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Catchment to Coast

Evaluating Coastal Water Quality Risks on the Isle of Arran: Utilising Catchment Models and Expert Elicitation

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Abstract

Diffuse pollution and subsequent monitoring of watercourses is a current ‘hot topic’ within research, however there are no standardised frameworks to examine either of these issues. For this reason ecological proxies, such as fine sediment, are often utilised to examine spatial trends in water quality.

The Community of Arran Seabed Trust (COAST) are interested in evaluating spatial variability in near shore water quality across Arran, with a view to future water sampling campaigns and allocation of bathing water status. To prevent the use of time consuming and expensive field or laboratory methodologies, the Sensitive Catchment Integrated Mapping Analysis Platform (SCIMAP) risk-based framework was employed to examine in-stream fine sediment risks to each catchment on Arran.

A total 41 catchments were examined, with 37 providing results detailing spatial distributions of in-stream fine sediment risk. These results were qualitatively ‘verified’ by a series of expert interviews from a variety of stakeholders on Arran.

While experts had varying levels of agreement with model predictions, they provided a first approximation of areas most at risk of in-stream fine sediment pollution, facilitating discussion and debate surrounding a topic not previously studied on Arran.

Model predictions were combined with expert opinions and additional catchment datasets to identify areas most at risk of in-stream fine sediment pollution and thus, poor water quality. These predictions can offer guidance to COAST in effectively targeting mitigation measures and any future research.

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List of Abbreviations

SCIMAP - Sensitive Catchment Integrated Mapping Analysis Platform

EU - European Union

WFD - Water Framework Directive

CSAs - Critical Source Areas

DST - Decision Support Tool

ICM - Integrated Catchment Management

RBMPs - River Basin Management Plans

FIO - Faecal Indicator Organisms

COAST - The Community of Arran Seabed Trust

NTZ - No Take Zone

MPA - Marine Protected Area

LCM - Land Cover Map

DEM - Digital Elevation Model

QGIS - Quantum Geographic Information System

OSM - Open Street Map

OS - Ordinate Survey

NS - NatureScot

NTS - National Trust for Scotland

FLS - Forestry and Land Scotland

GUEP - General University Ethics Panel

TA - Thematic Analysis

LMP(s) - Land Management Plan(s)

N/S - North-South

UKFS - The UK Forestry Standard

GBRs - General Binding Rules

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1. Introduction

Degraded quality, monitoring and pollution of watercourses are current ‘hot topics’ in the environmental sector, with issues surrounding bathing water status, combined sewage overflows (CSOs), sewage spills and diffuse pollution most prominent in contemporary media and research (Ford et al., 2025; Gonzalez Zapata, 2025; Krupska et al., 2024). Water quality and bathing water status are regularly monitored (Tiwari et al., 2021), especially due to the current increase in blue space recreational use. This ‘boom’ in recreational use is aided by the increased use and valuation of blue space environments by society (McDougall et al., 2021; Oliver et al., 2023), leading to legislative reform within the sector (DEFRA, Hardy and Reed, 2025).

Environmental organisations are utilising this ‘boom’ to study public perceptions of water quality information sharing and bathing water status (Quilliam, Taylor and Oliver, 2019; SEPA, 2025). Public opinion can play a crucial role in the policy process, primarily due to association between water quality and quality of health (Dwivedi, Ghanshyama Mahanty and Anilkumar Vemareddy, 2022). Experts are still trying to find the balance between managing bathing water sites based on public health alongside other social and cultural ecosystem services (Quilliam et al., 2015). However, increasing use of blue spaces calls for further robust water quality frameworks and legislation. This requirement for improved guidelines, coupled with potentially unclear and weaker legislation following the UK’s departure from the European Union (EU) (Howarth, 2017; Macrory, 2018) has made current and historic issues within the water sector more apparent. Watershed dynamics are complicated and intertwined, raising a number of challenges when determining pollution source, risk and mitigation methods.

While point source issues within the water environment are receiving lots of attention, a more subtle yet important contributor of pollution to water environments comes from diffuse sources. Diffuse pollution poses significant threats to water quality in the UK (Whelan et al., 2022) and yet is incredibly hard to capture, monitor and understand (Zahoor and Mushtaq, 2023). Diffuse pollution sources can vary but are often linked to land management practices, such as agriculture (Conroy et al., 2016). There is no one specific source of diffuse pollution within an area, rather a cumulative effect of many smaller individual sources which alone are not viewed as significant. However, when combined with catchment drainage waters, they can become extremely problematic. This lack of pinpoint sources and varied spatial ability of pollutants means environmental regulators struggle to identify where to implement mitigation measures within a catchment to best combat this issue. For this reason, diffuse pollution is often viewed as the Achilles' heel of water legislation frameworks, such as the EU Water Framework Directive 2000/60/EC (WFD) (European Commission, 2000). Environmental legislation attempts to conceptualise the ever changing, dynamic water environment and its subsequent pressures but social, political and hydrological systems make this increasingly difficult. Regulators require new approaches, different to those utilised for point sources, that enable them to identify where efforts should be focused for the biggest impact in terms of improving water quality, not explicitly mitigating diffuse sources.

1.1. Evaluating Water Quality - Issues, Pollutants and Proxies

1.1.1. Issues

Water quality can be examined in a number of ways including field, laboratory and visual methodologies. However these are heavily time, money and resource intensive. This variety of methodologies causes issues when trying to compare or standardise frameworks.

