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Design and designation of private water supply risk areas

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Research Summary

Research Questions

- Is it feasible to develop a method that targets monitoring of type A private water supplies to areas where concentrations of catchment-derived parameters may pose a risk to human health? How?
- Which parameters are best suited to risk-based monitoring?
- What are the implications?

Key findings

- A practical weight-of-evidence method has been developed to identify where the risk of contamination of the water served by type A- private water supplies (PWS) is greatest in relation to catchment influences and parameter concentration occurrences to inform risk-based monitoring.
- The method links the location of type A-PWS with waterbodies (surface and groundwater) and applies to parameters for which concentration data are available from (i) type A-PWS[1] monitored at tap water under the Drinking Water Directive (DWD), and (ii) waterbodies monitored at the catchment scale under the Water Framework Directive (WFD). The method also allows for literature data to be incorporated.
- For a parameter to be removed from monitoring in a given area, two criteria should be met:
  - o A statistical criterion: the upper 95% confidence limit for the probability of concentrations exceeding the threshold (30% of the parametric value during 2009-2015) should be less than 5% in a given area (i.e. waterbody, local authority and region).
  - o A spatial criterion: a parameter's concentrations should be below the 30% of the parametric value (i.e. the 30% threshold) and no pressures, monitored or known from literature, should be present in a given area (i.e. waterbody, local authority and region). This can be visualised through risk maps.
- Trials on five parameters (aluminium, nitrate, arsenic, cadmium and chromium) show that data from many local authorities are insufficient for reliable estimates of the statistical criterion. This is due to the majority of type-PWS in a given area being sampled only once between 2009 and 2015 and exhibiting a wide range of concentrations for each trial parameter.
- The weight-of-evidence method developed here combines monitoring evidence from type A-PWS and the catchment to enhance certainty of data interpretation and accounting of potential risks. As such it provides a pragmatic means of complying with the DWD's provisions, as amended, for flexible monitoring.

Trial results

The trials highlight uncertainties in the identification of risk areas due to lack of data on pressures from agriculture and industry for all waterbodies. However, the method helped to identify which areas are clearly not risk areas for a trial parameter and the risk areas where trial parameters should be monitored as in current monitoring programmes (Figure 1):

- Aluminium risk areas covered extensive parts of 21 local authorities; 16% of type A-PWS were outwith the identified risk areas.
- Nitrate risk areas were found in 25 local authorities, covering only small parts in Argyll and Bute and Highland; 55.5% of type A-PWS were outwith the identified risk areas.
- Arsenic risk areas were found in 25 local authorities, covering small parts in Highland; 33% of type A-PWS were outwith the identified risk areas.
- Cadmium risk areas were found in 24 local authorities, covering small parts in Highland; 73% of type A-PWS were outwith the identified risk areas.
- Chromium risk areas were found in ten local authorities; 91% of type A-PWS were outwith the identified risk areas.

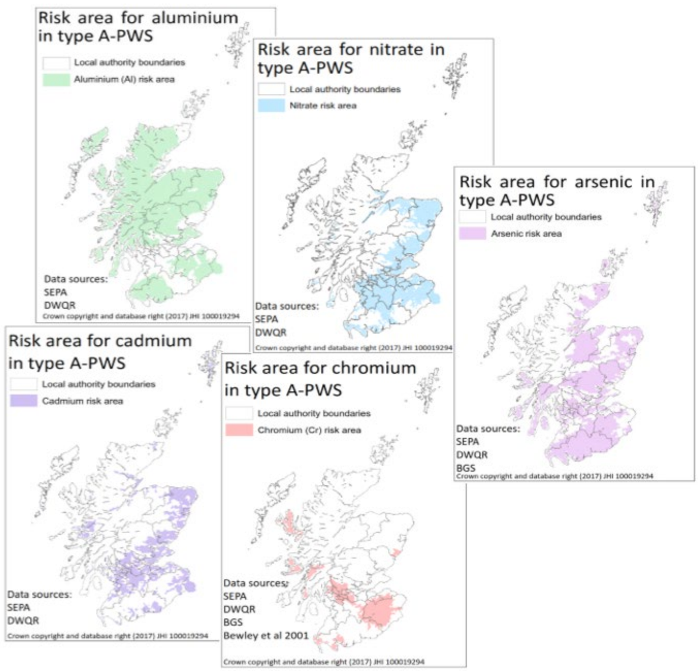


Figure 1 Risk areas where catchment-related trial parameters (aluminium, nitrate, arsenic, cadmium, and chromium) should be monitored as in current monitoring programmes.

[1] Type A-PWS refer to supplies serving more than 50 people or providing water as part of a public or commercial activity.

Background

Directive EU 2015/1787[2] amends the monitoring requirements of the DWD, specifying criteria for flexible monitoring of the parameters in Annex I/Part B in relation to their origin, variability and long-term trend. These parameters may be removed from compliance monitoring if monitoring results are all less than 30% of the parametric value over a period of at least three years from points representative of the supply zone and only if the risk assessment confirms that no factor that can be reasonably anticipated is likely to cause deterioration of the quality of the water intended for human consumption. This approach is introduced to help address risks, cost and practical relevance of monitoring and align the DWD with the provisions of the WFD for drinking water protected areas.

Research undertaken

Evidence in Scotland and internationally was reviewed to assess the factors influencing tap water quality in small rural supplies and to help select catchment-related trial parameters. The type A-PWS data were processed statistically and all available data were used for creating risk maps in Arc GIS. The results of statistical and spatial analyses were evaluated through the weight-of-evidence method developed here to identify risk areas specific to each trial parameter and areas where a specific catchment-related trial parameter can be removed from monitoring.

Recommendations to improve the method

- Risk-based monitoring should be carried out in each type A-PWS every year, within the identified risk areas specific to a catchment-related parameter.
- Risk assessment should carry on within and outwith risk areas and be combined with WFD monitoring (waterbody) data to account for any change in catchment conditions.
- WFD (waterbody) monitoring data for priority substances and specific pollutants must become readily available to enable reliable evaluation of risks for type A-PWS.
- A common documentation of catchment-related parameter concentration at the tap of type A-PWS and the associated waterbody is required so as to facilitate data alignment and incorporation of updates, when new data and catchment information become available.

1.0 Introduction

1.1 Scope

Private water supplies (PWS) are defined as those that are the responsibility of their owners and users rather than the licensed public water supplier. Local authorities under the supervision of the Drinking Water Quality Regulator (DWQR) in Scotland regulate the water quality of these supplies. PWS serve 3.5 % of the population in Scotland but these numbers may exceed 20% of the population locally (DWQR 2015). Monitoring is crucial in ensuring provision of safe and wholesome water to their users in accordance with the standards set for each parameter in Annex I of the European Drinking Water Directive (DWD) (Directive 98/83/EC). The Private Water Supply (Scotland) Regulations 2006 transpose the DWD's requirements in the private water supply context[3].

These regulations place a duty on local authorities to monitor each PWS serving more than 50 people or providing water as part of a commercial or public activity, at least once a year in line with Annex II of the DWD. These supplies, in Scotland, are known as type A-PWS. Currently, approximately 50 parameters and many more substances related to pesticides have to be sampled at each type A-PWS to assess compliance with the standards (parametric values) set in DWD for all supply zones serving more than 50 people.

For many of these parameters compliance rate is poorer in small, rural water supplies than in the public mains network in Scotland (DWQR 2015) and in European Union (EU) Member States (ETC 2016). In spite of this, certain parameters measured in type A-PWS pose no practical threat to public health by always being at or near the limit of detection, or only locally breaching the specified parametric values (DWQR 2015). In Scotland, such parameters must be monitored according to the regulations; monitoring exemptions may be granted only if the monitoring local authority is satisfied that a parameter is not present at or above 75% of the parametric value.

The latest amendment of the DWD by the EU Directive (2015/1787), hereafter reported as the Amendment, has introduced a risk-based approach to monitoring parameters of low practical relevance, whereby they can be removed from a drinking water monitoring programme or sampled at a lower frequency on the basis of the results of a risk assessment and monitoring at source.

[2] Directive 2015/1787 of the European Commission 6 October 2015 amending annexes II and III to Council Directive 98/83/ EC on the quality of water intended for human consumption. OJ L 260, 7.10.2015, p. 6–17.
[3] Appendix 1 in the separate appendices report describes the PWS Regulations in Scotland.

The Amendment specifies that all parameters, except E.coli, could be removed from monitoring provided that:
(i) The location of sampling is determined in relation to the parameter's origin, variability and long-term trend of its concentration at the tap.
(ii) Monitoring results are all less than 30% of the parametric value over a period of at least three years from points representative of the supply zone.
(iii) The results of risk assessment and monitoring of sources of drinking water confirm that human health is protected from the adverse effects of any contamination of drinking water resources.

Further, the frequency of all parameters, except E.coli, may be reduced provided that:
(i) Monitoring results are all less than 60% of the parametric value over a period of at least three years from points representative of the supply zone.
(ii) Risk assessment confirms that no factor that can be reasonably anticipated is likely to cause deterioration of the quality of drinking water at the tap.

These provisions must be transposed into national legislation by October 2017. In this context, the DWQR commissioned Scotland's Centre of Expertise for Waters (CREW) to develop a method of targeting a parameter's monitoring into an area of risk from contamination at source. The method should be suitable for any drinking water parameter that is source-dependent, i.e. derived at the source and not after abstraction from the source, and has been monitored at the tap and the source so as to enable its distribution and concentration range at the tap to be linked to conditions at the source.

The method was requested on the premise that a risk-based monitoring of PWS would provide a pragmatic means of complying with the provision for tailor-made monitoring informed by risk assessment, as prescribed in the Amendment. An added complexity is the Amendment's requirement that drinking water monitoring results should refer to samples from points that are representative of the supply zone. Applying this approach to PWS requires examining at least three years' worth of water quality data for uniformity at different scales of groupings, e.g. waterbody and local authority.

In view of these considerations, the specific objectives of the project were to deliver:

1) A method for identifying a risk-based monitoring area, specific to parameters that rarely breach specified parametric values and to the location of type A-PWS. The method should be based on monitored evidence and a review of the relevant literature.
2) Maps showing the risk-based monitoring areas for five trial parameters.
3) Recommendations for the implementation of the method.

1.2 Outline of the report

The work carried out in this project is presented as follows:
- Data needs and the rationale of the weight-of-evidence method are explained in Section 2.0; sources of drinking water contamination are presented in Appendix 2.0 of the separate appendices report.
- Key findings of the literature review are presented in Section 3.0 and detailed in Appendix 3.
- Trial results, risk areas and the weight-of-evidence method are presented and evaluated in Section 4.0 and Appendix 4.
- Opportunities and limitations of the method developed here are analysed in Section 5.0.
- Recommendations for improving the method are provided in Section 6.0.
- References to the appendices throughout refer to the separate appendices report.

2.0 Research undertaken

2.1 Literature review

A literature review was undertaken to:
- Understand the policy context applying to private water supplies, the adoption of the Amendment and the potential for availability of data that could help support the flexible approach specified in the Amendment.
- Assess the international evidence on monitoring considerations and risk-based approaches for small water supplies.

To capture the international evidence base, the literature review utilised definitions of small water supplies as defined in the review on the literature of small-scale water supplies by Hendry and Akoumianaki (2016). Literature was gathered through the Web of Knowledge, Google Scholar and organisational websites, e.g. DWQR; DEFRA; SEPA; Environment Agency; British Geological Survey (BGS); World Health Organisation (WHO); the United Nations Economic Commission for Europe (UNECE); and the web sites of national bodies of a range of countries, especially Environmental Protection Agencies and Ministries.

Capturing evidence on monitoring practise involved the use of the following search terms: 'water supply' refined by 'small OR Rural OR Community ' subsequently refined by 'uniform water quality ','uniform drinking water quality 'and 'monitoring OR risk-assessment'. The term 'water supply zone' was not used because it gave results relating to geological or ecological zones and centralised piped network interventions. Evidence on risks on the quality of drinking water in relation to monitoring were captured using the terms: 'small water supplies' refined by 'water quality' and then 'monitor*', then 'uniform' OR 'bedrock geology' OR 'agri*' OR 'diffuse pollution' OR 'industr*' OR 'domestic' OR 'waste water' OR 'waterbody OR 'groundwater' OR 'well' OR 'borehole' OR 'surface water' OR 'spring' and then UK and UK jurisdictions. The review on monitoring recommendations in relation to risks focused on findings from UK and especially Scotland.

2.2 Selecting trial parameters

Trial parameters were selected in consultation with DWQR. Two conditions must be met for a parameter to be selected for developing and trialing the method:

1. Catchment-related origin, whereby a parameter should enter drinking water at the source waterbodies of a PWS due to catchment land use.
2. Availability of catchment-based measurements, whereby sufficient quantitative evidence on a parameter's concentrations at the source waterbodies is required.

The trial parameters selected were: aluminium, nitrate, arsenic, cadmium, and chromium because they met both conditions. In particular, the selected parameters belonged to three out of the five groups of parameters which could be distinguished by origin (Table 1a). These three groups referred to catchment-related sources, i.e. they include naturally occurring (geogenic) parameters, agriculturally derived parameters, and parameters related to industrial sources and human dwellings (see Appendix 2 of the separate appendices report for review of evidence).

The trial parameters were also examined for availability of monitored data in type A-PWS and in the catchment (Table 1b). Initial inspections showed that catchment data were available for all trial parameters in Scotland. Of the catchment data available, the most useful were those collected under the Water Framework Directive (WFD) (Directive 2000/60/EC) monitoring at the waterbody scale, and those mapped to support SEPA's priority catchment approach (Akoumianaki et al 2014). Data from literature (e.g. reports from BGS) were often not from monitoring at the waterbody scale. Data available at the waterbody scale are essential in aligning type A-PWS monitoring with the Amendment's provision for taking into account WFD monitoring.

Table 1a. Trial parameters by origin (Modified from: WHO 2011)

Source of parameters	Relevant for this project	Trial parameters for this project (see also Appendix 2)
Naturally occurring when occurrence is related to • **catchment, e.g. soil conditions, geological formations, hydrology, and type of habitats** • **sewage effluents, industrial inputs and farmland runoff**	Yes	Arsenic Cadmium, Chromium Aluminium Nitrate
Industrial sources and human dwellings when occurrence is related to • **mining, manufacturing and processing industries** • **sewage, solid wastes, urban runoff** • **fuel leakages**	Yes	Arsenic Chromium
Agriculture when occurrence is related to • **grassland or arable land use** • **livestock farming** • **fertiliser (including manure) and pesticide use**	Yes	Cadmium Nitrate Arsenic (possibly)
Materials in contact with drinking water when occurrence is linked to water treatment (e.g. coagulants) and piping	No	Aluminium (as coagulant) Cadmium (piping material)
Pesticides used in water for public health	No	

[4] SEPA's priority catchment approach takes targeted action through a sequential process of assessing pressures, raising awareness, providing advice to land managers on compliance with the Diffuse Pollution General Binding Rules and delivering guidance on agri-environment options available via SRDP support to improve and protect water quality, beyond compliance with regulations (DPMAG 2011).

