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# Characterizing the Impact of Hydrants on Transients <sup>†</sup>

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**Abstract:** Attempts have been made to detect and locate leakage using hydraulic transients; however, there has been limited success under field-based conditions on operational systems. It is believed that this is partly due to fire hydrants, the most convenient access points, complicating the signal generated and received in the operational systems. Using the transient simulator TSNet based on the method of characteristics (MOC), this paper demonstrates that hydrants can have a significant impact on transient signals and that characterizing and filtering for the hydrant impact can lead to more accurate leak localization. A practical method for characterizing hydrant properties is proposed using an inverse transient analysis approach (ITA) and validated numerically.

**Keywords:** transients; wave generation; leakage; standpipe; hydrants; TSNet

## 1. Introduction

Hydraulic transients have been shown to be potentially useful for locating leakage, unknown faults, and other asset information in water distribution systems [1]. This is dependent on a well-characterized input signal [2]. The majority of research has been conducted in laboratory conditions with transients induced using valves located directly on the pipeline, either using side discharge or in-line valves. This is impractical for implementation in operational systems; it is more likely that transients will be induced through fire hydrants. Brunone et al. [3] highlighted the complications added to input signals when a transient is induced through a hydrant, with additional reflections generated by the hydrant bowl, standpipe, and other ancillaries. This work conceptualizes the ancillary features as composed of a standpipe, hydrant, and connector (Figure 1). The standpipe and hydrant are going to be relatively invariant from site to site; however, the connectors can vary more greatly. It should be noted that the hydrants which are complicating the transient signal are also the points used for signal capture.

This paper has two aims. Firstly, to determine the impact of hydrants and ancillary features on transient signals and the consequent impact on leak detection. This will be explored through simulation of the transmitted and received transient signal with different ancillary features and a correlation technique to determine the impact on leak localization. Secondly, a method for determining connector properties is proposed and validated, which should facilitate the accurate modelled representation of ancillary features in field-based conditions.



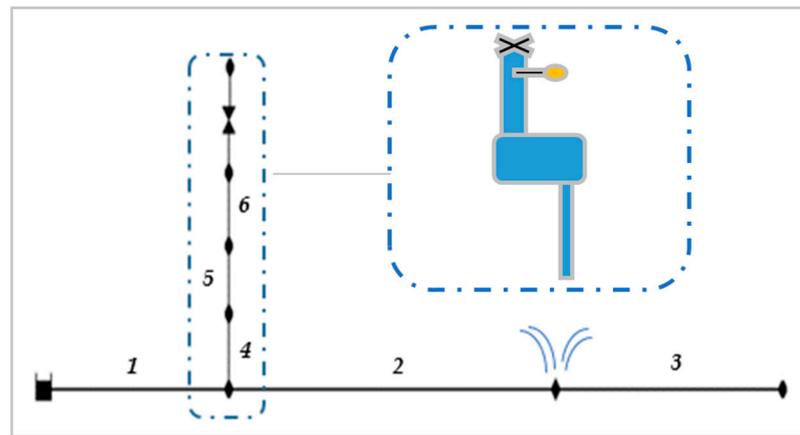
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**Figure 1.** Modelled pipeline.

## 2. Materials and Methods

### 2.1. Impact of Hydrant and Ancillary Features

To determine the impact of the hydrant and its ancillary features modelling work has been conducted using TSNNet [4] which is transient modelling software that uses the method of characteristics. Each feature is given its own length, wavespeed, and diameter, with relevant characteristics shown in Table 1. A wavespeed of 400 m/s would represent a plastic pipe, which would have corresponding viscoelastic properties; however, for the purposes of this study, steady friction alone has been modelled. The valve closure time is 5 ms, which is realistic for a mechanical valve closure attached to a hydrant [5].

**Table 1.** Properties of modelled pipeline.

Pipe	Length (m)	Diameter (m)	Wavespeed (m/s)
1	75	0.05	400
2	15	0.05	400
3	40	0.05	400
4	2	0.05	400/700/1000/1400
5	0.3	0.12	1000
6	1	0.08	1000

The connector pipe which attaches the hydrant to the main pipeline has been given a variable wavespeed of between 400 and 1400 m/s. The purpose of this is to determine whether accurately characterizing the ancillary features has a significant impact on the transient waves. The ‘modelled’ transient wave reflected back from the leak has been correlated with the ‘measured’ pressure signal to identify the location of the leak from the correlation peak. This process of identifying the leak location has been replicated for various levels of additional white Gaussian noise to verify the impact in more realistic conditions. The ‘Correlation confidence’ (Equation (1)) is then plotted for the various levels of additional noise.

$$\text{Correlation confidence} = \text{Correlation value} \times \frac{\text{Real leak time} - |\text{Real leak time} - \text{identified leak time}|}{\text{Real leak time}} \quad (1)$$

To identify the leak time determined by the correlations, the largest peak between 0.35 and 0.45 s has been identified. As there are multiple peaks in the signal, an identification ‘boundary’ had to be imposed, and this range was deemed appropriate.

