JNCC Report 817

System Level Indicator Project Report

E. Corbett, J. Chaplow, E. Forbes, S. Ozaki, M. Nichols, M. Tso, C. Wells, D. Green, T. Cuddy and I. Thorpe

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Summary

The System Level Indicator (SLI) project was a collaborative project led by the Joint Nature Conservation Committee (JNCC) and the UK Centre for Ecology & Hydrology (UKCEH), funded by the Department for Environment, Food & Rural Affairs (Defra) from October 2022 to March 2025. The SLI project aimed to use existing data to develop a proof-of-concept visual communication tool to demonstrate the state of the environment in the UK in relation to chemical pollution.

Data searches primarily used the UKCEH-hosted Environmental Information Data Centre as a source, and several hundred relevant datasets were identified during the initial search. Of these, 22 datasets have been uploaded to the proof-of-concept tool. The selection of data incorporated into the tool was guided by stakeholder engagement – specifically through the development of case studies based on stakeholders' priority issues, a Delphi survey to identify key chemicals and pressures relevant to the tool, and stakeholder workshops.

The SLI tool homepage consists of a map onto which up to five datasets can be overlaid at any one time, allowing relationships between them to be observed and research gaps to be identified. As well as the map, each dataset can also be viewed as a plot or table. The Indicator tab within the tool contains an illustrative version of a State of the Environment Indicator, which aims to show the overall quality of different environmental compartments within each country. This feature is currently a work in progress, with sufficient datasets and appropriate threshold values still to be identified and incorporated. Other tabs within the tool contain data sources for the spatial viewer and indicator, accessibility information, and an overview of the tool.

The tool was built as an R Shiny app using UKCEH's DataLabs research platform, chosen for its ease of use and suitability for development of interactive apps. Although the tool has been designed primarily for internal use by Defra, the code generated during the project is open source and can be used to support work on similar projects, limiting duplication of effort.

The proof-of-concept tool demonstrates the broad applicability of this type of data viewer and of the systems approach. By showing chemical pollution data alongside wider datasets, the tool allows users to identify patterns, gaps, and connections that can inform and target monitoring and research. By visualising datasets as points or areas on a map, the tool can aid communication of complex environmental information with, for example, policy professionals who may not have a scientific background.

Recommendations for future work to further develop and validate the tool include expanding the State of the Environment feature and incorporating additional data from a wider range of disciplines. The provision of statistical functionality within the tool would also increase its usefulness as a communication tool and aid decision-making, providing clear evidence of associations where they exist between datasets.

Contents

1. Introduction

1.1. Background

Pollution has been identified as one of the major drivers of biodiversity loss globally, along with climate change, land use change, direct exploitation, and invasive species (IPBES 2019). Chemical pollution in the UK must therefore be addressed urgently to meet national and global targets to halt and reverse biodiversity decline. Understanding and communicating the data that is currently available is a vital step in this process.

Currently, the majority of the UK's chemical pollution data is collected and stored for specific purposes, such as for environmental monitoring schemes and legislative reporting. For example, much of the data available for aquatic systems in England is based on Environment Agency (EA) monitoring under the Water Framework Directive (WFD). Though it can tell us where chemical pollution exists, this routine monitoring data is not able to show where that pollution originated or what effect it is having on the environment. For this, a systems approach is required, which considers exposure and effects datasets, sources and pathways of chemical pollution, and broader datasets relating to biodiversity, climate, etc.

There are many factors that influence the use of chemicals, their distribution in the environment and their effect on biodiversity. Contributing pressures such as climate change affect the nature and impact of chemicals in the environment. For example, increases in water temperature can lower the pH and increase the solubility of heavy metals (UKHSA 2023), and warmer temperatures can also increase the toxicity of chemicals (Kazmi *et al*. 2022). Integrating data from different components of the system may improve our understanding of the state of the environment, reveal factors and effects previously undiscovered, and help to prioritise policy interventions and management options for recovery.

Although a large volume of relevant data exists, integrating multiple datasets and understanding them at a system level is challenging. Data is gathered at varying spatial and temporal scales, reported in a wide range of formats, and produced to different quality standards. Weighting, normalising, visualising and connecting this data is time-consuming and difficult. Even prior to integrating the data, finding, accessing and storing data (especially data that you do not own) is a challenge in and of itself.

However, once the data has been integrated and visualised, the system-level view of pollution it could provide would greatly enhance the communication of complex environmental information, particularly to those without a scientific background. Such a view would allow connections and gaps to be identified and relevant questions to be asked and could therefore be a valuable tool for targeting policy and research.

The System Level Indicator (SLI) project was a collaborative project led by the Joint Nature Conservation Committee (JNCC) and the UK Centre for Ecology & Hydrology (UKCEH), funded by the Department for Environment, Food & Rural Affairs (Defra) from October 2022 to March 2025, which was created to begin to develop this system-level view.

1.2. Objectives

The SLI project aimed to bring together existing data in a way that is easy to understand, intended for internal Defra use in communicating with ministers and policy professionals. One of the key challenges the project aimed to address is that chemical pollution data is generally considered in isolation, despite the known interlinkages between pollution, climate change, land use change, and population growth/behaviour changes (Hader *et al*. 2022).

The project therefore used a systems approach and integrated data from a wide range of sources.

The primary objective of the project was to develop a proof-of-concept visual communication tool that could:

- give insight into how chemical pollutants impact the environment in conjunction with climate change and other contributing pressures.

- facilitate discussions with policy makers about priorities for chemical pollution interventions.

- allow long-term assessment of policy decisions and their effectiveness with respect to chemical pollution concentrations and impacts.

- indicate the state of the environment in relation to chemical pollution (including terrestrial, freshwater, and marine compartments).

To achieve this overarching objective, sub-objectives of the project were to:

- engage with cross-UK stakeholders through the setting up of a project steering group, stakeholder interviews and workshops, and a Delphi survey to identify themes for inclusion in the tool.

- identify relevant data and existing tools, indicators and data via discussions with stakeholders, use of databases such as the Environmental Information Data Centre, and searches of published and grey literature.

- collate the available data - using open access data where possible but setting up data sharing agreements/licences where necessary.

- identify data gaps related to the impacts of chemical pollution across terrestrial and aquatic habitats (excluding nutrient and air pollution).

- prepare a series of case studies to demonstrate proof-of-concept and guide data incorporation.

- create a framework for data incorporation that will allow the tool to be updated to include new data sources and the most recent available data.

2.   Methods

2.1.   Systems Approach

A scoping review of relevant literature was carried out during the early stages of the SLI project. The aim of this scoping review was to identify and define the key characteristics of a systems approach and establish the methods involved, including visualisation tools.

While specific definitions vary, systems thinking is generally described as a holistic approach, which views a system as a whole, rather than taking a reductionist view that focuses on its parts (Alfarisi *et al.* 2023; Shams Esfandabadi & Ranjbari 2023; Mhlongo & Daya 2023; Mousavi *et al.* 2023; Barnabè & Nazir 2021; Heaton & Baker 2021). Although a reductionist approach remains common practice in many areas of research, there are several examples of studies that have adopted or recommend a systems approach (Shams Esfandabadi & Ranjbari 2023; Luna Pinzon *et al.* 2023; McKelvie-Sebileau *et al.* 2022; Barnabè & Nazir 2021). This illustrates a shift to a more 'big picture' approach across many fields, particularly broad or complex subjects like environmental research. A system-level approach for the SLI project means the ecosystem-scale impact and interactions of chemical pollution can be assessed, particularly in relation to biodiversity loss and climate change.

The review determined that using both literature review and stakeholder engagement in combination for data collection is common and therefore these methods were used in the SLI project. This ensured that a broad range of data and knowledge regarding the system was considered. Stakeholder engagement methods are discussed further in Section 2.5.

Visualisation is an important aspect of the systems approach. Visualisation tools are used to map the components and connections within complex systems and enable their effective communication. The initial process of mapping is not viewed as exhaustive but as a foundation that is modified over time to reflect the current state of knowledge or data availability (Harris *et al.* 2023).

Causal Loop Diagrams (CLDs) were identified as a common mapping/visualisation technique. CLDs include variables, the links between variables, the identification of causal relationships and, therefore, the creation of feedback loops (Mousavi *et al.* 2023). The development of causal relationships and feedback loops within a CLD improves our understanding of the dynamics and behaviour of the system, enabling patterns to be established and making the CLD useful in informing and supporting decision-making (Barati *et al.* 2023; Shams Esfandabadi & Ranjbari 2023; Mousavi *et al.* 2023).

Based on the scoping review, an initial general conceptual map for the SLI project was created (Figure 1). This enabled sub-systems to be considered, provided a simplified structure of the entire system, and could be used as the foundation of the mapping process. CLDs were then used as a feature in individual case studies to provide more detailed mapping that captured system complexity (see Section 3.2).
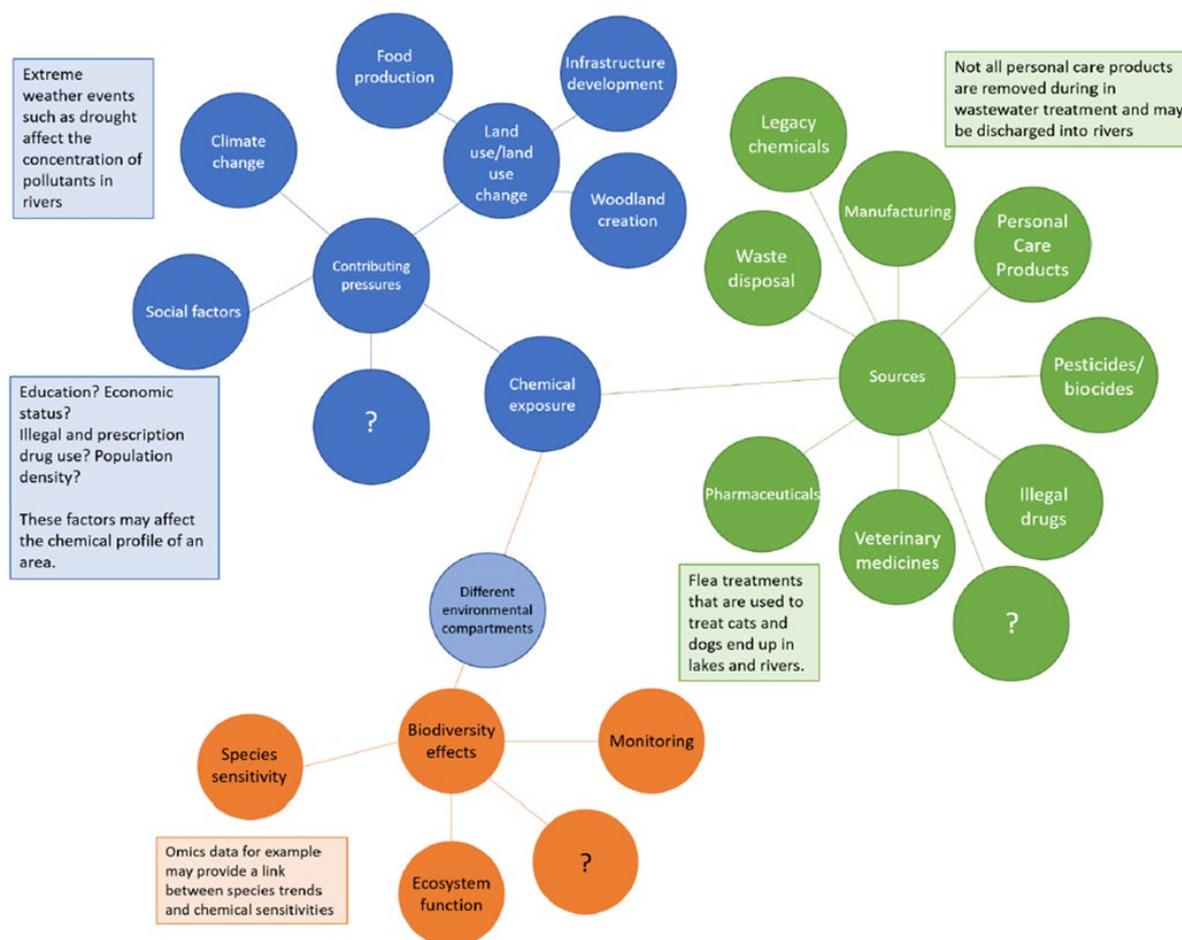
Figure 1: First iteration of an annotated general conceptual map of the system being studied within the SLI Project.

2.2. Project Governance

A project steering group, including representatives from Defra, JNCC, the Health and Safety Executive, the EA, and Natural England, was developed by Defra to oversee the project. The steering group provided feedback on the project activities, signposted data, and made suggestions around case study questions and addition of relevant stakeholders. The steering group met in September 2023, February and September 2024, and January 2025.

