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A metric for drinking water service reservoir performance as a sink or source of material

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ABSTRACT

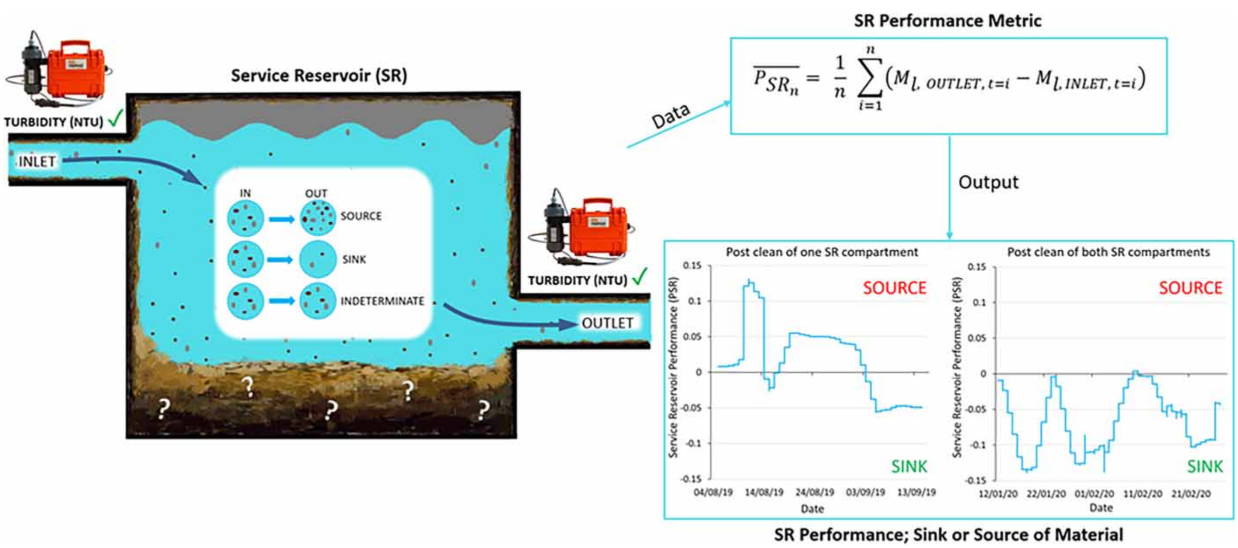
Service reservoirs (SRs) are a critical component of drinking water distribution systems that impact water quality. There are no performance measures to quantify or understand this impact. By applying the concept of sink or source behaviour to describe the processes of material accumulation and mobilisation within SRs, this research develops a practical metric to facilitate assessment and quantification of SR performance. It is demonstrated how a few weeks of continuous data from instrumentation deployment at both inlet and outlet of SRs is sufficient to reveal valuable insight into SR and network performance. Through real-world applications, we provide evidence that the metric was able to track SR performance showing both beneficial and detrimental impacts on water quality, as well as quantifying seasonality and the benefits of SR cleaning. Such insight is invaluable for proactive, justifiable, and targeted decisions on the location and frequency of maintenance and management interventions.

Key words: assessment, material accumulation, performance, service reservoir, source sink model, water quality

HIGHLIGHTS

- A sink or source concept was applied to service reservoirs to describe performance.
- A metric was developed to assess and quantify sink and source behaviour in service reservoirs.
- Sink behaviour is indicative of good asset performance.
- Source behaviour is indicative of deterioration in asset performance.
- Service reservoirs can have both a beneficial and negative impact on water quality.

GRAPHICAL ABSTRACT



ABBREVIATIONS

DWDS	Drinking water distribution system
DWI	Drinking water inspectorate
NTU	Nephelometric turbidity unit
SR	Service reservoir
WTW	Water treatment works

1. INTRODUCTION

Service reservoirs (SRs) store treated water to balance supply against demands in the drinking water distribution system (DWDS). They are crucial and integral components of the system. They have not been afforded the same attention as water treatment works (WTW) and pipes in monitoring and understanding their performance, condition, and maintenance requirements (NRC 2006).

The ability to assess SR performance and their effect on water quality is imperative to maintaining high-quality drinking water in DWDSs. SRs can be associated with water quality deterioration due to long retention times, ineffective mixing, accumulation/release of material, and ingress if there are structural faults. Drinking water quality problems related to SRs range from nitrification, stagnation, and degradation of disinfectant residual to significant waterborne disease outbreaks (Clark *et al.* 1996b; Craun & Calderon 2001; NRC 2006). SRs have been identified as a source of pathogen contamination that has resulted in serious illness and even death. For example, in 1993, a *Salmonella typhimurium* outbreak in Gideon, Missouri, which stemmed from an SR, resulted in 15 hospitalisations and 7 deaths (Clark *et al.* 1996a).

Despite the knowledge that SRs can cause water quality deterioration, these assets are often overlooked, and, at present, there is no effective way to assess or quantify their performance, leaving them as a black box of the system. This lack of understanding can prevent utilities from detecting potential water quality issues and means that most SR-related issues are dealt with in a reactive manner.

