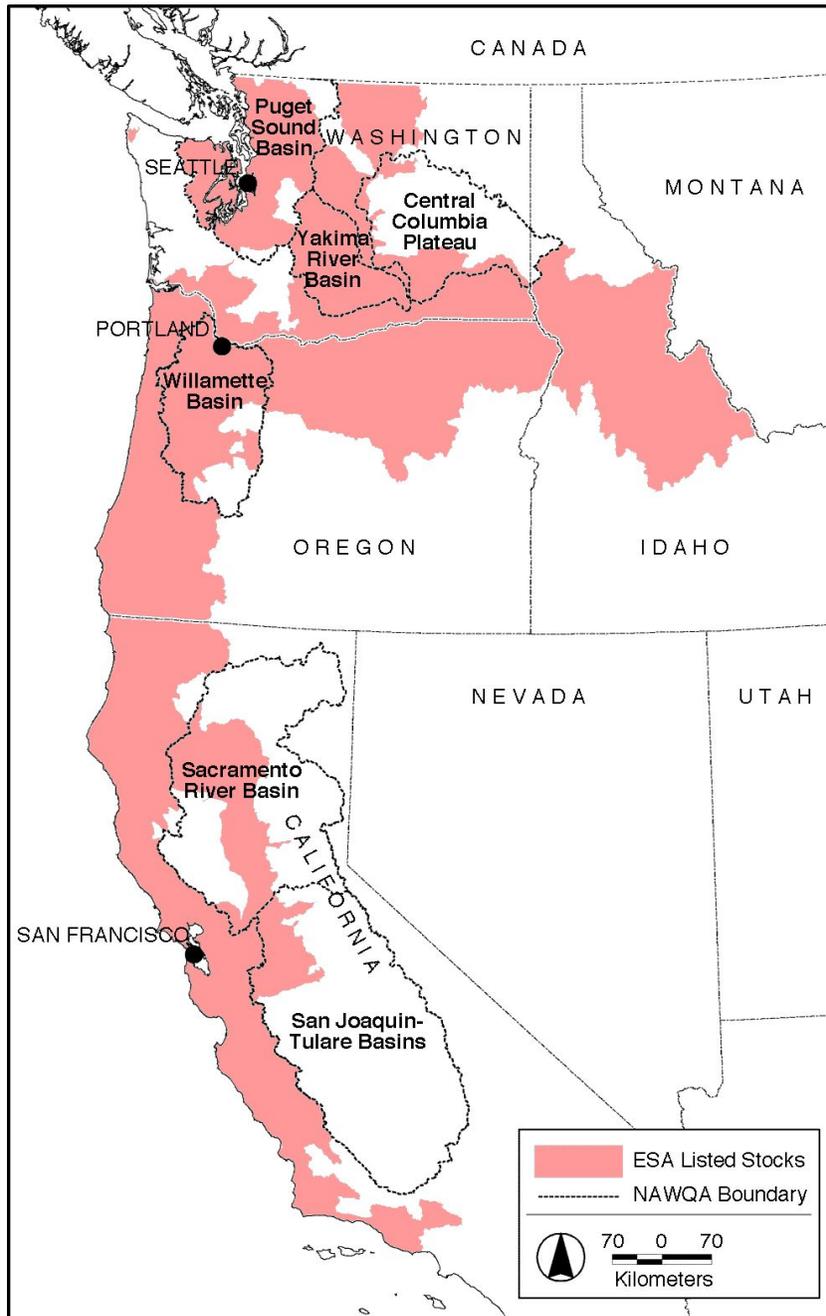
- Monitoring studies show frequent pesticide detections in surface water at some locations.
- Concerned communities – drinking water contamination.
- Protection of aquatic resources – Endangered Species Act listed salmonids, food web.



# Washington Toxics Coalition v EPA Ninth Circuit Court of Appeals (2001)

EPA failure to consult with NOAA regarding  
the registration of 54 pesticides.

ESA-listed salmon and steelhead  
28 Evolutionarily Significant Units



*Oncorhynchus kisutch*



*Oncorhynchus keta*



*Oncorhynchus nerka*



*Oncorhynchus mykiss*



*Oncorhynchus tshawytscha*

# Endangered Species Coalition, 2019



**WARNING**  
**Pesticides**  
Salmon tainted with toxins

POPULATION: A fraction of historic population

STATUS: Some threatened, some endangered

RANGE: Pacific Northwest and California

HABITAT: Clear, cool streams, migratory river corridors, estuaries, and the ocean

## Chinook Salmon

*Oncorhynchus tshawytscha*

Chinook salmon, the largest salmon, have sustained Native American tribes since time immemorial and supported thriving fishing communities throughout the Pacific Northwest and California. Born in cold, freshwater streams, these salmon migrate to the ocean, where they mature to adulthood and live for several years. For their final chapter, the Chinook journey hundreds of miles upstream—to the very waters where they were born—and then they breed and die. Their carcasses feed bears, eagles, and other wildlife and deposit rich marine nutrients in forests that shade and protect streams and rivers.

Toxic chemicals impair the Chinook's ability to swim and evade predators, and contaminate this salmon's fatty tissues.

Chinook salmon have declined due to human activities, including overfishing, development, and agriculture. Our dams block their migration and outright kill them. And they are impacted by pesticides, which enter salmon streams in contaminated runoff. These toxic chemicals kill salmon prey and aquatic plants that provide cover and shelter. They impair salmon's ability to swim and evade predators. And they deposit in the fatty tissues of the Chinook.

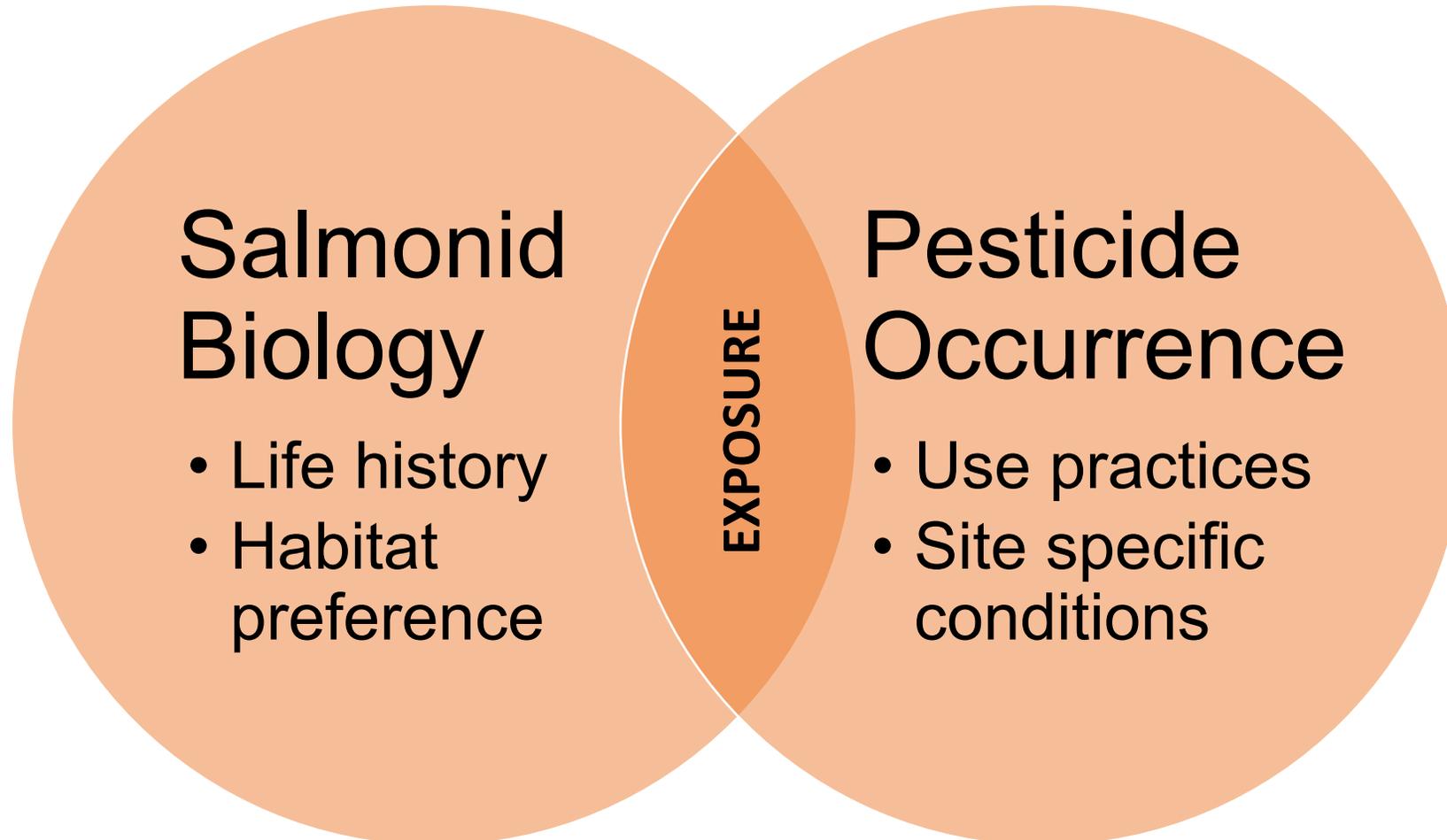
As the fattiest salmon, the Chinook are critical to the survival of endangered Southern Resident orca whales. These orcas swim in the Salish Sea—interconnected waters including Puget Sound, the Strait of Juan de Fuca, and Strait of Georgia—and in coastal ocean waters off the Pacific Northwest. They are fish-eating mammals that rely on salmon for survival, and they greatly prefer the fat-rich Chinook. Indeed, about 80 percent of their diet is comprised of these salmon, and they need 300 to 350 pounds of them every single day to avoid starvation.

But thanks to those migration-blocking and salmon-killing dams, the orcas' primary food supply is disappearing. And the Chinook they do consume are likely tainted with toxins that then deposit in the orca's own fatty reserves. This orca population has plummeted due to recent deaths from starvation, reproductive failures, and calf mortalities. Fewer than 75 remain. A tangled web of challenges—including the toxic impact of pesticides—is pushing each of these species closer to extinction.

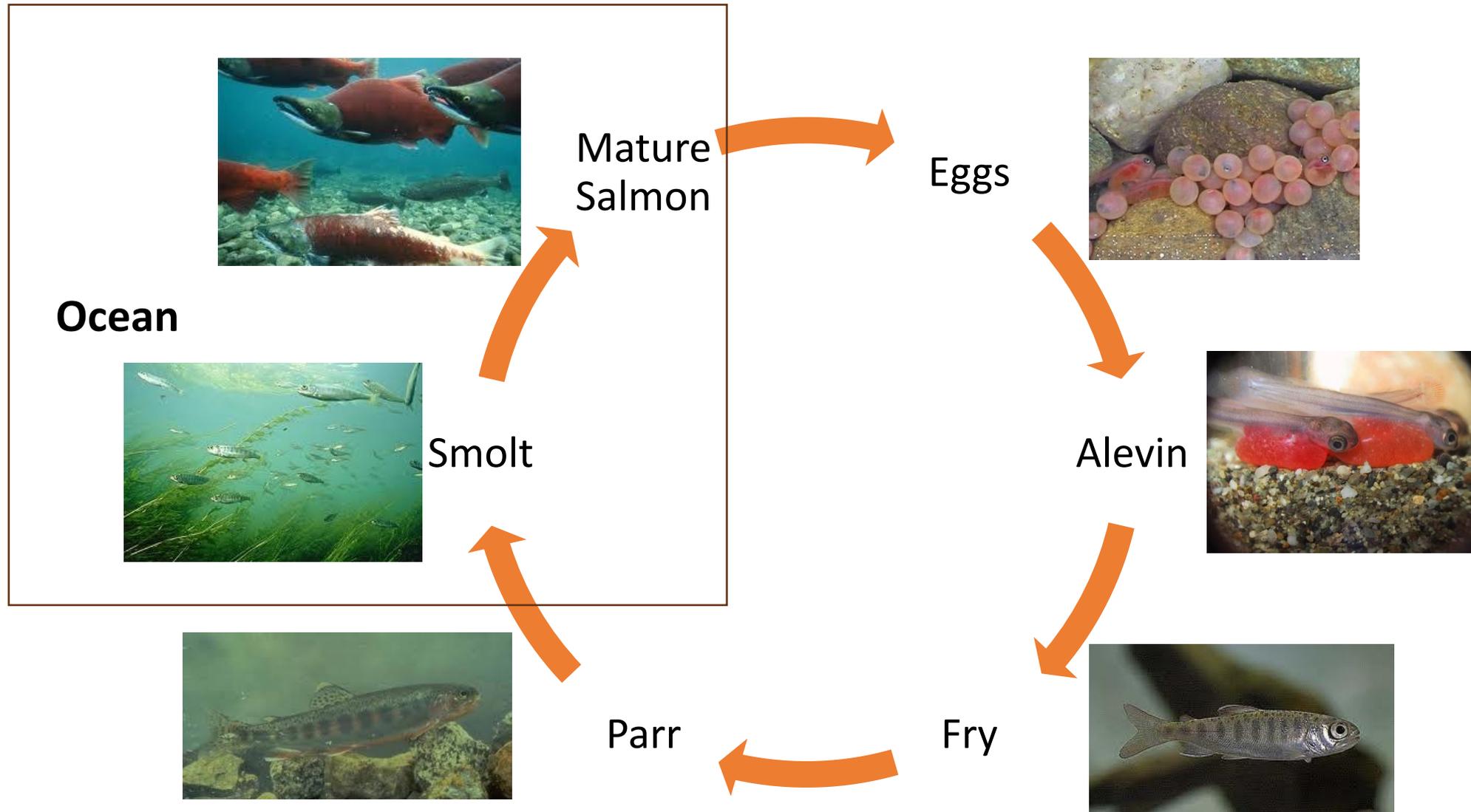
Young Chinook salmon  
Zureka/Wikimedia Commons



