Stream Monitoring for Evaluating Groundwater Methane Associated with Shale-Gas Development

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Stream-reach mass balance uses methane in gaining streams to evaluate groundwater concentration and potential contamination

- Baseflow of a gaining stream gives a weighted average
- Represents a larger capture area and at lower cost than monitoring wells

Presentation topics:
- Methane persistence in streams
- Gas transfer (atmospheric loss)
- Bacterial consumption (oxidation)
- Transport modeling to determine methane loads
- Isotopic fingerprinting
Why Care About Groundwater Methane?

- Public concern – increased contamination with proximity to gas wells (Jackson et al., PNAS, 2014)
- Explosive hazard (basements, pump houses)
- Early warning indicator of other contaminants:
  - Fracking fluids
  - Flow-back water with high salinity and radioactivity
- Potent greenhouse gas (IPCC reported greenhouse potency up to 84 x CO$_2$)
Conceptual Model

Methane pathways:
- Improperly completed well bores
- Fractures

Methane migration:
- Stray-gas transport
- Dissolved in fluids

(Jackson et al., PNAS, 2013)
Stream-Reach Methane Mass Balance

- Stream CH₄ [C] and load (C x Q), groundwater concentration (Cgw) and influx (Igw), loss to the atmosphere (λatm), and microbial oxidation to CO₂ (λmicr).


- Need to determine Q, Igw, C, *λ (λatm + λmicr) to solve for Cgw.

\[ Q \frac{\partial C}{\partial x} = Igw(C_{gw} - C) - *\lambda dwC \]  

(Heilweil et al., Groundwater, 2013)
Method Testing at Nine-Mile Creek

- Low-discharge (90 L/s) medium gradient (0.007 m/m) stream
- Bromide tracer dilution showed $I_{gw} = 30$ L/s (35% increase in streamflow over 2-km study reach)
- **Main objective**: Methane injection to evaluate downstream persistence and gas transfer velocity
• **CH$_4$** dissolved in stream water using Si tubing
• Injected **CH$_4$** persisted for >1,500 m
• Gradual decrease in **CH$_4$** from 5x background
Nine Mile Model Results

1-D Transport with gas exchange *(Cook et al., WRR, 2006)*

- Apparent gas transfer velocity (*k =* *λ x d*) of 4.5 ± 1 m/d
- Did not evaluate gas transfer to atmosphere (*λ*<sub>atm</sub>) versus bacterial consumption (*λ*<sub>micr</sub>)

(from Heilweil et al., Groundwater, 2013)
West Bear Creek Injection

- Medium-discharge (500 L/s), low-gradient (0.003 m/m) stream with high nitrate load due to hog & poultry concentrated animal feeding operations (CAFO’s) (Solomon & Genereux, NSF EAR-1045134)

- Bromide tracer dilution: $I_{gw} = 70$ L/s (15% streamflow increase over 2.7 km)

- **Main objective**: quantify fractions of methane loss to atmosphere ($\lambda_{atm}$) versus microbial oxidation ($\lambda_{micr}$)
Approach

- Side-by-side gas injection of CH$_4$ and Kr
- Theoretical $K_{CH4}$ (and $\lambda_{atm}$) can be calculated from $K_{Kr}$ based on the ratio of their diffusion coefficients
- More-rapid decline in CH$_4$ would indicate additional loss due to microbial oxidation ($\lambda_{micr}$)
West Bear Creek Methane Injection

- Injected methane persisted more than 2,000 m downstream

(from Heilweil et al., in review)
Larger decline in CH$_4$ indicates non-conservative behavior
• Additional loss ($\lambda_{\text{micr}}$) needed to fit observed data
• Indicates some CH$_4$ loss to microbial oxidation
• Smaller fraction of CH$_4$ oxidation expected in more turbulent streams with less nutrients

(from Heilweil et al., in review)
Sugar Run, Pennsylvania
Reconnaissance sampling in northeastern PA (from Heilweil et al., ES&T, 2015)
Sugar Run Stream Methane Sampling
May 21, 2013

- Small-discharge (40 – 100 L/s), high-gradient (0.04 m/m) stream
- **Main objective**: quantify groundwater methane load and determine its source

(from Heilweil et al., ES&T, 2015)
Stream Methane in Sugar Run

(from Heilweil et al., ES&T, 2015)
**200-m spacing**

$I_{gw}$: 9 L/s (18% of Q)

$K_{CH4}$: 10 ± 5 m/d

Calculated CH$_4$ load: 0.7 ± 0.2 kg/d
Sugar Run Isotopic Fingerprinting: $\delta^{13}\text{C}_{\text{CH}_4}$ versus $\delta^{2}\text{H}_{\text{CH}_4}$

(from Heilweil et al., ES&T, 2015)
Sugar Run Study Epilogue

- **September 2013**: PA DEP Violation letter stating 5 water wells were impacted by stray gas migration from a leaky horizontal gas well drilled beneath Sugar Run assumed to have defective casing or cement: “the gas well had caused or allowed gas from lower formations to enter fresh groundwater…”

- **June 2015**: With increasing public pressure, PA DEP assessed $9 million civil penalty “for failure to repair leaking gas well” under the Clean Streams Law.

- While our study showed thermogenic methane entering Sugar Run, we were unable to conclusively determine its cause without predevelopment sampling. Thus stream methane is an important metric to consider including in baseline environmental monitoring prior to unconventional oil and gas development.
Relation of gas transfer rate to groundwater inflow

Increasing certainty in stream-based determination of groundwater methane
Approach for Stream Methane Studies

Scaled approach:

- Reconnaissance stream CH₄ sampling
- Higher resolution stream & shallow groundwater sampling
- Hydrocarbon isotopes to identify source
- Gas & bromide stream injections to determine $I_{GW}$ and $K_{CH4}$
- Seasonal/annual sampling to establish baseline variability in CH₄ load and evaluate trends caused by development
Conclusions

• Km-scale persistence of stream CH$_4$ supports feasibility of method
• Transport modeling can quantify [CH$_4$] and loads
• Most CH$_4$ escapes to atmosphere
• Pilot-scale application of stream methane method in the Marcellus shale-gas play shows the utility of a scaled approach
• Establishing baseline stream methane prior to shale-gas development is key to evaluating potential contamination
  – Seasonal/annual data collection may be needed for temporal variability in CH$_4$ load
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More Information:

http://ut.water.usgs.gov/projects/methanestream/

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References


PA Dept of Environmental Protection Notice of Violation, *Gas Migration Investigation, Moreland Township, Lycoming County*: Oil and Gas Management Program, Eastern District Oil and Gas Operations, Green Valley GMI File, September 20, 2013.


