# Modeling Heat Loss During In-Situ Thermal Remediation

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The power and energy needed for in situ thermal remediation (ISTR) impacts costs and environmental stewardship. Unfortunately, competitive bidding scenarios could encourage ISTR vendors to provide optimistic estimates, resulting in designs that may not be appropriately sufficient. Perhaps the most critical design element is heat loss. At some sites the heat losses may exceed the energy required to achieve steaming temperatures, which are necessary to remove the target contaminants. This paper presents the complexities of calculating heat loss and the advantages of using a numerical model. w

TRS Group's (TRS) numerical Heatwave model uses first principles and keeps track of mass and energy throughout the remedy. The model, calibrated by more than 170 implementations, provides the basis for our energy budgets and estimated durations.

**Water content impacts soil heat capacities**

Figure 1 shows the energy density, expressed as energy per unit volume, required to raise the temperature from 10 to 100 degrees Celsius (°C) for solids with varying porosity and water content.

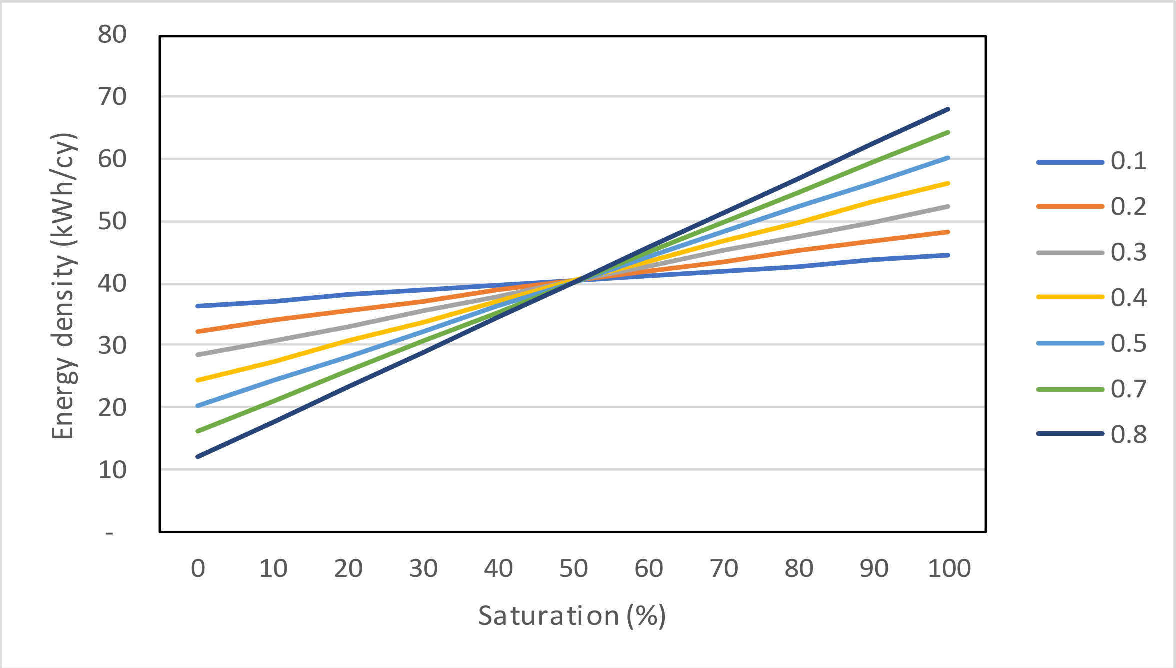


*Figure 1: Energy density required to raise the temperature 90°C for soils with different porosities. Heat losses are not included. Solid grain density of 2.65 g/mL is assumed (as quartz).*

For many sites, the starting water content of the soil is unknown, which means the energy density is uncertain. If the saturation is close to 50%, this uncertainty is less important; however, wet treatment volumes may need twice the energy to reach steaming conditions as dry zones. Further, targeted zones that straddle the water table might have different energy needs from top to bottom.

**Heat losses can be significant**

We provide an energy balance for an example site in Figure 2. Note that the heat losses amount to approximately 30% of the total energy delivered with another 35% extracted in the steam produced by boiling. As a result, the remediation energy is close to three times the energy needed to raise the temperature to boiling (shown as the green net heating line). Thus, minimizing heat losses will improve the remedy and lower costs.