Water quality monitoring and its associated challenges has been a topic of discussion since the 1940s, yet there is still no assessment strategy that is widely accepted, practical and holistic (Behmel et al., 2016; Strobl and Robillard, 2008). The EU WFD (2000/60/EC), transposed into Scots Law in 2003, states 26 Articles detailing various definitions, strategies and implementations to establish a framework for action in the field of water policy. However, various pollutants and factors are excluded from this directive. For example, suspended sediment is omitted from environmental quality standards and compliance targets (Perks et al., 2017). While it is not realistic to expect researchers to examine every possible pollutant and factor impacting water quality, this lack of standardisation causes issues when reporting, comparing and understanding water quality studies.

Researchers are moving towards interdisciplinary approaches (Donaldson et al., 2005). These interdisciplinary approaches facilitate more factors to be considered when assessing water quality, one such factor is diffuse pollution.

1.1.2. Diffuse Pollution

Diffuse pollution intrinsically impacts water quality. Diffuse pollution is the release of potential pollutants from a variety of activities that, individually, may not impact the water environment but have significant effect at catchment scale (SEPA, 2024). Diffuse pollution can be caused by a variety of activities such as agriculture, forestry, urban land use, atmospheric deposition and human activity, but have no specific point of discharge (European Environment Agency, 2018). If discharge sources can be identified, this is point-source pollution.

Diffuse pollution can adopt a ‘transfer continuum’ whereby it follows a source – mobilisation – delivery – impact pathway (Haygarth et al., 2005). Sources can be rural or urban with agricultural sources a key contributor to poor water quality (Oliver et al., 2009). Mobilisation

of diffuse pollutants often occurs during times of high flow, movement or activity. Delivery of these pollutants to receiving waters involves hydrological transport through surface or below ground pathways (Reaney et al., 2019). Diffuse pollution can impact on water environments causing eutrophication, biodiversity decline, food insecurity and human health impacts.

One such way to conceptualise diffuse pollution pressures is the Critical Source Area (CSA) concept (Sharpley, 1985). CSAs delineate areas within a catchment that have high source risk and strong transport pathways. CSAs are where most of the diffuse pollution in a catchment will originate, making them optimal places for mitigation measures. However, identifying CSAs is not an easy process. There are several approaches used to identify CSAs, but these are rarely compared or evaluated (Reaney et al., 2019). Therefore, robust decision support tools (DSTs) that spatially map CSAs and consider cost-benefit analysis are required (Cole, Stockan and Helliwell, 2020; Thomas et al., 2021). The CSA concept underpins a variety of water and diffuse pollution management tools such as phosphorus CSA Indices (Thomas et al., 2016) and many diffuse pollution models (Reaney et al., 2019). To ensure all relevant factors are considered, diffuse pollutants are often employed as ecological proxies to assess spatial water quality.

1.1.3. Ecological Proxies - Fine Sediment

Fine sediment, defined as small inorganic particles that are less than 2 mm in diameter (Gupta et al., 2023), is one such proxy and the focus of this research. While fine sediment is an essential and natural part of water systems (Anthony et al., 2021; Turley et al., 2016), fluxes and magnitude can cause profound changes in a system's function ability (Mohanavelu, Shrivastava and Naganna, 2022; Owens et al., 2005). Excessive levels of fine sediment can impact a water system's hydrology, ecology, morphology and integrity (Gupta et al., 2023; Owens et al., 2005;

Perks et al., 2015; Turley et al., 2014). Fine sediments can also enhance the survival of faecal indicator bacteria and transfer associated co-pollutants (Perkins et al., 2014; Wyness, A.J., 2017), contributing multiple contaminants and impacting on poor water quality.

Currently, suspended sediment is omitted from the EU WFD and compliance targets (Perks et al., 2017), leading to poor understanding of fine sediment concentration targets water quality managers should aim to achieve (Bilotta et al., 2012). Governing bodies have established their own recommended guidelines for fine sediment concentration (Bilotta and Brazier, 2008). However, these recommendations and thresholds can be blanket values that do not consider the natural spatial and temporal variations of fine sediment in watercourses (Grove et al., 2015). These blanket values are often not well-linked to biological and ecological impact evidence (Grove et al., 2015) or based on surrogate measures, such as turbidity (Bilotta and Brazier, 2008; Grove et al., 2015). Reliance on turbidity data should be treated with caution as turbidity levels can be impacted by other hydrological and physical factors within a system (Bilotta and Brazier, 2008).

Traditional sampling campaigns assessing fine sediment magnitude are unable to accurately determine levels to acceptable precision (Perks et al., 2017). A multi evidenced based approach is recommended to accurately assess fine sediment across spatial scales (Reaney et al., 2019). The intertwined nature of water systems and their associated pollutants indicates the need for an integrated and holistic approach.

1.2. At Catchment Scale

Water quality sampling and sustainable management of the water environment can occur at a variety of temporal and spatial scales. When designing a study, scale should be considered and chosen appropriately to ensure effective results and the identification of accurate landscape

metrics (Brunner, Zappa and Stähli, 2019; Wu and Lu, 2021). A catchment scale approach is conducive to fostering contribution, engagement and participation from stakeholders (Rollason et al., 2018).

1.2.1. Integrated Catchment Management (ICM)

The ICM process recognises the importance of social, economic and political context within an appropriate organising unit, capturing stakeholder views while also guiding communities towards an agreed vision of sustainable land and water resource management within their catchment.

