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# Detecting Sources of Drinking Water Contamination Originated by Wildfires

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## Abstract

The paper introduces a machine learning method of detecting multiple sources of water contamination caused by wildfire. The method includes changing the water flow regime, monitoring the time series of the contaminant concentration caused by regime changes, and associating the signature of the contaminant changes over time with sources locations. The contaminant signature from multiple sources starting at the moment of changing water velocity are defined by extending the approach for one contamination source. The intensity, location of each source, and diffusion coefficient are defined to satisfy the minimum square between monitoring and theoretical concentrations. The equations derived from the criteria of the best fit between experimental and modeling data are solved using the theory of hypernumbers. The initial values for hypernumber solutions are computed using the transient process of contaminant transport curve analysis. The defined in this paper algorithm can by used for detecting location of the arbitrary impurity in water network system.

**Keywords:** wildfire; water; contamination; source; detection; inverse engineering; theory of hypernumbers

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## 1. Introduction

### *1.1. The Contaminant Release into Water Distribution Systems as a Wildfire Consequence*

Wildfires in urban areas are often the cause of drinking water contamination (Researchers warn of a threat to water safety from wildfires, 2025, Whelton et al., 2023).

The mechanisms of the pollution release in the water supply system are covered below:

- Contaminant Release Due to Heat Damage to Pipes: Intense heat from wildfires can degrade plastic pipes and fittings, releasing volatile organic compounds (VOCs). Wildfires can introduce VOCs, such as benzene and toluene, into water systems due to the overheating plastics material (Solomon et al., 2021). Two ways overheated pipes introduce contamination are provided in recent research (Meadows, 2022). The paper lists methods for plastic pipe thermal state diagnostics. The modeling of the thermal impact on the pipe is covered in a research paper (Richter et al., 2022). The research covers experiments to determine the critical temperature and duration of heating at which contaminants migrate from pipes to contained water (Fischer, Wham, & Metz, 2022, Metz, Fischer, & Wham, 2023).
- Contaminant leaks into the pipeline due to loss of pressure: Firefighting efforts and system damage can lead to loss of water pressure, allowing contaminated water (including water containing bacteria) to be sucked into the system through leaks or damaged infrastructure (Pierce et al., 2021).

- Smoke and Ash Intrusion: As water systems lose pressure and drain, smoke containing chemicals can be drawn into the enumerate the pipes.

According to analysis covered in a recent publication (To Mitigate the Impact of Wildfires on Communities' Water, Report Fill Gaps in Guidance to Public Drinking Water System Staff. 2025), addressing damage to these systems from a wildfire has been insufficient, conflicting or inaccurate.

### *1.2. The Directions for Securing Pipeline from Contaminations*

The methods of detecting pipes that release toxic chemicals due to the thermal impact of a wildfire is covered in a research paper. (Meadows, 2022) are listed below.

- The RFID sensor, which does not need batteries and, when triggered, emits a signal that can be scanned. The goal is to put RFID sensors on the laterals of the fire hydrants, which are evenly spaced throughout the communities and buried at the same depth as the vulnerable part of the laterals of the service
- Color indicator sensor to let homeowners know if they should replace their pipes after a fire.

Water pipe temperature sensors provide a valuable tool for identifying potential water contamination risks. However, the drawbacks to such system implementation include:

- Deploying sensors across a complex network of pipes in fire areas where fire has a high tendency to occur might be expensive and logistically challenging.
- Maintenance and cost: The reliability and longevity of sensors in harsh environments and the potential need for frequent maintenance could be a significant factor for cost and feasibility.

For such a reason, there should be alternative methods for detecting pipes that are the source of water contamination.

The method of detecting the location of a source of contaminant in underground water pipes has been identified in a research publication (Dantsker & Brito, 2025). The method can be extended to multiple sources and such an approach is covered in the following.

