

Rusby Wood a Smart Network for Sustainable Discolouration Risk Reduction.

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ABSTRACT

Managing discolouration customer contacts has never been more important to UK Water Companies, with the Economic Regulator setting strict water quality customer contact targets, imposing large financial penalties if they are exceeded without providing additional funding to facilitate necessary network investment.

19% of discolouration customer contacts can be directly associated with the mobilisation of discolouration material from the trunk main distribution system, but these pipes due to their criticality of supply and size are extremely expensive to clean.

This paper presents a practical example demonstrating that with the addition of relatively inexpensive automated flow control, metering and instrumentation, a water supply system can be configured to automatically re condition itself. Five trunk main sections will sequentially run a maximum flow between service reservoirs before returning to normal operating flows. This produces a safety headroom between normal operating flow and the maximum hydraulically available flow this dramatically reduces discolouration risk should an un planned high flow event occur on the network.

The system is designed to ‘self check’ whereby sending and receiving reservoir levels and flow pressure and turbidity at strategic points are within set parameters before the reconditioning occurs.

In addition, if abnormal flows, pressures or turbidity levels are detected at any time on one of the trunk main sections, the inlet valve on the appropriate receiving reservoir will automatically close. This prevents discoloured water from entering the reservoir allowing the operator time to repair and flush the affected main.

Keywords: Discolouration, Mains Conditioning, DOMS

1 BACKGROUND

If ageing and deteriorating water distribution systems are to remain fit for purpose, capable of adapting to changing demands and resilient to increasing quality concerns, innovative maintenance strategies are required. In 2001 a novel approach to understanding the phenomenon of discolouration in water distribution systems was published [1]. It was proposed that discolouration, a major cause of customer dissatisfaction regarding water quality [2], is not due to gravitational sediment uplift but particulate erosion from pipe walls. Although low-level background flux of particulate material exists in the bulk water [3], it was postulated that elevated concentrations visible to consumers are caused by increases in hydraulic shear stress above typical values mobilising material from boundary surfaces [4]. With this concept the discolouration response was coded as a force balance between the cohesive retaining forces (material ‘sticking’ to the pipe wall) and the mobilising hydraulic shear stress in the freeware modelling software EPANET 2.00.07bTB2

[5]. This software, termed The Prediction of Discolouration in Distribution Systems (PODDS) has since been verified by extensive field trials at distribution pipe level [6] and demonstrated as equally applicable to trunk mains [7,8].

According to the PODDS concept, flow, and hence wall shear stress, exceeding peak daily shear stress leads to mobilisation of material from the pipe wall. Research investigating network discolouration responses have shown it to be an international and ubiquitous phenomenon and is now associating this behaviour with the presence of biofilms, irrespective of water source, treatment processes or residual disinfectants [9,10]. Furthermore it is the inherent composition of biofilms, a combination of cells and a supporting framework of extracellular polymeric substances, which facilitates the accumulation and trapping of particulate material from the bulk water. Discolouration complaints are typically observed when iron and manganese are present and this might be via the water source, from treatment steps or corroding mains within the network. It should also be noted that any substances present in the bulk water may accrue within the developing material layers, such as disinfection by-products or pathogenic microbes, which can then be released in significant concentrations if mobilised. As a result of this accumulation any customer observed discolouration response is also likely to exceed regulatory iron and/or manganese concentration values.

Discolouration is not an everyday occurrence; network operators understand that a regular daily peak hydraulic demand does not cause discolouration issues. This indicates that pipes, or more specifically the material on the pipe surfaces, is effectively conditioned by and is in equilibrium with the regularly experienced hydraulic conditions. It is atypical flow increases that create discolouration issues, such as seasonal demand fluctuations or asset failings, e.g. a pipe burst or valve failure. A significant cause of network flow increases are however directly attributable to water companies own operations. In 2014 the UK regulatory authority for water quality reported 57 significant discolouration events with 2.9 million people estimated to have been effected [11]. Of those nearly half were caused by water company planned operations.