Catchment management is difficult to grasp, understand and holistically encompass. There are many factors within a catchment that need to be managed, meaning multiple drivers should be considered (Guerra and Mancinelli, 2024). It is impossible to consider and manage every single pressure, factor or opinion within a catchment. This is why proxies and modelling are often utilised; they allow a general overview and first look of an area. This allows identification of high priority areas for further study, sampling and management.

Successful water policy is dependent on sound underpinning science, understanding of political context and policy implementation planning from inception. The WFD and ICM cohesively encompass these three factors with a view to deliver successful policy outcomes. Improvements to ICM strategies have formed an important part of international policy for several years (Ayre and Nettle, 2015) with ICM intrinsically engrained in the EU WFD alongside river basin management plans (RBMPs), central to the directive.

Various reviews have been conducted on the application of ICM (Behmel et al., 2016; O'Grady et al., 2020) and yet there is still no standardised methodology due to a lack of empirical studies

(Ayre and Nettle, 2015). Historically, the UK has had poor linkages between sectors concerned with development, a ‘rush to plan’ when issues occur (Slater, Marvin and Newson, 1994). This led to the development of relationships between land use planning and the water sector, moving towards an interdisciplinary approach (Slater, Marvin and Newson, 1994). Said interdisciplinary approach permits the integration and consideration of many relevant factors, both physical and socio-economic. This allows a more extensive variety of mitigations strategies to be explored while also considering the needs and responsibilities of landowners present in the catchment (Chadwick et al., 2008; Oliver et al., 2009).

While ICM is a powerful tool, there can be issues surrounding its implementation and uptake. If stakeholders present within catchments disagree with the proposed measures, it can be difficult for these mitigation methods to be accepted and employed effectively. This can be exacerbated by issues surrounding awareness, practicality, cost, willingness and scepticism from stakeholders. One way to counteract this is engaging stakeholders in the policy formulation and decision-making process.

1.2.2. Stakeholder Engagement

Stakeholders are vital during decision making, modelling or policy creation processes. They help bridge the gap between science and decision makers by helping navigate uncertain, complex issues and providing a diverse range of opinions and knowledge. Stakeholder engagement is embedded in the EU WFD with Article 14 a key requirement, encouraging the active involvement of stakeholders within the implementation of the directive (European Commission, 2000). This aims to broaden participation and move away from disjointed thinking towards the goal of idea sharing, reduction of conflicts and wider sharing of views to promote for effective and truly ICM approach.

Knowledge exchange between stakeholders and scientists is becoming increasingly necessary to support the development of effective DSTs (Oliver et al., 2017). 'Stakeholder engagement' has become a 'buzz word' in the sector, hardly any environmental or modelling assessments are presented without some form of stakeholder participation in the process (Voinov and Bousquet, 2010). Stakeholder engagement during decision making processes helps the effective validation, uptake and adoption of environmental policy, management, decisions and modelling (Newham, Jakeman and Letcher, 2007; Stosch et al., 2022b). Furthermore it builds trust and transparency not only between scientist and stakeholders, but in the stakeholder's opinions in modelled outputs, mitigation methods and subsequent uptake (Oliver et al., 2017; Oliver et al., 2018). Information can be captured and integrated in various ways (Reed et al., 2009), with a mixed-method approach favoured (Lane et al., 2010; Stosch et al., 2019). Stakeholder engagement within a project or process can have varying levels of participation ranging from non-participation to citizen control (Arnstein, 1969).

Naturally, the involvement of stakeholders comes with conflicting views, opinions and priorities (Stosch et al., 2022a; Stosch et al., 2022b). It is important to manage and mitigate conflicts where possible to ensure the best for the environment and all involved (Hodgson et al., 2021). This facilitates a trade-off between the needs of the environment and the needs of the stakeholders (Stosch et al., 2017; Quilliam et al., 2015), further reinforcing the need for an interdisciplinary approach to catchment management. One such interdisciplinary approach is the use of catchment models.

1.3. Utilising Interdisciplinary Frameworks

1.3.1. Catchment Modelling

Catchment models provide a simplified description of real-world systems (Wagener, 2003). If utilised effectively, catchment modelling is a powerful tool facilitating large area analysis in relatively short timeframes. Models can require large financial investment during creation and testing but have little monetary implications once fully developed. They allow multiple factors to be examined at large spatial scales, providing a 'first approximation' assessment.

Models can be used for prediction, forecasting, to improve understanding and as part of a scientific enquiry (in either experimental design or to test a hypothesis). They can improve local observations and present unique characteristics (Ouyang et al., 2017). As legislation progresses, it is increasingly important to be able to predict the impacts of land management practices and mitigation methods on spatial diffuse pollution patterns (Krueger et al., 2007).

Catchment models can be classified into perceptual, conceptual or procedural models. All have their strengths and weaknesses, but perceptual understanding will always be better than the translation of this understanding to conceptual or procedural models. Models can further be classified into different categories, for example: Risk Indices, Black-box, Grey-box, Physical/Process Based and Probabilistic (increasing in complexity respectively). Risk based models are the most simplistic type of catchment model producing figures that are visual, readable and easy to understand. This allows cross examination by both scientific and civilian lenses (Buckley, 2010).