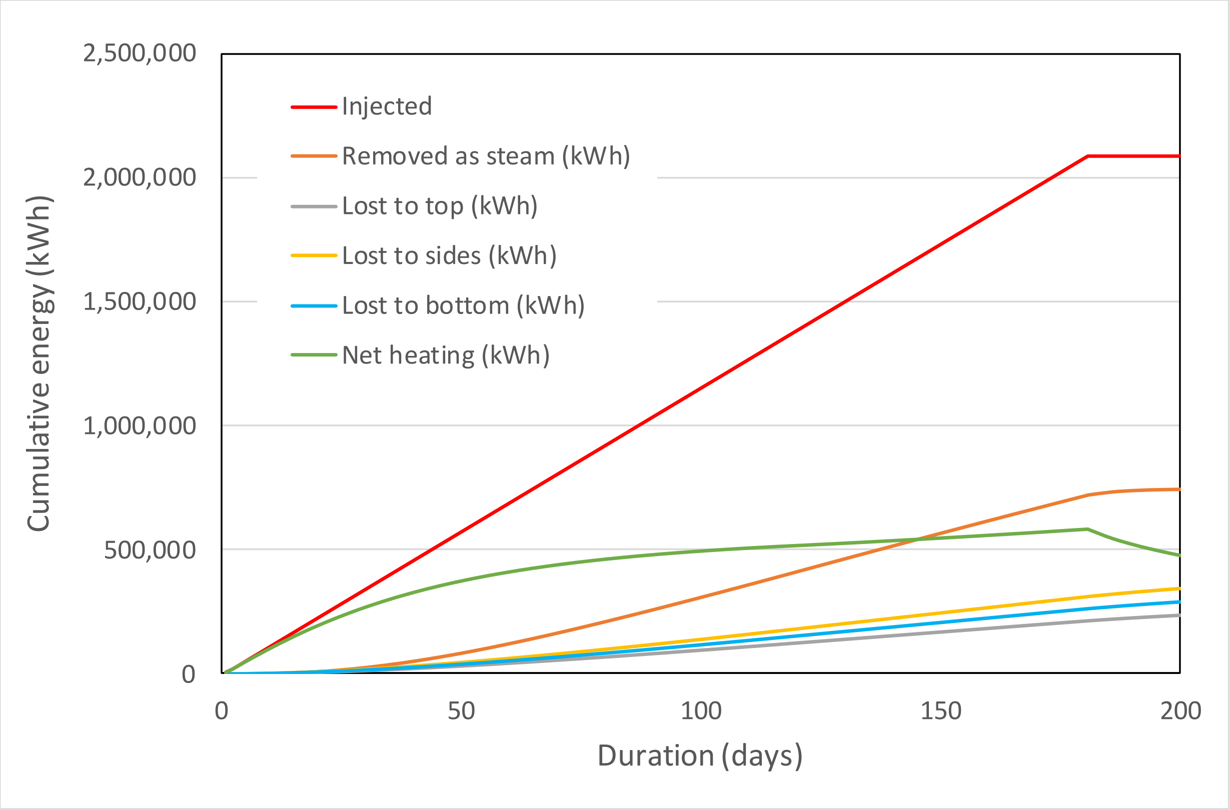


***Figure 2:*** *Energy balance for a 30-foot-deep site heated to boiling for removal of VOCs. Note the significant amount of energy lost and extracted.*

**Treatment zone geometry affects heat losses**

The ratio of surface area to treatment volume is a key parameter. A large ratio will result with excessive loss with heat flowing away from the target volume. Inversely, a low ratio will help minimize heat losses. Figure 3 illustrates energy densities required for the thermal treatment of a site impacted by tetrachloroethene (PCE).