# Pacific Salmonid: Opportunities for Pesticide Exposure



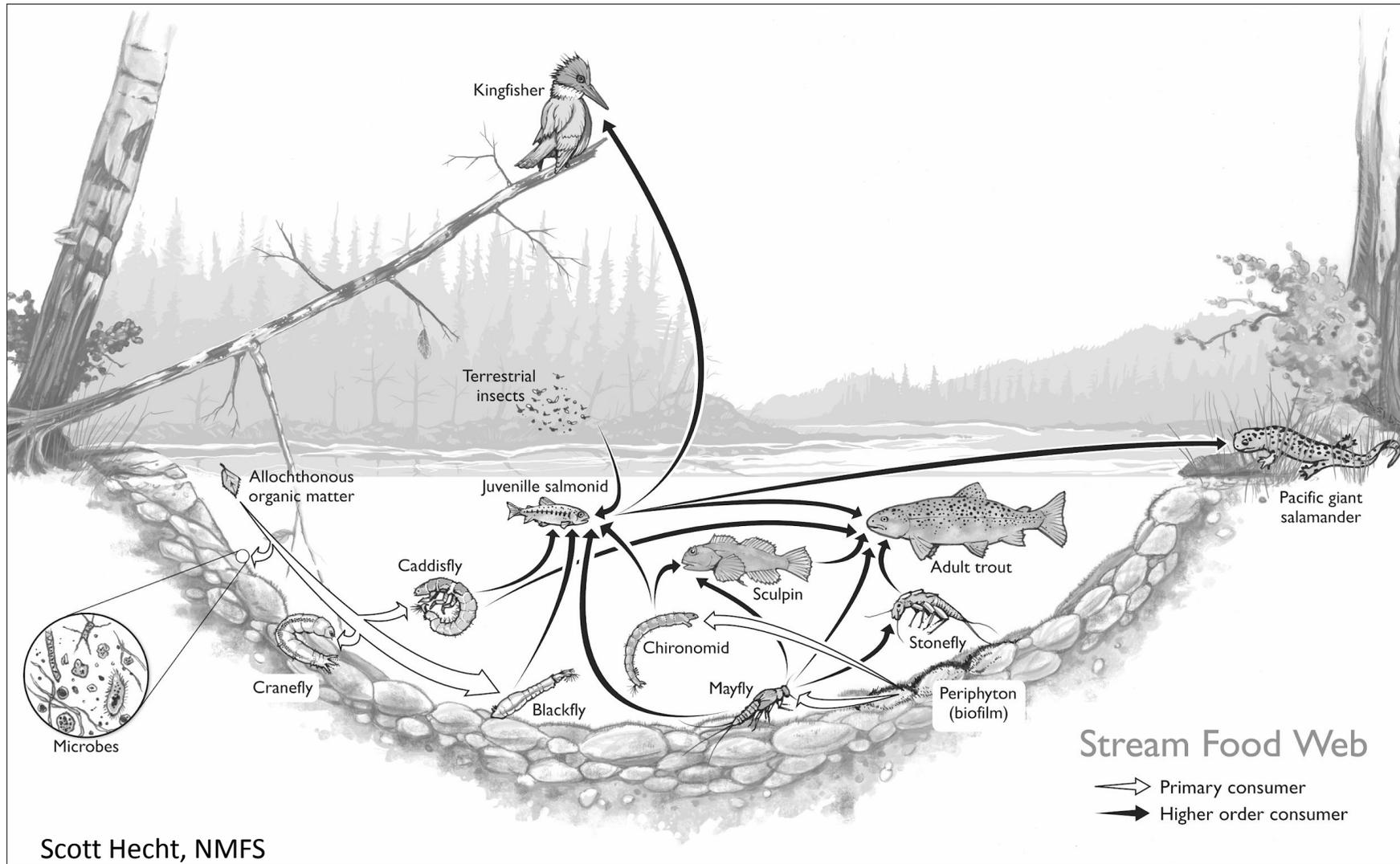
# Pacific Salmon Life Cycle

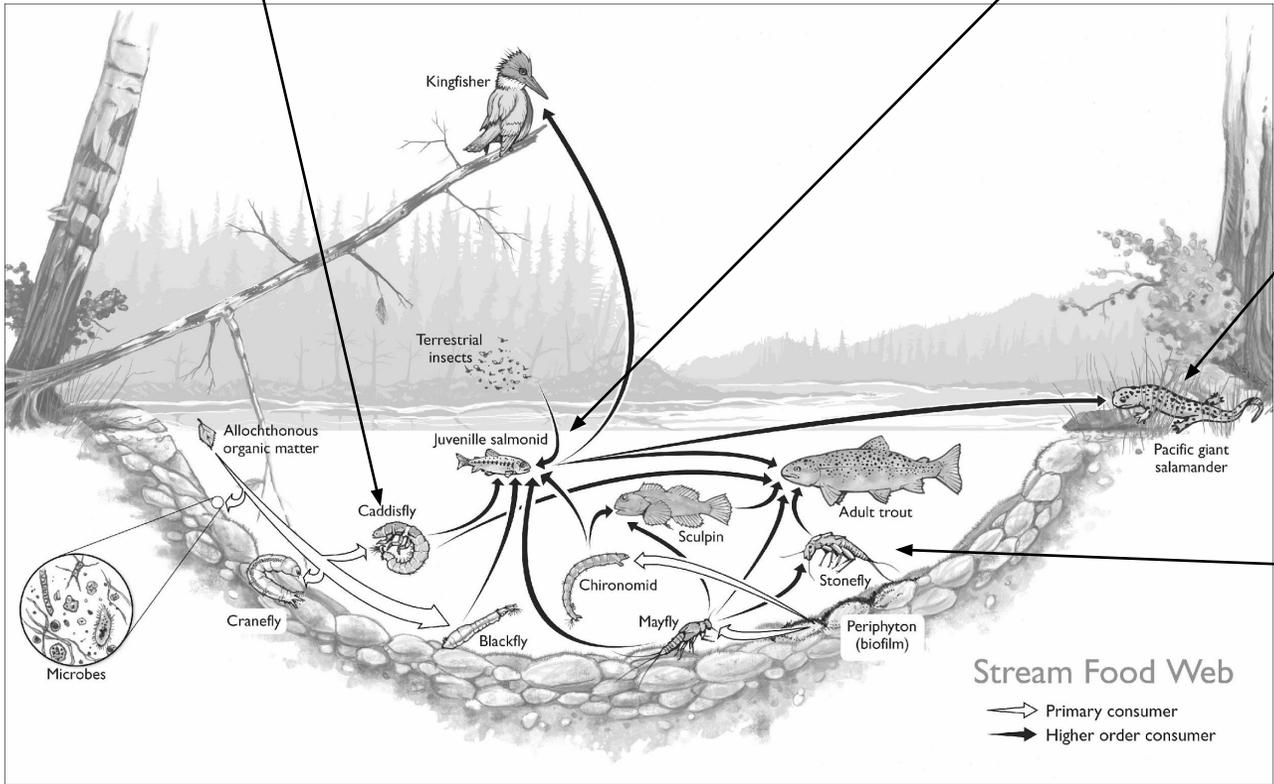


# Pacific salmon spawning habitat



# Pacific Salmonid Biology, Food Web and Critical Habitat



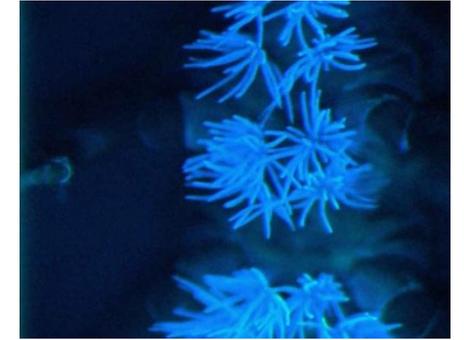
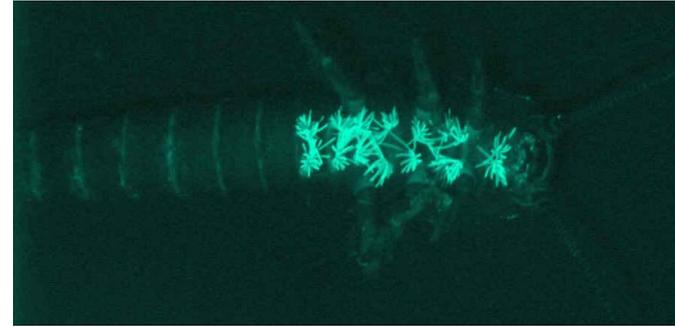


# Pacific salmon spawning habitat

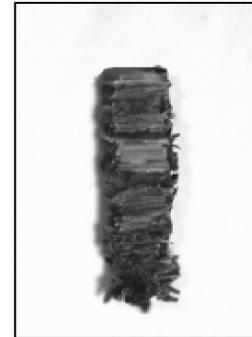


# Understanding Chemical Effects on Native Freshwater Species

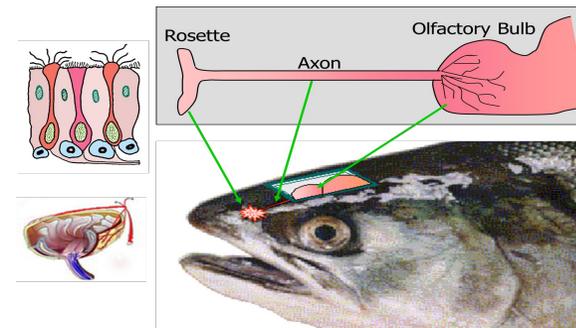
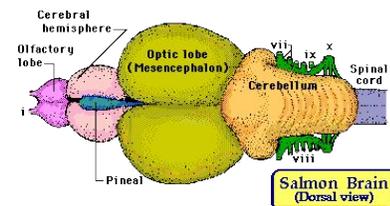
How aquatic insects breathe determines harm by chemicals.



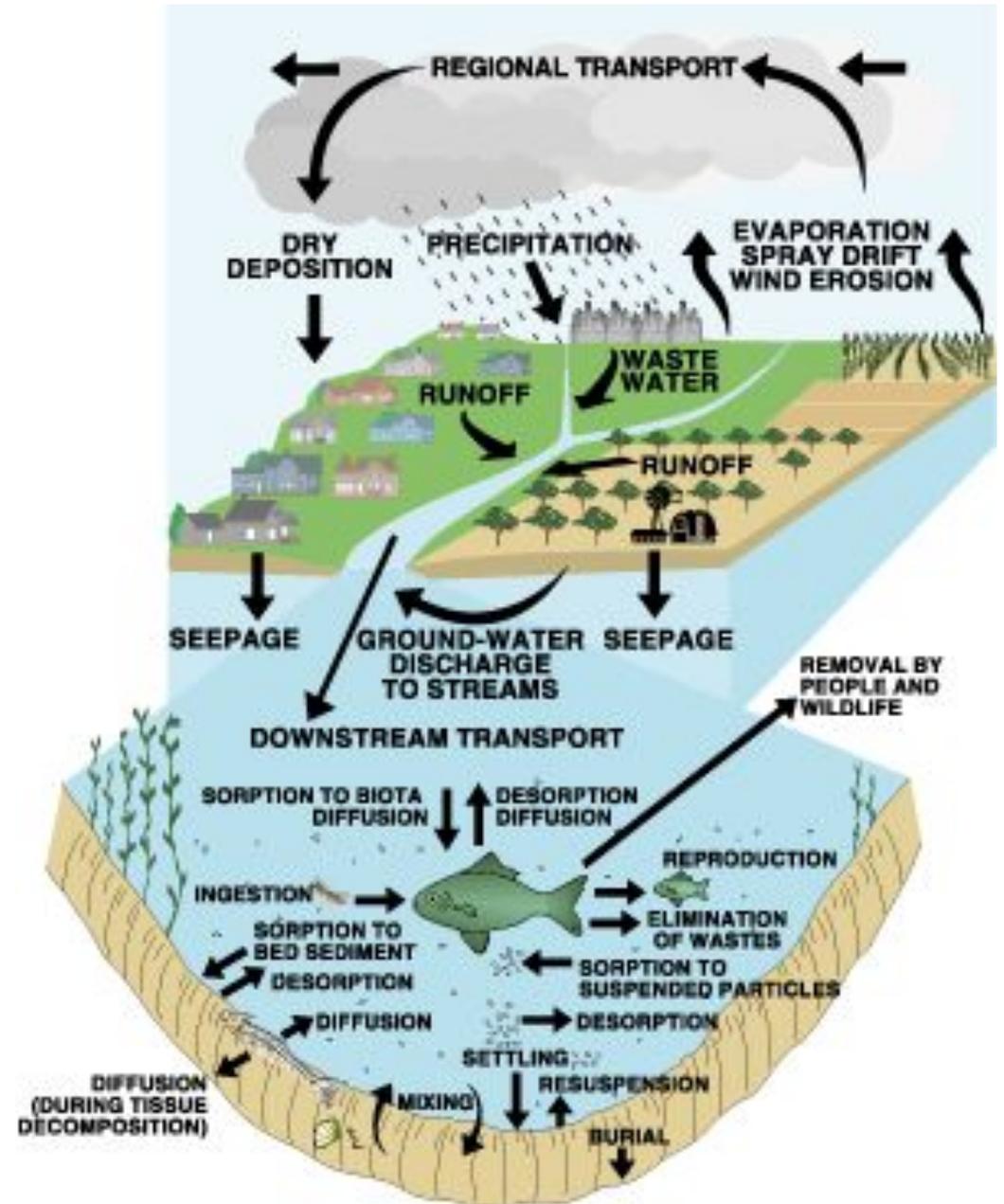
Caddisfly leave their case when exposed to chemicals.



Chemicals effect the juvenile salmon nervous system; how they smell, feed, and avoid predators.



What is agriculture's contribution to the chemical load and impact on human and environmental health in the Pacific Northwest?



# Pesticide Stewardship, Laws and Regulations

- USDA – An Integrated Pest Management (IPM) roadmap goal: reduce unreasonable adverse environmental effects from pests and the use of pest management practices.
- EPA – FIFRA: Pesticide labeled use if no unreasonable adverse effects to humans or the environment, or a reasonable certainty of no harm (FQPA).
- EPA – ESA allows pesticide uses that result in no harm to threatened or endangered species, in consultation with NOAA, USFW.
- EPA – Clean Water Act, Clean Air Act, Safe Drinking Water Act – potential for regulation at the farm level.

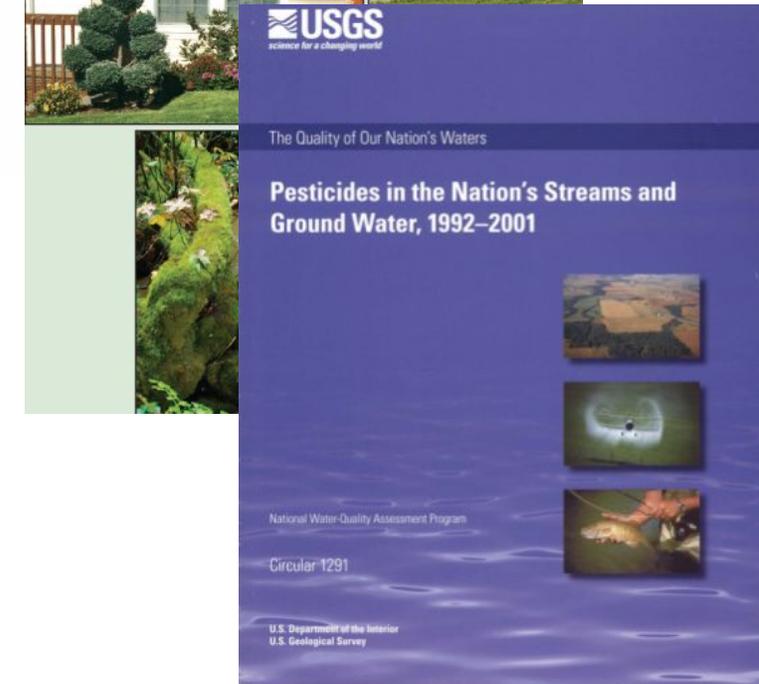
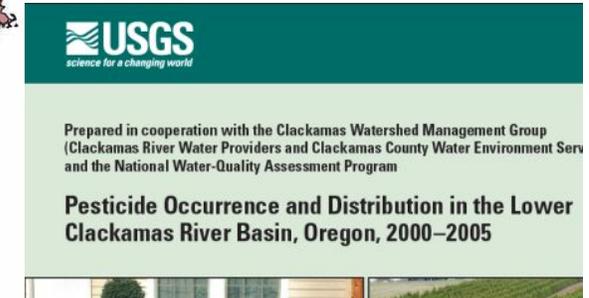
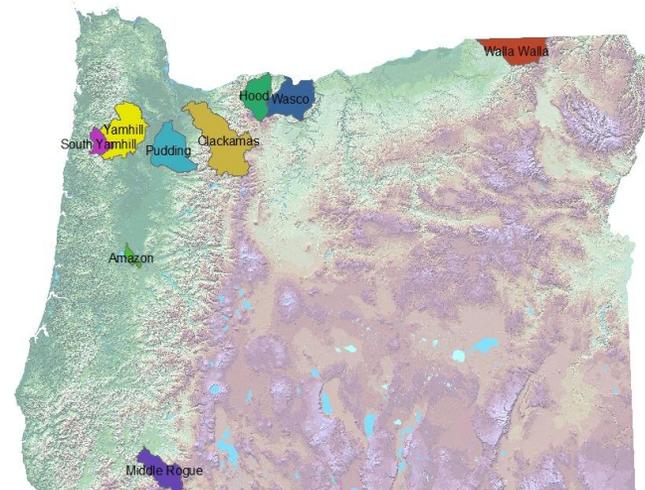
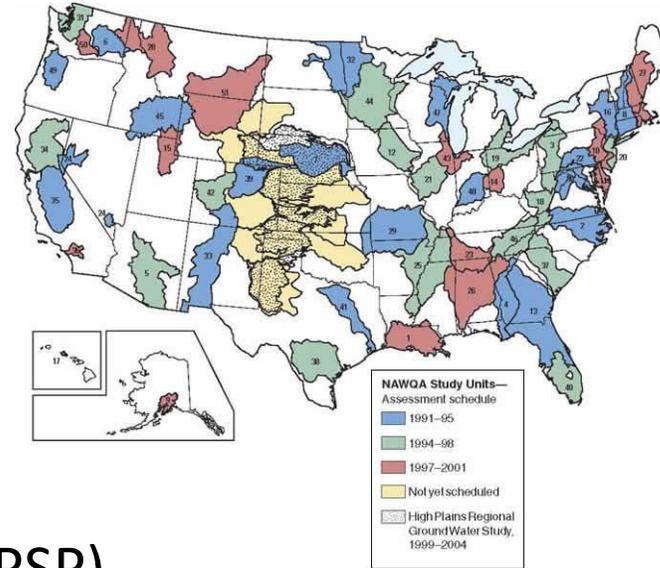
# Oregon Stakeholders

