GIG CYMRU NHS WALES
Iechyd Cyhoeddus Cymru
Public Health Wales

Understanding the health risks and harms associated with using private water supplies in Wales, in the context of a changing climate.

A rapid review of evidence to inform Public Health Wales policy and action

Version 2.0

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Version	Date	Revision lead by: -	Reason for update
Version 1.0	November 2024	Consultation version for Water Health Partnership for Wales	
Version 2.0	April 2026	Kristian James, Principal Environmental Public Health Specialist Public Health Wales	To incorporate changers to DWI online advice on Reg 16 and DWI role in Wales.

Executive Summary

In keeping with both the Well-being of Future Generations Act and the United Nations Sustainable Development Goals, everyone in Wales should have equal access to clean, safe and sustainable water and sanitation. For many people in Wales, access to this water is through a private water supply.

Although the exact number of users of PWS in Wales is unknown, data suggest that around 2% of the population (over 64,000 individuals) in Wales use a private supply. This is likely to be an underestimate and, in some areas of Wales, up to 43% of properties are dependent on private water supplies (PWS). An unknown number of people may also be using a PWS on a temporary basis, for example through holiday accommodation.

This rapid evidence review aimed to inform the future work of Public Health Wales (PHW), by supporting our understanding about the health risks and harms associated with using PWS in Wales and, importantly, whether these affect our population equally.

This rapid review has identified significant limitations in the available evidence on PWS and their users in Wales. Under the current regulatory system, we cannot definitively identify how many people in Wales use PWS; the exact location of these PWS; their underlying geology and water source; or any demographic characteristics or vulnerabilities of users. This review has also identified very limited available research evidence about the health risks and harms associated with the use of PWS in the UK, with even less evidence from Wales, including on the perceptions of users.

The non-systematic methodology adopted for this review, as well as the limited quantity and quality of available evidence, impact our ability to accurately assess the health risks and harms of using PWS. However, despite these limitations, there is published research evidence, including from Wales, that PWS are at risk of both microbiological and chemical contamination. This evidence suggests that there is a greater risk of microbiological contamination than in public water supplies. DWI records also show that there are a considerable number of PWS that are not being regularly tested or risk assessed to identify or prevent this contamination. There is also very limited evidence, from health protection records, which suggest that there have been some health harms associated with the use

of PWS in Wales, including for children. These data are likely to represent an underestimate of the health risks and harms that PWS users in Wales may have experienced.

Although the full geographical distribution of PWS users still needs to be identified, available evidence shows that more rural communities are more likely to be using PWS than urban communities and are therefore more at risk of any associated health harms. Limited evidence also suggests that young children may be more at risk of illness from microbiological contamination of PWS. There is insufficient evidence available to support greater understanding of potential inequalities related to gender, socio-economic status, or ethnicity. However, costs associated with testing and maintaining PWS have the potential to create health inequalities related to users' economic ability to maintain a clean and plentiful supply.

This review has also found that there is some evidence from the published literature that transient users of PWS may be more at risk of health harms from the use of contaminated PWS. This may also be of particular concern for users who are more vulnerable e.g., pregnant women, younger children, or immunocompromised individuals. PWS in Wales are known to supply some properties that are used by transient populations, for example holiday accommodation. Currently, these temporary users may be unaware that the water they are drinking is from a private supply.

Finally, this rapid review has identified limited evidence on how climate change may impact the quality and quantity of water from PWS in Wales, through increased rainfall events and periods of drought. These could lead to greater levels of contamination and insufficiency of supply, which, in turn, have the potential to affect the physical and mental health and wellbeing of PWS users.

During the development of this review, it has also become evident that information for the public in Wales on PWS is currently limited and difficult to find. The published evidence identified in this review, though limited, also supports PWS users' perception of a need for clearer and more easily accessible information on PWS.

In response to these, we have developed the following seven recommendations to further progress PHW's work on PWS:

Recommendation 1: PHW should advocate, to the Welsh Government and other partners in the Water Health Partnership, for the development of more accurate and complete records on PWS in Wales. This should include consideration of:

a. Whether any regulatory changes are needed to ensure information about all PWS in Wales are accurately collected, including on PWS location and risk assessments.

b. Any other approaches to increasing the number and accuracy of valid risk assessments completed and reported to the DWI, and to increasing the extent of other information that is collected by LAs. This should include enhanced information on vulnerability of supply e.g., previous episodes of insufficiency, any information on source of supply and underlying geology.

c. The use of data techniques or modelling, such as using water company records for locations not supplied with *public* water supplies, to identify likely locations of PWS.

Recommendation 2: PHW should scope options for understanding and modelling the risks and burden of disease from PWS, including systems for linking health outcome data with the use of PWS.

Recommendation 3: PHW should work with partners, through the Water Health Partnership, to consider development of mechanisms by which identification of an infection associated with a private water supply should trigger inspection, risk assessment or sampling of the supply, as appropriate.

Recommendation 4: PHW should recommend to Welsh Government that they consider whether further regulation is needed to ensure that owners of commercial PWS (e.g. holiday accommodation) make users aware if they are being served water from a PWS, so users can consider whether they need to take additional precautions to protect their health.

Recommendation 5: PHW should highlight to its partners (through work in the PHW Climate Change Programme Board, the Water Health Partnership, the Drought Liaison Group, and any other identified routes of advocacy) the likely vulnerability of PWS in Wales to the impacts of climate change, and the need for actions to adapt to and mitigate the effects of this.

Recommendation 6: PHW (including through the work of both its policy and health protection teams) should advocate, to Welsh Government, for consideration of regulatory changes so that PWS are included in processes related to building development, planning and sale of house regulations, in the same way that other services and utilities already are (e.g. sewerage).

Recommendation 7: PHW should support partners, through the Water Health Partnership, to develop high quality, easy-read and evidence-based information on PWS in Wales. In developing this work, multi-agency partners should consider examples of similar information available in the UK and consider qualitative evidence / behavioural analysis techniques to inform what information users need, and how it should be best presented to increase accessibility. At a minimum, it should include information on potential health risks and harms associated with using PWS; factors which may make PWS more vulnerable to contamination; and available sources of financial support.

Contents

Introduction

1. What is a private water supply?

A private water supply is 'any water supply which supplies one or more properties, that is not provided by a water company', (Dwr Cymru Welsh Water or Hafren Dyfdwy in Wales) (1). Private water supplies (PWS) are found across most regions of Wales but are more commonly found in rural areas, often where connection to the mains public supply is difficult or may even be impossible (1) (2). They serve both domestic properties and commercial premises, such as farms, bed and breakfast and other holiday accommodation, hotels, sports clubs, manufacturers, and other businesses (1). Individual PWS are supplied by different and sometimes mixed water sources, including groundwater sources (e.g., springs, wells and boreholes); surface waters (e.g., streams, ponds and lakes); and rainwater (e.g., rooftop and other catchment systems) (2).

2. Why this review is needed

The Drinking Water Inspectorate (DWI) reports that, in Wales in 2023, 64,187 people (approximately 2 %) of the population are served by PWS (1). In addition to regular users, other members of the public use water from PWS on a short-term or temporary basis through, for example, commercial and tourism sites (such as holiday homes). If PWS are not correctly installed or maintained, they can become contaminated (by microbes and / or chemicals), which can harm health.

To protect the public's health, it is important for us to understand **what health risks and potential harms there may be from using PWS, both for people who live in Wales as well as those who visit it.** We also need to understand **if these health risks or harms affect different parts of our population equally.** For example, some parts of the population of Wales may be more likely to use PWS and therefore be more *exposed* to these risks, and some people may be more *vulnerable* to any health harms. Finally, we need to understand **if the effects of climate change could alter any of the potential health risks and harms associated with using PWS in Wales.**

3. Aim of this rapid review

In response to these questions, we conducted a rapid review, with the following aims:

1. to identify what evidence sources are currently available to help us understand any health risks and harms from using PWS in Wales.
2. where we find evidence, to understand what this tells us about current health risks and harms, and any associated inequalities, and how these might be affected by a changing climate.

The findings of this review will be used to make recommendations so that Public Health Wales (PHW) can work, with partners, to support everyone in Wales to access enough clean and safe water to live healthily, now and in the future.

3. How was this rapid review completed?

The Environmental Public Health Team (EPHT) of the Health Protection Division of PHW led this review, bringing together expertise from other parts of PHW: the All Wales Acute Response Service (AWARe); the Communicable Disease Surveillance Centre (CDSC); Microbiology; and the Evidence Service. This review used evidence that was already available, either in the public domain or held by PHW as part of routine health protection / surveillance activities. In summary, the methods and data sources used were[1]:

1. **An agile (not systematic) scoping review of published literature on health risks and impacts of using PWS, and potential impacts related to climate change[2].** We searched the literature for evidence on any known health risks and impacts, as well as evidence on likely impacts from climate change. To be most relevant, the review focussed on evidence from Wales, UK or other European / Australian / North American countries, noting wider international literature where no other could be found. An initial scoping review found no robust secondary evidence (i.e. systematic reviews), so we then searched for primary studies. We

[1] Contact PHW for more detailed information on methods and data sources used.
[2] Full scoping review available at: publichealthwales.nhs.wales/services-and-teams/observatory/evidence/evidence-documents/private-water-supplies-agile-scope/

also looked for studies exploring views, perceptions, or experiences of users of PWS related to health. The search was not exhaustive and included a limited number of sources, however, it was supplemented by key documents and research already known to those working in PHW. We also made a limited assessment of the quality of identified evidence; however studies were not excluded on this basis.