Table 1b. Availability of data and any relevant evidence on trial parameters in Scotland (see also Appendix 2)

Parameter	Type A-PWS data	Catchment data availability/relevance to project				
		SEPA - WFD data for status classification		Literature review	SEPA's Priority Catchment approach	Land Use/Land Cover
		Surface water	Groundwater			
Aluminium	Yes	Non-statutory[1]		BGS[#]	No	Aluminium is related to peaty-soils. Maps of peaty soils occurrence are available but not useful because of widespread occurrence.
Arsenic	Yes	No Measured as Specific Pollutant where there are quantities[1]		BGS[#], SPRI*	No	Arsenic is related to industrial land use (ILU) and pesticide use. ILU maps are available but not explicitly associated with arsenic emissions. An explicit map of pesticides pressures in 2014 in SEPA's priority catchments is available.
Cadmium	Yes	No Measured as Priority Substance where there are quantities[1]		BGS[#], SPRI*	No	Cadmium is linked to phosphate fertilisers and by association to arable land use. Arable land cover maps are not explicitly linked to phosphate. An explicit map of phosphorus pressures in 2014 in SEPA's priority catchments is available.
Chromium	Yes	No Measured as Specific Pollutant where there are quantities[1]		BGS[#], SPRI* Bewley et al 2001	No	Chromium is related to ILU. Maps of ILU occurrence are available but their relevance to chromium emissions is not explicit.
Nitrate	Yes	Non-statutory in rivers and lakes[1]	No Measured to identify groundwater status[1]	BGS[#]	Nitrogen pressures (ammonium and nitrate) have been explicitly mapped in priority catchments	Nitrate is related to arable farming and improved grassland land use but these are not exclusively linked to nitrogen emissions. Mapped nitrogen pressures are more specific.

[1]SEPA 2007. [#]MacDonald and Dochartaigh 2005; MacDonald et al 2005. *Scotland Pollutant Release Inventory: possibly there is data but these are not readily available.

2.3 Framework of data

The trials were based on data authorized by DWQR and SEPA, literature and online spatial data. Available Type A-PWS data were collected between 2009 and 2015, reported as the study period hereafter. Table 2 summarizes data sources.

Table 2. Summary of available data, their sources and the policy context of their collection.

Data	Source	Policy context of data collection
Drinking water data from type A-PWS (2009-2015) • Parameter concentrations at a supply scale • No. of properties per supply • Population per supply • Type of source per supply	DWQR	Private Water Supply (Scotland) Regulation 2006 DWD
Surface water waterbody status classification from 2011 to 2014.	SEPA online	WFD
Groundwater waterbody status classification from 2012 to 2014.	SEPA online	WFD
Rural diffuse pollution pressures in waterbodies taken forward for the priority catchment approach in Scotland (latest update 2014). Maps available for nitrogen, phosphorus, pesticide, sediment, and faecal indicator organism pressures	SEPA Akoumianaki et al 2014	WFD Rural Diffuse Pollution Plan -Scotland
Trace metal concentrations from groundwater geochemical monitoring	BGS reports	Preparation of WFD-based management of groundwater resources (Baseline Scotland n.d.)
Groundwater vulnerability maps	BGS	WFD
Land use data from LULC07	CEH	Environmental policy in many areas including: biodiversity, ecosystem services, landscape planning, habitat connectivity and catchment management
Surface water and groundwater waterbody boundary data	SEPA	WFD
Local authority boundaries	Ordnance Survey UK OS	One Scotland Mapping Agreement (OSMA)
Postcode data	OS UK	OSMA
Location of type A-PWS	DWQR	Private Water Supply (Scotland) Regulations 2006

It should be noted that these data were used during the development of the method for identifying risk areas, but, ultimately, the data used for the trials included:

- Surface water and groundwater waterbody boundary data.
- Local authority boundaries.
- Location of type A-PWS.
- Trace metal concentrations from groundwater geochemical monitoring.
- Groundwater waterbody status classification from 2012 to 2014.
- Maps available for nitrogen, phosphorus, and pesticide pressures.
- Drinking water data from type A-PWS: parameter concentrations, population served by a supply, type of source.

2.4 The weight-of-evidence method

The term weight-of-evidence is commonly used in the scientific and policy-making literature. It is most often seen in the context of public health and environmental risk assessment. It broadly refers either to assessing the methods used for generating and interpreting evidence, or to providing a narrative or criteria to interpret combined evidence (e.g. Bradley et al. 2012).

The purpose of the weight-of-evidence method developed here is to evaluate the combined evidence from statistical and spatial criteria.

- The statistical criterion refers to the estimation of the upper 95% confidence limit (C.L.) for the probability of a parameter's concentrations measured in type A-PWS exceeding 30% of the parametric value (the 30% threshold) per local authority, waterbody type, and at a national scale. In order to be confident that a parameter's concentration at a location is below the 30% threshold, this upper C.L. should be less than 5%.
- The spatial criterion refers to the integration of spatial data on reasonably anticipated risks with a parameter's type A-PWS concentrations that were above or equal to 30% during the study period. Reasonably anticipated risks for catchment-related parameters could refer to diffuse pollution pressures at a waterbody scale and geochemical-geogenic risks specific to a given parameter. This requires that type A-PWS locations are matched with surface water and groundwater bodies. The result of this integration will be a parameter-specific risk area. In the context of the Amendment and for a specific parameter, type A-PWS that can be exempt from monitoring should be located outwith the parameter-specific risk area.

Agreement in the location identified under the statistical and spatial criteria will add weight on the available evidence from type A-PWS. Discrepancies in the identified location should be explored on a case by case basis to better understand whether the uncertainties are related to the type A-PWS data, the data measured at the waterbodies, the published evidence, their combination, or unaccounted risks. The combined evidence is needed to enhance certainty of interpretation of risks, or lack of, posing a threat to the quality of drinking water served by PWS. The method has been designed to evaluate and interpret parameter-specific evidence at the local authority, waterbody and regional scale.

The method encompasses four steps:

1. Statistical analyses at the local authority, waterbody (surface and groundwater) and regional (i.e. Scotland) scale and identification of the upper 95% C.L. for the probability of concentrations in a given area exceeding the 30% threshold. This step identifies the statistical criterion.
2. Classification of concentrations to address the 30% threshold (Table 3) and to help select waterbodies supporting type A-PWS with concentrations for each trial parameter above the 30% threshold, i.e. concentrations in range 2, range 3 and range 4 in Table 3.
3. Compilation of waterbodies from step 2 with waterbodies with pressures specific to a parameter to identify the integrated parameter-specific risk area. This step identifies the spatial criterion.
4. Comparison of areas outwith the integrated risk area identified in step 3 (spatial criterion) with the areas where the upper 95% C.L. is less than 5% (statistical criterion). If these areas coincide, then the type A-PWS located therein can be reliably removed from the current monitoring programme for a given parameter.

Table 3. Classification of concentrations by concentration range.

Range of concentrations relative to parametric value (p.v.)	Range of concentrations per parameter				
	Nitrate (NO3-) mg/l	Cadmium (Cd) µg/l	Chromium (Cr) µg/l	Arsenic (As) µg/l	Aluminium (Al) µg/l
Range 1 <30% of p.v.	<15	<1.5	<15	<3	<60
Range 2 ≥30% - <60% of p.v.	15-<30	1.5-<3	15-<30	3- <6	15-<120
Range 3≥60% - ≤100% of p.v.	30-50	3-5	30-50	6-10	120-200
Range 4>100% of p.v.	>50	>5	>50	>10	>200

The output of the weight-of-evidence method is a narrative specific to each parameter evaluated through this approach. All evidence used for developing the approach is monitored. No cause-effect assumptions were made but it was assumed that phosphate pressures could be used as a proxy for cadmium (Appendix 2) and pesticides can be used as partial proxy for arsenic (Appendix 2).

2.5 Trial data analyses

2.5.1 Statistical analyses

Simple summary statistics were calculated, including the percentage of observations in each range. An exact binomial test was used to calculate the 95% confidence interval for the probability of exceeding the 30% threshold. This depends both on the percentage of observed concentrations that are in Range 2, 3 or 4 and the total number of observations. In cases where all the observed concentrations are in Range 1 then at least 72 observations are needed for the upper 95% confidence limit (C.L.) to be less than 5%.

2.5.2 Risk maps for monitoring

Risk maps were tailor-made for each trial parameter in Arc GIS. Identifying the risk area involved the following generic steps for each trial parameter:

- Selection of surface waterbodies and groundwater bodies containing any type A-PWS where the parameter displayed a concentration within the Range 2 to 4 at the tap, i.e. concentrations that at least once exceeded 30% of the parametric value during the study period.
- Selection of waterbodies where pressures (i.e. elevated values, WFD failure[5]) relevant to a given trial parameter have been identified.
- These two groups of data were processed and spatially joined (integrated) with scripts written in Python programming language to produce a final spatial database of the risk for monitoring for a specific parameter.

3.0 Literature review of risk-based monitoring practices

Of the 423 studies selected through literature searches on the monitoring of small water supplies, fewer than 20 were peer reviewed articles providing information relevant to this project's objectives.

- Only three articles were explicitly related to the objectives of this project. These described a method for reducing the number of parameters measured in a certain area on the basis of concentration data and provided explicit advice on how to design a monitoring programme that is tailor-made on the basis of risk evidence. The articles were published in three parts and explored three different aspects of the economics of place-based monitoring under the Safe Drinking Water act in the US (Brands and Rajagopal 2008a; b; c).
- Sixteen referred to research findings on the risk factors that need to be addressed during the monitoring of private water supplies in the UK. In addition, a substantial body of evidence came from monitoring studies from elsewhere (mainly USA, Canada, New Zealand and Australia) but, as their conclusions were similar to those drawn from UK studies, they are not reviewed here.

The remainder of relevant literature related to the three areas of interest: (i) policy context of the Amendment and evaluation reports on the effectiveness of DWD with respect to monitoring; (ii) policy guidance and expert opinion reports on coping with resource constraints (e.g. staff, budget, expertise and emergencies) and the large number of dispersed small supply systems in rural or peri-urban areas; (iii) consolidation approaches and connections; and (iv) reports on the implementation of risk assessment in small water supplies. Useful insights on the factors that should be accounted for when designing a risk-based monitoring approach for small supplies came from the first two types of reports. Consolidation approaches were captured by the literature searches because they provided permanent cost-saving and risk-addressing opportunities. Of these, some examples on managerial consolidation were of practical relevance for private water supplies but their findings are outwith the scope of this project and therefore are not further examined. Risk assessment reports concentrated on water safety plan implementation and thus their scope is outwith the remit of this report.

[5] WFD specifies the same parametric values for the concentrations of the parameters included in Annex I of the DWD.

The terms applying to private water supplies are given in Appendix 3.1. Accordingly, private water supplies can be categorised as small supplies, i.e. supplies serving fewer than 5000 people, in terms of both regulations and technical challenges (European Commission 2015). The majority of private water supplies are also self-supply systems. The terms 'small supplies' and 'self-supply systems' are widely used in the literature and throughout this report.

On the whole, it was not possible to find examples of grouping non-interconnected supplies in the same geographic area into a zone of uniform water quality. There was also limited evidence on creating cost-saving opportunities for the monitoring of self-supply systems. In general, evidence was poorer for those self-supply systems than for small community-operated or municipal supplies relying on water that is centrally treated and served by a distribution network.

This lack of examples for risk-based monitoring for self-supply systems (i.e. supplies outwith a small distribution network) can be generally attributed to:

(i) A greater policy focus on evidence and practices for supplies serving a larger population base (Eureau 2011).

(ii) A legacy of centralised approaches to water supply management to achieve economies of scale and minimise liabilities, whereby standardised solutions are applied to operate and manage a supply with an as many as possible number of connections to a water distribution network, so as to lower the per-supply (zone) cost and effectively control contamination through the supply chain (Bakker 2016).

(iii) (As a result of ii) an increasing trend of consolidations of small municipal or community supplies and/or connection of self-supply systems on the 'mains' to increase cost-recovery and ensure efficient use of water resources under Art. 9 of WFD and similar legislative frameworks outwith the EU. Consolidation and enforcement of connections has also been practised as a sustainable risk-relief approach for all residents in an area.

(iv) Paucity of evidence on risk-based monitoring arrangements, especially in Europe, as there is no a) reporting obligation; b) provision for risk-assessment (which requires systematic reporting under WHO guidelines for Water Safety Planning); or c) a register for small supplies under the DWD (WHO 2012; Klaassens 2016; REFIT 2016). Many Member States have legislated reporting, a register for small supplies, or risk assessment. However, no rules for intra-national synchronisation apply in these reports, as shown in examples reported by Hendry and Akoumianaki (2016), and as these reports refer to national contexts, language is a considerable barrier.

(v) (Related to iv) Lack of uniform definitions and reporting protocol in reporting water quality data for small supply zones in the EU. Member States have to report compliance rates with monitoring and standards for small and large supply zones. In the case of small zones, they usually report data from small public (i.e. municipal) zones, but it is uncertain whether they include data on small individual, privately-operated and managed supplies (i.e. self-supply systems) as there is no uniform reporting protocol or obligation under the DWD (European Commission 2014a).

(vi) Lack of uniform operation and management conditions in the self-supply management model. This could promote uniform, standardised conditions in terms of parameter concentrations, compliance rates, protection at source, maintenance, use of treatment, handling, piping and fittings, expertise, understanding of risks, and application of risk-assessment procedures (Ford et al 2005; Peter-Varbanets et al 2009; Rickert and Schmoll 2011; Euraeu 2011; Hendry and Akoumianaki 2016).

The following sections provide the key findings of the literature review (Sections 3.1 to 3.4). The lessons learned from all of these studies were applied to build the data framework for the weight-of-evidence method developed here, as outlined in Sections 2.4 and 2.5.

3.1 Key findings from the review of policy context

A recent evaluation of the DWD's relevance to human health protection standards and citizens' expectations, and its effectiveness in achieving wholesome and clean water at the consumer's tap showed major shortcomings with respect to risk assessment, reporting, coherence with WFD's requirements and the monitoring frequencies in small supplies (Klaassens 2016; REFIT 2016). In response to this evaluation, the DWD's technical annexes referring to monitoring were revised by Commission Directive (EU 2015/1787), i.e. the Amendment, to allow for (i) a flexible list of parameters to be monitored on the basis of risk assessment and concentrations being below 30% of parametric value for three years or longer across a supply zone and (ii) links between the DWD and WFD to be developed. In parallel, risk assessment and reporting have been addressed in the regulations for private water supplies in the UK. However, there is no obligation for standardising the collection of information across local authorities or integrating risk assessment with compliance monitoring data. Therefore, the key finding of the review of the policy context is that a method needs to be developed to identify data needs and criteria to address the Amendment's provisions.

Details are given in Appendices 3.1.2 to 3.1.4.

3.2 Key findings from the review of place-based monitoring

Place-based monitoring refers to monitoring programmes that account for spatial and temporal patterns of contaminants (Brands and Rajagopalan 2008a). It has emerged from prior research, and common sense, showing that no region is uniform; rather, variables such as land use, soils, climate, and water resources exhibit significant variability. Using knowledge about particular locations and areas is a place-based approach to coping with this diversity.

A place-based approach to monitoring is defined by differential sampling of drinking water parameters (both spatially and temporally), specifically informed by evidence on the study area and historical data. The two major sources of evidence are (1) prior research (literature review) regarding water quality and factors influencing water quality in a given area, and (2) historical data from the supplies selected for this procedure. In the USA the approach was developed to address an amendment of the Safe Drinking Water Act calling for 'tailored alternative monitoring requirements for public water systems[6]' (USEPA 2002; SDWA § 1418(b)(1)). The place-based approach developed by Brands and Rajagopalan (2008a; b; c) consists of two parts.