JNCC led on stakeholder engagement, which included running a Delphi survey to establish priority chemicals, working with stakeholders to develop case studies and identify and locate relevant data, and organising a series of workshops where progress was presented and feedback was harnessed. UKCEH led on activities including searching for, accessing and cataloguing data, developing a methodology for integrating and visualising data, and creating the visual tool.

The SLI project underwent a UKCEH internal audit for ISO9001 Quality Management Systems in the last quarter of 2023. The UKCEH Quality Management System is committed to demonstrating continual improvement in project management. No non-conformances were identified during the audit.

2.3. Data

Initial activity to search for relevant data resulted in a list of hundreds of environmental datasets of differing format and complexity, available under various licensing and citation options. The datasets were prioritised for inclusion using the below search criteria:

Data search protocol:

- A saved record of all relevant datasets (including lab/field) is required before processing.

- Processing - apply criteria:

    - Lab/field:

        - Must be field data.

        - Exclude lab data.

    - Spatial:

        - Include UK, GB, Scotland, England, Wales, Northern Ireland, regional/catchment.

        - Exclude below regional/catchment scale.

    - Time - include:

        - Chemicals – must include data within the last 3 years.

        - Land use – must include data within last 10 years.

        - Biodiversity – must include data within last 2–3 years.

        - Climate – must include data within the last 2 years.

        - Exclude non-recent data.

Subsequent searches focused on the Environmental Information Data Centre (EIDC), part of the Natural Environment Research Council's (NERC) Environmental Data Service hosted by UKCEH, though other data sources were also examined, catalogued and included to a lesser degree.

The EIDC manages more than 2,000 nationally important datasets concerned with the terrestrial and freshwater sciences, most of which are publicly and freely available under the terms of the Open Government Licence, and have supporting documentation, detailed metadata, and a degree of quality in line with EIDC submission criteria. However, not all relevant EIDC datasets are publicly available. For example, some data from the Predatory Bird Monitoring Scheme (PBMS, Predatory Bird Monitoring Scheme | PBMS) must be licensed for inclusion and removed from the tool if its users extend beyond Defra in future.

Throughout the project, best practice guidelines were followed, including data protection principles and the FAIR guiding principles of data management and stewardship, which state that data should be Findable, Accessible, Interoperable and Reusable (Wilkinson *et al.* 2016).

2.4.   Visual Tool

The UKCEH DataLabs research environment was chosen as a platform for the tool, as it allows open and transparent collaboration on code development, access to data, and mitigation of users' system differences. DataLabs allows interactive apps to be built using the R Shiny package, without the need for extensive programming knowledge.

This project aimed to develop a reusable data integration methodology that would allow users to connect to data at source rather than download data - something that is particularly important in the age of big data. Wherever possible, Application Programming Interfaces (APIs) were used to access the data directly, avoiding the duplication of datasets and ensuring the most up-to-date data is available, thereby future proofing the tool. APIs link the data in the tool to the original dataset, so that when datasets are updated at source it will automatically (or at set times, e.g. every six months) update the tool, eliminating the need for manual updates - limiting the chance of errors and reducing maintenance costs. Clear versioning of data will make users aware of when updates have taken place.

Publicly available visualisation tools were identified and tested by the project team, and several mock-ups of a potential SLI tool were developed. The final design of the tool was based on feedback received from the steering group and through stakeholder engagement.

2.5.   Stakeholder Engagement

2.5.1.   Stakeholders

Stakeholders were identified to cover a wide range of relevant expertise from across the UK, including academics, regulators, conservation bodies, non-governmental organisations and industry representatives. Stakeholder engagement activities included semi-structured interviews to inform case study development, a Delphi survey, and several online workshops.

Stakeholder details were retained and managed by JNCC. Communication with stakeholders was through Mailchimp to comply with GDPR and Data Protection requirements. Invitations to stakeholder workshops were managed via Eventbrite.

Human Research Ethics Approval was gained within UKCEH to allow development of a workshop series and approaching stakeholders for opinion.

2.5.2.   Delphi Survey

A Delphi survey was carried out to gain consensus on the factors that contribute to pollution and their relative importance. The Delphi method involves a series of questionnaires over the course of weeks or months, where participants are provided with the results of the previous questionnaire before supplying their next set of answers (Barrett & Heale 2020). Each round of questions is developed based on the responses given to earlier questionnaires. Participant identities are confidential and responses are anonymised before sharing. This allows the participants the freedom to share their views and then adjust them if desired, based on their unbiased opinions of other expert responses. Delphi surveys are best suited for long-term issues where there are a number of unknowns – such as chemical pollution and the environment.

The first questionnaire comprised three sections: participant information, areas for inclusion in the tool, and suggestions of data relating to these areas. The second questionnaire aimed to prioritise data to be included in the initial phase of SLI tool development and asked respondents to rank areas of focus in terms of their significance for impacting the state of the

environment in relation to chemical pollution (namely sources of chemicals, contributing pressures, and effects on biodiversity). The third and final round sought to build consensus based on the responses given in the previous questionnaire.

2.5.3. Workshops

Workshops were held in May and November 2023, March and October 2024, and March 2025. A variety of tools including Mural and Slido were used for stakeholder engagement activities, as well as live demonstrations of the tool and an interactive session where stakeholders could use the SLI visual tool themselves.

2.6. Case Studies

Case studies were used to guide data choices and demonstrate the value of integrated data and a systems approach when determining policy priorities. The case studies were based around chemical contaminants and their effect on our environment, each covering a different part of the UK. The case studies were developed in collaboration with stakeholder organisations, ensuring that the SLI tool was relevant to work across chemical groups and the UK.

Five case studies were developed, each including the background to a particular issue, relevant scientific questions the tool might answer, and a CLD to visualise the system involved. Development of the SLI visual tool CLDs was informed by expert stakeholder opinion as well as literature review. The CLDs were created using a free, open-source tool designed to enable systems thinking: LOOPY (v1.1) (https://ncase.me/loopy/). LOOPY allows visualisation of a system using circles and arrows that can be weighted and animated to demonstrate the perturbation of that system.

2.7. Quality Assurance

Quality assurance of the SLI visual tool's functionality was managed by JNCC to ensure that the features worked as intended, data was relevant and incorporated accurately, and that there was adequate instructional information available to users.

3.   Outputs and Findings

3.1.   Delphi Survey

A three-round Delphi survey was carried out to inform tool development. The survey targeted respondents with expertise in chemicals and their impacts on biodiversity. The aims of the survey were to determine what groups of chemicals and environmental factors should be prioritised during the development of the tool, to identify potential data sources, and to establish anything additional that should be incorporated into the tool.

3.1.1.   Questionnaire One

The first round of the survey received 11 responses, the majority of which were from England and from regulators (Figure 2). It should be noted that some responses in each round came from organisations rather than individuals, with multiple perspectives from within one organisation incorporated into a single response.

Figure 2: Countries (top) and organisations (bottom) represented by respondents to the first round of the Delphi survey.

When asked if the SLI project was currently missing any broad areas that should be considered for inclusion in the tool, responses included "fertiliser use within agriculture", "new novel chemicals/changes in scale of existing chemical use", "contributing environmental pressures such as temperature (which can impact mobility and toxicity of some pollutants)", "cleaning products/detergents", "hormone and caffeine waste disposal", "pollution associated with transport", "sub-lethal effects on specific species rather than biodiversity as a whole", "chemical mixture effects", and "antimicrobial resistance". Based on these responses and other discussions with stakeholders, an updated conceptual map for the project was created (Figure 3).
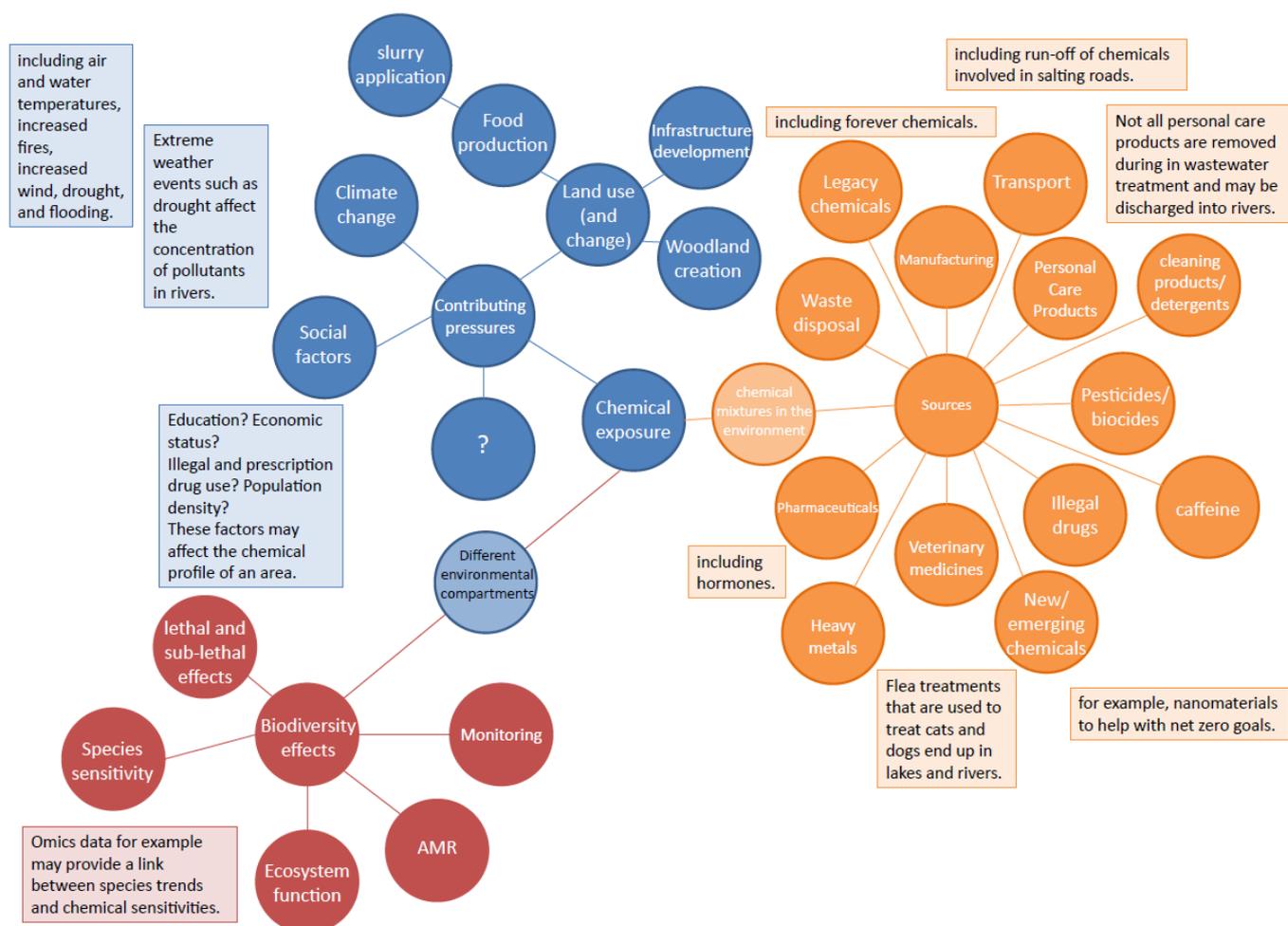
Figure 3: Conceptual map of the data areas that contribute to the environment & chemical pollution system, updated from the initial version (Figure 1) based on Delphi questionnaire one responses.

Respondents were then asked if they or their organisations dealt with any data that was directly or indirectly related to the topics covered by the SLI project. Responses included "monitoring data within terrestrial and aquatic ecosystems including pesticide usage", "rodenticides in predatory bird tissues", "veterinary antibiotic usage", and "fully quantitative and semi-quantitative monitoring for chemicals in surface/saline/groundwater". Additionally, the data sources from the ChemPop project were signposted as potentially useful for the SLI project. Many of the highlighted datasets are publicly available, and links were shared by respondents. The datasets varied in spatial and temporal coverage and included whole-UK and England-specific data, spanning from 1970 to the present day.

3.1.2.   Questionnaire Two

The second stage of the Delphi survey saw an increase in participation with 17 respondents, again with the highest proportion of responses representing England and regulatory bodies (Figure 4).