2. Review of existing data, from three different sources:

a. The latest in a series of DWI annual reports: Drinking Water 2023 – Private water supplies in Wales (1), which compile data from local authorities (LAs) in Wales on PWS drinking water quality issues, testing, risk assessments and enforcement.
b. EPHT records of environmental (e.g. chemical contamination and insufficiency of supply) incidents and enquiries relating to PWS in Wales, 1st January 2018 – 31st December 2022. Of note, *these data do not reflect all environmental issues related to PWS in Wales,* as they only include incidents or enquiries where individuals and / or other organisations (e.g. Environmental Health Officers (EHOs) in LAs) contacted PHW for notification purposes and / or to ask for advice.
c. AWARe records of gastrointestinal (GI) infections where there was also recorded use of PWS prior to illness, 1st January 2018 – 31st December 2022. There are several limitations to these data. Of note, these data only include cases where healthcare professionals or laboratories notified PHW; in practice this is frequently after laboratory investigations have identified a notifiable organism. Additionally, identification of prior use of PWS in these cases was based on subjective (non-quality assessed) assessments of whether PWS may have been a possible source of infection, as recorded by a LA EHO or AWARe. Finally, whilst in the majority of cases PWS are likely to have been in Wales, from some available records, it is not possible to exclude that individuals may have used PWS elsewhere e.g. in England. Therefore, *these data do not represent all cases of disease in individuals who have used PWS in Wales and, even in identified cases, PWS may not have been the source of infection.*

Background to PWS in Wales

1. The number and location of PWS and their users in Wales

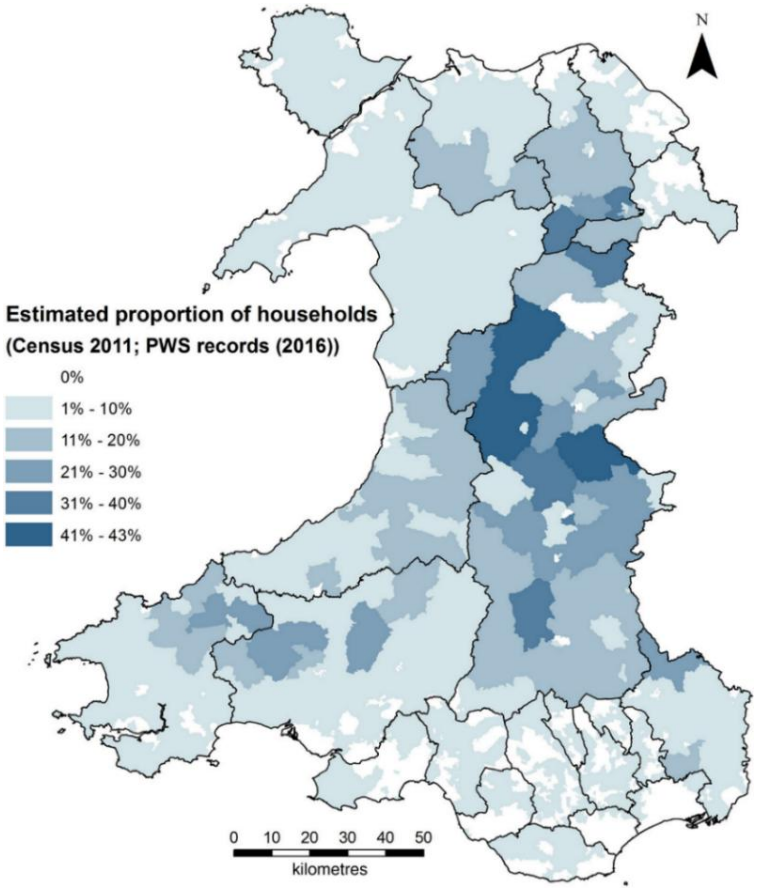
All PWS should be registered with LAs, and Regulation 16 requires each LA to maintain a record of all PWS in their area (3). LAs have a statutory duty to annually provide information relating to PWS to Welsh Government, and the DWI collates and reports this information on behalf of the Welsh Government, although this does not represent a 'public register' (3). Therefore, the most accurate, currently available information on PWS in Wales comes from LA records, as reported to and collated by the DWI.

From the latest information available, the DWI reports that, in 2023, 64,187 individuals (recorded as 75,442 in 2022 (4)), or approximately 2% of the population of Wales were served by PWS (1). In 2023, there were a reported 26,244 people living in single dwellings with PWS and 21,909 consumers served by large, commercial and public-use PWS (1). According to the DWI, LAs reported a total of 14,786 PWS in Wales in 2023 (1) (14,993 in 2022) (4).

However, there are recognised data quality issues with the information on PWS that LAs report, as evidenced, for example, by the considerable variation in the number of reported users of PWS in Wales annually (above) (1). Additionally, LA records may not include all PWS. This could be for a number of reasons, ranging from small, single-supply PWS that have not been reported to LAs, to larger PWS that are potentially being used illegally for distribution onwards without a licence. Finally, the number and distribution of PWS users may be affected by seasonality, notably for agriculture and tourism. This may, for example, increase the size of the population using PWS in holiday seasons. All these factors mean that it is very difficult to accurately assess the exact number of PWS and their users in Wales. Current figures are likely to represent an underestimate but, as is the case across the UK, the exact number, and location, of PWS and the number of people who use them in Wales is unknown.

Research from the British Geological Society (BGS) has added to our understanding of PWS locations by mapping LA DWI records to Lower Super Output Areas (LSOAs) in Wales (figure 1) (2). This has shown higher percentages of households using PWS in more rural areas, such as mid-Wales, with up to 43% of properties dependent on PWS in some areas (2).

Figure 1: estimated percentage of properties with PWS in Wales, per Lower Super Output Area level (2)



here is also some available evidence about the sources and geology underlying PWS, although there remains uncertainty, given that not all locations of PWS are known. Underlying source and geology are important because they may impact on quantity and quality (e.g. chemical composition) of supply to PWS. In 2023, the DWI reported that, based on available LA records, 31.73% of PWS in Wales are supplied by groundwater sources, 37.04% are surface water influenced, with 31.05% 'unknown' (1). However, in 2022, these were reported as 48.2% for groundwater, 50.2% for surface water and 0.43% for 'unknown', again highlighting uncertainties related to reported data (4). Additionally, BGS research has shown that 94% of all unlicensed (see regulation, below) potable PWS in Wales accounting for the vast majority of all PWS in Wales) were groundwater-sourced, and 97% of groundwater-sourced PWS are sourced from secondary aquifers, such as Ordovician and Silurian bedrock aquifers (2). Of note, these can have relatively low productivity and storage capacity and may be vulnerable to insufficiency in times of drought (2) (see also figure 9 below).

2. Regulation of PWS in Wales

The standards and requirements for drinking water are enacted in national regulations, with quality standards for PWS no different to those of public supplies (5). They are enforced in Wales through the Private Water Supplies (Wales) (Amendment) Regulations 2010 and The Private Water Supplies (Wales) Regulations 2017 (5), with LAs acting as regulators for this legislation. The DWI carries out a role on behalf of Welsh Ministers as a technical advisor to LAs in relation to the implementation of the regulations, including providing scientific advice, and, where needed, PHW provides them with public health advice. The approach to regulation of PWS is based on a number of factors, such as the number of dwellings the PWS serves, the amount of water used and whether it is used for commercial purposes (6). For small PWS serving a single owner-occupied dwelling there is no mandatory monitoring or risk assessment, however, where requested, LAs can support with risk assessment and / or monitoring (chargeable). This has changed from previous regulatory processes, in order to 'minimise the dependency on a sample which may be as infrequent as once in five years and serve little purpose as an assurance to a safe and secure supply' (1). For other types of PWS, regulation mandates risk assessments and monitoring, with frequency based on type and usage (6).

Risk assessment is intended to be a whole-system approach to ensuring water is safe (including for purposes such as toilet flushing and washing), replacing the previous system of potentially infrequent end-point monitoring (7). Risk assessment should include a range of factors, such as: likelihood of contamination; checks of collection chambers, storage tanks, treatment systems and pipe work; identification of hazards that may affect health; and remedial actions needed to make the supply wholesome and safe (8). If, after consideration of risk assessment, relevant local circumstances and specialist advice, a LA concludes that a PWS constitutes a potential danger to human health, they must serve a regulatory enforcement notice on any or all persons involved in the supply (1).

In 2023, the DWI reported that there were 2,962 PWS that required a risk assessment (2,990 in 2022 (4)) and only 54.1% (48% in 2022 (4)) had one that had not expired (1). In 2023, the percentage of PWS with an in-date risk assessment are:

- for private distribution systems (regulation 8 supplies): 29.6%.
- Large, commercial and public use (regulation 9 supplies): 68.2%.
- Small supplies and those as part of a domestic tenancy (regulation 11 supplies): 41.1%
- Untenanted single supply dwellings (regulation 10 supplies) are only risk assessed upon the owner's request and 4.9% have had an assessment.

The DWI have also outlined that PWS are not being tested at the frequency required, particularly for regulation 9 supplies (1). Overall, the DWI states that LAs are still not fully delivering their statutory duties which aim to protect public health (1).

Taken together, these factors mean that there are a considerable number of people who are using PWS without a valid risk assessment / testing and who may therefore not be aware of any potential health risks and harms from doing so. Of note, this number is in *addition* to the number who use water from PWS that do not have to have a risk assessment (small, single use supplies) and may also be unaware of any associated risks. Finally, it is important to note that, although contaminated PWS primarily put users at risk through drinking water from the supply, there is also the potential for risk if they inadvertently ingest or inhale water used primarily for other purposes, such as recreation (e.g. swimming pools) or even, potentially, through flushing toilets.

Findings of this rapid evidence review

1. Health risks and harms associated with microbiological contamination of PWS

Evidence on risks to health from microbiological contamination of PWS

We did not identify any robust secondary evidence (e.g. systematic reviews) about the microbiological health risks associated with the use of PWS. However, there was evidence from a limited number of primary studies. These identified a range of gastrointestinal pathogens that have been found in microbiological testing of PWS, although it should be noted that testing regimens often do not routinely include some organisms, such as Campylobacter, therefore this may affect these findings. Throughout much of this research, authors highlighted the likely positive relationship between heavy rainfall and contamination of the PWS, as well as other factors potentially associated with contamination, such as: seasonality; the kind of PWS, poor maintenance of the PWS; and animals near to the PWS.

