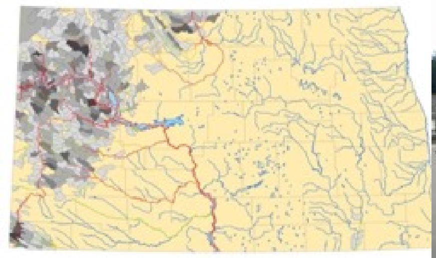






A Scientist’s Challenge: Tools for Identifying UOGD Impacts on Water Quality

Isabelle Cozzarelli, USGS, Research Hydrologist

HEI-Energy, Energy Production and Human Health
Webinar Series

May 18, 2021

U.S. Department of the Interior
U.S. Geological Survey

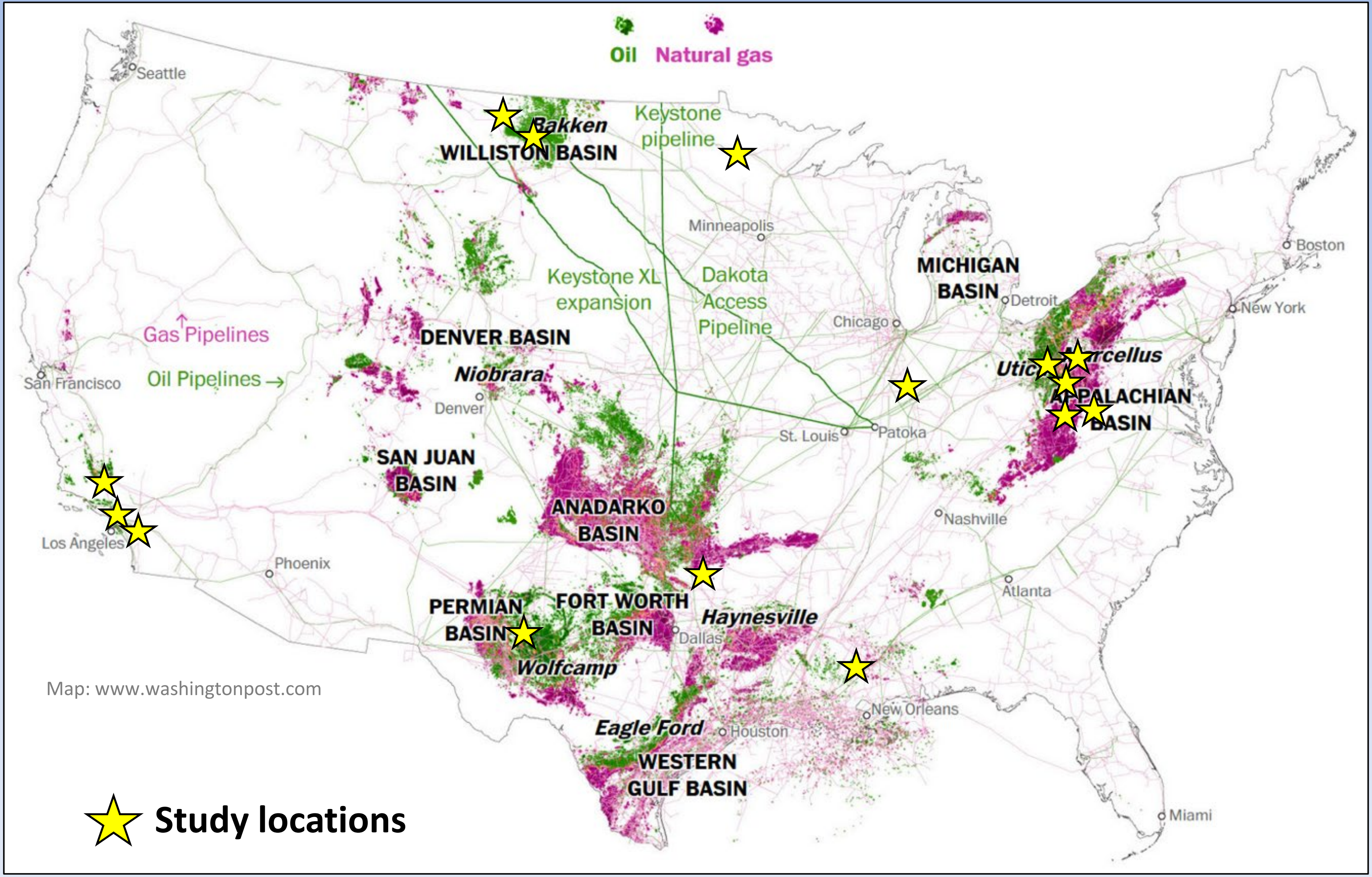
USGS Energy Life Cycle Project

Overarching Goal:

To understand the potential impacts of activities associated with the life cycle of energy development on water resources and environmental health, including the potential contaminant-associated threats and effects to humans, wildlife, and ecosystems.

USGS Environmental Health Programs (EMA) conduct studies to understand and mitigate actual versus perceived health hazards posed by byproducts from energy and mineral resource development.

Current Research Efforts



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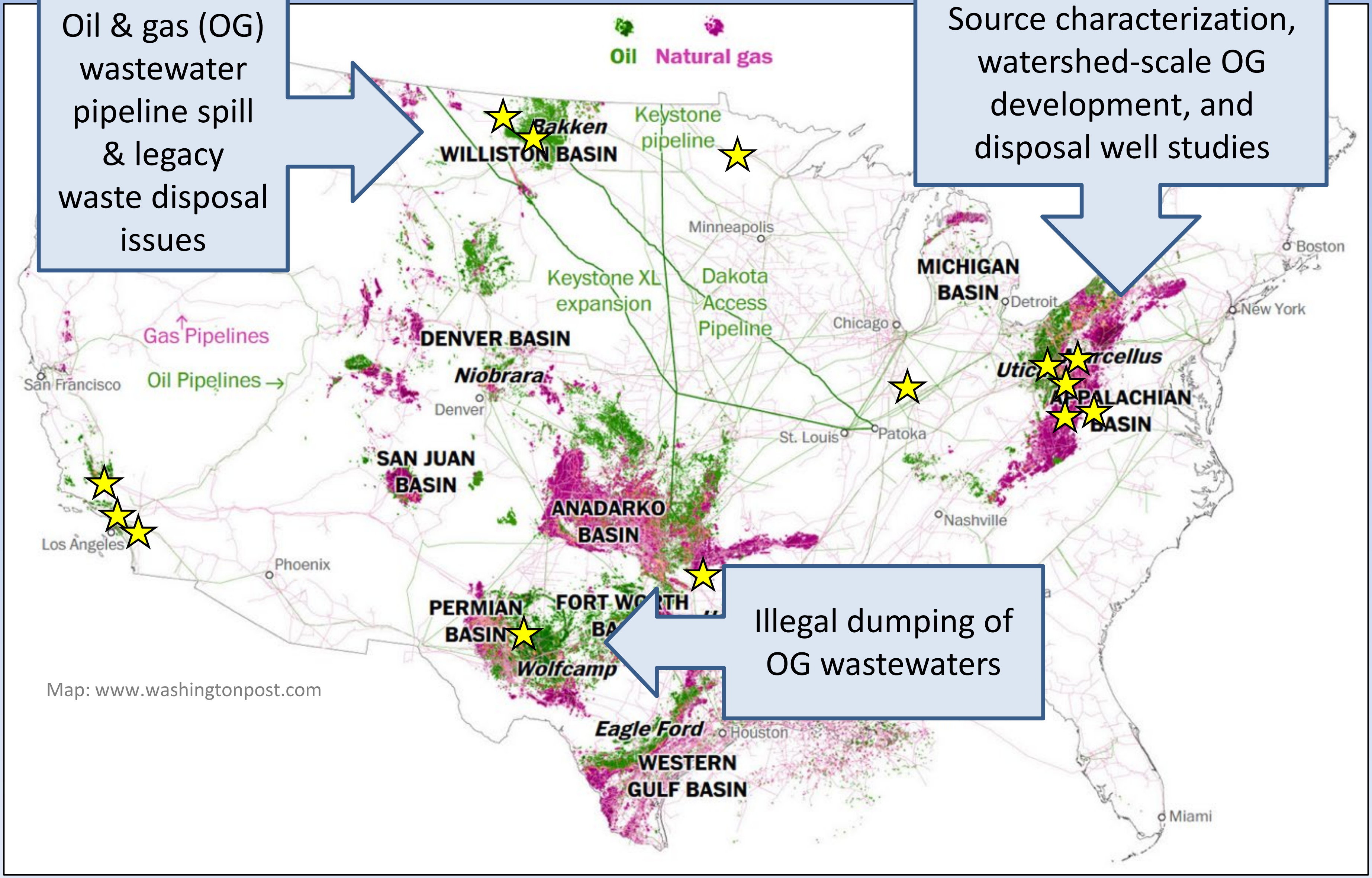
Current Research Efforts

Oil & gas (OG) wastewater pipeline spill & legacy waste disposal issues

Source characterization, watershed-scale OG development, and disposal well studies