However, it is vital to appreciate balance when utilising these tools, "All models are wrong, but some are useful" (Box, 1979). No model can be developed to predict every factor at every scale (Oliver et al., 2016). Yet, end-users often have unrealistic expectations of model ability (Dickey-Collas et al., 2014). This can be avoided by clarifying a model's expected outcomes

from project inception (Oliver et al., 2016). Challenges surrounding catchment models are similar to those encountered with water quality monitoring and ICM. They face several limitations which calls for an interdisciplinary approach, especially surrounding diffuse pollution models (Lane et al., 2006). This would facilitate common methodologies, practice and integration of hydrological, ecological and physical factors (Krueger et al., 2012; Lane et al., 2006). This requires confidence in model formulation and a strong predictive capability of models which may not be justifiable in many cases, especially where limited observation data is available to develop and test model assumptions (Krueger et al., 2012). Model uncertainty is inevitable when employing catchment models, it should be acknowledged and displayed transparently. One way to reduce model uncertainty is to utilise expert elicitation (1.2.2).

Key challenges with diffuse pollution models involve large scale applications, integration, usability, uncertainty and identifiability (Fu et al., 2019). There are also issues with overparameterisation, equifinality and adequacy whereby model methodologies are developed to obtain “the right answers for the right reason” (Wellen, Kamran-Disfani and Arhonditsis, 2015). The above limitations reinforce the need for model validation and verification.

1.3.2. SCIMAP - A Risk-Based Approach

Sensitive Catchment Integrated Mapping Analysis Platform (SCIMAP) is classed as a risk-based modelling framework. It was designed to identify where diffuse pollution is most likely to originate, making relative rather than quantitative predictions (Reaney, 2014a). SCIMAP is highly simplified, empirical and semi-distributed with an annual timestep and built on the source – mobilisation – transfer – delivery continuum (Haygarth et al., 2005). It delineates an area into CSAs by identifying transport potential and source potential risks, visualising these risks in relation to a particular impact (Reaney and Lane, 2021). The SCIMAP framework has

been tested against both ecological and water chemistry datasets in a variety of scenarios and catchments, showcasing its uses, accuracy, benefits and limitations (Buckley, 2010; Dixon, 2013; Dugdale, 2007; Milledge et al., 2012; Pearson et al., 2022; Porter et al., 2017; Reaney et al., 2011; Twohig, S., 2018).

SCIMAP has multiple versions measuring flood, fine sediment and FIO risks within watershed catchments (Reaney, 2022). SCIMAP-Fine Sediment is available in 2 forms, a Windows desktop version embedded within a custom SAGA GIS build (SCIMAP Fine Sediment) and a web-based application (my.SCIMAP/SCIMAP WebApp, available at: https://my.scimap.org.uk/app/auth.php) (Reaney, 2016; Reaney, 2024). my.SCIMAP (developed in 2016, hereby referred to as SCIMAP) is a much more simplistic, streamlined and user-friendly application facilitating end-user interactions via a graphic user interface without the need to run the model via code. SCIMAP operates with a minimum information requirement philosophy considering digital elevation model (DEM), land cover class (LCM) and average annual rainfall (Reaney, 2014c). Full data requirements for SCIMAP can be found in Table 1.

Table 1. SCIMAP datasets, their acquisition and citations.

SCIMAP Input Data	**Dataset Name**	**Data Details**	**Resolution**	**Available at**	**Citation**
DEM	NextMap Britain	Digital elevation	5m	NEXTMap Elevation Data | Intermap	Intermap Technologies (2007): NEXTMap British Digital Terrain Model Dataset Produced by Intermap. NERC Earth Observation Data Centre
LCM	Land Cover Map 2007	Land use type and class	25m	Land Cover Map 2007 (25m raster, GB) v1.2 - EIDC	Morton, R.D.; Rowland, C.S.; Wood, C.M.; Meek, L.; Marston, C.G.; Smith, G.M. (2014). Land Cover Map 2007 (25m raster, GB) v1.2. NERC Environmental Information Data Centre.
Rainfall	CEH-GEAR (1890-2019)	Average annual temporal rainfall	1km (data is averaged from the 1980-2010 period)	Gridded estimates of daily and monthly areal rainfall for the United Kingdom (1890-2019) [CEH-GEAR] - EIDC	Met Office; Hollis, D.; Carlisle, E.; Kendon, M.; Packman, S.; Doherty, A. (2024): HadUK-Grid Climate Observations by UK river basins, v1.3.0.ceda (1836-2023). NERC EDS Centre for Environmental Data Analysis

These datasets mirror the diffuse pollution transfer continuum (Haygarth et al., 2005) with land cover data determining source risk, average annual rainfall data considering mobilisation potential and DEM data identifying potential transfer pathways. Each land use type is assigned a risk coefficient, these can be generated with a standard or fitted approach (Wells and Reaney, 2014). These datasets combine to generate outputs displaying erosion risk potential, hydrological connectivity and ultimately a channel's accumulated risk to fine sediment pollution for individual catchments (Figure 1). Details of these processes can be found in Beven and Kirby (1979), Lane et al. (2004) and Reaney et al. (2011). These outputs profile areas where risk to in-stream fine sediment pollution is most likely to be found, facilitating further investigation, mitigation and management within catchments.