- Pesticide users
  - Industry
  - Agriculture
  - Forestry
  - Rights of Way
  - Municipal
  - Residential
- Federal Government
- State Government/PSP/WQPMT
- Tribes
- Land Grant university/OSU
- Watershed Councils/OWEB
- Non-Governmental Organizations
- Soil and Water Conservation Districts
- Irrigation districts
- Public

# Pesticide Surface Water Monitoring in the U.S. and Oregon

- US Geological Survey Monitoring
  - National Water Quality Assessment Program (NAWQA)
  - Clackamas River Basin studies

- Oregon Agency Monitoring
  - Pesticide Stewardship Partnership (PSP)
    - 9 Watersheds
    - 4 in Willamette Valley



# Causal diagram of factors affecting evaluation of in-stream pesticide monitoring (Chow et al., 2020)

R. Chow et al. / Water Research X 9 (2020) 100064

5

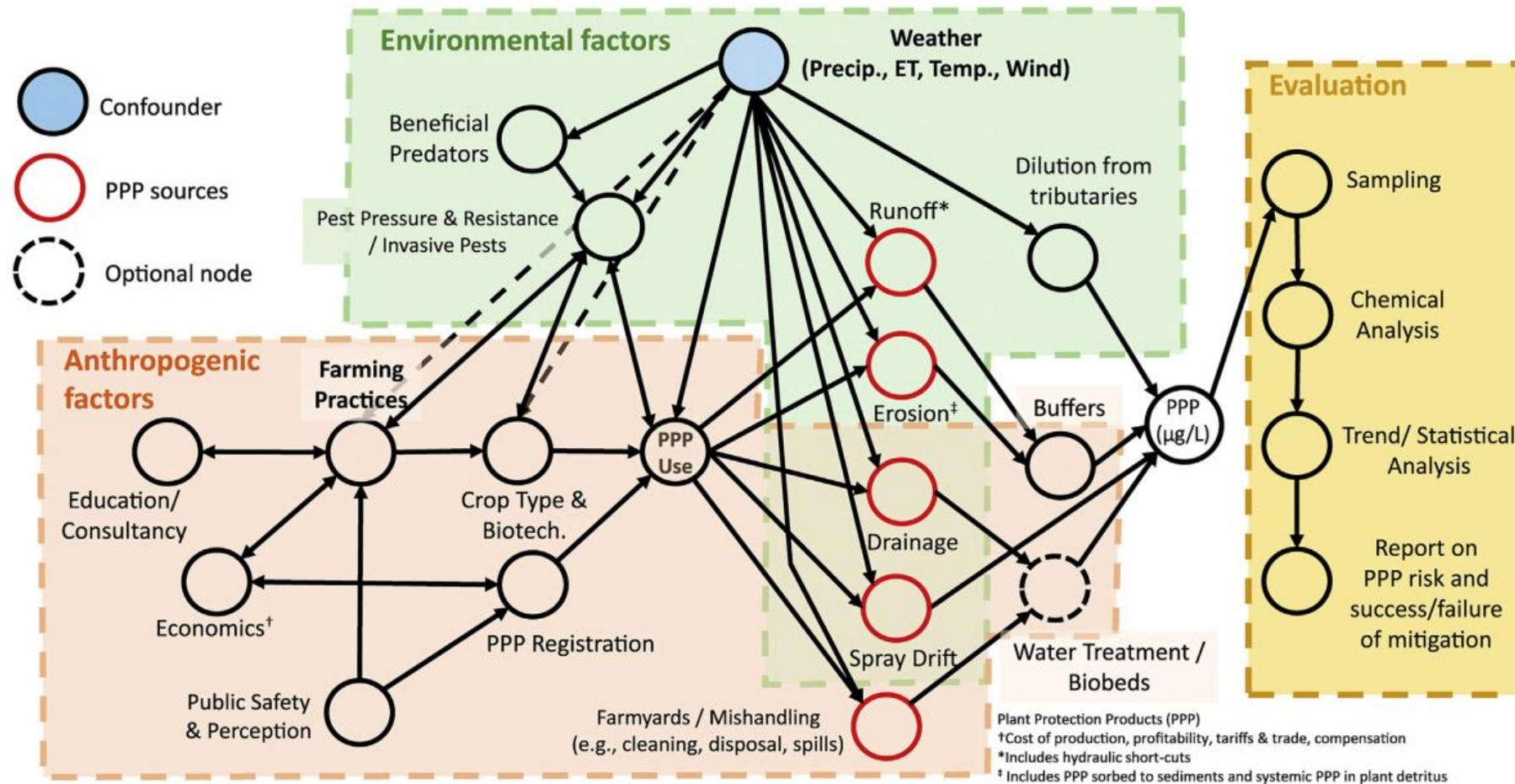


Fig. 1. Causal diagram of factors affecting evaluation of in-stream pesticide monitoring.

# Sustainable Agriculture

- The core concept of sustainability<sup>1</sup> is that lasting success requires an integrated approach to:
  - producing food and other products
  - farm profitability
  - quality of life for farmers, workers, and communities
  - stewardship of natural resources
- Sustainability requires recognizing and acting upon productivity, economic, social, and environmental goals as a simultaneous set of system attributes.

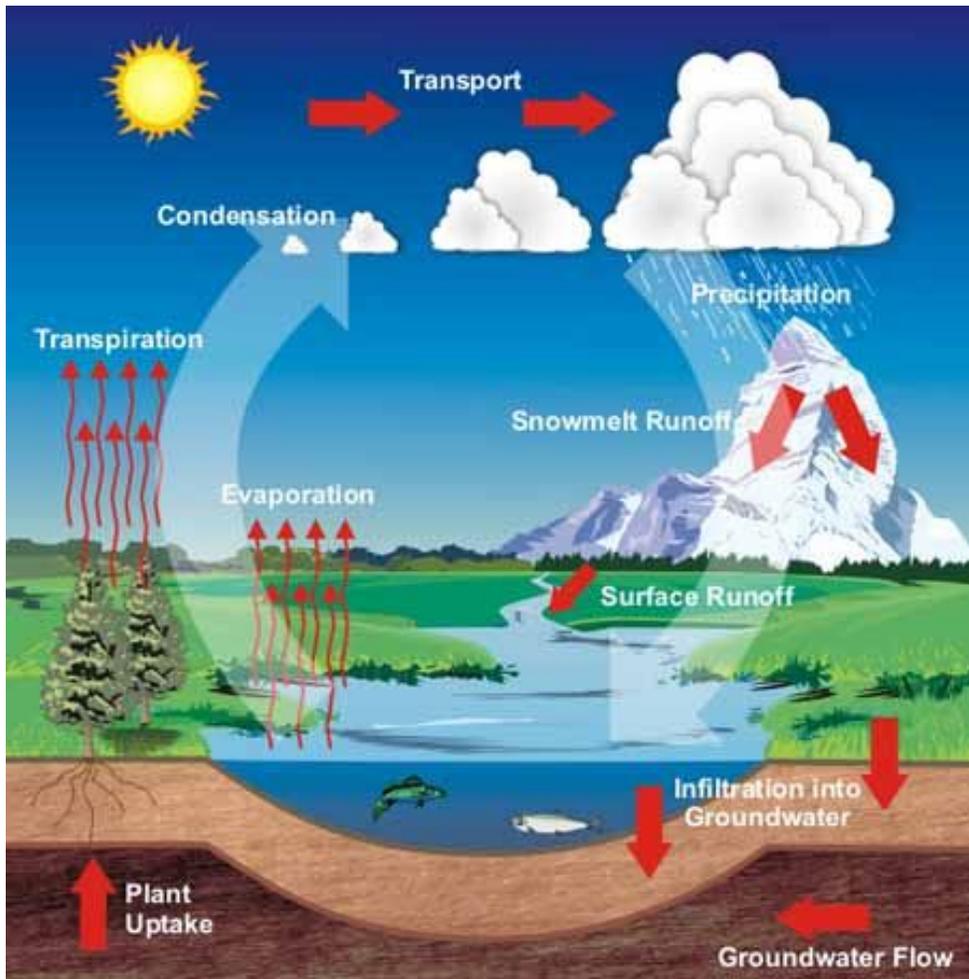
<sup>1</sup>Brundtland, G. H. (1987). Our Common Future. Annex to U.N. General Assembly document A/42/427.

# Technology to Enable Sustainable Agriculture

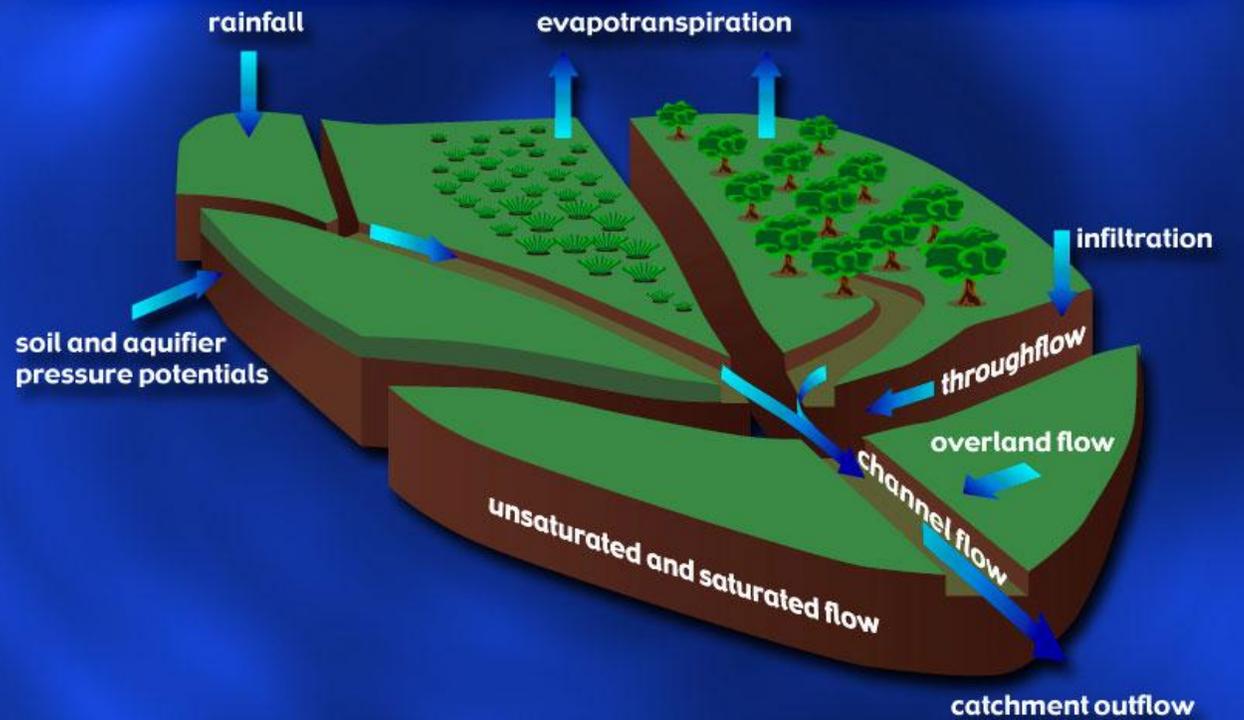
- Farm operations management
- Agronomy/horticulture/animal science
- Pest management
- Nutrient management
- Water Management
- Natural resource stewardship
- Supply chain management
- Information management

Farm  
Production  
System

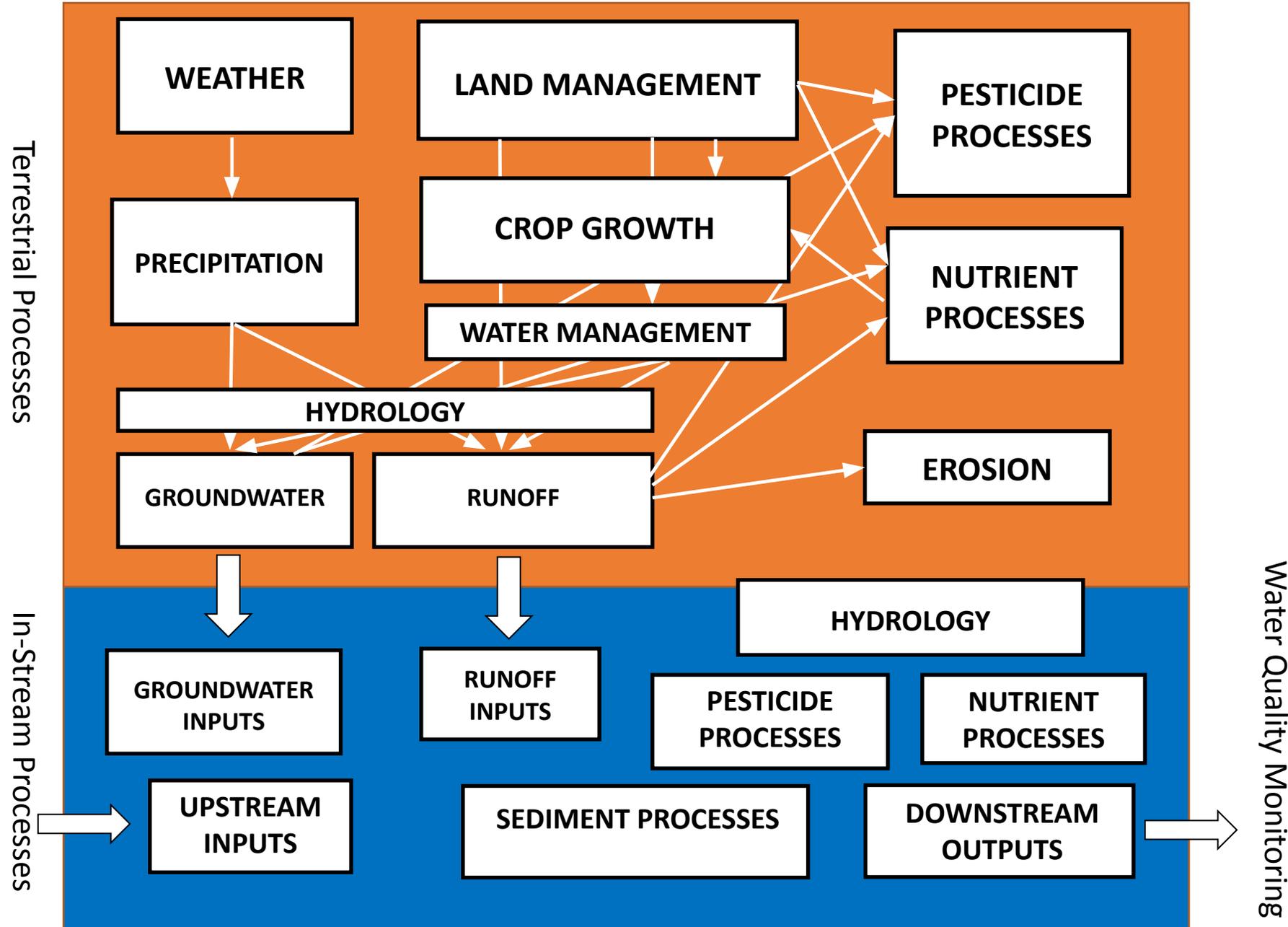
└─> Digital Agriculture



## Pesticide Loss at the Watershed Scale



# Water quality stewardship - conceptual model



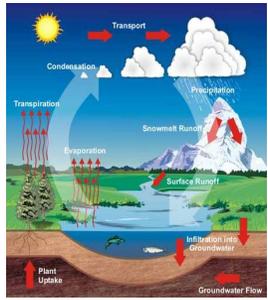
# Herbicides Commonly Used in the Pacific Northwest