The first part refers to developing a flexible approach to the list of contaminants, whereby the list of contaminants to monitor should be determined through a screening strategy that eliminates parameters with concentrations below 20% of the parametric value, in accordance with the USA drinking water regulations.

The second part refers to adopting a flexible sampling frequency for those parameters selected through screening, whereby the best frequency and time of sampling (e.g. during rainfall events) for a specific parameter is derived from historical concentration patterns.

Results of implementing this method showed that:

- Monitoring a revised list of contaminants (i.e. those selected through the screening strategy) captures most of contaminants occurring in an area, all of the concentrations above 75% of the parametric value, and all of the failing values.
- Combining the revised monitoring list with an event-based monitoring scenario can reduce annual monitoring costs to one-eighth that of the current requirements for a routine and uniform sampling regardless of place-based evidence.
- Incorporating historical evidence into temporal sampling strategies (i.e. allocating more samples to seasons in which concentrations of a parameter have historically been high) can significantly improve estimates of the higher percentiles of a parameter's distributions (i.e. those that are likely to exceed the parametric value).

These findings have significant implications not only for the design of alternative monitoring programs, but also in multi-billion-dollar decisions that influence the course of future drinking water infrastructure, repair, and maintenance investments, as highlighted by Brands and Rajagoplan (2008a). It has been recognised that the implementation of place-based monitoring is resource intensive, especially for small supplies unable to bear the cost of extra data analysis or event-based monitoring. In such cases, state agencies or larger supplies could provide technical and/or financial assistance to small supplies, given that the regulatory and statutory means exist for implementing place-based monitoring (Brands and Rajagopalan 2008c). It has also been acknowledged that the place-based method developed on the basis of historical data could be improved by integration with a detailed assessment of land use as well as potential catchment sources of contamination to inform decisions regarding which contaminants to monitor (Brands and Rajagopalan 2008c).

To sum up, place-based monitoring is an effective way of avoiding the 'data rich' but 'information poor' syndrome that characterises routine monitoring programmes (Ward et al 1986; USDA-NRCS 2003; WHO 2011). In this respect, place-based monitoring is allied with the rationale for flexible monitoring described in the Preamble (par. 6) of the Amendment, which introduces the concept of 'practical relevance' for parameters that rarely breach the specified standards to reduce the collection of data providing little or no information on drinking water quality. Place-based monitoring is also congruent with WHO guidelines for compliance monitoring (WHO 2011: 64-67) and the WSP approach (WHO 2012), as it allows for monitoring to be proportional to hazards and to the health-related risks involved and for an early detection of non-compliances.

[6] In the US public water systems are those regulated and serve water to more than 25.

3.3 Key findings from review of monitoring guidance for small water supplies

General guidelines for practising monitoring in the context of a small water supply have been described by WHO in the *Guidelines of drinking water* (WHO 2011) and in the *Guidance on Water Supply and Sanitation In Extreme Weather Events* (Sinisi and Aetgers 2013). These guidelines take into account experience in monitoring programmes in remote, typically rural or peri-urban supplies serving small communities through a piped network, or premises related to a commercial (e.g. holiday lets) or public activity(e.g. schools). Challenges facing these small-scale supplies during weather emergencies (e.g., floods, drought and water scarcity) have also been taken into account.

The most important guidelines in the context of reduced monitoring and accounting for parameter-specific risks include:

(i) A rolling programme of sampling visits to ensure that all supplies are monitored and that each supply in a given area is visited once every 3–5 years. This approach is suitable to inform strategic planning and policy rather than to assess compliance of individual drinking-water supplies.

(ii) Sampling at the source in addition to tap monitoring at sites where there is no guarantee for catchment contamination control. Sampling can be on an occasional, regular, or event-driven (e.g. spills) basis.

(iii) Continuous assessment of contamination control measures from catchment to tap, although this requires effective engagement of the owners and users in the risk-assessment procedure.

(iv) A higher monitoring frequency for microbiological and chemical parameters in unimproved sources (e.g. surface water, unprotected wells, boreholes with heads above ground) than for chemical parameters in improved supplies (deep groundwater).

3.4 Key findings from the review of monitoring of PWS in the UK

In addition to the WHO guidelines, a number of research studies have provided substantial recommendations for compliance monitoring programmes applied to PWS in the UK. These studies are reviewed in Appendix 3.2. A common conclusion of these studies was that microbiological and chemical sampling (including repeats collected after non-compliance) need to be both event-based, to take into account the known effects of rainfall; and risk-based, to target areas and seasons that are most likely to indicate the presence of pathogens or dangerous chemicals.

The factors that can influence the results of compliance monitoring in the UK were found to be:

- Hydrological factors, especially rainfall
- Agricultural activity, and specifically livestock density, manure spreading, and use of pesticides and fertilisers
- Soil conditions
- Bedrock geology
- Groundwater vulnerability, i.e. the tendency and likelihood for general contaminants to reach the water table within the uppermost aquifer after introduction at the ground surface
- Industrial land use
- Domestic sources of contaminants, e.g. septic tanks

The findings from UK research studies call for integrating compliance monitoring with risk assessment in a complementary way. However, no practical recommendation is given on whether or how to revise the list of parameters that must be monitored by each local authority or at each private water supply. The focus is mainly on how to achieve sufficient monitoring to ensure that maxima in concentrations of drinking water contaminants are captured. The studies reviewed in Appendix 3.2 provided no concrete methodology or advice on how many events should be sampled per year to provide sufficient information for local risks, or how to select the parameters that may pose a risk on human health in a given geographic area.

It should be noted that most of these studies refer to pre-WFD circumstances. It was WFD monitoring at the waterbody scale and the river basin management plans that provided data at the sources of drinking water supplies revealing the real extent and variety of pressures potentially influencing the quality of water in private water supplies in a given geographic area.

3.5 Evaluation of literature review findings

The most relevant recommendations to the context of private water supplies and the Amendment's provisions refer to:

- Place-based monitoring, whereby the list of monitored parameters is based on historical and current concentration data consistently or seasonally exceeding a specified low concentration in a given geographic area.
- Monitoring at the source in tandem with tap water monitoring.
- Targeted monitoring to address the influence of:
    - Agricultural practises: livestock density, manure spreading, pesticide/fertiliser use
    - Soil conditions
    - Bedrock geology
    - Groundwater vulnerability
    - Industrial land use

- o Domestic sources of contaminants, e.g. septic tanks

These recommendations were combined to develop a weight-of-evidence method for flexible monitoring, whereby the list of monitored parameters is revised to reflect the concentration patterns of each parameter and measured local pressures (see Section 2). The results of the trials of the method are presented in the next section.

4.0 Trials

The method was developed using trial data from five parameters: nitrate, cadmium, arsenic, chromium and aluminium. The aim of the trials was to assess the feasibility and credibility of the weight-of-evidence method for targeting the monitoring of source-dependent parameters to areas of risk.

4.1 Data availability

According to the Amendment's provision, the decision for removing a parameter from monitoring at a certain supply must be decided on the basis of three or more years of monitoring data across an area of uniform conditions. The number of type A-PWS sampled for the trial parameters during the study period was explored to test whether the Amendment's conditions are met. This was done at the scale of:

- Local authority, which presumably represents an area of uniform administrative conditions for the management and monitoring of private water supplies.
- Surface waterbody catchments, which under WFD represent a unit of uniform catchment management. In WFD, surface water catchments are defined as an area of land from which all surface run-off flows through a series of streams, rivers and, possibly, lakes to a particular point in the water course such as a river confluence; within this area, topography, hydro-morphological and ecological conditions as well as all types of anthropogenic pressures have been identified to enable the WFD status to be estimated and improved, if necessary.
- Groundwater waterbodies, which under WFD represent a unit of uniform groundwater resources management. Delineation of groundwater bodies in Scotland accounted for key groundwater flow characteristics related to surface waterbody catchment hydrology and geological controls in accordance with UK-wide guidance (UKTAG 2011; Dochartaigh et al 2015).

4.1.1 Grouping by local authority

4.1.1.1 Number of type A-PWS sampled per parameter/ year/local authority

For each of the five trial parameters, it was observed that in most local authorities, the number of type A-PWS sampled for three or more years was very small compared to the total number of type A-PWS sampled during the study period (2009-2015); see results in Appendix 4.1. This was more notable in certain large local authorities such as Aberdeenshire, Highland, Perth and Kinross, Dumfries and Galloway, and Scottish Borders. A striking exception was observed in Argyll and Bute where the majority of supplies were sampled for three or more years for all trial parameters (Appendix 4.1).

4.1.1.2 Upper 95% C.L. for the probability of concentrations exceeding the 30% threshold

The distribution of concentrations of each trial parameter in each local authority by type A-PWS and by type of water source (i.e. surface or groundwater), was also examined in relation to the 30% threshold specified in the Amendment. Given the observed number of times the 30% threshold was exceeded, the upper 95% confidence limit (C.L.) for the probability of each parameter exceeding the 30% threshold was calculated, if it was sampled a large number of times. This upper 95% C.L. should be less than 5%. Meeting this statistically-defined criterion gives a reliable measure of the certainty of available trial parameter data and the reliability of a decision in favour of, or against, removing a trial parameter from the current monitoring schedules.

Aluminium

Overall, the upper 95% C.L. for the probability of aluminium exceeding the 30% threshold was always above 9% (Table 4a) and the majority of median aluminium concentrations per local authority were below the 30% of parametric value (Figure 4a). Values above the parametric value were observed in groundwater type A-PWS in Aberdeenshire, Argyll and Bute, Highland, Dumfries and Galloway, Perth and Kinross and Scottish Borders and in surface type A supplies in Argyll and Bute, Highland, Dumfries and Galloway, and Perth and Kinross (Figure 4a).

A notable feature of this data is the wide range of values in certain local authorities, e.g. Aberdeenshire, Argyll and Bute and Perth and Kinross (Figure 4a). The wide range of values in combination with the insufficient number of samples collected in certain jurisdictions during the study period prevented a low (below 5%) estimate of the probability of aluminium exceeding the 30% threshold, as illustrated in the data from Aberdeenshire and Perth and Kinross. However, in the case of Argyll and Bute, where almost all type A-PWS were sampled for more than three years, the range of values was so wide that it precluded a low estimate of the upper 95% confidence limit (C.L.) for the probability of aluminium exceeding the 30% threshold.

Nitrate

Overall, the upper 95% C.L. for the probability of nitrate exceeding the 30% threshold was always above 11% (Table 4b). The median nitrate concentrations were below 15µg/l, the 30% threshold, in all local authorities except in groundwater supplies in Aberdeenshire (Figure 4b). Concentrations were generally higher in groundwater than surface type A-PWS.

The lowest values for the upper 95 % C.L. were observed in Highland (i.e. 12%) and in Argyll and Bute (i.e. 11%). In Highland, there were few concentrations above the 30% threshold during the study period, showing that the narrow range of values has contributed to a low estimate. In Argyll and Bute, a high number of nitrate samples collected during the study period and the majority of type A-PWS were sampled for three or more than three years (see 4.1.1.1), suggesting that a the greater number of available values has led to a lower estimate of the probability of nitrate exceeding the 30% theshold.

Arsenic

The upper 95% C.L. varied between 1 and 98%, with Highland shown to be the only local authority where arsenic could be removed from monitoring due to concentrations consistently below the 30% threshold during the study period (Table 4c). Many exceedances of the 30% threshold and the parametric value were observed for arsenic in other jurisdictions (Figure 4c). The highest values were observed in groundwater type A-PWS in East Lothian, Fife and Perth and Kinross, and in surface water type A-PWS in Dumfries and Galloway.

Cadmium

The upper 95% C.L. was below 5% in many areas such as Aberdeenshire, Dumfries and Galloway, Highland, Perth and Kinross (Table 4d). Cadmium median concentrations were always below the 30% threshold (Figure 4d). Concentrations exceeding the 30% threshold were observed in only four local authorities: Aberdeenshire, Argyll and Bute, Moray, and Scottish Borders. However, the concentration data showed that there was one location in Aberdeenshire where cadmium exceeded the 30% threshold, indicating that the whole area within Aberdeenshire may have to be sampled. Therefore, this result should be examined in the context of risks maps (Section 4.3).

Chromium

The upper 95% C.L. was below 5% in: Argyll and Bute, Dumfries and Galloway, Highland, Perth and Kinross, and Scottish Borders (Table 4e). Chromium concentrations exceeded the 30% threshold (15 µg/l) very rarely and only in groundwater type A-PWS in three local authorities: Aberdeenshire, W. Dunbartonshire and Scottish Borders (Figure 4e). This means that although the upper 95% C.L. was below 5% in Scottish Borders, there is one location that still needs to be sampled because of the occurrence of concentrations above the 30% threshold. This will be further explored in the context of risk maps (Section 4.3).

Table 4a. Aluminium: Number of samples collected during the study period and the upper 95% C.L. for the probability of Al concentrations exceeding the 30% threshold (i.e. ≥60 µg/l).

Local authority	no. of samples (2009-2015)	% <30% of p.v.	Upper 95% C.L.	Local authority	no. of samples (2009-2015)	% <30% of p.v.	Upper 95% C.L.
Aberdeenshire	328	84	21	Midlothian	13	100	25
Angus	3	100	71	Moray	522	70	35
Argyll and Bute	1906	40	62	North Ayrshire	4	100	60
Clackmannanshire	3	100	71	Orkney	45	27	85
Eilean Siar	8	63	76	Perth and Kinross	120	76	33
Dumfries and Galloway	144	66	42	Renfrewshire	12	100	26
East Ayrshire	4	100	60	Scottish Borders	101	93	14
East Lothian	33	79	39	Shetland	1	100	98
East Renfrewshire	2	100	84	South Ayrshire	51	80	33
Falkirk	1	100	98	South Lanarkshire	40	100	9
Fife	105	76	33	Stirling	2	100	84
Highland	162	39	69	W. Dunbartonshire	16	50	75
Inverclyde	11	100	28	West Lothian	53	34	78

