Design and designation of private water supply risk areas: Appendices

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Appendix 1: Regulations referring to private water supplies in Scotland

The private water supplies (PWS) in Scotland are regulated under the Private Water Supplies (Scotland) Regulations 2006. These regulations identify two types of supplies. Type A-PWS are defined as those serving more than 50 people or a commercial or public use. Type A supplies are further classified into A1, when serving less than 100 m3/day; A2, when serving between 100 and 1000 m3/day; and A3, when serving between more than 1000 m3/day. Type B-PWS are those serving fewer than 50 people for domestic purposes.

The PWS (Scotland) Regulations include provisions for the regulation of type A and B supplies.

- Monitoring type A-PWS: local authorities have the duty to collect and analyse samples from each such supply in their jurisdiction for the parameters referred to in Schedule 1. Sampling takes place on each individual supply at the tap in properties selected at random and at times representative of the quality of drinking water in an area. Sampling frequency depends on the volume of water supplies and parameter (Schedule 2), with audit monitoring taking place at least once a year although further samples may be collected for a parameter should the initial sample fail the parametric value. Certain parameters may be exempt from monitoring if the conditions reported in Schedule 3 of the Regulations are met.
- Monitoring type B-PWS: local authorities have the duty to collect and analyse samples from each such supply should the owners or users request it.
- Risk assessment: local authorities are required to risk assess type A-PWS from 'source to tap' as part of an effective drinking water monitoring programme (Part VI, R.16). The risk assessment should account for influences of geology and hydrology, meteorology and weather patterns, general catchment and river health, wildlife, competing water uses, land use pressures, other activities in the catchment that potentially release contaminants into source water, and planned future activities. Information on surface and groundwater characteristics is also required. Local authorities may also risk-assess type B supplies, whether or not on the request of a relevant person or consumer, taking into account the potential health risks associated with any Type B supply in their area (Part VIII, R.27).

The Drinking Water Quality Regulator has enforcing powers for public supplies and supervisory powers in relation to local authorities' duties for private water supplies. It publishes an annual report on public and private water supplies separately. The evidence published in these reports shows that water quality in type A-PWS is poorer than in public supplies (DWDR 2015).

Appendix 2. Occurrence of the trial parameters

Parameter	Source of drinking water contamination
Aluminium (Al)	Present in Al-containing rock, and in coal mining, industrial and municipal discharges (Poon 2012). Potentially present in all aquifers where or when pH is highly acidic or highly alkaline, and in peaty-environments (MacDonald and Dochartaigh 2005) Al use as a coagulant for water treatment often leads to higher concentrations of Al in the treated water than in the raw water itself. Al is used to enhance the removal of particulate, colloidal, and dissolved substances via coagulation processes. So it makes sense to expect that surface water has more particles that need to be removed before water reaches the tap (WHO 2011).
Arsenic (As)	Present in Ar-containing bedrock formations and related to volcanic and geothermal activity (WHO 2011). Derived from mining and smelting of metals, low-grade coal burning, used as pesticides in US, New Zealand, Australia mainly (Merian 1984)
Cadmium (Cd)	Cadmium is released to the environment in wastewater, and from fertilizers and local air pollution (e.g. Loganathan et al 2003). Contamination in drinking-water may also be caused by impurities in the zinc of galvanized pipes, solders, and some metal fittings (WHO 2011).
Chromium (Cr)	Chromium is naturally found in rocks, plants, soil and volcanic dust, and animals (WHO 2011). The major source of hexavalent chromium in drinking water is oxidation of naturally occurring chromium present in igneous geologic formations. There are locations where chromium compounds have been released to the environment via leakage, poor storage, or improper industrial disposal practices. Both trivalent and hexavalent chromium are very persistent in water (USEPA 2011). Hexavalent chromium has been primarily associated with groundwater, and to a lesser extent with surface water, even though total chromium has been found in both types of source waters (Frey 2004). However, most of Cr released into natural waters is particle associated, therefore ultimately deposited into the sediment (Smith et al 1995).
Nitrate (NO_3-)	The major sources of nitrate in drinking water are (MacDonald and Dochartaigh 2005; WHO 2011): runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits; leaching from forested areas; and from oxidation of nitrogenous waste products in sewage effluents, including septic tanks. Surface water nitrate concentrations can change rapidly owing to surface runoff of fertilizer, uptake by phytoplankton, and denitrification by bacteria. Groundwater concentrations generally show relatively slow changes.

Appendix 3.1 Policy context

Appendix 3.1.1 Terms and definitions applying to private water supplies

Definitions and terms relating to technical properties
Private water supplies can be defined as decentralised because of their location in rural, potentially remote areas, outwith any large or small standardised, centralised public water network (the 'mains') and because of the small scale systems for treatment/purification and water distribution (Peter-Varbanets et al 2009).

Definitions and terms relating to protection from source to tap
The United Nations (UN 2006) has defined 'improved' and 'unimproved' water supply systems in relation to the level of protection of drinking water from source to tap (Figure Appendix 3.1.1.a). Some private water supplies may be characterised as unimproved because they supply water from surface water sources or have a limited capacity for protection or control of contamination from source to tap.

Definitions and terms relating to availability of technical, human and financial resources
Some private water supplies may not have the resources required to operate a water supply sustainably and ensure safe water, thereby can be trapped in the 'circle of the three lows for small supplies' (Ford et al 2005):

- Low income (or subsidy) compared to operational cost.
- Low investment on infrastructure, maintenance, treatment, source protection, risk assessment or monitoring.
- Low compliance rates with water quality standards.

Definitions and terms relating to regulatory framework
Private water supplies are commonly subject to less stringent regulations than public water supplies (Ford et al 2005; Hendry and Akoumianaki 2016). For example, under the provisions of DWD a less frequent monitoring is applied in small supplies in European Union (EU) Member States (i.e. one to four times a year depending on the parameter) while there is no specific obligation for reporting to European Commission for water quality evaluations; see also Section 1.3.1.

Definitions and terms relating to volume of water and population served
In line with European Commission definition (European Commission 2015), private water supplies serving up to 5000 people a year can be defined as small water supplies. However, a variety of country-specific size-based definitions have been reviewed by Hendry and Akoumianaki (2016).

Definitions and terms relating to management and governance
Private water supplies can be considered as examples of the household-centred management model (also described as 'self-provision' or 'self-supply') applying to 'private wells' and individually-owned supplies. This model refers to simple improvements to water supplies that the owners of single or groups of domestic or commercial premises can finance and execute by using lower-cost technologies (Koppen et al 2007: 67; Sutton 2009). Self-provision usually applies to rural, sparsely populated areas.