1.1 Managing Discolouration

Prior to the advent of the PODDS concept, discolouration was considered a gravitationally dominated process caused by sediment uplift from the pipe invert [12]. This sedimentary approach is comprehensible to practitioners, both for devising risk assessment via basic modelling and network cleaning by flushing to achieve flow velocities above simple thresholds. Analysis of discolouration material however has shown it to be particulate in nature with a characteristic particle sizing of around 10 μm [1]. The consequence in combination with typical particulate density is that self-weight forces would be insufficient to cause settling in anything other than laminar flow regimes, which is significantly below design capacities [3]. In situations where flows are low, such as dead-end or network tidal points, material sedimentation however can create significant material deposition and associated discolouration risk. Low night time flows or between pumping regimes etc., may also occur allowing settling but concentrations of material available to accumulate over this short period of time do not cause issues when mobilised on resumption of peak daily flow.

Associated with the previous understanding that discolouration is a sediment issue is the idea of self-cleaning pipes, a threshold velocity where all material is removed. This self-cleaning effect has been demonstrated in smaller distribution pipes (<150 mm) and is now applied in the Netherlands [13], with 0.4 ms⁻¹ initially used as a self-cleaning network design velocity although 0.2 - 0.25 ms⁻¹

1 currently used. No evidence however of self-cleaning has been published for larger diameter mains.

Flushing, the opening of hydrants to mobilise and remove discolouration material, is a common intervention in smaller diameter pipes. Trials in the UK have shown that for pipes with low roughness values and diameters of 150 mm or less, a flushing velocity of 0.6 ms⁻¹ (derived from a mobilising shear stress of 1.2 Nm⁻²) is a threshold above which no significant further material is mobilised [6]. In the Netherlands a 1.5 ms⁻¹ flushing velocity has been adopted incorporating a significant safety factor to allow for possible shear stress events that could occur to mobilise material. It is important to note that although little further material may be mobilised, the pipes cannot be considered fully clean as some material resistant to the hydraulic forces remain [14,15]. This evidence goes against the sedimentation theory as the primary cause. Furthermore the research by Husband et al in 2010 notes that no threshold mobilising shear stress has been observed in rough walled or cast iron pipes. That is for non-smooth pipe surfaces (typically a result of corrosion tubercles), material was mobilised at every step increase in hydraulic shear stress, irrespective of the absolute value.

While flushing or other interventions may remove material and reduce risk, this material is known to immediately start to re-accumulate at the pipe surface. Such continual development of material layers has been widely evidenced. Husband and Boxall [16] reported that for smaller diameter pipes maximum risk, when layer development is back to equilibrium with daily hydraulic conditions, occurred between 2 to 5 years depending on bulk water quality and pipe material whilst Vreeburg et al [17] demonstrated that by reducing particulate material within the bulk water the rate of material accumulation was reduced. Hence any cleaning strategy is only ever a temporary measure. It is therefore unlikely that invasive cleaning techniques, although very effective initially, are the best long term option. Alternatively, with confidence in the PODDS concepts of cohesive layers and hydraulic conditioning, it becomes possible for network managers to apply regular flow conditioning in a pro-active fashion to mitigate discolouration and associated water quality risks. Application of this in the UK has focussed on trunk mains. This is for a number of reasons including; the direct discolouration risk and high consequences trunk mains pose, typically a better understanding of hydraulic conditions and control, they act as a source of material feeding downstream networks and because traditional cleaning methods are disruptive and expensive. The availability of mobile real-time and telemetry based monitoring equipment facilitates managing the impact of flow increases during normal operation. With the correct infrastructure such as automatic control valves or variable speed pumps, flow control, along with monitoring, can be conducted from a remote location and thereby at minimal cost. In addition the potential to predict the mobilisation response via tools such as the PODDS model allows the concentration (or turbidity) of entrained material to be planned to remain within regulatory levels. Repeated increments can therefore be programmed to increase network resilience and critically this is without mains being taken out of service or supply interruptions. This has been successfully applied by Water Companies as a method cost effectively managing discolouration risk at the trunk main level [18]. However rather than manage discolouration risk from individual trunk main sections, to fully maximise the potential of trunk main conditioning water companies need to take a full Water Supply System approach.