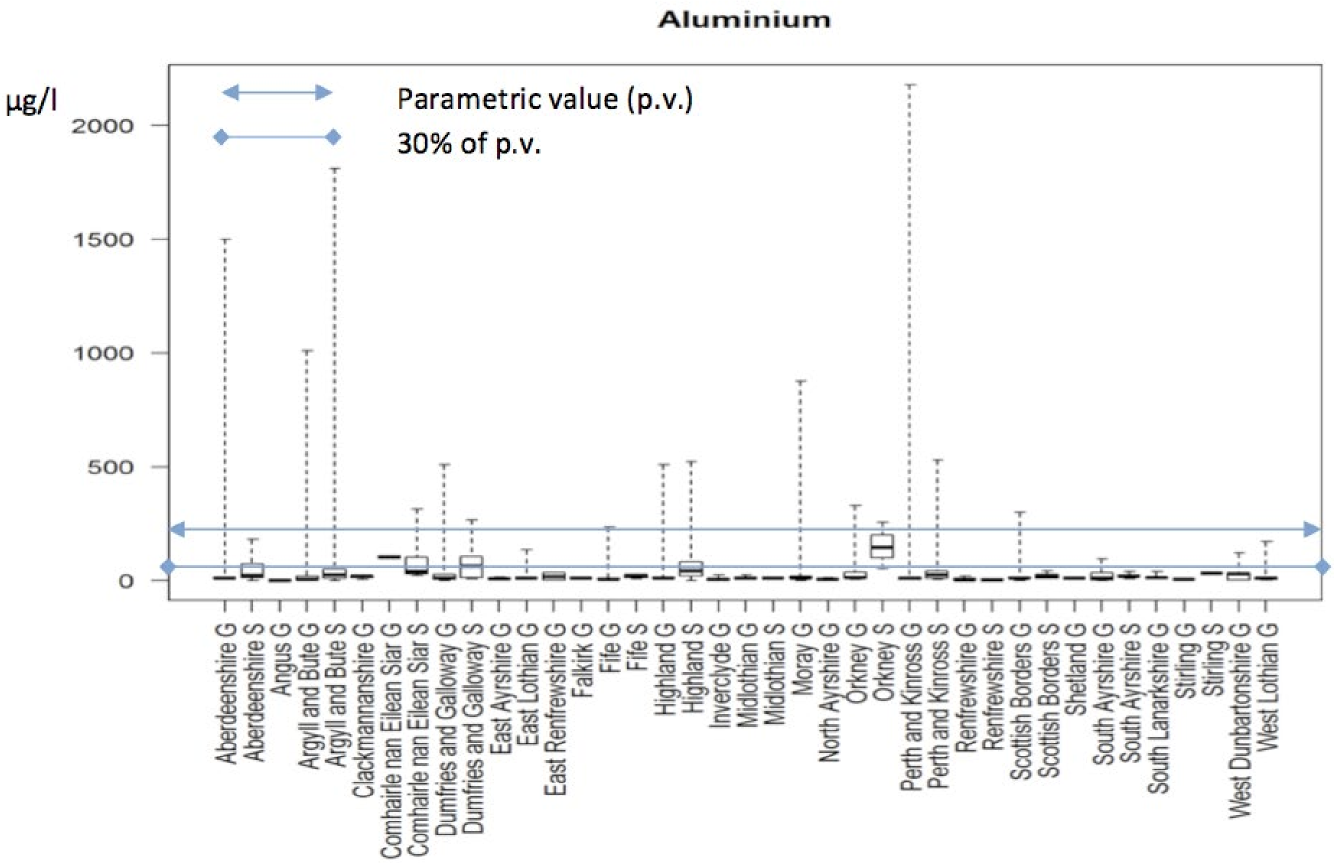


Figure 4a Box plots of aluminium concentrations in type A-PWS per type of water source (G-Groundwater, S-Surface water) in each LA during the study period (2009-2015). The top of the upper whisker represents the maximum value in each category, the top and bottom of each box represent the 75th and 25th percentile values, respectively. Median values are represented by horizontal lines located within each box. The bottom of the lower whisker represents the minimum values.

Table 4b. Nitrate: Number of samples collected during the study period and the upper 95% C.L. for the probability of nitrate concentrations exceeding the 30% threshold (i.e. ≥15 mg/l).

Local authority	no. of samples (2009-2015)	% <30% of p.v.	Upper 95% C.L.	Local authority	no. of samples (2009-2015)	% <30% of p.v.	Upper 95% C.L.
Aberdeen City	4	0	100	Inverclyde	12	100	26
Aberdeenshire	1052	46	57	Midlothian	13	62	68
Angus	39	36	79	Moray	486	71	33
Argyll and Bute	1963	90	11	North Ayrshire	8	100	37
Clackmannanshire	25	100	14	Orkney	11	100	28
Eilean Siar	8	100	37	Perth and Kinross	184	79	27
Dumfries & Galloway	286	54	52	Renfrewshire	11	100	28
East Ayrshire	2	100	84	Scottish Borders	420	63	41
E. Dunbartonshire	1	100	98	Shetland	1	100	98
East Lothian	33	82	35	South Ayrshire	97	66	44
East Renfrewshire	2	100	84	South Lanarkshire	98	43	67
Falkirk	1	100	98	Stirling	23	100	15
Fife	114	43	66	W. Dunbartonshire	17	100	20
Highland	366	91	12	West Lothian	53	66	48

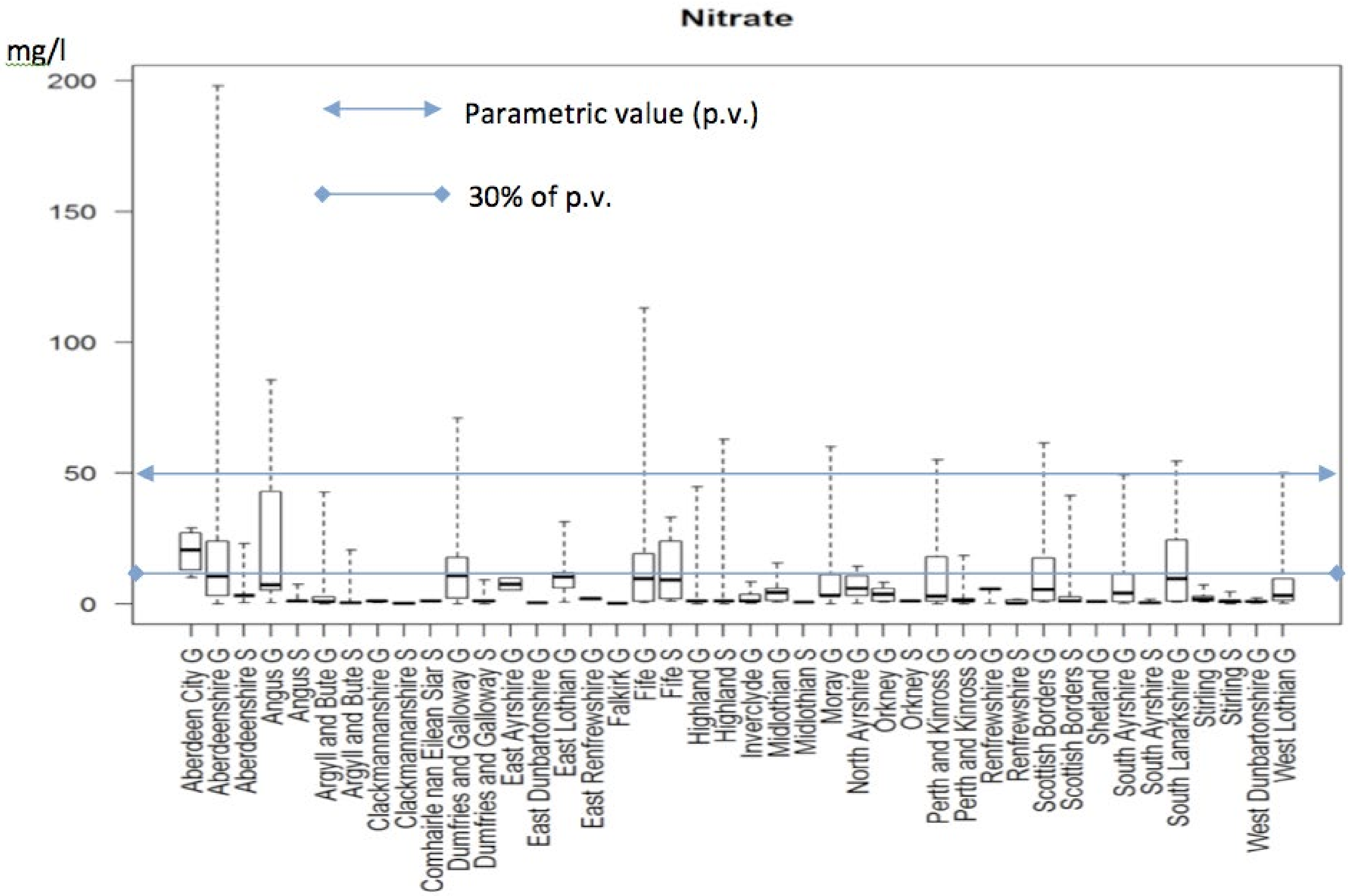


Figure 4b Box plots of nitrate concentrations in type A-PWS per type of water source (G-Groundwater, S-Surface water) in each local authority during the study period (2009-2015). Box plot mechanics as in Figure 4a.

Table 4c. Arsenic: Number of samples collected during the study period and the upper 95% C.L. for the probability of As concentrations exceeding the 30% threshold (i.e. ≥3 µg/l).

Local authority	no. of samples (2009-2015)	% <30% of p.v.	Upper 95% C.L.	Local authority	no. of samples (2009-2015)	% <30% of p.v.	Upper 95% C.L.
Aberdeenshire	289	95	8	Midlothian	3	100	71
Angus	35	77	40	Moray	56	100	6
Argyll and Bute	1821	94	8	North Ayrshire	4	100	60
Clackmannanshire	3	100	71	Orkney	8	100	37
Eilean Siar	3	100	71	Perth and Kinross	134	82	25
Dumfries and Galloway	129	95	11	Renfrewshire	11	100	28
East Ayrshire	2	100	84	Scottish Borders	155	93	12
East Dunbartonshire	1	100	98	Shetland	1	100	98
East Lothian	34	71	47	South Ayrshire	51	94	16
East Renfrewshire	2	100	84	South Lanarkshire	36	81	36
Falkirk	1	100	98	Stirling	1	100	98
Fife	42	52	64	W. Dunbartonshire	14	57	71
Highland	275	100	1	West Lothian	53	100	7
Inverclyde	10	60	74				

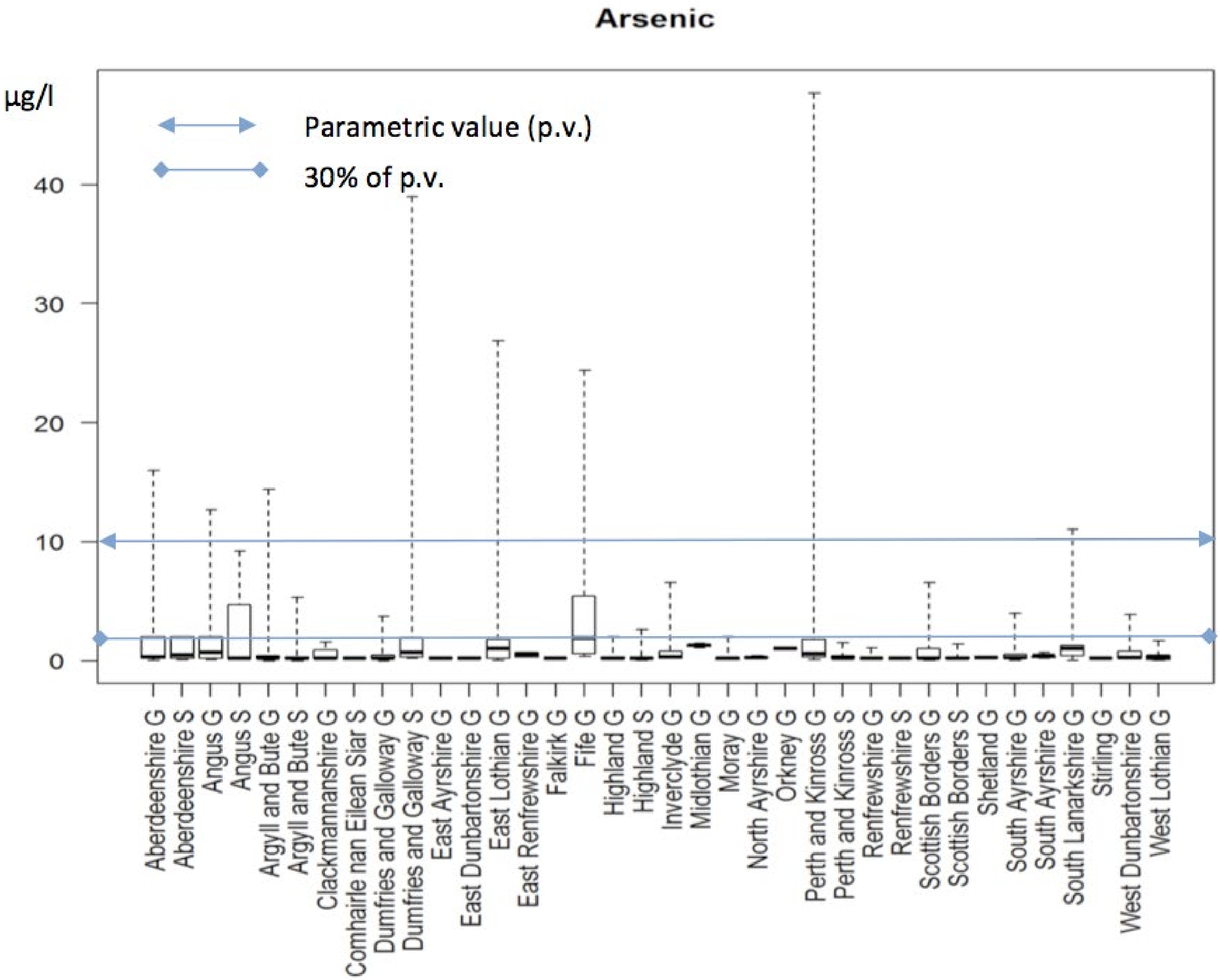


Figure 4c Box plots of arsenic concentrations in type A-PWS per type of water source (G-Groundwater, S-Surface water) in each local authority during the study period (2009-2015). Box plot mechanics as in Figure 4a.

Table 4d. Cadmium: Number of samples collected during the study period and the upper 95% C.L. for the probability of Cd concentrations exceeding the 30% threshold (i.e. ≥1.5 µg/l).

