Identifying Preferential Groundwater to Surface Water Flow Paths Using Discrete and Continuous Temperature Monitoring and Thermal Imaging Technology

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Presentation Overview

- Why understanding preferential groundwater-surface water (GW-SW) discharge pathways is critical to many site investigations.
- Dynamics of groundwater, sediment, and surface water interactions.
- Conservative tracers and thermodynamics.
- Techniques to identify preferential pathways using thermal infrared (TIR) imaging surveys and other tools.
- Outcomes and key considerations from a case study.
Importance of Understanding Groundwater-Surface Water (GW-SW) Discharge Pathways

• Groundwater contributions to sediments and surface waters are common, but often poorly understood, contaminant migration pathways.

• Surface waters are typically more temporally dynamic than groundwaters.

• Resolving the spatial and temporal extent of GW-SW interactions:
  – Supports conceptual site model development and data gap identification.
  – Informs human health and ecological risk assessments promoting better risk-based decision making.
  – Supports remedial decisions.
How Groundwater and Surface Water Interact

**Gaining Surface Waters**
- Baseflow
- Groundwater Inflow to Surface Waters
- Fine-grained Sediment Deposit

**Losing Surface Waters**
- Surface Water Losses to Groundwater

Adapted from Fetter, 1988
Mechanisms Influencing Fate and Transport

- COPC Sorption/Desorption
- Erosion/Resuspension
- Advection/Dispersion
- Deposition
- Porous Media Dispersion
- Preferential Groundwater Flow Path

Adapted from Massoudieh et al., 2010
Conservative Tracers, Mixing, and Thermodynamics

- Conventional evaluation of GW-SW interactions based on conservative tracers.
  - Rhodamine WT, chloride, etc.

Photos: (left) Parker; (right) Tripathi, 2016
Conservative Tracers, Mixing, and Thermodynamics

- Conservative tracers in the context of GW-SW interactions operate on the principles of end-member mixing.

\[ Q_{\text{in}} = Q_{dn} \left/ \left[ \left( C_{in} - C_{dn} \right) / \left( C_{up} - C_{dn} \right) \right] \right. \]

Where:
- \( C = \text{Solute concentration} \)
- \( Q = \text{Flow rate (L/s)} \)
Conservative Tracers, Mixing, and Thermodynamics

- Ground-based thermal infrared (TIR) imaging enables non-intrusive evaluation of groundwater-sediment-surface water dynamics.

  The first law of thermodynamics states that energy can be transformed from one form to another but cannot be created or destroyed.

- TIR imaging senses long-wave radiation (9-14μm) emitted by all objects.

- Water temperature acts as a conservative tracer.
Implementation of GW-SW Investigations

Multi-tiered evaluation:
1. Ground-based thermal infrared (TIR) imaging assessment
2. Continuous temperature monitoring
3. Longitudinal water quality parameter assessments.

• TIR imaging can be conducted in water bodies of various sizes.
Ground-Based TIR Imaging

• Scan waterbody for thermal anomalies.

• Success dependent on thorough understanding of hydrology and thermodynamics of system.
  – Flow conditions sensitive – base flow or rising limb preferred.
  – Optimal conditions seasonally dependent.

![Summer Assessment](image1)

![Winter Assessment](image2)

- Ambient Stream Temperature ≈ 20°C
- Spring Origin
- Thermal Mixing
- Groundwater Discharge
Continuous Temperature Monitoring

- Enables understanding of daily (diel) temperature cycles due to meteorological conditions.
- Permits normalization of in-stream measurements.
Longitudinal Water Quality Parameter Assessments

- Water quality parameters can provide important information, but they are temporally dynamic, which can make repeatability difficult.
- When combined with thermal imaging the uncertainty of water quality parameter data can be reduced.
Utilization of TIR Imaging Surveys

- Remediated Landfill Area
- Area of Historical Surface Water Detections
Utilization of TIR Imaging Surveys

- Thermal anomaly features to inform sediment and surface water sampling strategies.
- Supports CSM development through multiple lines of evidence approach.

Adapted from Harned, DA and Daniel, CC (1992)
Utilization of TIR Imaging Surveys

• Multi-tiered assessment approach identified features contributing from north and south banks as well as center channel.

• Flow from spring area and downgradient thermal anomalies resulted in observable changes to water temperature.
Utilization of TIR Imaging Surveys

- Floodplain spring and series of thermal anomalies responsible for reduction in water temperature, which were also linked to primary contaminant discharge pathway.
- Established background conditions during differing periods of flow.
- Determined spatial trend of constituents of interest away from preferential pathway.
Utilization of TIR Imaging Surveys

- Sediment and surface water concentrations showed similar pattern of downstream attenuation.
Project Outcomes and Key Considerations

• TIR imaging surveys are extremely useful for understanding GW-SW interactions where sub-surface contaminant migration is suspected.
  • Improved conceptual understanding led to better concurrence among stakeholders.
• Multiple lines of evidence approach provides robust understanding of hydrologic connectivity between sources and receptors.
• Can be implemented as cost-effective field reconnaissance or in-depth, repeatable evaluations depending on project needs.
• Provides a visual and quantitative thermal record of conditions and minimizes potential uncertainties.
Thank you!

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Literature Cited