The method of locating the contaminant release into the water distribution system from overheated or damaged pipes

The method of detecting the location of contaminant release sources in the main distribution system from multiple lateral service lines is shown in Figure 1. Water contamination is monitored by Total Dissolved Solids (TDS) sensors. The most common toxics released from the plastic pipe at temperatures exceeding the threshold for such release (Solomon, et al., 2021) are: bromodichloromethane, chloroform and trihalomethanes Such ingredients are dissolved solids. Due to this, the location of the thermally damaged pipe can be defined by following the origins of TDS release. In case of loss of pressure due to thermal damage to the pipe structure, the surrounding solids leak into the water supply system. Some of the solids are dissolved and the source can be detected with the proposed method. The transient process of the contaminant dynamic is analyzed using the source location identification algorithm software installed on the Raspberry PI computer.

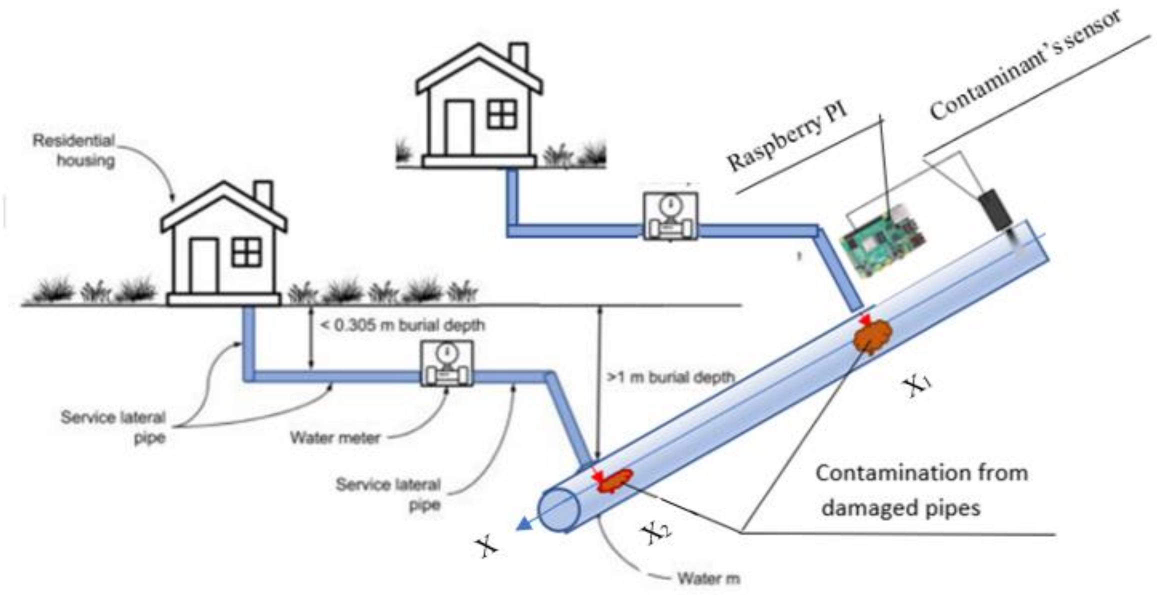

**Figure 1.** Locating the source of water contamination from the damaged pipes. The schema is extender from the Ritcher et al. chart.

The approximation of the signature of the contaminant from two sources is shown in Figure 2.