The term community-operated refers to supplies that are managed under the community-based water supply management model. This model requires the ownership and operation of a water supply to be under the control of a civic group (e.g. a non-governmental organization-NGO, a community-owned corporation, or a cooperative) (Heivo & Anttiroiko 2014; van Montfort et al 2014). However, in terms of infrastructure, maintenance, financial support, training, and risk assessment, private water supplies may face similar challenges as small supplies managed under the community-based model. In this regard, the evidence on monitoring practise and risk assessment approaches applied in small community supplies can be considered as relevant to type A-PWS.

The terms 'community', 'municipal' or 'public' may refer to supplies that serve water to small rural communities, whereby a small number of households are connected by

Improved	Unimproved
Improved systems include piped water, water from public standpipes, boreholes, protected wells and springs, rainwater and bottled water. These systems provide natural or technical protection of water from catchment sources of contamination, have a protection zone around them, and distribute water through a well maintained piped network.	Unimproved sources would be unprotected wells and springs, water from vendors and tankers, and from surface waters. These systems are inadequately protected by catchment sources of contamination, rely on ineffective treatment systems and poorly maintained infrastructure, and expose users to the effects of livestock, farmland runoff, sewage overflows and any other sources of contamination.

Figure Appendix 3.1.1 Drinking water supply protection: improved and unimproved supplies (UN 2006).

the same distribution network or share the same source of water (WHO 2011). A local (municipality) or central government, or a public corporation (such as Scottish Water) may have the ownership and responsibility of this type of small supply (Bakker 2003; Rickert & Schmoll 2011; van Montfort et al 2014). Many small supplies (i.e. serving fewer than 5000 individuals a year) in rural areas are owned and managed by small community or municipal authorities, as in Scandinavian countries (Sorensen 2010; Gunnarsdottir 2012); France (Levraut et al 2013) and Austria (Klein 2009); or small municipal (public) corporations, as in Germany (Profile of the Drinking Water Sector 2015); and Estonia and Italy (EEA 2013) In this context, type A-PWS may share the same challenges with small community, municipal, and public supplies as regards technical properties, availability of resources, and monitoring regulations under the DWD but these supplies are managed under a different framework of regulations and governance.

It must be noted PWS are not related to supplies managed under the:

- Private, or market-based management, which refers mainly to large urban networks (utilities) owned and operated by private (for-profit) companies (Bakker 2016);
- Delegated private management, which may refer to large or relatively small supplies operated by private (for-profit) companies, subcontracted by public authorities, e.g. municipal supplies serving more than 3500 people in France (Levraut et al. 2013).

Appendix 3.1.2 Drinking Water Directive's (DWD) weaknesses that led to the Amendment

The DWD is the key instrument of drinking water policy and governance in the European Union (EU). It came to force in 1998 and has recently had amendments made to the technical annexes referring to monitoring and risk assessment (EU Directive 2015/1787, i.e. the Amendment), which are not yet in force. In this report the DWD is used to refer to the regulations currently in force.

The overarching goal of the DWD is to protect human health from the adverse effects of contamination by ensuring that water intended for human consumption is wholesome and clean. Its intervention logic, i.e. how it is expected to work (Better Regulation toolbox 41), is to address all possible contamination causes at raw water sources and from treatment and distribution materials by setting specific actions that have to be complied with, the most important being to:

- Set a maximum acceptable standard value (parametric value), prescribed in Art 5 and Annex I, for each material (parameter) in contact with drinking water.
- Put in place a monitoring across supply zones, i.e. areas of uniform water quality, according to Art 3 and Annex II, whereby monitoring applies for supply zones serving more than 50 people (or more than 10 m^3 of water), or a commercial or public activity (Art 3); stricter national regulations may apply. Monitoring frequency depends on volume of water supplied across a supply zone, and is lower for small than for large supply zones[1].
- Take remedial action or measures in case of non-compliance with the parametric values.
- Report water quality to European Commission (EC) data to inform both consumers and the EC. Obligation for reporting to EC applies to water supply zones serving more than 5000 people. It is submitted every three years by each Member State and covers information relating to: general water supply arrangements; non-compliances, exemptions, monitoring of supply zones, and alternative methods used by the Member States; and updates on the quality of water in different supply zones at a national level.

This report to EC is the most important source of information about the implementation of the provisions of the DWD at a national and EU level. The conclusions of the Synthesis Report on the implementation of the Drinking Water Directive 98/83/EC covering data from 2008 to 2010, which was adopted in June 2014 (European Commission 2014a; b), show that the major policy concerns refer to small systems (i.e. supplies serving fewer than 5000 people) and relate to:

- Lower microbiological compliance than in large systems.
- Low compliance with the monitoring frequencies stipulated in the DWD; this problem is further exacerbated by the low monitoring frequency specified for small supplies (i.e. once to four times a year) and in cases results in some supplies being sampled less than once a year. In addition, in one third of EU Member States the frequency of monitoring was below that required and insufficient to allow for a proper analysis of the risks and quality of drinking water in a given area.
- Incomplete data or inaccessible information.
- Inequalities regarding access to water.
- Unclear accountability in case of a disease outbreak.

In parallel, small supplies attracted the attention of the first full evaluation of the DWD's relevance with human health protection standards and citizen's expectations, and its effectiveness in achieving wholesome and clean water at the consumer's tap. This evaluation was carried out as a follow up action to the first European Citizen's Initiative

[1] The European Commission (EC 2015) has defined large supply zones as those serving more than 5000 people and small supply zones as those serving fewer than 5000 people.

(ECI) Right2Water (European Commission 2014c) and it was part of the Commission Work Programme 2015 (REFIT 2016). The final evaluation was also supported by public and stakeholder consultations, targeted interviews with relevant actors and literature review as part of the EU project Safe2Drink (Klaassens et al 2016).

The results of the evaluation confirmed that the DWD fulfils its overarching purpose to ensure wholesome and clean drinking water, mainly in large supply zones (Klaassens et al 2016; REFIT 2016). In particular, the DWD has:

- Clearly improved compliance of parameters derived from piping and fittings (especially copper and lead), or from the treatment of water after abstraction, mainly due to the provisions of Art 5 and Art 10[2].
- Helped to reduce exceedances of naturally-occurring arsenic in deep groundwater, and probably other substances related to bedrock geochemistry, by detecting contaminated sources.
- Accelerated the chances of early detection of industrial spills and microbiological non-compliances related to accidental contamination of the water distribution network in large supplies.
- Been coherent with the Directive for control of pollution caused by nitrates from agricultural sources (Directive 91/676/EEC) and the Directive on environmental quality standards in the field of water policy (Directive 2008/105/EC), which are aligned with Annex I of the DWD and have thus contributed to producing safe raw drinking water.