Identified evidence included a quantitative microbial risk assessment of the risk of Cryptosporidium and Giardia in very small PWS in England and France, based on surveillance data and modelling (9). This estimated that, the risk of infection was very high, with the median annual risk being of the order of 25-28% for Cryptosporidium and 0.4% to 0.7% for Giardia, though, in the poorer quality supplies the risk could be much higher, concluding that this risk was substantially greater than for public water supplies (9). Another identified study tested for Cryptosporidium and Giardia in seven commercial PWS (establishments using a PWS for commercial uses; six PWS were treated) across the UK (two in Wales), serving hotels, holiday parks and food production enterprises (10). This found that all the sampled supplies experienced intermittent pathogen presence and only one, a chlorinated deep borehole supply, fully complied with UK water quality regulations throughout sampling (10).

Other identified evidence suggested that faecal contamination of PWS is common. For example, analysis of samples from a passive surveillance system of PWS in England, between 1995 and 2003, found that E. coli was detected in 18.87% of samples (11). Further modelling suggested that, had sufficient samples been taken, 54% of all PWS in England were likely to be unsatisfactory for E.coli standards (11). We also identified other UK studies which analysed public health records of statutory testing of PWS, from both commercial and non-commercial properties. In one study, 21% of

samples (and 33% of supplies) failed regulations for E. coli (12). Total coliforms, including E. Coli, were detected in 27% of samples, from 42% of supplies (12). Another older study analysed samples taken from PWS in Aberdeenshire and found that 41% failed for total coliforms and 30% for faecal coliforms (13). This study noted a seasonal trend, with failure rates greater during the latter half of the year, with part of the variability in failure rate explained by a significant positive relationship with rainfall amount (13). This evidence is also in keeping with another study from Ireland which found that the incidence rate of microbiological contamination with E. coli in PWS sampled between 2011 and 2012 was 58.4% (14)

This published literature is in keeping with evidence from DWI Annual Reports for Wales on the proportion of PWS failing for microbiological parameters (figure 2) (1). When E. coli, Enterococci and to a lesser extent Clostridium perfringens are found, this suggests that the contamination may be faecal in origin (1). In Wales in 2023, 7.38% of samples tested showed faecal contamination, with 7.12% of samples tested found to contain *E.* coli and 7.73% enterococci, both indicators of faecal contamination (1).

Figure 2: Summary of the percentage of sample tests of PWS in Wales failing for various microbiological parameters, as returned to DWI in 2023 (1)

Microbiological parameters	2022 (%)	2023 (%)
E.Coli	6.9	7.1
Coliform bacteria	12.9	13.6
Enterococci	7.2	7.7
Clostridium perfringens	4.4	5.0

The greatest proportion of tests failing for microbiological parameters was for coliform bacteria (13.6% of samples) which, although not always a direct indicator of faecal contamination, does indicate contamination of the source. DWI data have shown that there has been a general decline in the percentages of samples testing positive for E.coli and Enterococci over the last decade but this has now plateaued (figure 3) (1).

he DWI report also identifies that of the 109 enforcement notices returned to DWI, served under regulation 20 for supplies considered a potential danger to human health, the majority were for microbiological issues (figure 4) (1).

Figure 3: Percentage of PWS sampled in Wales in 2010 - 2023 found to contain E.coli or Enterococci, as returned to DWI in 2023 (1)

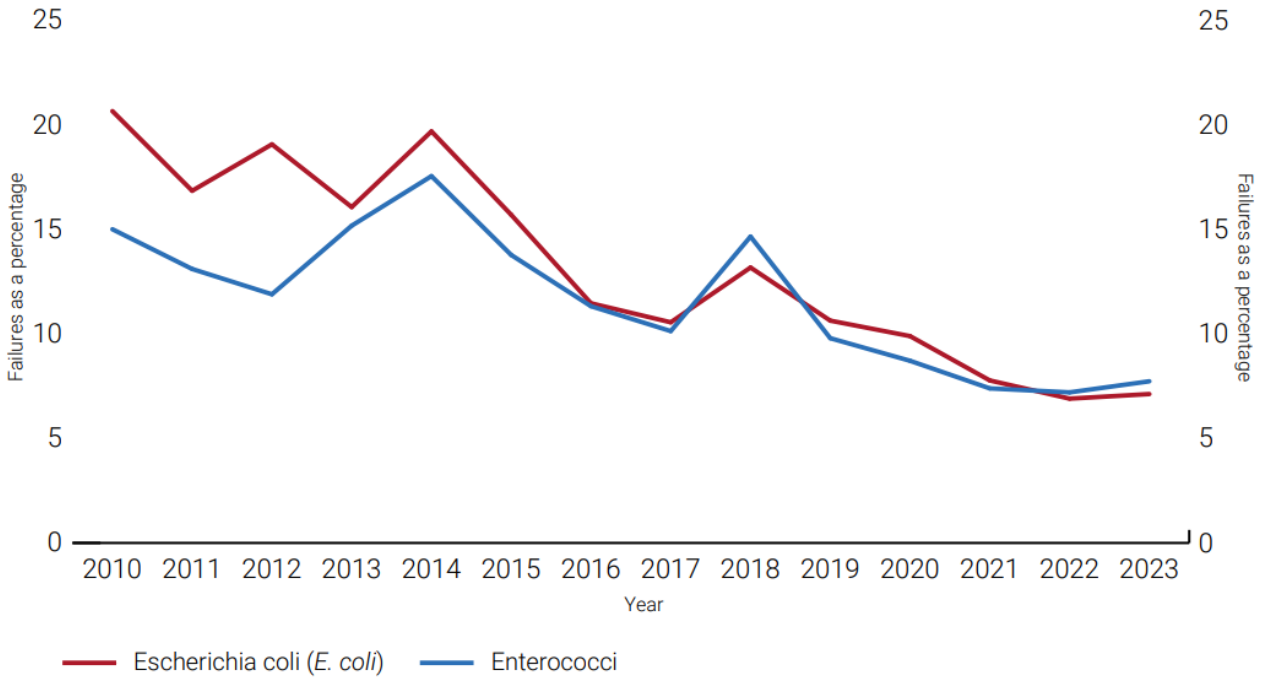


Figure 4: Number and reason for notices served for failure of standards, as returned to DWI in 2023 (1)

Reason for serving notice	Number
Bacteria	95
Lead	11
Multiple reasons	1
Risk assessment	1
No risk assessment	1

Evidence for health harms associated with use of a microbiologically contaminated PWS

We found limited, lower quality evidence from the published literature on health harms associated with microbiologically contaminated PWS, from both individual case reports of outbreaks of GI infection (15) (16), and from wider analyses of public health records on outbreaks (see below).

However, it should be noted that most of the evidence on outbreaks relies on descriptive epidemiology and environmental observations, rather than identification of causative organisms in the PWS. There are also potential barriers to fully understanding the burden of GI infection associated with PWS, including: a lack of reporting of symptoms to health services; a lack of stool sampling and/ or notification by clinicians; and the possibility that long-term PWS usage might confer partial immunity to pathogens, so users might be less likely to present to health services with symptoms (17).

Whilst noting these caveats, we identified several analyses of public health records which investigated association between PWS and disease outbreaks. For example, a UK analysis of public health records found that, between 1970 and 2000, there were 69 reported outbreaks of waterborne disease associated with drinking water in England and Wales; 25 of these (36% of the total) were associated with PWS (18). The authors found that the association between the PWS and illness was strong or probable in 76% and identified 1584 cases and at least 5190 people at risk in these 25 outbreaks (18). The most common reported symptoms were gastrointestinal (though there were two other outbreaks: paratyphoid fever and 'streptobacillary fever') (18). The most commonly identified pathogen was Campylobacter, which caused 52% of outbreaks; others included Giardia, Cryptosporidium and *E. coli* (18).

This research was updated by a DWI project, which re-reviewed this historical data and also analysed outbreaks of disease associated with PWS in England and Wales between 2001 and 2009 (17). This found 12 outbreaks linked to a PWS over this later timeframe (5 in Wales), although only one had strong evidence of an association, by demonstrating the outbreak organism in both cases and the PWS (17). For nine others, the evidence was probable and for one, it was possible (17). There was an identified increase in outbreaks in Wales when compared to the earlier research (though it should be noted that numbers overall were small and there were only 8 records for Wales in total in both studies) so this could have been due to chance (17). No deaths were associated with the outbreaks (17). As with the older research, the most commonly identified pathogens were

Campylobacter; *E. coli* O157; Cryptosporidium; Salmonella and Norovirus (17).

Other reviews have also supported an association with PWS and outbreaks of GI infection. For example, an analysis of 89 reported outbreaks of waterborne infectious intestinal disease infection in England and Wales between 1992-2003 found that PWS were implicated in 28% of the outbreaks; it also concluded that the incidence rate of outbreaks in recipients of PWS may be as high as 35 times the rate in those using public supplies (19). Again, Campylobacter was implicated in 52% of these (19). Another review of public health records from Ireland, reviewed records of Verotoxigenic *E. coli* (now referred to as STEC) transmission in Ireland between 2004 and 2012 (20). It found that, after person-to-person spread (the sole transmission route for more than half of all outbreaks and outbreak cases), the next most significant transmission route for infection was waterborne spread from untreated or poorly treated PWS (20). Finally, we also identified a more recent prospective cohort study of 611 individuals who used small PWS in England (21). Whilst noting the methodological limitations to this study (e.g. based on self-report of illness), this study found that contaminated small rural drinking waters supplies are an important risk factor for infectious intestinal disease (21).