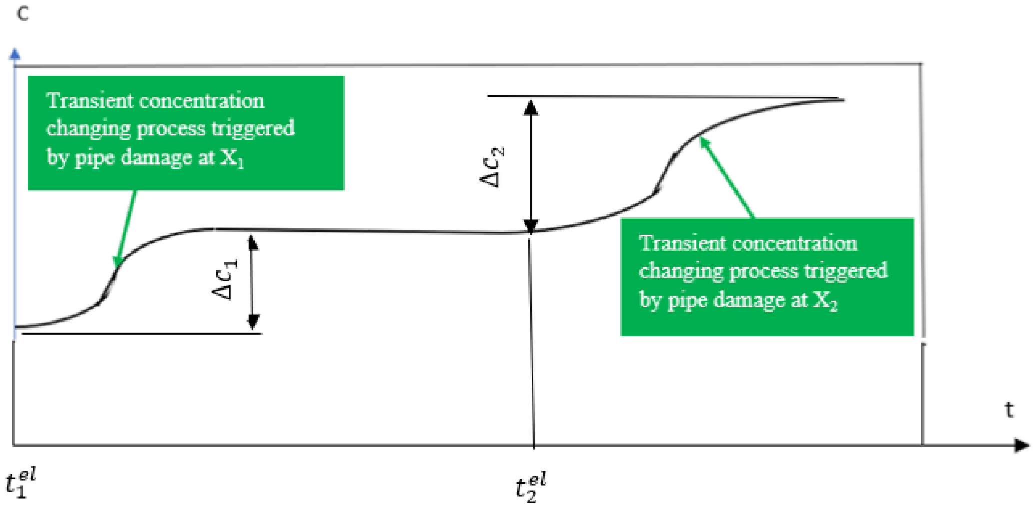

**Figure 2.** The transient process of contaminant concentration changes from multiple sources.

Based on the assumption that the transport of contaminants from each source does not depend on another one from the set of sources, the concentration can be defined as the sum of each source following the approach in the research paper (Dantsker & Brito, 2025).

$$c^{teor} = \sum_{l=1}^{k}\left(\int_0^t \frac{m_{pol,l} n_{pol.} e^{-\frac{(d_l - vn_{vel.}\tau)^2}{2D}}}{S\sqrt{2\pi D\tau}} d\tau + \int_{d_l-d_1}^{l} \frac{\frac{m_{pol,l}}{v} e^{-\frac{(x-vn_{vel.}t)^2}{2D}}}{S\sqrt{2\pi Dt}} dx\right) \quad (1)$$

The ill-posed problem for contaminant transport inverse engineering is defined with operator minimizing square difference between theoretical and monitoring contaminant concentrations.

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$$\mathcal{L} = min \sum_{i=1}^{n} \left(c_i^{exp} - c_i^{theor}\right)^2 \tag{2}$$

The system of equations (3) is defined to satisfy operator $\mathcal{L}$ .

$$\begin{cases} \frac{\partial \mathcal{L}}{\partial d_1} = \sum_{i=1}^{n} 2\left(c_i^{exp} - c_i^{theor}\right) \frac{\partial c_i^{theor}}{\partial d_1} = 0 \\ \qquad \dots \\ \frac{\partial \mathcal{L}}{\partial d_l} = \sum_{i=1}^{n} 2\left(c_i^{exp} - c_i^{theor}\right) \frac{\partial c_i^{theor}}{\partial d_l} = 0 \\ \qquad \dots \\ \frac{\partial c}{\partial d_k} = \sum_{i=1}^{n} 2\left(c_i^{exp} - c_i^{theor}\right) \frac{\partial c_i^{theor}}{\partial d_k} = 0 \\ \frac{\partial \mathcal{L}}{\partial m_{pol,1}} = \sum_{i=1}^{n} 2\left(c_i^{exp} - c_i^{theor}\right) \frac{\partial c_i^{theor}}{\partial m_{pol,1}} = 0 \\ \qquad \dots \\ \frac{\partial \mathcal{L}}{\partial m_{pol,l}} = \sum_{i=1}^{n} 2\left(c_i^{exp} - c_i^{theor}\right) \frac{\partial c_i^{theor}}{\partial m_{pol,l}} = 0 \\ \qquad \dots \\ \frac{\partial \mathcal{L}}{\partial m_{pol,k}} = \sum_{i=1}^{n} 2\left(c_i^{exp} - c_i^{theor}\right) \frac{\partial c_i^{theor}}{\partial m_{pol,k}} = 0 \\ \frac{\partial \mathcal{L}}{\partial D} = 0 \sum_{i=1}^{n} 2\left(c_i^{exp} - c_i^{theor}\right) \frac{\partial c_i^{theor}}{\partial D} \end{cases} \tag{3}$$