Respondent Countries

- Other 6%
- UK 29%
- England 53%
- Scotland 12%

Respondent Organisations

- Devolved government 12%
- Other government organisation 23%
- Industry representative 6%
- Conservation body 6%
- Academic 6%
- Consultant 6%
- Regulator 41%

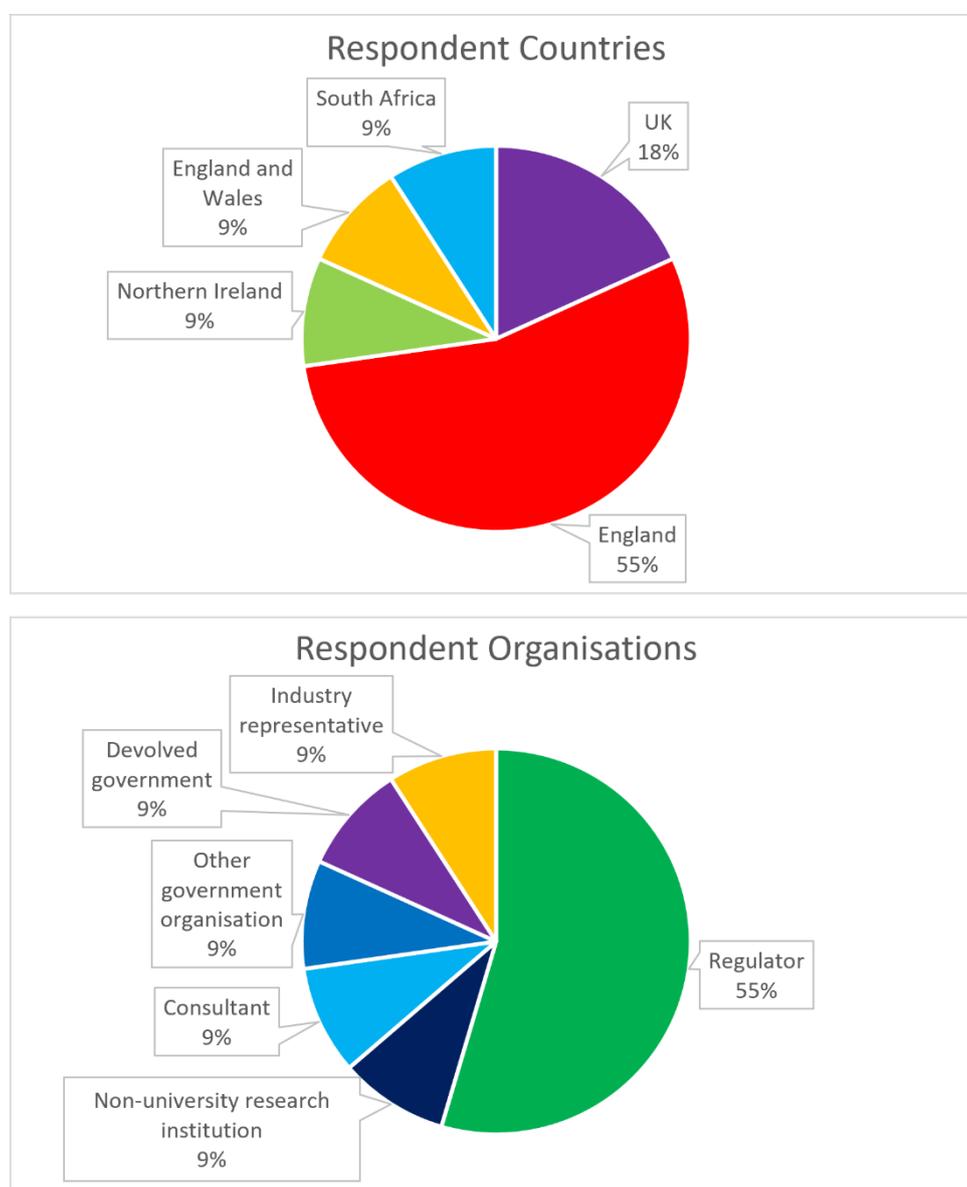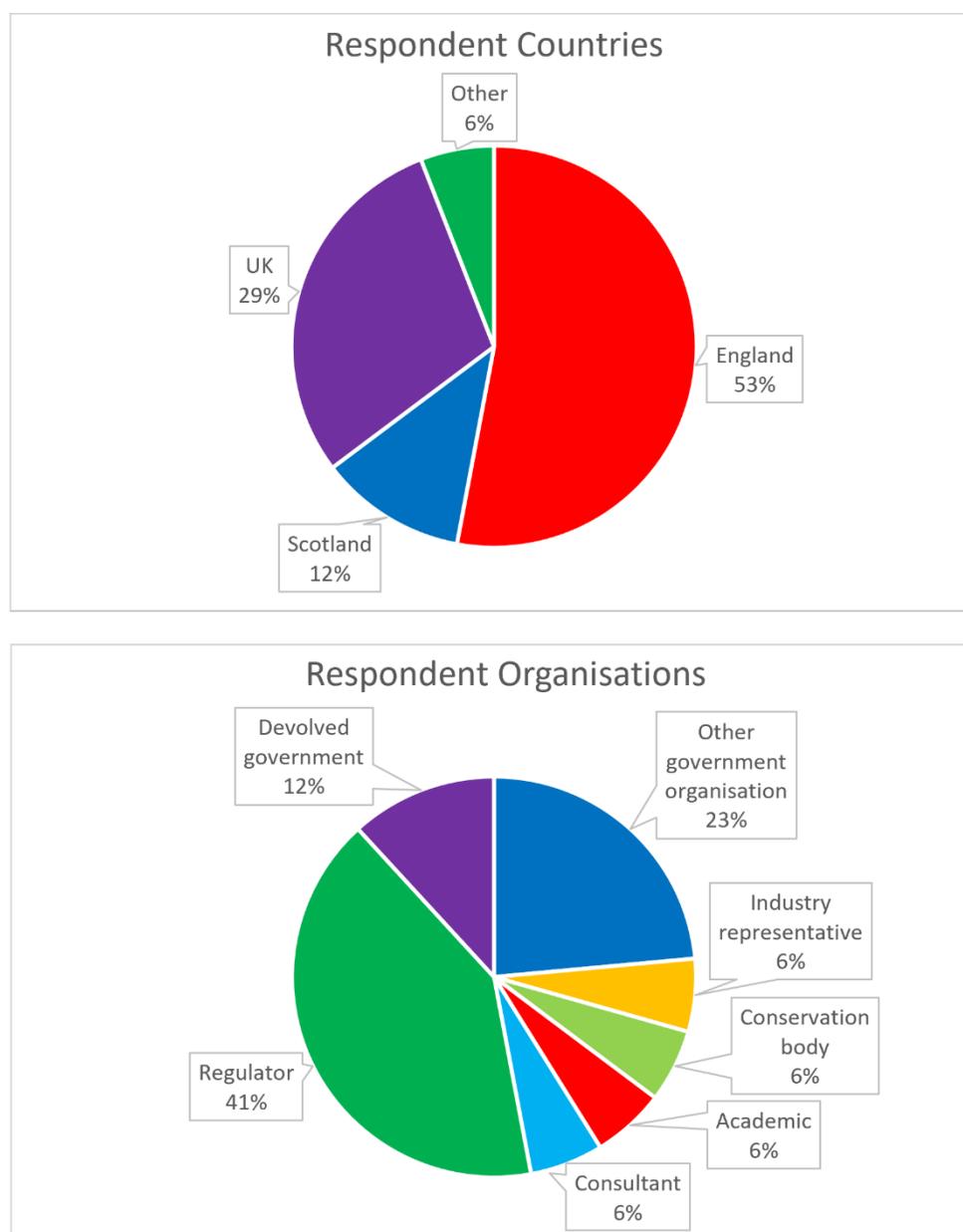**Figure 4:** Countries (top) and organisations (bottom) represented by respondents to the second round of the Delphi survey.

Respondents were presented with a set of chemical groups and asked to score them in terms of their relative importance to the environmental impact of chemical pollution, from one (not at all important) to five (extremely important). An average was calculated from all responses to give a final value between one and five, with higher values indicating higher environmental importance. Human pharmaceuticals were considered of highest importance with a score of 4.44. The lowest ranking chemical group was illegal drugs, which scored only 2.56 (Figure 5).
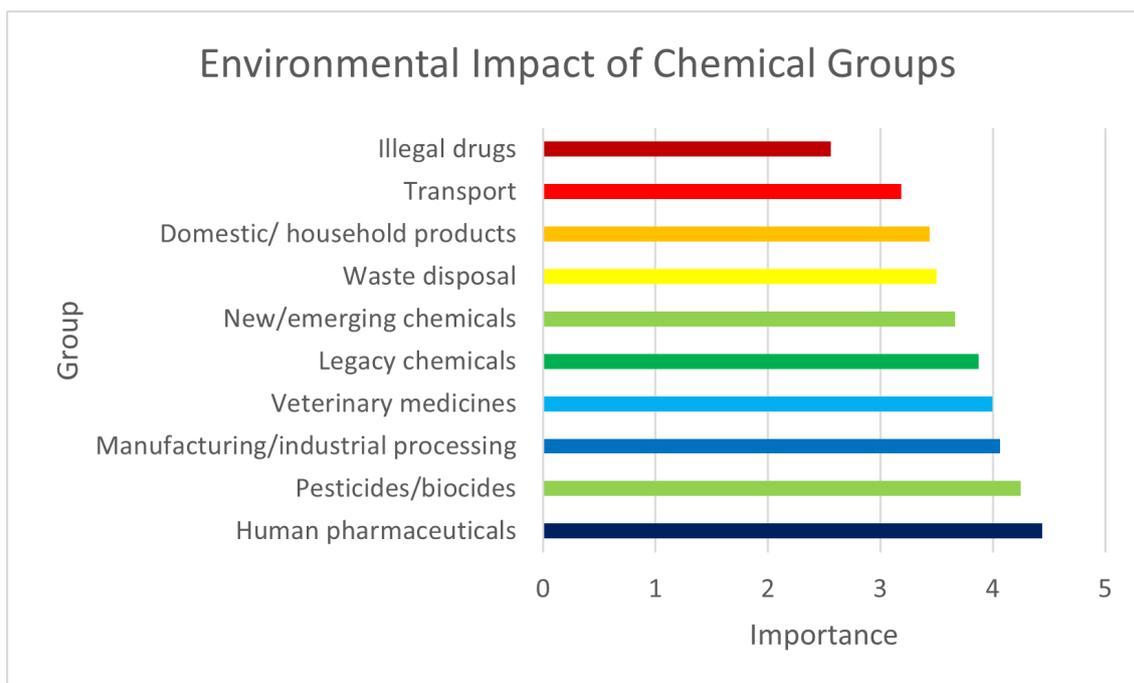
Figure 5: Bar chart showing the relative importance of certain chemical groups to the environmental impact of chemical pollution, based on the average of rankings from one (not at all important) to five (extremely important).

Respondents were then asked if there were chemical groups they believed were missing from the categories listed. Responses included "monomer release from resins and plastics", "food industry chemicals", "dietary supplements (nutraceuticals)", and "unintentionally produced persistent organic pollutants (POPs)".

Next, a range of factors which might contribute to chemical pathways into the environment and subsequent impact were presented and respondents were asked to score these according to the same system as chemical groups. Urbanisation was considered the most critical with a score of 3.94 and total family income was considered of least importance, scoring 2.47 (Figure 6). Factors respondents felt were missing from the list included "marine factors such as aquaculture", "ecosystem services", and "human population density".
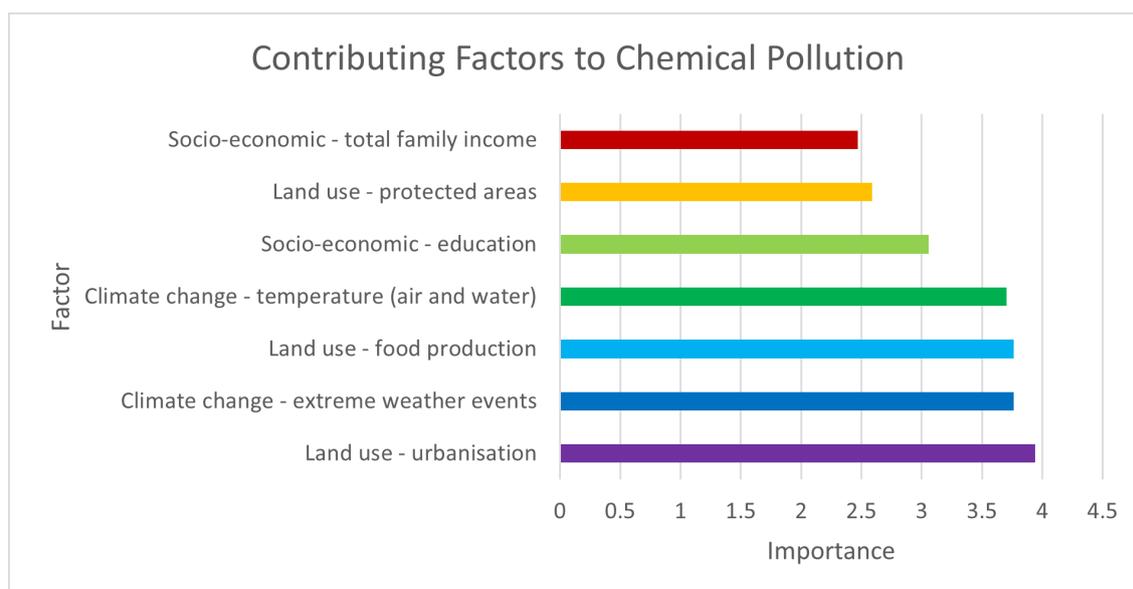
Figure 6: Bar chart showing the relative importance of factors that contribute to chemical pollution pathways and environmental impacts, based on the average of rankings from one (not at all important) to five (extremely important).

