Introduction to Pesticides in Surface Water and Groundwater
– Fate, Transport, and Source Attribution –

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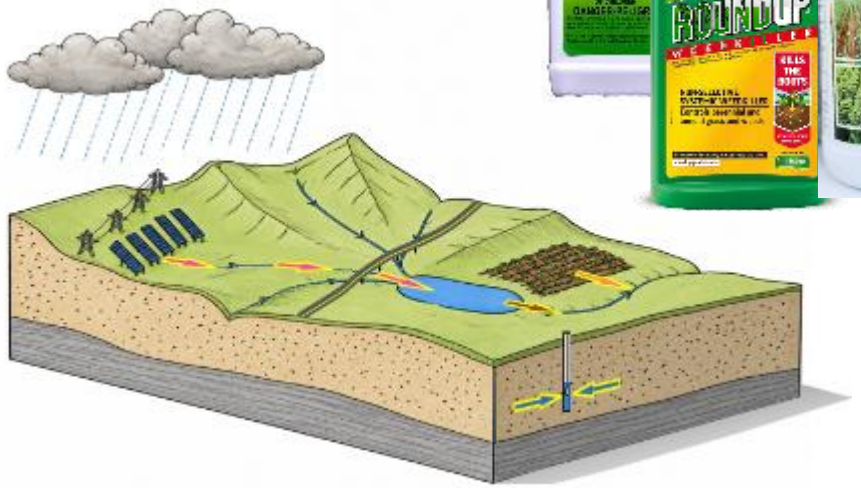
GeoEnviroPro Webinar
October 14, 2026

Today…

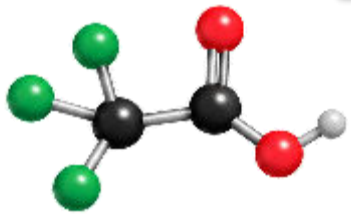
- Definitions
- Product History and Applications
- Fate and Transport
- Case Study
- PFAS in Pesticides











Pesticide Definition

- Substance used to prevent, destroy, repel, or control pests that damage crops, spread disease, or act as a nuisance.
- Categorized by the specific type of pest they target:
  - Insecticides: insects
  - Herbicides: unwanted plants and weeds
  - Fungicides: molds, rusts, and mildews
  - Rodenticides: mice, rats, and other rodents
  - Nematicides: microscopic roundworms (nematodes)

Today's focus



Many Different Chemicals and Brands

- Several hundred registered active ingredients.
- Hundreds of millions of pounds applied in U.S and Canada annually.



Examples



Atrazine



2,4-D



Glyphosate

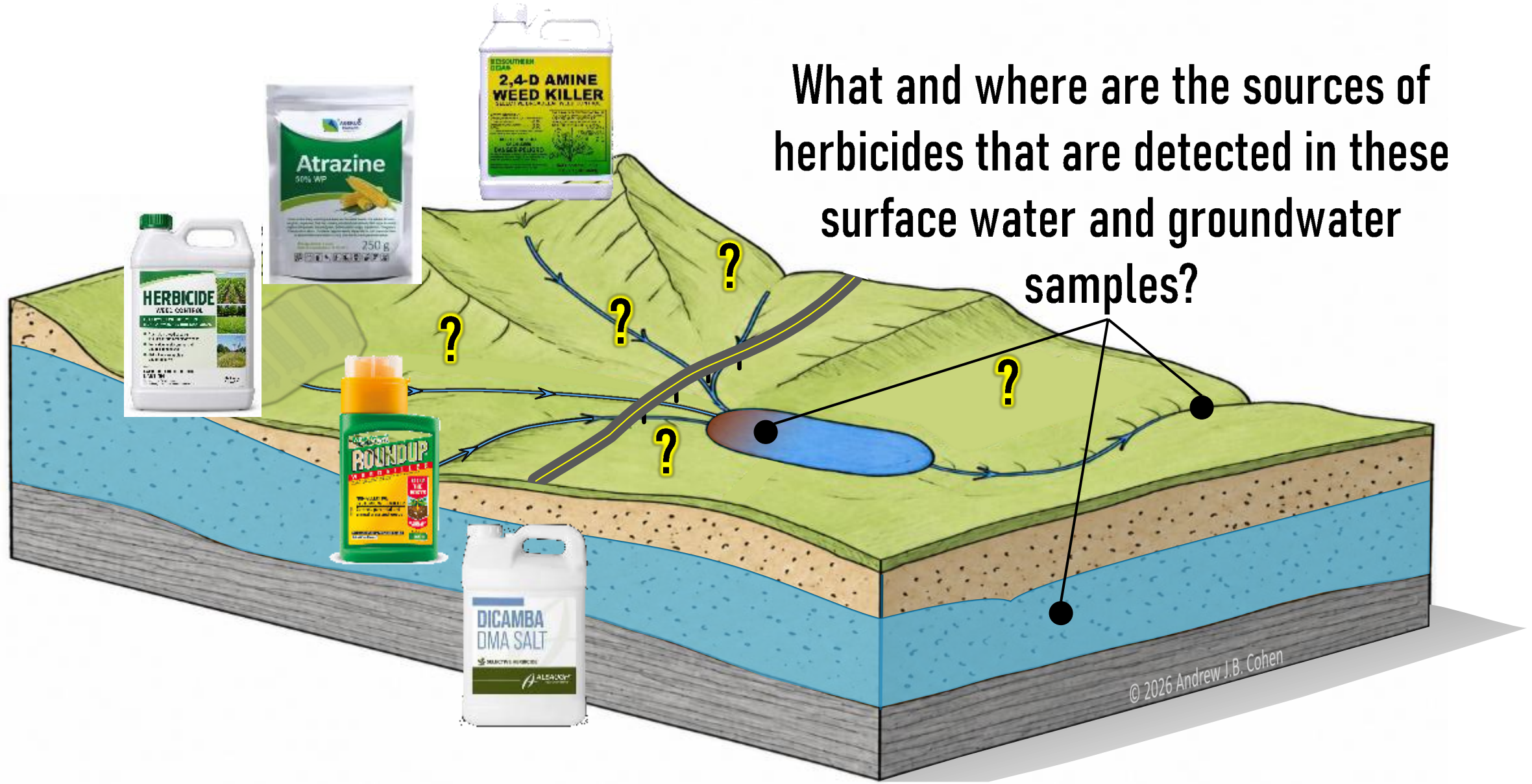


Dicamba



Acetochlor

Source Attribution



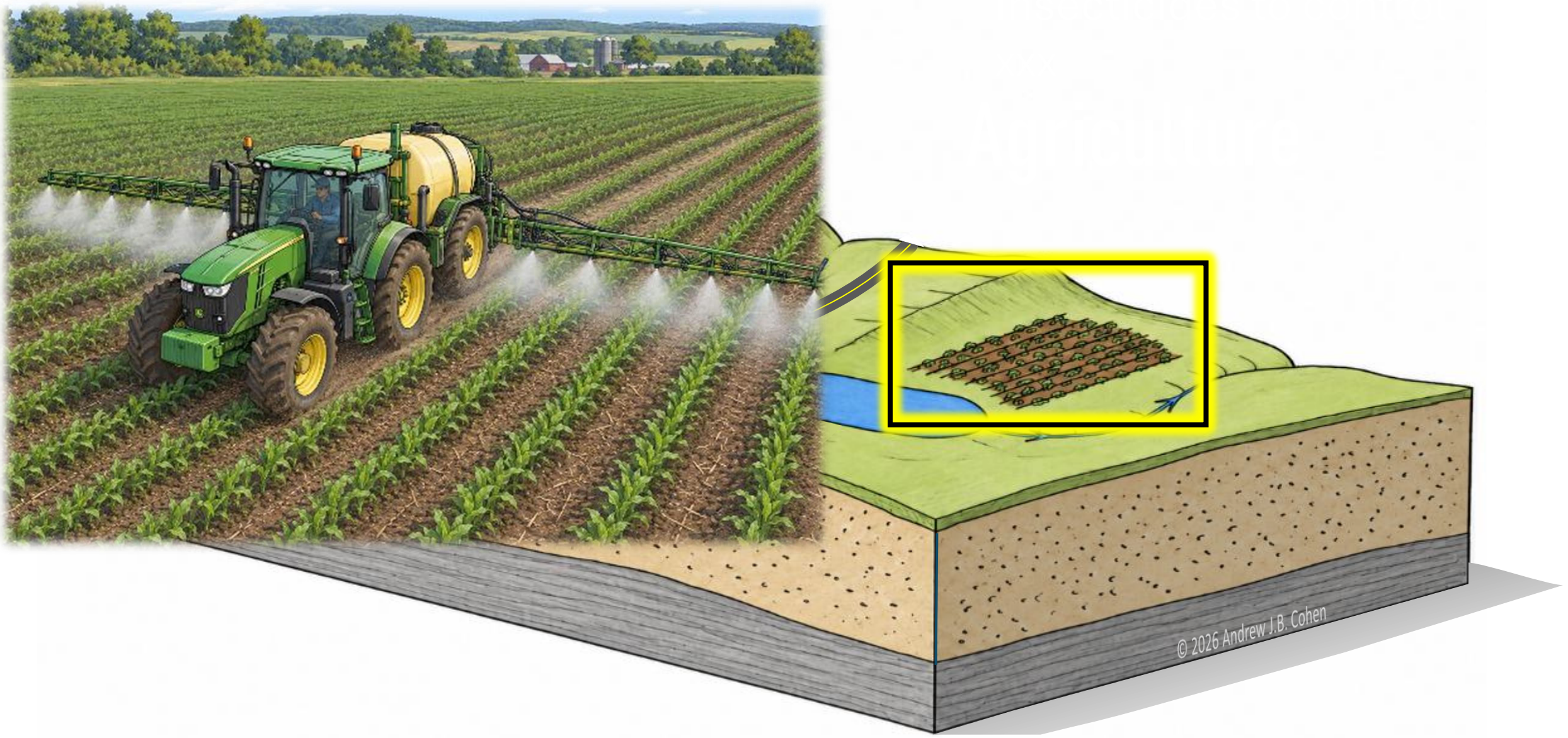
What and where are the sources of herbicides that are detected in these surface water and groundwater samples?