<b>Trade name</b>	<b>Common name</b>	<b>½ life (days)</b>	<b>Koc</b>	<b>water sol mg/L</b>	<b>vapor pressure (mm Hg)</b>
Sencor	metribuzin	40	60	1220	1.0x10 <sup>-5</sup>
Banvel	Dicamba (acid)	14	2	400000	3.4x10 <sup>-5</sup>
Milestone	aminopyralid	35	11	2480	7.1x10 <sup>-11</sup>
Garlon	trichlopyr	30	210	260	3.0x10 <sup>-8</sup>
Dual	metolachlor	90	200	530	3.1x10 <sup>-5</sup>
Roundup	glyphosate	47	24000	530000	0
2,4-D	2, 4 D acid	10	20	89	1.1x10 <sup>-7</sup>
2,4-D ester	2,4-D butoxyethyl ester	7	500	100	1.0x10 <sup>-7</sup>
Chopper	imazapyr	90	100	1100	1.3x10 <sup>-11</sup>
Velpar	hexazinone	90	54	3300	8.2x10 <sup>-11</sup>
Kerb	pronamide	60	800	15	8.5x10 <sup>-5</sup>
Oust	Sulfometuron methyl	28	78	70	1.7x10 <sup>-16</sup>
Goal	oxyfluorfen	35	100000	0.1	2.0x10 <sup>-7</sup>
Prowl	pendimethalin	90	500	0.3	9.4x10 <sup>-6</sup>
Buctril	bromoxynil	7	10000	0.8	4.8x10 <sup>-6</sup>
Dachthal	DCPA	100	5000	0.5	2.5x10 <sup>-6</sup>

# Soil and Water Assessment Tool (SWAT)

Conceptual model  
 ↓  
 Process model (computer)  
 ↓  
 ArcSWAT (GIS),  
 use of spatial data (maps)  
 ↓  
 Describe daily changes  
 in watershed  
 ↓  
 Pesticides in surface water

Conceptual model



Process model - computer

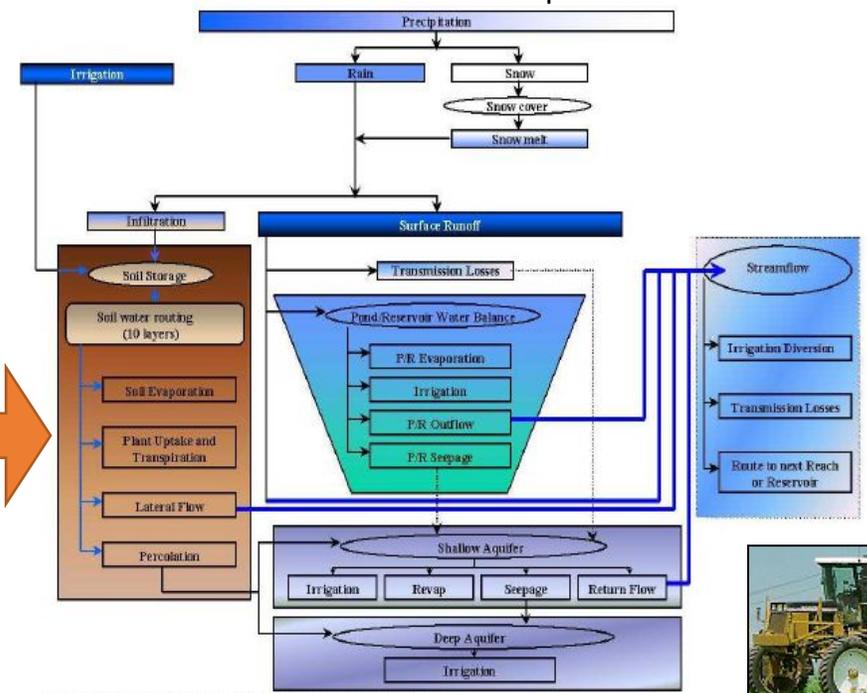
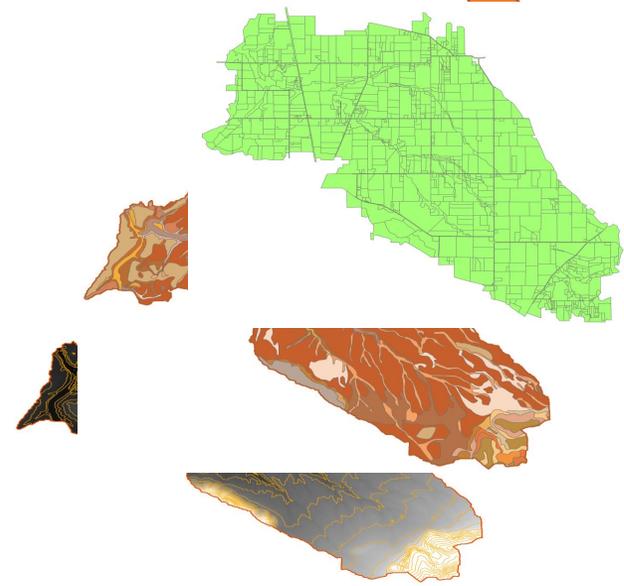
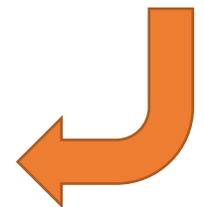
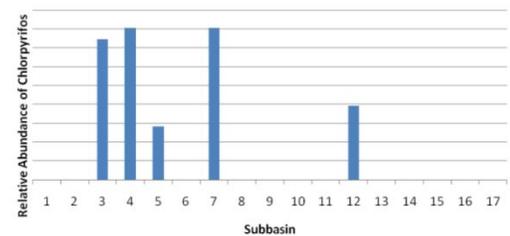


Figure 1.5: Schematic of pathways available for water movement in SWAT



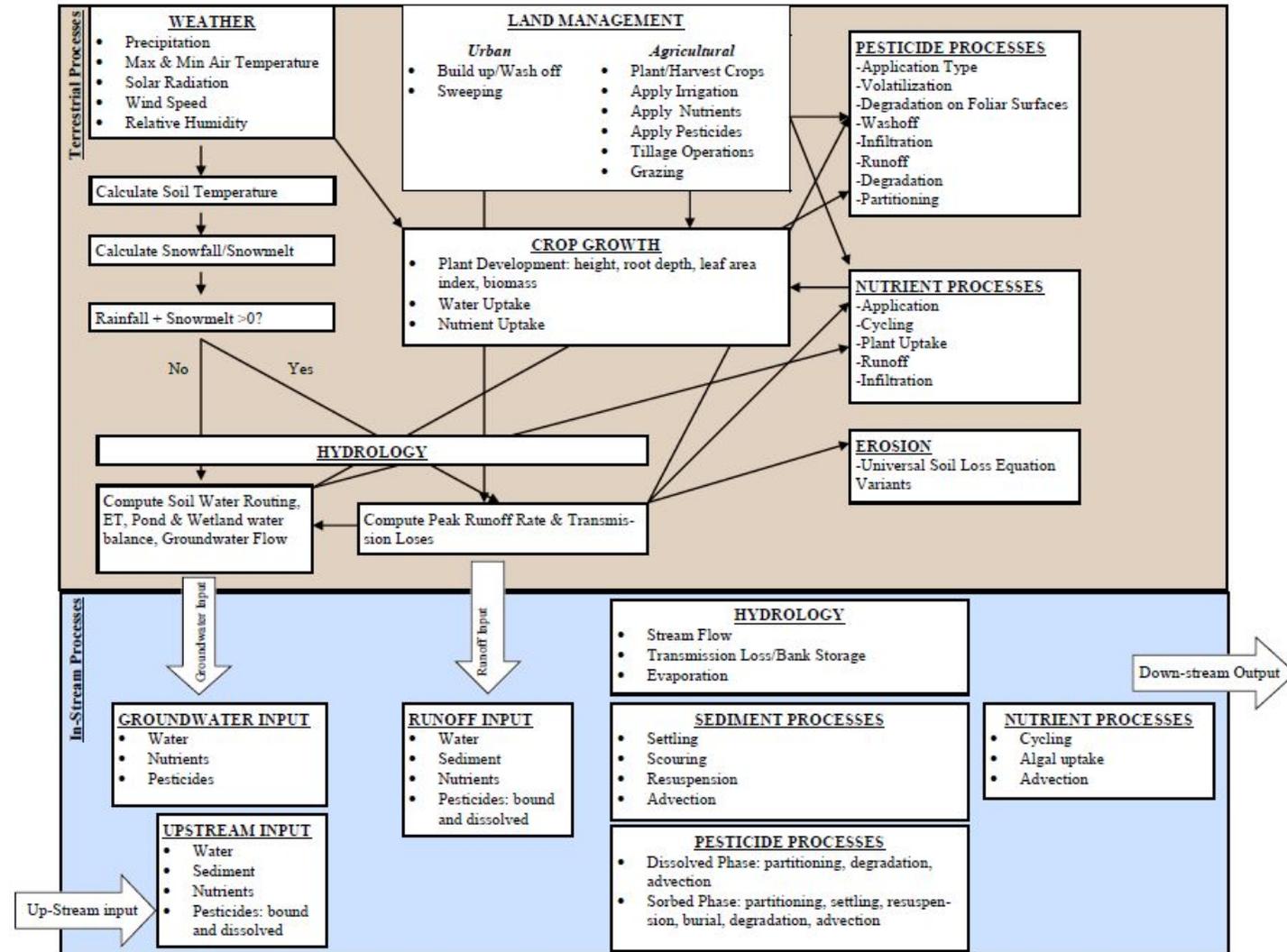
Daily Pesticide Load Following Early Season Application



# Soil and Water Assessment Tool (SWAT)



- Watershed scale model<sup>1</sup>
  - Developed by USDA Agricultural Research Service
  - Based on over 40 years of expertise
- Developed to evaluate the impact of land management practices on:
  - Hydrology
  - Erosion/Sediment transport
  - Nutrient fate
  - Pesticide fate
- Physically based process model that operates on a daily time step
- GIS interface, ArcSWAT, used for spatially explicit parameterization using readily available data



# Watershed scale modeling of pesticide fate



Contents lists available at [ScienceDirect](#)

Environmental Pollution

journal homepage: [www.elsevier.com/locate/envpol](http://www.elsevier.com/locate/envpol)

Modeling spray drift and runoff-related inputs of pesticides to receiving water<sup>☆</sup>

Xuyang Zhang<sup>\*</sup>, Yuzhou Luo, Kean S. Goh

California Department of Pesticide Regulation, Sacramento, CA, 95814, United States

Journal of Environmental Quality

TECHNICAL REPORTS

ENVIRONMENTAL MODELS, MODULES, AND DATASETS

Evaluation of Watershed-Scale Simulations of In-Stream Pesticide Concentrations from Off-Target Spray Drift

Michael F. Winchell,<sup>\*</sup> Naresh Pai, Benjamin H. Brayden, Chris Stone, Paul Whatling, John P. Hanzas, and Jody J. Stryker

We selected two watersheds near The Dalles (Supplemental Fig. S1) to evaluate a watershed-scale drift simulation approach using SWAT. We chose these watersheds based on the high cherry orchard area and the high malathion use intensity occurring during the dry season (May–August) (Supplemental

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Health & Ecological Risk Assessment

Soil and Water Assessment Tool Model Predictions of Annual Maximum Pesticide Concentrations in High Vulnerability Watersheds

Michael F. Winchell,<sup>\*†</sup> Natalia Peranginangin,<sup>‡</sup> Raghavan Srinivasan,<sup>§</sup> and Wenlin Chen<sup>‡</sup>

<sup>†</sup>Stone Environmental, Montpelier, Vermont, USA

<sup>‡</sup>Syngenta Crop Protection, Greensboro, North Carolina, USA

<sup>§</sup>Spatial Sciences Laboratory, Department of Ecosystem Science and Management, Texas A&M University, College Station, Texas, USA

Journal of Environmental Quality

TECHNICAL REPORTS

ENVIRONMENTAL MODELS, MODULES, AND DATASETS

A Systems Approach to Modeling Watershed Ecohydrology and Pesticide Transport

Philip Janney<sup>\*</sup> and Jeffrey Jenkins

Core Ideas

- Sequential model optimization incorporating local knowledge improved ecohydrologic estimates.
- Probabilistic pesticide application provided more realistic model estimates of solute transport.
- This modeling application allows a systems approach to sustainable agricultural practices.



## Review

# A review of pesticide fate and transport simulation at watershed level using SWAT: Current status and research concerns



Ruoyu Wang<sup>a</sup>, Yongping Yuan<sup>b</sup>, Haw Yen<sup>c</sup>, Michael Grieneisen<sup>a</sup>, Jeffrey Arnold<sup>c</sup>, Dan Wang<sup>d</sup>, Chaozi Wang<sup>e,\*</sup>, Minghua Zhang<sup>a,\*</sup>

<sup>a</sup> Department of Land, Air and Water Resources, University of California, Davis, CA 95616, United States

<sup>b</sup> USEPA/ORD/NERL, Research Triangle Park, NC 27711, United States

<sup>c</sup> Blackland Research and Extension Center, Texas A&M University, Temple, TX 76502, United States

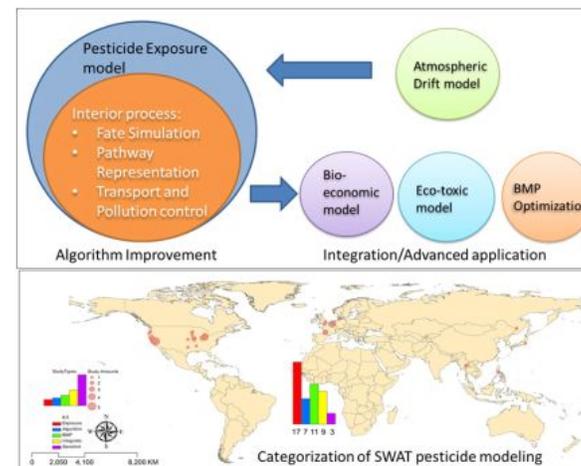
<sup>d</sup> Department of Pesticide Regulation, California Environmental Protection Agency, Sacramento, CA 95812, USA

<sup>e</sup> College of Water Resources and Civil Engineering, China Agricultural University, Beijing 100083, China

## HIGHLIGHTS

- Current pesticide modeling status and concerns reviewed at basin level using SWAT
- Algorithm improvement & advanced application recently attract more attention.
- Algorithm improvement: fate simulation, new pathways, transport & pollutant control
- Model integration helps assess ecological risks & conduct cost-effective analysis.
- Future improvements recommended for addressing research gaps and concerns

## GRAPHICAL ABSTRACT



~50 studies worldwide:  
available monitoring data  
inadequate for model  
evaluation.