Respondents were asked to rank the relative importance of biodiversity effects for understanding chemical impacts on the environment. Ecosystem function was considered the most important with a score of 4.53 and lethal effects the least important with a score of 3.41 (Figure 7). Missing biodiversity effects highlighted by respondents were "landscape scale", "inter-generational effects on species", "specific life histories", "the loss of beta diversity", and "the promotion of generalist species".

Respondents were then asked for their perspectives on different aspects of pollution such as scale and source. Respondents' work incorporated analysis of both acute and chronic effects of pollution, and they felt that both were important to consider. However, it was highlighted that chronic effects are more pervasive and may be less noticeable, and that long-term tests may be impacted by budget and planning. Additionally, in fields such as plant protection products, compounds with acute effects are typically banned – resulting in chronic impacts being the greater issue. Many respondents felt that diffuse sources of pollution were more impactful than point sources due to their widespread effects and potential for cumulative impacts, though both sources are again important to consider. Similarly, respondents felt that general leaching of chemicals into the environment is a more important exposure route than spill events, in terms of their effects on biodiversity. Responses stated that while spill events can be severely detrimental, they are more localised, and therefore likely easier to manage, and their effects are usually temporary. In contrast, constant leaching of chemicals can have long-term, widespread impacts that may not be detected until years of exposure have occurred.
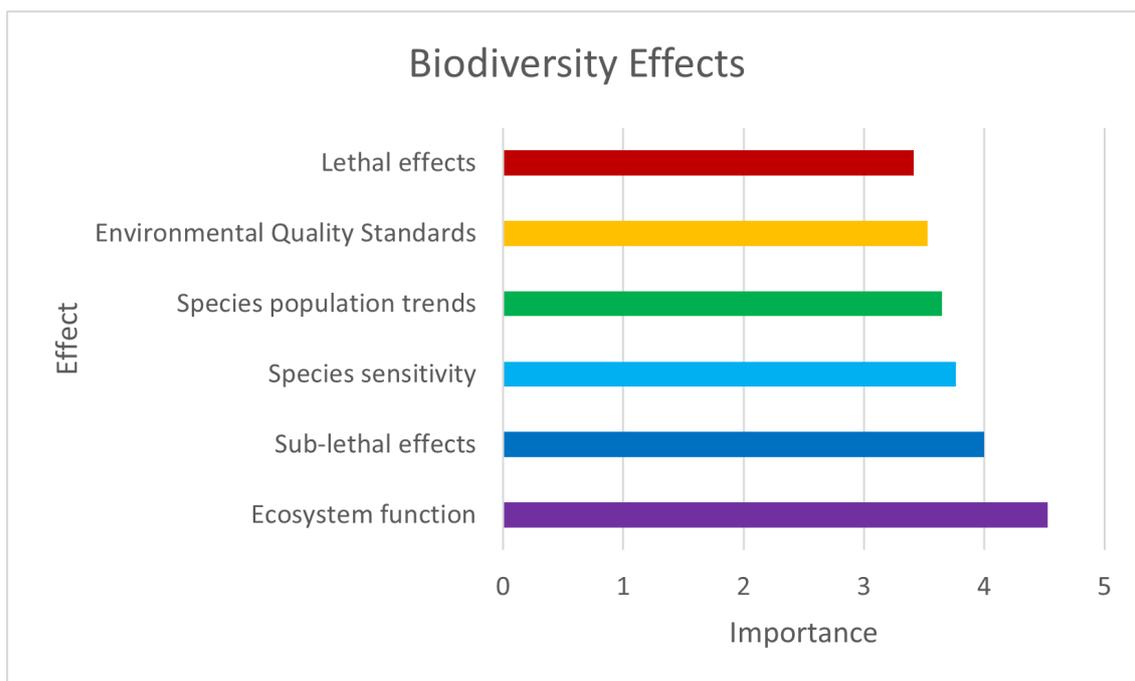
Figure 7: Bar chart showing the relative importance of biodiversity effects, based on the average of rankings from one (not at all important) to five (extremely important).

Free text comments at the end of the questionnaire stated that it would be helpful to combine scale mapping with hotspot mapping, that catchment morphometry is also important as it affects the delivery of chemicals to rivers, and that chemical impacts on the environment are not only about synthetic chemicals as we are also altering natural chemistry, making consequences very difficult to predict.

3.1.3. Questionnaire Three

The primary purposes of the third round of the Delphi survey were to determine whether respondents agreed with the outcomes of the second round and to identify remaining gaps in data inclusion.

There were 11 responses in this round, again mainly from England and from regulators (Figure 8).

Respondent Countries

Wales
9%

UK
27%

England
64%

Respondent Organisations

Other government organisation
18%

Academic
9%

Conservation body
9%

Non-government organisation
9%

Regulator
55%
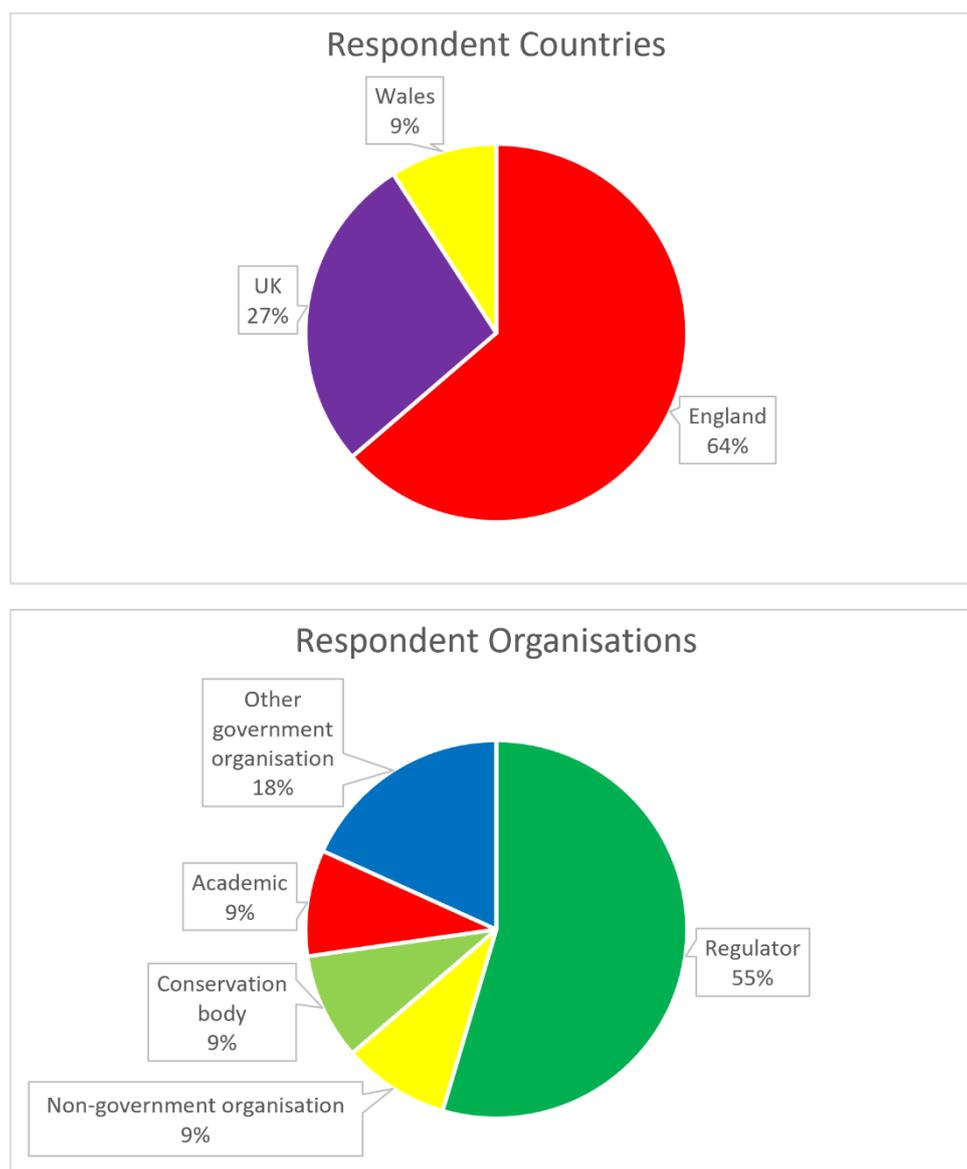
Figure 8: Countries (left) and organisations (right) represented by respondents to the third round of the Delphi survey.

Only 27% of respondents agreed with the rankings of chemical groups resulting from the previous questionnaire. The 73% of respondents that disagreed were asked to suggest a revised order. Each group was then given a score based on its position in the revised order and the total score per group based on responses from all revised orders was used to produce the list below.

Most important

- Pesticides/biocides

- Human pharmaceuticals

- Manufacturing/industrial processing

- Veterinary medicines

- Domestic/household products

- Waste disposal

- Legacy chemicals

- Transport

- New/emerging chemicals

- Illegal drugs

Least important

This resulted in pesticides and biocides moving to the top of the rankings, displacing human pharmaceuticals. Justifications from respondents included the lack of lethal effects from pharmaceuticals compared to pesticides/biocides and their concentrations generally being below PNECs. New and emerging chemicals moved lower in the ranking, with the reasoning that exposure and emissions of these chemicals are often lower in scale, compared to legacy chemicals that are known to have high persistence and hazard.

There was concern that the ranking resulting from the second round reflected where most research has been done and, as an extension, where most knowledge and popular concern is, rather than being representative of environmental impact. It was also stated that there is a lack of evidence to suggest that any of the groups could be considered "worse" than any of the others and that a representative ranking would require incorporation of both hazard and risk.

Respondents were then asked whether they agreed with the previous round's ranking of the contributing factors - 64% of respondents agreed, and 36% disagreed. The order below is based on the revised orders submitted by respondents that disagreed.

Most important

- Land use – urbanisation

- Land use – food production

- Climate change – extreme weather

- Climate change – temperature

- Socio-economic – education

- Land use – protected areas

- Socio-economic – total family income

Least important

The only change compared to the previous order is the movement of food production to second most important and extreme weather to third most. The reasoning given by respondents was that increased land use for food production (e.g. due to growing populations) brings increased use of pesticides and other agricultural chemicals. Climate change then acts as an additional pressure on top of this, rather than being the key driver. One respondent also noted the difficulty in ranking these factors due to their co-variability and instability on temporal and geographical scales.

For the ranking of biodiversity effects, 73% of respondents agreed with the previous ranking order and 27% disagreed. The order below was produced based on the revised orders suggested by respondents.

Most important

- Ecosystem function

- Sub-lethal effects

- Species population trends

- Lethal effects & Species sensitivity

- Environmental Quality Standards

Least important

Environmental Quality Standards fell to the bottom of the ranking, lethal effects moved up one rank and species sensitivity fell to equal position with lethal effects. A factor that was flagged was the lack of temporal and spatial scale for the listed effects and the varying relationships of the effects with chemicals and biodiversity. For example, lethal effects are short-term and may impact local biodiversity by driving adaptation, quality standards are anthropogenic limits, and their precautionary nature may limit the extent of their influence on biodiversity, and other factors may be influenced by predator-prey interactions, previous exposure to chemicals, or the ability of the ecosystem to adapt.

Respondents were asked to list chemicals within each group they felt were the most important when considering the state of the environment in relation to chemical pollution. The answers given were numerous (particularly human pharmaceuticals) and are provided in Appendix 1 (Tables 1 and 2). The potential for climate change to increase the usage of human pharmaceuticals and pesticides as well as impacting their efficacy was highlighted by respondents.

Finally, respondents were asked to identify any chemicals or other factors that hadn't been mentioned that they felt should be considered. Responses were biopesticides, heavy metals, antimicrobial resistance, endocrine disruption, and impacts at different trophic levels (bioaccumulation, biomagnification, etc.).

3.1.4. Outcomes

The results from the Delphi survey provided guidance on what data should be prioritised for integration into the SLI tool, both in terms of which datasets should be included as background data and which factors should contribute to the overall state of the environment feature.

These results are based on expert judgement and best currently available science. The SLI tool was designed to be future proof, with the capability to add data based on new evidence or future expert surveys.

3.2. Case Studies

We chose to have five case studies to ensure that we looked for data relevant to stakeholders from across the UK and weren't limited by focusing on a single topic early in the tool development process. We worked with stakeholders including Defra, the Scottish

Government, and the Northern Ireland Environment Agency to identify areas of interest and questions that the case studies could potentially answer. This interaction and the development of a CLD for each case study then informed our data searches.