Source Attribution Requires Integration of Multiple Lines of Evidence

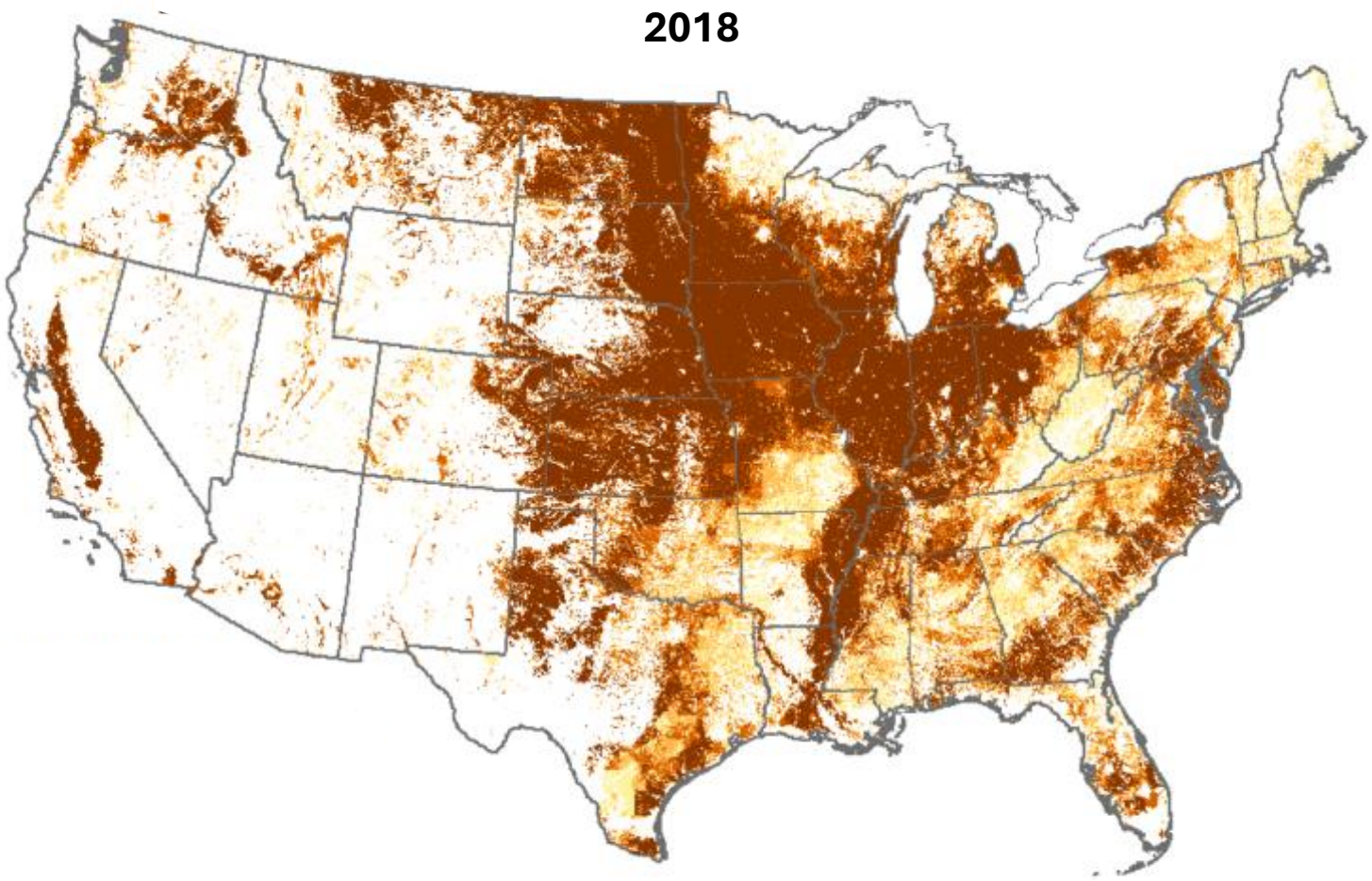
Partial List

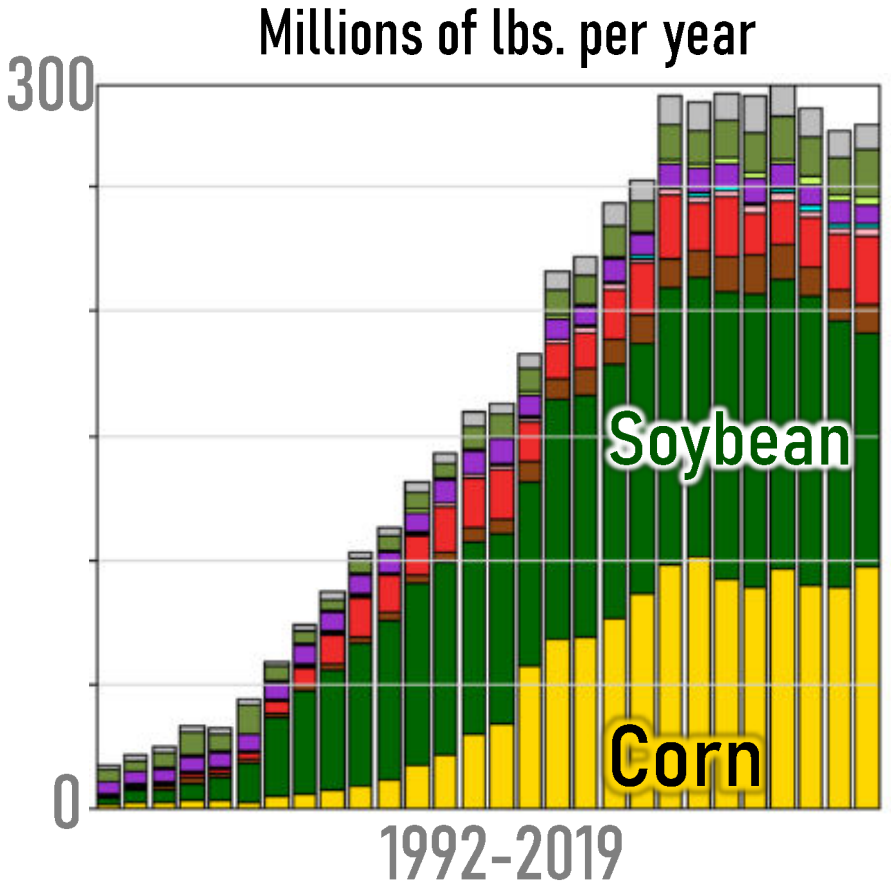
- Application history
- Active ingredients and formulations, patent histories
- Point and nonpoint sources
- Solubility, sorption, volatility, degradation half-life, transformation products, and other chemical properties
- Surface runoff and drainage catchments
- Streamflow and seasonal variability
- Precipitation patterns and storm events
- Timing of precipitation relative to application
- Soil characteristics
- Vadose-zone thickness
- Groundwater depth, flow directions and travel times
- Recharge, infiltration, and leaching
- Groundwater discharge to surface water
- Fate and transport calculations

Agricultural Use



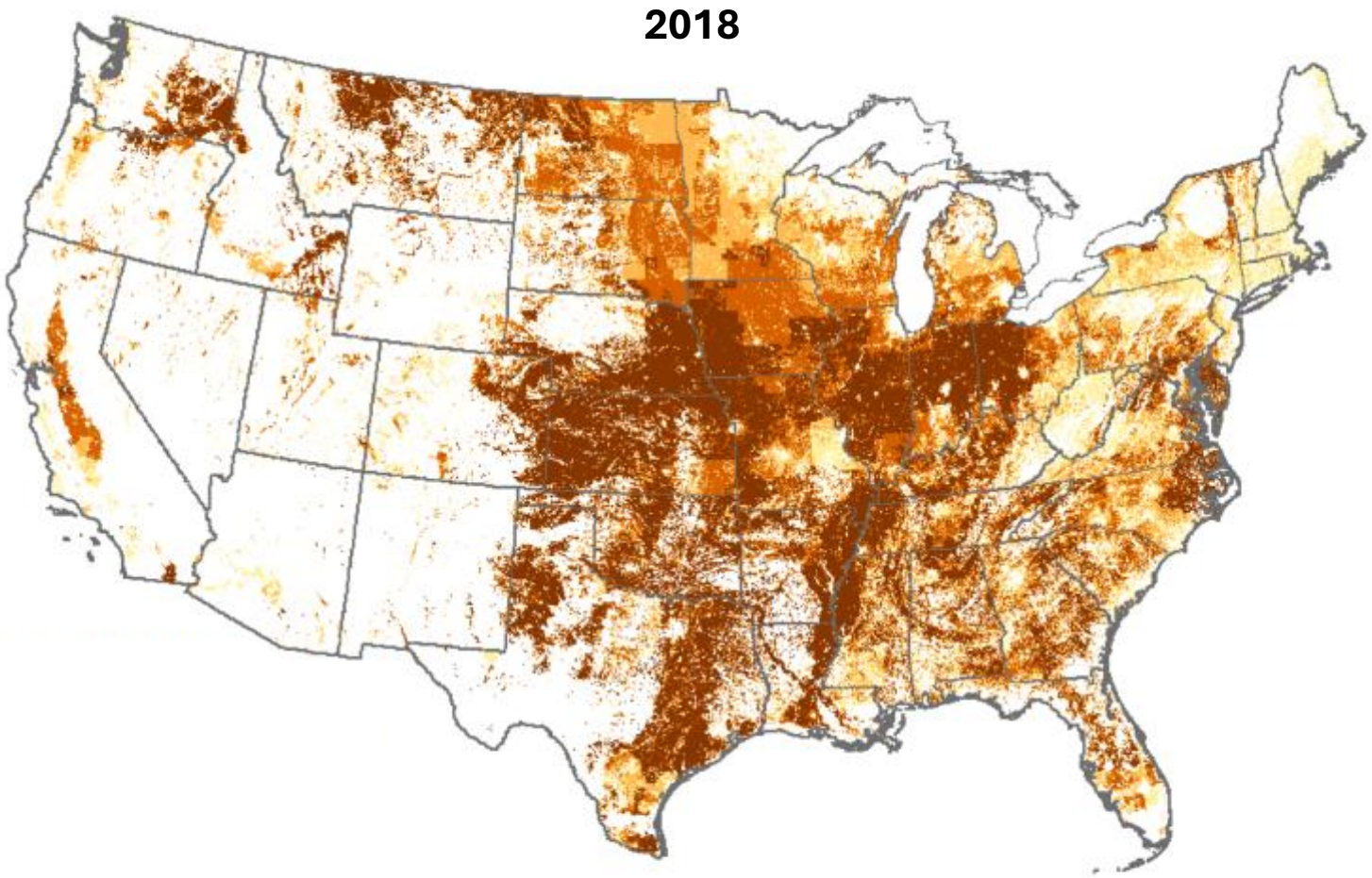
Glyphosate

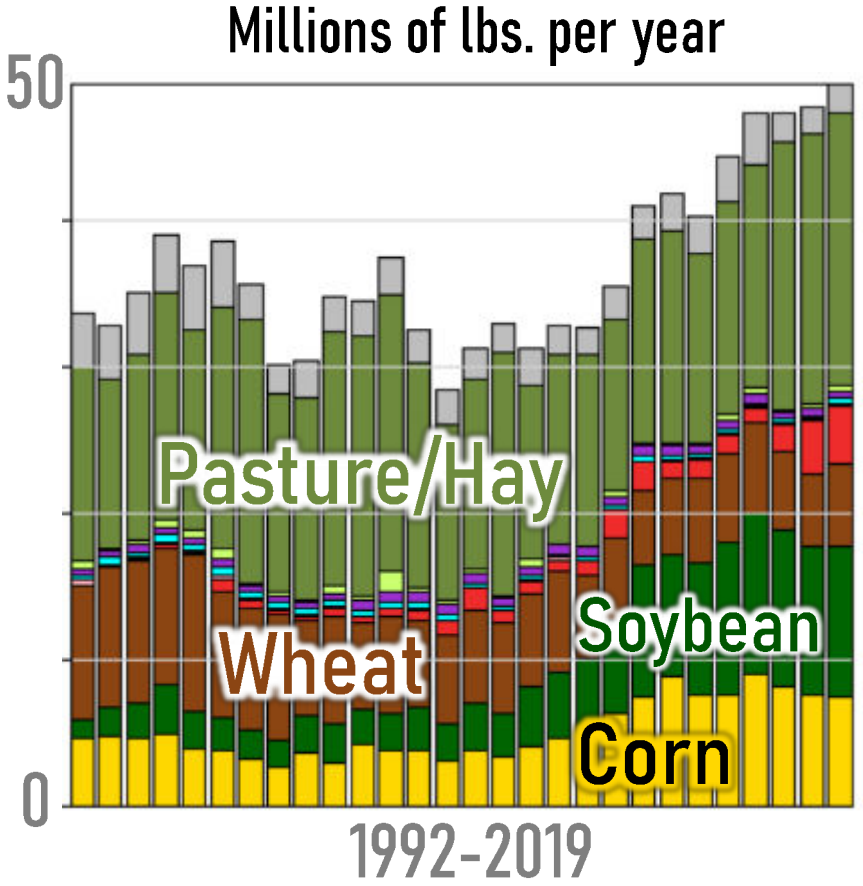




Sources: USGS Pesticide National Synthesis Project, https://water.usgs.gov/nawqa/pnsp/usage/maps/

2-4 D





Sources: USGS Pesticide National Synthesis Project, https://water.usgs.gov/nawqa/pnsp/usage/maps/

"D" = dichlorophenoxyacetic acid

Multiple ingredients in a brand is common

Example



An encapsulated herbicide for postemergence control of annual grasses and broadleaf weeds in field corn, field seed corn, field silage corn and popcorn.

Active Ingredients:

acetochlor	**30.0%**
topramezone	**0.5%**
clopyralid	**3.5%**

Other Ingredients

Example



An encapsulated herbicide for postemergence control of annual grasses and broadleaf weeds in field corn, field seed corn, field silage corn and popcorn.

Active Ingredients:

acetochlor: 2-chloro-N-ethoxymethyl-N-(2-ethyl6-methylphenyl)acetamide 30.0%

topramezone: [3-(4,5-dihydro-3-isoxazolyl)-2-methyl-4-(methylsulfonyl) phenyl] (5-hydroxy-1-methyl-1H-pyrazol-4-yl) methanone 0.5%

clopyralid MEA salt: 3,6-dichloropyridinecarboxylic acid, monoethanolamine salt 3.5%

Other Ingredients 66.0%

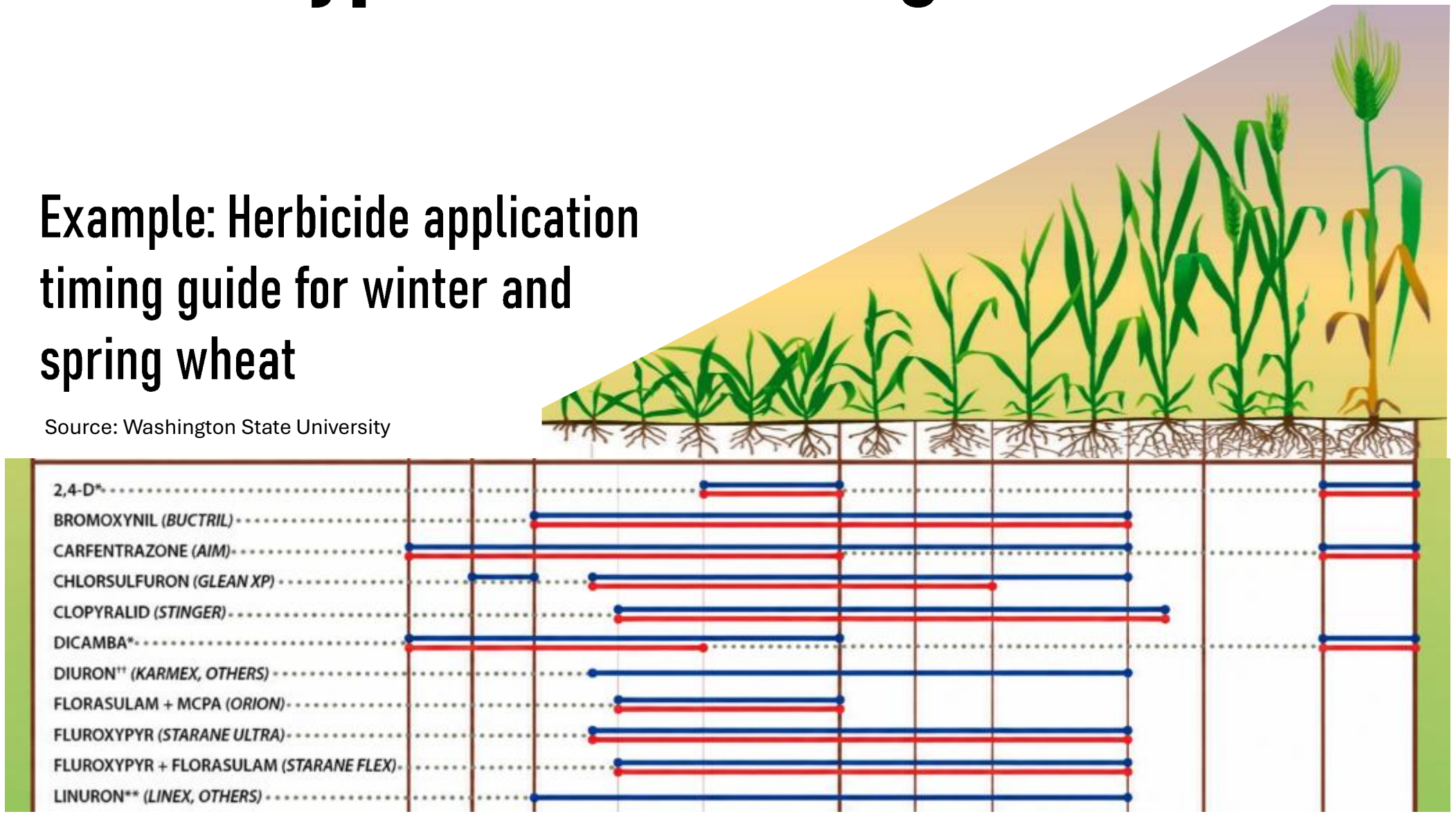
Total 100.0%

Surfactants, solvents and other "inerts" help a pesticide spread or remain effective.

Different Types Used Throughout the Season

Example: Herbicide application timing guide for winter and spring wheat

Source: Washington State University



Manufacturing History

Detection of a particular chemical may not be attributable to a single manufacturer.