In much of this evidence, common themes emerged about factors identified as important in the outbreaks associated with PWS. In both analyses of UK public health records, the authors noted that many of the outbreaks were located in places where the populations affected by them were transient (i.e. short-term or temporary residents) and newly exposed to the PWS, seen in 88% of the outbreaks in the older analysis (18). These included: holiday accommodation; military training sites; school/student residences; outdoor activity centres and camping/caravan sites, though the report, which covered the period up to 2009 identified no outbreaks linked to 'holiday accommodation' since 2001[3] (17). Other factors commonly identified from the wider evidence included: failure or lack of treatment; presence of animals (including carcasses) or slurry nearby; poor maintenance or building works; and heavy rain (15) (16) (18) (17). The prospective cohort study above also found a higher relative risk of infection in children drinking from contaminated PWS, when compared to older children and adults (21). It concluded that contaminated water supplies pose a substantial risk of infection to young children (under 10 years) who live in homes reliant on these supplies; in contrast,

[3] 'Holiday/guest house accommodation' was categorised differently to 'training/activity/adventure centre' and 'farm, caravan or campsite' by the authors.

older children and adults did not appear to be at increased risk (21).

Building on this published evidence, we searched health protection records for cases of GI disease where an EHO or member of the HP team had considered that a PWS was a possible route by which the case was exposed to infection (see methods above). As previously noted, there are significant caveats to these data, nevertheless, they represent the only currently available records to support our understanding of health harms that users of PWS in Wales may have experienced. Between 2018 and 2022 (inclusive), there were 176 records of individuals with GI infection who also had a PWS identified as a possible exposure source, having consumed water from a PWS prior to developing symptoms of infection. From existing records, it is possible to identify that 92 of these related to PWS in Wales. It is likely that the majority of the remaining recorded cases had also used PWS in Wales, however we are unable to confirm this. In many of these cases, alternate exposure pathways were also identified (such as contact with farm animals or eating at a restaurant prior to development of GI infection) therefore it is not possible to confirm that the PWS was the definitive source of infection.

There were a similar number of cases recorded annually across these years (figure 5), with a lower total number in 2020 (possibly related to reporting issues during the COVID-19 pandemic). Over this time, cases were reported from all Welsh health boards (location of residency), but the greatest number were in: Powys THB (31.2% of all recorded cases); Hywel Dda UHB (30.1%); and Betsi Cadwaladr UHB (21.0%); with proportions in the other HBs all under 10%. This geographical distribution may reflect the known locations of PWS (i.e. greater numbers in more rural HB areas) as well as variation in reporting. Campylobacter, and then cryptosporidium, were the most frequently identified causative organisms for notified infections (figure 6); giardia and E.coli were the next most frequently identified organisms in these cases. These organisms are in keeping with findings from the published literature (see above).

An analysis of the age and sex of cases of GI infection with associated prior use of a PWS shows that the greatest proportion of notified cases were under 10 years (figure 7). However, as noted above, these data are likely to be affected by the age ranges most likely to present to health professionals, and subsequently notified, and therefore we cannot conclude from this that this is the age range most affected. However, it does provide limited evidence that younger children in Wales

have been diagnosed with GI infection which a public health / environmental health professional felt may have been associated with prior use of a PWS.

Figure 5: Number of notified cases of GI infection, as recorded on health protection records, where a PWS was identified as a possible exposure source, by year, 2018-2022

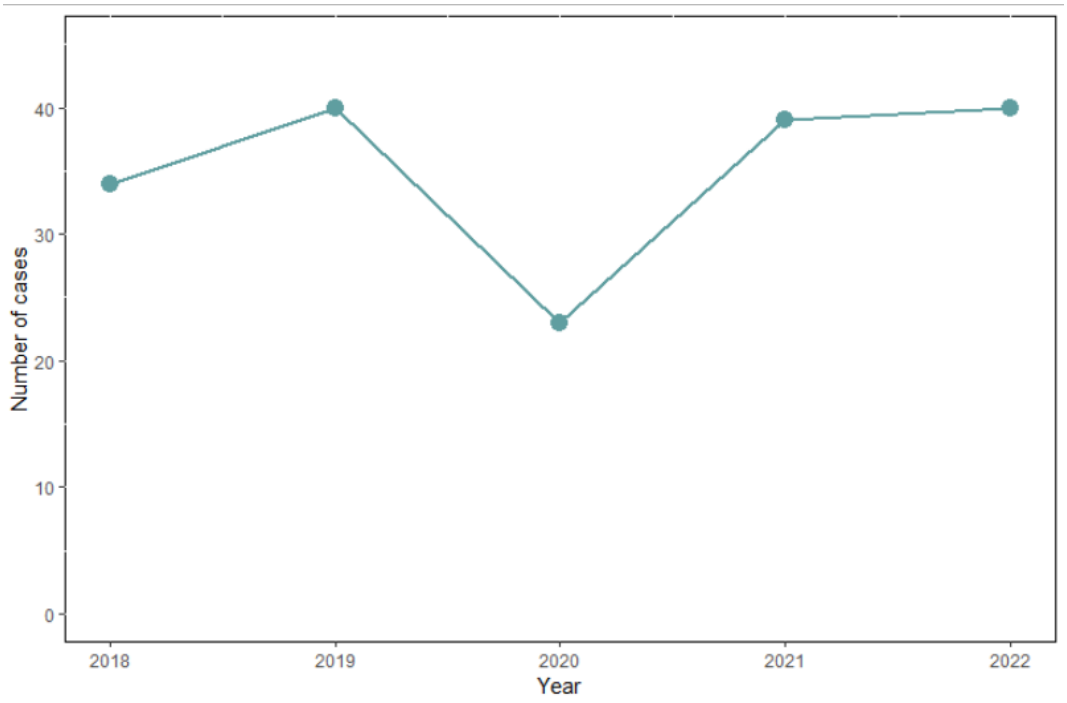
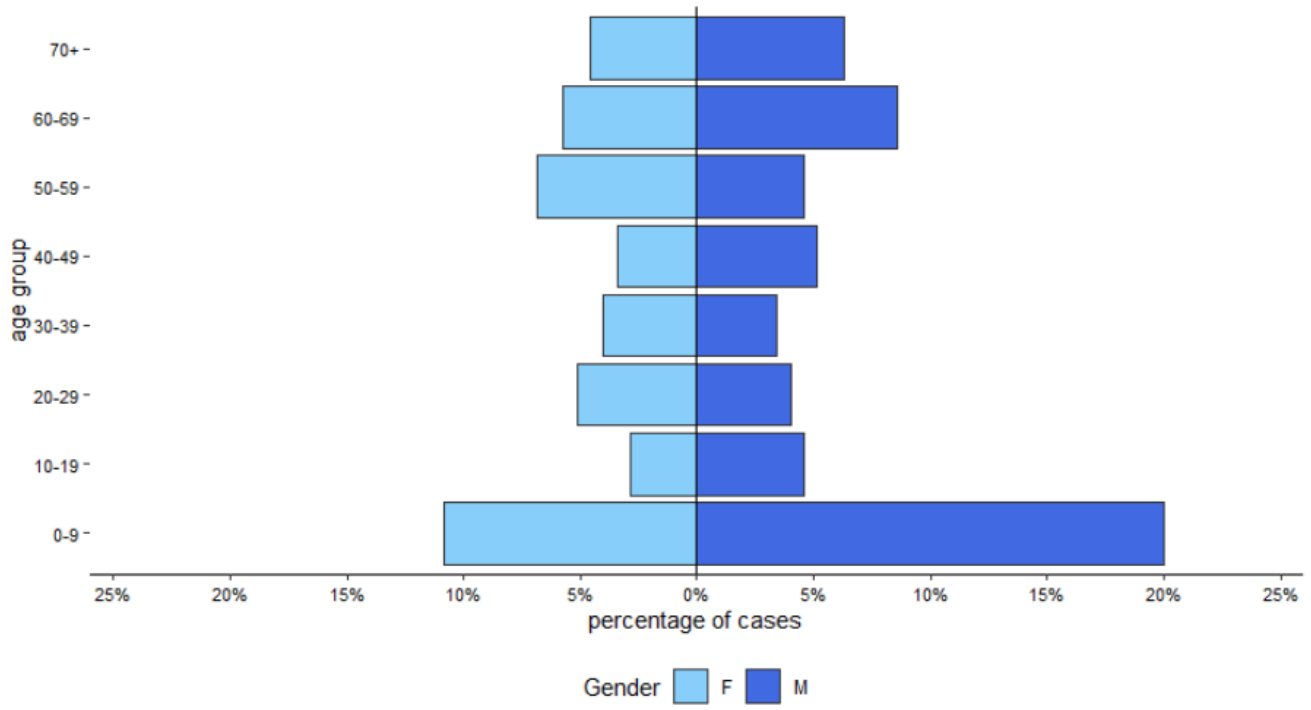


Figure 6: Total number of notified cases of GI infection, as recorded on health protection records, where a PWS was identified as a possible exposure source, by causative organism (2018-2022)

Notified organism	Number	% of total
Campylobacter	97	55.1
Cryptosporidium	41	23.3
Giardia	11	6.2
Listeria monocytogenes	<5	-
Salmonella	9	5.1
STEC	14	8
STEC non-O157	<5	-
Total	176	100

Figure 7: Age-sex chart of notified cases of GI infection, as recorded on health protection records, where a PWS was identified as a possible exposure source, 2018-2022



2. Health risks and harms associated with environmental issues affecting PWS

Evidence on risks to health from environmental issues affecting PWS

We did not identify any robust secondary evidence (systematic reviews) about the health risks from using PWS related to environmental issues (e.g., chemical contamination or insufficiency of supply). However, there was some limited available research which analysed the chemical quality of drinking water from various PWS in the UK and found low level compliance with water quality standards (22) (23). For example, one study sampled drinking water from 497 properties using PWS across Cornwall, analysing it for 25 chemical parameters, and found that 65% of samples exceeded one or more chemical standards set (22). For the parameters with health-based drinking water standards, the most frequently exceeded were nitrate (11%) and arsenic (5%); exceedances were also high for other parameters, such as pH, manganese and aluminium (22). Another, older, UK study collated sample data from 1297 PWS across the West Midlands Region and showed that over a quarter of the supplies tested were in breach of legislation (UK and EU) for chemical parameters (23). Other research has also highlighted the importance of considering underlying bedrock and geology on concentrations of chemicals in PWS, such as arsenic levels in Cornwall (24) and manganese concentrations in groundwater supplies in Scotland (25).