This paper introduces a water supply system in the North of England where a fully automated mains conditioning program is being applied at the water supply system level to cost effectively manage discolouration risk.

2 Rusby Wood WSS

Rusby Wood Water Supply System (WSS) supplies 50 (Distribution Management Areas) DMAs totalling 22000 properties through 77km of trunk mains. Over the last 10 years 1617 discolouration customer contacts have been reported in this WSS. Flow directional cluster analysis (summing contacts in immediately downstream DMAs that occur on the same day) indicates that 415 (25%) of these contacts directly relate from mobilisation of discolouration material from within the trunk main distribution system. Several DWI reportable incidents have occurred in this water supply system which have directly related to increased flows in the trunk mains.

On one such incident a flow control valve and meter on the inlet to Skelmanthorpe SRE was bypassed to facilitate repair. The exact flow rate of this operation was unknown, but from the rise in water level of the reservoir it was estimated that this bypass operation caused an increase in flow from its normal operating rate of 9 l/s to 32 l/s in the 2.3 km section of 8” cast iron main supplying the reservoir. This remobilised a significant amount of previously accumulated discolouration material and generated many discolouration customer contacts.

2.1 Field Trials

Three months following this significant flow event a field trial was performed whereby the flow on the main was significantly increased whilst recording the turbidity response. To facilitate this the reservoir was isolated and one compartment of the reservoir drained down. This left the supplied DMAs downstream running on storage in the second reservoir compartment. The inlet valve was then opened incrementally to generate flows higher than the previous incident. The duration of the test was limited to ensure that the turbidity in the 8” main would fall to acceptable levels and be brought back into service before the second compartment ran out.

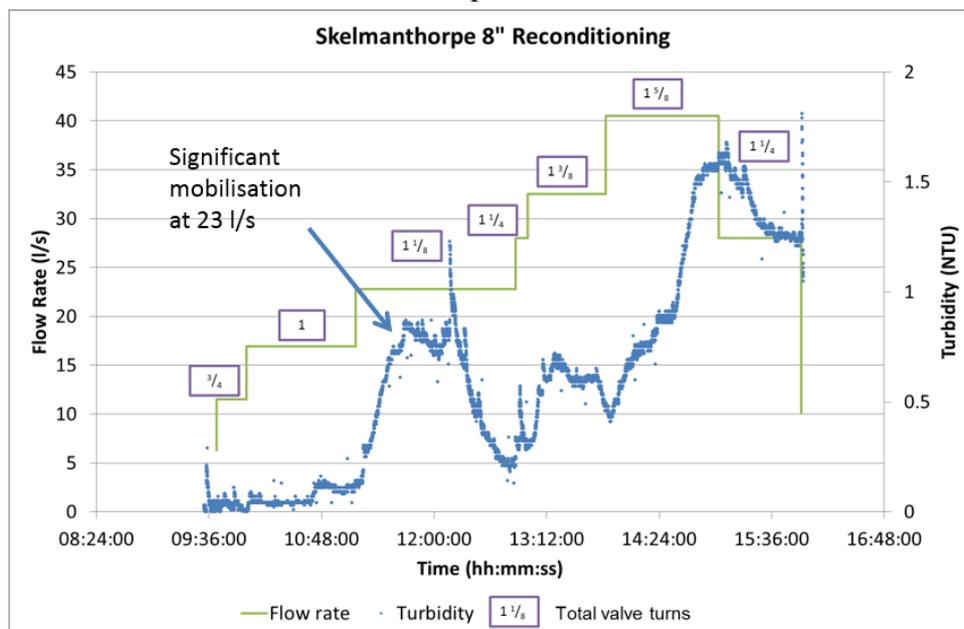


Figure 1. Turbidity results from the first field trial

Results from this field trial are shown in Figure 1. Here it can be seen that significant discolouration material was mobilised when the flow reached 23 l/s. This is a lower flow rate than occurred during the discolouration incidents that occurred only 3 months previously, indicating that discolouration

material had already started to re accumulate in this main. During this trial only 1 5/8 of a valve turn was required to generate over 40/l/s. This highlights the operational risks of manually operating valves on the network to rezone supplies.