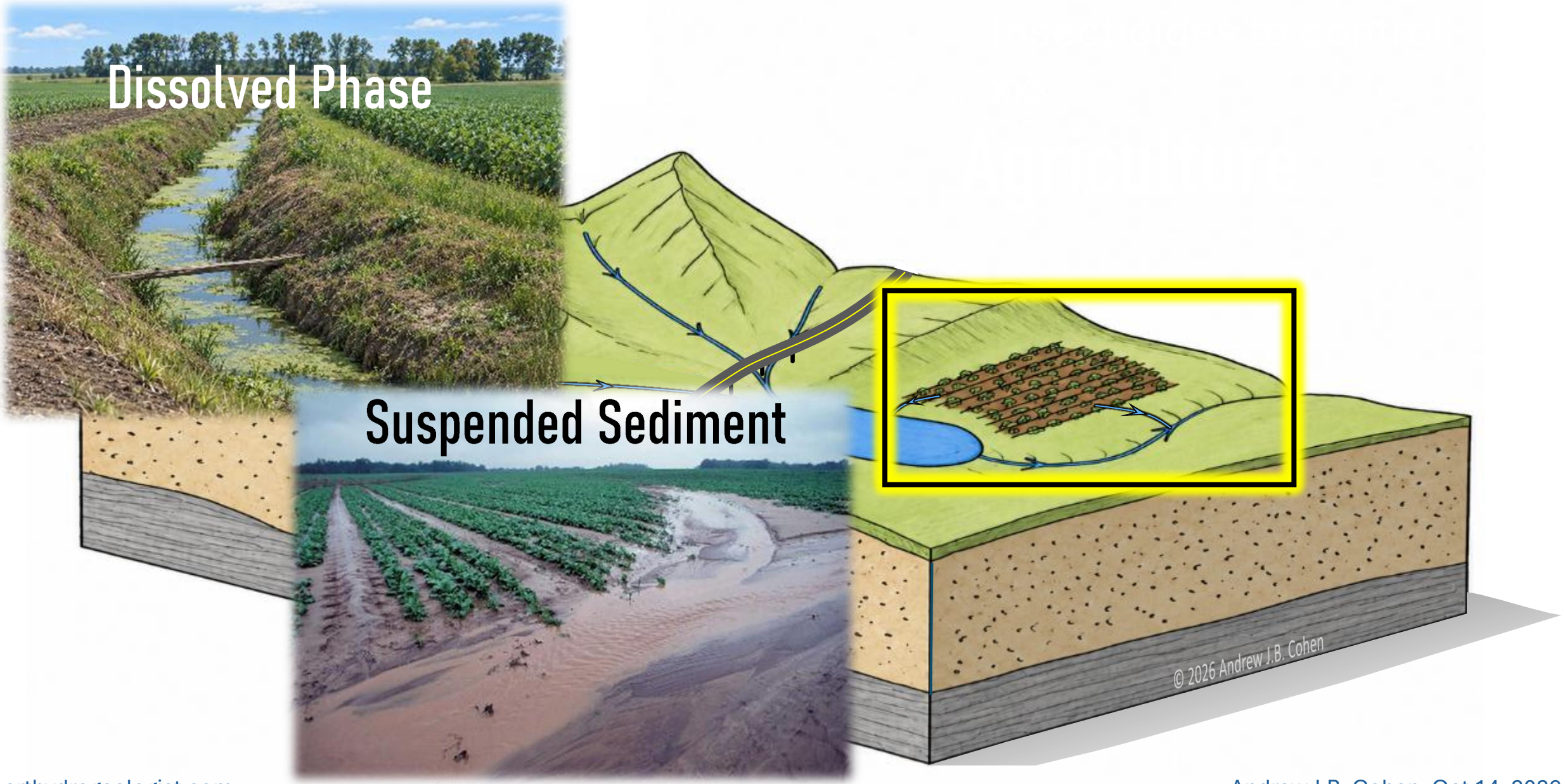


Monsanto (now Bayer)