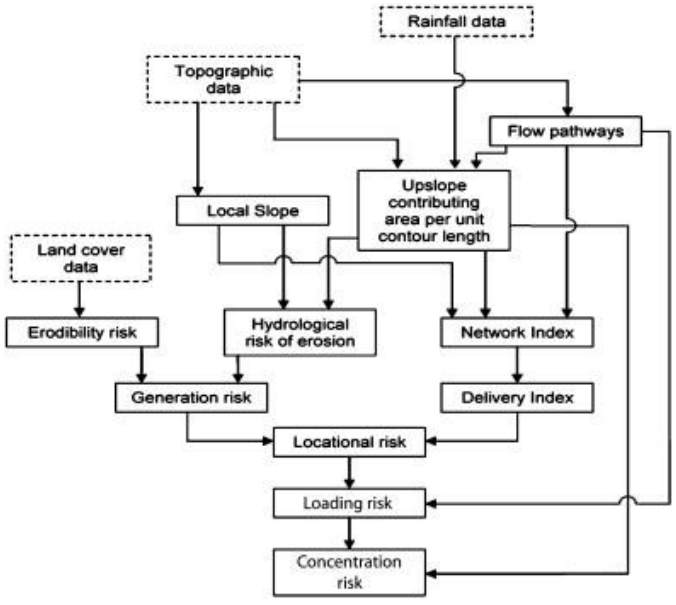


Figure 1. Overview of the SCIMAP model process for fine sediment risk (Reaney et al., 2011). Available at: https://www.sciencedirect.com/science/article/pii/S0304380010004175?via%3Dihub#fig0015

SCIMAP is easy to use, gives visual outputs and is transparent, with no hidden computer code. This makes it conducive to farm advisors, land users, stakeholders and end users. SCIMAP provides a rational framework to assess and indicate relative risk within a catchment, facilitating prioritisation of mitigation strategies and areas. Outputs provide preliminary predictions, a 'best guess', which is a powerful tool as part of a wider toolkit within interdisciplinary environmental management and ICM.

However, SCIMAP has several limitations, the key one being quality of data (Reaney, 2014b). If input data quality is poor, output data quality will follow suit. Furthermore, SCIMAP's risk weighting and ranking are subjective making them hard to justify, unify and evaluate. SCIMAP outputs only give a first approximation of areas predicted to be high risk, they have no exact values of any specific diffuse pollutants, but the intention is to highlight areas of focus. SCIMAP also has no process representation, meaning users cannot view why the model has identified an area as high risk or the data that contributed towards this prediction. The simplicity of SCIMAP allows engagement with end users but comes with drawbacks, simplicity masks detail. The simplification of data and processes by SCIMAP (and other catchment models) mean it is important to consider the limitations, uncertainties and inaccuracies with such models. Due to the above limitations, sites identified by SCIMAP as high risk should be 'verified' by on-the-ground knowledge or visits (Oliver et al., 2012; Reaney, 2014b). This reinforces the need for stakeholder engagement in an integrated catchment management approach. This qualitative verification process is a pragmatic approach to testing whether a model is fit for purpose. It is more cost-efficient in terms of both time and resources and more practical than physically sampling many water quality measurements from large spatial areas to verify outputs.

While SCIMAP is not a water quality model, it models risk of a key diffuse pollutant (fine sediment), the focal ecological proxy of this study. It gives a starting point, best guess approximation of areas most at risk. This allows the engagement of stakeholders within the process to qualitatively verify model outputs, facilitating an interdisciplinary and ICM approach which is crucial in this area of research (Stewardson et al., 2017).

1.4. Background

1.4.1. The Community of Arran Seabed Trust (COAST)

The Community of Arran Seabed Trust (COAST) was established in 1995 (COAST, 2020). Since their inception, COAST have spearheaded a number of successful campaigns such as the Lamlash Bay No Take Zone (NTZ) and South Arran Marine Protected Area (MPA) (COAST, 2020). COAST's vision is "Our seas become healthy - supporting marine life, enabling coastal communities to thrive and inspiring future generations" (COAST, 2024).

1.4.2. Study Rationale

COAST are interested in evaluating spatial variability within near shore coastal waters on the Isle of Arran, with a view to prioritising beaches to consider for bathing water status in the future. To target limited resources effectively, a risk scoping exercise is useful to assist in identifying possible sources of pollution that ultimately drain into coastal zones. Due to the gaps and limitations highlighted in the above literature, an approach utilising an ecological proxy paired with a risk-based model, verified through mixed method stakeholder engagement and additional datasets is advised. These recommendations were adapted to design a scoping study employing the SCIMAP framework to evaluate spatial patterns of in-stream fine

sediment risk across Arran. However, model outputs alone should not be taken as ‘gospel’. To qualitatively ‘verify’ SCIMAP model outputs, experts from a variety of different catchments, backgrounds and land use areas on Arran will be interviewed.

1.4.3 Research Location

The Isle of Arran is the largest island in the Firth of Clyde on the west coast of Scotland with an area spanning 430 km² (North Ayrshire Council, 2022) (Figure 2). Arran accommodates a number of significant marine areas, including the aforementioned Lamlash Bay NTZ and South Arran MPA (Figure 3).

Figure 2. An OS map of Arran at a 1:50,000 scale (Digimap, 2025).