However, the consultations and literature reviews also found weaknesses, particularly in relation to small supplies (Klaassens et al 2016; REFIT 2016):

- In relation to parameters, the DWD has not assessed whether the water quality parameters and values specified in Annex I remain up-to-date with latest scientific knowledge and emerging pressures. For example, certain substances with high or even 100% compliance rates may be 'false friends' in the case that they do not occur in the drinking water of some areas, or are not captured through the once-a-year sampling carried out in small supply systems.
- With regard to preventive, risk-based approaches, the DWD has not included the water safety plan (WSP)[3] approach to align with the guidance presented by the World Health Organisation (WHO) in 2011. This is especially important for small supplies, where monitoring frequency is insufficient to reliably capture non-compliances.
- With respect to the designation and monitoring of drinking water protection areas under the Water Framework Directive (2000/60/EC) (Figure Appendix 3.1.2), the DWD has not integrated into its main body the requirement for catchment protection and monitoring.

The EU's WFD (Directive 2000/60/EC) is widely recognised as the overarching water policy instrument in the European Union for protecting and restoring the water environment across EU Member States. It requires that all surface waterbodies and bodies of groundwater, including waters intended for human consumption, achieve the objective of 'good status' by means of six-yearly River Basin Management Plans (RBMPs). Water management under WFD is implemented at the scale of river catchments and nested waterbodies, the natural hydrological units for fresh waters. 'Good status' of surface waterbodies is based on the overall ecology of waterbodies, taking account of biological, chemical and hydro-morphological characteristics. 'Good status' of groundwater waterbodies is based on quantitative and chemical characteristics. Certain WFD goals are explicitly related to monitoring at areas of production and abstraction of drinking water:

Article 7 prescribes the threshold of 10 m^3 / 50 persons above which all abstraction points for drinking water must be identified and mapped as a 'protected area' to enable water treatment to be cost-effectively reduced; it also requires that Member States monitor waterbodies that will provide more than 100 m^3 / day of drinking water on average.

Article 8 refers to monitoring of surface water status, groundwater status and protected areas, including areas for the abstraction of drinking water (in accordance with Article 7). Waterbodies designated as monitoring sites for drinking water protected areas shall be monitored for all priority substances discharged and all other substances discharged in significant quantities which could affect the status of the body of water and which are controlled under the provisions of the DWD.

Figure Appendix 3.1.2. The Water Framework Directive and its provisions related to drinking water.

[2] Art. 10 of the DWD requires all Member States to take all measures necessary to ensure that no substances from new products in contact with drinking water remain in drinking water.

[3] Risk-assessment aims to prevent and control contamination from source to tap and provide systematic evidence to water supply users. The WSP approach is a continuous management of risks and can help target time and resources on risks that matter, thus enabling the burden of analyses on non-occurring parameters to be avoided or gradually reduced (WHO 2011). As such, it is pivotal in the management of small supplies, which are generally sampled at an insufficient monitoring frequency (WHO 2012).

- As regards monitoring of small supplies, the DWD has not ensured sufficient protection of human health for users of small supplies. Since the events leading to faecal contamination and chemicals in water are temporally variable, it is evident that the once-a-year or fixed date low frequency monitoring does not truly guarantee protection from contamination.
- As to reporting, the DWD has not ensured a template for year-to-year reporting for all supplies to enable systematic assessment of water quality problems on a national and EU basis. The Guidance Document on Reporting under the DWD indicates that the data is required to be prepared annually and submitted with the general report every three years but it does not indicate a clear objective in the reporting procedure.

The evaluation of the DWD and evidence of the shortcomings of compliance monitoring formed the background to the adoption of the revisions on monitoring, specified in the Amendment. This latter has addressed the DWD's weaknesses by making specific reference in the Preamble to risk assessment and catchment monitoring, as follows:

- Annex II specifying monitoring frequencies of the DWD should be aligned with the water safety plan (WSP) approach, developed by the WHO (2011) and the EN 15975-2 standard (2013) concerning security of drinking water supply.
- The potential risk for drinking water before and after treatment should be determined on the basis of the monitoring data collected under Article 7 for bodies that provide more than 100 m3 drinking water a day on average and Article 8 of the WFD (see Box 2).

As the Amendment was adopted about a year before the publication of the final reports on the evaluation of the DWD, a brief evaluation of its potential effectiveness was included in the REFIT and Safe2Drink reports (REFIT 2016; Klassens et al 2016). Accordingly, the introduction of risk-based monitoring and the link with catchment management provisions under the WFD have been welcomed as a step forward in improving the DWD's effectiveness and coherence with EU water policy and legislation However, the authors of the REFIT and Safe2Drink reports were disappointed that there was no provision in the Amendment for integrating the risk assessment in the main body of the DWD (REFIT 2016; Klassens et al 2016). This would mean having to include prevention of contamination from source to tap and document evidence relating to risks and controls in a systematic way, as in the WHO (2011) guidelines for the WSP approach. Combining monitoring under Art. 7 of WFD to test water quality compliance in drinking water protected areas and tap water supply monitoring (once to four times a year in small supplies) are part of risk assessment, but are not preventative measures. As a result of this, the REFIT and Right2Drink reports concluded that the benefit from using credible data on risk assessment to reduce monitoring regime remains unclear.

Appendix 3.1.3 The Amendment and monitoring in small supplies

A major consideration refers to the Amendment's requirement for establishing a reduced monitoring programme on the basis of at least three years of data from sampling points representative of the whole supply zone. The general practise in Member States is to define water supply zones in their regulations in the context of a water utility (Box 3). This is because utilities have to address the customer's desire for uniform drinking water quality at all times, regardless of seasonal changes in water availability and quality, and changes in demand (Kirmeyer 2000). Thus utilities have to standardise and centralise the operations to maximise uniformity, control, and coordination, as well as to reduce cost (Bakker 2016). Therefore, the provision for representativeness is easy to apply to small supplies provided that there is a shared distribution network and centrally applied treatment.

However, there is a variety of arrangements for small supply-systems across Europe ranging from small municipal supply zones to single premises serving water as part of a commercial/public activity, to supplies serving properties that are not interconnected through a common distribution network (Hulsmann 2005; Rickert and Schmoll 2011; Hendry and Akoumianaki 2016). To reflect this diversity, the 2014 Synthesis Report uses the term small supply zones and small supplies interchangeably (European Commission 2014a; b). In addition, the definition of water supply zones in the DWD (Figure Appendix 3.1.2) does not require a supply zone to be identified on the basis of uniform technical characteristics (i.e. a standardised water distribution network supplying centrally treated water) for a specified population size.