Illegal dumping of OG wastewaters



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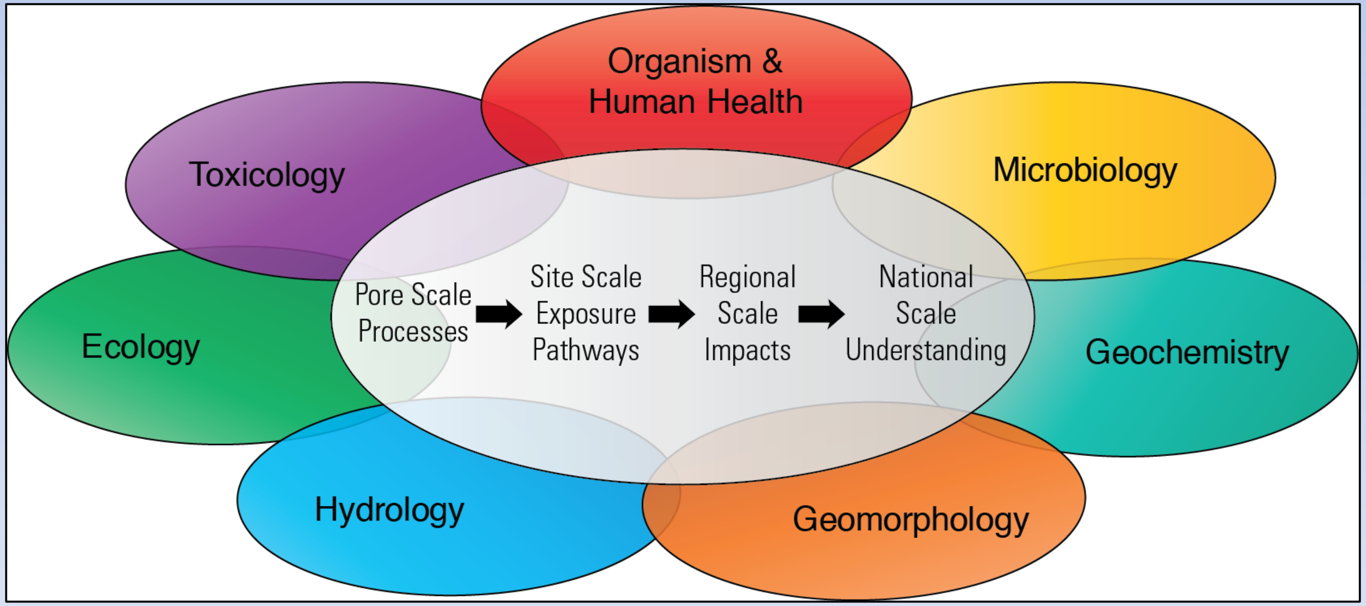
Approach



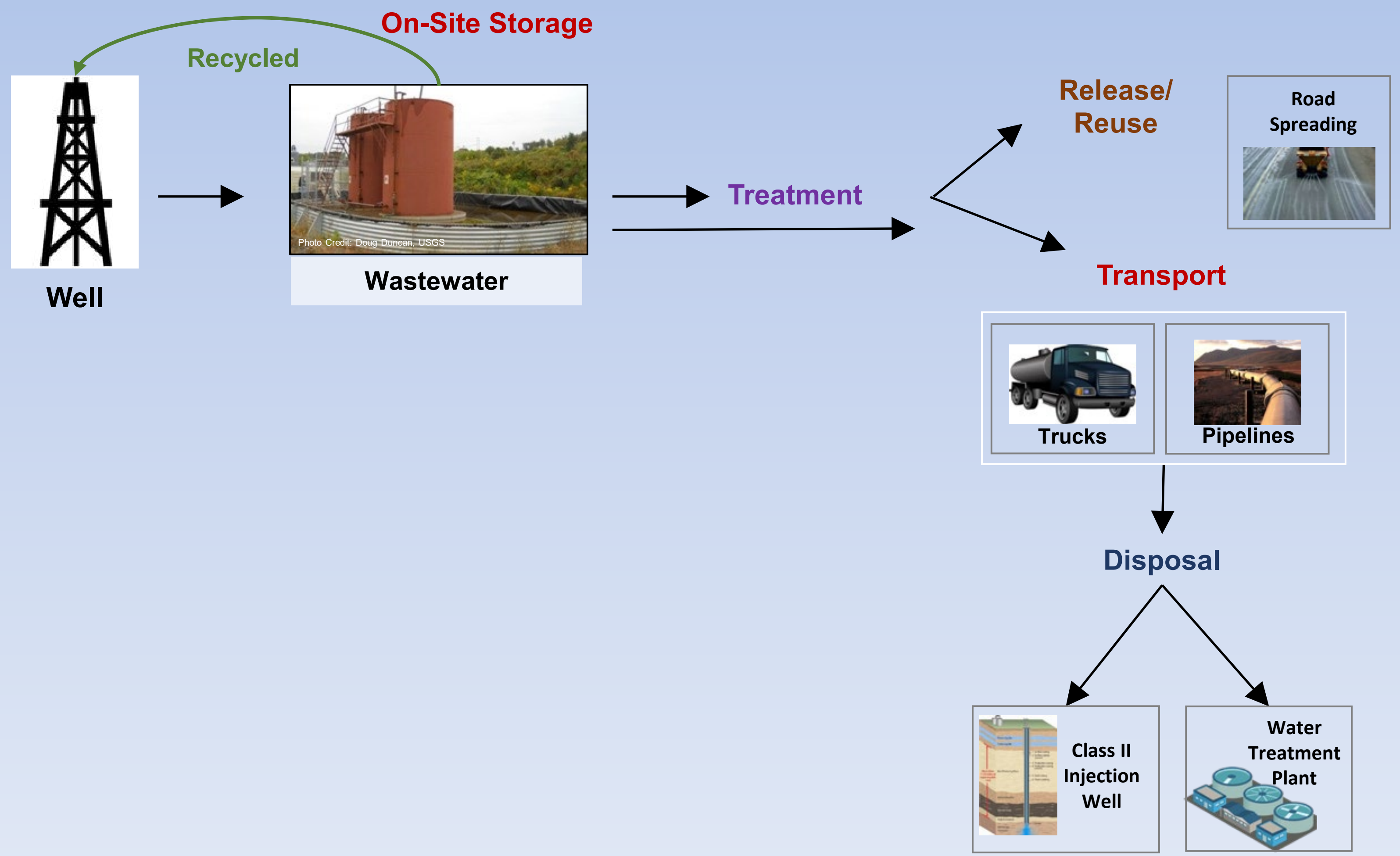




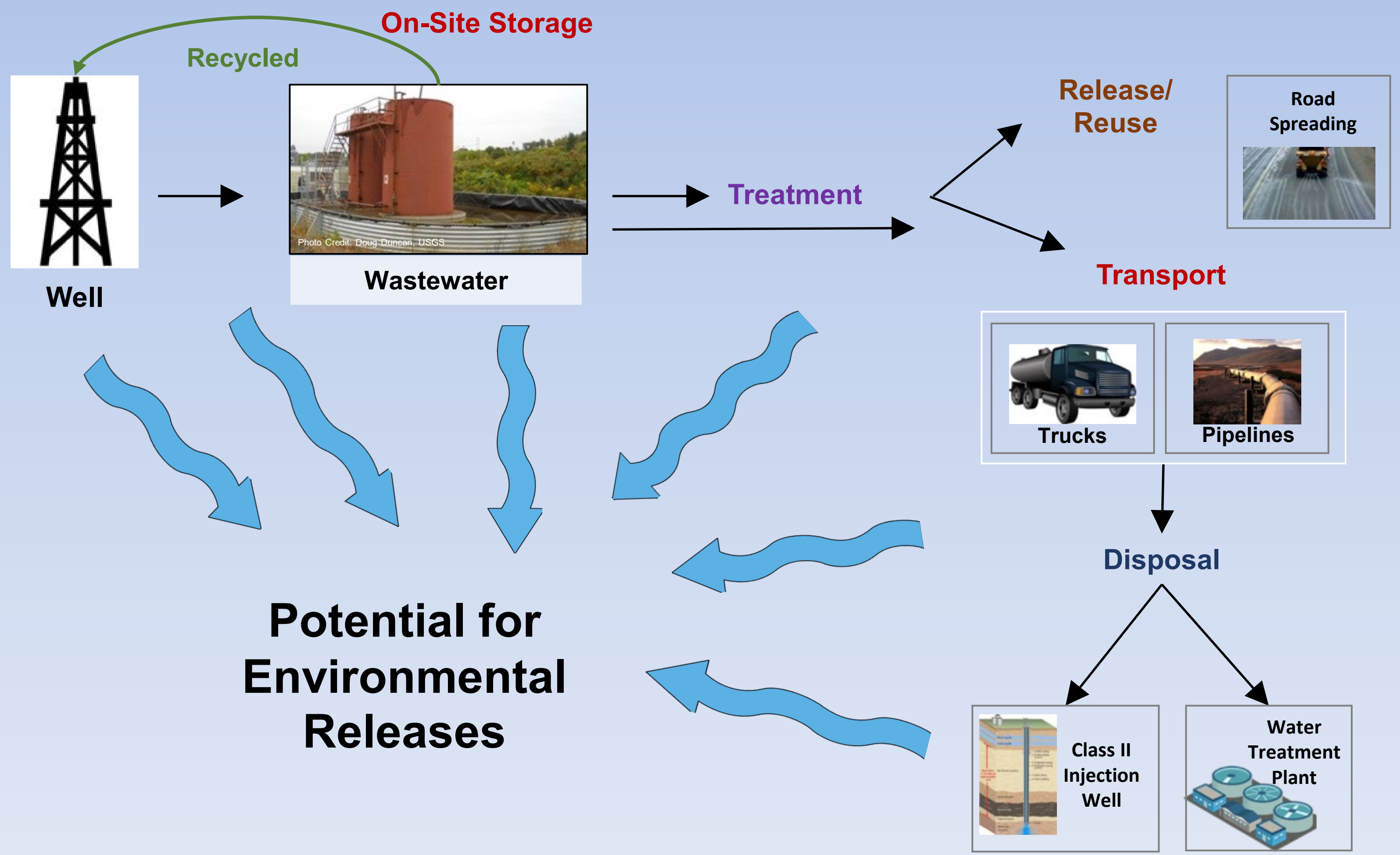


Collaborative project between USGS researchers, universities, and State and Federal Agency Partners