To gain further insight on return rate for this main, flows were again increased after a period of 18 months following the initial test. On this occasion, due to a better understanding of the discolouration performance of this main, and an operational need to shorten the test, only two flow increments were applied of 25 and 40 l/s. During the test a similar turbidity response between the two flow rates was seen, Figure 2. This indicates that the regeneration rate in this main was at least 18 months and could be quicker.

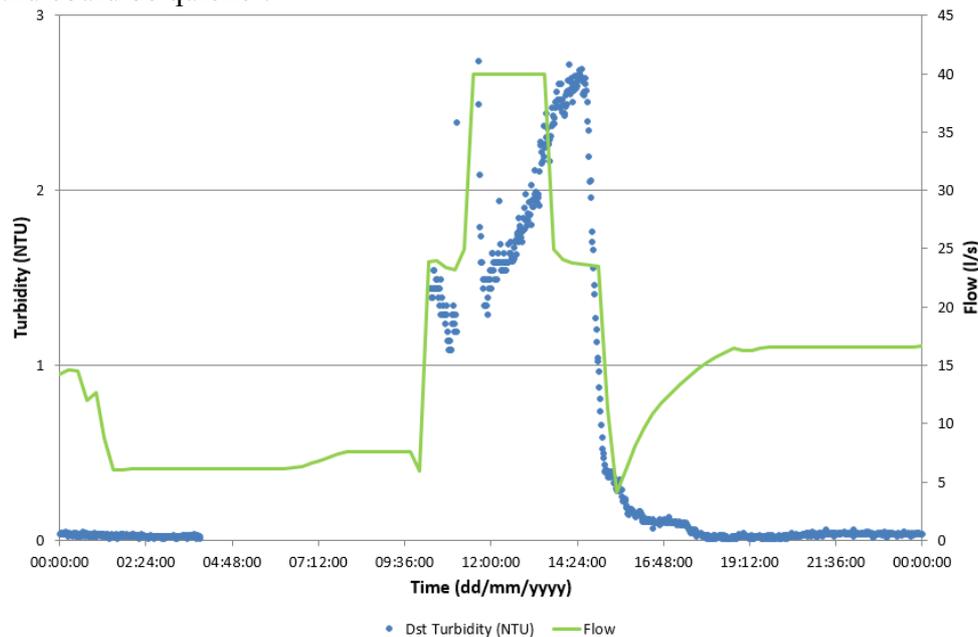


Figure 2. Turbidity results from the second field trial

2.2 Discolouration Risk Mitigation

Since one of the major influencing factors on regeneration rate is bulk water chemistry (Cook, D. M. & Boxall, J. 2011) it can be assumed that the rest of the water supply system would have a similar regeneration rate as the trailed section. This poses a problem as any potential evasive cleaning techniques for this system would be extremely expensive, disruptive to customers and should be repeated often. Therefore, to cost effectively manage the discolouration risk of this system, an automated mains conditioning system is being proposed whereby on a cyclical bases maximum achievable flows are automatically generated systematically in the major trunk main sections. This means that each main will be conditioned to its maximum achievable flow rate. Thus, is an un planned high flow rate occurs, as long as it is below this maximum conditioning flow rate, no discolouration material will be mobilised.