Available at: https://digimap.edina.ac.uk/roam/map/os

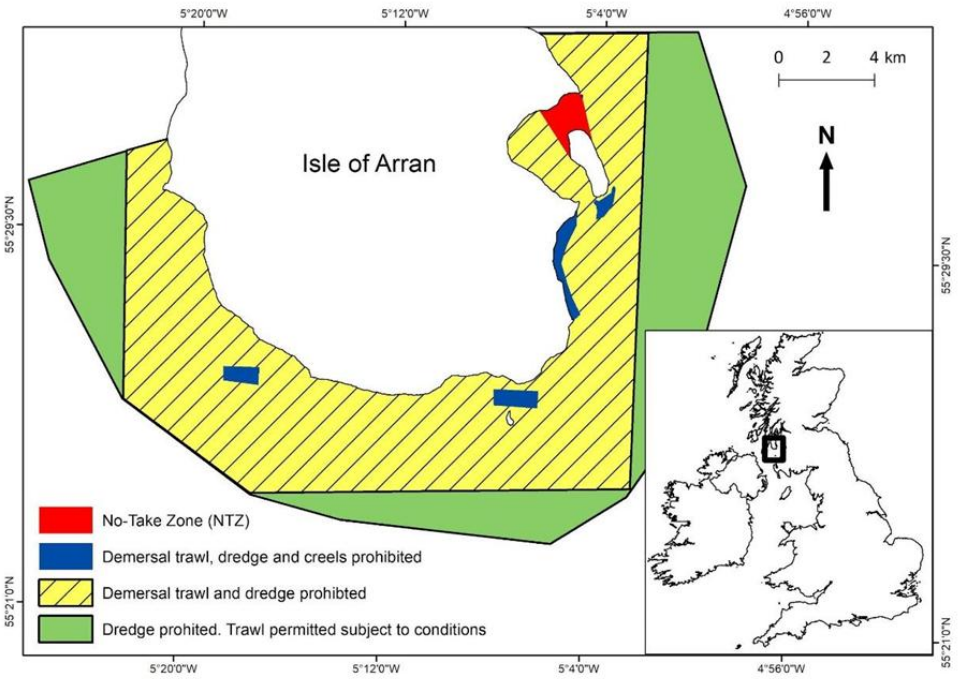


Figure 3. Map of the marine protected areas around Arran, including the Lamlash Bay NTZ and South Arran MPA, which has different zones as indicated. Source: Stewart et al. (2020).

Recently, Arran was named the tenth UNESCO Global Geopark in the UK, inscribed on the 17/4/25 (UNESCO, 2025a), one of only three in Scotland (BGS, 2025). UNESCO's Global Geoparks, while grounded in geology, focus on responsible and sustainable conservation, education and management.

Arran is often referred to as 'Scotland in miniature', a microcosm geographically, geologically, agriculturally and historically (Arran Geopark, 2024; Farm Advisory Service, 2024; UNESCO, 2025b) facilitating effective trial studies or initiatives. From 2019-2023 Arran was the study site for 20 dissertations and theses, as well as featuring in 17 peer-reviewed publications (Arran Geopark, 2023). More studies were undertaken before this time period, with many published on COAST's website. These studies are predominately marine, social and perception based, very few terrestrial studies have been completed on Arran. The above factors, coupled with the recent UNESCO designation of Arran a Global Geopark and gap in terrestrial studies, strengthens Arran's validity as a scientific research location and make it conducive to the proposed approach of this study.

2. Aims and Objectives

The overarching aim of this study is:

To investigate how catchment contributing areas impact on coastal water quality risks on the Isle of Arran using catchment models and expert elicitation.

To deliver on this aim, the following objectives were identified:

1. To derive, using the SCIMAP model, catchment maps of in-stream fine sediment risk for all catchments on the Isle of Arran.

2. To interview stakeholders (using an online platform) to discuss SCIMAP model outputs and enable a qualitative verification of the quality of the modelled predictions, based on expert knowledge.

3. To combine SCIMAP model outputs with a range of other catchment datasets to help understand pollution pressures on the Isle of Arran.

4. To synthesis SCIMAP outputs, expert opinion and additional datasets to identify where intervention or mitigation measures would be most effective on the Isle of Arran.

5. Advise COAST on possible areas where water quality sampling would be most beneficial with a view to determining future bathing water status.

3. Methodology

To achieve the above aim and objectives, a variety of software programmes, methodologies and analyses were employed (outlined in Figure 4).

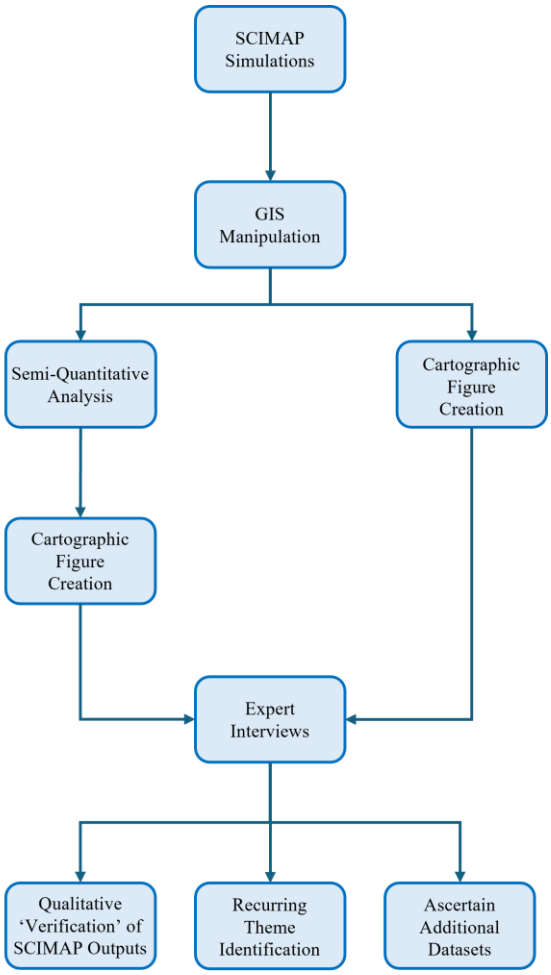


Figure 4. Flowchart outlining general project methodology.