The partial derivatives of the contamination concentration $c_i^{theor}$ are identified in (4-6) using expression (1).

$$\frac{\partial c_i^{theor}}{\partial d_l} = -2 \int_0^t \frac{m_{pol,l} n_{pol.} e^{-\frac{(l - v n_{vel.} \tau)^2}{2D}}}{S\sqrt{2\pi D\tau}} e^{-\frac{(d_l - v n_{vel.} \tau)^2}{2D}} (d_l - v n_{vel.} \tau)\, d\tau + \frac{\frac{m_{pol,l}}{v} e^{-\frac{(x - v n_{vel.} t)^2}{2D}}}{S\sqrt{2\pi D t}} \tag{4}$$

$$\frac{\partial c_i^{theor}}{\partial m_{pol,l}} = \int_0^t \frac{n_{pol.} e^{-\frac{(d_l - v n_{vel.} \tau)^2}{2D}}}{S\sqrt{2\pi D\tau}} d\tau + \int_{d_l - d_1}^{l} \frac{\frac{1}{v} e^{-\frac{(x - v n_{vel.} t)^2}{2D}}}{S\sqrt{2\pi D t}} dx \tag{5}$$

$$\frac{\partial c_i^{theor}}{\partial D} = \sum_{l=1}^{k} \left( \begin{array}{l} \int_0^t \frac{m_{pol,l} n_{pol.} ((d_l - v n_{vel.} \tau)^2 - D\tau) e^{-\frac{(d_l - v n_{vel.} \tau)^2}{2D\tau}}}{S\sqrt{2\pi}\, D^{5/2} \tau^{3/2}} d\tau + \\ \int_{d_l - d_1}^{l} \frac{\frac{m_{pol,l}}{v} e^{-\frac{(x - v n_{vel.} t)^2}{2Dt}} ((d_l - v n_{vel.} t)^2 - Dt)}{S\sqrt{2\pi}\, D^{5/2} \tau^{3/2}} dx \end{array} \right) \tag{6}$$

The solution for complex non-linear equations (4) is defined with theory of hypernumbers (Burgin, 2010, 2012) and derived from this theory method of solving operator equations (Burgin & Dantsker, 1995), where hypernumber solutions $d_{l,s}^{h}, m_{pol,l,s}^{h}, D_s^{h}$ for $d_l, m_{pol,l}, D$ are the sequences:

$$d^h_{l,s+1} = d^h_{l,s} + \delta d^h_{l,s} \quad (7)$$

$$m^h_{pol,l,s+1} = m^h_{pol,l,s} + \delta m^h_{pol,l,s} \quad (8)$$

$$D^h_{l,s+1} = D^{hm}_{l,s} + \delta D^h_{l,s} \quad (9)$$

The method of finding solutions for hypernumbers deviations is covered in research papers (Burgin & Dantsker, 2022, Dantsker & Burgin,2022).

The $d^h_{l,0}, m^h_{pol,l,0}$ are identified by analyzing the form of the transient concentration curve by detecting the start of the elevation of the concentration and the difference between the stabilized concentrations before and after the elevation.

$$d^h_{i,0} = t^{el}_i v$$

$$m^h_{pol,l.0} = \Delta c_i v\, S$$

where $t^{el}_i$- the consequent start time of increasing concentration, $\Delta c_i$ the difference between consequent stable concentrations.

The $t^{el}_i$ and $\Delta c_i$ are shown in Figure 2.

The algorithm is defined for arbitrary amount of pollutant sources.

## 2. Conclusions

The proposed method allows solving the complex problem of detecting pipes that release contamination in the water distribution system. The method is inexpensive and does not require permanent device installation for such identification. The arbitrary number of sources can be identified. The method can be used for any process in which multiple sources of contamination affect the system. The unknown parameters are computed by solving a nonlinear equation using the theory of hypernumbers. The method guarantees solution convergence.