For three of the five case studies, a catalogue of relevant data was gathered and incorporated into the tool. For the remaining two case studies, limited progress with integration and visualisation was made, due to difficulties finding specific data within the timeframe of the project.

Where relevant data has been incorporated into the tool, the associated CLD for that case study has also been provided as an animation in the tool's About tab. A screenshot of a CLD illustrating uptake of Second-Generation Anticoagulant Rodenticides (SGARs) by predators is shown below (Figure 9). The CLDs developed during the project were based on literature and expert opinion and were intended to guide data inclusion rather than be fully comprehensive illustrations of each system.

The final proof-of-concept tool could not answer every question we put forward in the case studies due to data availability and time constraints. However, the case study approach and use of CLDs means that we can begin future work with an understanding of the systems involved and the types of data that we require, and strong existing relationships with relevant stakeholders. We recommend that a primary case study be chosen for future work, building on the broad foundation of data incorporated so far and creating a focused output that demonstrates the tool's functionality in depth. This could be supported by the incorporation of additional data relevant to the existing case studies.

Possible uptake route of Second Generation Anticoagulant Rodenticides (SGARs) by predators

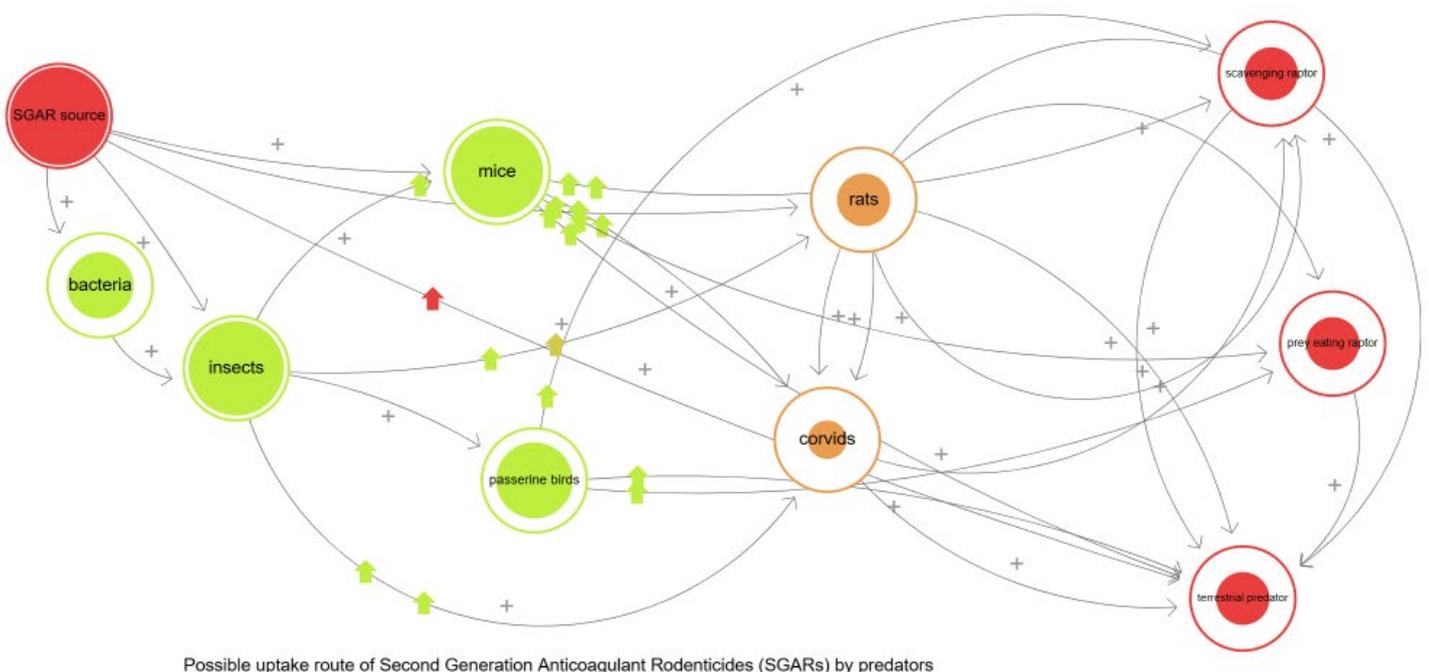**Figure 9:** A CLD illustrating SGAR uptake by predators, made using the LOOPY online tool. Arrows between circles represent positive or negative relationships between parts of the system (circles). The extent to which the circles are filled represents the strength of the interaction, which then impacts the system by generating a smaller or larger number of filled arrows that are passed through the system.

3.3. Workshops

The workshops presented progress and harnessed feedback and next steps from attendees. Stakeholder input was sought throughout the project, including on preferences from existing tools, essential features, and "nice to have" features. Suggestions and feedback from workshop attendees that informed tool development included the inclusion of a chemical history timeline in the project with the intention of overlaying this on data in future, using a map-style data viewer as opposed to solely graphs or other visualisations, using APIs to access data, and allowing the causal loop diagrams for each case study to be viewed within the tool.

In May 2023, the project team held a workshop to introduce wider stakeholders to the project and highlight upcoming engagement opportunities. A second workshop was held in November 2023 to update stakeholders on project progress, including presenting the results of the first two rounds of the Delphi survey and reviewing existing tools and features that could be incorporated into this tool. An October 2024 workshop presented the results of the third round of the Delphi survey, the approach the project will take to the overall state of the environment feature, and a demonstration of the tool (including an interactive trial session for stakeholders). The final workshop in March 2025 demonstrated the overall tool proof-of-concept and laid out next steps for the SLI project.

The live demonstrations and trial session were mixed in their success because DataLabs is a UKCEH research environment and not always robust enough for the number of attendees (approximately 45). When moving forward with the project, an alternative platform for the tool should be considered to increase the capacity for simultaneous users.

3.4. Data Catalogue

More than 850 potentially relevant datasets were identified in the EIDC catalogue, including 50 that were published during the SLI project. Many of these datasets are openly available and provided for download free of charge.

Of these, 230 datasets were identified as useable in the visualisation tool, based on our updated data mining protocol (see Section 2 Methods). Data for potential inclusion was categorised as per- and polyfluoroalkyl substance (PFAS) data, other pollution data, landscape data, biodiversity/environmental community (e.g. plant/animal/microbe) data and environmental abiotic factor (e.g. meteorology) data, based on headings included in the Delphi survey. The resultant catalogue is stored in Microsoft Excel and is provided as a separate document entitled (Appendix 2). There are separate tabs for each data category and a tab for data prioritised for possible inclusion in the SLI visual tool.

The data that was selected and included in the tool is publicly available under the Open Government Licence v3 (OGL) or equivalent.

3.5. Existing Tools Catalogue

A catalogue of publicly available data visualisation tools (Appendix 3) was developed and maintained throughout the project. Best practice based on this catalogue was agreed with stakeholders and the steering group to ensure the resultant SLI Visual Tool reflected current visualisation capability and was fit for purpose.

3.6.   Visual Tool

The SLI visual tool allows users to view a broad range of UK spatial and temporal data including chemical pollution (various PFAS, metals, rodenticides and fipronil), weather data (e.g. rainfall, air temperature), and other related data (e.g. cat and dog populations). The tool is a prototype developed specifically for this project to demonstrate proof-of-concept for Defra. The methodology that underlies this work is publicly available and will be reused for further data integration and visualisation projects. Development of the SLI visual tool was progressed using a case study approach – building up capacity in the tool in response to environmental science questions that the tool might help to answer.

The code for this web application is written entirely in the R programming language with the R Shiny package. R Shiny was chosen for its easy prototyping that doesn't require specialist web development skills and for the potential to eventually link the app to advanced statistical analysis in R. The codebase includes built-in modules and templates for easy additions and updates of datasets in the future.

Where available APIs were utilised to connect to data. A catalogue of available APIs was developed (Appendix 4). APIs enable applications to interact and share data, features, and functionality and can be used:

- for data integration to simplify integrating services and data from different applications,

- for reusability as they allow developers to re-use existing functions and data,

- to facilitate communication between different software components and systems.

The current tool can present up to five datasets on one map in the Spatial Trends tab (Figures 10 and 11). Users can select a data point to view details, where available. There are 22 datasets currently uploaded to the tool, details of which are provided in the tool's Data Catalogue tab and Appendix 5 of this report.

When adding a new dataset, the user interface changes dynamically based on the dataset selection to allow bespoke filtering. This allows for selections that are dataset specific such as year range, matrix, or substance. The Plot function allows further data exploration by making use of a simple x-y plot that lets a user plot any two variables from the dataset against each other and colour by a third variable. A table of raw data that changes based on user selections can be viewed using the Table function.

To aid interpretation, six base map styles are available in the map viewer. In addition, there are three additional map layers that can be toggled on and off, showing land cover, integrated hydrological units, and night light intensity.

The tool also includes a currently illustrative State of the Environment Indicator feature, discussed further in Section 3.7. The tool's Data Sources tab lists the datasets that have been incorporated into the indicator so far. This is a work in progress and future work on the tool will include gathering additional datasets and identifying suitable threshold values for each.

The underlying code for the SLI visual tool developed throughout the project has been made available from GitHub: https://github.com/NERC-CEH/sli_visualTool. The code has been written to allow future users to add new datasets to the spatial trends map, which should also allow for easier editing and re-use of the code.

R Shiny is designed for rapid prototyping and may not be ideal for delivering a robust experience for complex web apps. Significant time was not spent optimising the performance of the visual tool, and some performance issues are present, especially when the tool is being accessed by multiple users simultaneously. This is partly due to the web tool allowing users to display data for the entire UK rather than having to pre-select a small region, so all datasets are loaded when the tool is loaded. To improve performance if the tool is progressed beyond a proof of concept, the tool could be rewritten in a different web framework. Alternatively, an arcGIS online web viewer may be used for this purpose but this would come with a licensing cost and decreased flexibility. We note that there are Defra dashboards that are delivered as Shiny apps (e.g. EA Ecology & Fish Data Explorer), so workarounds for the performance issues may be possible without changing the framework.

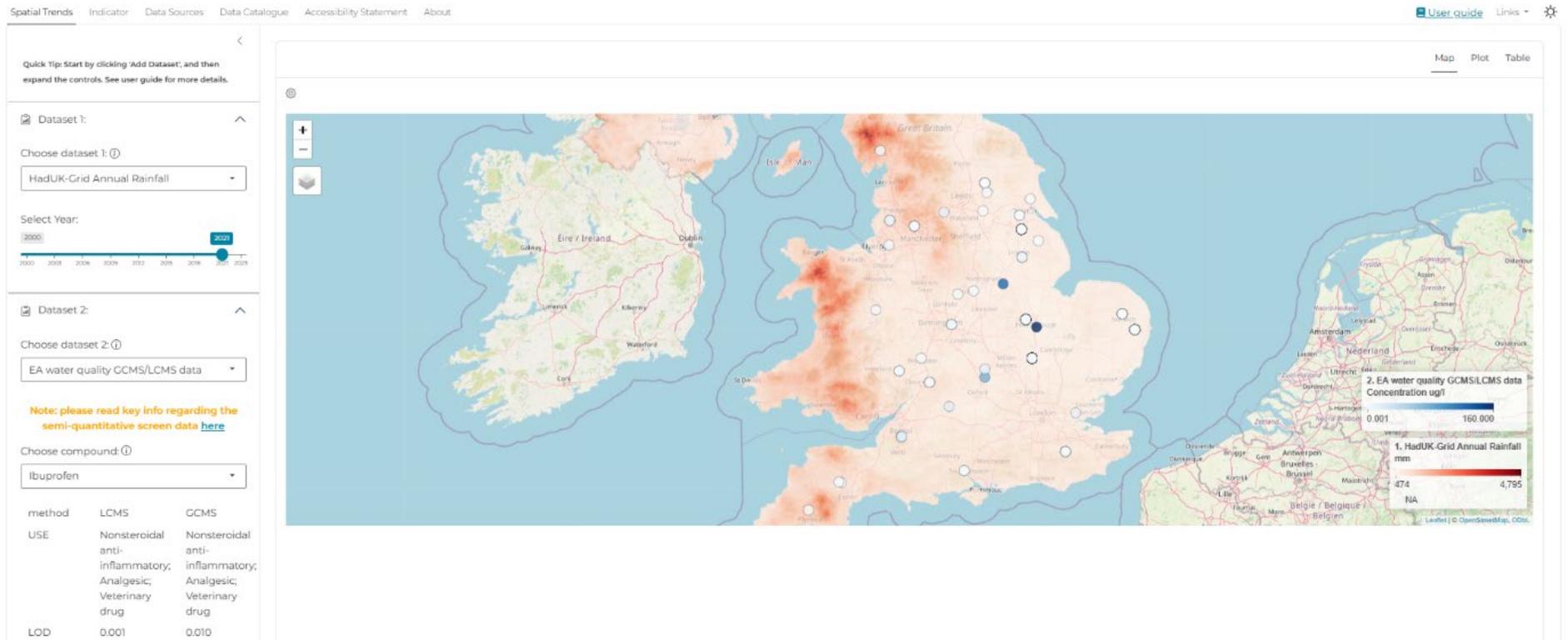**Figure 10:** Home page of the tool (the Spatial Trends tab), prior to data being loaded onto the map.