Oil and Gas (OG) Wastewaters

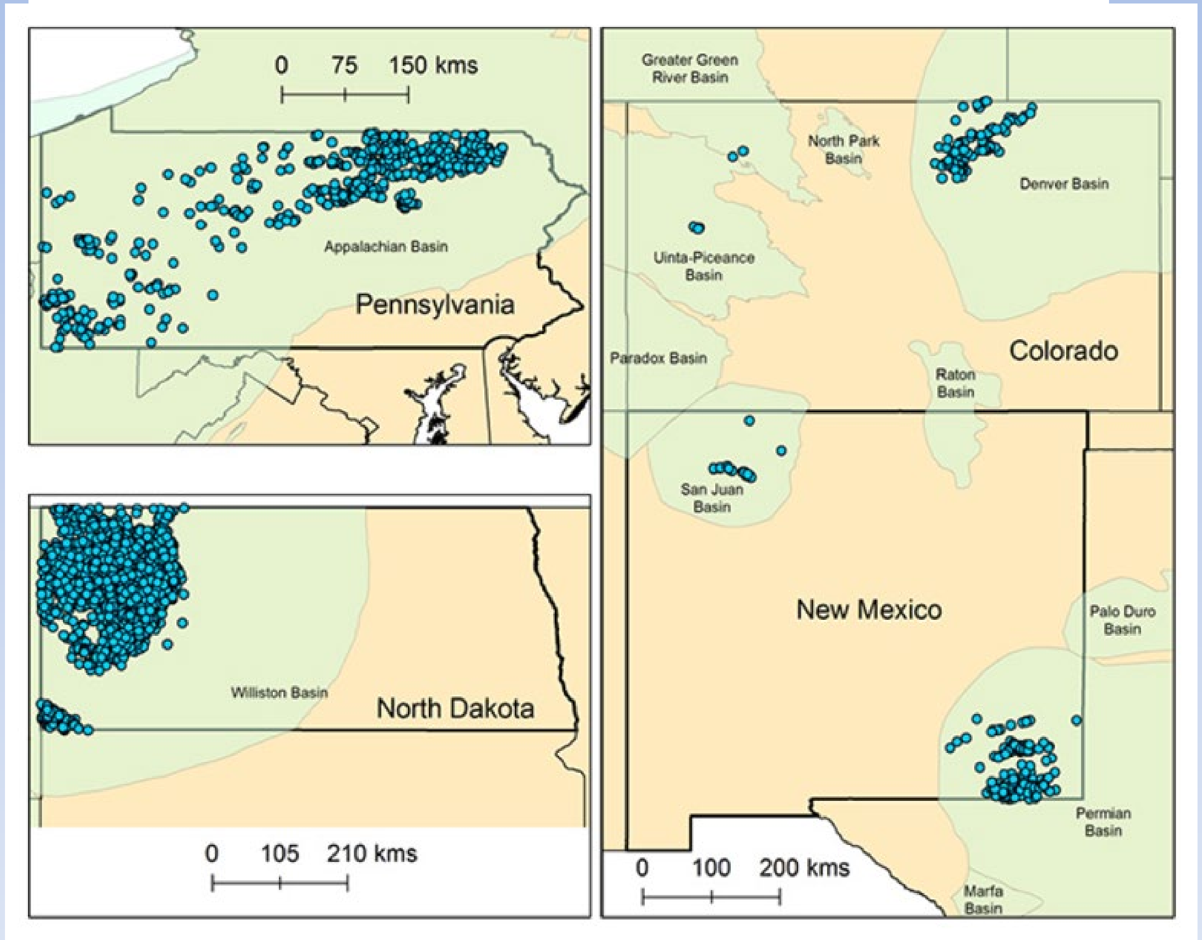


Oil and Gas (OG) Wastewaters



Product and Wastewater Releases

↓ Distribution of spills attributed to OG wells by state. Light green polygons indicate shale basins.



Maloney et al. 2017 Science of the Total Environment

Patterson et al. 2017: https://pubs.acs.org/doi/10.1021/acs.est.6b05749

- Releases are occurring across the USA and affecting large geographical areas.
- Maloney et al. and Patterson *et al.*, 2017, assessed spill data from 2005 to 2014 at UOG wells in Colorado, New Mexico, North Dakota, and Pennsylvania.

➢ 2–16% of wells reported a spill each year.

➢ The largest spills exceeded 100 m^3

➢ **50% of spills were related to storage and moving fluids**

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North Dakota Wastewater Pipeline Spill: Blacktail Creek

Objective: To identify and characterize the fate and transport of constituents released during a spill and evaluate the health impacts to wildlife and humans due to the spill.

Crews work to recover oil from Blacktail Creek north of Williston, N.D., on Sunday, Jan. 25, 2015, after the pipeline leak. Photo courtesy of Environmental Protection Agency.
See more at: http://oilpatchdispatch.areavoices.com/tag/environment/#sthash.XSZ26pjX.dpuf

- Approximately 11 million L of wastewater leaked from a pipeline into Blacktail Creek, discovered January 2015.
- At the time, it was the largest wastewater spill in North Dakota.
- Wastewater had ~300,000 mg/L TDS and contained hydrocarbons.

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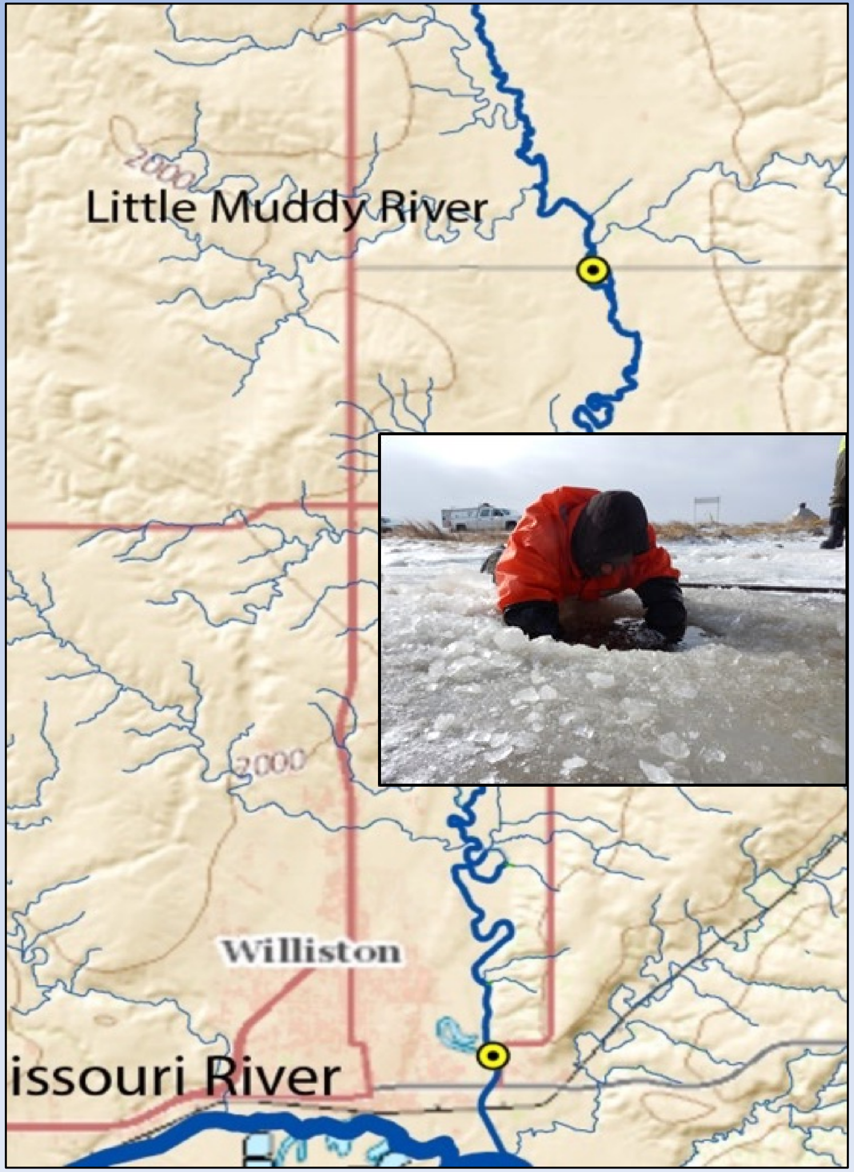
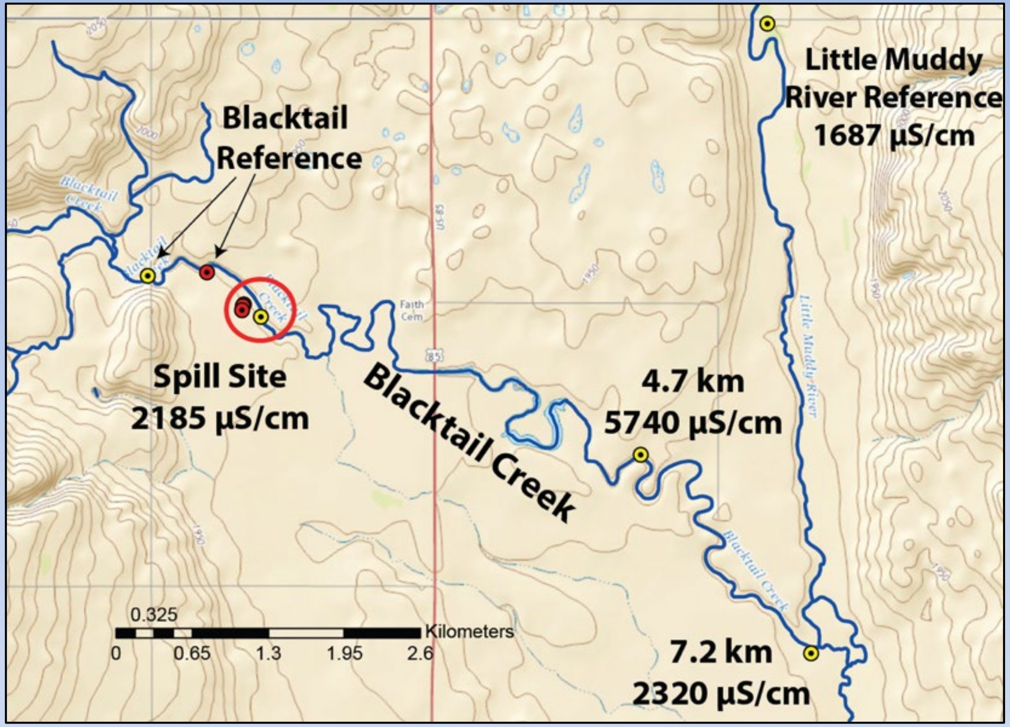
North Dakota Wastewater Pipeline Spill: Blacktail Creek