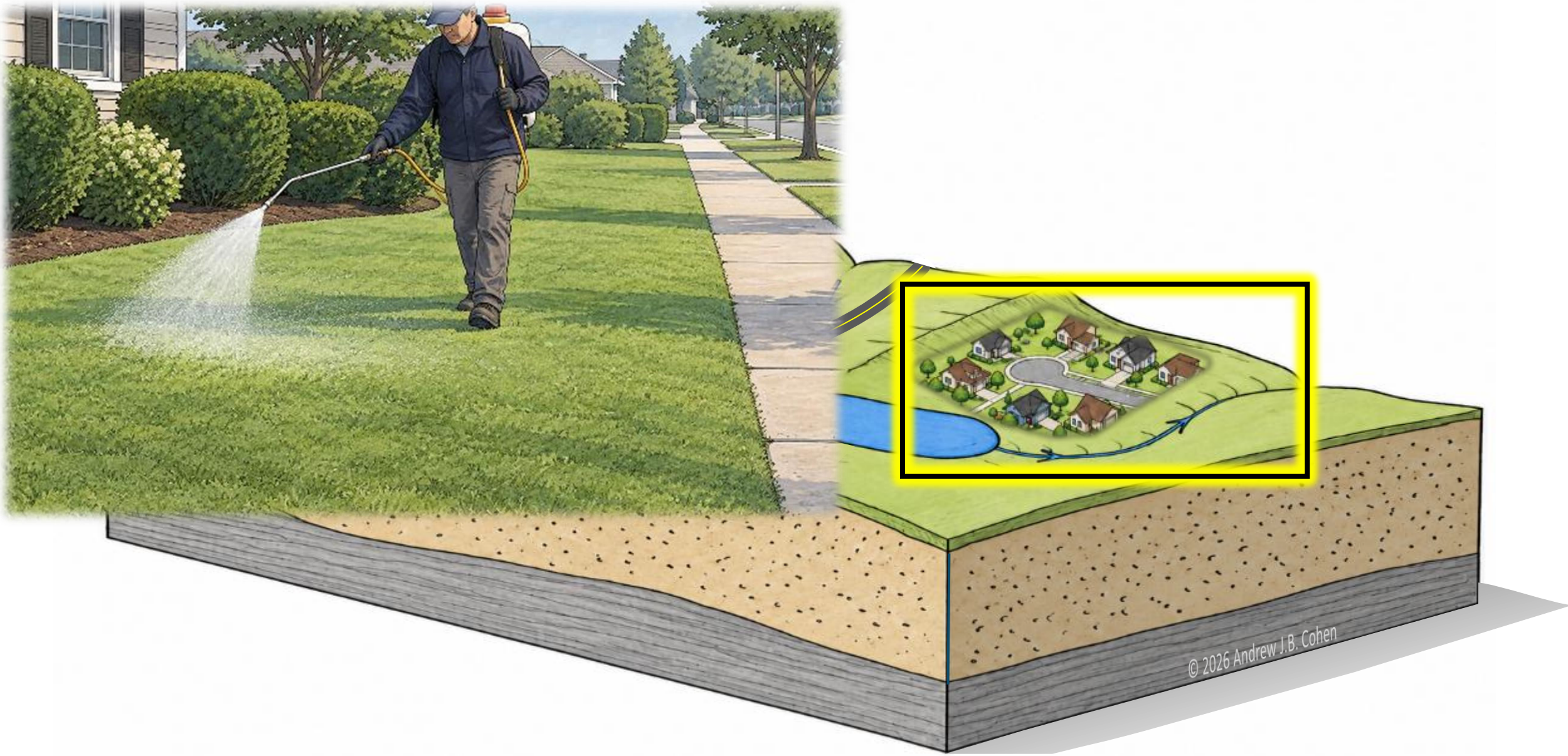
Patent Expirations 1991-2000



Migration to Surface Water



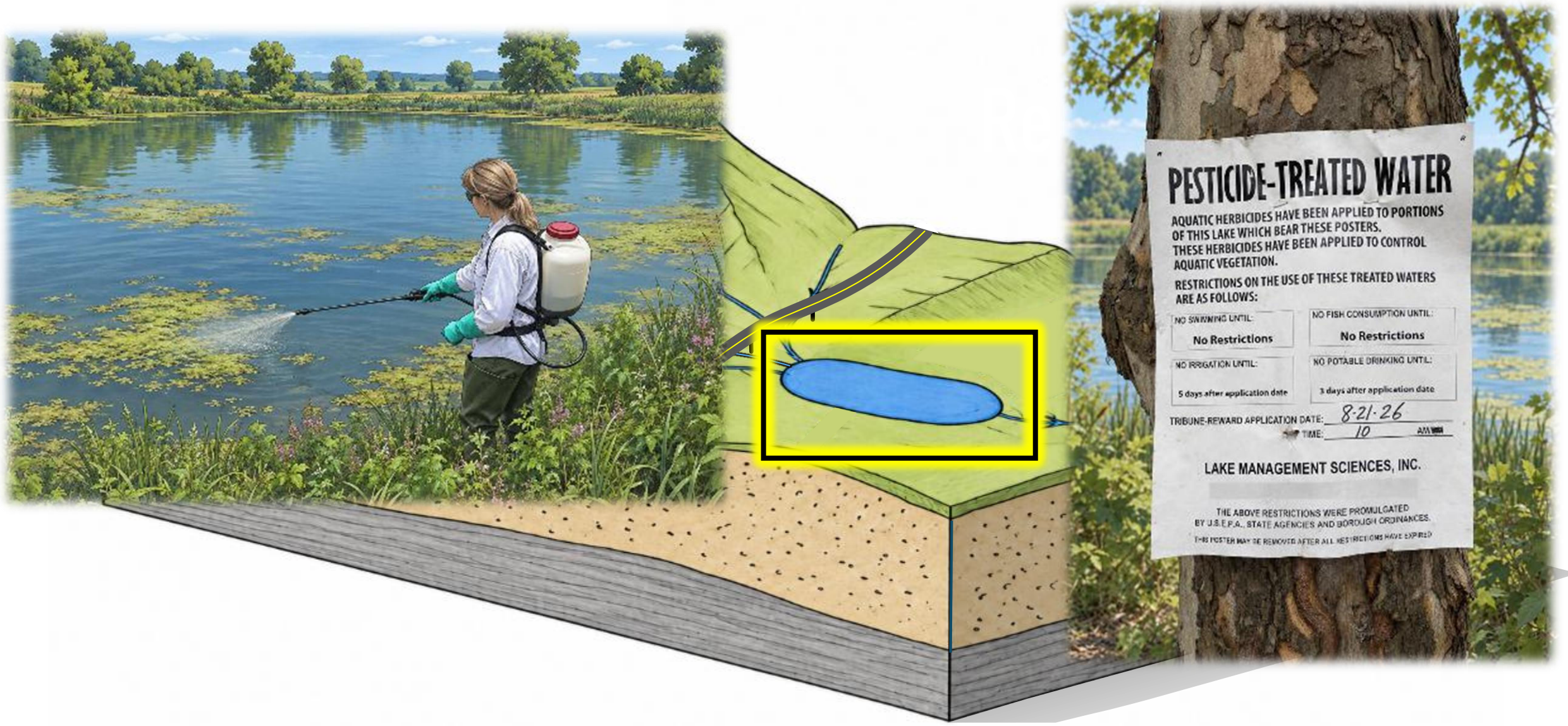
Residential



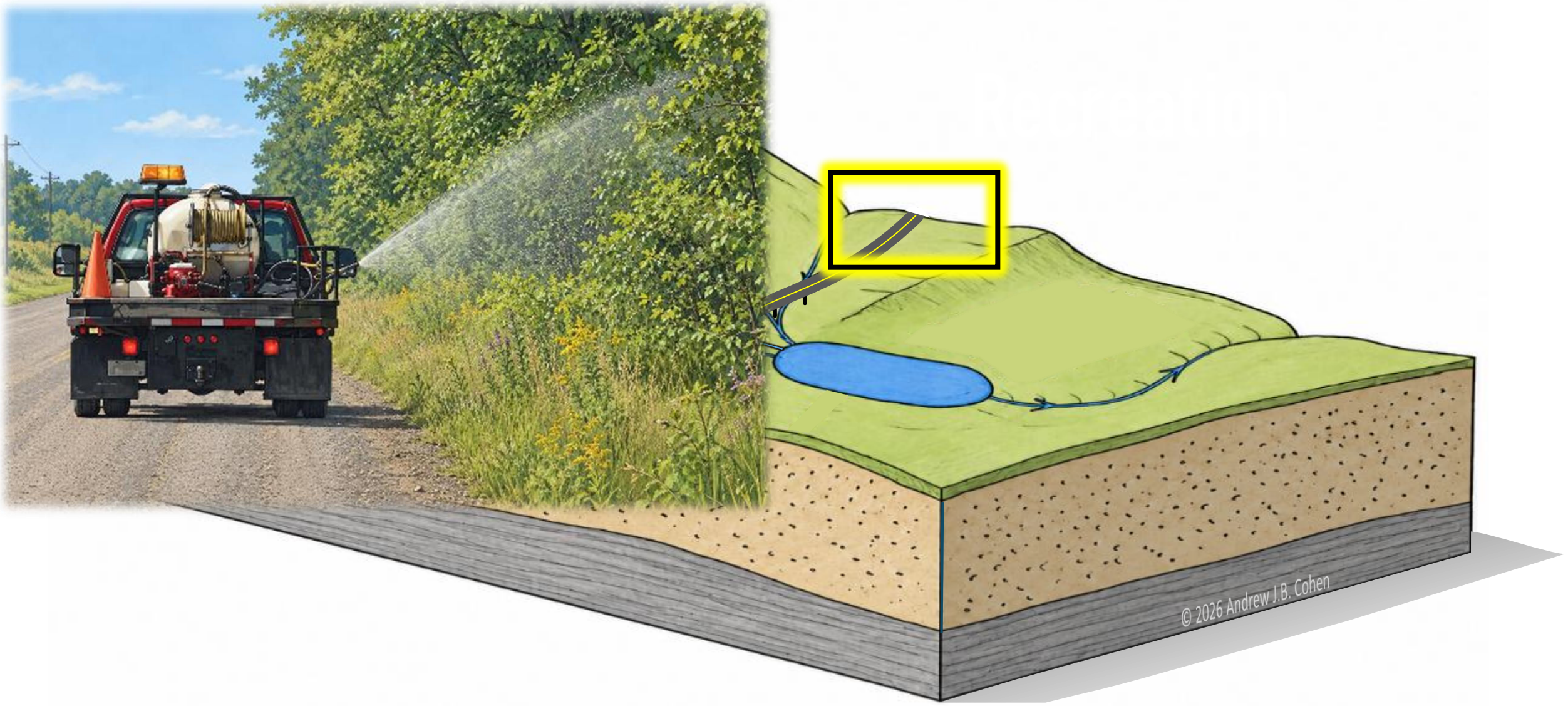
Application → Storm Water → Stream



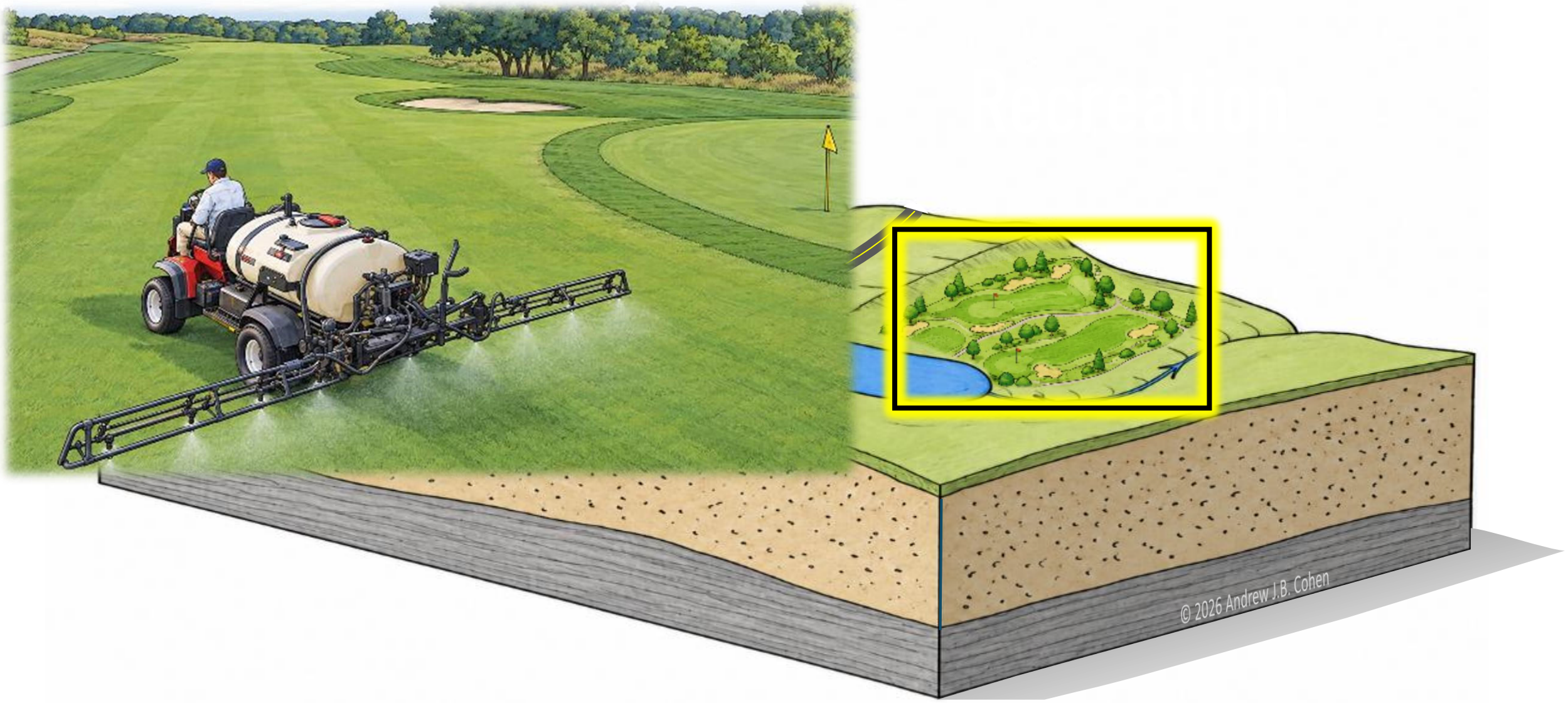
Direct Application



Rights-of-Way



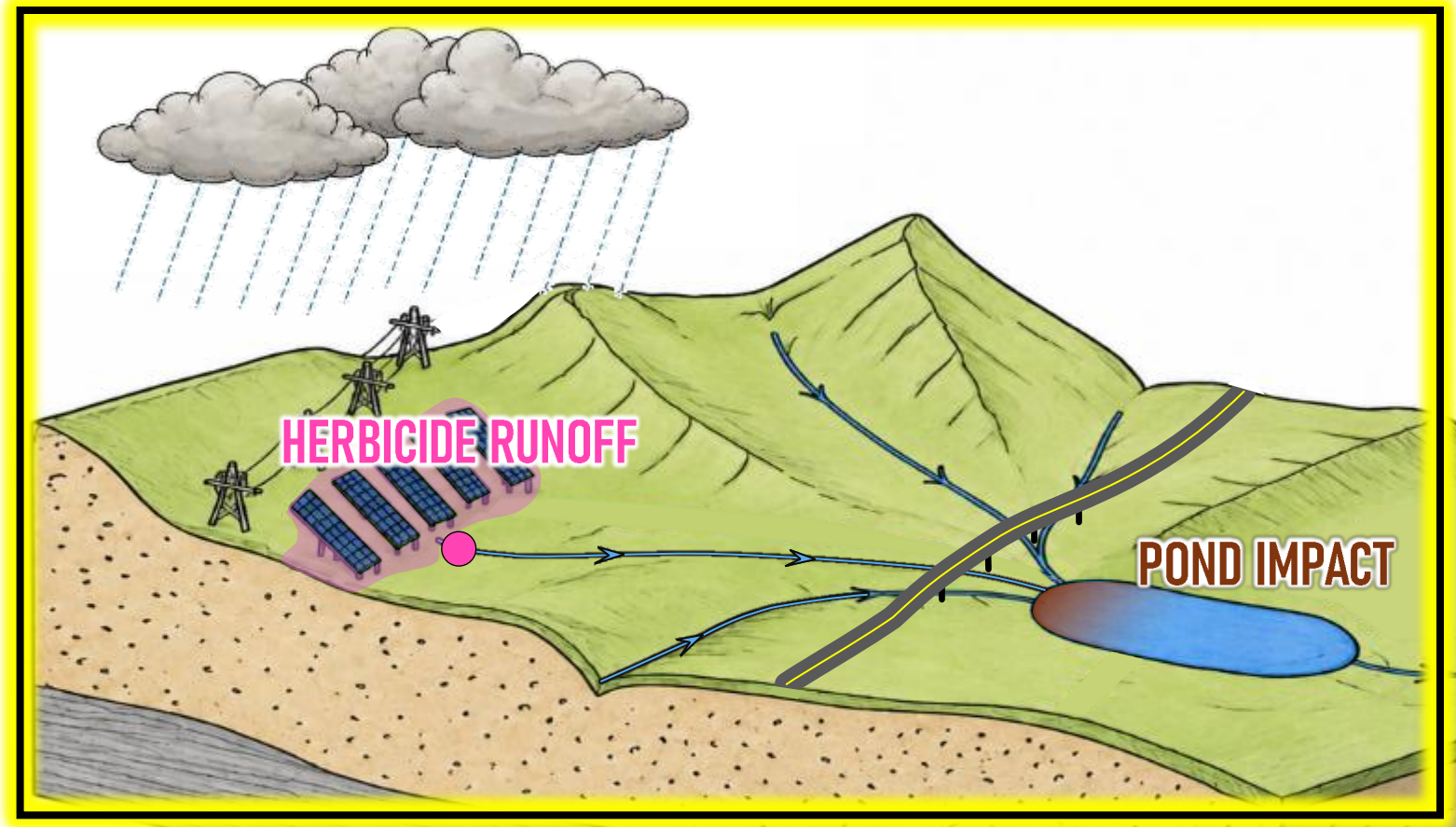
Turf



Utilities



Long-Distance Transport



Extent and magnitude of impacts to receptors affected by pesticide solubility, sorption, volatility, degradation half-life, soil moisture, dilution, and timing of precipitation relative to application.

$$C_{pond} = \frac{M_{delivered} + C_0 V_0}{V_0 + V_{runoff}}$$

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Stream Concentrations

Source: Gilliom, R., et al., 2007. Pesticides in the nation's streams and ground water, 1992–2001 : the quality of our nation's waters, U.S. Geological Survey circular 1291.





Stream Concentrations

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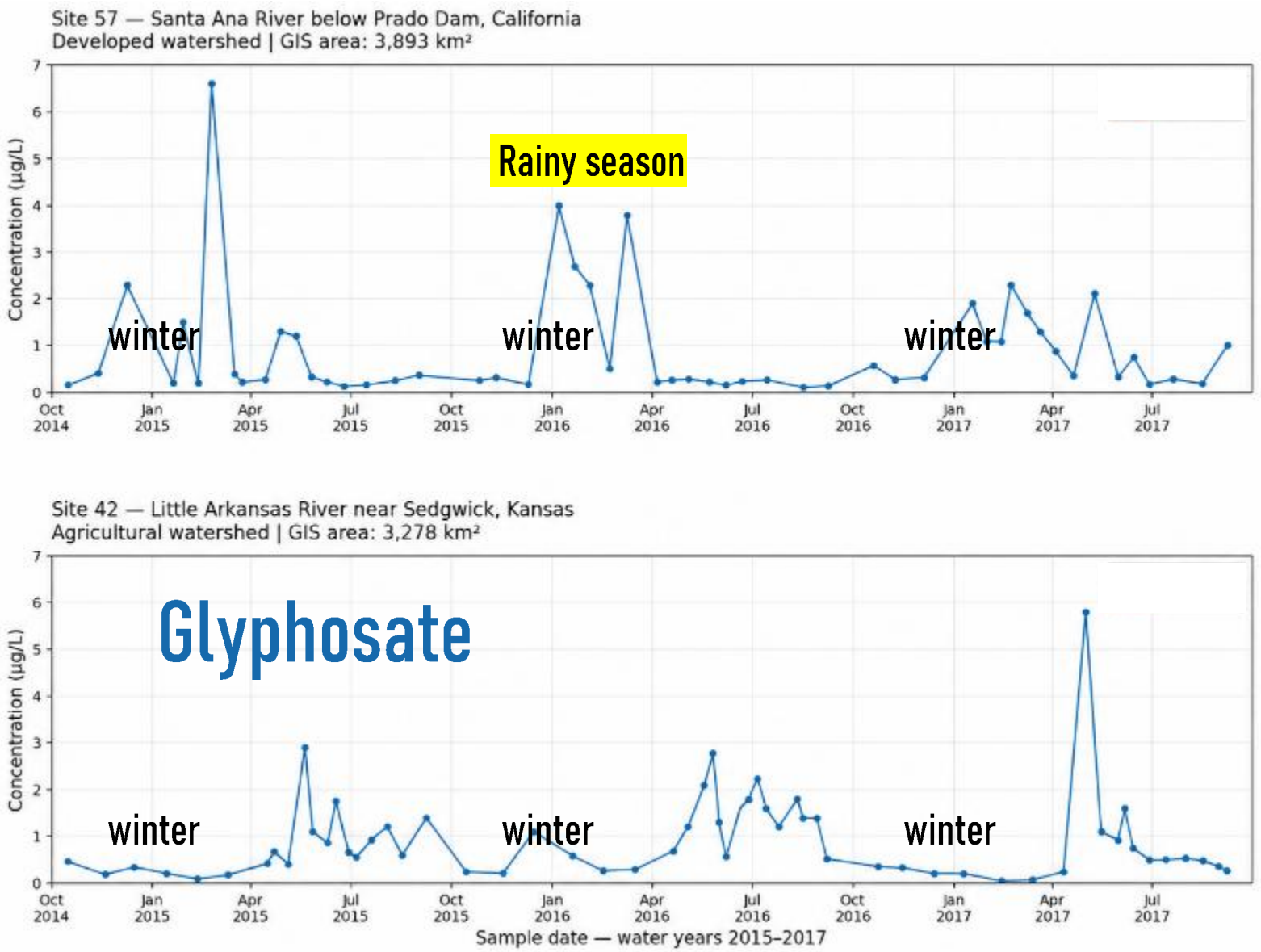
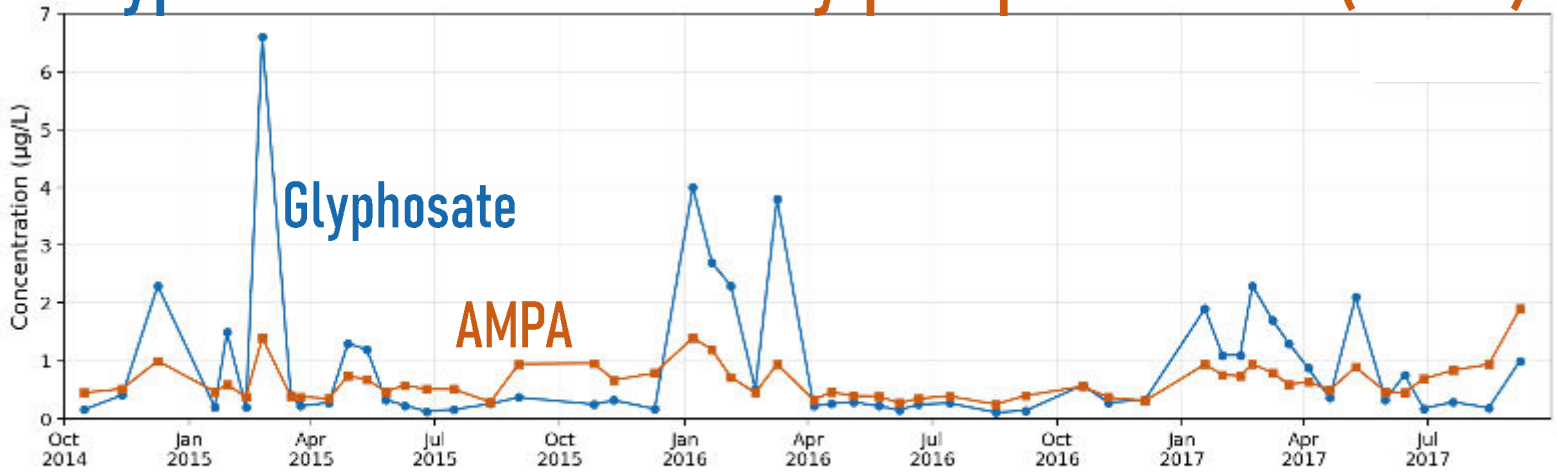
Differences Due to Climate and Land Use