The published literature is in keeping with LA records compiled by the DWI in their 2023 Annual Report for Wales, which show that 3.89% (3.5% in 2022) of PWS samples tested for iron, manganese and aluminium failed the relevant standards (1). In addition, lead and nickel were detected in 3.9% and 5.2% of tests respectively, affecting 797 and 55 consumers (1). A proportion of tests also failed for iron, manganese and aluminium (see figure 8 below), though all these metals can be found naturally occurring in source waters and these results therefore need to be considered in this context (1). In 2023, the percentage of tests failing the standards for taste and odour were 3.92% and 0.52% respectively (1). Future testing and data returns are also likely to include further assessment of PFAS (per- and poly fluoroalkyl substances).

Whilst the majority of enforcement notices served by LAs were for microbiological issues, there were also a number served for lead (see figure 4). Two notices were also served under section 80, for unwholesome or insufficient supply (1).

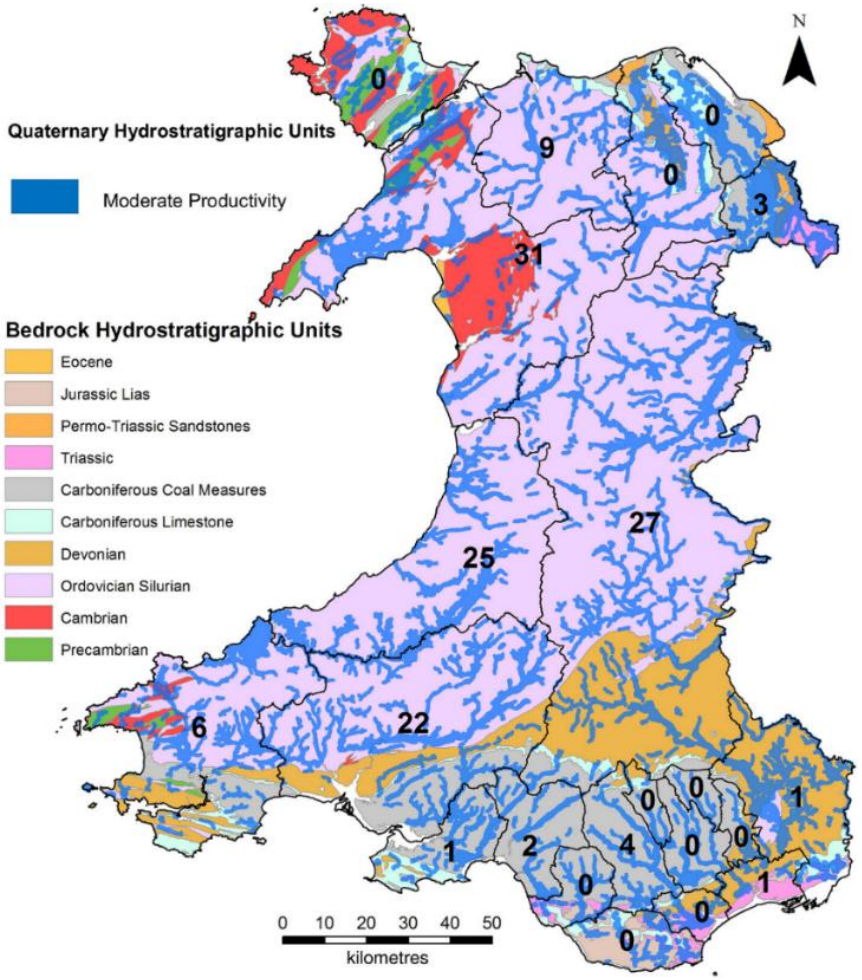
Figure 8: summary of the percentage of sample tests taken on PWS failing for various chemical parameters in 2022 and 2023 in Wales, as reported by the DWI (1)

Chemical parameters	2022 (%)	2023 (%)
Odour	1.5	0.5
Taste	2.2	3.9
Manganese	6.6	6.6
Iron	3.5	3.2
Aluminium	1.9	1.7
Turbidity	1.3	1.5
Colour	0.9	1.9
Lead	3.8	3.9
Nickel	5.6	5.2
Pesticides	0	0
Fluoride	0	0
Others	2.1	1.8

There is also limited but direct evidence of previous vulnerability of PWS in Wales to insufficiency. Of note, it is the responsibility of owners to ensure their supply is sufficient and they must incur any costs for covering alternate supplies as needed (e.g. for bottled water). In practice, although under no legal obligation to do so, LAs and ultimately water companies may offer some chargeable support to users.

In the Summer of 2018, the joint hottest Summer on record, a total of 132 dry PWS supplies were recorded by LAs (figure 9) (2). This number is likely to represent an underestimate as there is no obligation for dry PWS to be reported to LAs and this may be even less likely on subsequent episodes of insufficiency, once a household has developed resilience to a dry supply. It is also important to recognise that, even when experiencing difficulties with insufficiency, some owners / users of PWS may be reluctant to make LAs aware of their supply or issue with it. This could be, for example, because of concerns about increased costs they may face if problems are identified that need rectifying and if a notice is subsequently served on them (26) (27).

Figure 9: Number of reported occurrences of dry PWS during 2018 per LA area, underlain by the geology of that area (2)

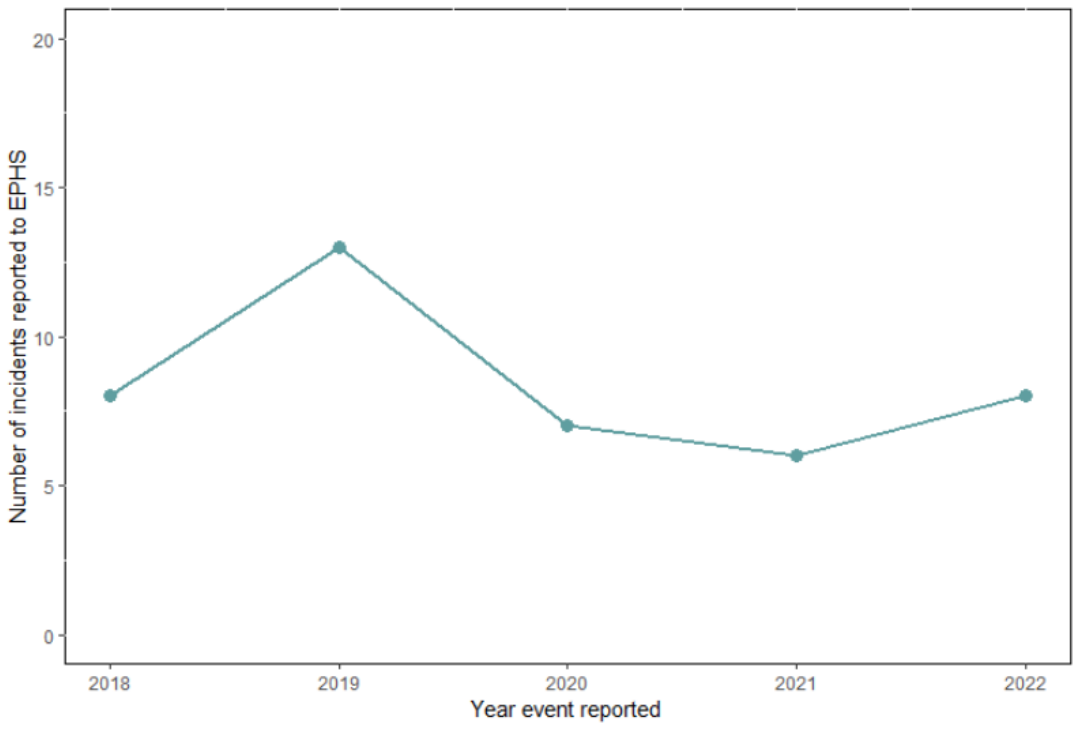


Evidence for health harms associated with environmental issues affecting PWS

When considering potential health harms from the evidence on chemical contamination, it is important to note that not all statutory limits for contaminants are based on toxicological grounds, therefore breaches of these standards (as identified above) do not necessarily imply a risk to health. However, there is clear scientific evidence that regular consumption of drinking water with raised chemical concentrations can be harmful. For example, acute and chronic consumption of lead in water, a neurotoxin with no safe threshold level, can have long-term and irreversible impacts on health, particularly for children and pregnant women (28).

In our review of the published literature, we were unable to identify any evidence about health harms arising from chemical contamination or insufficiency of water from PWS. We also reviewed health protection records of the EPHT, to identify any evidence on whether PWS users in Wales have experienced potential health harms from environmental contamination of PWS (see *methods* above). These records show that, over the last five years, there were 42 contacts with the EPHT about environmental issues ('incidents') relating to PWS in Wales. The greatest number were reported in 2019 (figure 10). There was a decrease in reports during 2020 and 2021 (likely to have been affected by a reduction in testing / reporting during the Covid-19 pandemic) and this number has increased again in 2022. The majority (74% over the last 5 years) of contacts with the EPHT about PWS were from LAs notifying public health and / or seeking public health advice. Other informing sources were considerably lower; the second group most commonly contacting EPHT were members of the public seeking advice (8%).

Figure 10: Number of environmental 'incidents' (enquiries / issues notified / where public health advice has been sought) related to usage of PWS in Wales, as reported to PHW by year, 2018-2022



The greatest number of records related to reports of issues with PWS in the Powys Teaching Health Board area (32% of all records where a location was recorded (n=41[4]), based, in the majority of cases, on recorded PWS location). This is in keeping with the higher proportion of PWS in the Powys LA (see above, figure 1). This was followed by incidents related to PWS in the Cwm Taf Morgannwg University Health Board area, where, since 2018, 24% of all incidents were reported. Over the five years, there were records about issues related to PWS in all HBs in Wales. However, there are some caveats to these data. For example, there may have been a small number of records where the address may have related to a resident / reporter address which might be different to the PWS location, and it is possible that areas which have a high number of PWS may have developed greater expertise in managing health issues and may therefore not contact PHW as often for advice.