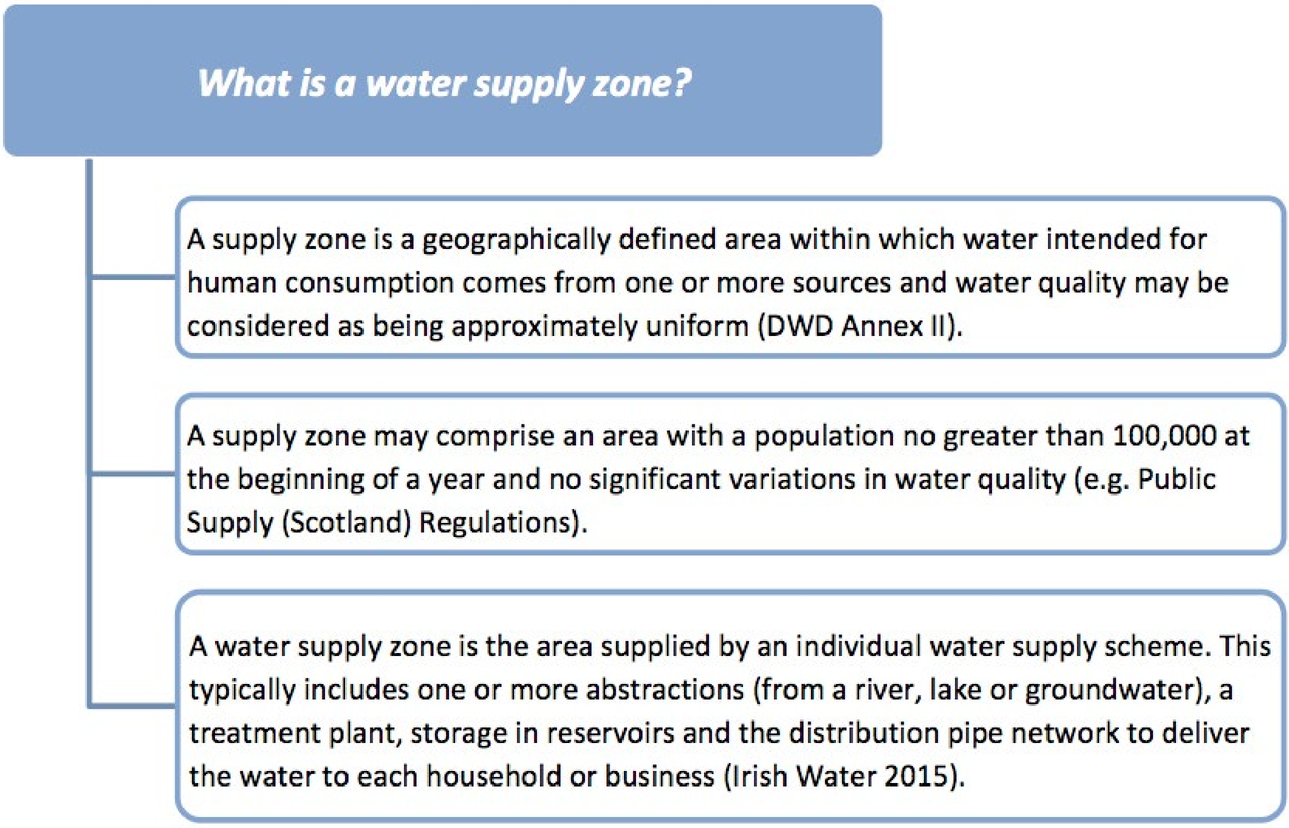

Figure Appendix 3.1.3 Definitions of water supply zones.

Identifying uniform conditions and representative points of sampling for small supplies dispersed in a given geographic area is not a straightforward task. Type A-PWS are sampled individually, however close they may be located. In addition, it is unknown to what extent individual technical characteristics, handling, and maintenance practices would influence the quality of water of private water supplies located in the same area and potentially being subject to the same catchment risks and factors. Also, there is no obligation on local authorities for a uniform reporting protocol or for analysis of spatial patterns in occurrences of concentrations for certain or all parameters. These considerations show that water quality conditions in private water supplies and small water supplies in the EU in general, remain largely unmapped. Therefore, finding reliable criteria on how to identify the areas where concentrations are below the 30% of the parametric value (the 30% threshold), in accordance with the Amendment's provision, can be difficult for private water supplies.

An additional limitation of the Amendment's provisions is related to the provisions of Art 7 of WFD. There is no obligation for waterbody monitoring where less than 100 m3 of water a day is abstracted for human consumption. However, the volume of water per private water supply in the UK is not documented per waterbody. Therefore, it is uncertain whether designation of drinking water protected areas has accounted for the volume abstracted by private water supplies. The monitoring of waterbodies used for the abstraction of less than 100 m^3 /day remains unaddressed.

Appendix 3.1.4 The Amendment and data from private water supplies

The DWD's weaknesses related to risk-assessment and reporting for small supplies have already been addressed in the regulations for private water supplies in Scotland (Appendix 1 –this report). Firstly, the Private Water Supply (Scotland) Regulations (2006) place a duty on local authorities to conduct a risk assessment and, once they spot risks and failures, to liaise with owners and /or users of the supplies in defining a holistic and sustainable approach to control risks (Appendix 1). There is detailed guidance on risk assessment available to local authorities in Scotland (Scottish Executive 2006); see also related information for England (DWI 2016) and for Wales on local authority web sites. Secondly, the DWQR publish an annual report on the quality of water served by private water supplies. These reports are online and open-access to the general public and have documented rates of compliance with specified standards, monitoring frequency requirements, and risk assessment obligation.

However, there are major limitations in the relevance of the risk assessment results and the annual reports with the goal of the DWD. These are summarised here:

(i) The risk assessment collects qualitative evidence based on inspections and visual observations of the factors potentially influencing the supply system from catchment to tap, but it does not include measurements or evidence about actual concentrations of parameters at the source.

(ii) There is no obligation for local authorities to integrate compliance monitoring data and risk-assessment results and report them on a local authority level, or analyse the results on a national level to draw conclusions on the factors influencing non-compliances of specific parameters measured in private water supplies in a given area.
(iii) The annual reports provide little or no information on temporal and spatial patterns of water quality non-compliances. As for risk assessment, these reports give little or no information on the results of the risk assessments in a given geographic area.

Appendix 3.2. Research considerations for PWS monitoring in UK

This is a brief review of research findings and recommendations on the monitoring of private water supplies in the UK. Overall, there is much more evidence on microbiological sampling as compared to chemical sampling.