- We completed 4 rounds of sampling, including sediment, water, and biota, February and June 2015, June 2016, June 2017.

- Samples were collected upstream and downstream from the spill along a 22-km reach

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Initial Study Results

Science of the Total Environment 579 (2017) 1781–1793

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Environmental signatures and effects of an oil and gas wastewater spill in the Williston Basin, North Dakota

I.M. Cozzarelli [a,*], K.J. Skalak [a], D.B. Kent [b], M.A. Engle [c], A. Benthem [a], A.C. Mumford [a], K. Haase [a], A. Farag [d], D. Harper [d], S.C. Nagel [e], L.R. Iwanowicz [f], W.H. Orem [c], D.M. Akob [a], J.B. Jaeschke [a], J. Galloway [g], M. Kohler [b], D.L. Stoliker [b], G.D. Jolly [a]

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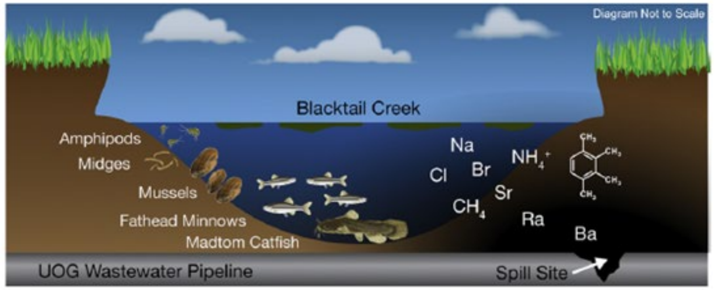
HIGHLIGHTS

- UOG wastewater (>11 million liters) spilled into Blacktail Creek, ND in January 2015.
- Elevated Na, Cl, Br, Sr, B, Li, NH_4 and hydrocarbons were detected in creek waters.
- Geochemical baseline deviations persist months after remediation efforts started.
- B and Sr concentrations, and Ra activities were up to 15 times background in sediment downstream.
- Biological impacts include reduced fish survival and estrogenic inhibition downstream.

GRAPHICAL ABSTRACT



Cozzarelli IM, et al. Environmental signatures and effects of an oil and gas wastewater spill in the Williston Basin, North Dakota. Science of the Total Environment 2017; 579: 1781-1793. https://doi.org/10.1016/j.scitotenv.2016.11.157

- Semi Volatile Hydrocarbons
  - 1,3,5- trimethylbenzene
  - 1,2,3,4- tetramethylbenzene
  - 1- methylnaphthalene
  - Numerous di-and tri-methylnaphthalenes
  - Detected in downstream unfiltered samples, but not filtered samples, indicating these compounds might be associated with suspended particulates. In June 2015 these compounds were not detected.
- Volatile Hydrocarbons
  - Light hydrocarbons (C1-C6) showed distinct thermogenic hydrocarbon signature.
  - This signature was still present in June 2015 at 7.2 km downstream.

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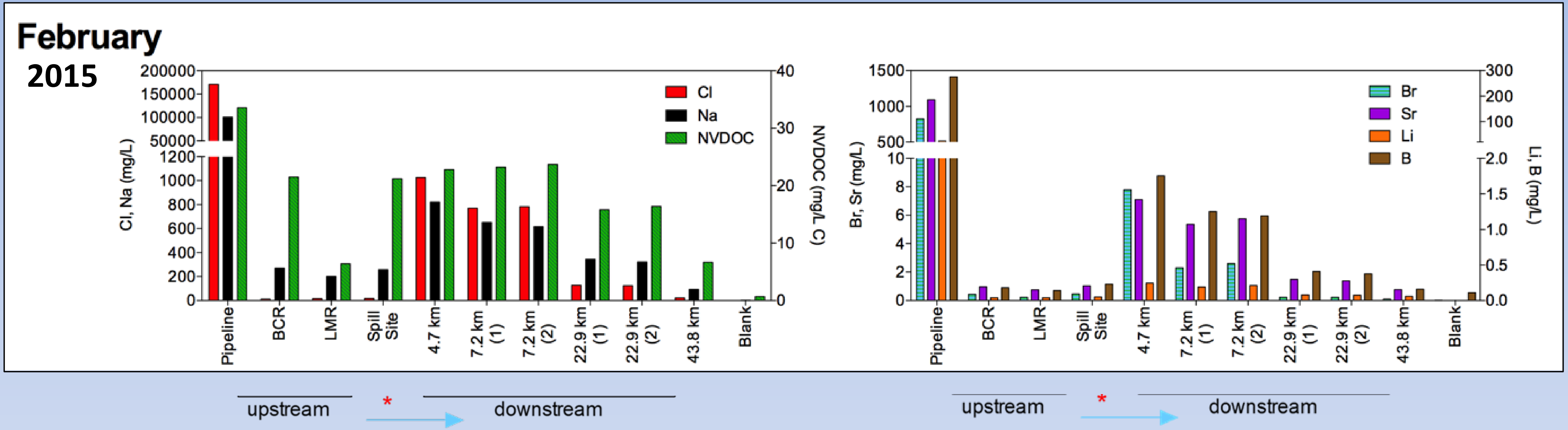
Initial Study Results



- Pipeline sample had very high concentrations of Na, Cl, Br, Sr, Li, B

- The Sr had a distinct radiogenic signature making it a good tracer and useful in mixing models