Figure 11: The tool's map view, showing rainfall as raster data and ibuprofen concentrations as point data. Sources: MetOffice HadUK-Grid (rainfall); Environment Agency water quality monitoring data GC-MS and LC-MS semi-quantitative screen (ibuprofen).

3.7.   State of the Environment Indicator

The aim of the State of the Environment Indicator feature was to provide a high-level visualisation of multiple integrated datasets from across the system. During the proof-of-concept phase of the project, the focus was on the identification of key variables at the country scale and the demonstration of how to go from data points to a country-wide status and how this will be communicated in the tool. The approach to indicator development was decided via discussions with the project steering group. The specific technical details of how the minimum data requirements, data gaps and thresholds, etc., will be set will be determined during future work on the project.

Three options were discussed with the steering group. The option taken forward takes the most holistic view, assigning a status to each environmental compartment. Other options discussed were to look at chemical groups or individual chemicals. Whilst each option had its merits, the selected approach was considered most closely aligned with the original aims of the project. The approach has largely been based on a similar visualisation in the EU soil health dashboard (EUSO Dashboard), although the approach will be adapted to provide a percentage of each compartment that is affected by chemical pollution rather than a healthy/unhealthy status. This will allow changes over time to be more easily identified. The option presented is designed to show the approach - the specific chemicals/species can be changed.

This option provides an overview and status for terrestrial, freshwater, marine and air compartments. A mock-up is shown in Figure 12. Each overall status will consider data from chemical concentrations in the environment, biota and contributing factors. There will also be a 'no data' classification. Initial searches for data relevant to the indicator were carried out during this phase of the project.

For the terrestrial compartment, soil chemistry data including heavy metal concentrations is available from the British Geological Survey, though some datasets require additional payment or licensing agreements so may not be suitable for the SLI project, which has so far focused on openly available data. The UKCEH Countryside Survey collects data for land contamination and physicochemical properties including heavy metal concentrations, alongside invertebrate data. The UKCEH Land Cover plus Pesticides dataset (Jarvis *et al.* 2020) would also be relevant to this compartment in place of environmental concentrations of pesticides. There is data for a range of contaminants in predatory birds through the PBMS. Flood risk maps are available for all four countries of the UK, which is an important contributing factor for the spread of chemicals onto land and the washing away of chemicals from soils into rivers.
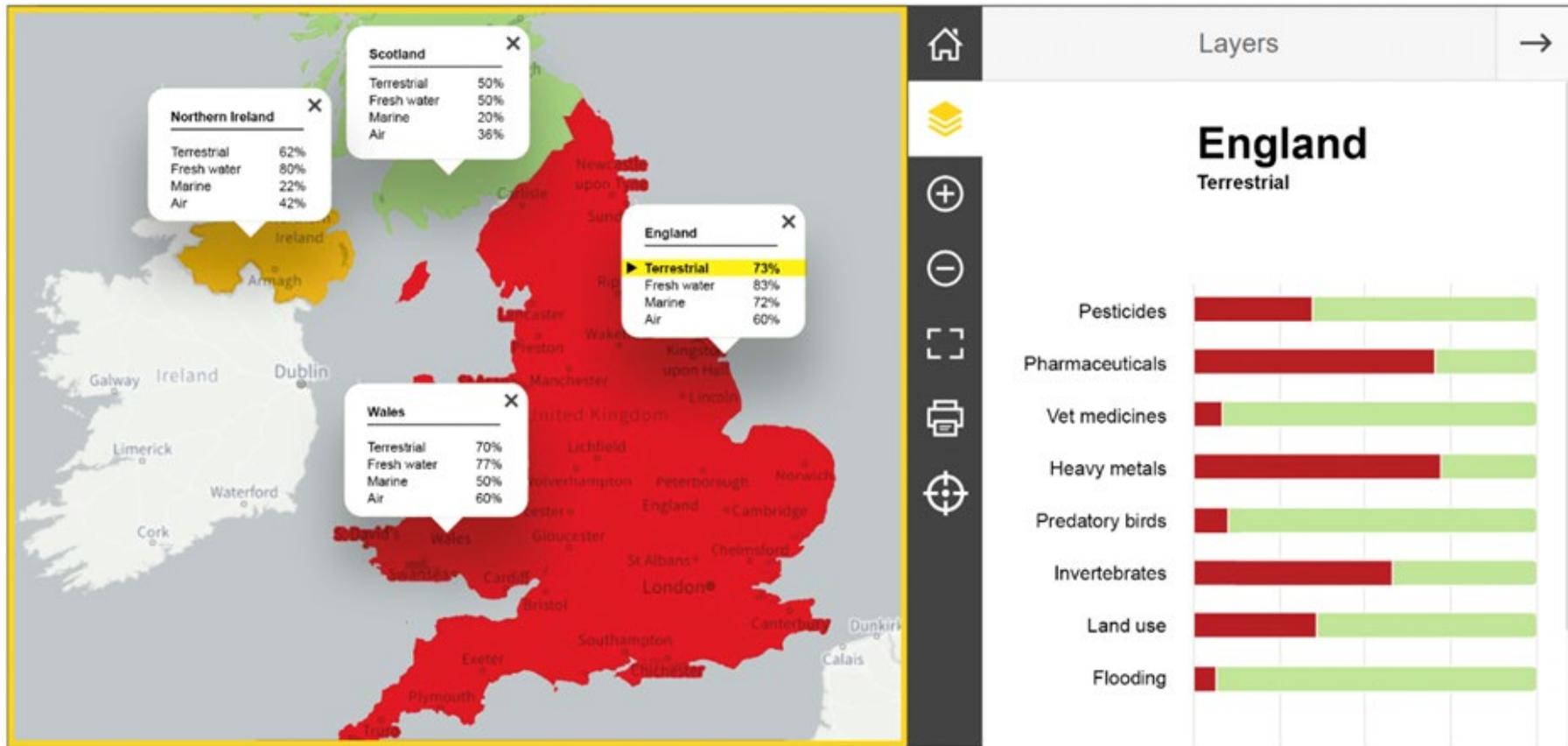
Figure 12: Mock up of the overall state of the environment feature at a country level, split by environmental compartment with the factors included shown in the pane on the right. Numbers are arbitrary to show what the feature could look like in the tool.

For freshwater, there is a vast amount of data available for environmental concentrations, primarily due to requirements for monitoring under the WFD (Directive - 2000/60 - EN - Water Framework Directive - EUR-Lex). Chemicals included within these datasets include (but are not limited to) pharmaceuticals, veterinary medicines, pesticides and manufacturing/industrial chemicals. Freshwater macroinvertebrate data is available, which includes indicator species. Integrated biodiversity-based water quality indicators such as SPEAR$_{pesticide}$ could be incorporated to provide insight into the effect of pesticides. Fish are also monitored for selected contaminants. Additionally, there is data available for otters for liver metal concentrations in England and Wales (Brand *et al.* 2019) and polybrominated diphenyl ethers (PBDEs) in Scotland (Walker *et al.* 2016). Weather is an important aspect of the chemical pollution system, which can impact chemical pathways and effects. The Met Office have historic data records of rainfall and temperature (Historic station data - Met Office), and flood risk maps are available for across the UK.

The chemicals monitored under the WFD in coastal waters (the marine compartment) include metals, perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), polychlorinated biphenyls (PCBs), pharmaceuticals, veterinary medicines and pesticides. There is some data available from OSPAR for mussels (PBDEs, metals, PCBs), fish (PBDEs, PCBS, PFOS, metals) and harbour porpoises (PBDEs and PCBs). The PBMS collects data for gannet eggs and organochlorine pesticides, total mercury, and total PCBs (Crosse *et al.* 2012).

Many air quality data focuses on ammonia and NO$_X$. However, metals and Persistent Organic Pollutants (POPs), including PCBs, PBDEs and polycyclic aromatic hydrocarbons (PAHs) are monitored across the UK by Defra's air quality monitoring network. There are some additional datasets available for metals (Tomlinson *et al.* 2023).

When presenting an overall state of the environment, it is vital that uncertainties are communicated clearly and that it is obvious which datasets are contributing to the status for each compartment. The overall status is indicative - it won't include all possible chemicals or wildlife effects. The proposed approach includes a supporting table with the datasets listed and a summary of the methodology for averaging the data across each region and the thresholds applied. At present, the Data Sources tab in the tool lists the datasets incorporated into the indicator.

Countries within the UK differ in their monitoring regimes and data availability. This means that there are limits to making direct comparisons between countries and the indicator should be used only for interpreting one country's data at a time. This must also be communicated clearly within the tool.

Certain decisions will need to be made, for example, when assigning thresholds where there are no recognised values (e.g. for flooding and rainfall). The minimum data requirement and how to deal with data gaps will also need to be addressed. Interpolation to fill gaps is one potential option or, where data is sparse, spatial modelling. However, both will increase uncertainty in the indicator as they will not be fully "real" data. If there is no interpolation, then a minimum data requirement for allocating a state of the environment status must be set. A method for assessing minimum data requirements will be part of the next steps for the project as this may be partly dependent on the type of data used.

The Indicator tab currently contains a map that demonstrates the ability to calculate statistics for different nations within the UK (Figure 13). Example thresholds and statistics are shown in a pop-up when a region is clicked. Illustrative data shows how the indicator will present the environmental status for different compartments, as bars of red and green in various categories including heavy metals and land use. This serves as a placeholder for the full State of the Environment metric, which could be developed further in a future version.

Significant work remains to determine what data and thresholds to use for this purpose, a process which will require input from stakeholders from the research community and government agencies.
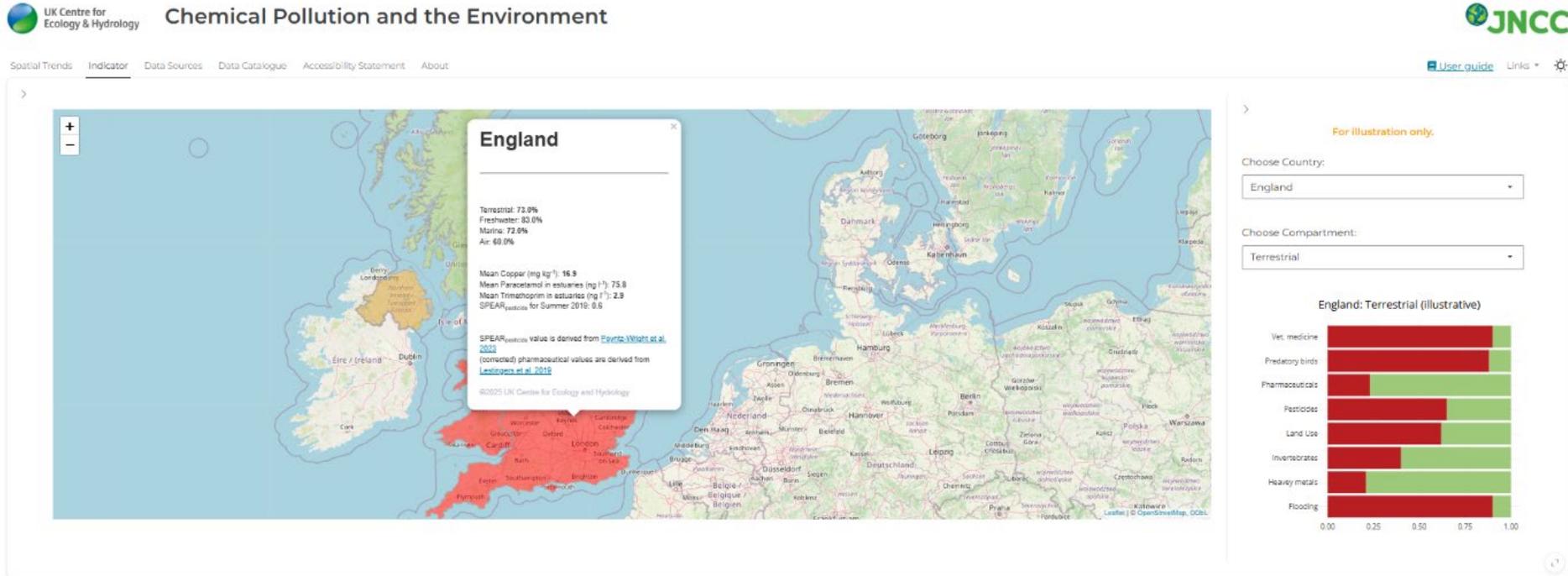
Figure 13: State of the Environment Indicator as it currently appears within the SLI tool. This is intended for illustrative purposes only and the status presented is not based on real data.