Enquiries related to raised manganese (21.0%) and aluminium (12.9%) levels were the most frequently recorded reason for contacting PHW for advice (figure 11). This is in keeping with the DWI 2022 report, which found that manganese and aluminium were two of the chemicals with the highest proportion of tests failing to meet standards in Wales (figure 8). Other commonly occurring chemicals involved in recorded environmental incidents were lead, iron and copper.

We were not able to identify any published evidence of health harms related to PWS insufficiency. There was however one recorded incident on health protection records related to an enquiry about a PWS and insufficiency in Wales. Nevertheless, drying up of PWS has the potential to impact health, as users might reduce their water intake (risking dehydration) or use other contaminated water sources (e.g., community wells) that they might not normally turn to. Beyond physical health, it is also important to consider potential associated mental health and wellbeing impacts (e.g., from anxiety about the PWS and potential financial or wider implications), particularly if a PWS is also being used to support business or tourism.

[4] In one record, there was no location recorded.

Figure 11: Number of environmental incidents (enquiries / issues where public health advice has been sought) associated with PWS, reported to PHW by reason / chemical involved, 2018-2022. (N.B. incidents may involve more than one reason / chemical therefore figures will not sum to total number of incidents).

Chemical / issue of concern	Number	% of total
Manganese	13	21.0
Aluminium	8	12.9
Lead	7	11.3
Iron	6	9.7
Other*	<5	-

* *inc.* copper; pH; ammonia; hydrocarbons; other; chloride; herbicide; insufficiency; nickel; nitrate; nitrite; odour; sewage; slurry; sodium; turbidity

3. How climate change may affect health risks and harms associated with using PWS in Wales

The third UK Climate Change Risk Assessment (CCRA3) for Wales identifies that 'the changes in climate we are already experiencing are projected to continue and intensify' (27). The CCRA3 outlines that annual temperatures in Wales are expected to rise, with associated risks of more extreme heatwave events (27). In addition, winter rainfall is expected to increase, increasing the likelihood of flooding, and, whilst summer rainfall is expected to decrease, when it does rain, projections suggest that rainfall will be more intense (27). These predicted climate and adverse weather changes have the potential to impact on both the quality and quantity of water supplied through PWS, with associated health risks.

Heavy rainfall has the potential to wash contaminants, such as sediment, nutrients, pollutants, rubbish, and animal waste, into PWS (27). High temperatures and low flow can cause increased concentrations of pollutants and algal blooms in rivers and lakes (27), which also has the potential to impact on the quality of water supplied by PWS. Although it is not possible to know exactly what these impacts will be, there is some lower-quality evidence available from *current* seasonal trends which provides an indication of how these changes might impact on PWS water quality in the future, for both microbiological and chemical contamination. For example, as noted above, evidence suggests that the microbiological quality of supplies can be affected by heavy rainfall events (29). Whilst noting the small number of outbreaks with which to base conclusions on, multiple analyses have noted an association with heavy rainfall preceding the start of an outbreak (10) (14) (29) (30). Microbiological contamination may relate to a number of factors such as: heavy rainfall which may lead to flow through channels that would not normally occur, e.g., across fields where animals are; overflow of storm drains that may be combined with sewage which could enter rivers; and possibly through other mechanisms, such as increased nutrient content and therefore bacterial and plankton (cyanobacteria) growth after heavy rain and in combination with warmer weather (29).

The evidence about the impacts of periods of drought on water quality is less clear. Limited evidence has suggested that low rainfall events *followed* by high rainfall events may increase contamination (31). For example, a case-crossover study analysed historic drinking water related outbreak data (from public *and* PWS) and found a significant association with excess rainfall over the previous week and low rainfall in the three weeks before the week of the outbreak (30). It has

been suggested this could be because drought events can lead to lowering of the water table, resulting in changes in underground water flows and incursion of surface water into groundwater that is not normally so affected by contamination (32). Drought periods alone could potentially also cause source water contamination, through less dilution of sewage effluent and animal wastes in surface watercourses (32). However, a recent opportunistic field study in Ireland, which assessed microbiological contamination of PWS during the drought period of 2018, found frequent faecal contamination, irrespective of precipitation patterns and temperatures, and highlighted the need for more research into this (33). There is also some evidence to suggest that drought can increase chemical concentrations in groundwater sources, because water treatment systems or source protection measures fail, e.g. due to reduced dilution of contaminants (34). The impact of drought on arsenic contamination has also been modelled in a US study, which suggested that drought could increase concentrations in domestic wells (35).

However, when considering this evidence on how climate change may affect PWS, it should be noted that contamination of water sources is also likely to be impacted by multiple other factors, such as: seasons (12) (13); agricultural practice (10) (36); the nature of the water source; and underlying geological characteristics (2). These are also likely to interact with each other and modify the impacts that climate change may have on PWS in Wales (14) (10). For example, climate change may influence agricultural practices, such as livestock locations, type and density, and, consequently, the fate and transport of pathogens that are associated with livestock.

Drier, warmer weather also increases vulnerability of PWS to drying up (insufficiency) for both domestic and commercial PWS (27). A recent Scottish review found that meteorological drought can propagate through the hydrological system and, if prolonged, lead to a hydrological drought (below-normal water availability in rivers, streams, reservoirs, lakes, or the groundwater table) (34). There is also direct evidence that insufficiency of PWS has already been a problem in Wales in previous hot Summers, such as 2018 (see above) and that PWS in Wales may be particularly vulnerable to this due to underlying geology of low-storage and low-permeability aquifers (2).

We did not find any good quality published reviews or studies that modelled how any increased risks of contamination or insufficiency related to climate change might impact the health of PWS users. However, as outlined above, increased microbiological or chemical contamination can harm health and insufficiency has the potential to impact on physical and mental health. Finally,

though less likely in the UK, climate change has a theoretical potential to increase health impacts by increasing users' exposure to vector-borne diseases (e.g. mosquitos), that may become more prevalent in the UK and whose life-cycles may be supported by water storage (37).

Many users of PWS are likely to be underprepared for these future risks. For example, the CCRA3 report for Wales has highlighted that many businesses did not have a contingency plan in place to allow them to continue operation with a reduced PWS through an extended drought scenario (27). Additionally, for many owners of PWS, connection to public supplies can be geographically difficult and costly, leaving them with few alternatives (26). Importantly, planning processes for new housing developments do not currently consider the availability of water supplies for drinking or sanitation, whereas they do consider drainage and wastewater removal (26). This means that consideration of PWS' future vulnerability is not currently embedded in the planning system.

4. Users' perceptions of health risks and harms associated with PWS

We identified very limited evidence on the perceptions and/or experiences of PWS users about potential health risks and impacts from their use. The evidence we did identify was methodologically limited and may be subject to bias and, for some, their focus on specific communities outside the UK and Ireland limits generalisability and applicability to the Welsh population. Further, it should be noted that we did not use formal qualitative theming approaches to review this qualitative evidence but instead relied on authors' own conclusions.

We identified qualitative studies (focus group, semi-structured interview, or survey-based) from a number of countries, including Ireland (38), Canada (39), (40) and the USA (41), (42), though, as noted above, several of these are likely to be significantly limited in their applicability to Welsh PWS users. A theme that emerged from several studies was that many participants held generally positive perceptions about the quality of their PWS (water described as 'pure' and 'beautiful water' (38)), although the factual basis for this was reported as less certain (38) (39). Perception of health risks were also reportedly based on sensory information (i.e. taste/smell) (38), and concerns about contamination were often around surface contamination (e.g. agricultural) (38) (42), rather than the possibility of geological contamination (38) (42).

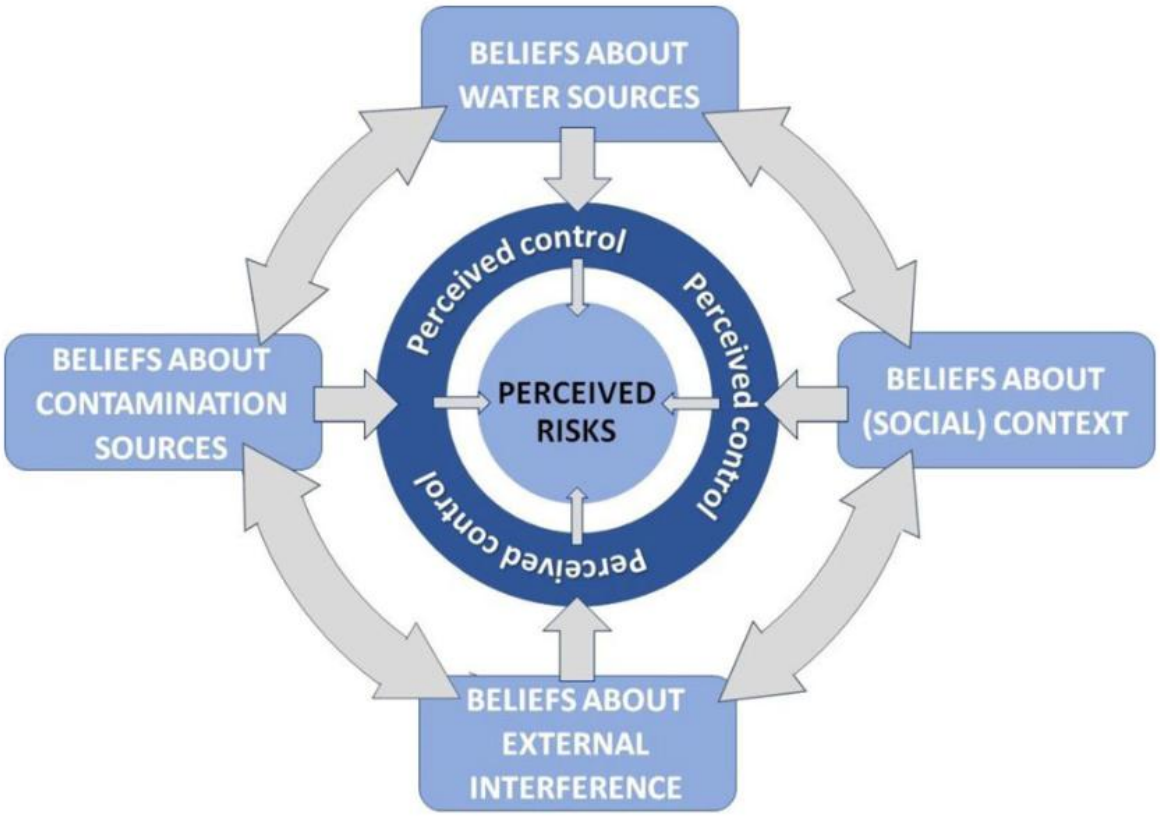
However, some participants expressed considerable concerns about contamination and identified ways they mitigated these, such as through use of bottled water and water treatment devices (42) (40). These included concerns about bacterial and chemical contamination of their PWS from nearby agricultural activities, illegal dumping of pollutants and a lack of an official monitoring system (39) (42). Generally, participants reported minimal testing of supplies and less than the recommended frequency (38) (39) (42) and that this was the norm for what others did around them (38). However, some felt that protecting family was important and that a change in circumstance or the presence of protecting vulnerable family members (e.g. children, elderly) could be a prompt for testing (42) (38), as could a change in taste, odour or colour (41). The studies also identified a range of barriers to testing PWS, including: inconvenience of testing; economic limitations; resident complacency and lack of knowledge; reassurance from an acceptable test result in the past; a lack of actionable information and technical support; and issues with neighbours and landlords (38), (42) (39) (41).

