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Influence of Service Reservoir Construction Age on the Likelihood of Bacteriological Failure Occurrence

A.V. Doronina[a], S. P. Husband[b], J. B. Boxall[b], and V. L. Speight[b]

[a]Panton McLeod, Unit 4B, Tweed Mills, Dunsdale Road, Selkirk, TD7 5DZ

[b]Department of Civil and Structural Engineering, The University of Sheffield, Sheffield, S1 3JD, UK

Abstract

Service reservoirs (SRs) are crucial components in drinking water distribution systems (DWDSs). These assets are often associated with water quality issues, including significant waterborne disease outbreaks. To ensure safety of supply, monitoring is conducted at SR outlets for disinfectant residual and bacteriological indicators. Older SRs are often believed to be a source of bacteriological failures as old or poorly constructed SRs can be prone to structural issues, which can lead to ingress and contamination of the stored water. However, there is a lack of evidence to support the existence of a genuine relationship between SR age and risk of failure. In this study, historical bacteriological failure data at SR outlets and company-wide SR construction age data collected from three large UK water utilities was used to assess the potential relationship between the duration of time a SR has been in service and the likelihood of bacteriological failure. Findings showed that there was no relationship between the two parameters. Analysis also revealed instances where newer SRs, no older than twenty years old, experienced one or more bacteriological failures, challenging the ingrained association that older SRs are at a higher risk of ingress and bacteriological contamination.

Keywords

Service reservoir, water quality, bacteriological failures, construction age, contamination, risk

Introduction

Service reservoirs (SRs) store treated water and balance supply to continuously meet demands in the drinking water distribution system (DWDS); they are crucial and integral components of the system.

SRs have been documented to have an effect on water quality, with associated problems ranging from the degradation of disinfectant residual to significant waterborne disease outbreaks, which have resulted in serious illness and even death (Craun and Calderon, 2001). For example, a 1993 *Salmonella typhimurium* outbreak in Gideon, Missouri, which stemmed from a SR, resulted in 15 hospitalisations, and 7 deaths (Clark et al., 1996).

To ensure the safety of supply and to assess SR performance, water utilities in the UK are required to monitor water quality at the outlet of SRs on a weekly basis (DWI, 2018). The water quality parameters stipulated by regulation to be monitored at SR outlets are disinfectant residual and bacteriological indicators (DWI, 2018). The current UK SR monitoring programme is considered good practice in comparison to other countries, like the US, where there is no specific regulatory requirement for routine sampling at SRs at all, although some utilities still carry out sampling at SRs (Kirmeyer et al., 1999). However, the lack of inlet monitoring at SRs in the UK makes it difficult to attribute any observed changes in water quality directly to the SR, as it lies between the previous upstream sampling point and the outlet. One study found that over 66% of bacteriological failures in water quality samples collected at SR outlets in the UK have not been directly attributed to the SR (UKWIR, 2019), potentially because the source of failure was actually upstream of the asset. It can be argued that to successfully assess SR performance, pinpoint the location of water quality problems, predict and prevent potential future issues, and avoid costly repeat errors, routine sampling at SRs should include both inlet and outlet monitoring (Kirmeyer et al., 1999; UKWIR, 2019; Doronina et al., 2020).

There is an assumption in the water industry that the likelihood of occurrence of bacteriological failures is higher in older SRs. Old or poorly constructed SRs can be prone to structural issues, which can lead to ingress and contamination of the stored water with pollutants and bacteria (Craun and Calderton, 2001; Brandt et al., 2016). For example, a *Salmonella* outbreak in Alamosa, Colorado, which resulted in 434 cases, 20 hospitalisations, and 1 death, was linked to animal contamination of a SR that had numerous cracks and inadequately protected entry points (Ailes et al., 2013). Washouts, drainage, overflows, and access hatches in particular present a high contamination risk as they are exposed to the outside environment (DWI, 2018). Protective entry mesh and sealants can become damaged through excessive hydrostatic pressure, corrosion, poor workmanship, age related deterioration, and vermin (UKWIR, 2019). Ensuring water tightness of the SR is difficult and SR components such as roof membranes and wall and floor joints are often the sources of ingress (Hope, 2016). Cracks can form in the walls, roof, and floor of concrete SRs as a result of structural and operational defects like corrosion, thermal contraction, overloading, and poor construction (UKWIR, 2019). Some examples of the aforementioned issues and defects can be seen in Figure 1.