3.1. SCIMAP

3.1.1. Modelling and Simulations

The web-based version of SCIMAP (Reaney, 2024) was used to generate fine-sediment pollution risk maps for each inland catchment on Arran. The SCIMAP graphic user interface displays drainage network pathways for Scotland, England and Wales, enabling catchment

delineation. Catchment areas were calculated by selecting a drain point (where the watercourse meets the sea) for each watercourse on Arran. In total, 41 catchments were identified, catchment numbers and locations can be found in Figure 5. 'Standard' simulations, using pre-defined tabular-based risk weighting parameters (Table 2) (Wells and Reaney, 2014) were run for each individual catchment on Arran. These weightings represent the risk of fine sediment erosion from different land cover types, details of these risk weightings can be found in Milledge et al. (2012). The SCIMAP 'Standard' simulation was selected over the 'Fitted' simulation due to the absence of field observation data (Wells and Reaney, 2014) for Arran and the scoping nature of this study.

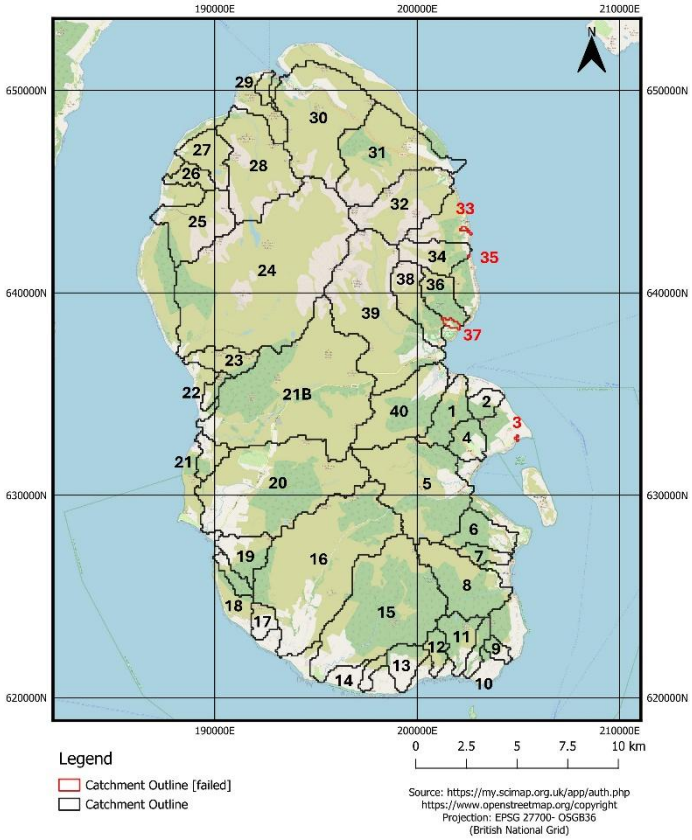


Figure 5. Each catchment on Arran, its outline and associated number. Catchments returning failed SCIMAP simulations are marked in red.

Table 2. SCIMAP assigned risk weightings for each land cover class, further details can be found in (Milledge et al., 2012).

Land Cover Class	Risk Weighting
Freshwater	0
Inland Rock	0
Littoral Rock	0
Littoral Sediment	0
Saltmarsh	0
Saltwater	0
Supra-littoral Rock	0
Supra-littoral Sediment	0
Suburban	0.01
Urban	0.01
Bog	0.05
Broadleaved Woodland	0.05
Coniferous Woodland	0.05
Heather	0.05
Heather Grassland	0.05
Montane Habitats	0.05
Acid Grassland	0.15
Calcareous Grassland	0.15
Fen, Marsh and Swamp	0.15
Neutral Grassland	0.15
Rough Grassland	0.15
Improved Grassland	0.3
Arable and Horticulture	1

Simulation results were numbered in line with their relevant catchment. Each catchment undertook a separate simulation but with the same pre-defined risk weighting parameters. SCIMAP simulations combined the pre-set risk weightings and displayed drainage network with nationally available data packages detailing LCM, long term average annual rainfall, DEM. The model then calculates streams, hydrological connectivity, erosion risk potential and ultimately, a channel's accumulated risk of fine sediment pollution (detailed in 1.3.2).

Overall, 37/41 catchments ran successful simulations, 4 catchments returned failed simulations. SCIMAP outputs were displayed in the form of colour coded maps, generating associated vector and raster data for each catchment. These associated data layers were individually exported into Quantum Geographic Information System (QGIS).

3.1.2. Processing Outputs

QGIS is an open-source software application that performs various digital mapping tasks (QGIS, 2024). It was used to manipulate and style SCIMAP outputs in preparation for subsequent expert interviews, occurring in projection EPSG:27700 OSGB36 (British National Grid). Each simulation's respective data layers were imported and overlayed on a base Open Street Map (OSM Standard) of Arran (accessed via QuickMapServices). Respective 'Merge' tools for vector and raster data were utilised to merge layers, detailing the same type of information but from different catchments, to allow styling and ease of data processing.

Basin rasters were polygonised, then styled with black outlines and no fill. Drainage network (streams) were basic line vectors, styled black. This supported readability and visual clarity. Channel accumulated risk was displayed as a point vector. The point symbology was changed to 'Graduated' and classified by the 'value' column from the associated attribute table. Points were classified into 20 equal interval classes with values ranging from 0 to 1. Due to erosion

risk potential and connectivity being raster layers, the render type was changed to ‘singleband pseudocolour’ and classified into 20 equal interval classes with values ranging from 0 to 1, facilitating the use of a colour ramp. Erosion risk potential, hydrological connectivity and channel accumulated risk layers were then styled with the colour ramp ‘Turbo’ (with red shades made brighter) to match the associated SCIMAP legend (Figure 6).