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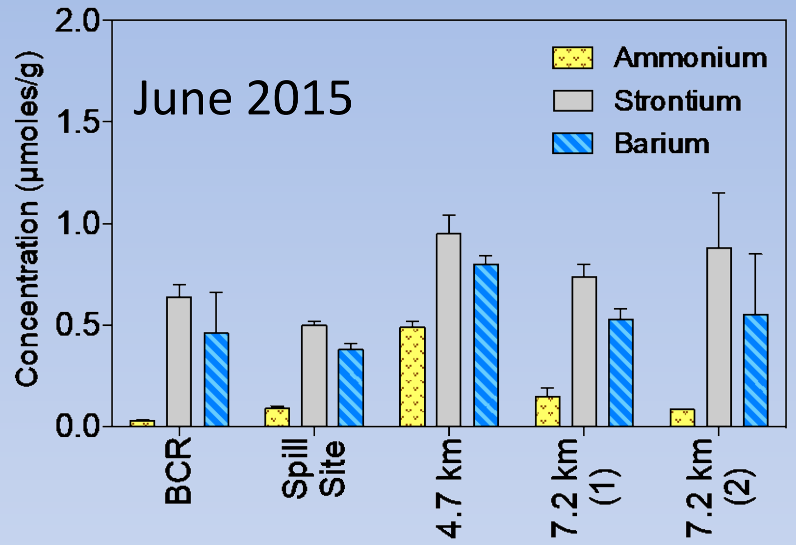
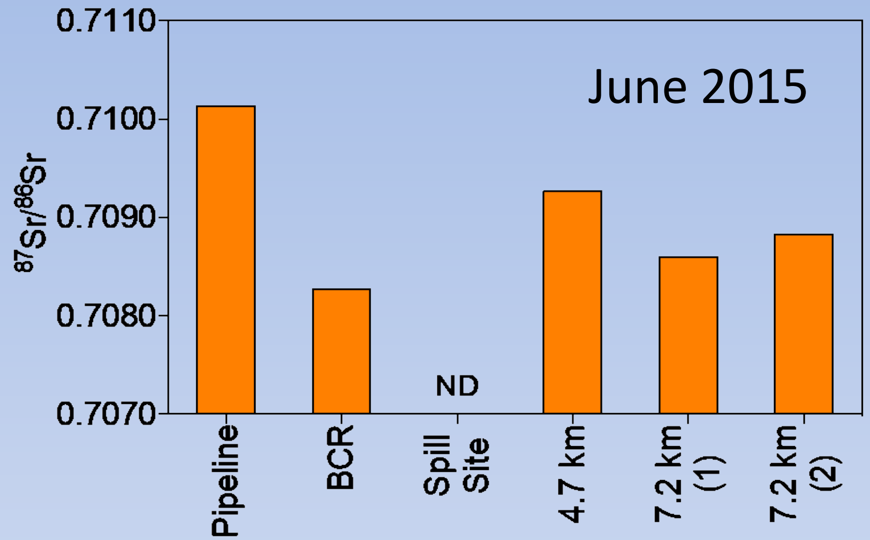
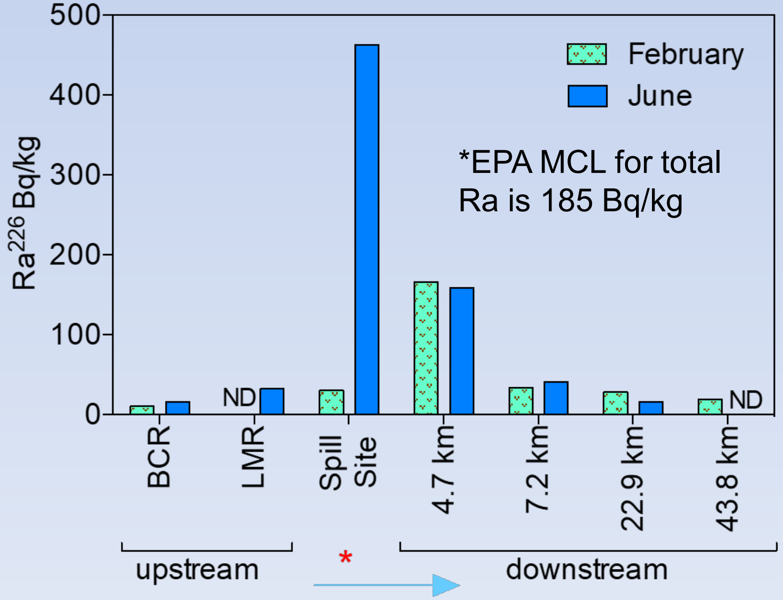
Cozzarelli et al., 2017, STOTEN

Contaminants are Transported with Sediment







- Sediment-bound NH_4, Ba, Sr, Ra are elevated downstream
- Sr in downstream sediments retains radiogenic signature reflecting pipeline.
- Ra^{226} was 29 times background activity, 464 Bq/kg in stream sediments.
- Ra^{226} was also found in surface soils of floodplain in 2016.

Cozzarelli et al., 2017, STOTEN

In Situ Study of Survival of Early Life Stage

Fathead Minnows – June 2015


Source: http://wildlife.ohiodnr.gov/

- Fish In-situ Exposure Experiment
  - → 96 hour caged bioassay with fathead minnows.
- Most notably, survival of fathead minnows after 96 h:
  - 88.6% and 94.7% at the background sites
  - 2.5% at 7.2 km downstream
- Mortality of two native Madtom catfish observed at 7.2 km

- Live resident fish were observed at all sites, except for the 7.2 km site where no live resident fish were observed

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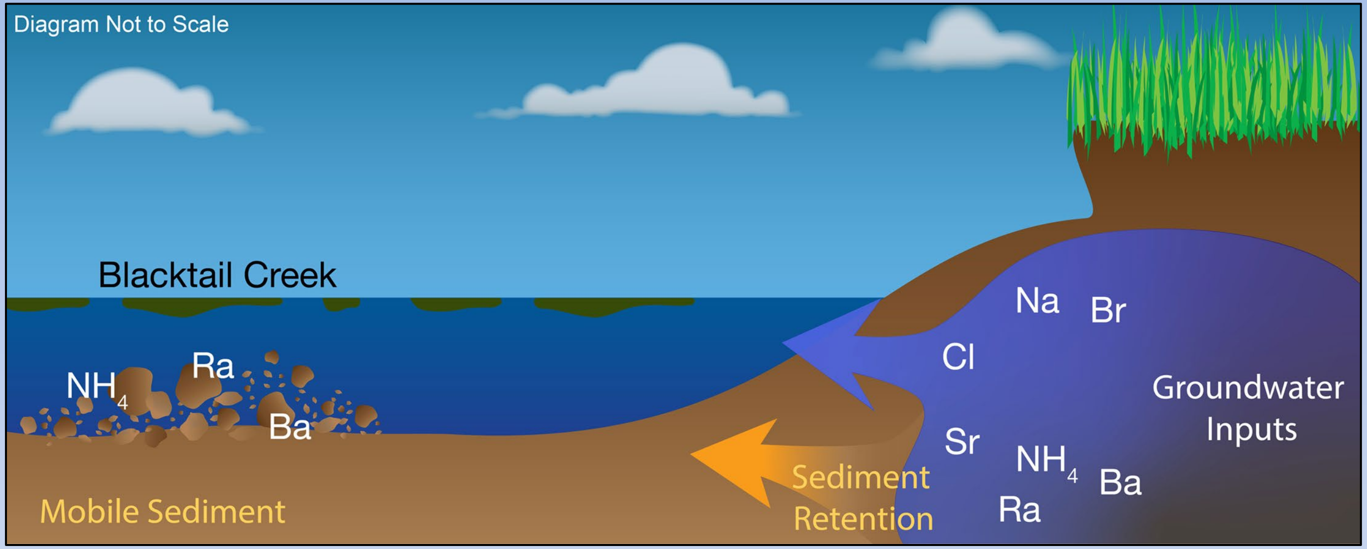
Cozzarelli et al., 2017, STOTEN

Groundwater Seeps as Input Source to the Creek



Fish mortality hypothesized related to focused groundwater discharge as a pathway of wastewater into the creek.

Approach: Can we identify seeps using hydrogeochemical and geophysical tools and assess the contribution to the creek composition?

Cozzarelli et al (2021). Geochemical and Geophysical Indicators of Oil and Gas Wastewater Can Trace Potential Exposure Pathways Following Releases to Surface Waters. *Science of The Total Environment* **755**(1): 142909, https://doi.org/10.1016/j.scitotenv.2020.142909.

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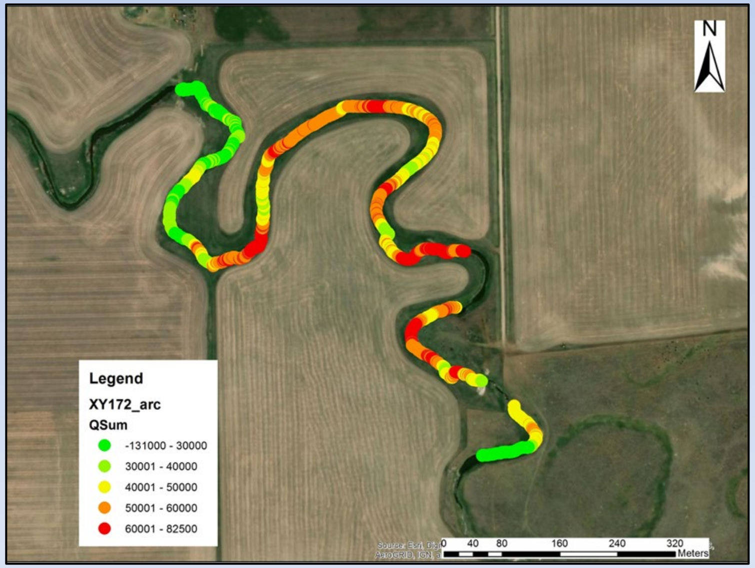
Groundwater Seeps as Input Source to the Creek

Geophysical tools employed included:

- Shallow sediment bulk conductivity (EC) via hand-held electromagnetic imaging
- High spatial-resolution electrical resistivity profiles (ERT)
- Infrared camera and temperature sensors to identify groundwater discharge