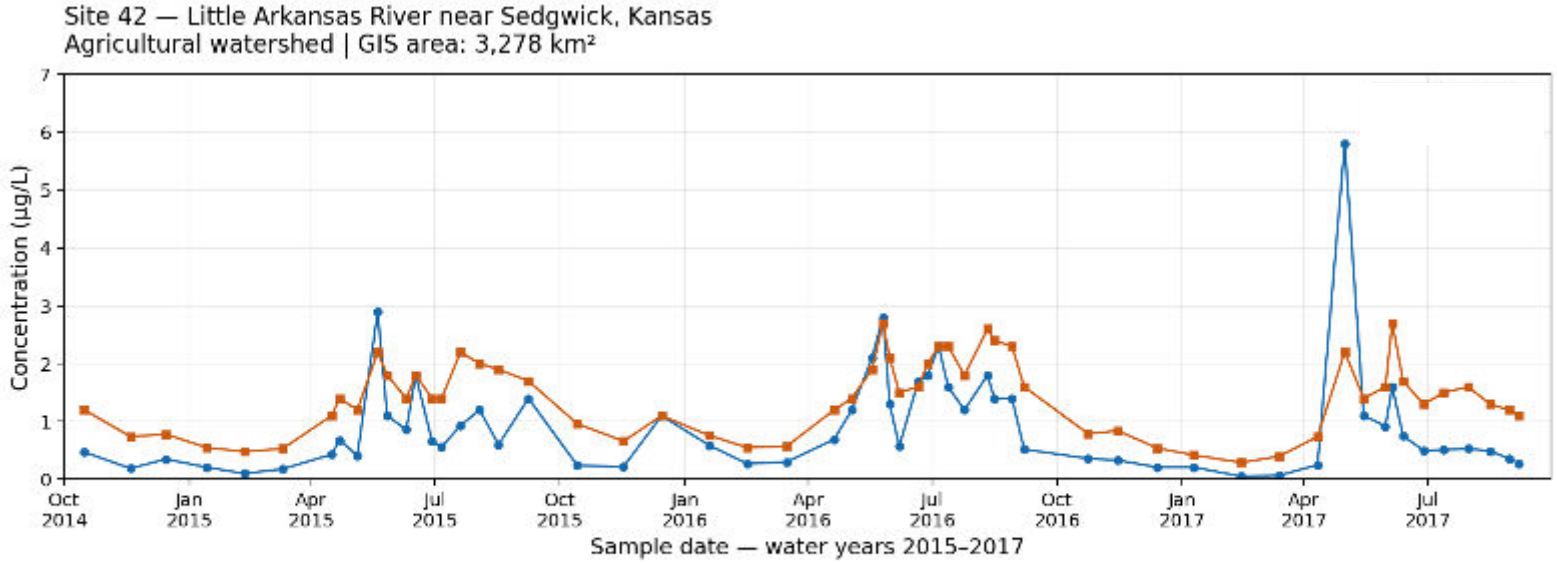


Both panels: 0–7 µg/L; October 2014–September 2017. All results at these sites were detections.
Lines connect sampled concentrations; they do not represent continuous monitoring.
Source: supplied USGS Tables 1 and 2.

Degradation Compounds

Glyphosate → aminomethylphosphonic acid (AMPA)





Both panels: 0–7 µg/L; October 2014–September 2017. All results at these sites were detections.
Lines connect sampled concentrations; they do not represent continuous monitoring.
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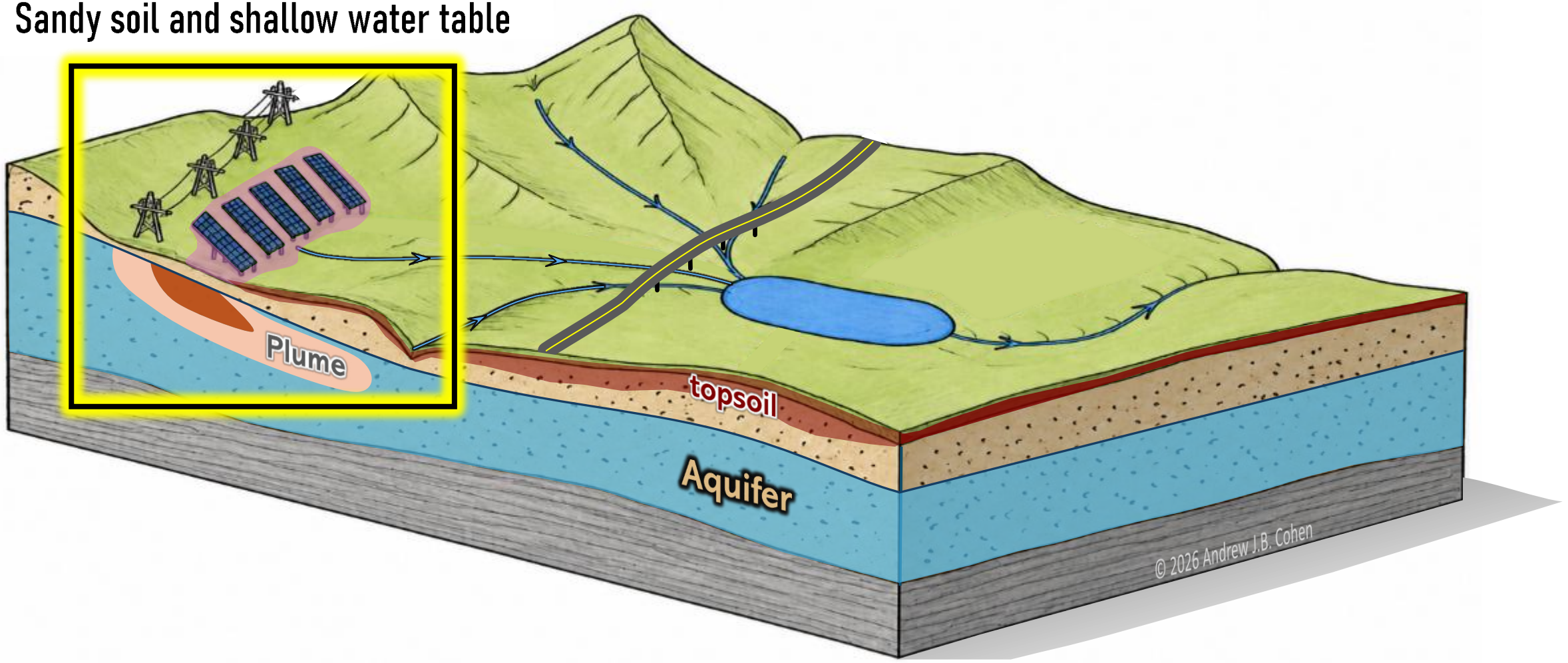
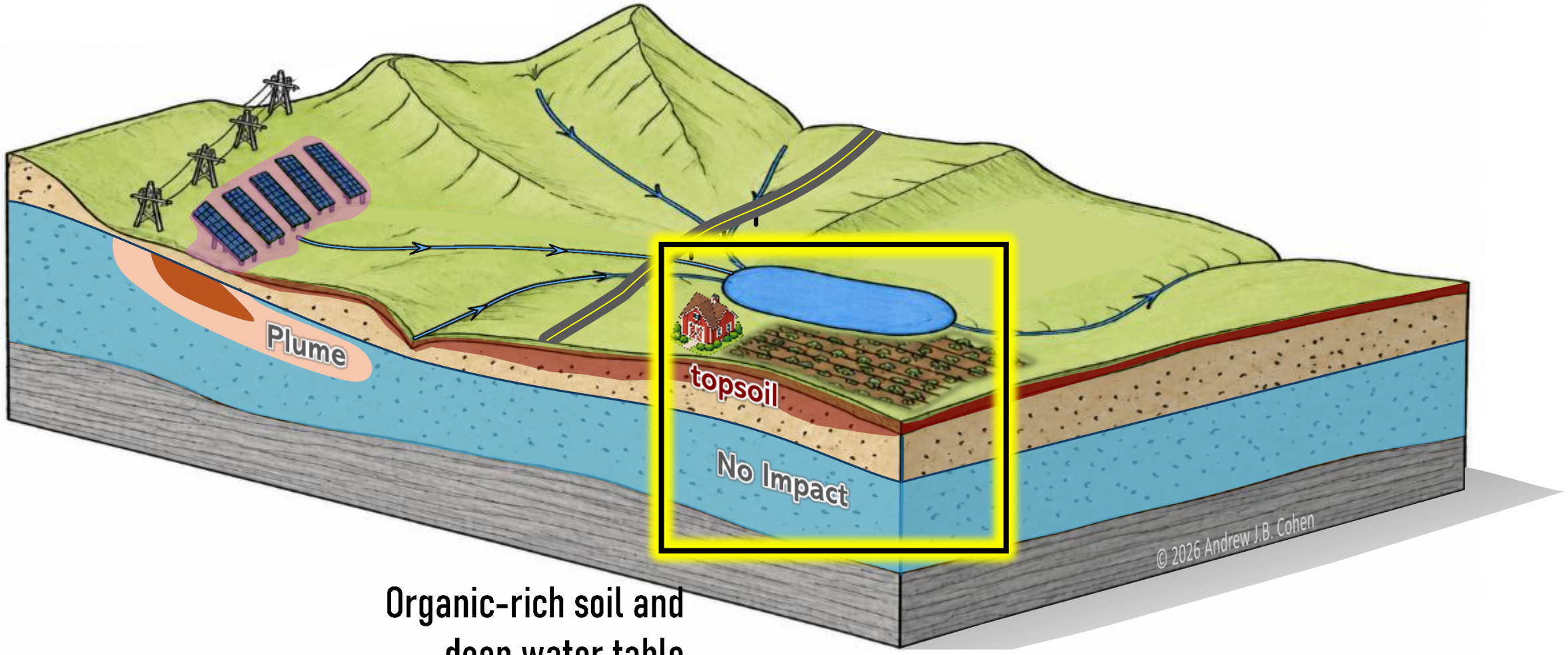
Groundwater Impacts



Groundwater Impacts



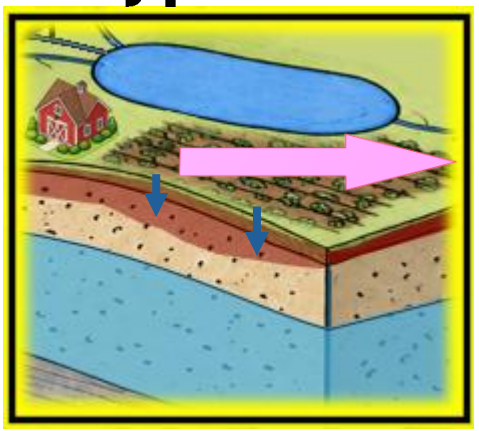
Organic-rich soil and
deep water table

Chemical Properties Need to be Considered

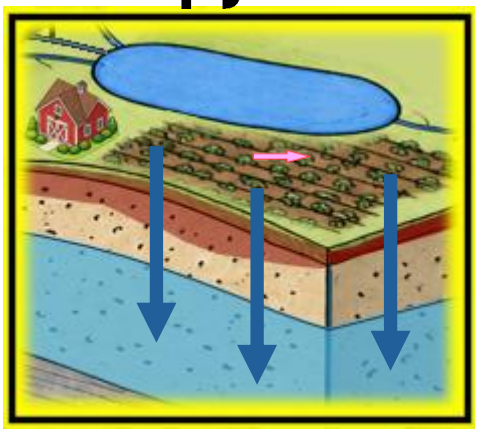
Glyphosate

Runoff=high potential

Infiltration=negligible



Clopyralid



Infiltration=high potential

Runoff=very low potential

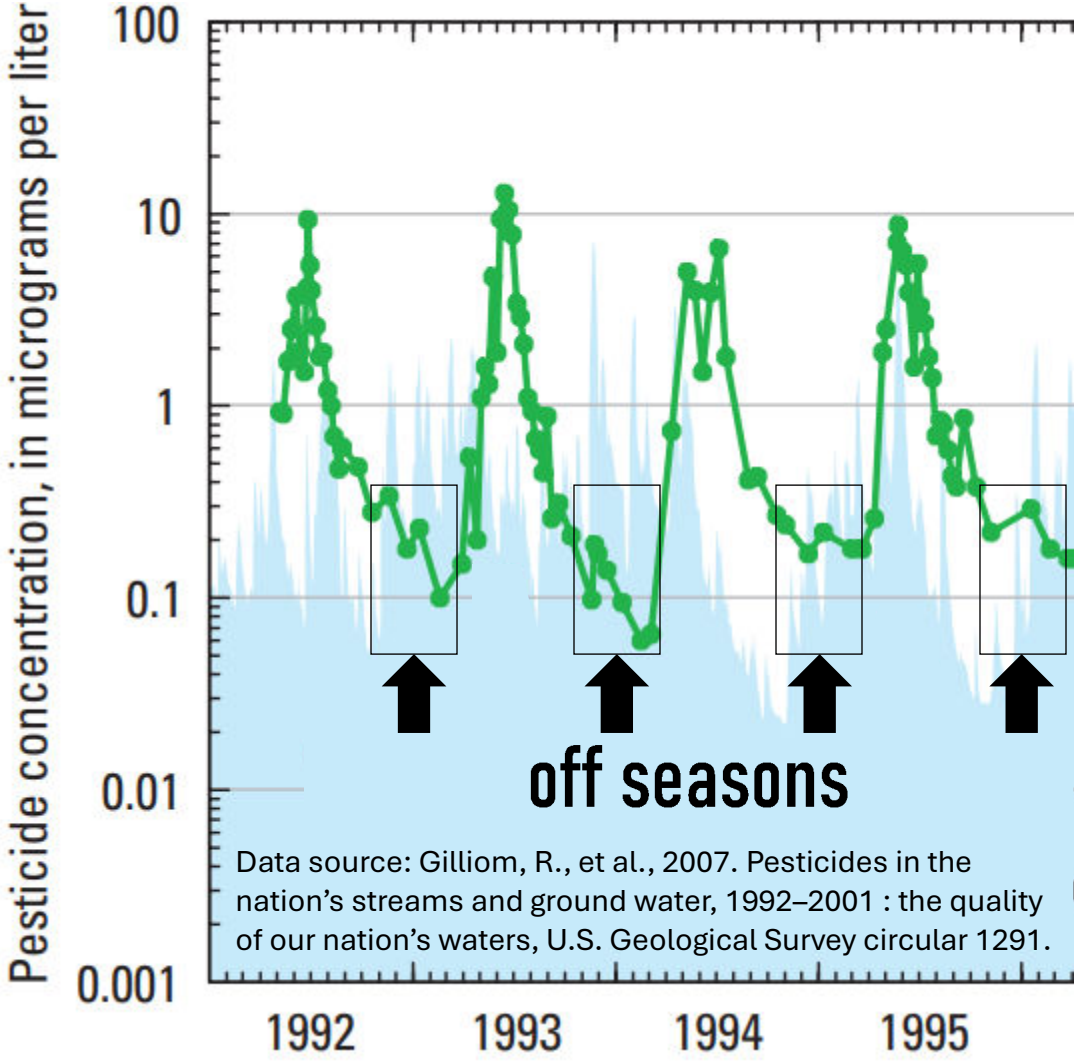
Chemical	Soil degradation half-life (days)[1]	Koc (L/kg)[1]	Calculated GWS	Potential Migration to Groundwater	Potential Migration to Surface Water via Suspended Sediment
Glyphosate	47	24,000	-0.6	Extremely Low	Extremely High
Atrazine	60	100	3.6	High	Low
Dicamba	14	2	4.2	Very High	Very Low
Clopyralid	55	5	5.7	Extremely High	Very Low