Figure 1 – A collection of photos showing some common issues seen in service reservoirs: A broken and corroded air vent (A), corrosion of internal structures (B), staining on walls and cracks in the roof (C), and ingress through the seam of an access hatch (D).

Despite the association of increased contamination risk with older SRs, there is a lack of evidence to suggest that there is a genuine relationship between the two. Although water quality deterioration is often associated with older and more stressed systems, problems also arise in new or recently improved ones (Brandt et al., 2016). Additionally, age does not always correlate with structural issues, which is evidenced by a significant number of SRs built in the 19th century that are still fully functional to this day.

Another, non-structural, cause for bacteriological failures in SRs can be related to the presence of bacteria in biofilm and SR accumulated material (LeChevallier and Au, 2002; Speight et al., 2008). Both processes are prevalent in SRs, primarily due to low velocities in these assets, which allow suspended material to settle and allow biofilm to grow undisturbed (Grayman and Kirmeyer, 2000). If regularly inspected and well maintained, many SRs will remain operational long after their original design life expiration, with limited water quality issues (UKWIR, 2019).

This paper presents results from a comparison analysis carried out on company-wide operational SR construction age data against the number of SRs with one or more bacteriological failures at the outlet. Analysis was conducted on data collected from three UK water utilities to assess whether there is a relationship between the duration of time a SR has been in service against the likelihood of it experiencing a bacteriological failure, to test the hypothesis that older SRs are more likely to fail. Results provide a quantifiable measure of the relationship between asset age and risk of bacteriological contamination.

Methods

Historical data for bacteriological failures at SR outlets between 2012-2018, alongside company-wide data on the construction age of operational SRs, was collected from three large UK water utilities and used to assess the potential relationship between the duration of time a SR has been in service against the likelihood of it experiencing a bacteriological failure. Table 1 presents the raw data used for analysis, showing the number of operational SRs categorised by construction age and the quantity of those SRs that had one or more identified bacteriological failures between 2012 to 2018. The water utilities are located across various geographical regions of the country, with data from Company B split into two categories (1 and 2) as there are two distinct geographical regions covered by this utility, with highly varying topographies. Some SRs were without a known construction age and were omitted from the analysis. The biggest omittance was for Company C, with 654 SRs out of which 466 experienced one or more failures, followed by 15 SRs for Company B with 8 experiencing one of more failures (across both regions), and 5 SRs for Company A (Table 1).

Table 1 – Operational service reservoir data, 2012 to 2018

Year built	Number of operational service reservoirs					No. of service reservoirs with 1≥ bacteriological failures 2012-2018				
	Company A	Company B (1)	Company B (2)	Company C	Total	Company A	Company B (1)	Company B (2)	Company C	Total
1841-1850	NA	NA	NA	2	**2**	NA	NA	NA	0	**0**
1851-1860	NA	1	0	NA	**1**	NA	0	0	NA	**0**
1861-1870	NA	1	0	1	**2**	NA	1	0	0	**1**
1871-1880	2	0	1	1	**4**	0	0	1	1	**2**
1881-1890	2	2	1	3	**8**	0	0	1	1	**2**
1891-1900	3	4	1	2	**10**	1	2	0	1	**4**
1901-1910	11	1	0	9	**21**	0	0	0	1	**1**
1911-1920	3	7	0	5	**15**	0	3	0	0	**3**
1921-1930	11	5	7	14	**37**	1	1	3	3	**8**
1931-1940	22	8	11	19	**60**	3	2	1	6	**12**
1941-1950	23	15	4	54	**96**	0	6	1	13	**20**
1951-1960	99	33	21	154	**307**	11	8	2	26	**47**
1961-1970	79	45	27	179	**330**	11	20	8	50	**89**
1971-1980	31	32	6	106	**175**	5	13	1	30	**49**
1981-1990	16	20	5	87	**128**	3	12	2	27	**44**
1991-2000	11	18	6	128	**163**	1	10	3	30	**44**
2001-2010	3	5	6	46	**60**	1	0	0	7	**8**
2011+	1	1	0	NA	**2**	0	1	0	NA	**1**
Total	**317**	**198**	**96**	**810**		**37**	**79**	**23**	**196**	
No known construction age	5	13	2	654		0	6	2	466	