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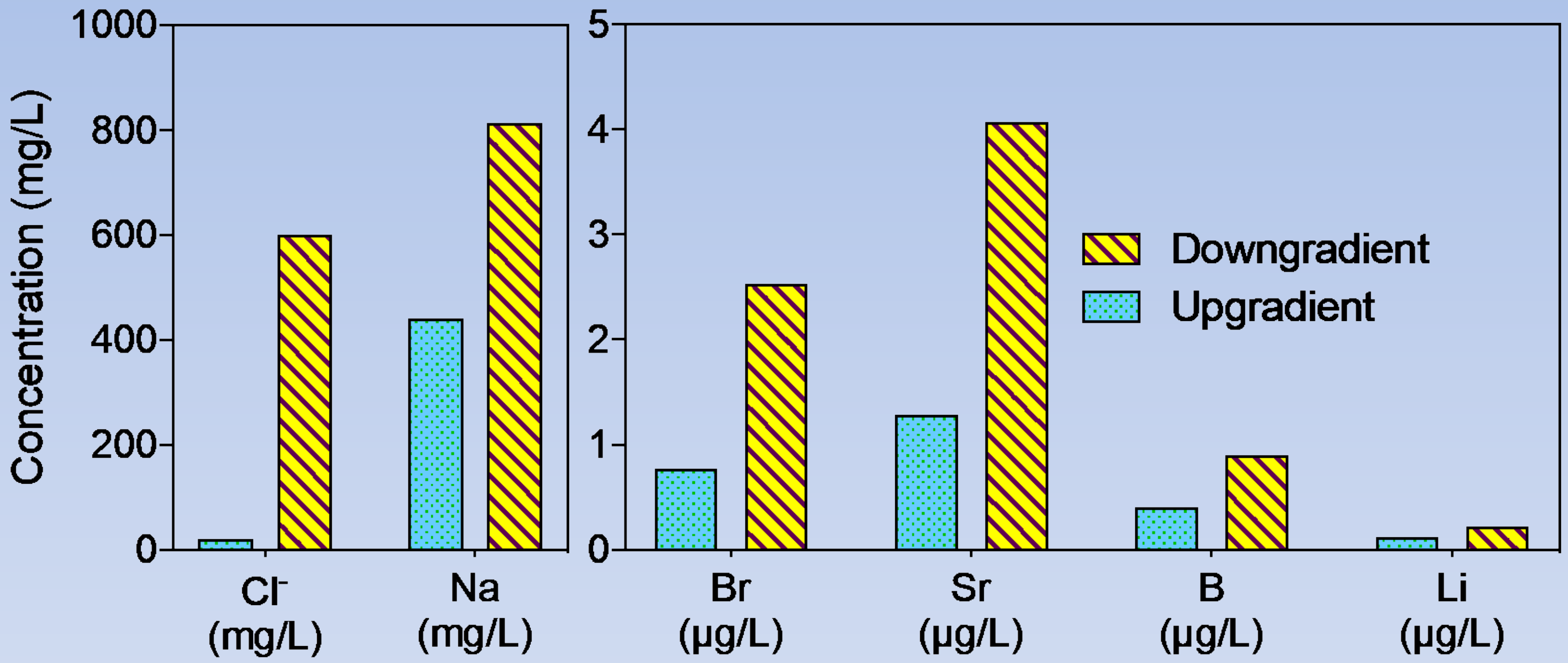
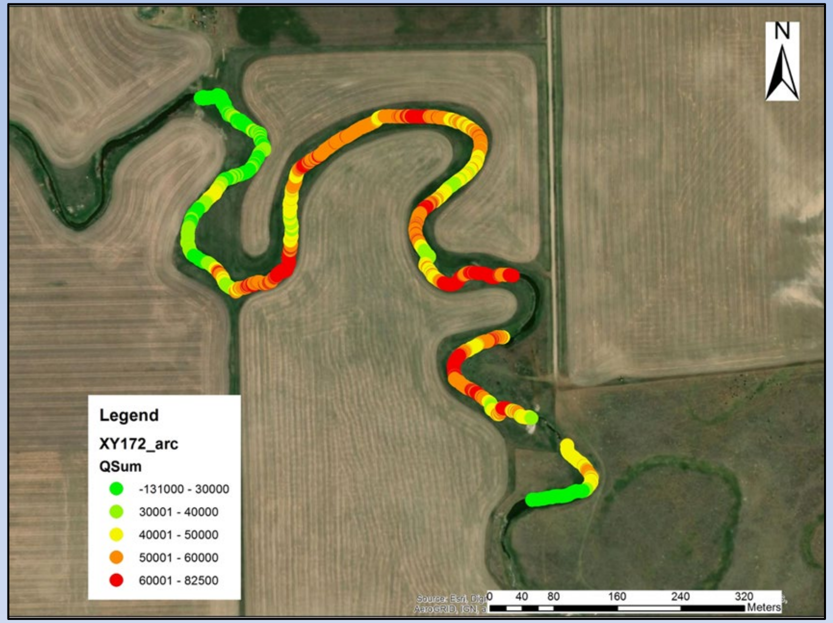
Cozzarelli et al., 2021, STOTEN

Wastewater Signature in Downgradient Seep

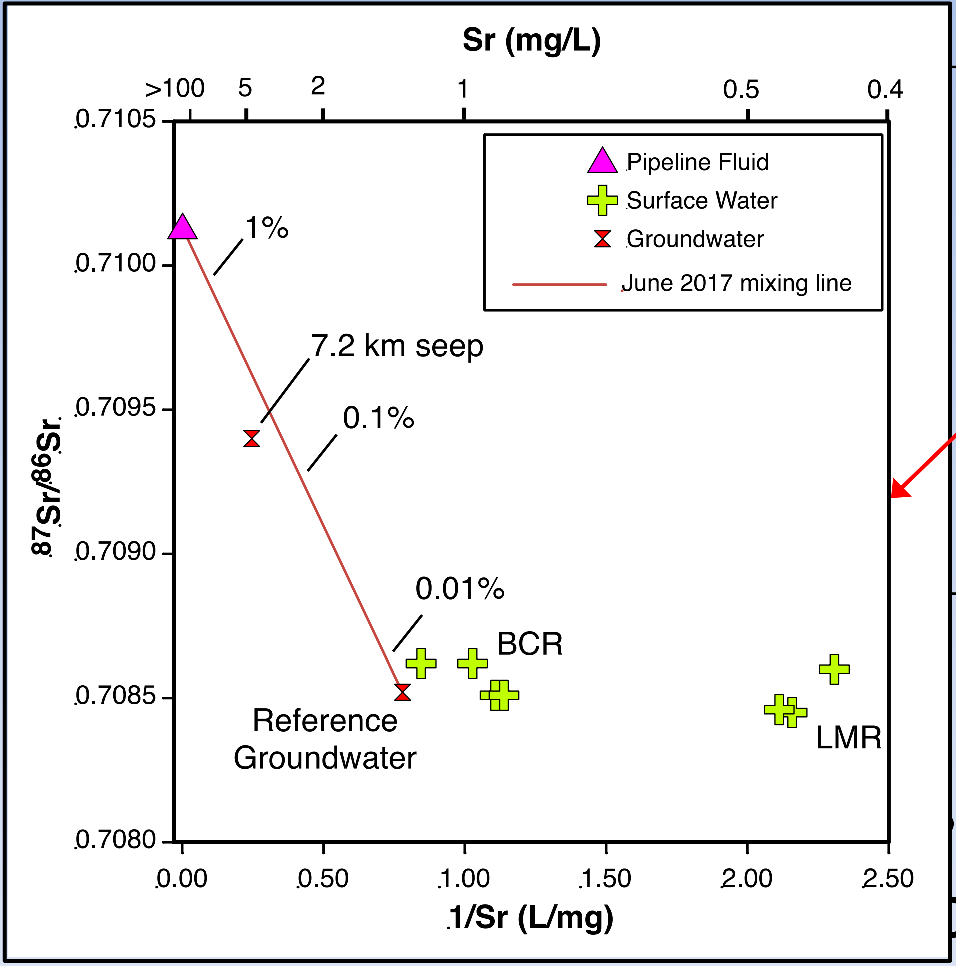


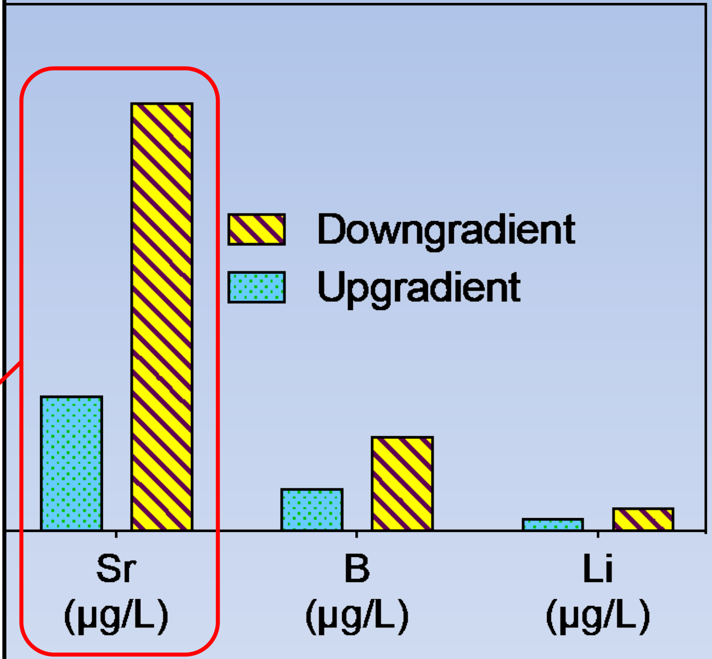


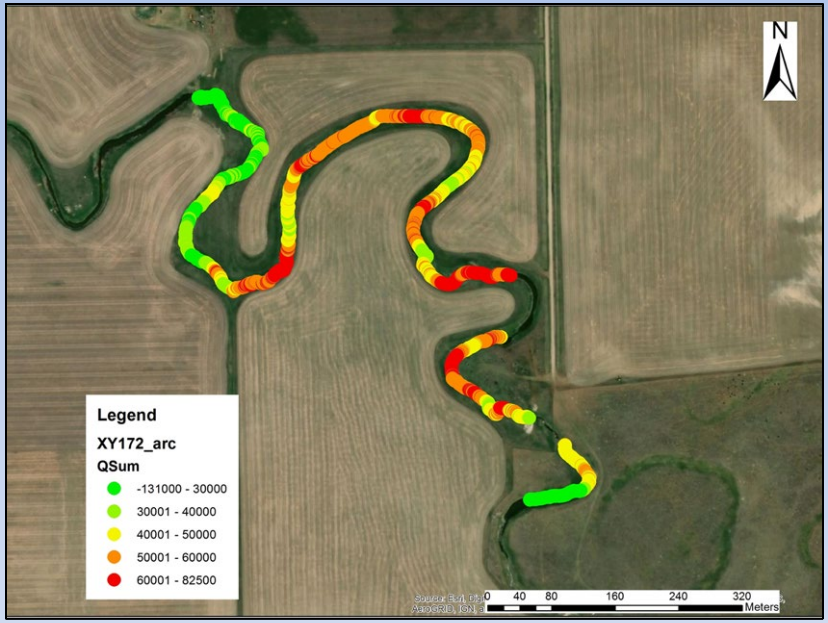
- Downgradient seep has a chemistry consistent with signature of OG wastewater.