### 2.2. Determining Connector Properties

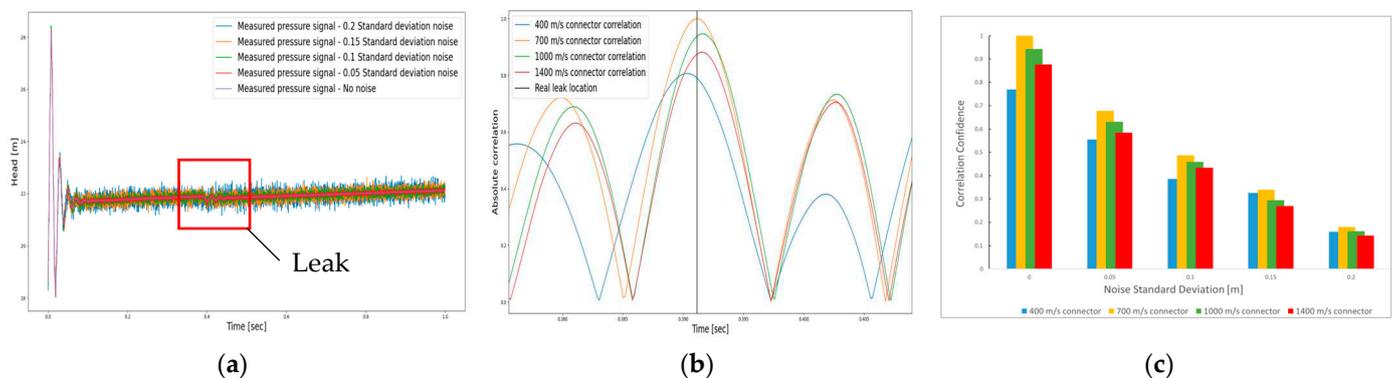
The standpipe and hydrant properties can be determined in advance through a combination of physical measurement and fitting transient data. This is because the same standpipe can be used for testing and its features determined beforehand, and hydrants

are built to the same standard and are relatively invariant. Of the ancillary features this alone leaves the connector as uncharacterized. To determine connector properties an initial transient test is proposed using a high sampling frequency and solenoid valve, followed by an inverse transient analysis (ITA) approach to fit the ‘modelled’ transient signal before any reflections are received from the main pipeline to the ‘measured’ transient signal. All work conducted is based on a modelling approach; however, for the purposes of this paper, the ‘measured’ signal is assumed to be when the connector has a wavespeed of 700 m/s, diameter of 0.05 m, and length of 2 m. The three properties of the connector—wavespeed, diameter, and length—are varied using a brute force optimization algorithm with the root mean squared error (RMSE) being the output. This is carried out to characterize the search space when connector properties are varied giving an indication of what optimization techniques may be appropriate.

### 3. Results and Discussion

#### 3.1. Impact of Hydrant and Ancillary Feature

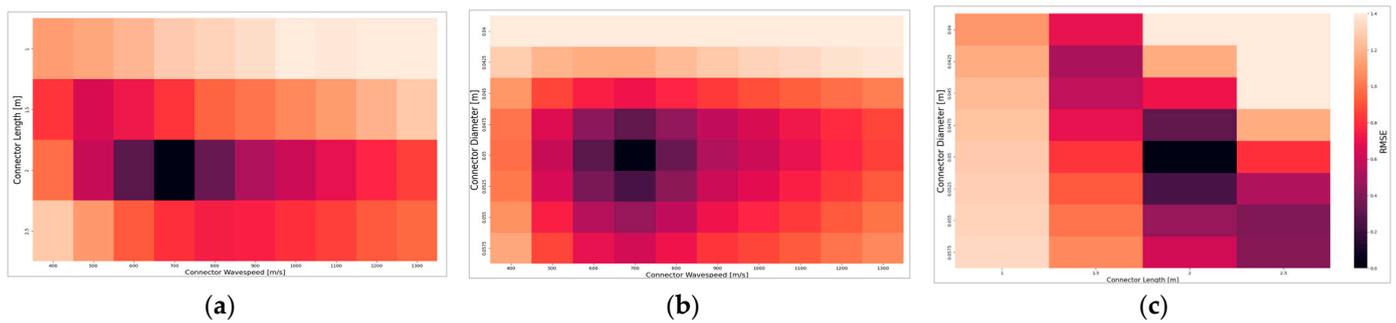
Results from Figure 2c show the correlation confidence (Equation (1)) results and how they vary with different levels of additional noise. With no noise and the correct connector wavespeed (700 m/s), the correlation confidence is 1, and this confidence decreases as noise is added and incorrect connector wavespeeds are used. This shows that correctly identifying the connector wavespeed increases the leakage localization accuracy, and this relationship is maintained even when the noise added to the signal becomes large enough so as to obscure any discernable pattern in the leak reflection (Figure 2a). These results support the conclusion that correctly determining the properties of ancillary features is important for accurate transient based leakage detection even in noisy conditions.



**Figure 2.** (a) ‘Measured’ pressure signal with noise; (b) noiseless correlation results; (c) correlation confidence with noise.

#### 3.2. Determining Connector Properties

The optimization results show clearly that the correct connector properties are identified when using a brute force optimization method. Local minima are identified for Figure 3c (diameter and length), but not for Figure 3a (length and wavespeed) or Figure 3b (diameter and wavespeed). This suggests that if the length or diameter of the connector can be identified beforehand, the problem is convex and a simple gradient-based optimization algorithm will work for determining the connector properties. Otherwise, if length and diameter are unknown, a more sophisticated optimization technique will be required to avoid local minima traps. However, the principle of using the initial transient signal as a basis for an ITA-based approach to determine connector properties is shown to work.



**Figure 3.** Connector calibration results. (a) Length and wavespeed, (b) diameter and wavespeed, (c) diameter and length.

#### 4. Conclusions

Modelling work has been performed which shows the importance of correctly modelling hydrants and ancillary features for transient based leakage detection. To increase the accuracy of transient-based methods, it is important to include and accurately model the ancillary features. Of particular note is the connector, which is buried underground, with features that cannot be predetermined. An ITA analysis-based approach, which uses the initial wave reflection to accurately model these features, has been suggested and has been shown to be successful. Future work will look at applying these findings in field-based conditions.

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