Other, non-peer-reviewed, evidence is also available that supports our understanding of how users of PWS in the UK may perceive health risks and impacts, although these are also based on very small numbers of PWS users. For example, Citizens Advice Scotland conducted in-depth interviews with PWS users and found that, in keeping with the evidence above, there was a common belief that PWS were pure and wholesome and even better than public supplies (43). This report similarly identified that some owners had a lack of understanding of: risks of PWS (particularly if they were not associated with a discernible smell, taste or aesthetic); how to manage their PWS; the benefits of risk assessment; and also of financial support available to them (43). Many users were also unaware of public information available to them to support them in understanding more about their PWS and highlighted the need for more of this (44) (43).

There was also evidence from this Scottish report that found that some PWS owners could be hostile towards water quality sampling and sampling could be viewed as interference (43). It also found that maintenance was broadly ad hoc, when an obvious issue was found, but that users took pride in their own inventiveness, self-sufficiency and understanding of what is required to make water safe, finding workarounds for issues with their supply, e.g. buying bottled water until the appearance of their water improved (43). These findings are in keeping with the Irish study discussed above, which developed a theoretical model to illustrate how PWS owners felt a perceived sense of their own control over their PWS in terms of managing it and any risks associated with it, as outlined in their theoretical framework for PWS' users beliefs (figure 12) (38). The authors argue that, as a result of this 'illusion' of being in control over their water quality, many users may underestimate contamination risks, which subesquently impact negatively on water testing behaviours (38).

We did not identify any good quality primary studies about the views, perceptions and/ or experiences of users of PWS regarding the impact of climate change on PWS and the risks associated with the use of PWS.

Figure 12: theoretical framework for risk perception towards drinking water quality among private well owners in Ireland: the illusion of control (38).



Summary and discussion of findings

1. Potential for public health impacts: in keeping with both the Well-being Of Future Generations Act and the United Nations Sustainable Development Goals, everyone in Wales should have equal access to clean, safe and sustainable water and sanitation. For many people in Wales, access to this water is through a private water supply. This rapid evidence review aimed to understand more about the health risks and harms of using PWS in Wales and, importantly, whether these affect our population equally.

   Although the exact number of users of PWS in Wales is unknown, DWI data suggest that around 2% of the population (over 64,000 individuals) in Wales use a private supply. This is likely to represent a significant underestimate, particularly for single-use (unregistered) domestic supplies. In some areas of Wales, records suggest up to 43% of properties are dependent on PWS. Importantly, an unknown number of people may also be using a PWS on a temporary basis, for example through holiday or other commercial premises, or through 'pop-up' events. This means that if health risks and harms are associated with the use of a PWS, they have the potential to be a more significant public health issue in Wales than for many other parts of the UK, although one that is equally faced by some, such as rural parts of England, and in Scotland.

   Currently, regulatory systems do not mandate that all PWS in Wales are registered or inspected (as was previously the case in the UK). Regulation is based on a system of risk assessment and, for some, mandatory testing, depending on type of PWS. In 2023, around 46% of PWS which were meant to have had a risk assessment did not have a valid one. Additionally, there is no mandated risk assessment or monitoring for single-use domestic PWS, which are often unregistered. Taken together, this means that a significant proportion of PWS in Wales have not been risk assessed or tested, making it difficult to know the exact size of the population potentially exposed to the public health risks and harms outlined below.

2. Health risk and harms associated with the use of PWS: this review has identified that the use of PWS may be associated with health risks and harms related to microbiological contamination of supply; chemical contamination of supply; and insufficiency of supply.

a) *Health risks and harms from microbiological contamination:* we identified limited evidence (from outbreak reports and analysis of public health records) about the risk of microbiological contamination of PWS and any associated health harms. Much of this research is now historical and of variable quality, however it does include evidence specific to Wales. When considering this evidence, it is also important to note that most evidence is based on descriptive epidemiology rather than a direct link between microbiological source and case.

Evidence from the identified research literature suggests that the risk of contamination of PWS is higher than for public supplies, with evidence of contamination in both residential and commercial PWS. Much of the identified literature, considered and found evidence of contamination with Cryptosporidium and / or Giardia. Faecal contamination, including with E.coli., was also a commonly identified finding. The published literature is in keeping with DWI data that show that 7.38% of samples tested for faecal contamination in 2023. The majority of enforcement notices on PWS were also served for microbiological contamination.

There is also evidence from the published literature on associated health harms from this contamination, predominantly from gastrointestinal (GI) infection. This shows a disproportionate number of waterborne disease outbreaks in the UK associated with PWS, when compared to public supplies. In the identified literature, the greatest proportion of disease was associated with Campylobacter, although other associated organisms included Giardia, Cryptosporidium and E.coli. Multiple factors were also identified as being potentially associated with these outbreaks, such as the transient or temporary nature of affected populations; heavy rain; the presence of animals and farming; poor maintenance of PWS; and failure of lack of treatment. There was also very limited evidence to suggest that young children might be at a greater risk of GI infection from contaminated water in PWS than older children and adults.

Using PHW health protection records, we have also found evidence of 176 cases (including children), over a 5-year period, where GI infection was associated with prior use of a PWS. There are significant caveats around these data (see above) and it is not possible to draw the conclusion that these infections were caused by a contaminated supply. However, they still highlight that the health of some PWS users in Wales may have been

harmed by microbiological contamination of a PWS. The most frequent causative organisms of these GI infections were also in keeping with those most commonly identified in the published literature as being associated with outbreaks of contaminated PWS.

b) *Health risks and harms from environmental issues:* we identified very limited, lower-quality evidence from the literature about health risks and harms for users of PWS from environmental contamination or insufficiency. However, there is some evidence for exceedance of water quality standards of various chemicals in UK-based research studies. The published evidence also suggests that variation in underlying geology may affect concentrations of chemicals in PWS. In keeping with this evidence, DWI records have shown evidence of chemical contamination of supply in Wales, including that, in 2023, 3.89% of PWS samples tested for iron, manganese and aluminium failed standards.

We did not identify any published evidence about health harms directly linked to the ingestion of environmental contaminants in water from PWS. However, PHW health protection records have shown that individuals and organisations have had to contact PHW for public health advice about chemical contamination of PWS in Wales. The highest proportion of contacts were for notifications / queries related to manganese, aluminium, lead and iron, respectively. There is also a clear scientific mechanism by which chemical contamination can be harmful for health. For example, the effects of exposure to lead through drinking water can be wide-ranging and life-long, particularly for children.

There are currently no routinely collected data on sufficiency of PWS, however LA records show there were 132 reports of dry PWS in Wales in 2018. Insufficiency of supply has the *potential* to harm physical health, for example through use of alternative, less high-quality water supplies (e.g. community wells) and through risk of dehydration, and mental health and wellbeing, including from stress and financial implications.

3. Evidence on how climate change may affect health risks and impacts: there is a growing body of evidence about the likely impacts that a changing climate will have in Wales, including an increase in extreme events, such as prolonged periods of drought and heavy rainfall events.

Extreme weather events have the potential to impact the *quality* of water from PWS through both microbiological and chemical contamination. For example, heavy rainfall events

(potentially also exacerbated by preceding dry weather) may increase runoff, washing sediment, nutrients, pollutants, rubbish, animal waste, and other materials into water supplies.

Several published analyses of outbreaks have also suggested an association between heavy rainfall events preceding the start of outbreaks of GI infections.

Conversely, increased occurrences of prolonged drought may potentially also affect PWS through microbiological and chemical contamination, though the evidence is limited. Higher temperatures and low flow have the potential to increase concentrations of pollutants and algal blooms in water, and modelled data suggests chemical contamination of PWS could also be increased during drought periods. However, many other factors are also likely to be important when considering how individual PWS will be affected by climate change, e.g., changing agricultural practices.