Cozzarelli et al., 2021, STOTEN

Wastewater Signature in Downgradient Seep



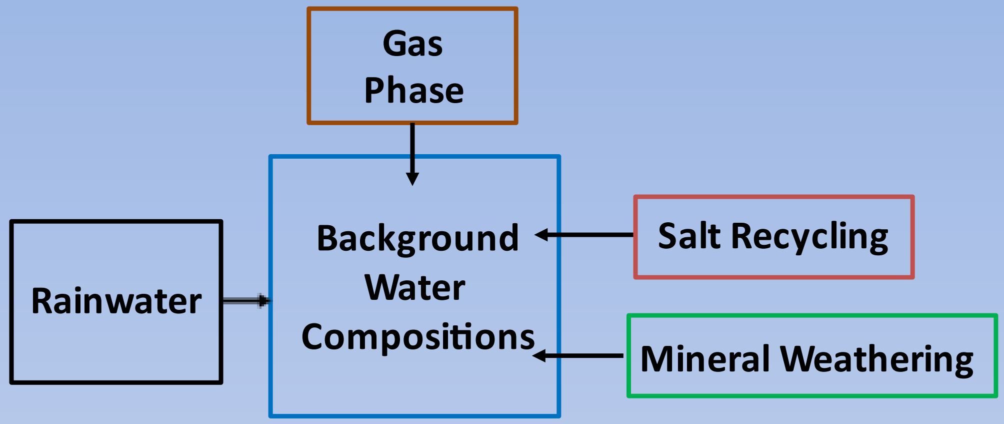




→ Downgradient seep is a mixture of upgradient groundwater and pipeline composition.

Cozzarelli et al., 2021, STOTEN

Geochemical Modeling



- Modeling is another tool used to test hypotheses re OG wastewater inputs.

- Conducted with "inverse modeling" capability in PHREEQC
  - Propose a set of reactions to account for a range of background compositions
  - Calculate contributions of reactions to background compositions

- Compositions from 4.7 and 7.2 km sites in February and June 2015 required mixing with the wastewater, 0.3% and 0.1% respectively, in addition to background water composition reactions.

- Wastewater constituents, stored in bank sediments following transport in the stream channel, are released episodically as wastewater discharges into the stream.

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Cozzarelli et al., 2021, STOTEN

Water Quality and Biological Trends from Legacy Brine Pits in MT and ND

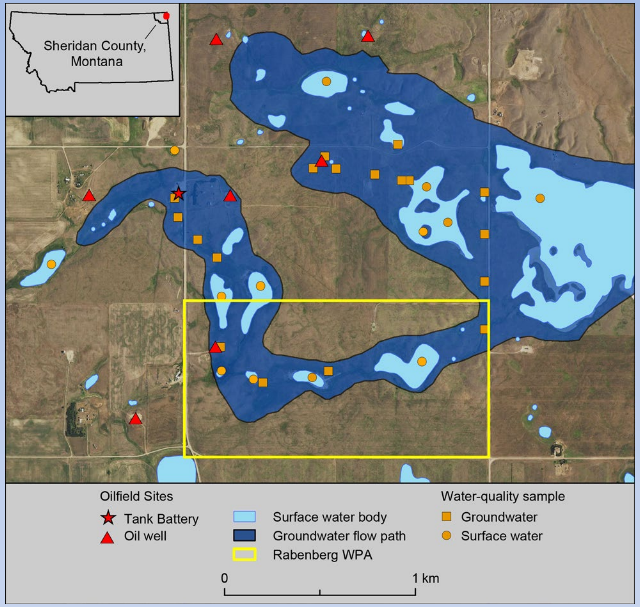
Goal: To evaluate effects of long-term contamination from historical OG wastewater disposal activities and major ions associated with OG development on invertebrates, plants and amphibian populations.

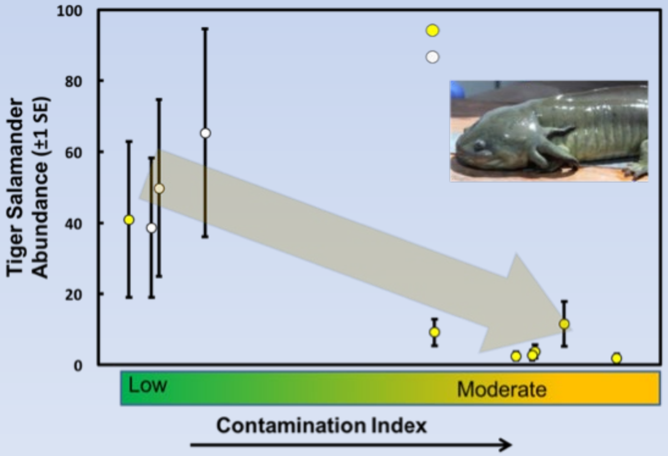
Key findings:

- Major ions (Cl) and ecological impacts from OG wastewaters exhibit multi-decadal to century persistence in the MT Prairie Potholes region.
- Using water chemistry data, we can determine how amphibian population dynamics or other ecological effects may be influenced by OG historic waste disposal practices.

Northern leopard frog tadpole collected from a pond in ND.

- Sediment is an important route of exposure to contaminants, particularly for grazers.
- Freshwater organisms such as mussel and mayfly can have greater sensitivity than fish to certain water quality measures.
- Measures of effects from legacy brine releases and toxicity of major ions (SO_4, Mg, Ca, K, HCO_3, Na, Cl) are important for federal (EPA) and state (e.g. LA) agencies in charge of resource protection and remediation.





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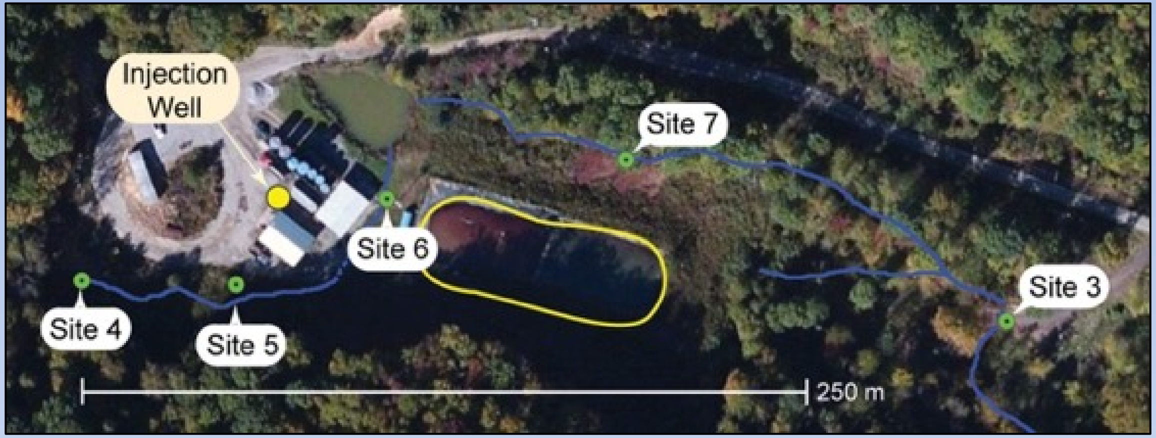
Hossack et al., Env. Poll. 2017 and Biol. Cons. 2018, Smalling et al. Env. Poll. 2019 and Preston et al., STOTEN 2019

Impacts of an OG Wastewater Injection Facility on a WV Stream

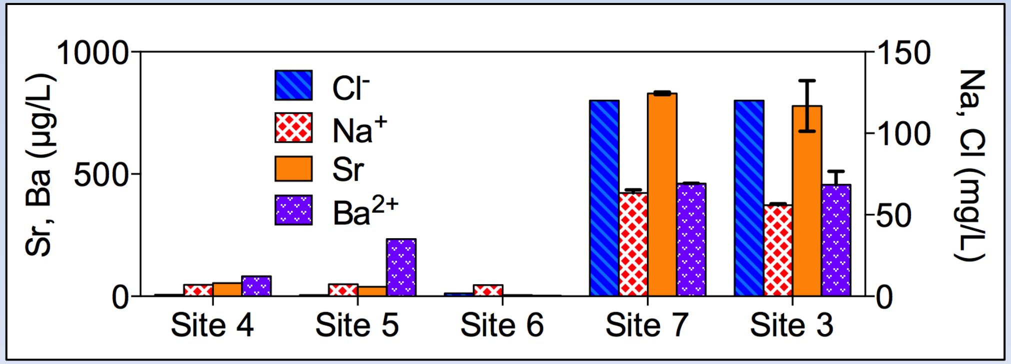
Objective: To identify and characterize the impact of OG wastewater disposal activities on stream biogeochemistry and health.