Results

Figure 2 shows the percentage of operational service reservoirs with a known construction age that had one or more bacteriological failures at the outlet between 2012-2018 for data collected from three water utilities.

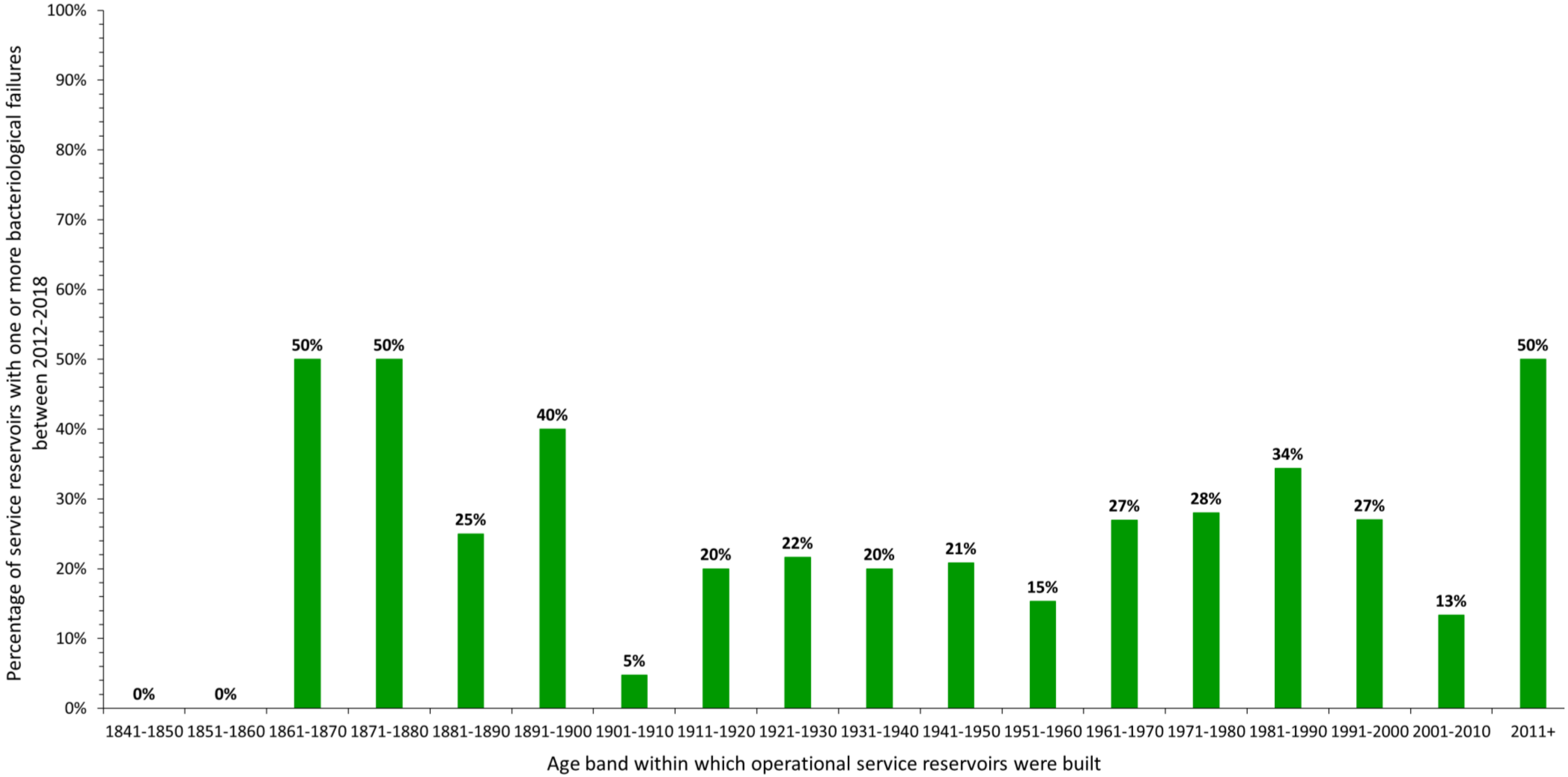

Figure 2 – The percentage of operational service reservoirs with one or more bacteriological failures at the outlet between 2012-2018

Results in Figure 2 show that a number of failures have occurred in most SR age bands, with no clear trends in the relationship between the duration of time an operational SR (with a known construction age) has been in service and the occurrence of bacteriological failures. It is important to highlight that there were some operational SRs that experienced one or more bacteriological failures between 2012-2018, but as they were without a known construction age, they were not included in the analysis above. For Company C data, the inclusion of these SRs could affect observations made in Figure 2, as the number of Company C SRs without a known age was 654, out of which 466 had experienced a bacteriological failure between 2012-2018. However, the inclusion of this data for Company B (both regions) is unlikely to influence above observations as there were only 2 SRs in region 2 and 13 in region 1, out of which 2 and 6 experienced bacteriological failures respectively. Company A had only 5 SRs without a known age, none of which has experienced a bacteriological failure between 2012-2018 (Table 1).

Also of interest is that records show only 4% of operational SRs with a known construction age are older than 100 years old and it is likely that many older SRs are no longer in operation or have been rebuilt (Table 1). Based on the data collected for this study, it appears that there was either an increase in construction of SRs or improved record keeping from the 1950's onwards, predominantly between 1950's to 1970's for the studied water utilities (Table 1). This observation is supported by UKWIR (2019), who highlight that there is a peak in the number of SRs constructed between 1950 and 1980, with nearly 60% of those currently in operation constructed by 1970.

Discussion and Conclusions