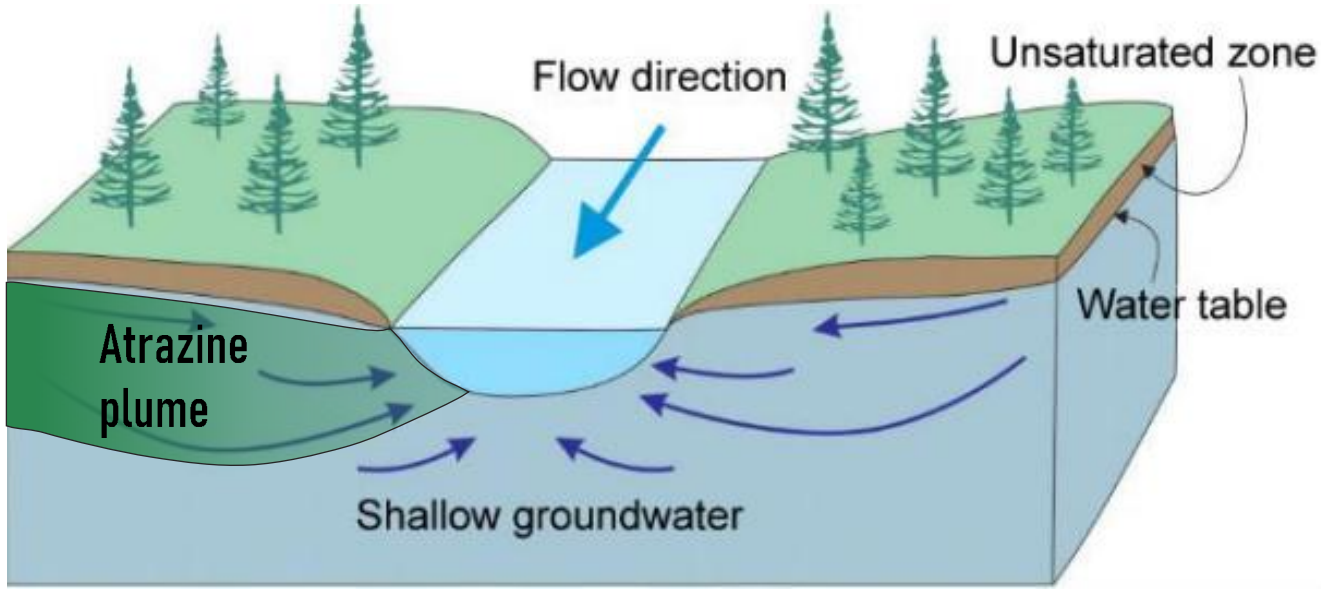
[1]National Pesticide Information Center, https://npic.orst.edu/ingred/ppdmove.htm

GWS=Groundwater Ubiquity Score

Groundwater to Surface Water Recharge

Groundwater recharge may contribute to low concentrations during off-season



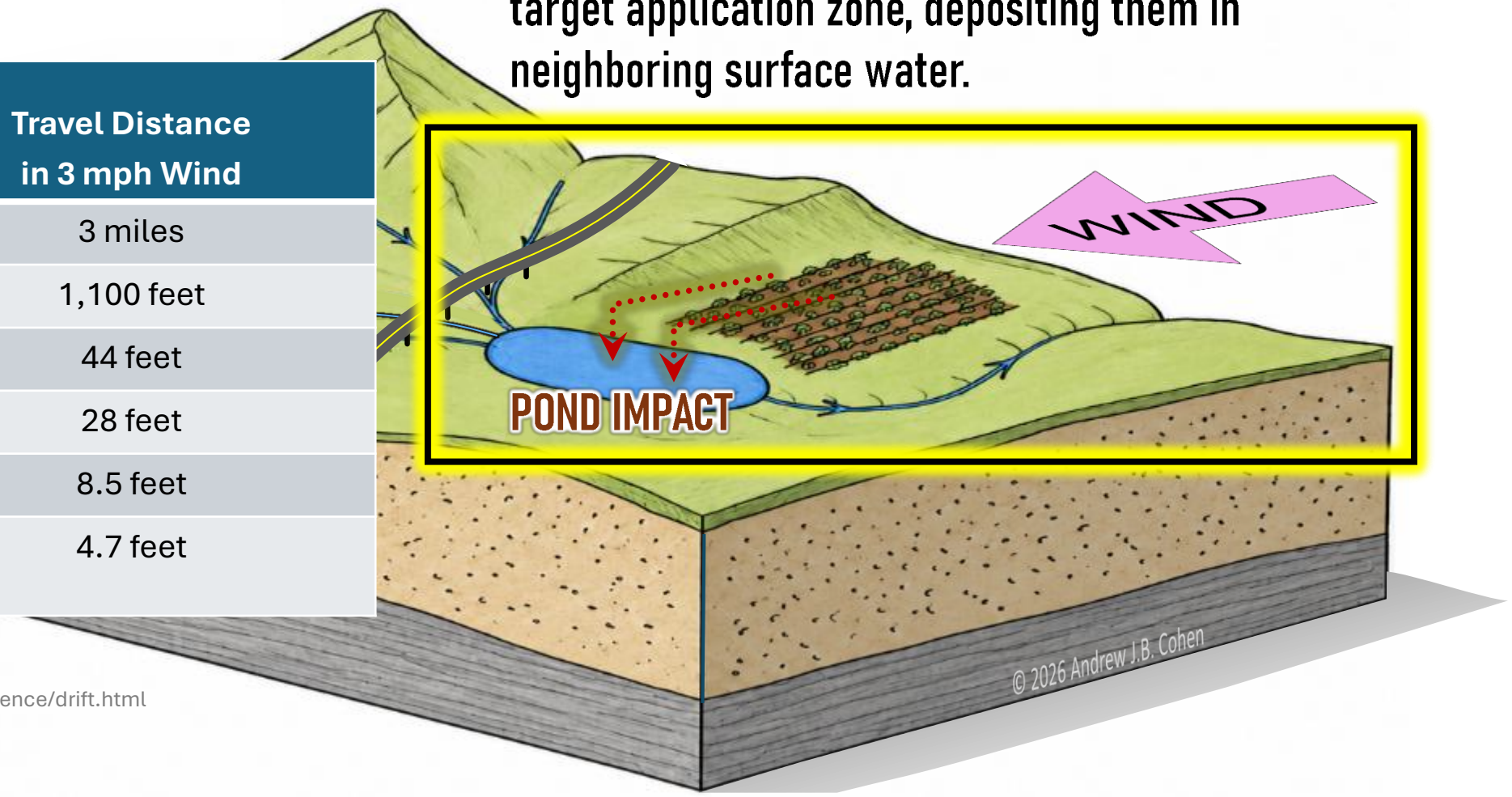


Particle Drift

Droplet	Width (µm)	Time to Fall 10 Feet	Travel Distance in 3 mph Wind
Fog	5	66 min	3 miles
Very Fine	20	4 min	1,100 feet
Fine	100	10 s	44 feet
Medium	240	6 s	28 feet
Coarse	400	2 s	8.5 feet
Extra Coarse	1000	1 s	4.7 feet

Source: Pesticide Education Program
Montana State University
https://www.montana.edu/extension/pesticides/reference/drift.html

Wind carries fine spray droplets away from the target application zone, depositing them in neighboring surface water.



Key Data: Herbicide Application Form



Active Ingredient:
Aminocyclopyrachlor

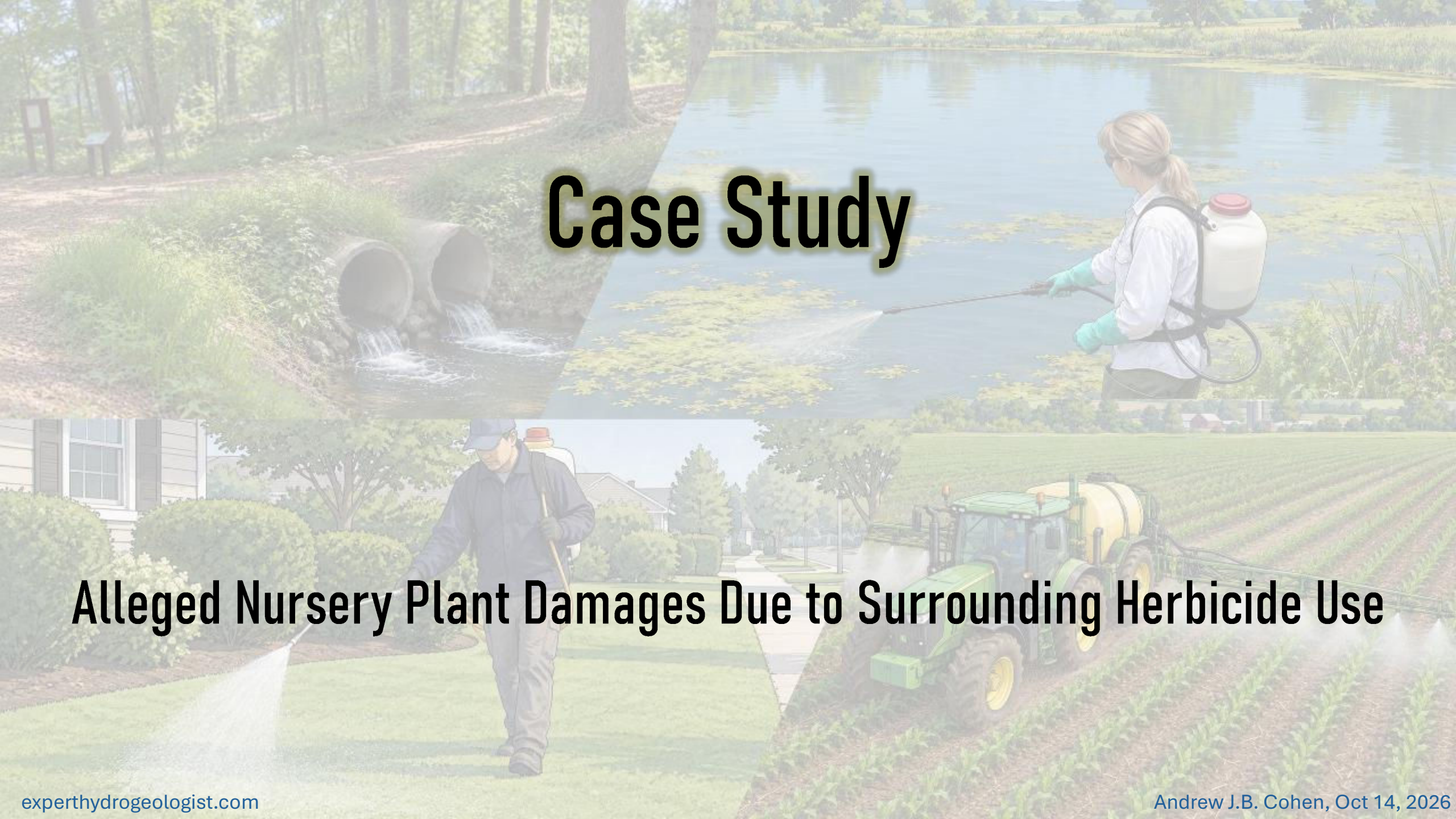
PESTICIDE APPLICATION RECORD

Applicator [redacted]
License # [redacted]
Date of Application [redacted]
Time Completed 11:30 AM

PRODUCT	RATE	TOTAL AMOUNT USED
Method	48 oz	3,792 oz
MSO	32 oz	2,528 oz
Arrigo	24 oz	1,896 oz
Glyphosate	11oz	143 oz

SPRAYER TYPE: GNC
SPEED : 8 MPH
PSI: 100
NOZZLE TYPE: Fan
WEATHER: 91°

LOCATION OF AREA: [redacted]
[redacted]
SIZE OF TREATED AREA: [redacted]
TARGETS: Broadleaf weeds
RESTRICTED USE?: Y / N
R.U.P EPA REGISTRATION #:



Case Study

Alleged Nursery Plant Damages Due to Surrounding Herbicide Use

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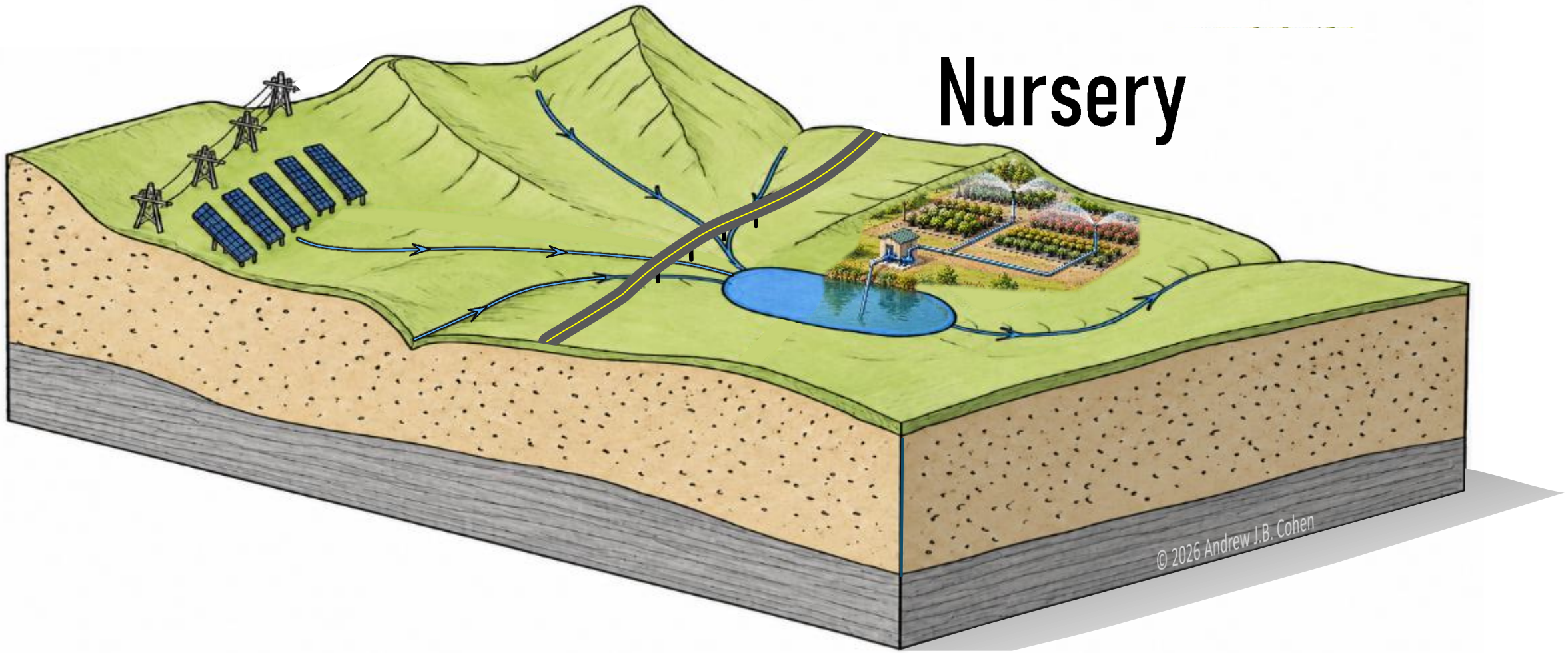
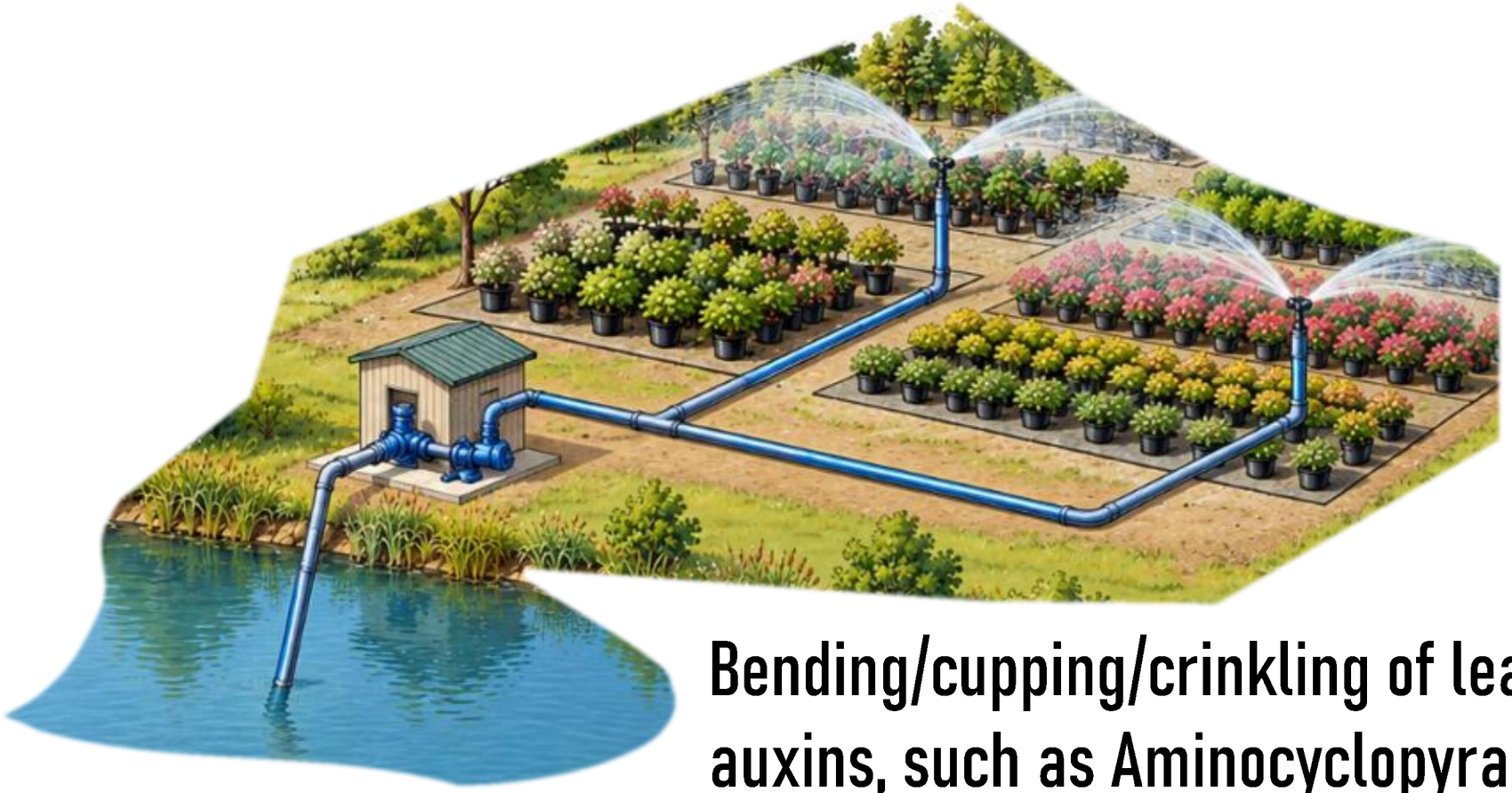
Nursery Contamination Case Study



Nursery Contamination



Irrigation Pond



Bending/cupping/crinkling of leaves indicative of synthetic auxins, such as Aminocyclopyrachlor, “2-4 D”, Triclopyr, and Dicamba.

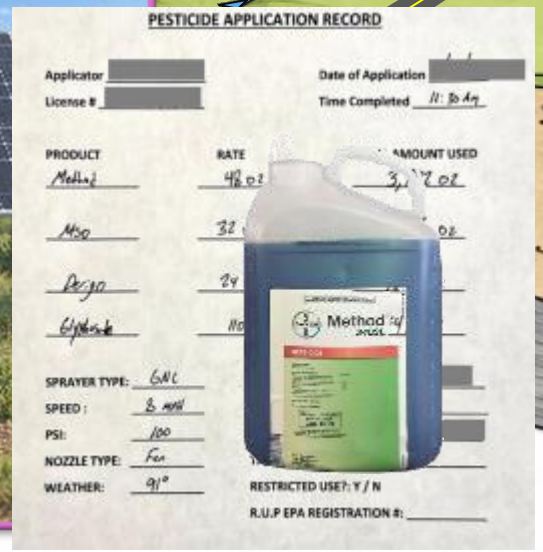


Surrounding Herbicide Use









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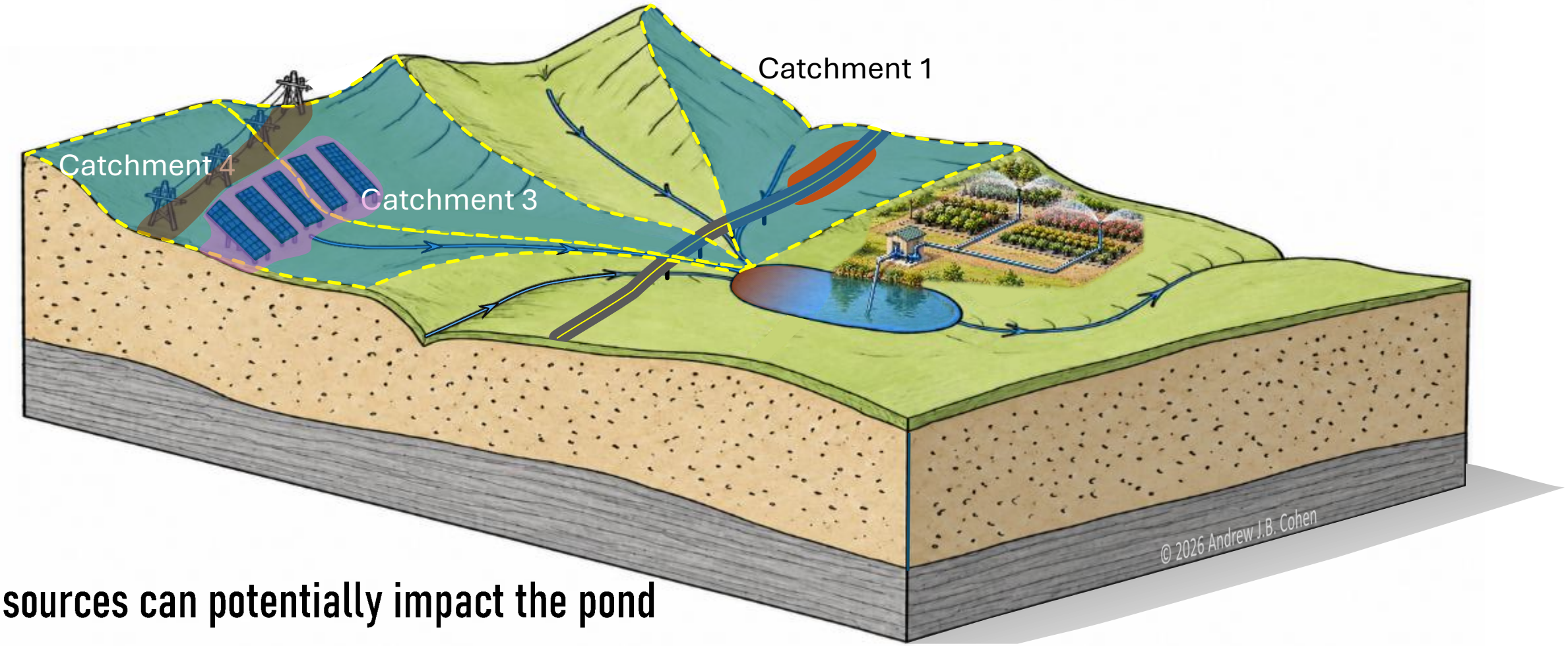
Consideration of Catchment Areas

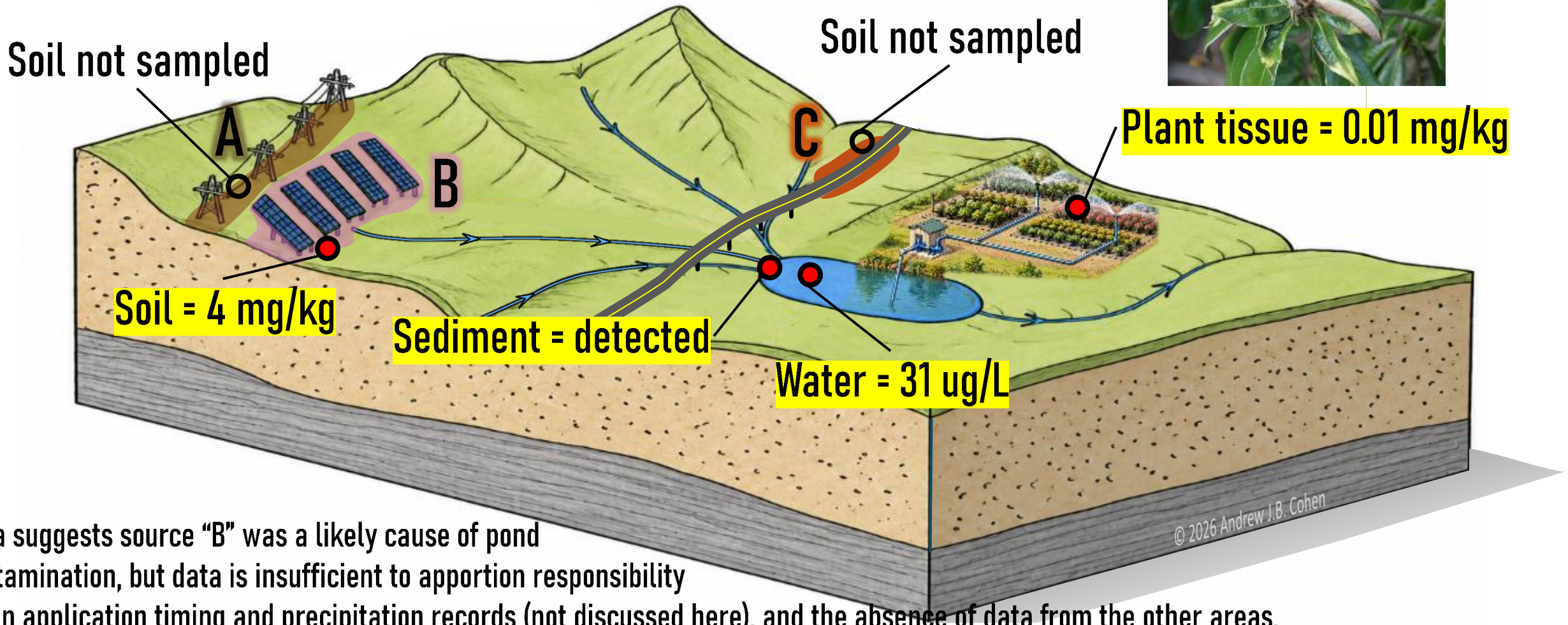


All 3 sources can potentially impact the pond

Sampling Results

Aminocyclopyrachlor



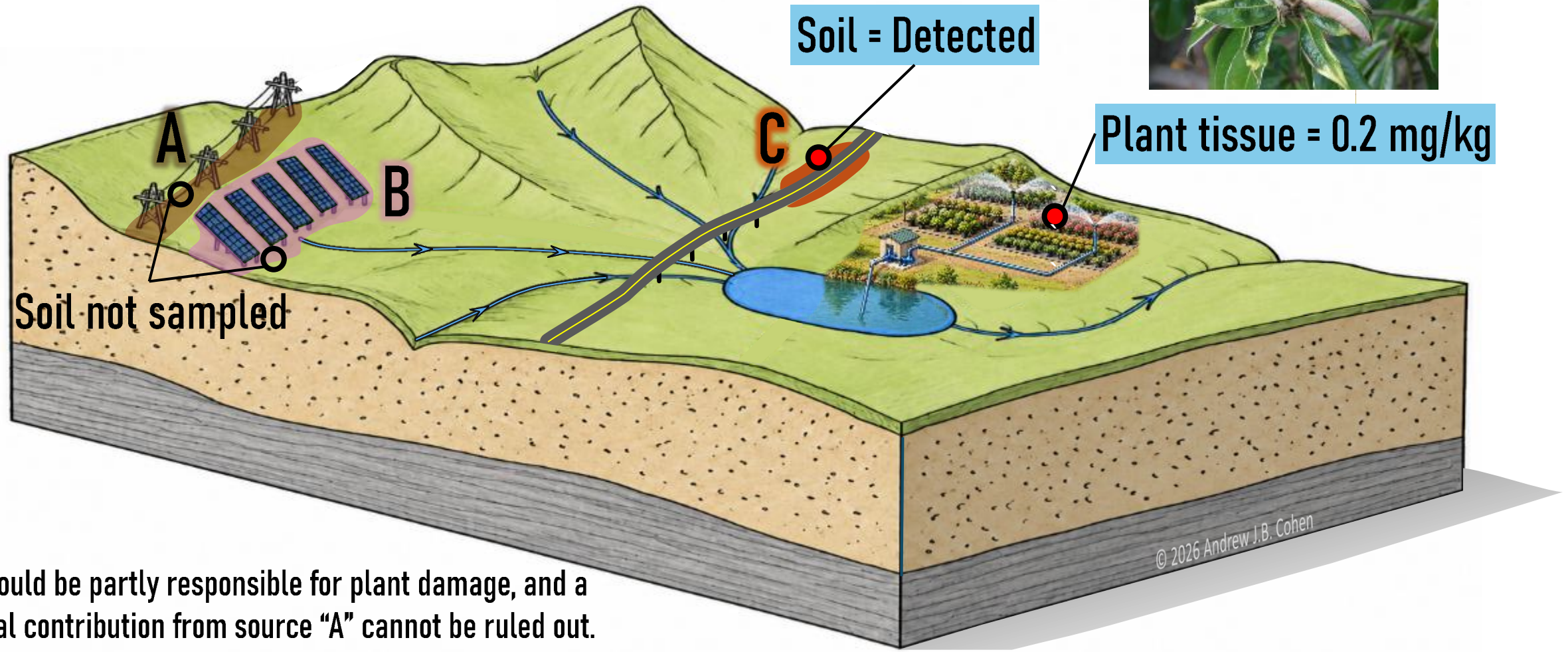


Data suggests source "B" was a likely cause of pond contamination, but data is insufficient to apportion responsibility given application timing and precipitation records (not discussed here), and the absence of data from the other areas.