Monitoring considerations for chemical parameters
It is widely known that the concentrations of many chemicals depend on groundwater geochemistry. In general, the concentrations of naturally occurring chemicals in private water supplies are expected to be aligned with available spatial groundwater geochemical information[4] (WHO 2011). Concentrations of chemicals in the tap water of private water supplies are also influenced by certain anthropogenic factors. Compliance monitoring should account for all these factors.

Firstly, domestic treatment of water can reduce substantially, if properly applied and maintained, the concentrations of naturally-occurring trace metals. For example, treatment for low pH can reduce the concentrations of aluminium, cadmium, copper, lead, and nickel, and treatment for iron and manganese can reduce arsenic concentrations (e.g. Ander et al 2016).

Secondly, over-pumping can cause saline intrusion in coastal areas, as observed in some areas in Scotland (e.g. Dochartaigh et al 2006). Saline intrusion may also be due to natural processes. However naturally or anthopogenically derived, it is largely unknown how it may affect concentrations of sodium and chloride in private water supplies.

Thirdly, rainfall and the hydrological regime in a given area are key factors for the transport of chemicals. However, evidence on the dependence of chemical concentration in drinking water on location and time of sampling is not available for all chemical parameters sampled in private water supplies. For instance, failure in nitrates in drinking water was found to be related to direct contamination of groundwater sources but was not linearly related to rainfall in Aberdeenshire, Scotland (Reid et al 2003). Iron, manganese, aluminium and lead from spring-served private water supplies in England were also found to be influenced by rainfall and atmospheric pollution from nearby industrial land use (Petrie et al 1994).

Finally, a key process of contamination is trough leaching of chemicals derived from catchment activities such as agricultural practices or the disposal of domestic and industrial wastes (Lilly et al 2003a; b; Dochartaigh et al 2005; Carey and Thursten 2014). The tendency and likelihood of general contaminants reaching the water table within the uppermost aquifer after introduction on the ground surface is defined as groundwater vulnerability (e.g. Dochartaigh et al 2005). The concept of vulnerability recognises that the risks of pollution from a given activity are greater in certain hydrological, geological and soil situations (Dochartaigh et al 2005; Carey and Thursten 2014). Accounting for groundwater vulnerability is key to implementing the groundwater protection aspects of WFD, and as such to controlling the quality of water served by private water supplies. Mapping methods have been developed separately, but underpinned by the same principles, in Scotland (Dochartaigh et al 2005) and England and Wales (Carey and Thursten 2014). These maps show that:

- Groundwater is most vulnerable to catchment factors where fractured aquifers with a shallow water table are overlain by a thin cover of superficial deposits and/or soil. It can be concluded that private groundwater supplies in such areas are at high risk from contamination from agricultural practices and the disposal of domestic and industrial wastes, regardless of protection measures at abstraction point.
- Groundwater is least vulnerable in areas where aquifers are protected by a thick unsaturated zone (deep water table) and a thick cover of low permeability clayey superficial deposits.

[4] In Scotland, recent and detailed data sets have been compiled as part of Baseline Scotland, a joint project between BGS and SEPA seeking to provide new groundwater chemistry data for Scotland for sustainable water resource management, but results are not available yet in a spatial format that could inform the identification of risk areas for private water supplies (Dochartaigh et al 2015). Similarly, groundwater chemistry data in selected aquifers of England and Wales has been compiled by BGS and the Environment Agency and presented in a synthesis report by Shand et al 2007. More recent regional reports are also available on line in Baseline England and Wales (n.d.).

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- Groundwater is least vulnerable in areas where aquifers are protected by a thick unsaturated zone (deep water table) and a thick cover of low permeability clayey superficial deposits.

Monitoring considerations for microbiological parameters

Fewtrell and Kay (1996) demonstrated that annual or multiannual monitoring frequencies have little potential to characterise the bacteriological quality of private water supplies. Several studies in England and Scotland stressed that microbiological sampling should account for seasonality in rainfall regime (Rutter et al 2000; Reid et al 2003; Kay et al 2007; Richardson et al 2009) and the number of sheep (or generally livestock) in the area (Richardson et al 2009). Inadequate disinfection is an additional risk factor (Keevil 2000; Richardson et al 2009); however, Rutter et al (2000) showed that chlorination, filtration or UV light improved bacteriological quality of supplies but did not remove the need for sufficient monitoring frequency for early detection of microbiological non-compliances.

Several studies showed that routine (i.e. fixed date) monitoring is insufficient to capture the episodic nature of pathogen contamination (Petrie et al 1994; Shepherd & Wyn-Jones 1997; Fewtrell et al 1998; Kay et al. 2007). Surveys in England and Scotland found that microbiological samples were more likely to fail in supplies served by springs or surface water than by groundwater sources (Petrie et al 1994; Lilly et al 2003a; b; Richardson et al 2009). Lilly et al. (2003a; b) found that the sources that were surrounded by agricultural land as opposed to woodland or moorland were more likely to be contaminated and there was a greater degree of contamination on the more fertile agricultural land. These authors also found that microbial contamination of wells and boreholes may be induced by surface flow during heavy or prolonged rainfall and that soil leaching potential may play an important role depending on local conditions (Lilly et al 2003a; b). In areas of high groundwater vulnerability travel time of microbial contaminants to the water table would be faster than their degradation rate, thus leading to microbial contamination of groundwater bodies (Dochartaigh et al 2005).

Recommendations for alternative monitoring

The importance of risk assessment and event-based sampling for early detection of any exceedances in both chemical and microbiological parameters has also been emphasised. For example, Kay et al. (2007) recommended adopting the risk-assessment paradigm in the regulation of private water supplies in combination with event-based sampling to reliably indicate the presence of microbial contamination. Likewise, Clapham (2004) suggested that sampling programmes should always take into account the known effects of rainfall rather than collecting samples randomly and that microbiological samples should be collected when the supply is likely to be at its worst.

The suggestion for event-based monitoring is corroborated by studies showing that random sampling, as currently implemented in the UK under the provisions of the DWD, generates a general microbiological failure rate of about 30 per cent in the UK (e.g. Rutter et al 2000). Clapham (2004) asserts that under a compliance monitoring programme accounting for the risk of rainfall, the percentage of failures would be much higher. This is because microbiological samples collected outwith rainfall events are most likely to be false negatives (Clapham 2004; Kay et al. 2007; Richardson et al 2009). Thus routine monitoring fails to record reliably the potential risks to human health. However, there is no explicit recommendation on the number of events required to be sampled to ensure that exceedances of standards in microbiological and chemical parameters are captured reliably.