Local authority	no. of samples (2009-2015)	% <30% of p.v.	Upper 95% C.L.	Local authority	no. of samples (2009-2015)	% <30% of p.v.	Upper 95% C.L.
Aberdeenshire	278	99.6	2	Midlothian	3	100	71
Angus	28	100	12	Moray	58	95	14
Argyll and Bute	1820	95	6	North Ayrshire	4	100	60
Clackmannanshire	3	100	71	Orkney	8	100	37
Eilean Siar	3	100	71	Perth and Kinross	104	100	3
Dumfries &Galloway	125	100	3	Renfrewshire	11	100	28
East Ayrshire	2	100	84	Scottish Borders	184	98	5
East Dunbartonshire	1	100	98	Shetland	1	100	98
East Lothian	33	100	11	South Ayrshire	51	100	7
East Renfrewshire	2	100	84	South Lanarkshire	36	100	10
Falkirk	1	100	98	Stirling	7	100	41
Fife	12	100	26	W. Dunbartonshire	14	100	23
Highland	273	100	1	West Lothian	53	100	7
Inverclyde	10	100	31				

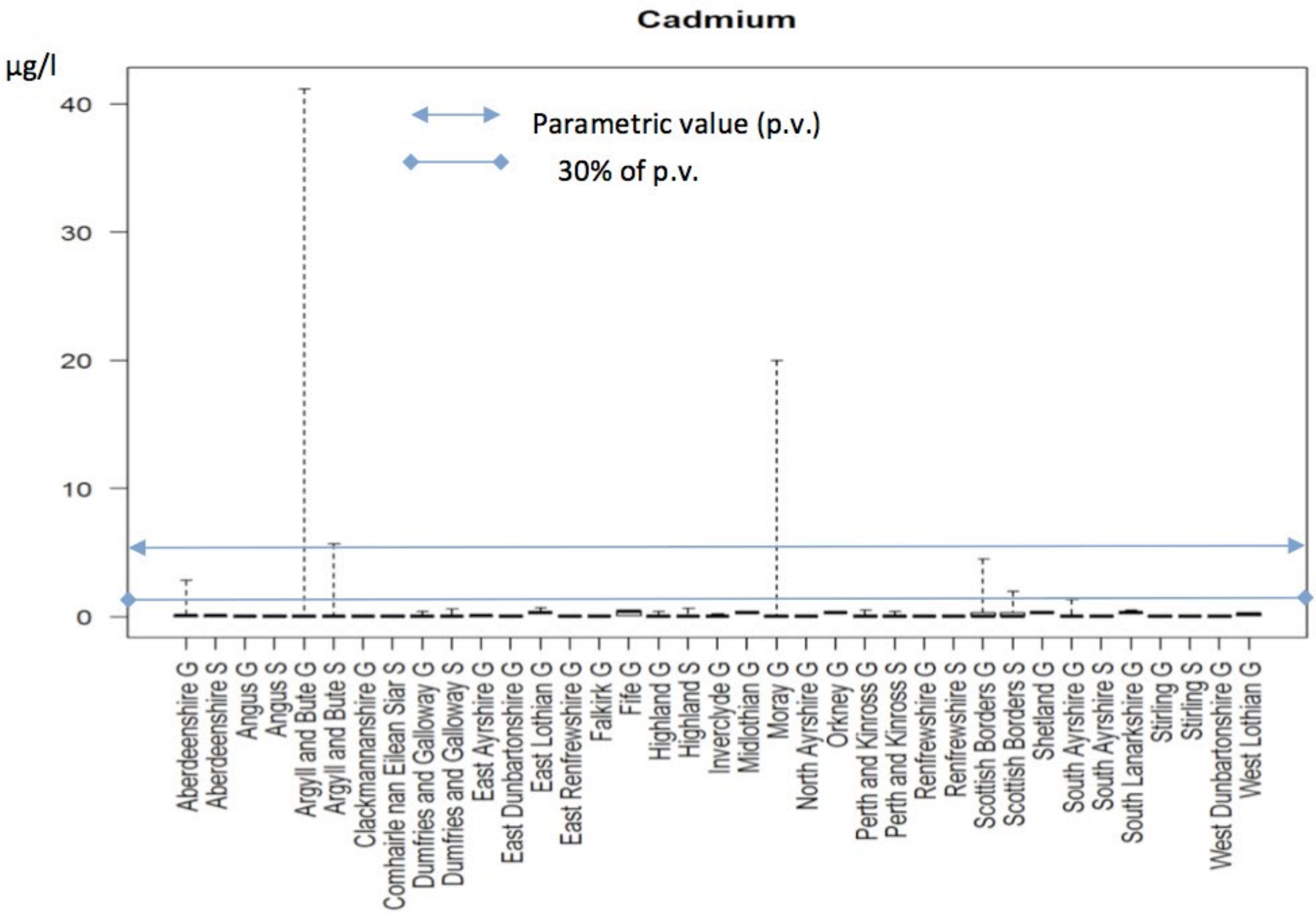


Figure 4d Box plots of cadmium concentrations in type A-PWS per type of water source (G-Groundwater, S-Surface water) in each local authority during the study period (2009-2015). Box plot mechanics as in Figure 4a.

Table 4e. Chromium: Number of samples collected during the study period and the upper 95% C.L. for the probability of Cr concentrations exceeding the 30% threshold (i.e. ≥15 µg/l).

Local authority	no. of samples (2009-2015)	% <30% of p.v.	Upper 95% C.L.	Local authority	no. of samples (2009-2015)	% < 30% of p.v.	Upper 95% C.L.
Aberdeenshire	95	99	6	Midlothian	3	100	71
Angus	29	100	12	Moray	56	100	6
Argyll and Bute	1822	100	0.2	North Ayrshire	4	100	60
Clackmannanshire	3	100	71	Orkney	8	100	37
Dumfries & Galloway	121	100	3	Perth and Kinross	101	100	4
East Ayrshire	2	100	84	Renfrewshire	11	100	28
East Dunbartonshire	1	100	98	Scottish Borders	153	99	4
East Lothian	33	100	11	Shetland	1	100	98
East Renfrewshire	2	100	84	South Ayrshire	51	100	7
Falkirk	1	100	98	South Lanarkshire	36	100	10
Fife	13	100	25	Stirling	8	100	37
Highland	270	100	1	W. Dunbartonshire	14	79	51
Inverclyde	10	100	31	West Lothian	53	100	7

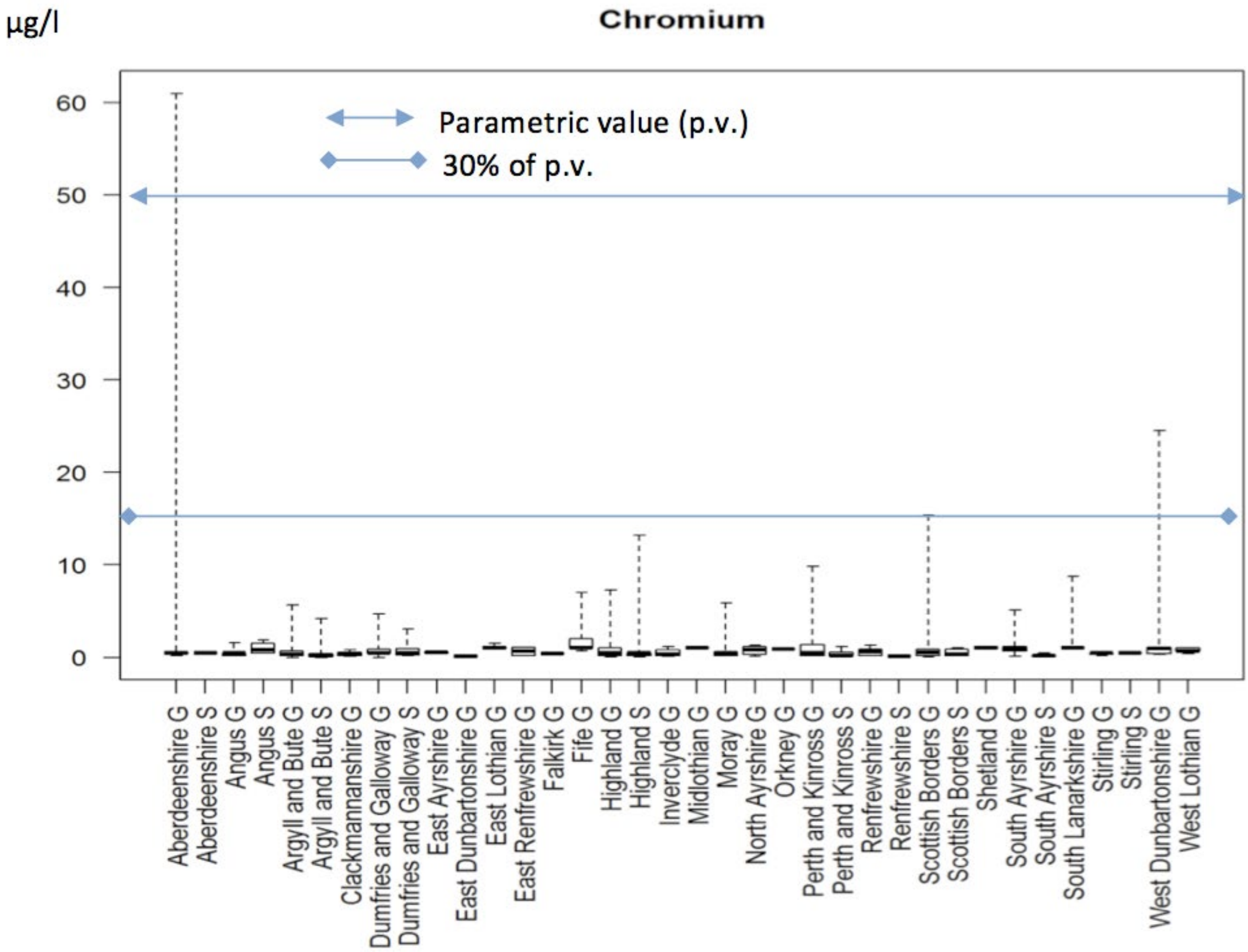


Figure 4e Box plots of chromium concentrations in type A-PWS per type of water source (G-Groundwater, S-Surface water) in each local authority during the study period (2009-2015). Box plot mechanics: as in Figure 4a.

4.1.1.3 Conclusion for grouping data per local authority

Type A-PWS in areas defined on the basis of local authority jurisdictions have been sampled in an inconsistent way during the study period. Certain local authorities, such as Argyll and Bute, have sampled the majority of the supplies under their jurisdiction for three or more years. In contrast, many other local authorities, such as Aberdeenshire, Highland, Dumfries and Galloway, Perth and Kinross have sampled only a very small proportion of the supplies in their jurisdiction for three or more years. The reason for this must be further explored. One explanation may be that some of the type A-PWS have been characterised as type A for only one year during the study period, but recharacterised later as type B-PWS, which would exempt them from the current compliance monitoring duty.

It must be stressed, however, that concentration data are available for all years of the study period in each local authority, therefore it is feasible to examine whether the values are below the 30% threshold, as prescribed in the Amendment.

A high value for the upper 95 % C.L. for the probability of a parameter's concentrations exceeding the 30% threshold showed that there were high concentrations or a low sample size. This is clearly related to the wide range (spread) of concentrations in the case of aluminium. In the case of the remainder trial parameters high values for the confidence limit are generated by a combination of the wide range of values within the local authority and the low number of samples collected during the study period. According to the statistical criterion, the upper confidence limit for the probability of exceeding the threshold in aluminium and nitrate is too high to allow for reliable decision on their removal from monitoring duty in any of the local authorities by just accounting for the available type A data. Removal of nitrate from certain areas within Highland and Argyll and Bute should be explored in the context of the spatial criterion (i.e. risk maps).

On the other hand, cadmium, chromium and arsenic concentrations were found to be below the 30% threshold with high certainty in certain local authorities, as follows:

- Arsenic in Highland.
- Cadmium in Dumfries and Galloway, Highland, Perth and Kinross.
- Chromium in Argyll and Bute, Dumfries and Galloway, Highland, and Perth and Kinross.

To sum up, grouping data by local authority is feasible as there are data for longer than three years in each local authority. However, the decision on revising the list of parameters to be monitored in each local authority cannot be based exclusively on tap water concentration data grouped by local authority because it is not possible to be sufficiently confident that there is a low probability of concentrations of trial parameters exceeding the 30% threshold, as prescribed in the Amendment. The effect of type of water source is discussed conclusively in Section 4.2.

4.1.2 Grouping by waterbody

4.1.2.1 Number of type A-PWS sampled per waterbody type

The number of surface water type A-PWS per surface waterbody, and the number of groundwater type A-PWS per groundwater body were also examined for each trial parameter. Surface water type A-PWS include supplies served by water abstracted from streams or lakes/lochs. Groundwater type A-PWS include supplies served by water abstracted from wells, boreholes or springs. In general, the vast majority of waterbodies contained one or up to two type A-PWS, thus making grouping supplies by waterbody practically infeasible. The results are detailed in Appendix 4.2.

4.1.2.2 Confidence limits for the probability of concentrations exceeding the 30% threshold

The upper 95% C.L. for the probability of exceeding the 30% threshold –given the observed number of times it was exceeded- was estimated per waterbody type. The results for each trial parameter are summarised below:

- For aluminium, nitrate and arsenic, the upper 95% C.L. was always above five regardless of waterbody type (data not shown).
- For cadmium and chromium, the upper 95% C.L. was below five in groundwater type A-supplies in two, large groundwater bodies in Argyll and Bute, supporting 15 and 75 type A-supplies, respectively (data not shown).

4.1.2.3 Conclusion for grouping data per waterbody

The majority of surface and groundwater bodies support up to two type A-PWS. Not all of these waterbodies have been sampled each year. Therefore it would be infeasible to group together data and meet the requirement of the Amendment for three or more than three years of sampling. In addition, there was high uncertainty as to whether concentrations grouped by waterbody exceeded, or not, the 30% threshold, as prescribed in the Amendment. To sum up, available tap water data per waterbody are insufficient to inform decisions on revising the list of parameters to be monitored.

4.1.3 Scotland-wide data

Summary statistics (mean, minimum and maximum, range, and coefficient of variation) and the upper 95% C.L. for the probability of concentrations exceeding the 30% threshold for each trial parameter over Scotland are given in Table 5a. The table also presents the number of observations below and above 30% of parametric value; above 60% of parametric value (for reducing a parameter's sampling frequency, according to the Amendment); and above the parametric value.

Table 5a. Summary statistics for national scale data on trial parameter concentrations. p.v.: parametric value.

Summary statistics		Aluminium	Nitrate	Arsenic	Cadmium	Chromium
no. of samples (2009-2015)		3690	5330	3174	3125	2901
mean		34	8	1	0	1
min		0	0	0	0	0
max		2179	198	48	41	61
coefficient of variation %		256	174	311	846	247
Upper 95% C.L. for probability of exceeding threshold		46	29	8	4	0
no. of samples (2009-2015)	Conc. <30% of pv	2036	3861	2941	3027	2896
no. of samples (2009-2015)	Conc. ≥30% and <60%	654	818	155	38	4
no. of samples (2009-2015)	Conc. ≥60% and ≤pv	411	452	20	33	0
no. of samples (2009-2015)	Conc. >pv	593	205	58	27	1

These analyses showed that:

- A different number of samples have been collected for each trial parameter during the study period. Repeat samples were collected in the case of exceedances of the parametric value. This may partly explain the greater number of samples available for nitrate and possibly aluminium.
- The majority of concentrations of all trial parameters were below 30% of their parametric value. However, the ratio of the number of samples with concentrations below the 30% threshold to samples with concentrations above it depended on trial parameter. For example, a ratio of 3 means that there are three times as many samples with concentrations below the 30% threshold as above. The ratios are shown in Table 5b.

Table 5b. Ratios of the number of samples with concentrations below the 30% threshold to samples with concentrations above it in Scotland-wide data.

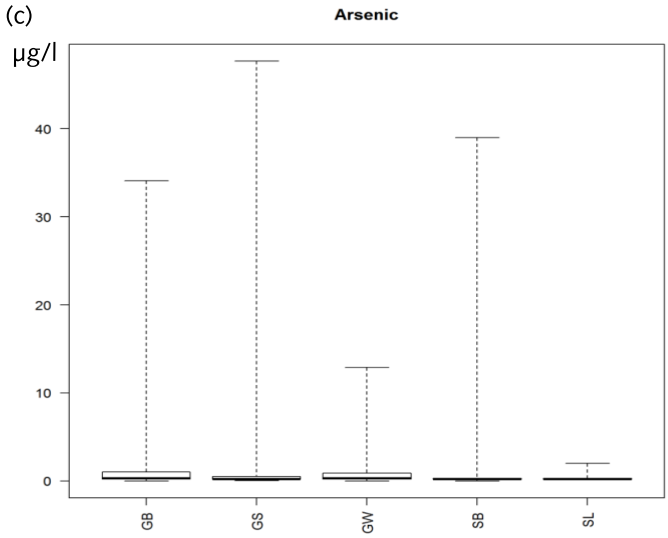
Trial Parameter	Ratio (no. samples below:above threshold)
Aluminium	1.2
Nitrate	3
Arsenic	13
Cadmium	31
Chromium	579

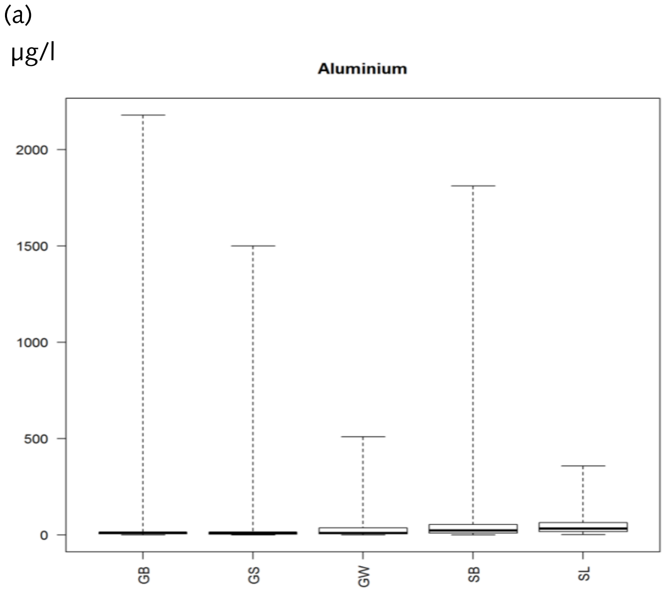
- The number of exceedances of parametric values (non-compliances) depended on the trial parameter. The greatest numbers of non-compliances were observed for aluminium (in 593 out of 2036 samples) and nitrate (in 205 out of 3861); the lowest rate of non-compliances was observed for cadmium (in 27 out of 3027 samples) and chromium (in 1 out of 2896 samples).
- The upper 95% confidence limit for the probability of exceeding the 30% threshold was below 5% for cadmium and chromium, suggesting an additional weight-of-evidence in favour of removing the monitoring of these parameters outwith areas for risk for cadmium and chromium. Uncertainties as to the reliability of the available dataset to draw conclusions on removing a parameter from current monitoring schedules remained for aluminium, nitrate and arsenic.