# Willamette Basin, Oregon, Salmonid Critical Habitat

Willamette Basin (HUC 4)<sup>1</sup>

12 HUC 8 subbasins

388 HUC12 watersheds

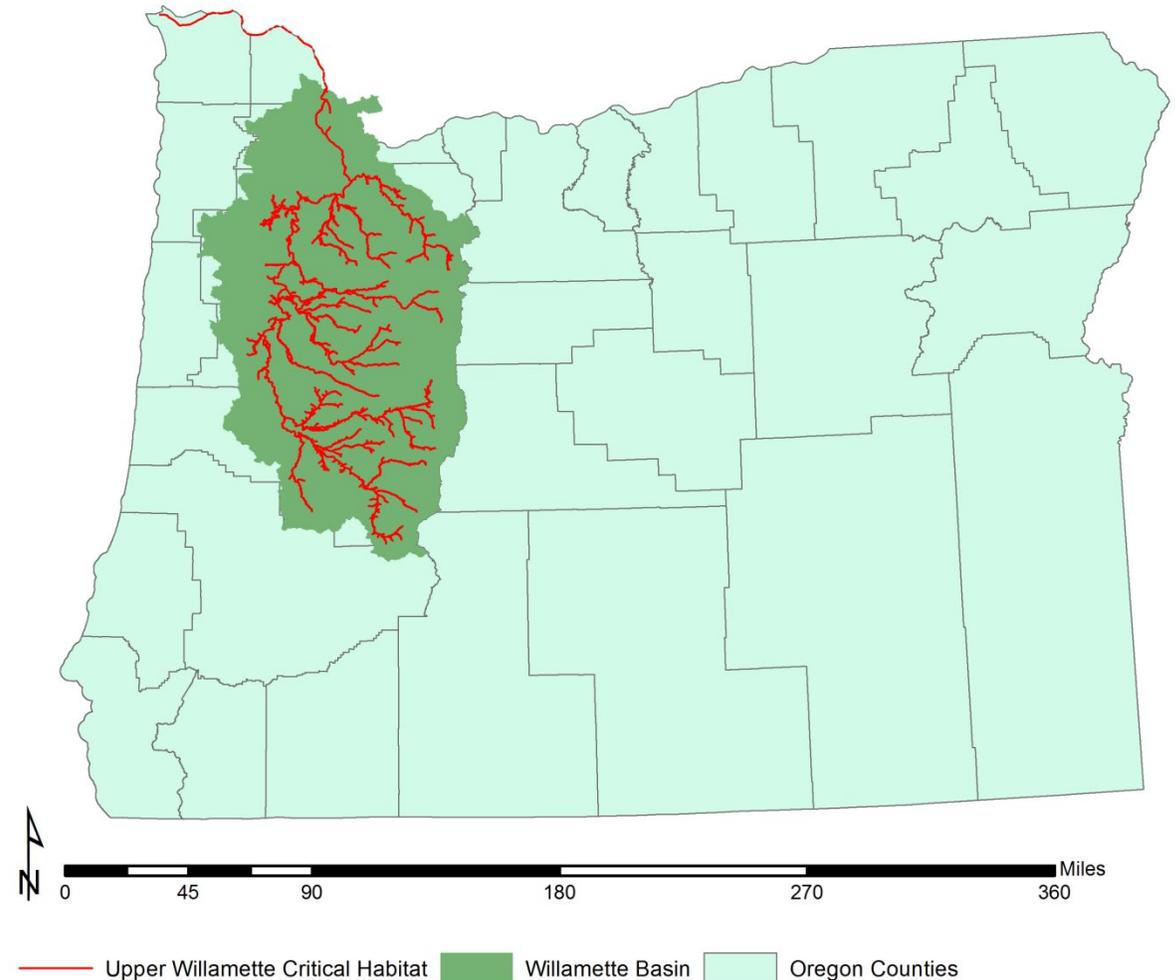
~10,000 catchments

Diverse agriculture (170 crop varieties),  
forestry, urban pesticide use practices

More than 500 pesticide active ingredients  
registered in Oregon

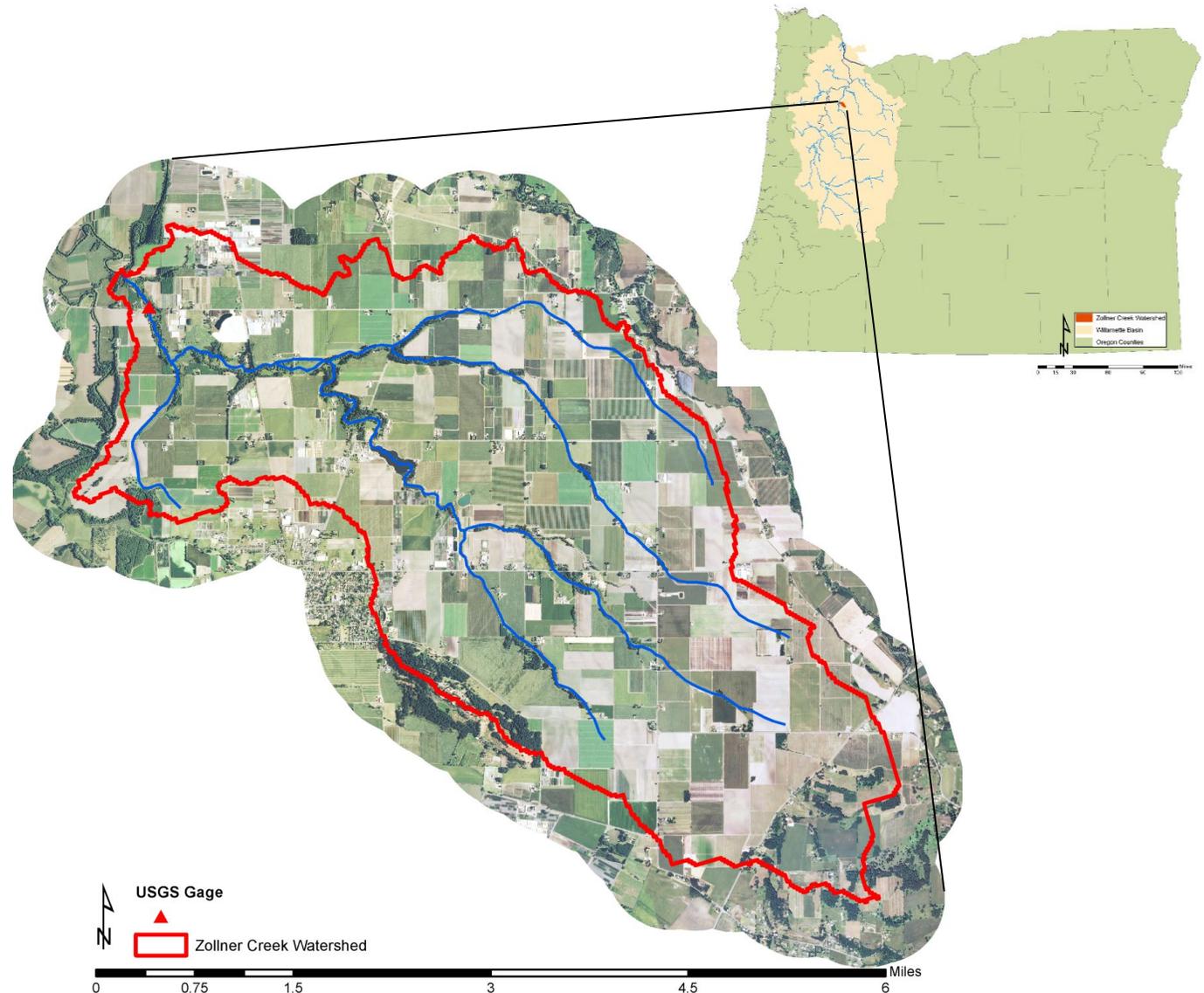
Pesticide co-occurrence with salmon/food  
web life histories?

<sup>1</sup> Hydrologic Unit Code

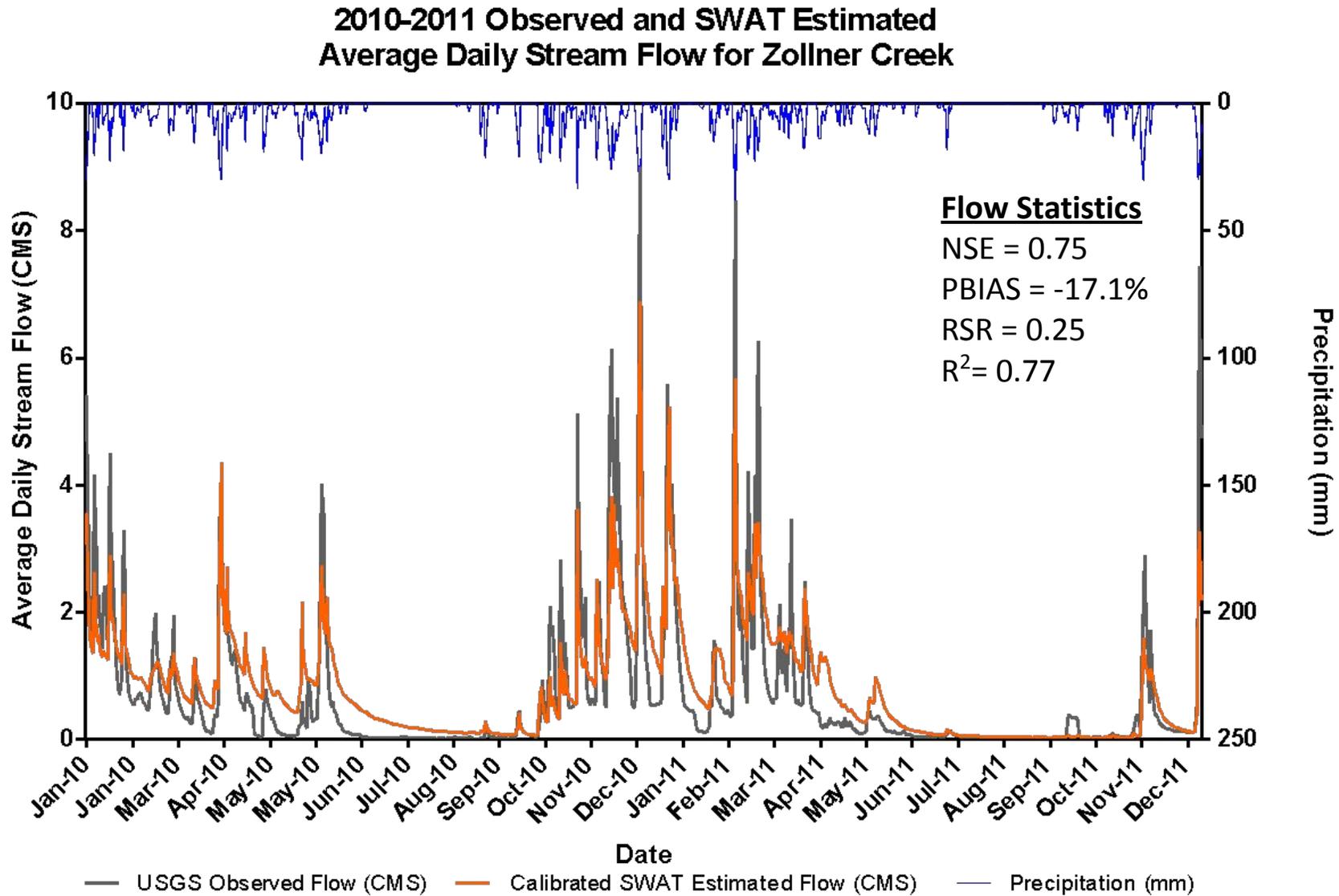


# Zollner Creek Watershed, Willamette Basin, Oregon

- HUC12 - 15mi<sup>2</sup> watershed
- Watershed area 90% agriculture:  
> 600 fields, >30 crops
- Pesticide surface water monitoring  
since 1993 (USGS and Oregon DEQ)
- Contains critical habitat for Upper  
Willamette chinook and steelhead  
ESUs
- Weather characterized by dry  
summers and wet winters
- USGS stream flow gage (Station ID:  
14201300)



# Zollner Creek Watershed: SWAT Hydrologic Characterization<sup>1</sup>



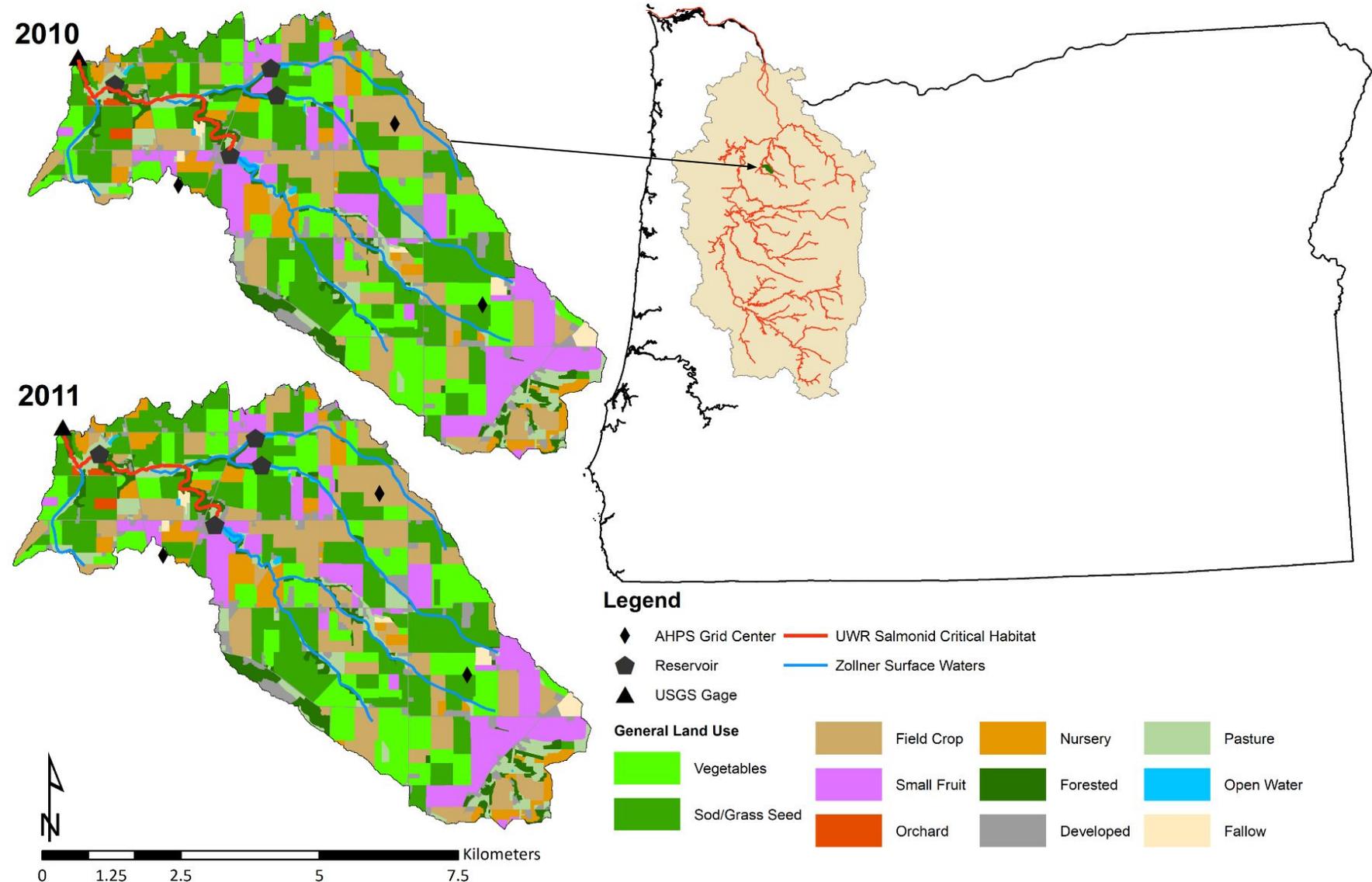
<sup>1</sup>Janney, P., and J. Jenkins. 2019. A Systems Approach to Modeling Watershed Ecohydrology and Pesticide Transport. J. Environ. Qual. 48:1047-1056.