## References

Burgin M, Dantsker A. Pollution information acquisition and discovering pollution sources. Journals Proceedings. 2022; 81(1).

Burgin M, Dantsker AM. A method of solving operator equations by means of the theory of hypernumbers. Not. Nat. Acad. Sci. Kurt. 1995: 8; 27–30.

Burgin M. Nonlinear partial differential equations in extrafunctions. Integr. Math. Theory App. 2010; 2(1): 17–50.

Burgin M. Hypernumbers and extrafunctions: extending the classical calculus; Springer: New York, NY, USA, 2012.

Dantsker A, Burgin M. Monitoring Thermal Conditions and Finding Sources of Overheating. The 2021 Summit of the International Society for the Study of Information [Internet]. 2022 Mar 24; Available from: http://dx.doi.org/10.3390/proceedings2022081038

Dantsker, A., & Brito, J. (2025). Leak Location Detection in Underground Pipeline Using Transient Pollutant Propagation Concentration Signature Analysis with Theory of Hypernumbers. Research & Reviews: Discrete Mathematical Structure, 12(1), 13-22.

Fischer, E. C., Wham, B. P., & Metz, A. (2022). Contaminant Migration from Polymer Pipes to Drinking Water under High Temperature Wildfire Exposure. *Lifelines 2022*. https://doi.org/10.1061/9780784484432.060

Meadows, R. (2022, August 3). *FEATURE: How Wildfire-damaged Plastic Pipes Contaminate Drinking water – and What We Can Do About It*. MAVEN'S NOTEBOOK | California Water News Central. https://mavensnotebook.com/2022/08/03/feature-how-wildfire-damaged-plastic-pipes-contaminate-drinking-water-and-what-we-can-do-about-it/

Metz, A. J., Fischer, E. C., & Wham, B. P. (2023). Behavior of Service Lateral Pipes during Wildfires: Testing Methodologies and Impact on Drinking Water Contamination. *ACS ES&T Water*, *3*(2), 275–286. https://doi.org/10.1021/acsestwater.2c00248

Pierce, G., Roquemore, P., & Kearns, F. (2021). Wildfire & water supply in California, https://innovation.luskin.ucla.edu/wp-content/uploads/2021/12/Wildfire-and-Water-Supply-in-California.pdf

Richter, E.G., Fischer, E.C., Metz, A., &Wham, B.P. (2022). Simulation of Heat Transfer Through Soil for the Investigation of Wildfire Impacts on Buried Pipelines. Fire Technology, 58(13). https://doi.org/10.1007/s10694-022-01232-3

Researchers warn of a threat to water safety from wildfires. (2025) ScienceDaily, http://www.sciencedaily.com/releases/2025/04/250417145511.htm

Solomon, G.M., Hurley, S., Carpenter, C., Young, T.M., English, P., & Reynolods, P. (2021). Fire and Water: Assessing Drinking Water Contamination After a Major Wildfire. ACS EST Water, 1, 1878-1886. https://pubs.acs.org/doi/10.1021/acsestwater.1c00129

To Mitigate Impact of Wildfires on Communities' Water, Report Fill Gaps in Guidance to Public Drinking Water System Staff. (2025) Lyles School of Civil and Construction Engineering – Purdue University. https://engineering.purdue.edu/CCE/AboutUs/News/Environmental_Features/to-mitigate-impact-of-wildfires-on-communities-water-report-fills-gaps-in-guidance-to-public-drinking-water-system-staff

Whelton, A. J., Seidel, C., Wham, B. P., Fischer, E. C., Isaacson, K., Jankowski, C., MacArthur, N., McKenna, E., & Ley, C. (2023). The Marshall Fire: Scientific and Policy Needs for Water System Disaster Response. AWWA Water Science, 5(1), https://doi.org/10.1002/aws2.1318.