A fundamental method to quantify the performance of DWDSs is to monitor water quality via collection of discrete samples, laboratory-based analysis, and checking against prescribed concentration values. Key indicator water quality parameters (e.g., metals, turbidity, pH, conductivity, disinfectant residual, and bacteriological indicators) are regulated at WTW and customer taps, whereas measuring disinfectant residual and sampling for bacteriological indicators is the only monitoring currently required at SR outlets in the UK (DWI 2020). Water utilities report that these regulatory requirements are limited in providing information on SR performance and in identifying the root cause of water quality failures at SRs (UKWIR 2019). There is also no requirement to monitor water quality at SR inlets, making it difficult to determine if the SR is the cause of observed changes in water quality between the previous sampling point and the SR outlet (Doronina *et al.* 2020). Kirmeyer *et al.* (1999) and UKWIR (2019) argue that to successfully assess SR performance, pinpoint the location of water quality problems, predict and prevent potential future issues, and avoid costly repeat samples, routine sampling at SRs should, at the least, include both inlet and outlet monitoring. Sampling for other key parameters, such as turbidity, metals, temperature, and pH, can provide additional information on asset performance such as water age, seasonal impacts, and rate of water quality deterioration (Grayman & Kirmeyer 2000; AWWA 2012).

Sampling at SR outlets under current UK regulations is typically conducted once per week, which cannot capture real-time changes in water quality or rapidly evaluate developing trends, ultimately restricting operational insight into SR performance (ATi 2023b). The use of continuous online monitoring equipment for water quality parameters, commonly chlorine, pH, temperature, and turbidity, is becoming more popular in DWDSs (DWI 2020; Gleeson *et al.* 2023). However, at present, online monitoring is rarely utilised at SRs (UKWIR 2019).

Improving monitoring programmes and the development of performance metrics for SRs would provide the ability to detect and measure changes in SR condition and performance over time. This would help locate sources of deterioration and provide information to support asset management (UKWIR 2019). This would be of value to water utilities in saving effort, time, and expense that can go into unnecessary and often reactive investigations (Hope 2016). It may also help alleviate some of the pressure water utilities experience with the low replacement rate of ageing assets by improving understanding of asset performance and therefore management, thus extending asset life (Ellis *et al.* 2018; Speight *et al.* 2019).

1.1. Factors influencing SR water quality performance

Physical, chemical, and biological changes to water quality in DWDSs can result from accumulation of organic and inorganic particulate material (Larson 1966; Kirmeyer *et al.* 2000; USEPA 2002) that can have an external or internal source (Vreeburg & Boxall 2007). Externally, material can enter through ineffective treatment of source water, the addition of particles as part of treatment, or external contamination (e.g., through ingress) (Gauthier *et al.* 2001; Vreeburg *et al.* 2004; Douterelo *et al.* 2018). Internally, material can come from corrosion by-products, leaching of compounds from coatings of construction material, biological growth, and chemical reactions (Gauthier *et al.* 2001; Slaats *et al.* 2003; AWWA 2011). Boxall *et al.* (2023) review and show how the two dominant theories for understanding material accumulation and mobilisation within DWDS combine, but they consider only pipe infrastructure. The concepts and ideas are equally applicable to SRs, with processes of sedimentation more likely to dominate due to the low hydraulic conditions.

Typical locations for material settling are areas of low flow, such as dead-end pipes and SRs (Brandt *et al.* 2016; Qin *et al.* 2017). Accumulation of material in SRs is an especially prevalent process, primarily due to low velocities in these assets, which allows suspended material to settle on interior surfaces (Grayman & Kirmeyer 2000). This accumulation couples with the long residence time and low Reynolds number conditions to favour flocculation and precipitation processes for the formation of particles. The rate of material accumulation in SRs can also be exacerbated by poor mixing conditions (Grayman & Kirmeyer 2000; Speight *et al.* 2009). It should be noted that biofilms will also grow on all surfaces of an SR.

The accumulation of material impacts water quality through several mechanisms. Particles can shield bacteria from disinfectants (Smith *et al.* 2006; Brandt *et al.* 2016) and carry nutrients that support biofilm growth (Zacheus *et al.* 2001). Material from SRs has been found to be colonised by microorganisms (Gauthier *et al.* 1996; Qin *et al.* 2017). Mobilisation of accumulated material can decrease disinfection efficacy and introduce viable microorganisms into the system (Twort *et al.* 2000; AWWA 2011). For instance, *S. typhimurium* that caused a deadly outbreak in Missouri in 1993 was isolated from a material that had accumulated in an SR, which entered the downstream network upon mobilisation (Kramer *et al.* 1996). Mobilised material can also alter the aesthetic quality of the water by discolouring it and changing its taste and odour (Husband & Boxall 2011; Mounce *et al.* 2015).

Mobilisation of accumulated material can be triggered by changes to the normal operating flow regimes of water in DWDSs, including planned works, flushing activities, unplanned bursts, high demand, and filling and draining cycles of SRs (NRC 2006; Vreeburg & Boxall 2007; Husband *et al.* 2008). In SRs, water is often drawn from the bottom to encourage mixing and maximise usable storage volume. However, the bottom is where material accumulation is prevalent, presenting a mobilisation risk if the accumulative capacity of material is exceeded (Kirmeyer *et al.* 1999; Speight *et al.* 2009; AWWA 2011).

Controlling the accumulation of material in DWDSs to prevent water quality problems is a challenge for water utilities (Ginige *et al.* 2011). Periodic cleaning of the DWDS and removal of material is considered a necessary control measure (NRC 2006). In the UK, inspection and cleaning of SRs is currently recommended every 3–10 years to mitigate issues related to the accumulation of material (Lambertini *et al.* 2011; Brandt *et al.* 2016). Some argue that irrespective of the lengths water utilities take to remove material, DWDSs can never be fully free of particles or microorganisms (Carrière *et al.* 2005). Careful assessment and proactive management of the rate and location of material accumulation should therefore be considered as a critical water quality management strategy.