# Zollner Creek Watershed: Characterizing Land Use

Watershed land use 90% ag  
> 600 fields, >30 crops  
determined from NASS CDL,  
refined with local knowledge

Pesticide use practices:  
authorized use (PICOL),  
refined with local Knowledge

Crop growth and management  
timelines: PNW handbooks,  
refined with local knowledge



# Characterizing Pesticide Use Patterns

- All authorized uses (federal/state labeled uses)
- Actual use records
  - Proprietary
  - Logistically difficult
  - Retrospective
- Probabilistic methods based on local knowledge
  - Realistic boundary conditions (pest management along crop timelines)
  - Characterize complex decision-making process (producers, CCAs, Extension)
  - Both retrospective and prospective – evaluate future outcomes

Labels for Oregon – PICOL database



Collaborate with CCAs and growers to refine use estimates



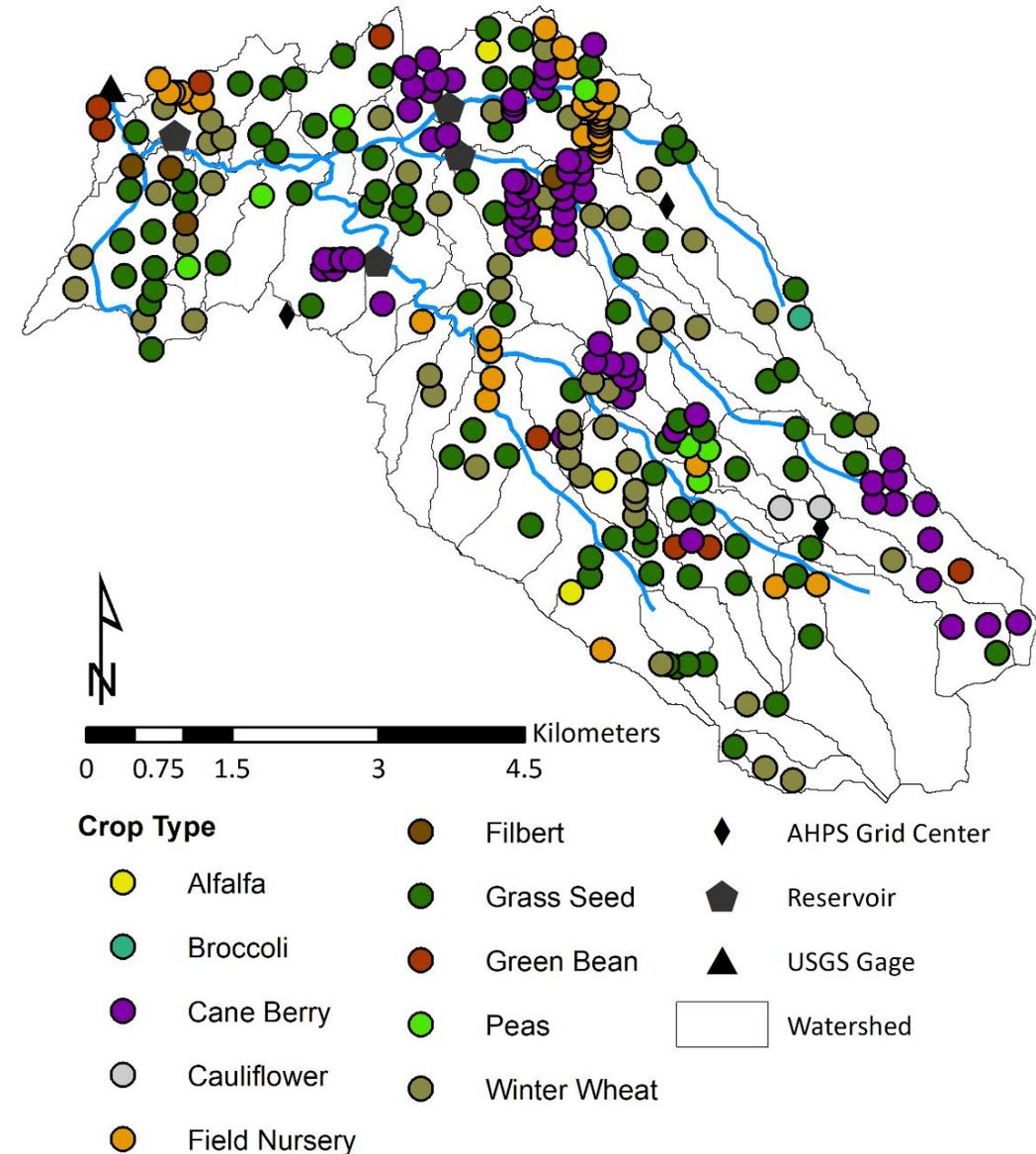
Create boundary conditions for probabilistic analysis of application practices

# Probabilistic Assessment of Application Patterns

- Management operations randomized by field
  - Applications limited to workable days
  - Application rates were both probabilistic and deterministic
  - PPBD pesticides properties data base representative values
- Monte Carlo methods utilized to create spatial and temporal distribution of application patterns
  - 500 SWAT scenarios generated and run
- Generate a distribution of spatial and temporal patterns of pesticide use practices
  - Estimate likely pesticide use patterns

# Trifluralin Use - PNW Herbicide Handbook

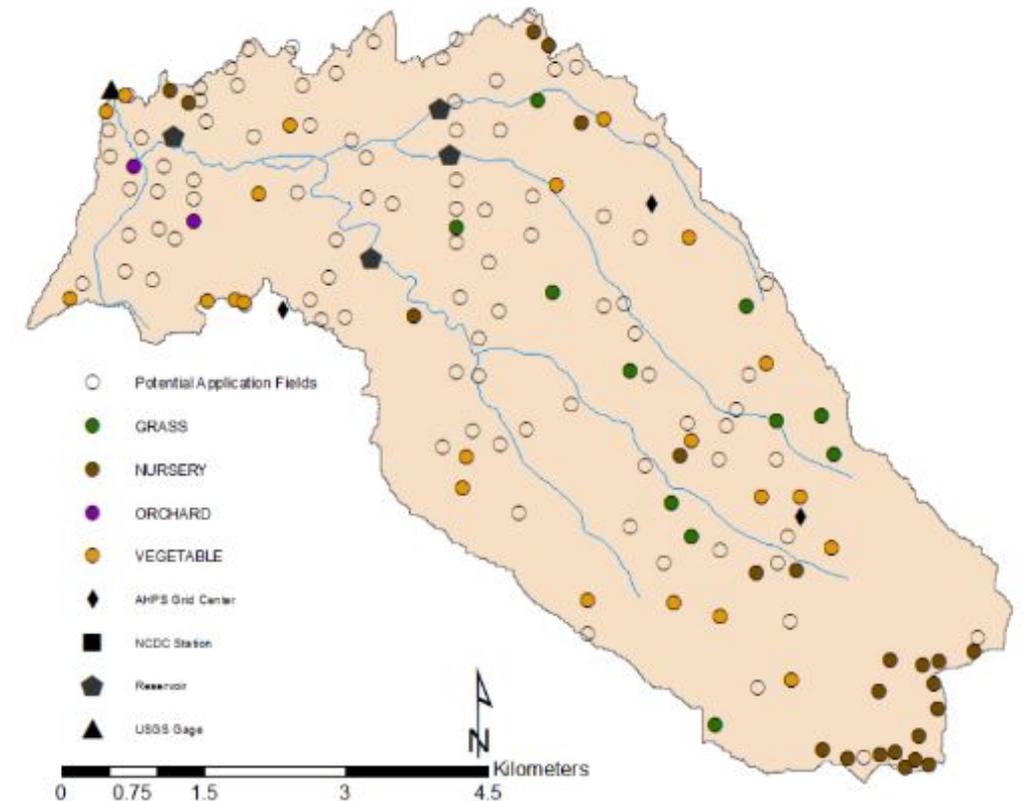
- Pre-plant soil incorporated:
  - Broccoli: May-July; 0.5-1 lb AI/A; 3-4" incorporation
  - Cauliflower: May-July; 0.5-1 lb AI/A; 3-4" incorporation
  - Green beans: May-July; 0.5-0.75 lb AI/A; 2-3" incorporation
  - Peas: May-July; 0.5-0.75 lb AI/A; 1-2" incorporation
- Spring pre-emergent:
  - Caneberries (nonbearing): March-April; 2.5-5lb AI/A; activate with single rain event or 0.5" irrigation or mechanically incorporate
  - Field grown nursery: March-April; 2-5lb AI/A; activate with single rain event or 0.5" irrigation or mechanically incorporate
  - Filberts: March-April; 0.5-1lb AI/A; activate with single rain event or 0.5" irrigation or mechanically incorporate
- Fall pre-emergent:
  - Alfalfa: September-October; 2lb AI/A; activate with single rain event or 0.5" irrigation or mechanically incorporate
  - Grass seed: September-October; 2lb AI/A; activate with single rain event or 0.5" irrigation or mechanically incorporate
  - Winter wheat: October-November; 0.5-1lb AI/A; activate with single rain event or 0.5" irrigation or mechanically incorporate



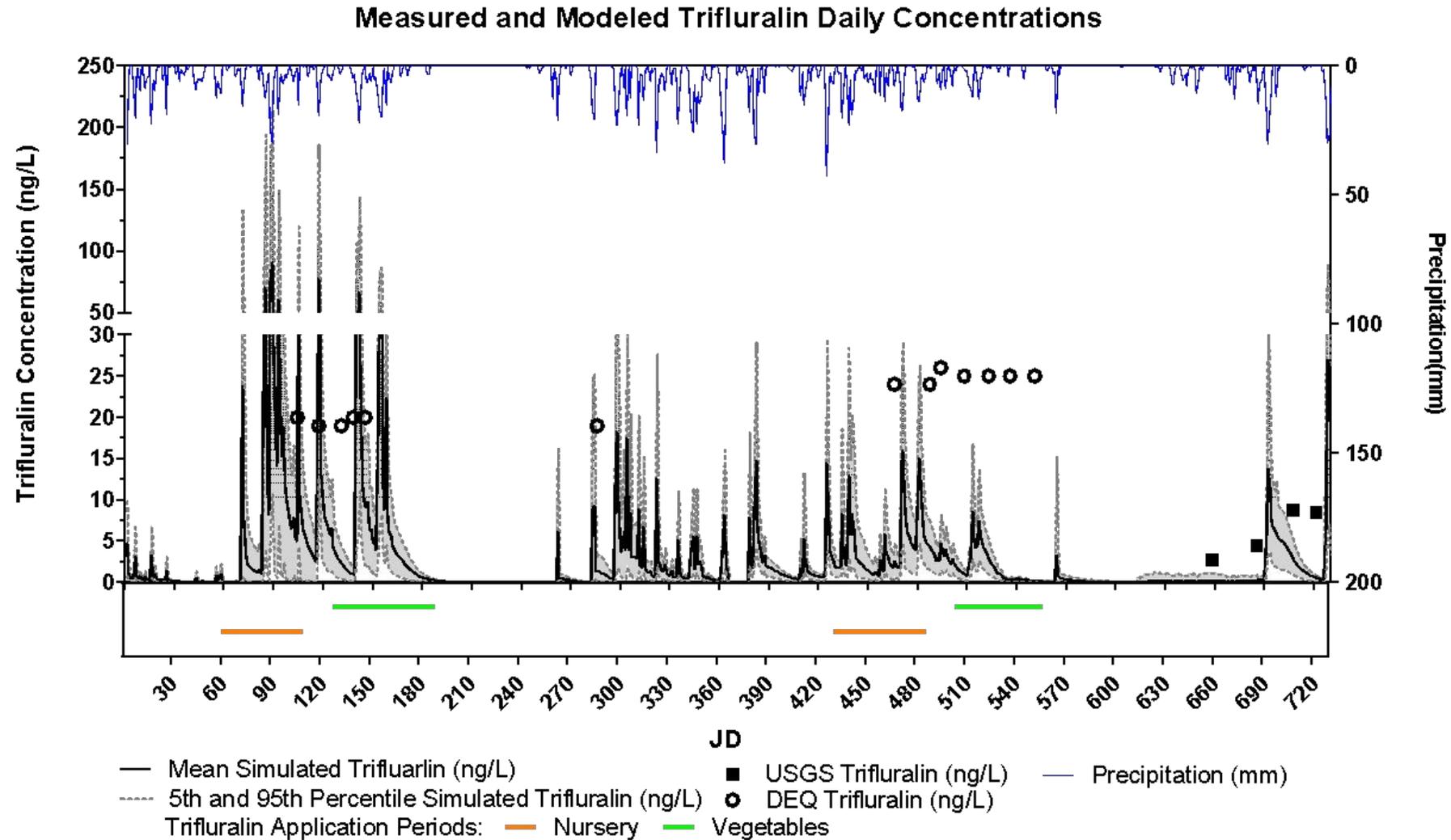
# Generalized Distribution of Chlorpyrifos Applications - 2011

Monte Carlo approach: 1 of 500 daily simulations

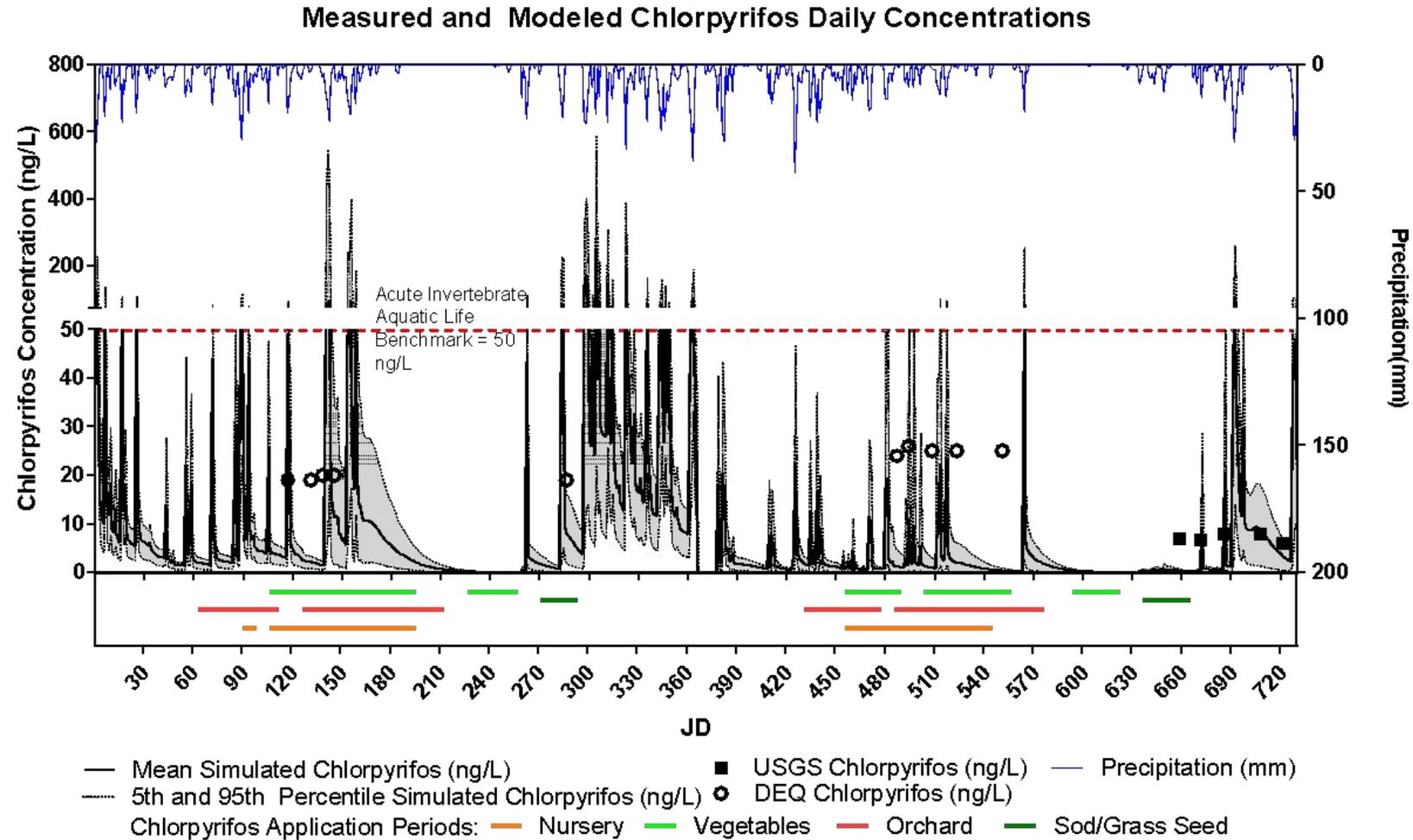
CROP TYPE	# POTENTIAL APPLICATION SITES	APPLICATION PERIOD	PROBABILITY OF APPLICATION	# WORKABLE DAYS
Seed/Sod Grass	82	Sept-Oct	0.1	15
Nursery	35	Apr-July	0.4	36
Orchard	3	Mar-Apr	0.75	12
	3	May-Aug	0.1	54
Vegetable	2	Apr-May	1	14
	10	Apr-June	1	16
	7	May-July	1	33
	1	June-July	1	23
	1	Aug-Sept	1	30