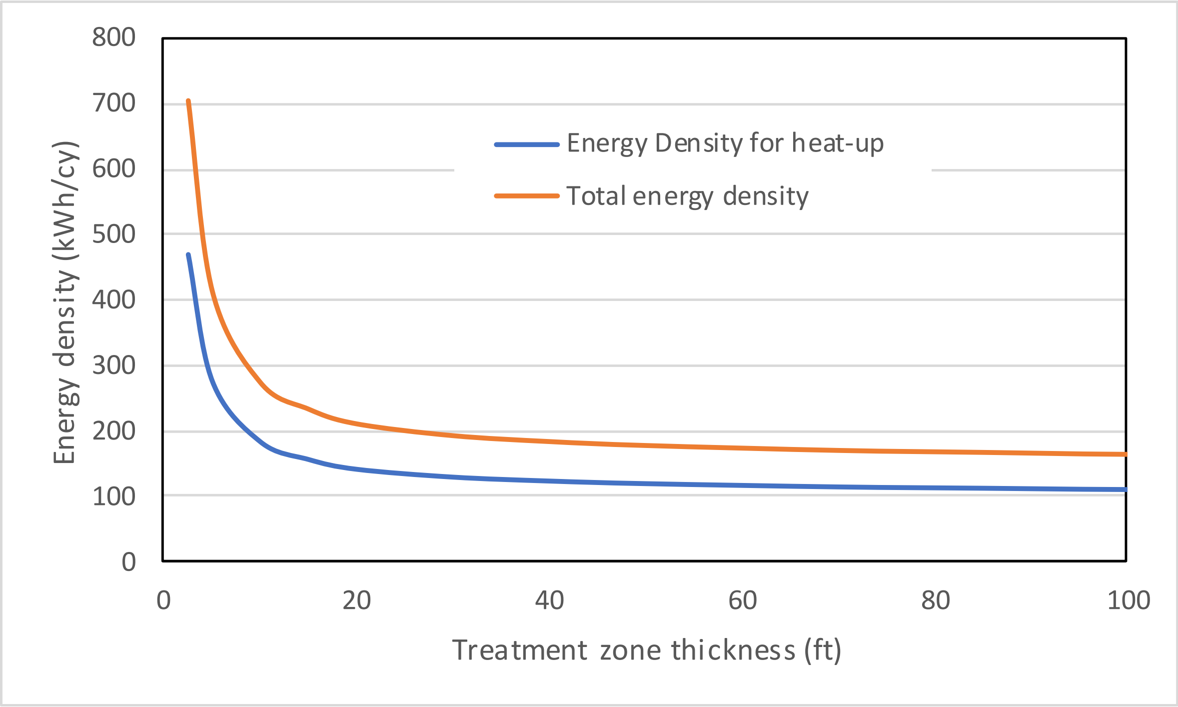


***Figure 3:*** *Energy density required as a function of treatment zone thickness. Example case with 99% reduction of PCE in a wet soil with 40% porosity. Heat losses and energy removed by extraction are included.*

Note that for sites with a treatment interval of 10 feet or less, the energy densities are high. For sites thicker than 20 feet the change is modest, as other factors such as surface insulation and groundwater flow become more dominant.

**Groundwater flow and liquid extraction remove energy**

Using the same site geometry and power input as above, we show in Figure 4 the impact of groundwater flow into the treatment volume.

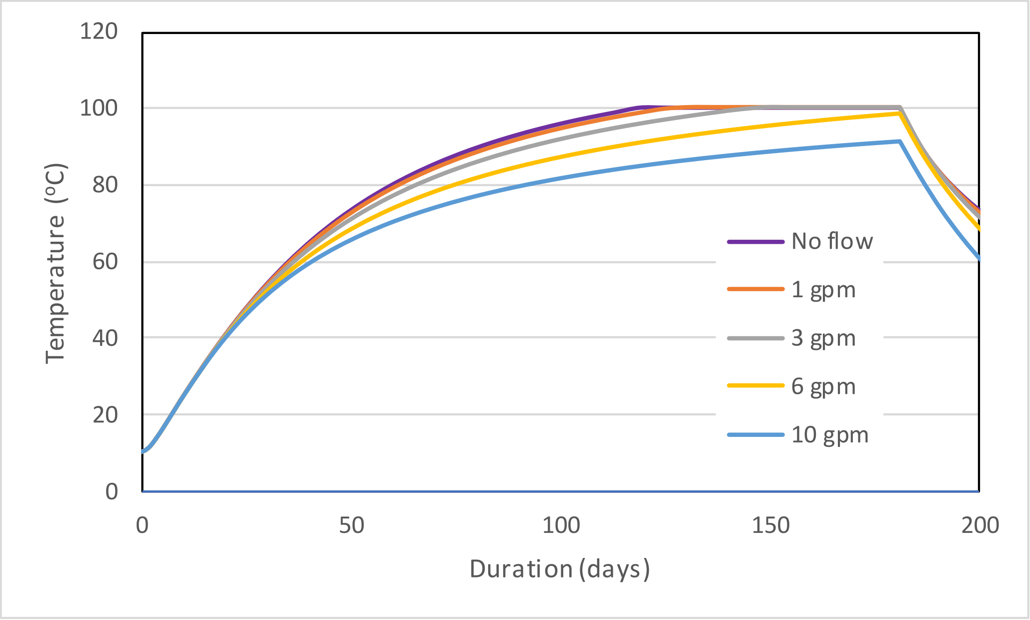

***Figure 4***: *Heating progression influenced by groundwater extraction rate. Example case with 40% porosity and wet soil and a 30-foot-deep treatment zone.*

Note that in the absence of an alternative heating strategy, the site does not reach steaming temperatures in the cases of 6 and 10 gallon per minute (gpm) inflow. Alternative strategies could include delivering more power, extracting water up-gradient of the treatment volume to reduce the gradient and slow groundwater velocity, or injecting steam into the flow zones, all of which add cost and implementation time.