1.2. Material sinks and sources

Under regular and stable operational conditions, DWDSs can be described to be functioning as sinks of material (Parsons & Jefferson 2006; Vreeburg & Boxall 2007). If material mobilises and enters the downstream network, the DWDS becomes a source of material (Vreeburg & Boxall 2007). Describing the behaviour of a system as a sink or source is not a new concept in other disciplines. For example, the concept is applied to research on ecosystems and construction materials with respect to their sequestration and release of nutrients, elements, and compounds (Oechel *et al.* 1993; Kumar & Little 2003; Chen *et al.* 2008; Ma *et al.* 2021). However, the concept has not been widely applied to the water industry as a way to assess DWDS performance other than in reference to corrosion scales in pipes serving as a source or sink of various organic and inorganic contaminants (Rushing *et al.* 2003; McFadden *et al.* 2011; Benson *et al.* 2012; Sun *et al.* 2017).

By applying the concept of sink or source to the process of material accumulation and mobilisation in SRs, this research develops an innovative metric to facilitate assessment and quantification of SR performance and hence its effect on water quality. Through application to real-world examples, the paper evidences how the application of this concept was able to provide information on changes in SR performance over time and how this helped inform proactive management.

2. METHODS

The 'sink or source' concept was applied to quantify the processes of material accumulation and mobilisation occurring within SRs. This needs to be applied to continuous turbidity data collected at both the inlet and outlet of SRs. The resulting metric can be used to assess and quantify SR performance.

2.1. Assessing and quantifying SR performance in terms of sink or source of material

SR performance with respect to sink or source behaviour of material is defined as follows. If more material enters than leaves an SR, it can be considered to be acting as a 'sink' as entrained material is removed and therefore outgoing water quality is improved. Conversely, if more material leaves than enters an SR, it can be considered to be acting as a 'source' by contributing to material loading entering the downstream network.

Turbidity was used as a surrogate measure for material loading as it is a primary indicator of suspended particles in water. Online monitoring at the inlet and outlet of SRs has the potential to provide information about real-time changes in SR performance with respect to accumulation and mobilisation of material, but changes are often subtle and hard to assess visually in large volumes of data, an example of which can be seen in Figure 1.

To move beyond simple visual interpretations of raw data, a performance SR (PSR) metric was developed to quantify performance using a moving average of SR net material accumulation and is calculated using Equation (1).

$$\overline{\mathrm{P}_{\mathrm{SR}_n}} = \frac{1}{n}\sum_{i=1}^{n}(M_{l,\,\mathrm{OUTLET},\,t=i} - M_{l,\,\mathrm{INLET},\,t=i}) \quad (1)$$

where Ml is material loading as NTU (nephelometric turbidity unit), t is time, n is the number of time steps in the observation time window, and PSR is the SR performance. A PSR >0 means that the SR is performing as a source, a PSR <0 means that the SR is performing as a sink, and a value of PSR $=0$ is indeterminate. For simplicity, the metric is calculated using the inlet and outlet turbidity values at the same time step.

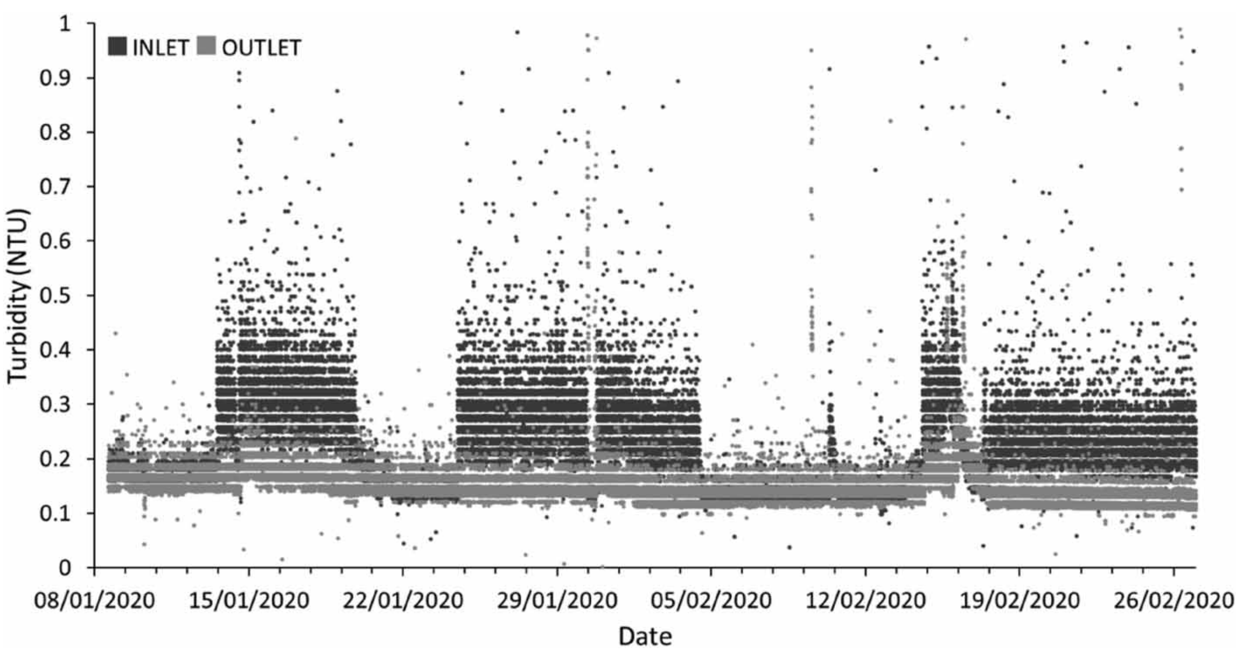


Figure 1 | An example of variability in raw online turbidity data at the inlet and outlet of a project SR.