3.8.   User Manual and Supporting Documentation

A user manual for the SLI tool was created and is available for users to access within the tool.

An Accessibility Statement based on the UKCEH Accessibility Statement was developed and is embedded within the SLI visual tool.

3.9.   Chemicals Timeline

A timeline of the history of chemicals relevant to the SLI project (when they came into use, when they were regulated, and major changes in production/use) has been developed by UKCEH. The timeline is currently a draft in the form of an Excel spreadsheet and accompanying written document. During future work on the tool, this draft could be converted into a format that can be viewed within the tool (e.g. overlaid on a graph – Figure 14).

Proposed potential uses for this timeline include:

- Prioritising substances.

- Selecting samples by year for analysis.

- Backdating baselines.

- Interpreting data.

Incorporating the timeline into the tool would allow straightforward comparison of key dates with environmental data. Regulatory milestones, major changes in chemical use, or other events such as significant storms/heatwaves could be overlaid on data plots to show how environmental concentrations of a chemical have changed based on policy, industry, and climate.

If the tool was expanded to include modelling functionality, future milestones such as climate change scenarios could also be added to the timeline.

Figure 14: Mock-up of how a timeline might be incorporated into the SLI plot view.

3.10. Website

A project website was developed by JNCC and published at https://jncc.gov.uk/our-work/system-level-indicator/. The website is hosted by JNCC and includes sections on the project aims, project team, systems approach, and stakeholder engagement.

4.   Conclusions and Recommendations

This project used an innovative approach to communicating the extent of chemical pollution in the UK environment, providing a system-level view that incorporates a broad range of data including contributing pressures. Integrating evidence from different sources and visualising it clearly allows assessment of environmental status, showing relationships, gaps, and priority areas for potential interventions.

This project benefitted from significant input from stakeholders, including the project steering group, workshop participants, and individual interviewees. We recommend that this continues during any future work on the project, to ensure that the tool is relevant to practitioners and provides an accurate view of chemical pollution in the UK. The use of a Delphi survey allowed prioritisation of the vast array of chemical datasets available, in a way that limits bias.

For the proof-of-concept phase, the decision to use a multiple case study approach allowed us to create a broad foundation of chemical data and build relationships with stakeholders from across the UK. Five case studies were developed and possible data sources identified, but time constraints and data availability meant that only three case studies progressed to completion (i.e. with relevant data incorporated into the tool). If work on the SLI is continued, we recommend focusing on a single, comprehensive case study that fully demonstrates the potential of the tool, including the State of the Environment Indicator. This approach would reduce the time constraints that impacted case study development during the proof-of-concept phase and allow prioritisation of data searches and targeted stakeholder engagement. This case study would allow users to understand the full potential of the tool for visualisation of systems affecting chemical pollution. Time permitting, the development of additional smaller scale, "light touch" case studies would also be beneficial for demonstrating the versatility of the tool and highlighting its usefulness in situations where data is currently limited.

The CLDs created during the project are a useful accompaniment to the tool, especially when animated, as they provide simplified visual overviews of the complex systems described by the case studies and can guide users towards relevant datasets within the tool. Greater involvement of stakeholders in the development of CLDs for future case studies is recommended, to ensure that the CLDs are aligned with both the literature and expert opinion.

The SLI visual tool takes us a step towards answering scientific questions about chemical pollution in the UK. It enables us to look for unexpected relationships between various datasets through visual inspection of their spatial and temporal trends. However, the current functions of the SLI tool provide only visual representations of data without statistical evidence. A possible next step is to integrate mathematical and statistical modelling into the tool and establish flexible and user-friendly functions that allow users to manipulate data, check the outputs of the modelling, and export significant results as evidence.

Other opportunities for expansion of the tool in future phases include the addition of further chemical, species, and habitat data as well as contextual datasets covering extreme weather events, temperature, etc. Future work must also consider practical aspects such as where the tool should be hosted long-term and ensuring that it meets accessibility requirements.

The State of the Environment Indicator feature within the tool demonstrates the provision of system-level information on the health of terrestrial, freshwater, marine, and air compartments within each country of the UK. However, this feature is incomplete and currently displays only illustrative data due to time constraints. In future phases of the SLI

project, additional data and thresholds must be sought, and detailed methods for determining environmental status agreed with stakeholders.

As it currently stands, the tool can make contributions to policy and decision-making by serving as a communication aid. It can provide high-level visualisation of chemical pollution and contributing factors, providing an overview of the data that is currently available to answer specific questions. It allows users to identify associations between datasets and gaps in research - information that can guide further work and ensure that funding is well targeted. With sufficient temporal data, the tool could be used to assess the impacts of existing policy interventions.

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Weblinks

Table 1: Full URLS for weblinks used in the text.

Weblink text	Full URL
ChemPop project	https://www.ceh.ac.uk/our-science/projects/chempop-does-discharge-chemicals-environment-harm-wildlife-populations
Directive - 2000/60 - EN - Water Framework Directive - EUR-Lex	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060
EA Ecology & Fish Data Explorer	https://environment.data.gov.uk/ecology/explorer/
Environment Agency water quality monitoring data GC-MS and LC-MS semi-quantitative screen	https://www.data.gov.uk/dataset/0c63b33e-0e34-45bb-a779-16a8c3a4b3f7/water-quality-monitoring-data-gc-ms-and-lc-ms-semi-quantitative-screen
EUSO Dashboard	https://esdac.jrc.ec.europa.eu/esdacviewer/euso-dashboard/
Historic station data - Met Office	https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data
MetOffice HadUK-Grid	https://catalogue.ceda.ac.uk/uuid/b963ead70580451aa7455782224479d5/
OSPAR	https://www.ospar.org/
Predatory Bird Monitoring Scheme	PBMS	https://pbms.ceh.ac.uk/

Glossary

Table 2: Glossary of terms.

Term	Definition
API	Application Programming Interface
CLD	Causal Loop Diagram
Defra	Department for Environment, Food & Rural Affairs
EA	Environment Agency
EIDC	Environmental Information Data Centre
JNCC	Joint Nature Conservation Committee
NERC	Natural Environment Research Council
PAH	Polycyclic aromatic hydrocarbon
PBDE	Polybrominated diphenyl ether
PBMS	Predatory Bird Monitoring Scheme
PCB	Polychlorinated biphenyls
PFAS	Per- and polyfluoroalkylated substance
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
POP	Persistent organic pollutant
SGAR	Second-Generation Anticoagulant Rodenticide
SLI	System Level Indicator
UKCEH	UK Centre for Ecology and Hydrology
WFD	Water Framework Directive

Appendix 1

Table 1: Chemicals highlighted by Delphi survey respondents as being of importance when considering the state of the environment in relation to chemical pollution, and the group(s) they were associated with by respondents.

Chemical	Group	Chemical	Group
Second-Generation Anticoagulant Rodenticides	Biocides/pesticides	**Paraquat**	Biocides/pesticides
Pendimethalin	Biocides/pesticides	**Pyrethroid**	Biocides/pesticides Veterinary medicines
Chlormequat	Biocides/pesticides	**Dieldrin**	Biocides/pesticides
Glyphosate	Biocides/pesticides	**Ammonia**	Manufacturing/industrial
Chlorothalonil	Biocides/pesticides	**Mercury**	Manufacturing/industrial Legacy chemicals
Cypermethrin	Biocides/pesticides	**Per- and polyfluoroalkyl substances**	Manufacturing/industrial Legacy chemicals
Diazinon	Biocides/pesticides Veterinary medicines	**Polychlorinated biphenyls**	Manufacturing/industrial Legacy chemicals
Imidacloprid	Biocides/pesticides Veterinary medicines	**Bisphenol A**	Manufacturing/industrial
Fipronil	Biocides/pesticides Veterinary medicines	**Triphenyl phosphate**	Manufacturing/industrial
Chlorpyrifos	Biocides/pesticides	**Bis(2-ethylhexyl) phthalate**	Manufacturing/industrial
Methoprene	Biocides/pesticides	**Benzo(a)pyrene**	Manufacturing/industrial
Permethrin	Biocides/pesticides Veterinary medicines	**Benzo(g,h,i)perylene**	Manufacturing/industrial
Asulam	Biocides/pesticides	**Selamectin**	Veterinary medicines
Glyphosate	Biocides/pesticides	**Flumethrin**	Veterinary medicines

Chemical	Group	Chemical	Group
Ivermectin	Veterinary medicines	**Fluralaner**	Veterinary medicines
Flubendazole	Veterinary medicines	**Moxidectin**	Veterinary medicines
Allethrin	Veterinary medicines	**Pyripole**	Veterinary medicines
Avermectins	Veterinary medicines	**Dinotefuran**	Veterinary medicines
Clarithromyin	Veterinary medicines	**S-methoprene**	Veterinary medicines
Erythromycin	Veterinary medicines	**Persistent organic pollutants**	Legacy chemicals
Dichlorodiphenyltrichloro-ethane	Legacy chemicals	**Heavy metals (lead, zinc, cadmium)**	Legacy chemicals
Polycyclic aromatic compounds	Legacy chemicals	**Polybrominated diphenyl ethers**	Legacy chemicals

Table 2: Human pharmaceuticals highlighted by Delphi survey respondents as being of importance when considering the state of the environment in relation to chemical pollution, and their medical use.

Pharmaceutical	Use	Pharmaceutical	Use
Ketamine	Anaesthetic	Tamoxifen	Hormone medication
Esketamine	Anaesthetic/ Antidepressant	Fluoxetine	Antidepressant
Psilocybin	Hallucinogen	Carbamazepine	Anticonvulsant
MDMA	Stimulant/ Hallucinogen	Vancomycin	Antibiotic
Nirmatrelvir	Antiviral	Amoxicillin	Antibiotic
Ritonavir	Antiretroviral	Futibatinib	Anticancer medication
Remdesivir	Antiviral	Fexofenadine	Antihistamine
Molnupiravir	Antiviral	Desvenlafaxine	Antidepressant
Tocilizumab	Immunosuppressant	Griseofulvin	Antifungal
Dexamethasone	Corticosteroid	Sulphapyridine	Antibacterial
MRNA vaccines	Vaccine	Venlafaxine	Antidepressant
Cannabis	Sedative	Lamotrigine	Anticonvulsant
Atorvastatin	Cardiovascular medication	Cetirizine	Antihistamine
Metformin	Diabetes medication	Diclofenac	Anti-inflammatory
Glutamatergic drugs	Excitatory amino acid modulator	Progesterone	Hormone
Desflurane	Anaesthetic	Ibuprofen	Anti-inflammatory
Ritalin	Stimulant	Paracetamol	Analgesic/ Antipyretic
Methiopropamine	Stimulant	Tramadol	Opioid
Ephenidine	Anaesthetic	Atenolol	Cardiovascular medication
Methoxyphenidine	Hallucinogen	Cefalexin	Antibiotic
Spiramycin	Antibiotic/ Antiparasitic	Rifampicin	Antibiotic
Sertraline	Antidepressant	Phenoxymethylpenicillin	Antibiotic

Appendix 2

See attached document 'jncc-report-817-appendix-2-delphi-survey-data-areas.xlsx'.

Appendix 3

Visual Tool Catalogue

1. Oxford Rivers portal: https://oxfordrivers.ceh.ac.uk/

2. AquaPLAN Visualisation Portal: https://aquaplan-project.eu/results/datasets/aquaplan-visualisation-portal/

3. Catchment Based Approach Data Hub: https://data.catchmentbasedapproach.org/pages/explore-data

4. Natural England Open Data Geoportal: https://naturalengland-defra.opendata.arcgis.com/

5. SEPA Data publication: https://www.sepa.org.uk/environment/environmental-data/

6. Normal background concentrations of contaminants WMS BGS Technologies — Web map services: https://www.bgs.ac.uk/technologies/web-map-services-wms/contaminants-wms/

7. UK Soil Observatory hosted by the British Geological Survey (BGS): https://mapapps2.bgs.ac.uk/ukso/home.html

8. ECOTOX Knowledgebase US EPA: https://cfpub.epa.gov/ecotox/

9. South West Water storm overflow map: https://www.southwestwater.co.uk/environment/rivers-and-bathing-waters/waterfitlive/storm-overflow-map.