Appendix 4.1. Trials: Type A-PWS data per number of years per local authority

Aluminium (Table Appendix 4.1.1):

In Highland, only one out of the 158 supplies sampled for Al during the study period, was sampled for three or more than three years; 155 supplies were sampled only once during the study period. In Aberdeenshire, only seven out of 184 supplies sampled for Al during the study period, were sampled for three or more years; 130 supplies were sampled only twice during the study period. In Scottish Borders only one out of 86 supplies were sampled for three or more years for Al. However, in Moray, Fife and Argyll and Bute more than half of the type A-PWS sampled during the study period were sampled for three or more years for Al.

Table Appendix 4.1.1. Aluminium data per number of years per local authority in type A-PWS.

Local authority / Aluminium	2009-2015	1 year	2-years	≥ 3 years
Aberdeenshire	184	47	130	7
Angus	1	0	0	1
Argyll and Bute	426	44	33	349
Clackmannanshire	2	1	1	0
Eilean Siar	7	6	1	0
Dumfries & Galloway	80	55	13	12
East Ayrshire	2	0	2	0
East Lothian	6	1	0	5
East Renfrewshire	2	2	0	0
Falkirk	1	1	0	0
Fife	29	5	2	22
Highland	158	155	2	1
Inverclyde	6	2	3	1
Midlothian	5	1	2	2
Moray	97	6	10	81
North Ayrshire	4	4	0	0
Orkney	25	11	9	5
Perth & Kinross	97	84	8	5
Renfrewshire	4	2	0	2
Scottish Borders	86	72	13	1
Shetland	1	1	0	0
South Ayrshire	19	8	5	6
South Lanarkshire	14	6	2	6
Stirling	2	2	0	0
West Dunbartonshire	6	2	1	3
West Lothian	10	0	1	9
All	1274	518	238	518

Nitrate (Table Appendix 4.1.2):
In Highland, only three out of the 317 supplies sampled for nitrate during the study period, was sampled for three or more than three years; 271 supplies were sampled only once during the study period. In Perth and Kinross, only nine out of 127 supplies sampled for nitrate during the study period, were sampled for three or more years; 91 supplies were sampled only once during the study period.

In Scottish Borders 89 out of 317 supplies sampled for nitrate during the study period, were sampled for three or more years. In Aberdeenshire 171 out of 317 sampled for nitrate during the study period, were sampled for three or more years.

Table Appendix 4.1.2. Nitrate data per number of years per local authority in type A-PWS.

Local authority / Nitrate	2009-2015	1 year	2-years	≥ 3 years
Aberdeen City	2	0	2	0
Aberdeenshire	203	18	14	171
Angus	17	14	0	3
Argyll and Bute	438	42	33	363
Clackmannanshire	3	0	0	3
Eilean Siar	6	4	2	0
Dumfries & Galloway	134	69	24	41
East Ayrshire	2	2	0	0
East Dunbartonshire	1	1	0	0
East Lothian	6	1	0	5
East Renfrewshire	2	2	0	0
Falkirk	1	1	0	0
Fife	30	3	1	26
Highland	317	271	43	3
Inverclyde	6	1	4	1
Midlothian	5	1	2	2
Moray	97	8	8	81
North Ayrshire	5	4	0	1
Orkney	10	9	1	0
Perth & Kinross	127	91	27	9
Renfrewshire	4	2	0	2
Scottish Borders	131	22	20	89
Shetland	1	1	0	0
South Ayrshire	20	1	3	16
South Lanarkshire	23	3	1	19
Stirling	20	17	3	0
West Dunbartonshire	6	2	0	4
West Lothian	10	0	1	9
All	1627	590	189	848

Arsenic (Table Appendix 4.1.3):
In Highland, only one out of the 261 supplies sampled for arsenic during the study period, was sampled for three or more than three years; 248 supplies were sampled only once during the study period.

In Perth and Kinross, only five out of 97 supplies sampled for arsenic during the study period, were sampled for three or more years; 84 supplies were sampled only once during the study period.

Table Appendix 4.1.3. Arsenic data per number of years per local authority in type A-PWS.

Local authority / Arsenic	2009-2015	1 year	2-years	≥ 3 years
Aberdeenshire	159	59	70	30
Angus	15	13	0	2
Argyll and Bute	426	44	34	348
Clackmannanshire	2	1	1	0
Eilean Siar	3	3	0	0
Dumfries & Galloway	113	106	5	2
East Ayrshire	2	2	0	0
East Dunbartonshire	1	1	0	0
East Lothian	6	1	0	5
East Renfrewshire	2	2	0	0
Falkirk	1	1	0	0
Fife	20	11	3	6
Highland	261	248	12	1
Inverclyde	6	2	4	0
Midlothian	3	3	0	0
Moray	50	44	6	0
North Ayrshire	4	4	0	0
Orkney	7	6	1	0
Perth & Kinross	97	84	8	5
Renfrewshire	4	2	0	2
Scottish Borders	118	85	29	4
Shetland	1	1	0	0
South Ayrshire	19	8	5	6
South Lanarkshire	11	4	1	6
Stirling	1	1	0	0
West Dunbartonshire	6	2	0	4
West Lothian	10	0	1	9
All	1348	738	180	430

Cadmium (Table Appendix 4.1.4):
In Highland, only one out of the 259 supplies sampled for cadmium during the study period, was sampled for three or more than three years; 246 supplies were sampled only once during the study period.

In Perth and Kinross, only one out of 92 supplies sampled for cadmium during the study period, were sampled for three or more years; 87 supplies were sampled only once during the study period.

Table Appendix 4.1.4. Cadmium data per number of years per local authority in type A-PWS.

Local authority / Cadmium	2009-2015	1 year	2-years	≥ 3 years
Aberdeenshire	156	61	68	27
Angus	15	14	0	1
Argyll and Bute	426	44	34	348
Clackmannanshire	2	1	1	0
Eilean Siar	3	3	0	0
Dumfries & Galloway	110	104	4	2
East Ayrshire	2	2	0	0
East Dunbartonshire	1	1	0	0
East Lothian	6	1	0	5
East Renfrewshire	2	2	0	0
Falkirk	1	1	0	0
Fife	11	10	1	0
Highland	259	246	12	1
Inverclyde	6	2	4	0
Midlothian	3	3	0	0
Moray	50	43	6	1
North Ayrshire	4	4	0	0
Orkney	7	6	1	0
Perth& Kinross	92	87	4	1
Renfrewshire	4	2	0	2
Scottish Borders	124	77	35	12
Shetland	1	1	0	0
South Ayrshire	19	8	5	6
South Lanarkshire	11	4	1	6
Stirling	7	7	0	0
West Dunbartonshire	6	2	0	4
West Lothian	10	0	1	9
All	1338	736	177	425

Chromium (Table Appendix 4.1.5):
In Aberdeenshire, none of the 94 supplies sampled for chromium during the study period, was sampled for three or more years; 93 supplies were sampled only once during the study period.