The intended use of the metric was to assess the general trend in SR performance over time and not be unduly influenced by short-term changes in normal operating flow regimes (e.g., daily fluctuations related to diurnal demand patterns). To enable this, the length of the observation time window (n) needed to be long enough to smooth over changes in performance in response to normal daily operation but not so long that it was no longer sensitive enough to capture fluctuations in performance related to other factors, such as operational events outside of normal operation. In addition, the moving average time window needed to be at least of the order of the residence time of selected SRs to account for retention time effects.

2.2. Project field site selection

Field data were essential to prove the metric. Three SR sites were selected from three UK water companies for examination based on (1) having a consistent source water and treatment; (2) being completely post treatment; (3) having separate inlet and outlet pipes; and (4) either having a pre-existing accessible inlet and outlet sampling line and tap or having the scope for installation. Table 1 provides summary information about the three selected SRs: A, B, and C.

2.3. Data collection

The UK regulatory requirement for SR monitoring only requires sampling at the outlet so there was no suitable inlet sampling location at the selected sites. Therefore, inlet sample lines and taps were installed by the participating utilities at each site.

To capture real-time changes in water quality, a continuous sampling programme for turbidity was established at the SRs through the installation of online turbidity monitors at the inlet and outlet of each site. ATi MetriNet water quality monitors were installed at SR A as this site had its own power supply and suitable space for connections. The functioning range of the monitors was 0–40.00 NTU, with readings set to log at a 1-min frequency, an accuracy of $\pm 1\%$ of reading, and sensitivity of $\pm 0.1\%$ (ATi 2023a). Data were collected across a period of 18 months at the outlet of SR A and across two time periods of 5 and 4 months, with a time interval of 3 months in-between, at the inlet of SR A. With no accessible power supply, battery-run ATi NephNet turbidity monitors (ATi 2023a) with infrared nephelometric measurement processing were installed at SRs B and C. The NephNets were set to log at a 1-min frequency, with logger functioning range set to 0–20.00 NTU at an accuracy of

Table 1 | Summary information about project SRs

SR	Geometry and material	Volume (ML)	Height (m)	Average retention time (hours)	Inlet pipe (direct upstream main) length, diameter (inches), and material	Source water	Secondary and on-site disinfectant (where applicable)	Last inspected and cleaned
A	Overground Donut shape One compartment No columns Coated concrete	0.9	6	26.8	Length: ~10.1 km 11" PE (62.86%) 10" PVC (27.46%) 9.8" DI (9.64%) 7" CI (0.04%)	Ground: blended from six boreholes in a chalk aquifer Very hard water	Secondary: Chlorine	March 2018
B	Underground Rectangular Twin compartment 24 columns (12 per compartment) Reinforced concrete	4.8	5.3	41.3	Length: 50 km 44" ST for 22 km down to 18" unlined CI for 28 km	Surface (highland reservoir) Soft water	Secondary: Chlorine On site: Chlorine (dosed at the inlet)	June/July 2018
C	Underground Rectangular Twin compartment 24 columns (12 per compartment) Reinforced concrete with a brick dividing wall	9.1	5.4	28.1	Length: 0.223 km 23.6" DI cement lined	Surface (reservoir) Soft water	Secondary: Chlorine On site: Ultraviolet irradiation (dosed at the inlet)	March 2019: South comp. August 2019: North comp.

$\pm 5\%$ of reading or ± 0.02 NTU, whichever is greater and sensitivity of $\pm 0.1\%$. Data were collected across five separate time periods, which equated to a total of 7.5 months of continuous turbidity data at the inlet and outlet of SR B. At SR C, data were collected across two separate time periods, which equated to a total of 3 months of continuous turbidity data at the inlet and outlet. Gaps in data collection were related to requirements for regular maintenance of the monitors, which resulted in them being taken offline at various times.

To identify whether the difference between continuous turbidity values at the inlet and outlet of project SRs was related to genuine water quality changes with travel through the SRs or due to chance, parametric (*t*-test/Welch *t*-test) or non-parametric (Wilcoxon signed-rank test/Wilcoxon–Mann–Whitney *U* test) statistical tests were conducted on the data, as appropriate.

3. RESULTS

3.1. Metric window

Several moving average time windows were tested to establish which would be the most appropriate. Figure 2 shows the output of 10 moving averages applied to 6 weeks of online turbidity data collected under normal operating conditions at one of the SRs. Using a time window of less than 24 h (Figure 2(a)), data are highly variable, and the moving average windows are too short to smooth over the effect of changes in performance related to diurnal demand patterns, making it difficult to see genuine SR performance. The 36- and 48-h moving averages (Figure 2(b)) are still quite variable and do not account for the highest average retention time of the SRs, which is estimated to be 41 h (Table 1) under fully mixed conditions (that are not considered likely, so likely an underestimate). Moving averages of a week or longer (Figure 2(d)) tend to mask subtle changes in SR behaviour and also would require longer periods of data collection to obtain an understanding of asset performance. The 72- and 96-h moving averages (Figure 2(c)) both meet the criteria for the intended usage of the metric, and both produce similar results. The 96-h window was chosen over the 72-h one to allow for a longer tail of retention time effects in poorly mixed SRs.

3.2. Real-world applications

Figures 3–5 present results from the application of the performance metric to continuous turbidity data collected at the three SRs.

SR A performance data (Figure 3) is split into two time periods of continuous turbidity data across 2019 and 2020, covering cold weather (October 2019 to February 2020) as well as warm weather operating conditions (June to August 2020). It is a groundwater site (Table 1), which generally has stable water quality in the DWDS (assessed from low concentration values and little change in regulatory sample data, including low total organic carbon (TOC) in final water). This stability is reflected in the largely unvarying SR net material accumulation, sink behaviour, across a year. The performance metric tentatively reveals a seasonal temperature effect, whereby the SR is acting more like a sink in warmer months. The average performance value of this SR was −0.054 NTU across a time period of 11 months. The differences in turbidity at the inlet and outlet of SR A were statistically significant at a *p*-value of 2.2×10^{-16}, which suggests that the observed changes are unlikely to have resulted by chance.