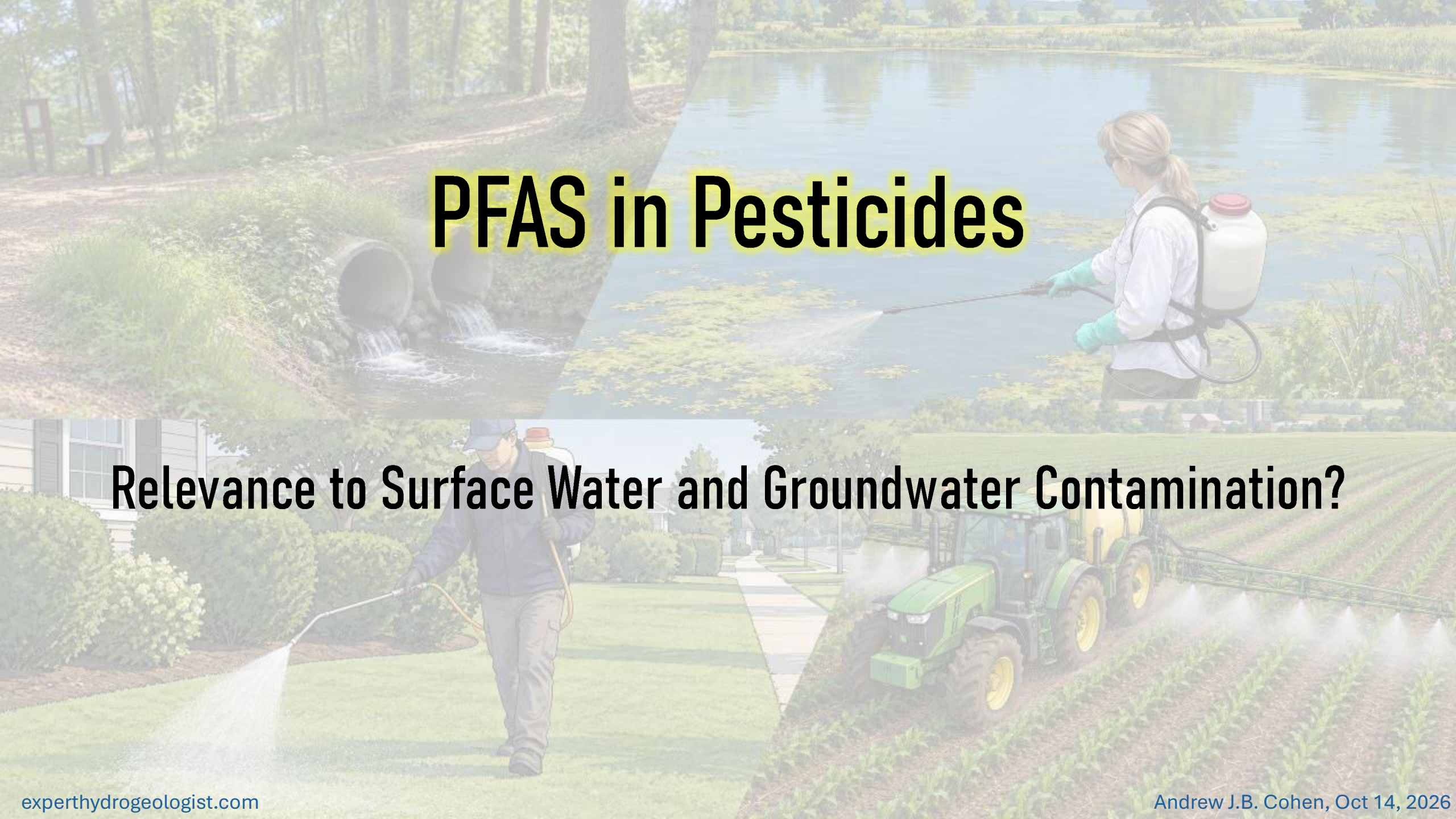
Sampling Results

2-4 D





2-4 D could be partly responsible for plant damage, and a potential contribution from source "A" cannot be ruled out.



PFAS in Pesticides

Relevance to Surface Water and Groundwater Contamination?

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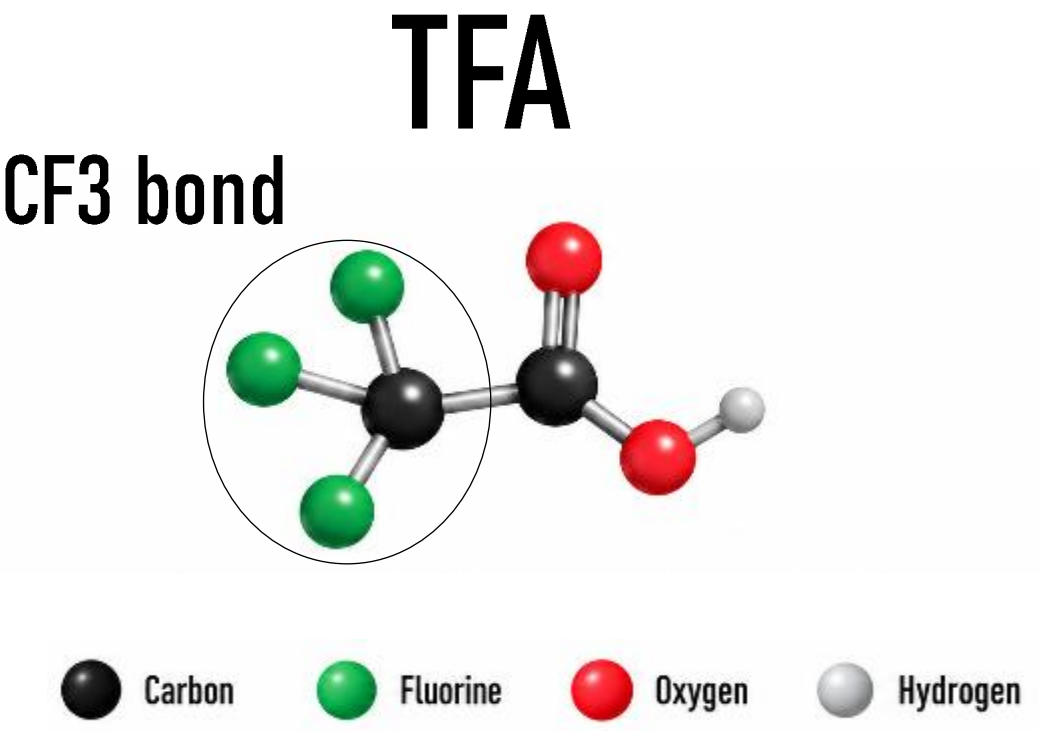
Today's Example: Trifluoroacetic acid

- Ultra short-chain subclass of PFAS
- Very mobile, persistent, and wide-spread globally.
- Receiving increased public and regulatory scrutiny and lawmaking.

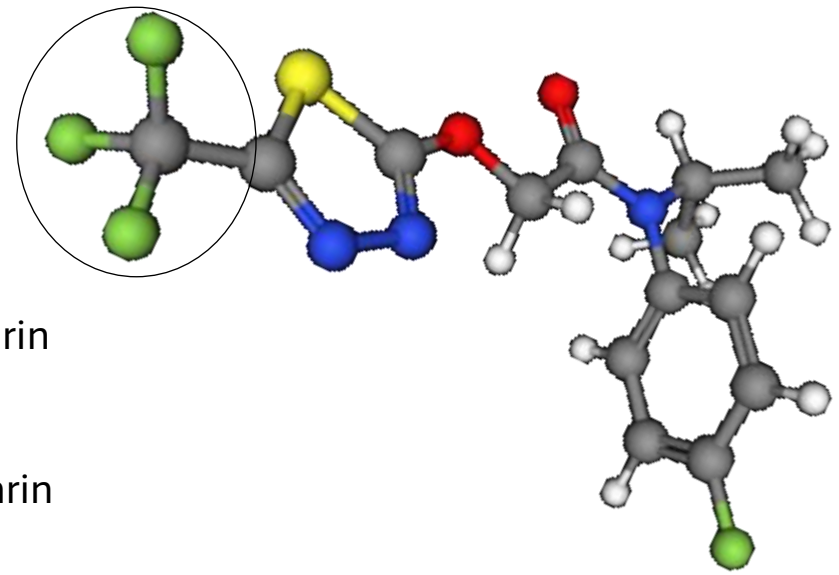


TFA via Degradation of CF3 Pesticides

Known and potential parent chemicals

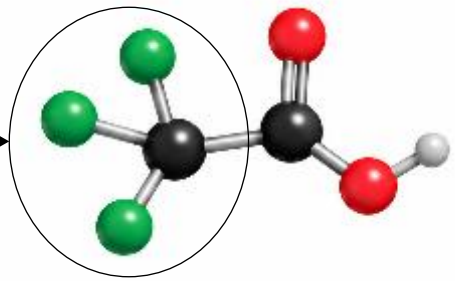
- Beflubutamid
- Cyflufenamide
- Diflufenican
- Flazasulfuron
- Flonicamide
- Fluazifop-P
- Fluazinam
- Flufenacet
- Fluopicolide
- Fluopyram
- Flurtamone
- Gamma-cyhalothrin
- Haloxyfop-P
- Isoxaflutole
- Lambda-cyhalothrin
- Metaflumizone
- Oxathiapiprolin
- Penoxsulam
- Picolinafen
- Others

CF3 bond



DEGRADATION

TFA



Carbon Fluorine Oxygen Hydrogen

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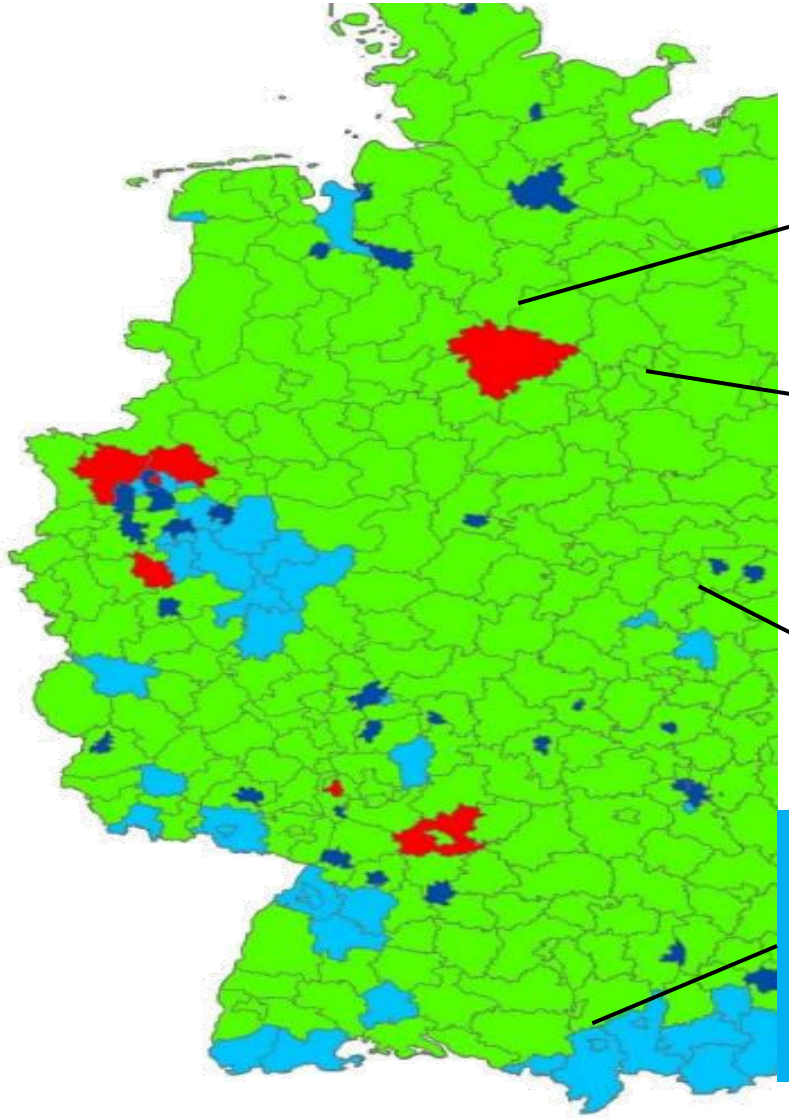
Estimated Primary TFA Input Pathways





Agriculture (pesticides)

Wastewater

Industry

Precipitation of atmospheric degradation of anthropogenic refrigerants and longer chain PFAS

Source: Trifluoroacetate (TFA): Laying the Foundations for Effective Mitigation—Spatial Analysis of the Input Pathways into the Water Cycle. German Environment Agency, 2023.
https://www.umweltbundesamt.de/system/files/medien/11850/publikationen/167_2023_texte_tfa_eng_v2.pdf

Emerging Pesticide Contaminants – Big Picture

- TFA may present new challenges involving persistence, mobility, and potential sources.
- However, like traditional pesticide chemicals, integration of multiple lines of evidence and an understanding of fate and transport processes is essential for:
  - Identifying and distinguishing potential sources
  - Evaluating exposure pathways and risks
  - Supporting defensible regulatory and legal conclusions

Thank You

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