In the Scottish Borders, only three out of 118 supplies sampled for chromium during the study period, were sampled for three or more years; 86 supplies were sampled only once during the study period.

Table Appendix 4.1.5. Chromium data per number of years per local authority in type A-PWS.

Local authority / Chromium	2009-2015	1 year	2-years	≥ 3 years
Aberdeenshire	94	93	1	0
Angus	15	14	0	1
Argyll and Bute	426	44	34	348
Clackmannanshire	2	1	1	0
Dumfries & Galloway	106	100	4	2
East Ayrshire	2	2	0	0
East Dunbartonshire	1	1	0	0
East Lothian	6	1	0	5
East Renfrewshire	2	2	0	0
Falkirk	1	1	0	0
Fife	12	11	1	0
Highland	256	243	12	1
Inverclyde	6	2	4	0
Midlothian	3	3	0	0
Moray	50	44	6	0
North Ayrshire	4	4	0	0
Orkney	7	6	1	0
Perth and Kinross	89	84	4	1
Renfrewshire	4	2	0	2
Scottish Borders	118	86	29	3
Shetland	1	1	0	0
South Ayrshire	19	8	5	6
South Lanarkshire	11	4	1	6
Stirling	8	8	0	0
West Dunbartonshire	6	2	0	4
West Lothian	10	0	1	9
All	1259	767	104	388

Appendix 4.2. Trials: Statistical analyses at the waterbody scale

Aluminium

There were 410 **surface water** type A-PWS distributed in 205 surface waterbodies overall. During the study period 155 surface waterbodies supported up to two surface type A-PWS, the remainder containing a varying number between 3 and 15 of surface supplies (Figure Appendix 4.2.1a). Less than half (192) of the total number of type A supplies were sampled for three or more years for aluminium and not in the same waterbody. There were 864 **groundwater** type A-PWS distributed in 157 groundwater waterbodies overall. During the study period 90 groundwater bodies supported up to two surface type A-PWS, the remainder containing a varying number between 3 and 70 of groundwater supplies (Figure Appendix 4.2.1b). Only 326 groundwater type A supplies were sampled for three or more years for aluminium and not in the same waterbody.

Nitrate:

There were 524 **surface water** type A-PWS, distributed in 304 surface waterbodies overall. During the study the majority of surface waterbodies (254 out of 304) contained up to two surface water type A-PWS, the remainder containing a varying number between 3 and 11 supplies period (Figure Appendix 4.2.2a). Less than half (223) of the total number of these supplies were sampled for three or more years for nitrate and not in the same surface waterbody. There were 1103 **groundwater** type-PWS, i.e. wells, boreholes or springs, in 173 groundwater bodies overall. During the study period, more than half groundwater waterbodies (93 out of 172) contained up to two type A-PWS sampled during the study period, the remainder containing a varying number between 3 and 75 supplies (Figure Appendix 4.2.2b). 625 groundwater type A-PWS were sampled for three or more years for nitrate.

Arsenic:

429 **surface water** type A-PWS, distributed in 249 surface waterbodies were sampled for arsenic overall. During the study 208 contained up to two surface water type A-PWS, the remainder containing a varying number between 3 and 15 supplies period (Figure Appendix 4.2.3a). Less than half (185) of the total number of these supplies were sampled for three or more years for nitrate and not in the same surface waterbody. 919 **groundwater** type-PWS in 157 groundwater bodies were sampled for arsenic overall. During the study period, 89 groundwater waterbodies supported up to two type A-PWS, the remainder containing a varying number between 3 and 70 supplies (Figure Appendix 4.2.3b). Only 245 groundwater type A-PWS were sampled for three or more years for arsenic.

Cadmium:

434 **surface water** type A-PWS, distributed in 254 surface waterbodies were sampled for cadmium overall. During the study period 212 surface waterbodies contained 2 surface water type A-PWS, the remainder containing a varying number between 3 and 15 supplies period (Figure Appendix 4.2.4a). Less than half (186) of the total number of these supplies were sampled for three or more years for cadmium and not in the same surface waterbody. 904 **groundwater** type-PWS in 158 groundwater bodies were sampled for cadmium overall. During the study period, 90 groundwater waterbodies supported up to two type A-PWS, the remainder containing a varying number between 3 and 70 supplies (Figure Appendix 4.2.4b). Only 239 groundwater type A-PWS were sampled for three or more than three years for cadmium.

Chromium

423 **surface water** type A-PWS, distributed in 244 surface waterbodies were sampled for chromium overall. During the study period 202 surface waterbodies contained up to two surface water type A-PWS, the remainder containing a varying number between 3 and 15 supplies period (data not shown). Less than half (182) of the total number of these supplies were sampled for three or more years for chromium and not in the same surface waterbody. 836 **groundwater** type-PWS in 157 groundwater bodies were sampled for chromium overall. During the study period, 93 groundwater waterbodies supported 2 type A-PWS, the remainder containing a varying number between 3 and 70 supplies (data not shown). Only 206 groundwater type A-PWS were sampled for three or more years for chromium.

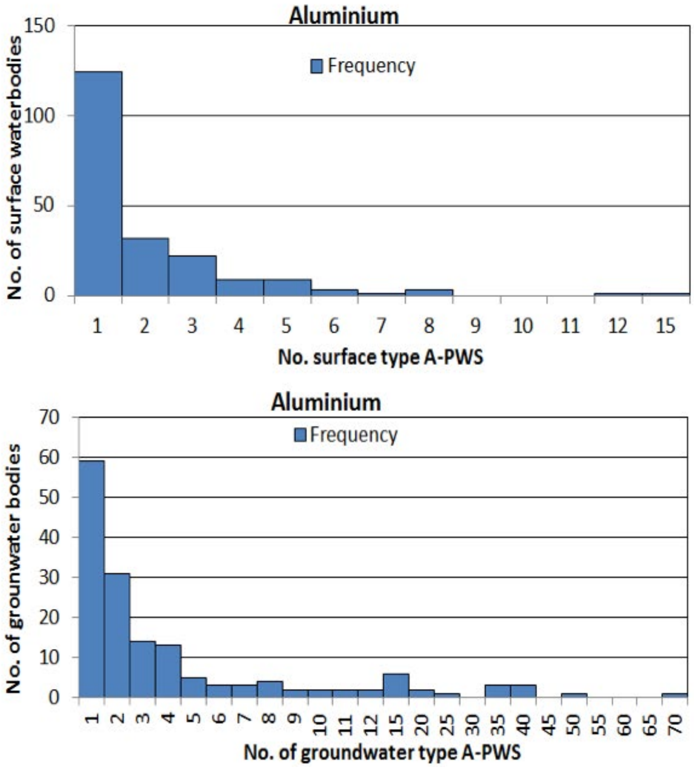

Figure Appendix 4.2.1 Number of type A-PWS by type of water source (horizontal axis) per number of waterbodies (vertical axis) sampled for aluminium from 2009 to 2015. (a) Surface type A-PWS in surface waterbodies, (b) Groundwater type A-PWS in groundwater bodies.