SR B performance (Figure 4) shows five periods of continuous turbidity data across 2019 and 2020. The performance metric values show that the SR was initially a sink, becomes a slight source or shows neutral behaviour, and then in the final period becomes a source of material. The initial sink behaviour is expected as the SR had been cleaned only a year prior. It was unexpected that the SR would become a source of material after only 24 months from cleaning. Subsequent investigation by the water utility established that the upstream 50 km trunk main, of which 28 km is unlined cast iron, is a likely source of material accelerating loading into this SR and hence the rapid accumulation of material leading to saturation and hence change from sink to source. The water utility has subsequently undertaken proactive management measures to flow condition (Husband & Boxall 2016) to remove some of the accumulated material within it and change its loading behaviour (Sunny *et al.* 2020). The average performance value of this SR was 0.038 NTU across a time period of 13 months. The differences in turbidity at the inlet and outlet of SR B were statistically significant ($p = 2.2 \times 10^{-16}$).

The performance of SR C (Figure 5) covers two periods. This SR has two compartments that were individually cleaned in March and August 2019 (Table 1). The PSR metric captures the effect of cleaning the first compartment with a reduction in source behaviour and then cleaning the second with a further reduction, to then become a sink. The second data period shows that this sink behaviour is maintained ~6 months later. The variations observed in SR performance during the second time

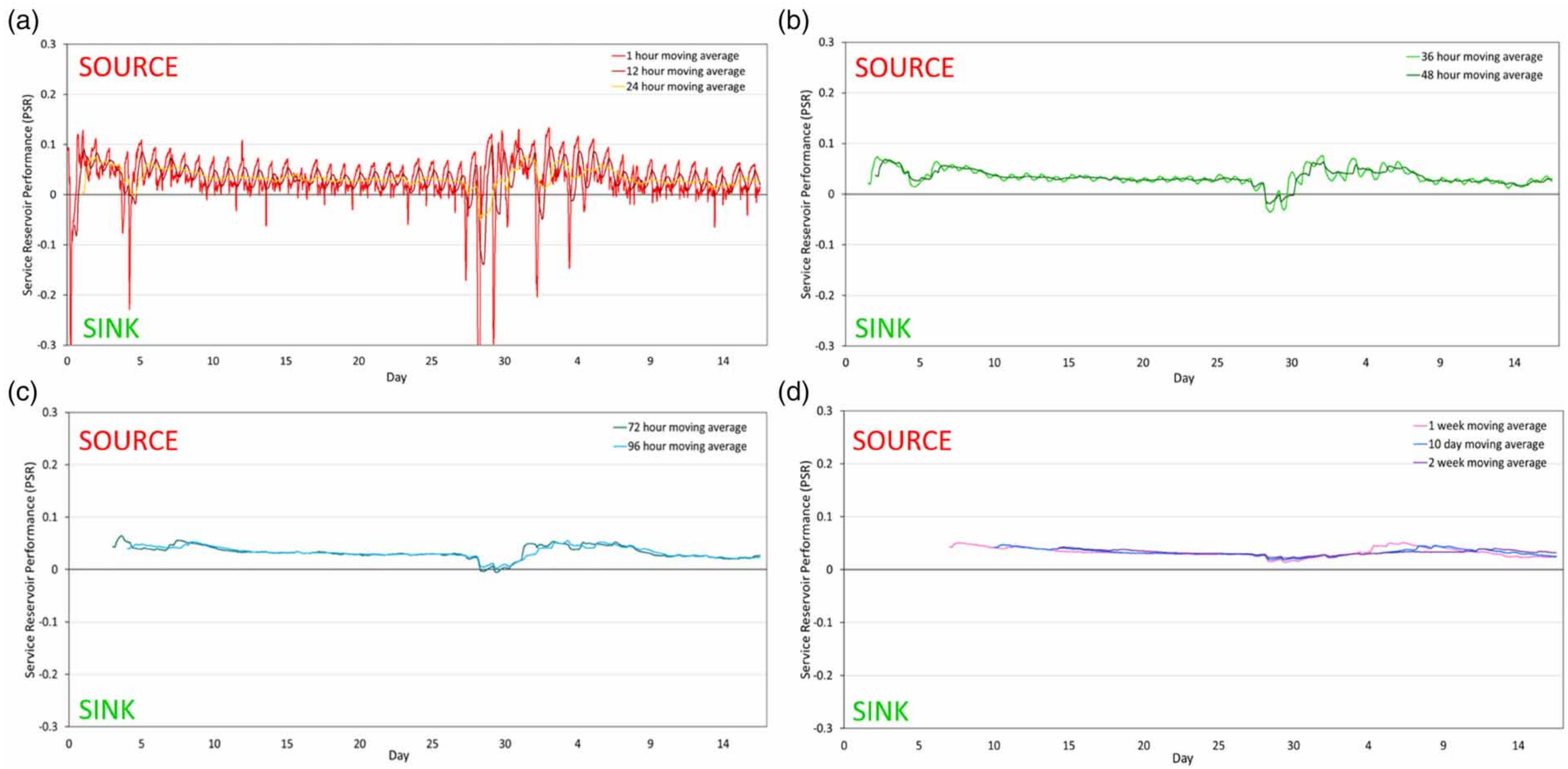


Figure 2 | Examples of various moving average periods ran on 6 weeks of online turbidity data, expressed as PSR metric (Equation (1)). Moving average periods: (a) 1, 12, and 24 h; (b) 36 and 48 h; (c) 72 and 96 h; and (d) 1 week, 10 days, and 2 weeks.