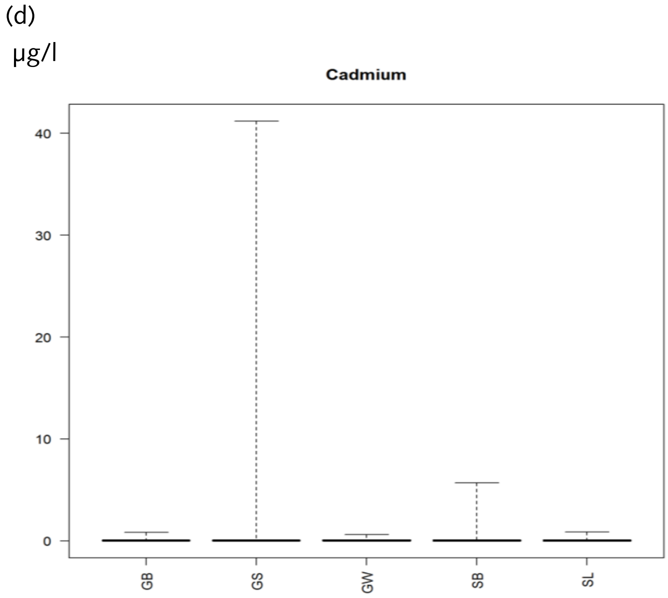
The distribution of concentrations for each parameter by type of source was also analysed using data collected during the study period (2009-2015) from all over Scotland (Figure 5). The following patterns of distribution were observed:

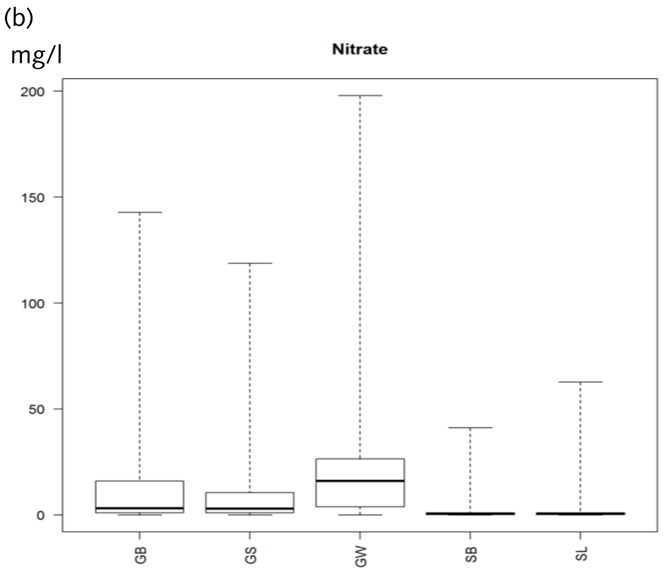
- Aluminium concentrations exceeding the 30% threshold were observed in all types of sources but the highest median values were recorded in surface stream and lake sources (Figure 5a). It remains unknown if this is related to use of coagulants to remove suspended solids, which are generally much higher in stream or lake waters than in groundwater, or to environmental factors, such as peat covered catchments.

- Nitrate concentrations were significantly higher in groundwater than surface type A-PWS, with the largest range of values measured in wells; concentrations exceeding the 30% threshold were observed in all types of sources (Figure 5b).
- Arsenic exceeded the 30% threshold in wells, boreholes, springs, and stream sources (Figure 5c).
- Cadmium exceeded the 30% threshold in springs and stream sources (Figure 5d).
- Chromium exceeded the 30% threshold in groundwater type A-PWS (Figure 5e).









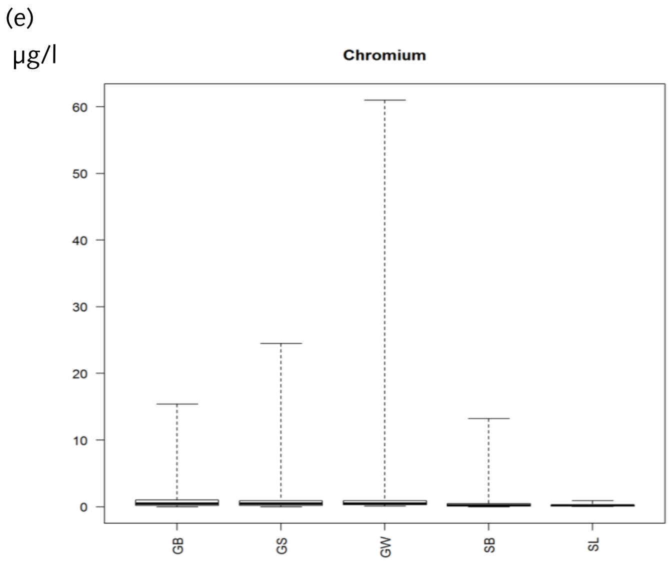


Figure 5 Concentration range per type of source of type A-PWS. (a) Aluminium. (b) Nitrate (c) Arsenic. (d) Cadmium (e) Chromium. GB-Boreholes; GS-Springs; GW-Wells; SB-Streams; SL-Lochs.

With the exception of nitrate, for which it is known that it is generated by agricultural land use and accumulates at the receiving groundwater systems (Appendix 2), the remainder of trial parameters were not clearly associated with groundwater or surface water sources. This finding was also examined in the context of groundwater vulnerability maps. It was observed that a large part of Scotland is characterised by mosaic groundwater vulnerability but classes of high vulnerability prevail.

Figure 6 shows an example of this mosaic in relation to the surface waterbodies associated with a specific groundwater body and the location of groundwater and surface water type A –PWS. This figure suggested that it would be difficult to distinguish between risks of catchment-driven contamination to surface water and groundwater. This is in line with the finding of exceedances of the parametric value and the 30% threshold in both surface and groundwater sources of water and the significantly greater concentrations of nitrate, which is generally related to land use (e.g. agriculture) and land cover (e.g. forest) and not to the bedrock in contact with groundwater, in the receiving groundwater bodies in each catchment. In view of these findings, and given the growing evidence of groundwater contributing to low flows and flood flows in streams and rivers in Scotland (e.g. Dochartaigh et al 2015), it was decided to produce risk maps of type A-PWS regardless of type of source and accounting for the combined area covered by surface waterbodies draining to groundwater bodies.

4.2 Risk maps

4.2.1 Aluminium

The risk area for aluminium was compiled by combining:

- Surface waterbodies supporting type A_PWS with concentrations equal or above the 30% threshold (i.e. 60 µg/l) during the study period (2009-2015).
- Groundwater bodies intersecting the selected surface waterbodies.
- Aquifers explicitly described in BGS reports as displaying elevated concentrations of aluminium and only when the concentrations were reported. In the case of aluminium, exceedances of aluminium parametric value for groundwater (which is the same as in the DWD) were reported for Lewis, Skye, and granites of Southwest Scotland (MacDonald and Dochartaigh 2005). However, the concentrations projected on the maps of this BGS report showed great spatial variation in southwest Scotland, thereby this information could not be generalised to include southwest Scotland as a risk area.

The resultant risk area for aluminium is shown in Figure 7. A notable feature of this map is that it covers an extensive area over Scotland; thereby the identification of a risk area for the monitoring of aluminium had a small impact on the number of type A-PWS that could be removed from compliance monitoring under the Amendment's provisions (i.e. only 16% outwith the risk area) (Table 6a).

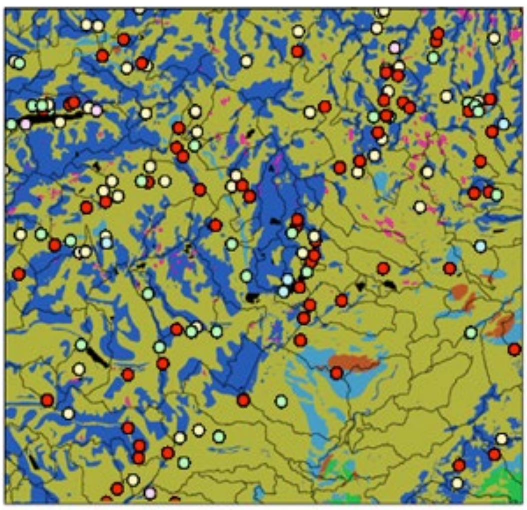


Figure 6 Groundwater vulnerability in relation to surface waterbodies draining into a groundwater body and location of type A –PWS by type of water source. Source of data: BGS, DWQR, SEPA.

Table 6a. Number of local authorities, supplies, and people served with current and risk-based monitoring for aluminium.

Aluminium	Current monitoring			Risk-based monitoring		
	No. of local authorities	No. of type A-PWS	Population	No. of local authorities	No. of type A-PWS	Population
	26	1274	54,483	21	1068	46,596

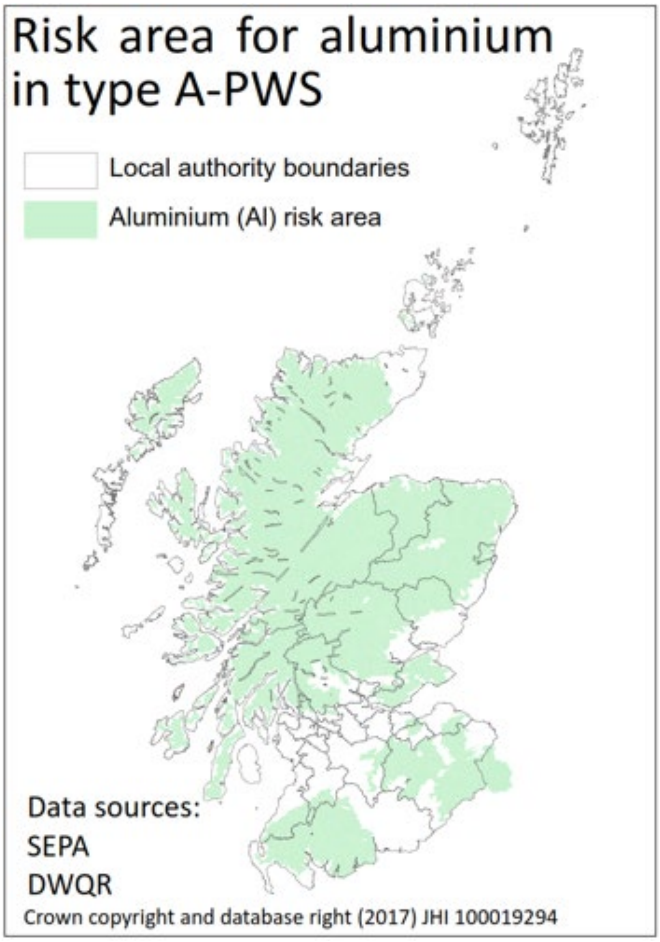


Figure 7 Risk area for aluminium in type A-PWS

4.2.2 Nitrate

The risk area for nitrate was compiled by combining:

- Surface waterbodies supporting type A-PWS with concentrations equal or above the 30% threshold (i.e. 15 mg/l) during the study period (2009-2015).
- Surface waterbodies with nitrogen pressures observed through SEPA's monitoring data for WFD. These waterbodies were selected by SEPA under the priority catchment approach and mapped to help targeting of agri-environment options available via the Scotland Rural Development Programme (SRDP) (Akoumianaki et al 2014).
- Groundwater bodies intersecting the selected surface waterbodies.
- Groundwater bodies at less than good status (which is usually due to nitrate failure) intersecting surface waterbodies supporting type A-PWS with concentrations below the 30% threshold (i.e. 15 mg/l) during the study period (2009-2015).

It must be noted that surface waterbodies where type A-PWS nitrate exceeded the 30% threshold and surface waterbodies with nitrogen pressures greatly overlapped, suggesting that the exceedances of the 30% threshold in tap water of type A-PWS were related to agricultural land use.

The resultant risk map for nitrate is given below (Figure 8). The map shows that lowland areas in East Scotland, which are within the nitrate vulnerable zones (NVZ) for Scotland, mainly comprise the risk area for nitrate in type A-PWS. Scattered risk spots in Highland and relatively small risk areas in the jurisdictions of Stirling and Dumfries and Galloway were also part of the risk area for nitrate. The identification of a risk area for nitrate has a considerable impact on the number of supplies monitored under the current schedules, with approximately half of them (55.5%) being outwith the risk area (Table 6b).

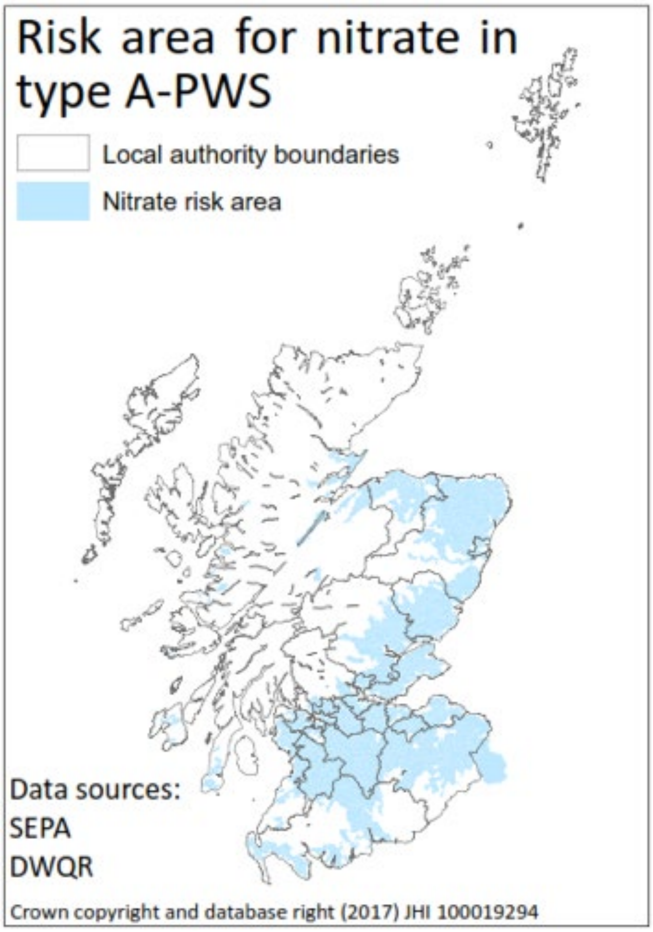


Figure 8 Risk area for nitrate in type A-PWS.