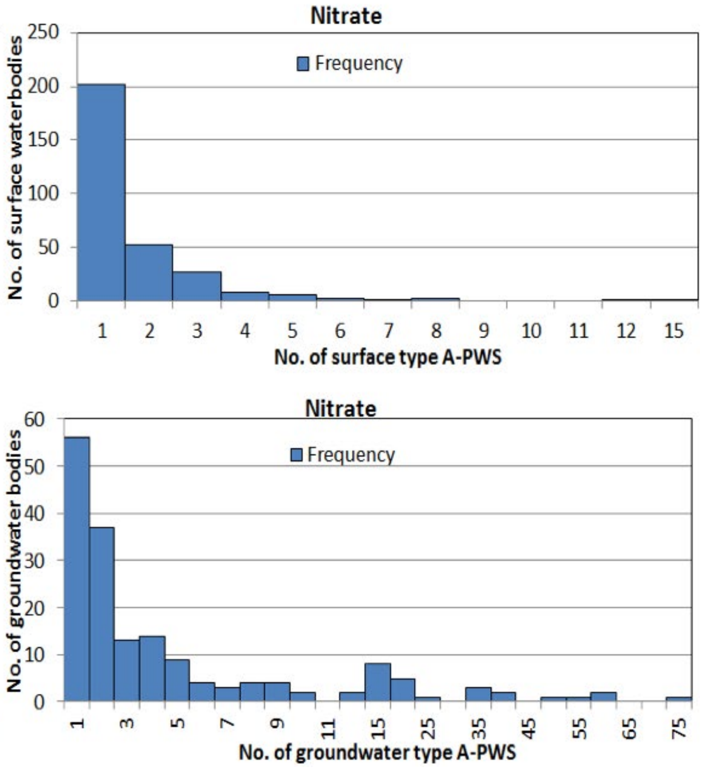

Figure Appendix 4.2.2 Number of type A-PWS by type of water source (horizontal axis) per number of waterbodies (vertical axis) sampled for nitrate from 2009 to 2015. (a) Surface type A-PWS in surface waterbodies, (b) Groundwater type A-PWS in groundwater bodies.

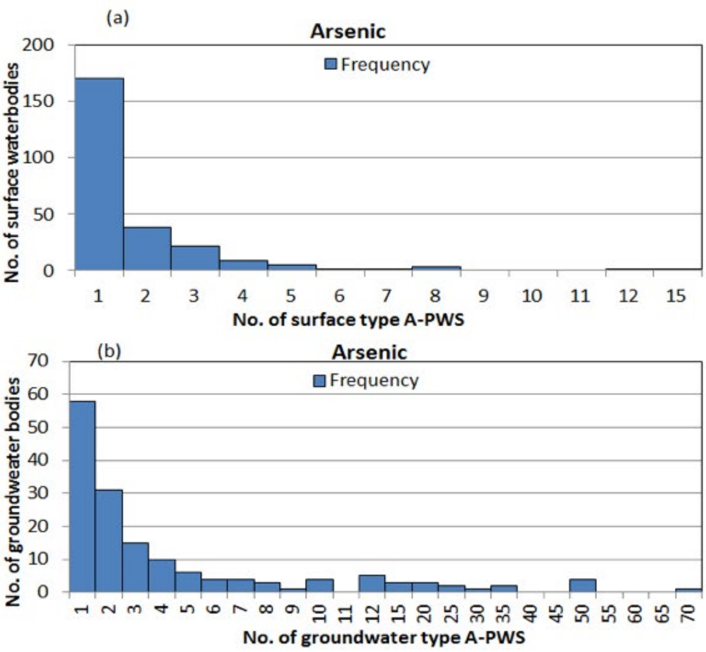

Figure Appendix 4.2.3 Number of type A-PWS by type of water source (horizontal axis) per number of waterbodies (vertical axis) sampled for arsenic from 2009 to 2015. (a) Surface type A-PWS in surface waterbodies, (b) Groundwater type A-PWS in groundwater bodies.

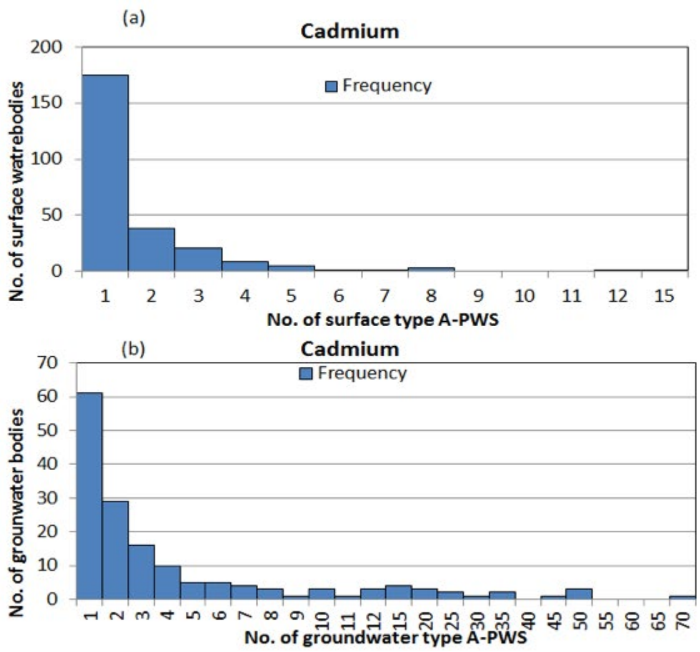

Figure Appendix 4.2.4 Number of type A-PWS by type of water source (horizontal axis) per number of waterbodies (vertical axis) sampled for cadmium from 2009 to 2015. (a) Surface type A-PWS in surface waterbodies, (b) Groundwater type A-PWS in groundwater bodies.