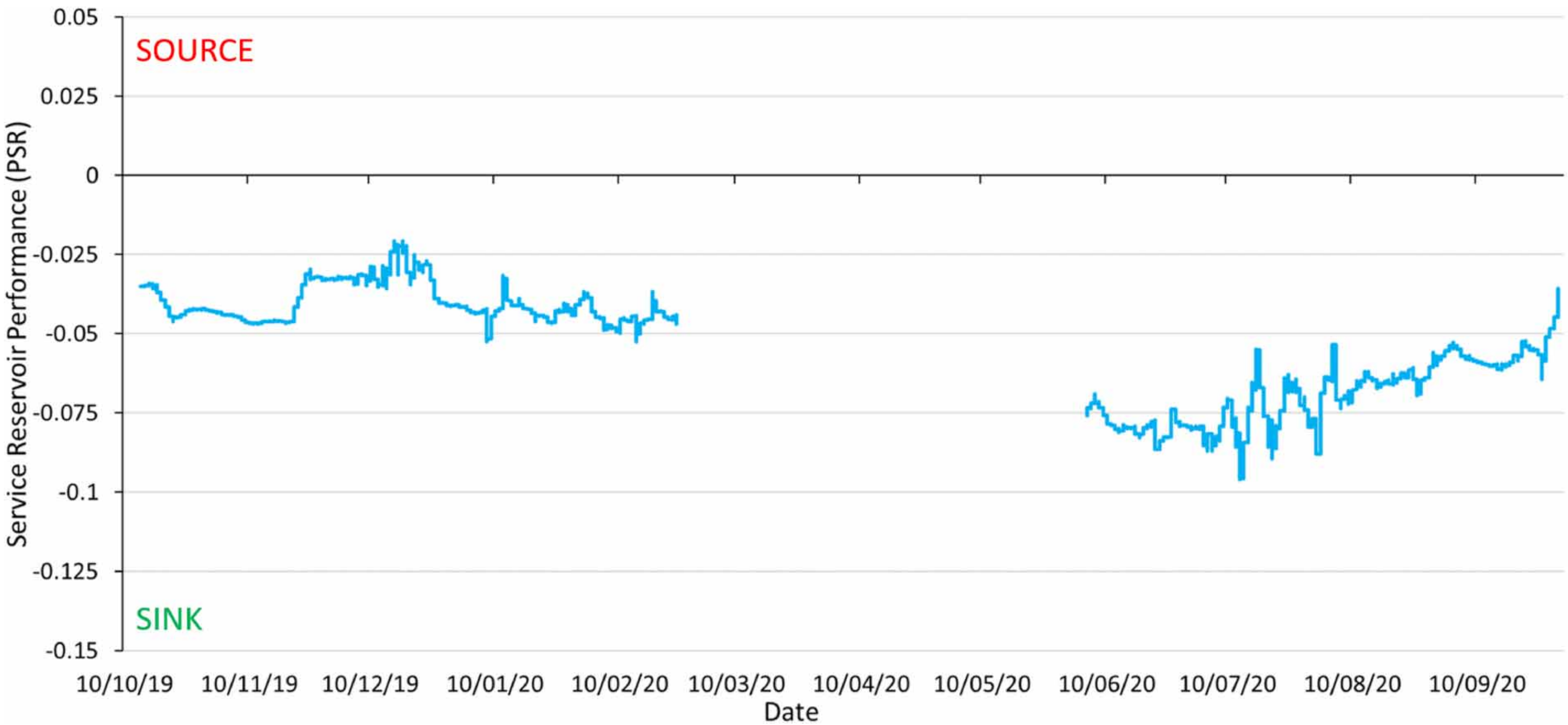


Figure 3 | Two time periods of calculated sink–source performance for SR A based on data from October 2019 to September 2020.