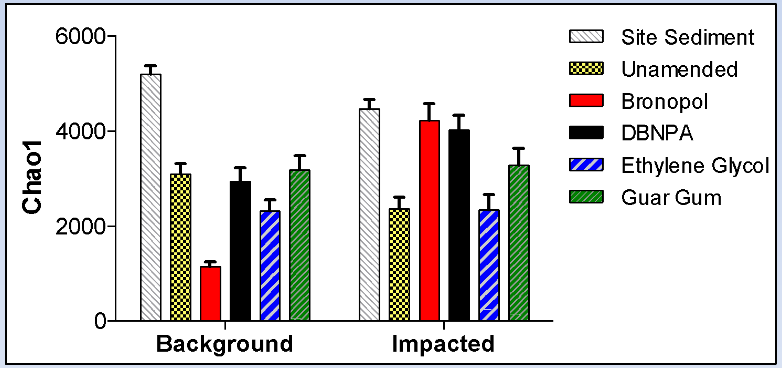


Key Findings:

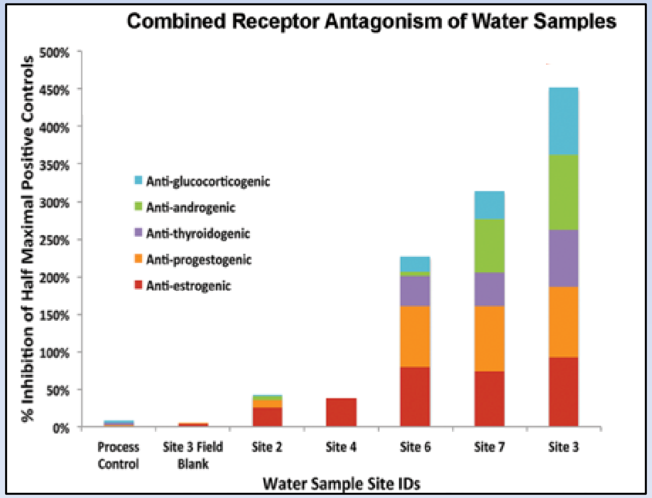
- Water and sediment samples collected downstream from the disposal facility are impacted by the offsite movement of contaminants associated with OG wastes.

- Although the health of aquatic organisms was not assessed these findings show the potential for adverse health effects due to:
  - Endocrine disrupting activity in surface waters
  - Altered nutrient cycling and microbial community structure and activity in downstream sediments.





Microbial community diversity shifts in response to OG wastewater inputs



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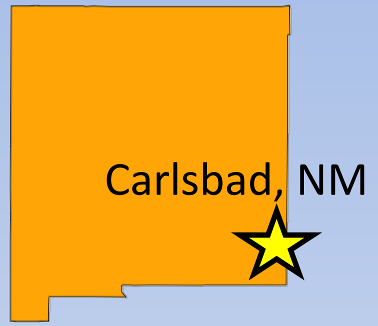
Akob et al., 2016, Kassotis et al. 2016, Fahrenfeld et al. 2016; Orem et al. 2017; Mumford et al. 2018

Evaluating the Potential Impact of Illegal OG Wastewater Dumps in the Permian Basin



- Starting in November of 2017, an area of BLM land experienced a rash of illegal oil and gas wastewater dump.
  - Wastewaters are a mixture of brine and hydrocarbons
  - Dumped directly onto soil
  - Fracking fluid dumps also observed
  - 39 sites have been identified

Objectives:

- To identify the sources of spilled wastewater.
- To evaluate environmental impacts due to wastewater spills.
  - Soil chemistry
  - Soil microbiology
  - Biological impacts –food web transfer of contaminants

Photo: Terry Gregston, BLM.

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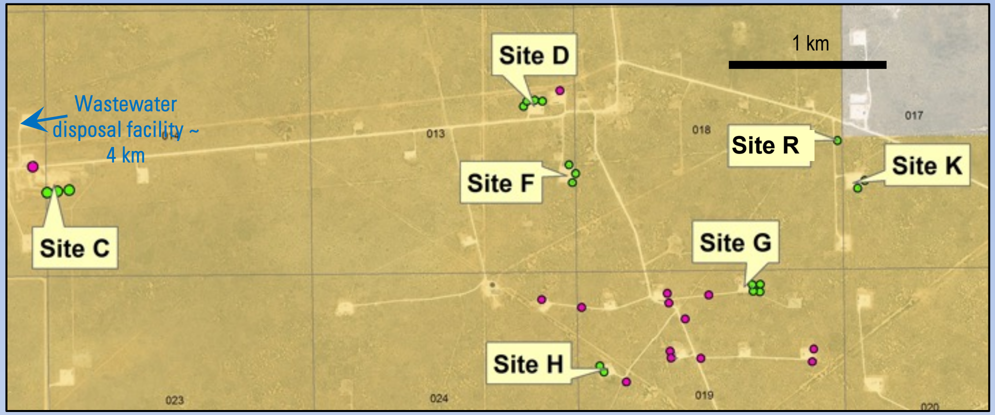
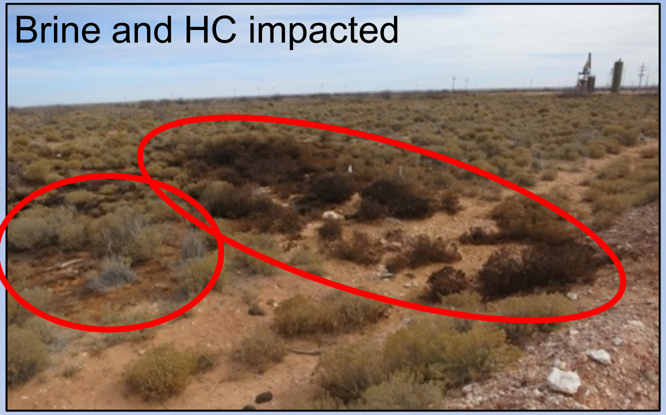
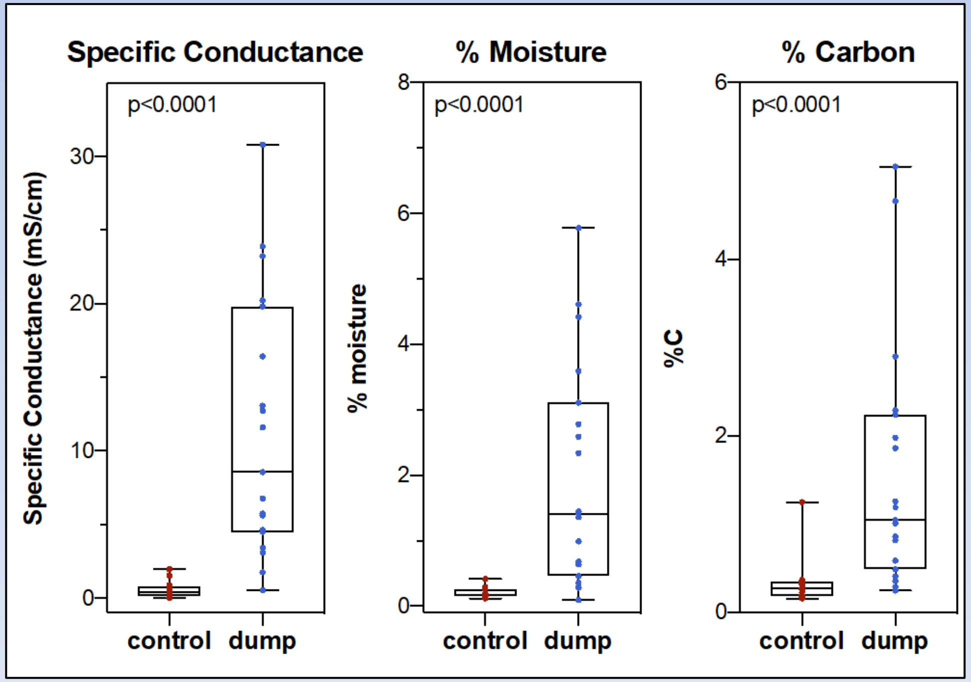
Illegal OG Wastewater Dumps in the Permian Basin







Key Findings:

- Dump zone samples have elevated conductivity, soil moisture, % carbo, and are enriched in compounds found in local OG wastewaters.
- Total Hg is low (< 20 ng/g) overall but modestly elevated in 4 of 5 spill sites.

Next steps:

- Analyze Ra and extractable hydrocarbons.
- Assess biological effects from OG wastewater dumps by:
  - Characterizing the responses of arid soil microbial communities to OG wastewater inputs.
  - Evaluating uptake of salts into resident plant tissue.

Take Home

- Identified numerous geochemical indicators of OG wastewater that can be used to track and identify spills: hydrocarbons, organic additives, Cl, Br, Li, B, Ba and Sr, and $^{87}Sr/^{86}Sr$ ratios.
- Partitioning of chemicals onto sediment (e.g., Ra, metals) limits movement of wastewater components but could provide a long-term source of contaminants to organisms.
- OG wastewater spills pose potential health risks including fish mortality, amphibian population effects, and endocrine disrupting activity.
- Reactions and dynamic hydrologic conditions, such as variable groundwater pathways, can cause the potential exposure routes to change over time.
- National-scale OG production highlights the need to understand the effects of OG wastewater releases across a range of landscape types.

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