In this study, the association between older SRs and the increased likelihood of them experiencing a bacteriological failure was assessed. The analysis showed that there was no relationship between the duration of time an operational SR has been in service and the occurrence of bacteriological failures (Figure 2). Analysis also revealed instances where newer SRs, no older than 20 years old, had experienced one or more bacteriological failures. A similar observation was made in a 2016 assessment of bacteriological failure rates in Severn Trent SRs, which uncovered that the highest probability of failure occurs at SRs an average 28 years after construction (Hope, 2016).

A limitation in the study data used was that some operational SRs that had experienced a bacteriological failure did not have a known construction age, inclusion of which could have altered some of the results. Nevertheless, results indicating that SR age does not link directly to bacteriological failure occurrence were in agreement across data from all water utilities in this project.

In industry, the ingrained association of older SRs with ingress and risk of bacteriological contamination could be a consequence of most bacteriological failures being detected at SR outlets. For example, in 2020, there were 112 bacteriological failures at SR outlets, in comparison to 77 at WTW outlets and 15 at customer taps in England (DWI, 2020). At present, SR outlets are a convenient sampling point for bacteriological indicators in the DWDS but just because a failure is identified at the SR outlet, it does not necessarily mean that the root cause of the issue is the SR itself as opposed to the upstream network. Additionally, the source of bacteriological failure in SRs may not be related to the structural condition of the asset, but to other processes that can exacerbate bacteriological growth, such as the presence of biofilm and accumulated material.

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Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

A. V. Doronina http://orcid.org/0000-0001-9240-1992

S. P. Husband https://orcid.org/0000-0002-2771-1166

J. B. Boxall http://orcid.org/0000-0002-4681-6895

V. L. Speight http://orcid.org/0000-0001-7780-7863

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