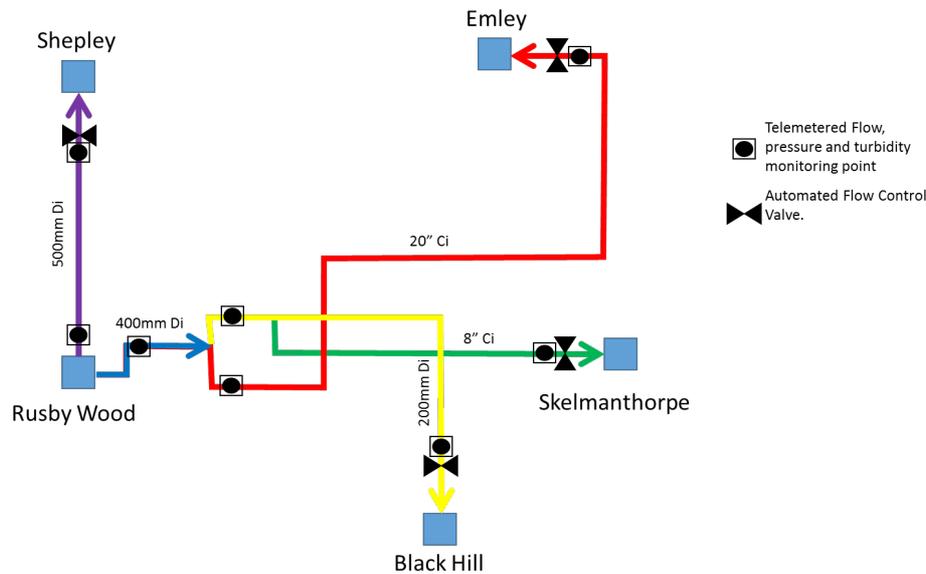


Figure 3. Turbidity results from the second field trial

A Stylised schematic of the automated mains conditioning system for Rusby Wood WSS shown in figure 3. Automated flow control valves are being installed at the four receiving reservoir inlets. Telemetered flow, pressure and turbidity monitoring stations are also being installed at the beginning and end of all the 5 trunk main sections (figure 3). All flow, pressure, turbidity, reservoir level and valve position data will be visible remotely in Yorkshire Water's telemetry system RTS. All sites will be visible and communicate with the Programmable Logic Controller (PLC). On day one of the conditioning cycle the system will let the reservoir level in the first receiving reservoir, Shepley, fall. The system will then check that there is sufficient water in the supplying reservoir, Rusby Wood, and that flows and pressure through the system are within normal operating parameters. The flow control valve at Shepley Reservoir will then fully open to achieve the maximum possible flow rate down the 500mm main for two pipe turnovers before returning to its normal operating regime.

On the second day of this conditioning regime, the reservoir level at Emley reservoir will be allowed to fall, before the inlet flow control valve fully opens to generate maximum flow down the 20" main for two pipe turnovers. Black Hill and Skelmanthorpe sections will be conditioned to the same manner on day three and four respectively. On day five Black Hill and Emley inlet valves will open simultaneously to condition the 400mm section of main.

During a flow conditioning cycle, if a turbidity response is seen greater than 0.5 NTU the flow will be reduced and will not increase again until the turbidity has fallen to background levels. Flow pressure and turbidity will be closely monitored at all times and if the PLC detects values outside a specific range along any of the trunk main sections an alarm will be generated and the flow control valve on the appropriate receiving reservoir will be automatically closed. This will enable the DMAS to be supplied from clean storage water and allow 24 hours to identify and rectify the problem and prevent discoloured water being supplied to customers.

This scheme is currently being built at a cost of £600K and is expected to be completed in October 2017. However, prior to commissioning each trunk main section will be manually conditioned using stepped flow increases designed using the PODDS model. Here each flow increase will be planned

to keep the turbidity response to below regulatory levels and the actual turbidity response in the field will be very closely monitored.

This method of automated mains conditioning is far more cost effective than traditional invasive mains cleaning techniques and it is expected that upon successful completion of this pilot, the control philosophy will be rolled out across Yorkshire Water's network.

3 CONCLUSIONS

Rusby Wood Water supply system has been shown to pose significant discolouration risk. 25% of discolouration customer contacts in this water supply system directly result from the mobilisation of discolouration material from the trunk main distribution system. There have been several DWI reportable incidents which have related increased flows in the trunk mains. Field trials on the 8" main to Skelmanthorpe have indicated that the regeneration of discolouration material in this main is quite fast, less than 18 months. Therefore, in this water supply system any traditional invasive mains cleaning activity would have to be regularly repeated at great cost. In this case mains reconditioning whereby flows regularly increased above normal operating conditions is a more appropriate and cost effective mains cleaning approach. A fully automated system is currently being built to condition all the trunk mains in this water supply system and is due for completion in October 2017.

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