Use of Temperature to Track Subsurface Conditions and Process Dynamics

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Plan for Presentation

• Context for use of temperature to track process dynamics
• Different types of temperature monitoring tools
• Examples of using temperature for process monitoring
Heat Transfer Processes

- **Conduction** – passive movement of heat through media that is physically connected

- **Convection** – active movement of heat via fluid flow through connected open spaces through media
Types of Heat Sources

• Sunlight (regular cyclic variation)
• Chemical reactions
  – Exothermic (cement curing, iron rusting)
  – Endothermic (liquid water evaporation)
• Biochemical reactions (typically exothermic)
• Engineered source
  – Steam injection (mobile heat source)
  – Electrical resistance (static heat source)
Monitoring Heat Transfer

Track Heat Transfer via Temperature

• Heat transfer modifies the temperature distribution over space and time

• Temperature sensors must be compatible with environmental media and have suitable response characteristics (range, accuracy, resolution, response time)

• Ability to monitor large areas over extended periods governed by sensor cost and data acquisition capabilities
Different Sensor Types to Address Objective

• **Initial Site Screening**
  – Looking for variation across space
  – Hand-held devices

• **Continuous Monitoring**
  – Looking for variation across time
  – Logging devices, internal non-volatile memory

• **Continuous, Remote Monitoring**
  – Facilitate active intervention
  – Logging devices, external memory & telemetry
Hand-held Devices

- Screening measurements to look for variations in space
- Subsurface measurement can be biased by heat conduction from above-ground portion of instrument
- Variations in ambient temperature during measurements can be a problem
Temperature Monitoring Tools

Omni Instruments Tinytag Aquatic 2
-40°C to +70°C, +/-0.5°C accuracy, 0.01°C resolution
Waterproof, non-volatile memory (32,000 measurements)
~$129 each, replaceable battery

ONSET TidbiT v2
-20°C to +70°C, +/-0.21°C accuracy, 0.02°C resolution
Waterproof, non-volatile memory (42,000 Measurements)
~$133 each, non-replaceable battery (5 yrs)

STAR ODDI Starmon mini
-2°C to +40°C, +/-0.025°C accuracy, 0.001°C resolution
Waterproof, non-volatile memory (262,000 measurements)
~$425 each, replaceable battery
Temperature Monitoring Tools

Remote Systems

- Telemetry-based systems possible
- Local power supply (battery, solar, etc.)
- Temperature would need to be a critical measure to justify
Process Monitoring Examples

- Subsurface heating events at landfills (wellhead gas, leachate, waste mass)
- In-situ thermal remediation of contaminated soil or aquifer
- Biosolids composting operations
- Heat as a tracer for stormwater infiltration into soil
- *Heat as a tracer for groundwater flow*
Process Monitoring Examples

- Heat conduction influenced by GW-SW temperature gradient
- Heat convection influenced by flow up (discharge) or flow down (recharge)
- Shape of temperature profile influenced by magnitude and direction of GW flow

Process Monitoring Examples

Sediment Temperature Profile

- No Flow – heat conduction leads to a linear temperature change
- Upward Flow – cooler temperature propagates up profile
- Downward Flow – warmer temperature propagates down profile
• EPA 600/R-15/454 December 2014
• Provides background and technical guidance on appropriate application of technology
• Illustrates use of spreadsheet-based analysis tools for calculating seepage flux magnitude and direction from sediment temperature profile data
Process Monitoring Examples

- Nested Piezometers, Cove Piezometers
- Seepage Flux, Chemistry (Water & Sediment)

Seepage Flux (GW Discharge)

- Continuous sediment temperature profile logs
- Several month deployments
- Logging temperature sensors with non-volatile memory and internal battery
- Equipment cost $2,000/yr (4yr period)
Purpose for monitoring seepage flux

• Initial site characterization
  – Establish link between contamination observed in sediments/SW and discharge of upland plume
  – Assess the spatial extent and variability over time

• Remedy performance monitoring
  – Determine reduction in seepage flux into SW
  – Couple with chemical measurements to demonstrate reduction in contaminant flux
Process Monitoring Examples

Temperature Profile Data

• Sensors have non-volatile memory & programmed for unattended data acquisition

• Temperature monitoring network installed in 1-2 days

• Deployed for 2-3 months & retrieved in 1 day – data downloaded and analyzed
Continuous temperature logs...

Give daily temperature profiles

Temperature (°C)
Depth Below Surface (cm)
Process Monitoring Examples

Water & Sediment Properties

- $k = 1.56 \text{ J/(m.s.C)}$
- $\rho/\theta F = 4.19E+06 \text{ J/(m}^2\text{.C)}$

Measured Temperatures

- $T_0 = 19.87 ^\circ C$
- $T_2 = 17.53 ^\circ C$
- $T_1 = 16.21 ^\circ C$

Sensor Spacing

- $z = 0.30 \text{ m}$
- $L = 0.70 \text{ m}$

Calculated Flux!

- $q_z = 0.0807 \text{ m/day}$

Calculate Seepage

Reset
Process Monitoring Examples

Sediment Temperature Profile Method

Comparison over entire monitoring period…

Middle of Cove (June - August)
- Pre-Installation (2008)
- Post-Installation (2014)
- Upland GW Flux

Calculation of Seepage Flux (cm/d)

Water Flux, cm/d

Calendar Year

Calendar Day
Temperature monitoring can provide a cost-effective approach to assess process dynamics in systems in which heat transfer is occurring.

There is a wide selection of commercial devices with a range of performance characteristics that are sufficiently rugged for long-term deployment in harsh environments.

With sufficient understanding of process details and environmental media characteristics, temperature data can be used as either a qualitative tracer or for quantitative assessments of system response.
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Questions or Discussion?