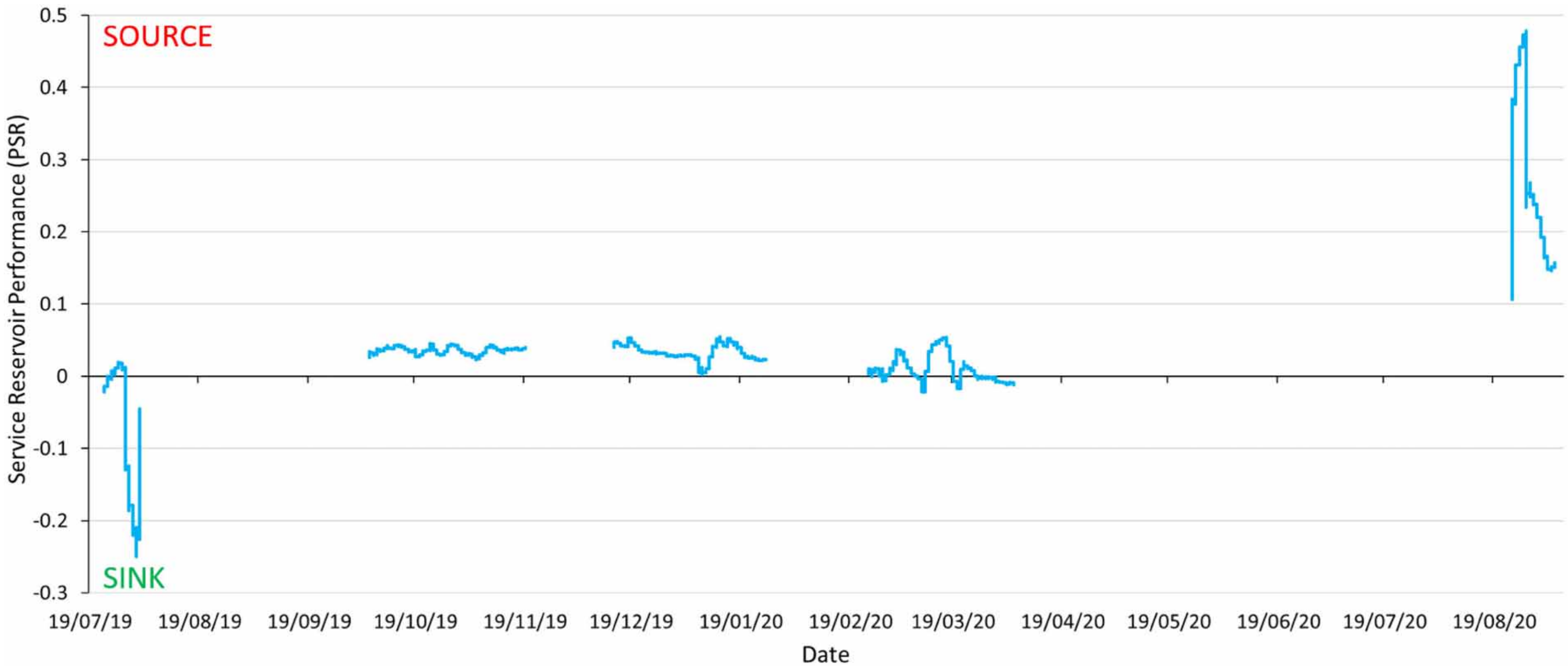


Figure 4 | Five time periods of calculated sink–source performance for SR B using data from July 2019 to August 2020.

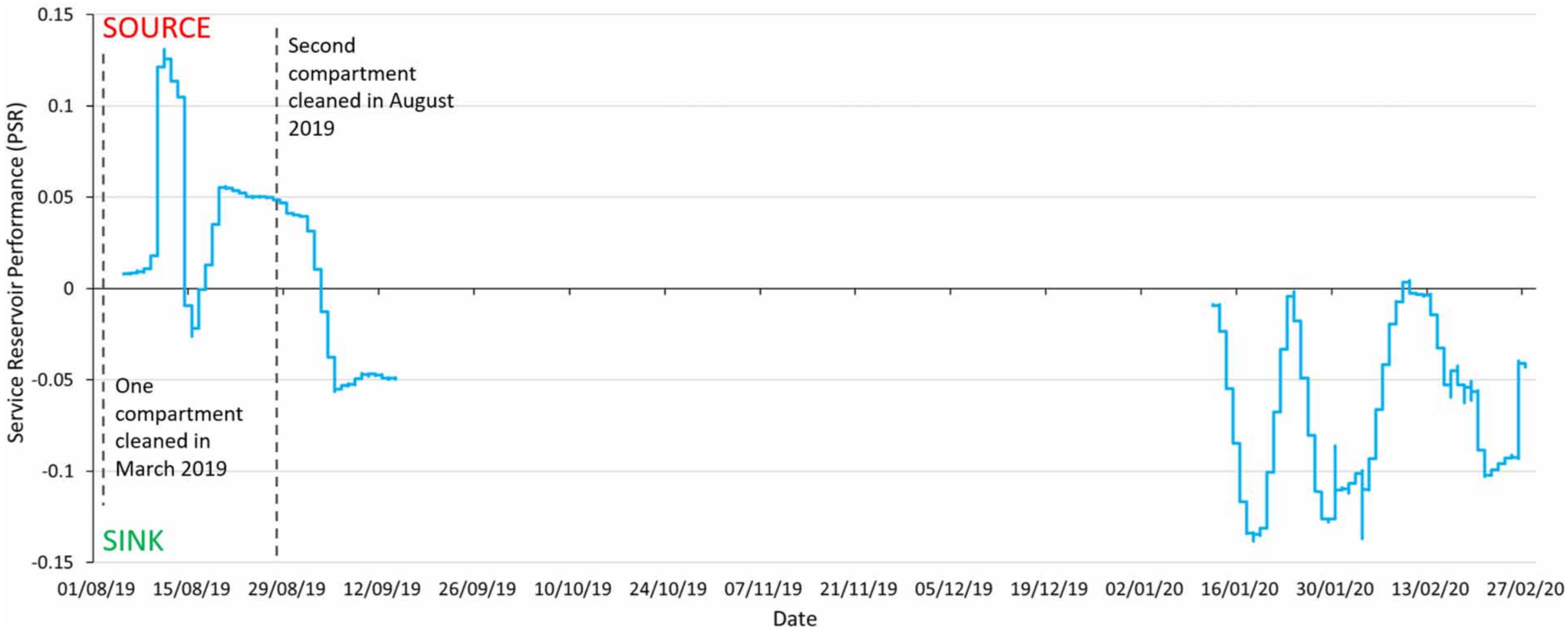


Figure 5 | Two time periods of calculated sink–source performance for SR C using data from August 2019 to February 2020. Note that the two compartments within SR C were individually cleaned during this time, as labelled.

period were considered to be unusual and were subsequently investigated. This investigation revealed that the supplying WTW was experiencing problems with dosing equipment and had been overdosing lime at intervals. Determining the SR performance alerted the water company to this issue, allowing repair and direct savings through reduced lime dosing while also showing how SR C was buffering this incoming material. This buffering, however, has consequences in that the mobilisation risk from this SR increases while the required interval between cleaning is reduced. These outcomes would not have been possible with outlet monitoring alone. The average performance value of this SR was −0.029 NTU across a time period of 7 months. The differences in turbidity at the inlet and outlet of SR C were also statistically significant ($p = 2.2 \times 10^{-16}$).