Table 6b. Number of local authorities, supplies, and people served with current and risk-based monitoring for nitrate.

Nitrate	Current monitoring			Risk-based monitoring		
	No. of local authorities	No. of type A-PWS	Population	No. of local authorities	No. of type A-PWS	Population
	28	1627	69,741	25	725	37,991

4.2.3 Arsenic

The risk area for arsenic was compiled by combining:

- Surface waterbodies supporting type A_PWS with concentrations equal or above the 30% threshold (i.e. 3 µg/l) during the study period (2009-2015).
- Surface waterbodies with pesticide pressures, because of evidence that arsenic had been used as pesticide in the past (see Appendix 2). It is uncertain whether this happened in Scotland, but it could not be ruled out at this stage of method development.
- Groundwater bodies intersecting the selected surface waterbodies.
- Aquifers explicitly described in BGS reports as displaying elevated concentrations of arsenic and only when the concentrations were reported. In the case of arsenic, exceedances of parametric value for groundwater (which is the same as in the DWD) were reported for Morayshire and the Dumfries basin (MacDonald and Dochartaigh 2005).

The resultant risk map for arsenic is given in Figure 9. This map shows that large areas of Highland were outwith the risk area for arsenic. However, the identification of a risk area for the monitoring of aluminium had a small impact on the number of type A-PWS that could be removed from compliance monitoring under the Amendment's provisions, with approximately 33% being outwith the risk area (Table 6c).

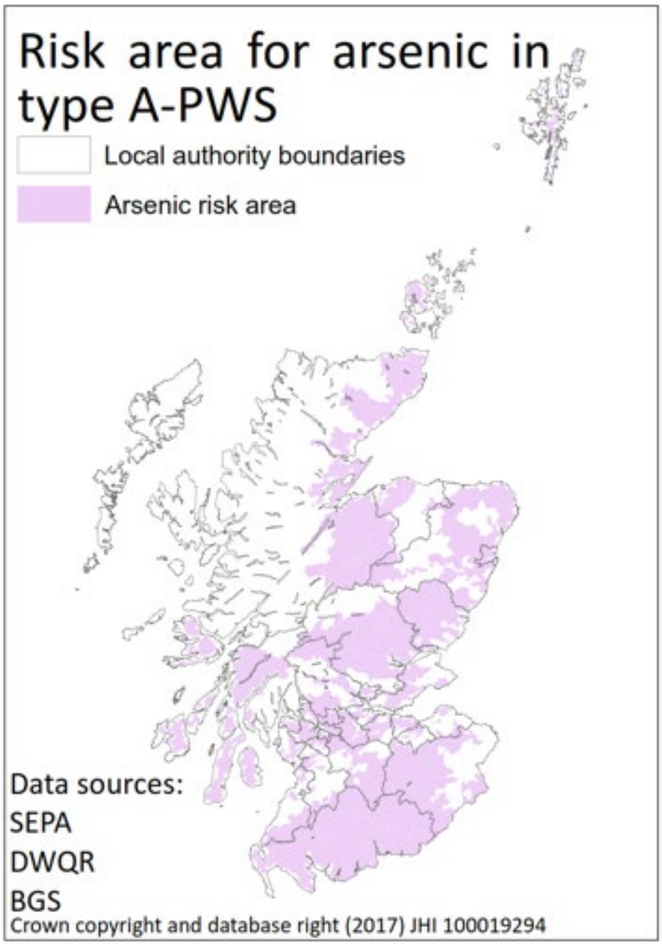


Figure 9 Risk area for arsenic in type A-PWS

Table 6c. Number of local authorities, supplies, and people served with current and risk-based monitoring for arsenic.

Arsenic	Current monitoring			Risk-based monitoring		
	No. of local authorities	No. of type A-PWS	Population	No. of local authorities	No. of type A-PWS	Population
	27	1348	54,680	25	892	39,462

4.2.4 Cadmium

The risk area for cadmium was compiled by combining:

- Surface waterbodies supporting type A_PWS with concentrations equal or above the 30% threshold (i.e. 1.5 μg/l) during the study period (2009-2015).
- Surface waterbodies with phosphorus pressures, because of evidence that some cadmium is contained in phosphate fertilisers (Appendix 2). The waterbodies with phosphorus pressures were selected by SEPA under the priority catchment approach and mapped to help targeting of agri-environment options available via SRDP (Akoumianaki et al 2014).
- Groundwater bodies intersecting the selected surface waterbodies.

It must be noted that surface waterbodies with exceedance of the 30% threshold and surface waterbodies with phosphate pressures greatly overlapped, suggesting that the exceedances of the 30% threshold in drinking (tap) water were related, at least partially, to agricultural land use. Also these surface water and groundwater bodies covered aquifers in East Lothian and Fife and the metamorphic rocks of the highlands, which were indicated by MacDonald and Dochartaigh (2005) as having elevated cadmium concentrations.

The risk area for cadmium is shown in Figure 10. This map shows that relatively extensive areas in Dumfries and Galloway, Perthshire, Highland and Aberdeenshire were outwith the risk area for cadmium. Indeed, the identification of a risk area for the monitoring of cadmium resulted in targeting monitoring to a substantially smaller number of type A-PWS, with 73% of type A-PWS being outwith the risk area. However, the number of local authorities with a duty to monitor cadmium remained high (Table 6d).

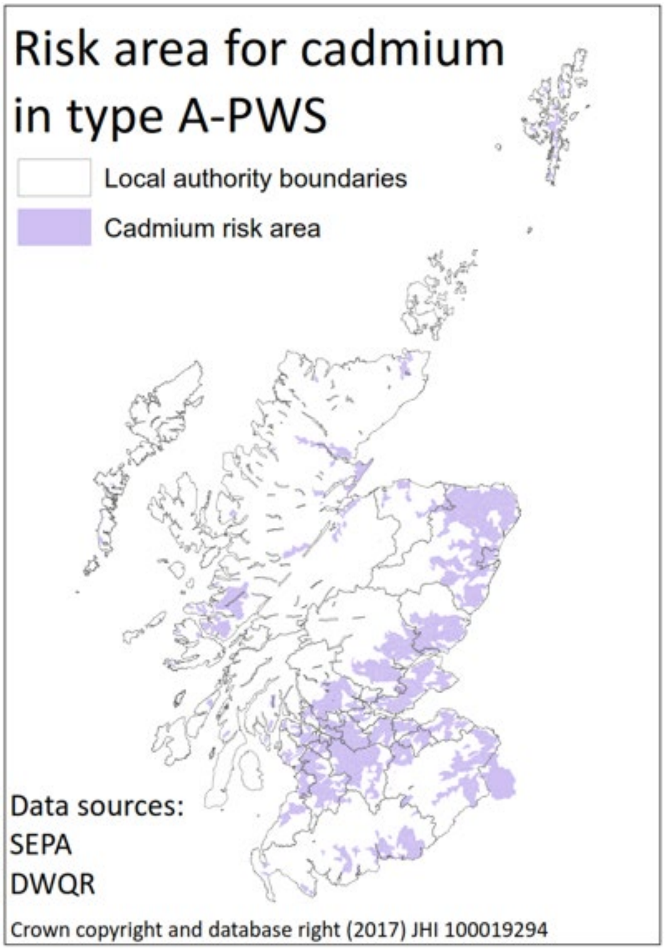


Figure 10 Risk area for cadmium in type A-PWS in Scotland.

Table 6d. Number of local authorities, supplies, and people served with current and risk-based monitoring for cadmium.

Cadmium	Current monitoring			Risk-based monitoring		
	No. of local authorities	No. of type A-PWS	Population	No. of local authorities	No. of type A-PWS	Population
	27	1338	53,420	24	360	19,404

4.2.5 Chromium

The risk area for chromium was compiled by combining:

- Surface waterbodies supporting type A_PWS with concentrations equal or above the 30% threshold (i.e. 15 µg/l) during the study period (2009-2015).
- Groundwater bodies intersecting the selected surface waterbodies.
- Groundwater bodies in the area of Glasgow. Chromium ore processing residue (COPR) contamination in the south-east of Glasgow has long been recognised as a significant regional issue (Fordyce et al 2004). The contamination has originated from chemical works in Shawfield for about a century until 1968. During this period, an estimated 1.5 million cubic meters of COPR were landfilled in various sites located in the Rutherglen and Cambuslang areas of the city. Some of this waste was deposited in clay pits or in mounds, for example under football terracing. The area is covered by buildings or hard standings which prevent people from being exposed directly to the contamination. However, chromium has been leaching into groundwater and into culverted streams flowing into the River Clyde. As a result of this, groundwater has been shown to be highly contaminated with both, total chromium and hexavalent chromium (Bewley et al 2001).
- Areas reported by MacDonald et al (2005) as potentially having high concentrations of chromium in the groundwater and stream sediments. These areas included: Skye, Mull and Ardnamurchan; the coast of Ayrshire; igneous intrusions in Aberdeenshire; areas influenced by Lewisian gneiss on Lewis and near Scourie in the northwest Highlands; areas influenced by the Devonian sediments of Strathmore between Stirling and Coupar Angus; and areas influenced by the Silurian-Ordovician succession of the Scottish Borders. Concentration ranges were reported for these areas but location data were not available for all of them, thus making it difficult to include all of these areas in the risk map.

The risk map for chromium is shown in Figure 11. The map shows that type A-PWS in Renfrewshire, S. and N. Lanarkshire, Glasgow City, E. and W. Dunbartonshire and the coastal areas of Inverclyde may be at risk from man-made chromium contamination. Actual measured natural concentrations were generally low (MacDonald et al; 2005; MacDonald and Dochartaigh 2005). However, outwith type A-PWS monitoring, samples have been collected from very few areas across Scotland. In addition to this source of uncertainty, SEPA's chromium measurements in streams were not readily available as a spatial data set to inform this project. Therefore this map is possibly underestimating the number of locations with elevated chromium values but, on the other hand, presents the most recent quantitative evidence on chromium concentrations in surface water and groundwater bodies in Scotland. The overall identification of the risk area for the monitoring of chromium in type A_PWS led to a substantial reduction in the number of local authorities with a duty to monitor chromium and in the number of type A-PWS to be monitored, with 91% of them being outwith the risk area (Table 6e).

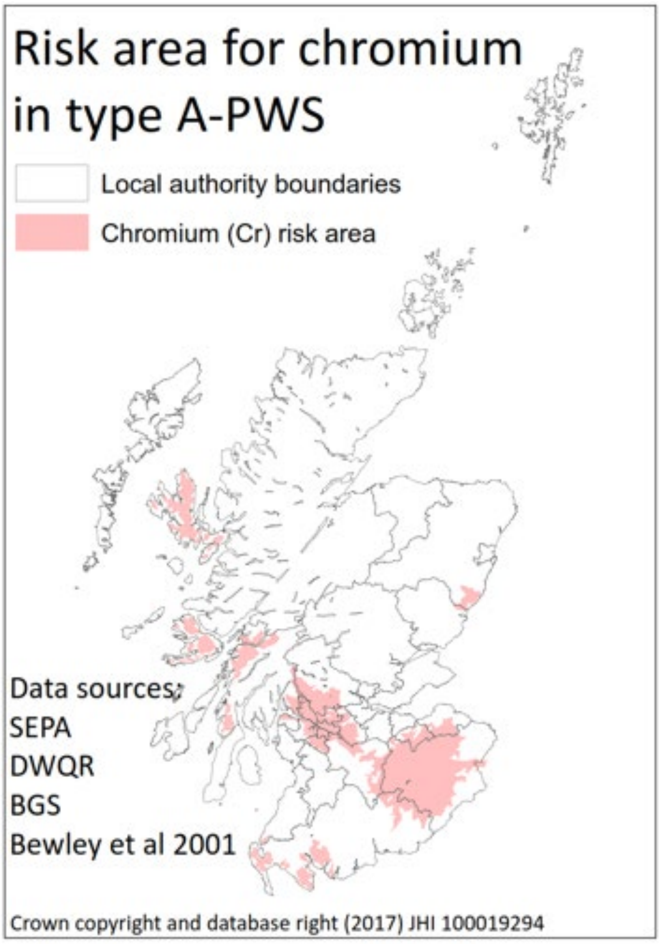


Figure 11 Risk area for chromium in type A-PWS.

Table 6e. Number of local authorities, supplies, and people served with current and risk-based monitoring for chromium.

Chromium	Current monitoring			Risk-based monitoring		
	No. of local authorities	No. of type A-PWS	Population	No. of local authorities	No. of type A-PWS	Population
	26	1259	51,549	10	115	4315

4.3 Weight-of-evidence results

The results of Sections 4.1 and 4.2 were integrated and evaluated by the weight-of-evidence method for all trial parameters. The results are presented below and are summarised in Table 7.

- Aluminium: there is agreement between the statistical and spatial analyses that local authorities should carry on with the current monitoring programme. Statistical analysis suggested that all the local authorities and waterbodies must be monitored, since the upper 95% C.L. for the probability of aluminium concentrations of exceeding the 30% threshold is above 5%. Spatial analysis of the waterbodies where aluminium concentrations in type A-PWS exceeded the 30% threshold showed that the areas of risk are scattered across Scotland. Besides it was uncertain whether (and, if so, where) exceedances were caused by the use of coagulant or not. An additional source of uncertainty was the lack of aluminium measurements at the surface waterbody scale which could help illuminate the issue of catchment- or treatment –related origin of aluminium in the tap water of type A-PWS. Also, there was no map layer on coal mining to infer the risk from this activity.
- Nitrate: there is agreement between the statistical and spatial analyses that local authorities should carry on with the current monitoring programme. However, the statistical analyses showed that the upper 95% C.L. for the probability of exceedance of the 30% threshold is relatively low for Argyll and Bute and Highland. These two local authorities have very few areas at risk from nitrate contamination; therefore it should be explored whether they could remove nitrate from their monitoring schedule.
- Arsenic: The combined evidence from Upper 95% C.L. for the probability of arsenic exceeding the 30% threshold and the analysis of spatial risks shows that the map can help target the monitoring of arsenic in certain type A-PWS in Highland.
- Cadmium: There is agreement between the statistical and spatial analyses that local authorities could revise their current monitoring programme in Aberdeenshire, Argyll and Bute, Moray, and Scottish Borders. The map can help target the monitoring of cadmium to certain type A-PWS within these jurisdictions. A caveat that applies specifically to the cadmium risk area is that this area has been identified on the basis of phosphate pressures in agricultural areas. SEPA is measuring cadmium under WFD; however, information on where this sampling is carried out is not readily available. Therefore, it remains unknown whether and where exceedances of cadmium have been recorded in waterbodies of Scotland and whether cadmium concentrations are indeed correlated with phosphate pressures. This must be further explored in consultation with SEPA.
- Chromium: The risk map largely agrees with the statistical analyses. Within Argyll and Bute, Dumfries and Galloway, Highland, Perth and Kinross and Scottish Borders chromium has a low upper 95% C.L. for the probability of exceeding the 30% threshold. Large parts of these jurisdictions are outwith the risk area for chromium in type A-PWS. However, parts of Scottish Borders are within the risk area for chromium and thus Scottish Borders should be monitored under the current monitoring programmes. For Argyll and Bute, Dumfries and Galloway, Highland, Perth and Kinross, the map can help target the monitoring of chromium to certain type A-PWS. It should be also noted that large areas of Aberdeenshire, Moray, Angus, Fife, and S. and E. Ayrshire are outwith the risk area but statistical analysis showed that there is no confidence that the probability of exceeding the 30% threshold is below 5%. In addition to this uncertainty, baseline chromium surveys by MacDonald et al (2005) had indicated that these areas are likely to deliver elevated chromium concentrations in stream sediments and in the groundwater. Therefore, monitoring in these local authorities must carry on as is.