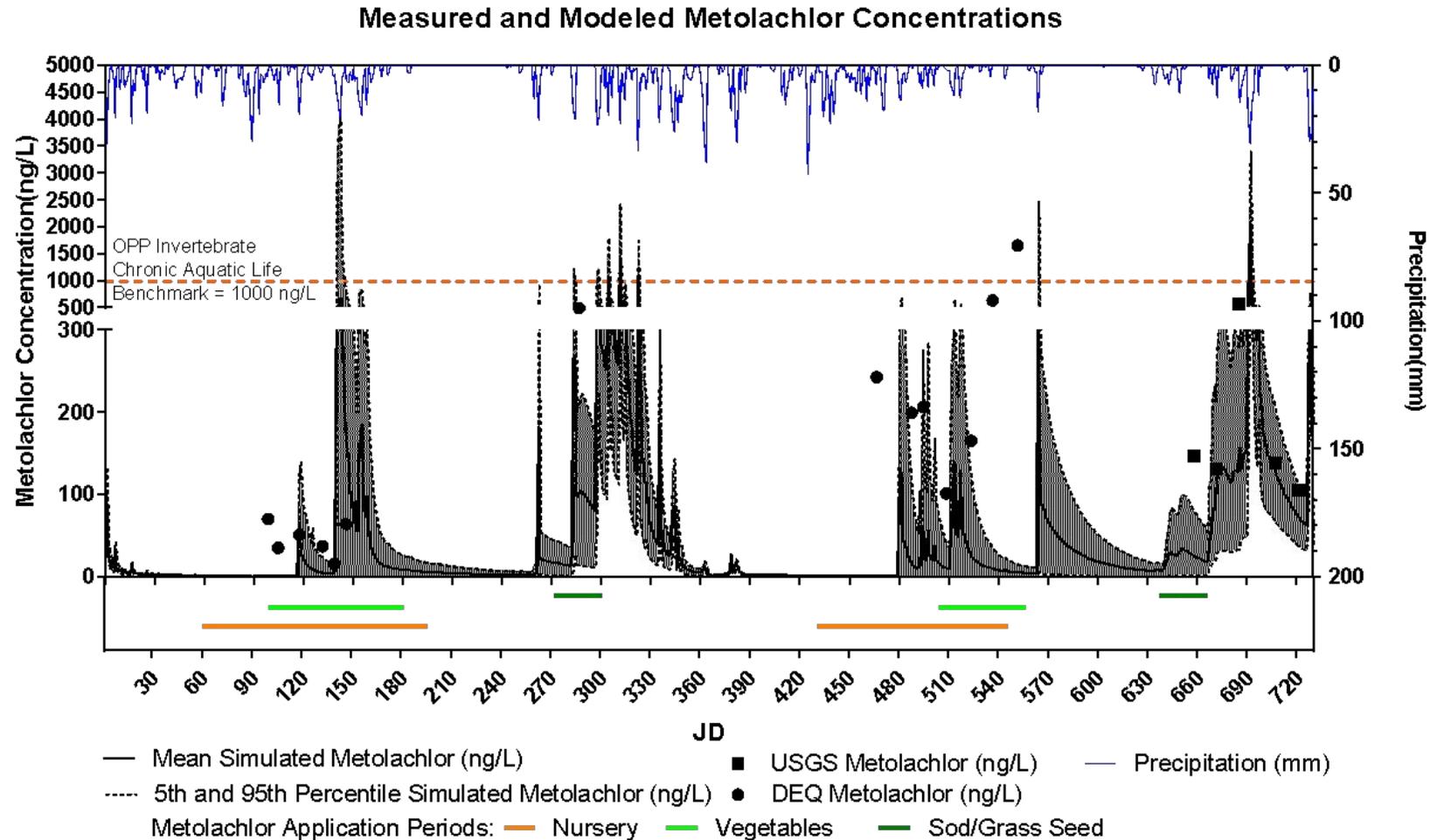
# 2010-2011 Zollner Creek SWAT Estimated Average Daily Trifluralin Surface Water Concentration



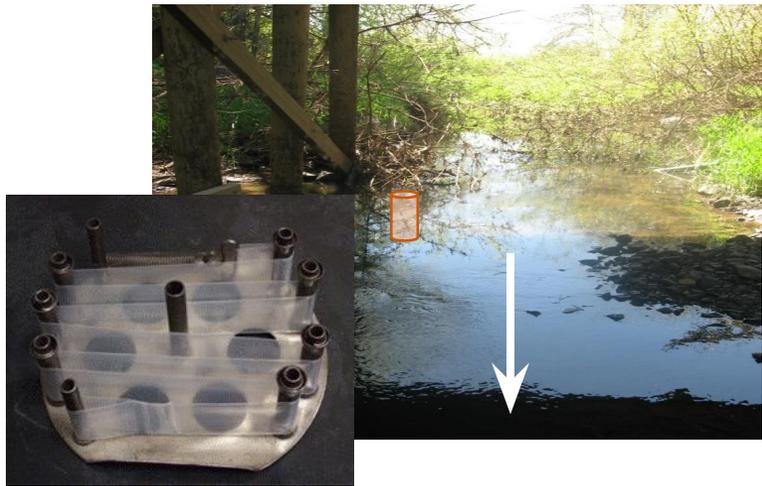
# 2010-2011 Zollner Creek SWAT Estimated Average Daily Chlorpyrifos Surface Water Concentration



# 2010-2011 Zollner Creek SWAT Estimated Average Daily Metolachlor Surface Water Concentration

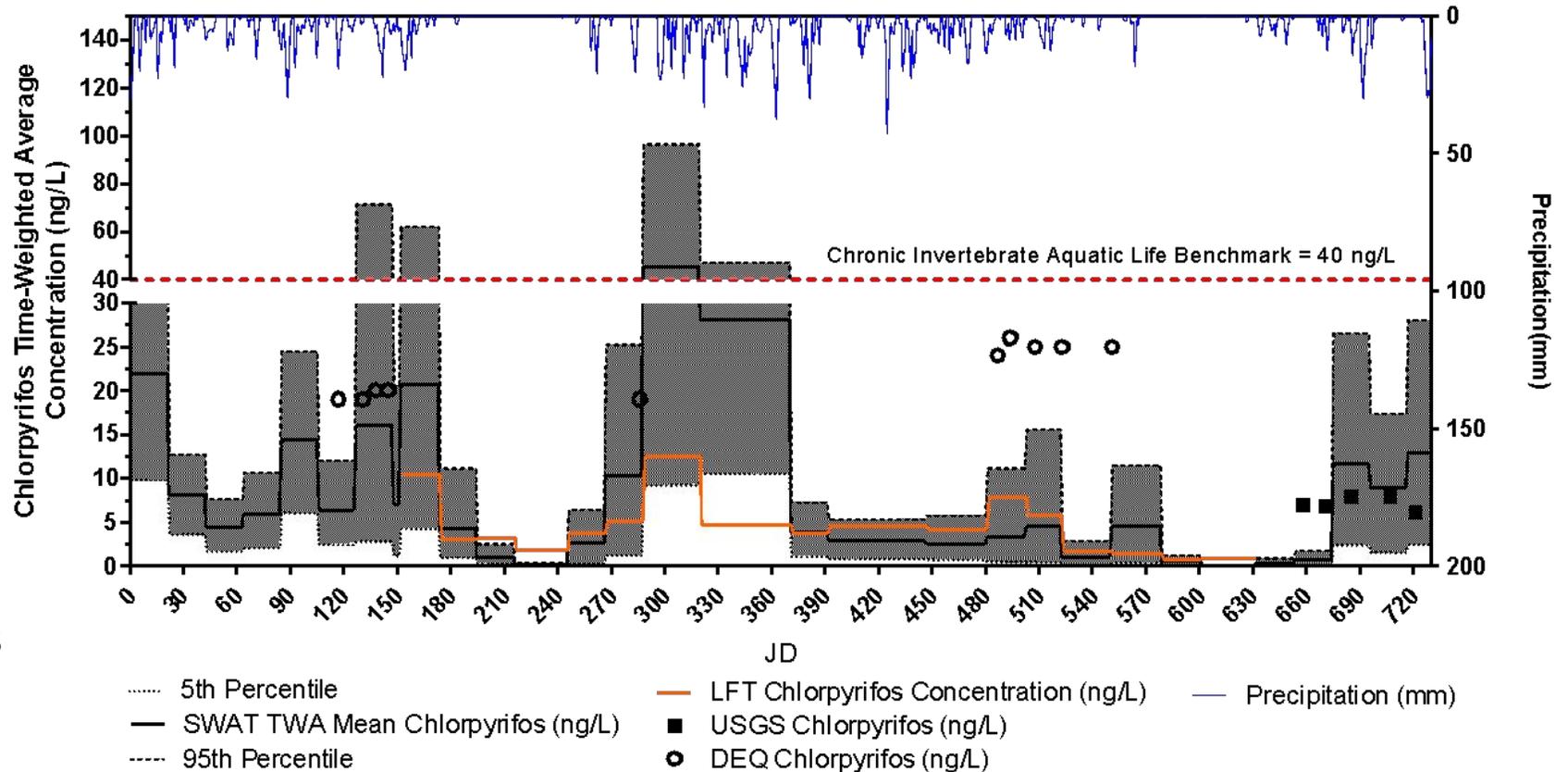


# Chlorpyrifos 21 day Time-weighted-average Concentrations in Zollner Creek Surface Water

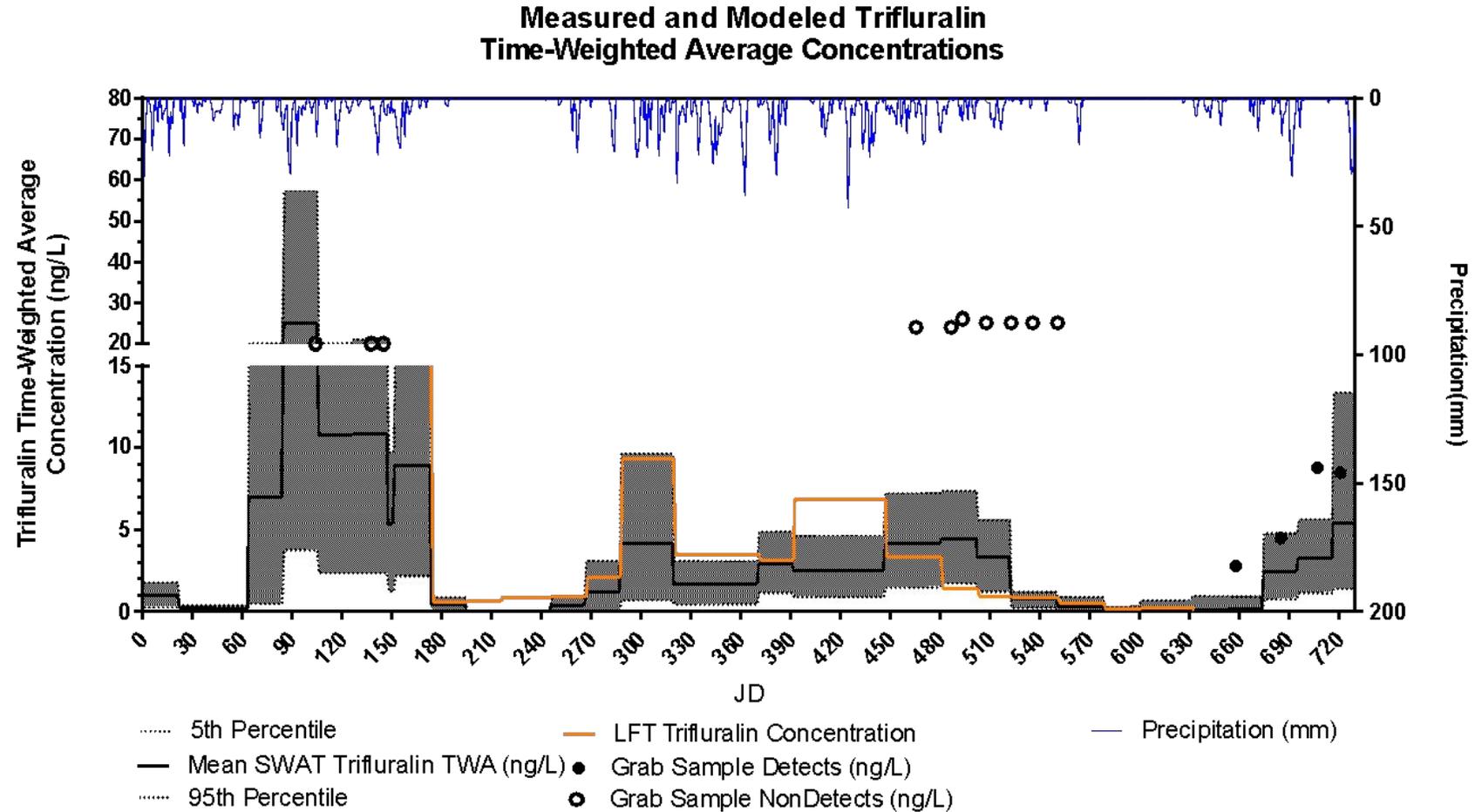


Lay Flat Tubing (LFT) passive samplers deployed continuously every ~21 days

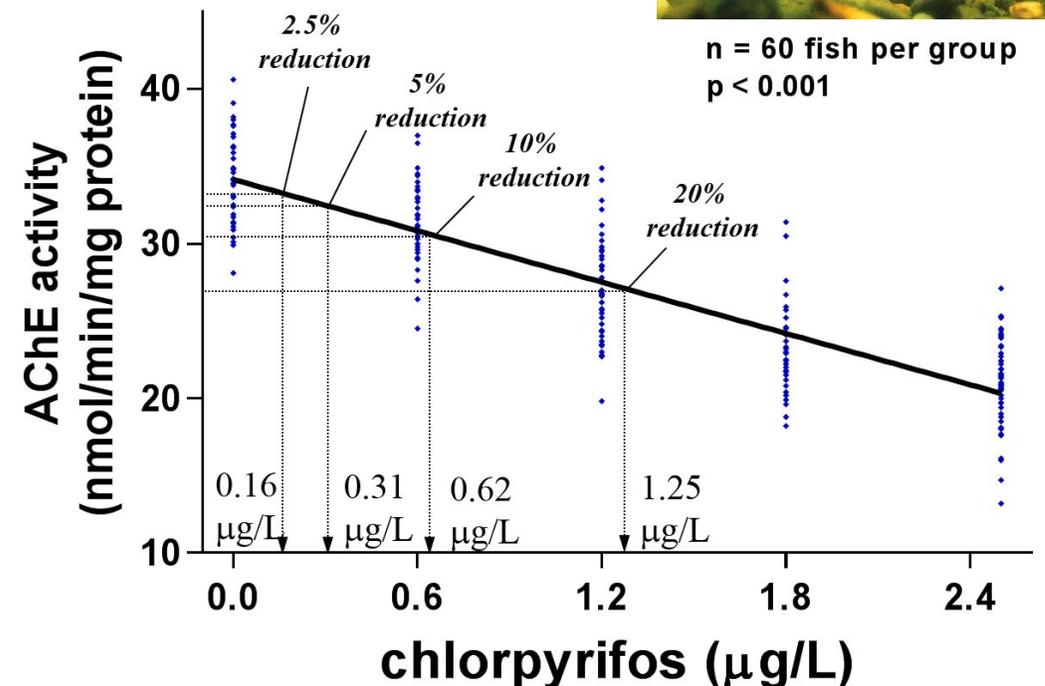
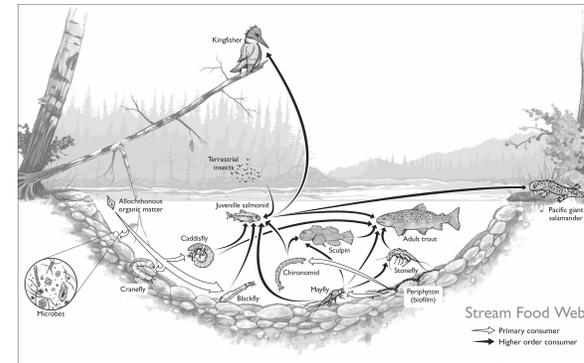
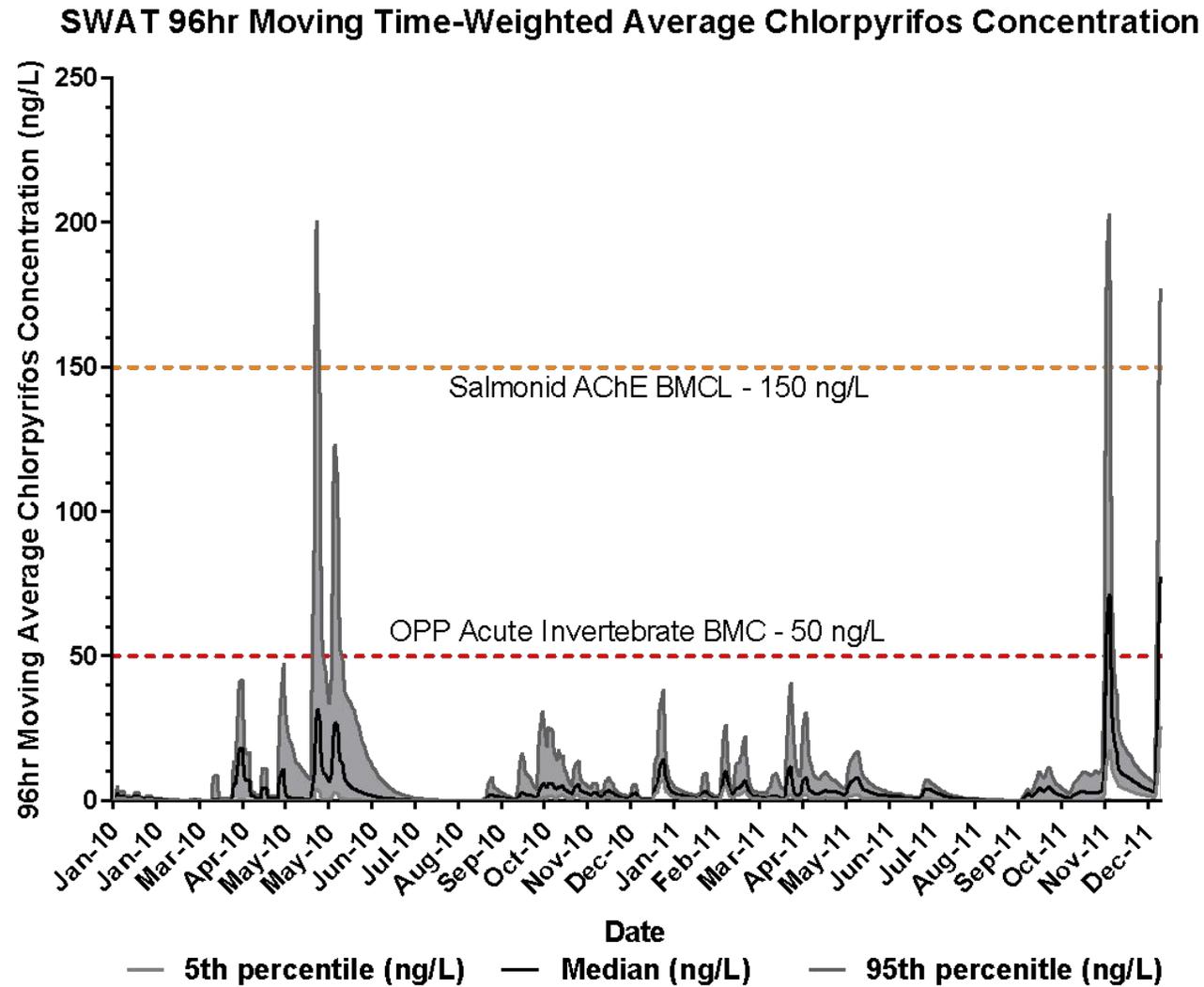
Measured and Modeled Chlorpyrifos Time-Weighted Average Concentrations