There is also some evidence to suggest that the *quantity* of water supplied by PWS in Wales could be impacted by climate change. PWS in Wales may be particularly vulnerable to drought due to their underlying geology of low-storage and low-permeability aquifers. This may mean that, as periods of drought increase, there may be increased insufficiency of PWS, both for domestic and commercial uses. There is already evidence of insufficiency in PWS in Wales during previous hot weather, though there is currently no routine system for recording this and data on this are likely to be underestimates. As outlined above, insufficiency of water has the potential to impact users' physical and mental health and wellbeing.

Importantly, many domestic and commercial PWS owners and users are likely to be underprepared for these future risks. Consideration of the potential future vulnerability of PWS is also not currently embedded in the planning system, for example for new housing developments, meaning that the number of people potentially impacted may increase further in the future.

4. PWS users' perceptions and beliefs: we identified very limited information about PWS users' perceptions and views on health risks and harms of using their supply; the evidence that we did identify is likely to have limited generalisability to Wales. However, this evidence was also

supported by some non-peer reviewed reports which did focus on UK PWS users. From the available literature, several authors noted that users had a perception that PWS water is of good and even higher quality than public supplies. The evidence also suggests that users undertook limited testing of supply and that concerns about PWS contamination were commonly based on sensory triggers, e.g., taste or smell of water. Identified barriers to testing

PWS included: inconvenience; economic limitations; complacency; lack of knowledge of risks and technical information; and reassurance from previous tests.

The evidence also supported users' perceived need for easier to understand and clearly accessible information about PWS. However, some also identified users' perception of a sense of control about self-management of PWS and potential mistrust of official involvement. It is important to recognize that this suggests that some users of PWS may be less willing to engage with regulation and risk assessment of their supply, as well as reporting of health impacts or insufficiency.

5. Evidence on health inequalities related to the use of PWS: PWS are used across many parts of Wales, however their use is not evenly distributed, with use of PWS predominantly in rural areas. Although the full geographical distribution of PWS still needs to be identified and documented, from what is known, more rural communities are more likely to be using PWS than urban communities and are therefore more at risk of any associated health harms. The very limited data available on health harms potentially associated with PWS also support this, with greater evidence of reported GI disease and queries about environmental issues in more rural HBs (e.g., Powys UHS, Hywel Dda UHB and Betsi Cadwaladr UHB areas), though there are significant caveats to these data (see above).

   Limited evidence from the published literature also suggests that young children may be more at risk of illness from microbiological contamination of PWS. This is in keeping with the albeit limited available data from health protection records which show that children under 10 years old made up the greatest proportion of cases with GI disease that were recorded by PHW as also having used a PWS. that used a PWS (PHW data). Based on scientific understanding, rather than published evidence, more vulnerable adults (e.g., the elderly, those with underlying conditions) may potentially also be more at risk of these harms.

Finally, the published literature suggests that individuals who transiently use PWS (e.g., holiday-makers) may also be more at risk of the health harms associated with contaminated supplies. This could be for a number of potential reasons, including that regular users are taking greater precautions (e.g. boiling water); may be less likely to report health concerns; or through the potential for immunity through long-term exposure. These findings are also in keeping with the DWI Chief Inspector of Drinking Water's recent comments that, in Wales, 'the primary risk from contaminated private supplies is to children under ten years old, and an area of concern is holiday accommodation with such supplies where they may visit' (26).

There is insufficient evidence available to support greater understanding of other potential inequalities related to the use of PWS e.g. for gender, socio-economic status and ethnicity. However, it is important to recognize that many aspects of testing and maintaining PWS are likely to be costly and therefore this has the potential to create health inequalities related to users' economic ability to maintain a clean and plentiful supply.

6. Availability of data and evidence: we have identified significant limitations in the data available to support our understanding of PWS numbers and locations in Wales. We do not accurately know the size of the population served by PWS in Wales, as LA records (and thereby DWI records) do not record all PWS. There are currently no alternative data sources for this, however there is some published research which adds to our understanding, for example, on the proportion of PWS reliant on groundwater sources.

We also identified very limited published evidence about the health risks and harms associated with using PWS, particularly related to PWS in Wales. We did not identify any secondary (systematic review) level evidence and the available primary-level evidence was generally of lower methodological quality. There was particularly little published qualitative evidence on the views and perceptions of UK users of PWS. Finally, it is important to recognise that there are other recognised or potential risks to public health for which no significant evidence was identified for this review, but which should be considered going forward, for example, related to the potential impacts of exposure to fungi (45), biofilms, pesticides, microplastics, disinfection by-products. radon (46) and fittings in PWS. Beyond the published research literature, there is very limited available data to understand how users' health may have been

impacted in Wales. Data from health protection records are affected by inherent limitations (e.g., based only on those cases reported to health professionals and then notified to PHW, and on subjective assessments of whether a PWS may have been associated) and therefore do not represent a complete picture of those impacted. Another significant issue is a lack of data about individuals who developed GI disease after using a PWS in Wales but who then returned to their homes elsewhere (e.g., holidaymakers from England), as PHW may not always be aware of these cases. This may be particularly important given the identified published evidence about an association between transient users of PWS and previously reported outbreaks.

Conclusions and recommendations

This rapid review has highlighted significant data limitations, which impact on our ability to accurately assess the health risks and harms of using PWS in Wales. Under the current regulatory system, we cannot definitively identify: how many people in Wales use PWS; the exact location of these PWS; their underlying geology and water source; or any demographic characteristics or vulnerabilities of users. We are therefore limited in being able to understand how significant an issue the use of PWS is for public health. This evidence is needed to inform understanding of whether the current regulatory system on testing and risk assessing of supply is sufficient to protect the health of PWS users in Wales. It is also needed to further understand the extent to which climate change may impact associated health risks and harms, and the extent of any health inequalities related to their use.

Recommendation 1: PHW should advocate, to the Welsh Government and other partners in the Water Health Partnership, for the development of more accurate and complete records on PWS in Wales. This should include consideration of:

a. Whether any regulatory changes are needed to ensure information about all PWS in Wales are accurately collected, including on PWS location and risk assessments.

b. Any other approaches to increasing the number and accuracy of valid risk assessments completed and reported to the DWI, and to increasing the extent of other information that is collected by LAs. This should include enhanced information on vulnerability of supply e.g., previous episodes of insufficiency, any information on source of supply and underlying geology.

c. The use of data techniques or modelling, such as using water company records for locations not supplied with *public* water supplies, to identify likely locations of PWS.

This rapid review has identified that there is very limited available research evidence about the health risks and harms associated with the use of PWS in the UK, with even less evidence from Wales. Much of the available evidence comes from lower quality primary studies. There is also a lack of available evidence on the perceptions of PWS users, which is likely to be important for informing and underpinning any future work aimed at supporting users of PWS to protect their health. In response to this, there is a need to develop further, higher-quality, evidence on the health risks and impacts

associated with the use of PWS in the UK, in the context of a changing climate.

Recommendation 2: PHW should scope options for understanding and modelling the risks and burden of disease from PWS, including systems for linking health outcome data with the use of PWS.

Despite the limited quantity and quality of available evidence, there is published research evidence, including from Wales, that PWS are at risk of both microbiological and chemical contamination. This evidence suggests that there is a greater risk of microbiological contamination than in public water supplies. DWI records also show that there are a considerable number of PWS that are not being regularly tested or risk assessed to identify or prevent this contamination. There is also limited evidence from health protection records which suggest that there have been some risks to health and harms associated with the use of PWS in Wales, including for children. However, this is likely to represent a significant underestimate of the health risks and harms that PWS users in Wales may have experienced.

Recommendation 3: PHW should work with partners, through the Water Health Partnership, to consider development of mechanisms by which identification of an infection associated with a private water supply should trigger inspection, risk assessment or sampling of the supply, as appropriate.

PWS in Wales are known to supply some properties that are used by transient populations, for example holiday accommodation. There is some evidence from the published literature that transient users of PWS may be more at risk of health harms from the use of contaminated PWS. This may also be of particular concern for users who are more vulnerable e.g., pregnant women, younger children, or immunocompromised individuals. Importantly, in Wales, these users may be unaware that the water they are drinking is from a private water supply. This is in contrast to Scotland where there is a requirement that owners of commercial premises served by a private supply are required to display a poster to notify users (47).

Recommendation 4: PHW should recommend to Welsh Government that they consider whether further regulation is needed to ensure that owners of commercial PWS (e.g. holiday accommodation) make users aware if they are being served water from a PWS, so users can consider whether they need to take additional precautions to protect their health.

This rapid review has identified limited evidence on how climate change may impact the quality and quantity of water from PWS in Wales, through increased rainfall events and periods of drought. These could lead to greater levels of contamination and insufficiency of supply, which, in turn, have the potential to affect the physical and mental health and wellbeing of PWS users in Wales.

Recommendation 5: PHW should highlight to its partners (through work in the PHW Climate Change Programme Board, the Water Health Partnership, the Drought Liaison Group, and any other identified routes of advocacy) the likely vulnerability of PWS in Wales to the impacts of climate change, and the need for actions to adapt to and mitigate the effects of this.

Recommendation 6: PHW (including through the work of both its policy and health protection teams) should advocate, to Welsh Government, for consideration of regulatory changes so that PWS are included in processes related to building development, planning and sale of house regulations, in the same way that other services and utilities already are (e.g. sewerage).

During the development of this review, it has become evident that information for the public on PWS in Wales is currently limited and difficult to find. This includes information on testing regimens and regulation, as well as more general public health advice, which can currently only be found through multiple different websites / organisations. The published evidence identified in this review, though limited, also supports PWS users' perception of a need for clearer and more easily accessible information on PWS.

Recommendation 7: PHW should support partners, through the Water Health Partnership, to develop high quality, easy-read and evidence-based information on PWS in Wales. In developing this work, multi-agency partners should consider examples of similar information available in the UK and consider qualitative evidence / behavioural analysis techniques to inform what information users need, and how it should be best presented to increase accessibility. At a minimum, it should include information on potential health risks and harms associated with using PWS; factors which may make PWS more vulnerable to contamination; and available sources of financial support.

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