Table 7. Results of the weight-of-evidence method developed here to identify areas where a parameter can be removed from current monitoring with sufficient confidence. wb: waterbody; GW: groundwater.

Criteria	Aluminium	Nitrate	Arsenic	Cadmium	Chromium
Statistical criterion: Upper 95% C.L. for the probability of concentrations exceeding the 30% threshold	Upper 95% C.L.<5% in: None of the local authorities	Upper 95% C.L.<5% in: none of the local authorities	Upper 95% C.L.<5% in: Highland	Upper 95% C.L.<5% in: Aberdeenshire, Argyll and Bute, Moray, Scottish Borders	Upper 95% C.L.<5% in: Argyll & Bute, Dumfries &Galloway, Highland, Perth & Kinross, S. Borders.
Spatial criterion					
WFD data	Not available	Nitrogen pressures (due to failures and land use risks) available at the surface wb scale. Gw status – less than good status used to indicate nitrate exceedances	Not readily available Proxy of pesticide pressures at the waterbody scale used instead	Not readily available Proxy of phosphate pressures at the surface waterbody scale used instead	Not readily available
BGS data	No data	Not necessary	No data	No data	No data
Literature review	MacDonald and Dochartaigh 2005	Type A-PWS concentrations ≥30% of parametric value for three or more years	MacDonald and Dochartaigh 2005 MacDonald et al 2005	MacDonald and Dochartaigh 2005 MacDonald et al 2005	MacDonald and Dochartaigh 2005 MacDonald et al 2005 Bewley et al 2001
Output of spatial analysis	Extensive risk area	Highland, Argyll and Bute, Stirling, Dumfries and Galloway have extensive areas outwith the risk area	Only Highland clearly outwith the risk area	Highland, Argyll and Bute, Dumfries and Galloway, Moray and Scottish Borders have extensive areas outwith risk area	Only Scottish Borders, E. and W. Dunbartonshire, Midlothian, N. Lanarkshire have extensive areas within risk area
Evaluation/Decision	Current monitoring as is in all local authorities	Current monitoring as is but areas in Highland and Argyll and Bute could be exempt	Highland can be exempt from monitoring	Could be removed from monitoring obligation in certain areas in: Aberdeenshire, Argyll and Bute, Moray, and Scottish Borders	Could be removed from monitoring obligation in certain areas in: Argyll and Bute, Dumfries and Galloway, Highland, Perth and Kinross. For the remainder of local authorities current monitoring as is to collect sufficient data for future revisions.
Caveats/Uncertainties	Uncertainties due to the: • wide range of aluminium concentrations from type A-PWS • insufficient data from all type A-PWS during the study period • origin of aluminium due to its use as coagulant • lack of sufficient number of measurements at waterbodies	Uncertainties due to the: • lack of understanding of the exact causes of high values in certain locations in Highland and Argyll and Bute • insufficient data from all type A-PWS during the study period	Uncertainties due to the: • use of proxy (i.e. pesticide) instead of actual measurements to identify risk area • insufficient data from all type A-PWS during the study period • lack of sufficient number of measurements at waterbodies	Uncertainties due to the • use of proxy (phosphate) instead of actual measurements to identify risk area • insufficient data from all type A-PWS during the study period • lack of sufficient number of measurements at waterbodies	Uncertainties due to the: • insufficient data from all type A-PWS during the study period • lack of sufficient number of measurements at waterbodies

5.0 Policy Implications

5.1 Opportunities

The method developed here aligns monitoring in type A-PWS under the DWD with waterbody catchment and groundwater monitoring under WFD and any other readily available evidence. The method helped to identify areas within each local authority where there is simultaneously (i) sufficient type A-PWS data for three or more years to estimate the probability of exceedances of the 30% threshold in drinking (tap) water reliably and (ii) credible evidence about all potential risks of contamination at source catchments (waterbody scale).

The weight-of-evidence method developed here opens up a range of opportunities:

- Combining evidence from type A-PWS monitoring and WFD monitoring (prescribed in articles 7 and 8), as well as other measurements at the source, is a pragmatic way of complying with the Amendment's requirement for decisions on derogations from monitoring programmes to be based on evidence from WFD monitoring (Amendment's Preamble par. 7).
- Matching each type A-PWS location with a surface waterbody catchment and groundwater body addresses the Amendment's provision for a drinking water monitoring that bridges the evidence gap between water abstraction and supply and allows for aligning the DWD and WFD objectives to protect human health from the adverse effects of drinking water contamination (Amendment's preamble par. 5)
- Targeting type A-PWS monitoring to areas of risk is in line with the principles of water safety planning, whereby monitoring is designed to enable detection of non-compliances and implementation of remedial measures. Therefore it has a greater potential to protect human health from the adverse effects of drinking water contamination. Although the surface waterbody and groundwater data have been used to inform risk-based monitoring, they can also be integrated with the risk assessment procedures already in place to help build a consistent template of the information required to assess risks on a Scotland-wide basis.
- Removing certain parameters from the monitoring obligation in certain areas, on the condition that these areas present no risk of contamination, is a way of prioritising the collection of information that is relevant to actual risks to human health. As such it enhances the value of monitoring evidence for the users of type A-PWS.
- Tailoring monitoring to catchment land use and natural, geological risks specific to each parameter presents potential cost-saving opportunities, as it can reduce the number of sampling visits and sample analyses.

In addition, the method is:

- Flexible, as risk areas can be updated when new data from type A-PWS and WFD monitoring and literature become available without affecting the weight-of-evidence method or the scope of risk-based monitoring.
- Robust, as it is based on a detailed dataset of monitored data, i.e. local authority type A-PWS data; SEPA's assessments at the waterbody scale to inform the river basin management plans; and a growing body of evidence on occurrences of parameters in groundwater.
- Transparent, as the criteria (i.e. confidence on the probability of a parameter's concentrations to exceed the 30% of parametric values and pressures at the same waterbody and hydro-geological unit) are based on measured data and not on assumptions.
- Repeatable, as the steps for selecting parameters and risk areas are described in detail. Therefore, the method could easily be repeated in the future or elsewhere.

5.2 Limitations

It is acknowledged that applying a risk-based approach to compliance-monitoring raises significant challenges.

- The weight-of-evidence method developed here can be applied on chemical parameters monitored at the waterbody scale. In this context, it could be applied on chemical parameters derived from land use (agricultural, industrial or domestic), and especially on parameters monitored and controlled under article 8 of WFD, which includes many of the chemical parameters measured in private water supplies. The limitation refers mainly to microbiological parameters. In the UK and across EU, faecal indicator organisms (FIOs) are monitored at bathing waters under WFD provisions but not at contributing waterbodies within designated bathing water protected areas (Akoumianaki and Potts 2017). Therefore, there is no monitored evidence about the risks from microbiological contamination at waterbodies supporting private water supplies.
- The decision on keeping current monitoring in place was based on an insufficient amount of data for the given range of concentrations. This uncertainty may also apply in other parameters, which have not been tested yet.
- Many of the type A-PWS have been monitored only once between 2009 and 2015. Therefore, spatial maxima in concentrations may not have been captured reliably by this monitoring.
- Current routine monitoring has not targeted rainfall or temporal variation. However, the actual frequency of occurrences of a parameter at concentrations exceeding the 30% of parametric value in drinking (tap) water depends on the interaction between geology and the temporal variation in environmental factors, such as rainfall, and in land use practices that influence transport

and mobilisation of contaminants in a variety of ways. For example, aluminium concentrations are linked to changes in pH, nitrate concentrations in groundwater depend on local catchment conditions, arsenic concentrations depend on mineralisation, cadmium is mobilised under acidic conditions, and hexavalent chromium is mobile in the water environment under high pH conditions (MacDonald et al 2005).

- Access to WFD monitoring data is easy for online status classification data and agriculture-derived diffuse pollutants, such as phosphate and nitrogen. However, it is not straightforward for specific parameters such as priority substances[7], which include toxic organic substances and pesticides, and specific pollutants[8]. WFD has adopted the same, if not stricter for some parameters, parametric values as in DWD for many of these parameters. Therefore, aligning the two directives for all of these parameters and updates is feasible but requires planning, time and collaboration, and potentially an extra budget specific for the analysis of the findings and data updates. The positive side of this is that the method developed here has already linked type A-PWS locations to waterbodies, so the alignment of type A-PWS and waterbody data for a specific chemical parameter can be automated.
- The concept of a risk-based area specific to each parameter is a new paradigm, opposite of routine monitoring. As such it may take extra effort to enable its endorsement by local authorities and may require a certain time for adjustment.
- Risk-based monitoring alone is unable to sustainably reduce the cost of monitoring. Without effective control measures at the catchments within the risk area, the need for repeat samples, in the case of non-compliances, will keep placing a burden on monitoring local authorities.
- Certain risks to drinking water may remain unaccounted for by the approach developed here. This is mainly because of the uncertainties in the type A-PWS data (i.e. short-term data, low confidence on the probability of no- exceedance of the 30% threshold, few type A-PWS sampled for three or more years) and the waterbody data (i.e. use of proxy data for some parameters to identify risk areas specific to each trial parameter). Exceedances of the 30% of parametric value outwith the parameter-specific risk areas are not reasonably anticipated but cannot be ruled out, therefore necessitating regular updating of the risk areas.

6.0 Recommendations to improve the methodology

The weight-of-evidence method developed here provides a tool for reliable, evidence-based decisions on targeting the monitoring of type A-PWS to risk areas specific to each parameter. Certain evidence gaps and uncertainties, however, need to be tackled to improve understanding of occurrences of concentrations exceeding the 30% threshold and enhance confidence in data. The review of literature helped develop recommendations on what needs to be done to enhance the weight-of evidence-method for risk-based monitoring of type A-PWS. The weight-of-evidence method developed here can be further improved by:

- Collecting data from each type A-PWS each year. It remains unclear why certain so-called large local authorities have sampled the majority of the type A supplies in their jurisdictions only once between 2009 and 2015.
- Making WFD monitoring data for priority substances and specific pollutants collected at the waterbody readily available to enable reliable evaluation of risks.
- Carrying out risk assessment within and outwith risk areas and in combination with WFD monitoring (waterbody) data to account for any change in catchment conditions.
- Carrying out extra monitoring where the weight-of-evidence method indicates data uncertainties. The analyses showed that the uncertainties were due to insufficient number of type A-PWS samples for the range of values observed to allow for reliable estimates on the probability of concentrations exceeding the 30% threshold.
- Putting in place a common documentation of catchment-related parameter concentration at the tap water of type A-PWS and the associated waterbody so as to facilitate data alignment and incorporation of updates, when new data and catchment information become available.

[7] According to Annex V, point 1.4.3 of the WFD and Article 1 of the Directive on Environmental Quality Standards (EQSD) 2008/105/EC, good chemical status is reached for a waterbody when it complies with the EQS for all priority substances and other pollutants listed in Annex I of the EQSD.
[8] UKTAG (2008) considers as specific pollutants under WFD the following: 2-4 D, chromium, cypermerthrin, diazinon, dimethoate, linuron, niecoprop, phenol toluene, 2-4 dichrophenol, ammonia (salt water), arsenic, chlorine, copper, cyanide, iron, permethrin, zinc; these have to be sampled in all waterbodies.

7.0 Conclusion

This report provided a review of the literature on risk-based monitoring in the context of small, rural supplies and piloted a method enabling risk areas specific to catchment-related drinking water parameters to be identified and taken forward for risk-based monitoring. A practical weight-of-evidence method has been developed to help decide where the risk of contamination of the water served by type A-PWS is greatest in relation to catchment influences and parameter concentration occurrences to inform risk-based monitoring.

The key findings can be summarised as follows:

- A practical weight-of-evidence method has been developed to identify where the risk of contamination of the water served by type A- PWS is greatest in relation to catchment influences and parameter concentration occurrences to inform risk-based monitoring.
- The method links the location of type A-PWS with waterbodies (surface and groundwater) and applies to parameters for which concentration data are available from (i) type A-PWS monitored at tap water under the Drinking Water Directive (DWD), and (ii) waterbodies monitored at the catchment scale under the Water Framework Directive (WFD). The method also allows for literature data to be incorporated.
- For a parameter to be removed from monitoring in a given area, two criteria should be met:
  - o A statistical criterion: the upper 95% confidence limit for the probability of concentrations exceeding the threshold (30% of the parametric value during 2009-2015) should be less than 5% in a given area (i.e. waterbody, local authority and region).
  - o A spatial criterion: a parameter's concentrations should be below the 30% of the parametric value(i.e. the 30% threshold) and no pressures, monitored or known from literature, should be present in a given area (i.e. waterbody, local authority and region). This can be visualised through risk maps.
- Trials on five parameters (aluminium, nitrate, arsenic, cadmium and chromium) show that data from many local authorities are insufficient for reliable estimates of the statistical criterion. This is due to the majority of type-PWS in a given area being sampled only once between 2009 and 2015 and exhibiting a wide range of concentrations for each trial parameter.
- The weight-of-evidence method developed here combines monitoring evidence from type A-PWS and the catchment to enhance certainty of data interpretation and accounting of potential risks. As such it provides a pragmatic means of complying with the DWD's provisions, as amended, for flexible monitoring.

The trials highlighted uncertainties in the identification of risk areas due to lack of data on pressures from agriculture and industry for all waterbodies. However, the method helped to identify which areas are clearly not risk areas for a trial parameter and the risk areas where trial parameters should be monitored as in current monitoring programmes.

- Aluminium risk areas covered extensive parts of 21 local authorities; a 16% of type A-PWS were outwith the identified risk areas.
- Nitrate risk areas were found in 25 local authorities, covering only small parts in Argyll and Bute and Highland; a 55.5% of type A-PWS were outwith the identified risk areas.
- Arsenic risk areas were found in 25 local authorities, covering small parts in Highland; a 33% of type A-PWS were outwith the identified risk areas.
- Cadmium risk areas were found in 24 local authorities, covering small parts in Highland; a 73% of type A-PWS were outwith the identified risk areas.
- Chromium risk areas were found in ten local authorities; 91% of type A-PWS were outwith the identified risk areas.

This report provided recommendations on the basis of the trials in Scotland's type A-PWS. These can be summarised as follows:

- Risk-based monitoring must be carried out in each type A PWS every year within the identified risk areas specific to a catchment-related parameter.
- Risk assessment should carry on within and outwith risk areas and be combined with WFD monitoring (waterbody) data to account for any change in catchment conditions.
- WFD (waterbody) monitoring data for priority substances and specific pollutants must become readily available to enable reliable evaluation of risks for type A-PWS.
- A common documentation of catchment-related parameter concentration at the tap water of type A-PWS and the associated waterbody so as to facilitate data alignment and incorporation of updates, when new data and catchment information become available.

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