# Trifluralin 21 day Time-weighted-average Concentrations in Zollner Creek Surface Water

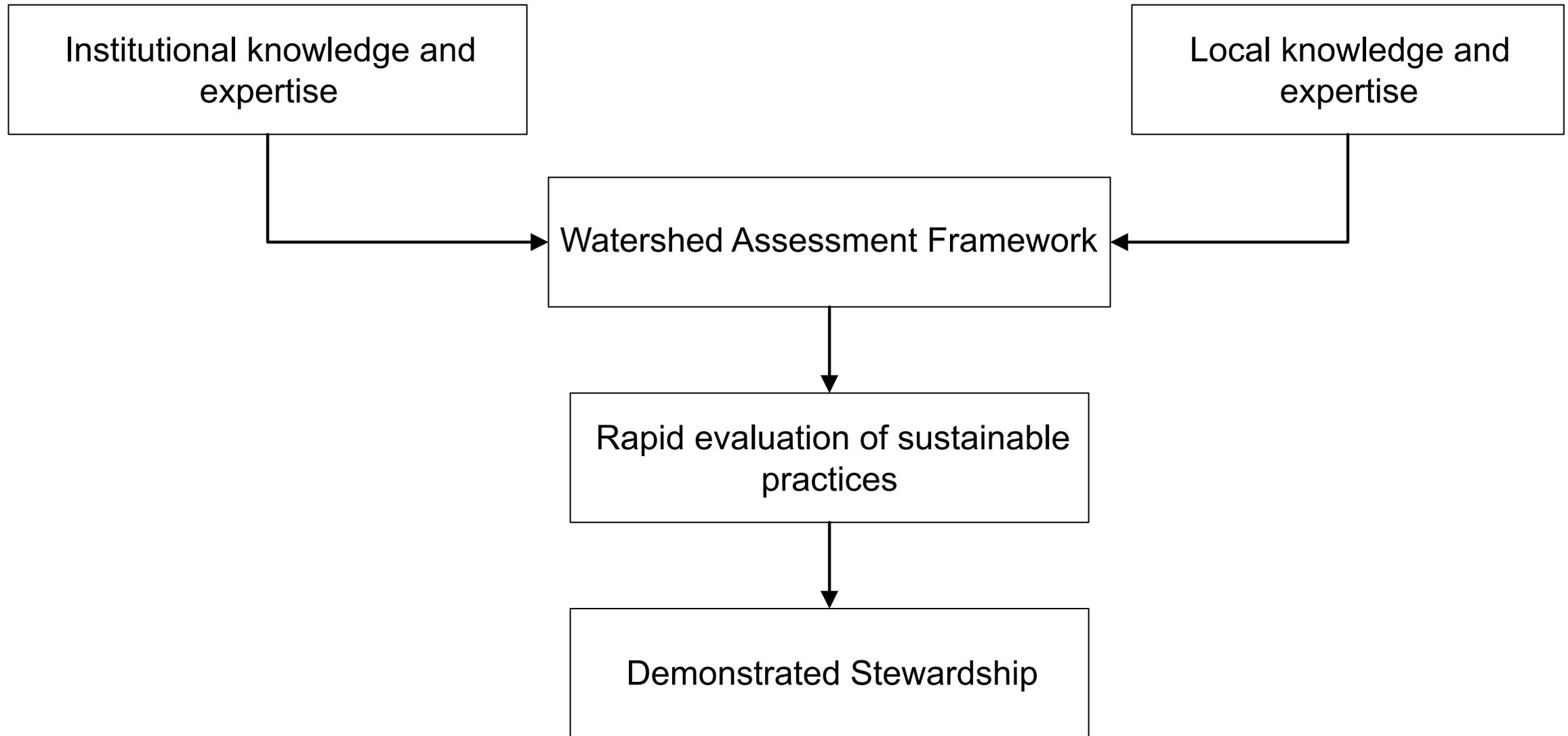


# SWAT Estimates of 96hr Moving TWA Chlorpyrifos Concentration

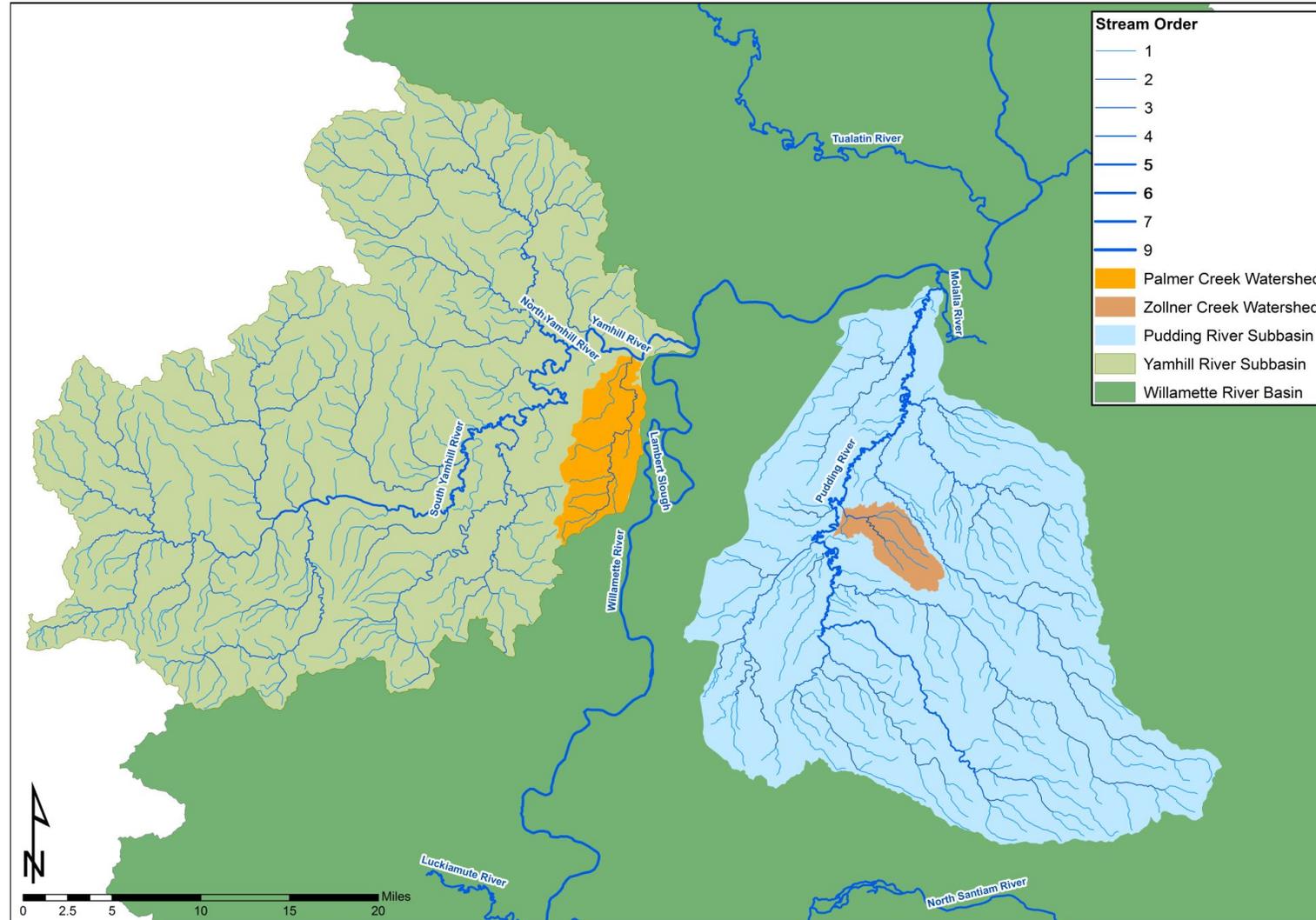


Juvenile Steelhead 96 hr Exposure/Cholinesterase Inhibition

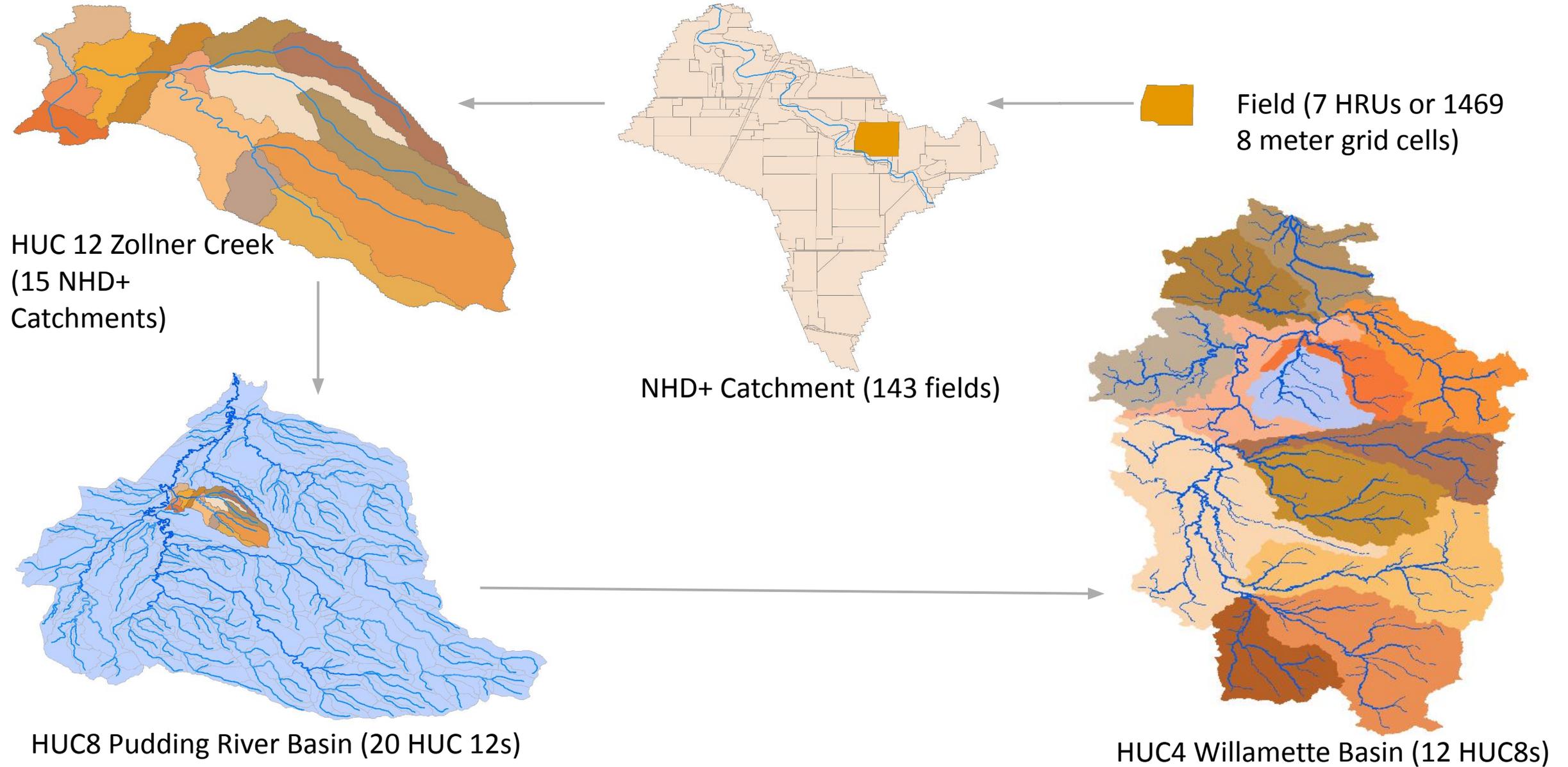
# Fostering sustainable practices through participative modeling



# Transferability of Watershed Assessment Framework



# Modeling Spatial Scales in the Willamette Basin



# Modeling Informs Risk Assessment and Sustainability

- This application of SWAT strives to significantly reduce uncertainty in the spatial and temporal relationship between pesticide use practices, surface water loading, and patterns of aquatic receptor exposure.
- A mechanistically-based modeling approach designed to optimize transferability to other watersheds.
- A primary goal is stakeholder engagement in the rapid evaluation of “what if” scenarios as candidate sustainable practices.

# Discussion points

- Are probabilistic approaches to risk assessment useful?
- Does this modeling application reduce uncertainty to better characterize ecological risk?
- Does this modeling application suggest that label risk mitigation measures meet the FIFRA standard of “will not result in unreasonable adverse effects on human health or the environment” for farming practices in the Zollner Creek Watershed?
- Does modeling integrate local and institutional knowledge to better address sustainability goals?

# Sustainable Agriculture - Reduce Pesticide Risks

- Government resource agency/NGO policy options – often a precautionary approach with goal to reduce the **possibility** of harm (hazard).
- Clearly defined pesticide use restrictions; requires limited knowledge of agricultural system attributes that impact water quality.
  - Use alternative pest management practices
  - Reduce or eliminate pesticide use
  - Use less harmful (least toxic) pesticides
  - Prescriptive water resource setbacks (buffers)
- Science-based sustainability; better understanding of ag systems – evaluate pesticide use practices to reduce the **probability** of harm (risk).
  - Requires significant knowledge, but adaptable to individual farm management needs
  - Enables effective balance of production and environmental protection goals
- Environmental policy tends to favor acting on the **possibility** of harm when **uncertainty** is great regarding the **probability** of harm.