**Minimizing surface heat losses**

The surface cover and insulation properties govern the heat losses to the atmosphere. Figure 5 shows the temperature progressions for a site with different R-values. The plot represents the range of no insulation (R1) to a 2-foot thick layer of air-entrained concrete with a thermal conductivity of 0.22 W/mK (R30).

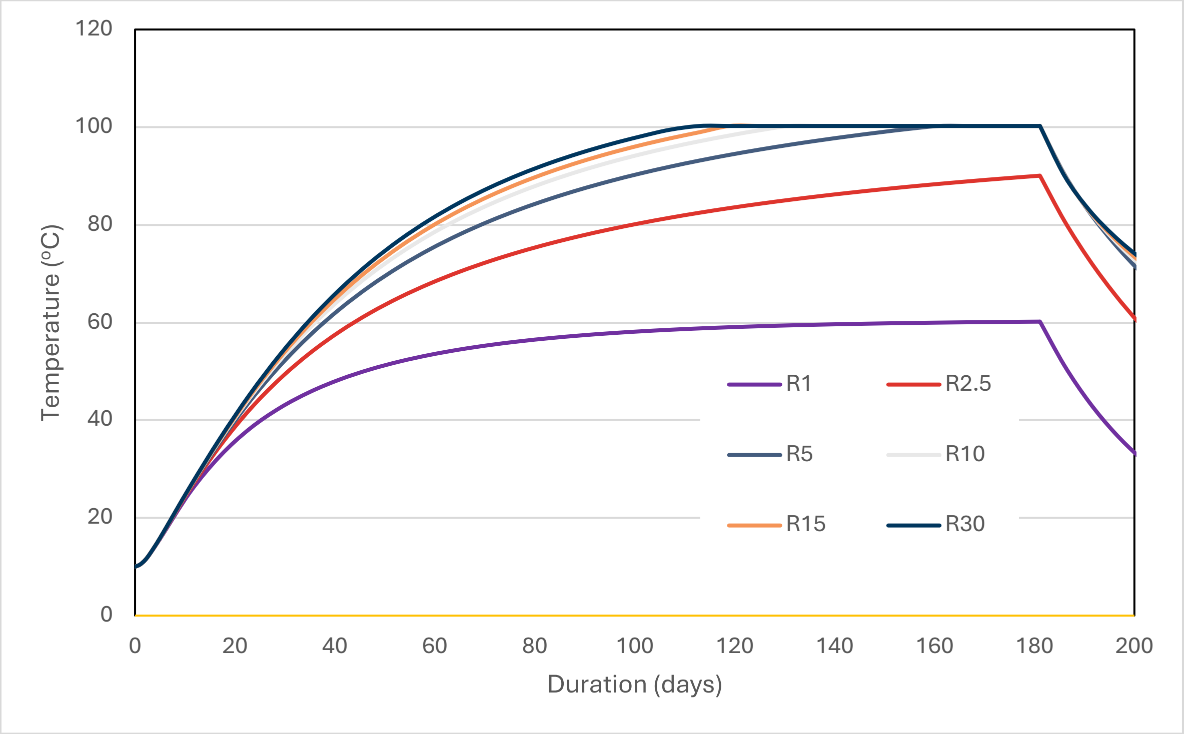


***Figure 5***: *Heating progression at a site with varying insulation values at the surface. Example case with 40% porosity and wet soil and a 30-foot-deep treatment zone with the same power input in all cases. R1 represents a 1-foot-thick concrete or asphalt later (no insulation).*

For this example, achieving boiling after four months of heating requires a minimum R-value of 10. Solutions with simple pavement or a thin sprayed layer (R2.5-R5) would lead to extended operations or greater power input, resulting in larger energy bills.

**Vapor extraction increases energy demand**

While we capture and treat the generated contaminant vapors, dry air moving through the vadose zone will have a cooling effect. By extracting enough vapor to create inward gradients and pneumatic control, but not so much as to facilitate excessive cooling, we optimize energy use.

### Estimating energy and project duration

To get a reliable estimate of the energy need and duration required to meet project goals, the following parameters are essential:

- Site geometry (surface area, volume, thickness)
- Groundwater flow and location
- Surface insulation properties
- Energy density needed to vaporize contaminants
- Vapor extraction rates
- Changes in gradients during the remedy

Applying our HeatWave numerical model, TRS can predict power and energy requirements and treatment duration, enabling TRS to stay on time and on budget, avoiding unpleasant surprises.

## Author Biographies

**Gorm Heron, Ph.D. –** As TRS's Chief Technology Officer, Dr. Heron focuses on technology selection, development, and optimization. Additionally, he supports domestic and international business development.

**Emily Crownover, Ph.D.-** is a Lead Engineer at TRS Group, Inc., working on a variety of ISTR projects and maintaining client-relationships.