Applying the metric to turbidity data revealed information about asset performance not apparent in raw data. For example, data in Figure 1 corresponds to the second time period of collected data for SR C (Figure 5), where the difference in the value obtained from applying the metric can clearly be seen between the two figures.

4. DISCUSSION

In this study, we developed and demonstrated the application of the sink or source concept for SRs, providing a novel and effective way to assess and quantify their performance. Describing system performance in terms of sink or source behaviour has been shown to be valuable in other disciplines. As with these other disciplines, the SR interpretation of sink–source behaviour is that sink behaviour is generally considered beneficial (e.g., carbon sequestration; Oechel *et al.* 1993) and source behaviour detrimental (e.g., nutrient input into rivers; Ma *et al.* 2021). The SR interpretation is that sink behaviour shows net accumulation of material within the SR, leading to a reduction in downstream chronic loading, and hence improvement to water quality. Sink behaviour is unlikely to continue indefinitely as there will be some point at which the capacity of the SR is reached. At this stage, the behaviour will switch to either neutral, simply passing material through with little or no change, or potentially to source behaviour when the SR is effectively contributing material. Such source behaviour may be sporadic and/or observed over a shorter period, for example, if it is related to a response to hydraulic changes such as increased throughput due to changing demands. The PSR metric developed here has been shown to provide valuable insight to inform this change in behaviour.

Accumulated material in SRs is not necessarily harmful, but it can present a mobilisation risk potentially leading to discolouration contacts, elevated concentrations of metals, etc. It is therefore desirable to periodically clean SRs, removing material and reducing such risks. Applying the metric to data collected from SR C (Figure 5) clearly showed the benefits of invasive cleaning, changing the PSR from source to sink. Thus, the metric has demonstrated ability to help inform both the need for cleaning and the efficacy of the intervention. It is interesting to speculate if perhaps some of the cleaning benefit observed at SR C could have been achieved with less invasive methods, such as those based on carefully managed hydraulic changes to effectively have a similar effect as flow conditioning in trunk mains (Husband & Boxall 2016). Carefully managed hydraulic change in the SR could mobilise small amounts of material within safe limits, making accumulation capacity available and moving towards sink behaviour. Such changes could include drawing down or cycling of the level in the SR, or increased throughput. As with flow conditioning, careful planning, monitoring, and control would be needed to ensure that water quality passed forward was within regulatory limits. The implementation of this approach would require a good understanding and modelling of mobilisation processes from within SRs that we do not currently have but the PSR is one step towards that capability. It may be perceived that such in-service cleaning and passing material forward, moves and increases the water quality risks further into the DWDS. However, Sunny *et al.* (2020) provided evidence that such acute loading has very little downstream impact and is readily outweighed by benefits from reduced chronic loading.

A simplification made for the proposed PSR metric is that it compares values at the inlet and outlet at the same point in time, ignoring the retention time of the SR. The 96-h moving average smoothed out some of the effects of SR retention time. However, a more accurate representation of SR performance could potentially be obtained by shifting the outlet values in accordance with retention time. However, retention time is not constant and is not easily measured so the selected simplification allows for the metric to be widely implemented. Future research may find that an SR-specific customised retention time estimation improves the SR performance metric calculation. However, simply dividing average throughput by SR volume is unlikely to yield a usable estimate of SR residence time as poor mixing effects, such as short circuiting, are known to be common. It is interesting to note that suitable information about SR-effective residence time could potentially be obtained from inlet and outlet time series data, as was done for network travel times in the study by Gleeson *et al.* (2023). There were insufficient repeating patterns in the turbidity data available to apply this technique in this research and parameters such as conductivity or chlorine are likely required as used by Gleeson *et al.* (2023).

A key enabler in this research was the inclusion of continuous inlet and outlet monitoring of SRs. Previous research has shown that monitoring water quality at both the inlet and outlet of SRs is vital to differentiate water quality impacts related to an SR from upstream infrastructure (Doronina *et al.* 2020). This previous work was mainly based on discrete sample data. The additional advantages of moving to continuous monitoring at the inlet and outlet demonstrated here is to quantify performance of the SR and to track this over time. Furthermore, a simple surrogate measure like turbidity was sufficient to produce actionable results; more sophisticated monitoring of chlorine or other parameters was not required. The results also demonstrate that permanent implementation of continuous monitoring equipment was not necessary to obtain meaningful SR performance assessment; rather a few weeks of continuous turbidity data collected periodically, perhaps every few months, were sufficient to reveal changes in SR performance. Such short deployment periods should enable the collection of good quality data, with little time for instrumentation fouling or drift. The types of turbidity instrumentation suitable, and as deployed here, are often communications enabled, which coupled with the simplicity of the metric calculation readily enables it to be an online, near real-time metric to inform and enable effective proactive management.

5. CONCLUSIONS

This research has contributed a novel sink/source metric that quantifies SR performance and its effect on water quality.

- A sink or source concept has been successfully applied to drinking water SRs to describe performance in terms of material loading, where sink behaviour is an indication of good asset performance and source behaviour is an indication of deterioration in asset performance.
- A metric was developed to assess and quantify sink and source behaviour in SRs using continuous inlet and outlet turbidity data.
- Applying the metric revealed changing and seasonal SR performance trends and evidenced the effectiveness of asset maintenance in improving SR performance.
- SRs can have both a beneficial and negative impacts on water quality.
- The ability to assess SR performance over time and identify sources of deterioration makes it possible for water utilities to make proactive, justifiable, and targeted decisions on the location and frequency of network maintenance and management.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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