10. Ofwat Innovation Fund: https://waterinnovation.challenges.org/winners/river-deep-mountain-ai/

11. Tableau Public: https://public.tableau.com/app/profile/amethyst.eicher/viz/Mobile_optimised_map/MapLayers2

12. Interim H4 indicator 2022: Interim H4 indicator: exposure and adverse effects of chemicals on wildlife in the environment (publishing.service.gov.uk)

13. AstraZeneca Pharmaceuticals: https://www.astrazeneca.com/sustainability/environmental-protection/pharmaceuticals-in-the-environment.html

14. PFAS Explorer: https://hcdc.hereon.de/PFAS-explorer

15. OECD Data: https://data.oecd.org/united-kingdom.htm

16. PBMS Map of bird submissions: https://pbms.ceh.ac.uk/content/map-bird-submissions

17. CHESS: https://catalogue.ceh.ac.uk/documents/7de9790e-66a2-44b5-988e-283d764ef52f

18. UKCEH digital river network of Great Britain (1:50,000): https://www.ceh.ac.uk/data/15000-watercourse-network

19. Land Cover Map: https://www.ceh.ac.uk/data/ukceh-land-cover-maps

20. UK Lakes portal – map and graphs: https://eip.ceh.ac.uk/apps/lakes

21. WWF Digital rivers: https://www.wwf.org.uk/uk-rivers-map

22. Canal & river network map: https://canalrivertrust.org.uk/enjoy-the-waterways/canal-and-river-network

23. The Nanodatabase: https://nanodb.dk/en/search-database/

24. EU SOIL OBSERVATORY EUSO Soil Health Dashboard: https://esdac.jrc.ec.europa.eu/esdacviewer/euso-dashboard/

25. Green Infrastructure focus – Mayor of London: https://apps.london.gov.uk/green-infrastructure/

26. Mapping GM: https://mappinggm.org.uk/about/

27. SEPA Aquaculture: https://informatics.sepa.org.uk/MarineFishFarm/

28. SEPA Scottish Pollutant Release Inventory: https://informatics.sepa.org.uk/SPRI/

29. OECD Pollutant Release and Transfer Registers: https://www.oecd.org/chemicalsafety/pollutant-release-transfer-register/

30. Eurostat data visualisations: https://ec.europa.eu/eurostat/web/main/data/data-visualisations

31. Sewage Pollution Alerts: https://www.sas.org.uk/water-quality/sewage-pollution-alerts/

32. Natural England Open Data Geoportal: https://naturalengland-defra.opendata.arcgis.com/

33. https://www.sepa.org.uk/data-visualisation/water-classification-hub/

34. https://waterwatchwales.naturalresourceswales.gov.uk/en/

35. Living Atlas of the World: https://livingatlas.arcgis.com/en/home/

36. RSC Drinking Water Map: https://www.rsc.org/policy-evidence-campaigns/environmental-sustainability/sustainability-reports-surveys-and-campaigns/cleaning-up-uk-drinking-water/#interactive-map

37. Harnessing Data for Climate Resilience: https://eds.ukri.org/news/impacts/harnessing-data-climate-resilience-sensors-schools

Appendix 4

Data Portals & Product Catalogue

Data Portals and APIs

URL	Resource
https://data.cefas.co.uk/	CEFAS Data Portal
https://uk-air.defra.gov.uk/data/about_sos	Defra UK-AIR Sensor Observation Service
https://nbnatlas.org/	Biodiversity data on the NBN Gateway
https://www.api.gov.uk/ea/#environment-agency	The API catalogue contains the following 10 Environment Agency (EA) APIs: Asset Management Bathing Water Catchment Data Ecology and Fish Data Flood-monitoring Hydrology Public Registers for Environmental Information Rainfall Tide Gauge Water Quality
https://eip.ceh.ac.uk/hydrology-ukscape/help	The organisations that have data available in this API are: National river flow archive (NRFA); various data-types available. Met Office (MO); recently observed and forecast weather data. Environment Agency (EA); near real-time river flow and water quality data. EA-local is a copy of the EA dataset downloaded into the NRFA database. Scottish Environment Protection Agency (SEPA); rainfall data available from approx. October 2017. Environment Agency (EA); water quality data.
https://www.eea.europa.eu/en/datahub/datahubitem-view/fbf3717c-cd7b-4785-933a-d0cf510542e1	Waterbase is the generic name given to the European Environment Agency's databases on the status and quality of Europe's rivers, lakes, groundwater bodies and transitional, coastal and marine waters, on the quantity of Europe's water resources, and on the emissions to surface waters from point and diffuse sources of pollution. Direct data and metadata download available.

URL	Resource
https://data-canalrivertrust.opendata.arcgis.com/	Canal and river trust open data
https://datamap.gov.wales/layers/geonode:nrw_water_quality_archive_stations	Maps of NRW water quality sampling points
https://naturalresourceswales.sharefile.eu/share/view/s137b47af533f42eb871b4e9f7dba2725/foe1292d-b245-4e52-82fd-5f48b09c969c	NRW Water Quality Archive data 2000-2021
https://catchmentbasedapproach.org/ And data: https://catchmentbasedapproach.org/forums/discussion/data-evidence/ And https://data.catchmentbasedapproach.org/ (Find your local CaBA Partnership) and new open data site (ArcGIS Hub) https://data.catchmentbasedapproach.org/pages/explore-data - need an ESRI account	Catchment based approach: Connect and learn with thousands of organisations who are delivering collaborative catchment management for the benefit of future generations. CaBA partnerships make use of the best available data and evidence to develop a shared understanding of the issues and target their actions and funds where they will have multiple benefits for all the partners. Catchment Based Approach data Hub
https://naturalengland-defra.opendata.arcgis.com/search?collection=Dataset	Natural England Open Data Geoportal
https://environment.data.gov.uk/	Defra Data Services Platform
https://www.therrc.co.uk/uk-projects-map	The River Restoration Centre's (RRC) interactive project map.
https://data.oecd.org/api/	OECD data for developers: About the API. The OECD has application programming interfaces (APIs) that provide access to datasets in the catalogue of OECD databases. The APIs allow you to query the data in several ways, using parameters to specify your request so that you can create innovative software applications which use OECD datasets. The APIs are available in JSON and XML formats. You can read more about the technical specifications of the data interfaces for JSON format in the API Documentation (JSON) and in API documentation (SDMX-ML).
https://data-explorer.oecd.org/	OECD Data explorer: Find, understand and use the data you need.

Web Portals and Digital Tools

URL	Resource
https://eip.ceh.ac.uk/hydrology-ukscape/waterQuality	It allows user to find available sites within 20 miles and plot time series determinants at a point. It uses the EA Data API.
https://eip.ceh.ac.uk/hydrology-ukscape/help	
https://environment.data.gov.uk/hydrology/explore	Water Quality, river flow, rainfall.
https://environment.data.gov.uk/bwq/profiles/	Swimfo: Find a bathing water. Swimfo allows you to look up details of a designated bathing water by name or location. To get an overview of multiple bathing water locations, or to download data extracts, see the data page.
https://nrfa.ceh.ac.uk/content/uk-water-resources-portal	UK Water Resources Portal.
https://www.food.gov.uk/our-work/pathogen-surveillance-in-agriculture-food-and-environment-programme#:~:text=PATH%2DSAFE%20programme%20background,-Foodborne%20disease%20(FBD&text=Most%20human%20disease%20is%20caused,animals%2C%20humans%2C%20and%20water	FSA PATH-SAFE: Tracking foodborne pathogens and antimicrobial-resistant microbes. Output of meeting: Efficient use of resources, by establishing a joint database, so that the same data can be used by multiple departments for different reasons.
https://environment.data.gov.uk/	Defra Data Services Platform
CDAP: https://defradigital.blog.gov.uk/2022/09/29/data-tools-and-people-introducing-the-three-enablers-of-defras-data-analytics-and-science-hub/	Defra Data Analytics & Science Hub (DASH) are working on the Common Data Analytics Platform (CDAP). This cloud-based platform, accessed through a web browser, offers a central location to access data, programming languages and tools, along with scalable compute power to do calculations, often with big data.
https://eip.ceh.ac.uk/hydrology/cc-impacts/	The Climate Change Impacts tool provides estimates of the impacts of climate change on river flood peaks across Great Britain, using a sensitivity-based approach which combines a grid-based hydrological model (Grid-to-Grid) with the UKCP18 probabilistic projections for river basin regions.
https://data.oecd.org/searchresults/?hf=20&b=0&r=f/type/datasets/api+access&l=en	OECD data catalogue.

Reports

URL	Resource
Defra ENVWLB00626R Water Quality Innovation Scoping study	Cedric Laize *et al.* (UKCEH) for DEFRA. 2023.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1134438/Roadmap_for_the_Defra_Earth_Observation_Centre_of_Excellence_2023_to_2028.pdf	Defra Earth Observation Centre of Excellence. **Data Access** Provide leadership as an intelligent customer, to facilitate work by other teams to ensure Earth Observation data are findable, accessible, and interoperable. **Build Capacity** Bring together internal and external expertise, to build a community for sharing ideas, knowledge, and methods, developing common tools, and integrating products.
https://www.gov.uk/government/publications/natural-capital-and-ecosystem-assessment-programme/natural-capital-and-ecosystem-assessment-programme	Natural Capital and Ecosystem Assessment Programme Policy Paper.
https://oifdata.defra.gov.uk/ And https://oifdata.defra.gov.uk/outcome-indicator-framework/	Defra 25 year plan - Outcome Indicator Framework for the 25 Year Environment Plan.

Appendix 5

Dataset	Publisher/Source
Land Cover Map 2021 (1 km summary rasters, GB and N. Ireland)	Environmental Information Data Centre https://catalogue.ceh.ac.uk/documents/a3ff9411-3a7a-47e1-9b3e-79f21648237d
Pollution Inventory (2021)	Environment Agency https://www.data.gov.uk/dataset/cfd94301-a2f2-48a2-9915-e477ca6d8b7e/pollution-inventory
Water quality monitoring data GC-MS and LC-MS semi-quantitative screen (2007–2024)	Environment Agency https://www.data.gov.uk/dataset/0c63b33e-0e34-45bb-a779-16a8c3a4b3f7/water-quality-monitoring-data-gc-ms-and-lc-ms-semi-quantitative-screen
Forever Pollution Map - PFAS	The Forever Pollution Project https://foreverpollution.eu/map/dataset-and-maps/
Concentrations of second generation anticoagulant rodenticides (SGARs) in Eurasian sparrowhawk livers, 1995–2015 for Great Britain	Environmental Information Data Centre https://catalogue.ceh.ac.uk/documents/1af003b1-2f70-4e45-a31a-b07a5fe6e929
Buzzards metals and rodenticides (unpublished) (2001–2019)	Predatory Bird Monitoring Scheme
Biological characteristics, liver metal concentrations, habitat biogeochemistry and habitat contamination sources of UK otters (2006–2017)	Environmental Information Data Centre https://catalogue.ceh.ac.uk/documents/0fbb2c90-5b54-427a-a083-55c022802a80
Estimates of anthropogenic emissions of metals and air pollutants in the UK at a 1 km resolution, 1750–2100	Environmental Information Data Centre https://catalogue.ceh.ac.uk/documents/4b392dc0-0219-4494-8420-82e42b93b445
UK Protected Area Datasets	JNCC https://jncc.gov.uk/our-work/uk-protected-area-datasets-for-download/
Biotoxin Results for England and Wales (2023)	Food Standards Agency https://www.data.gov.uk/dataset/7b232689-92ef-4f89-a490-559c21057f5a/biotoxin-results-for-england-and-wales
Scottish Pollutant Release Inventory	Scottish Environment Protection Agency https://informatics.sepa.org.uk/SPRI/
Aquaculture – Marine Fish Farms	Scottish Environment Protection Agency https://informatics.sepa.org.uk/MarineFishFarm/
Freshwater river macroinvertebrate surveys (Biosys)	Environment Agency https://environment.data.gov.uk/dataset/fa98090d-d715-4d34-80f9-bb7621aa7101
National Atmospheric Emissions Inventory – Gridded Emissions	National Atmospheric Emissions Inventory https://naei.energysecurity.gov.uk/data/maps/download-gridded-emissions

Dataset	Publisher/Source
Cadmium in topsoils of the European Union – An analysis based on LUCAS topsoil database (2023)	European Soil Data Centre https://www.sciencedirect.com/science/article/pii/S0048969718314451?via%3Dihub
Copper distribution in European topsoils: An assessment based on LUCAS soil survey (2018)	European Soil Data Centre https://www.sciencedirect.com/science/article/pii/S0048969718314451?via%3Dihub
UK Cats & Dogs Density	Aegerter *et al.* 2017 https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0174709
NORMAN Ecotoxicology Database — Lowest PNECs	NORMAN https://www.normannetwork.com/nds/ecotox/lowestPnecsIndex.php
Input to Yield Ratio (IYR) maps for wheat farming in England, 2010–2017	Environmental Information Data Centre https://catalogue.ceh.ac.uk/documents/dfe2a4a5-2b3a-4731-ba7f-aea7e926f1dd
Integrated Hydrological Units of the United Kingdom	Environmental Information Data Centre https://catalogue.ceh.ac.uk/documents/cca47088-8cdd-4d7a-86b4-90f0a1766364
NASA Earth at Night 2012	NASA https://science.nasa.gov/earth/earth-observatory/
HadUK-Grid Gridded Climate Observations on a 1 km grid over the UK, v1.3.0.ceda (1836–2023)	CEDA https://catalogue.ceda.ac.uk/uuid/b963ead70580451aa7455782224479d5/