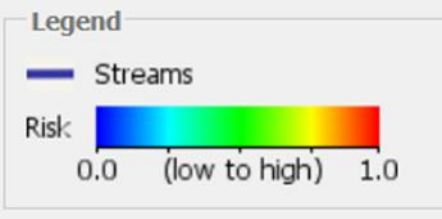


Figure 6. SCIMAP map legend.

‘Preview Mode’ was used to check whether ‘Turbo’ was suitable for different types of colour-blindness. The ramp is readable overall, but an alternative greyscale colour ramp (‘Greys’) was prepared in case of accessibility requirements (e.g. colour-blindness).

The resulting figures detailed spatial distribution of in-stream fine sediment risk across Arran. Once processing was complete, maps were captured and exported as high-resolution JPEGs for use during interviews.

3.1.3. Semi-Quantitative Attribute Manipulation

Attribute data from channel accumulated risk vector layers facilitated semi quantitative risk analysis, completed in Microsoft Excel. Due to the nature of SCIMAP, channel accumulated risk cannot be unified or evaluated between catchments. This means that risk is relative to each catchment, preventing island wide conclusions or comparisons. As an additional step to somewhat circumvent this issue and facilitate some cross catchment assessments, the percentage of each catchment’s drainage network above key risk thresholds was determined.

This was calculated by identifying the number of channel accumulated risk datapoints in each catchment with values ≥ 0.9, relative to the total number of datapoints in the catchment. Datapoints were identified in vector attribute tables using the 'Select by expression' tool where "values" ≥ '0.9'. The selected features were then exported, saved as separate layers and overlayed on the stream outlines and OS map. These datapoints were styled as simple red points, allowing the highest risk zones in each catchment to be quickly identified and highlighted without having to look at the channel accumulated risk values of the entire catchment. These figures were then captured and exported as high-resolution JPEGs for use during interviews.

The total number of datapoints and those identified as ≥ 0.9 for each catchment were inputted into Microsoft Excel with the formula: (total 0.9 datapoints/total catchment datapoints) * 100. This calculated the percentage of each catchment identified as a 'high risk zone'. These percentages allowed some comparisons between 'high risk zones' in each catchment but were not statistically measurable.

3.2. Expert Elicitation

To synthesise the accuracy of SCIMAP findings and qualitatively verify model outputs, experts with relevant knowledge were interviewed. This level of stakeholder engagement is classed as 'Consultation' (within Tokenism) on Arnstein's Ladder (Arnstein, 1969) and is considered a mixed method approach, favoured in the sector (Lane et al., 2010; Stosch et al., 2019). COAST helped identify and engage with stakeholders who had knowledge and expertise of the catchments on Arran in areas such as land management, soils, water quality, pollution or in-stream ecology. Not all experts had scientific backgrounds but are experts within their

catchments in terms of on-the-ground knowledge and experience. The list of experts, their roles and associated organisations can be found in Table 3.

Table 3. Experts' numbers, names, roles and associated organisations.

Expert Number	Name	Role	Organisation
E1	N/A	Island Officer	NatureScot
E2	Malcolm Wilkinson	Operations Manager	Arran Geopark
E3	Malcolm Whitmore	Access User	Arran Access Trust
E4	Lucy Wallace	Walking Guide	Arran Wild Walks
E5	Andy McNamara	Outdoor Instructor	Otter's Tail (outdoor adventure tourism)
E6	Alexander Pirie	Senior Consultant and Area Manager	SAC Consulting (Part of SRUC)
E7	Kate Sampson	Senior Ranger	National Trust for Scotland
E8	Jackie Kemp	Forester	Forestry and Land Scotland

Expert 1 wished to remain anonymous for this study but agreed for their organisation and role to be attributed to their comments.

3.2.1. Ethical Approval

Ethical approval for this project and associated interviews was requested through the University of Stirling General University Ethics Panel (GUEP) and approved on 18/10/2024. Ethical approval was obtained before any experts were contacted and interviewed.

3.2.2. Interviews

Once ethical approval was granted, experts were contacted and provided with a participant information sheet (available in S1) and consent form (available in S1). Once they agreed to participate in the study, experts were presented with an information packet (available in S1) detailing study background, model outputs and proposed interview questions. This was

provided a minimum of three working days ahead of interviews to allow experts time to view and understand presented information.

Experts were individually interviewed through Microsoft Teams to share their views on the SCIMAP model outputs and whether said outputs corroborate their own knowledge and opinions. During the interview, experts were asked eight open-ended questions (Table 4) but were also prompted to disclose any information they thought relevant. Most experts spoke about current projects, initiatives or plans that could impact on model outputs. The resulting data provided a qualitative verification of whether they think the model outputs are 'fit for purpose'. All interviews were recorded for recall purposes, but transcripts were not coded.

Table 4. Full list of interview questions.

Question Number	Question
1	From your own knowledge about Arran, which geographical areas (in general and more specifically) do you identify as being the riskiest in terms of contributing to fine sediment pollution of watercourses? Can you expand on your reasoning?
2	Looking at the selection of model outputs provided, do these spatial predictions of in-stream fine sediment reflect your views on the distribution of fine sediment pollution across the selection of catchments?
3	The model outputs are an annual average of in-stream sediment risk. How dynamic do you think the in-stream fine sediment pollution risk is – i.e., would risk vary a lot over time? Can you expand?
4	Was there anything in the model output that surprised you? (for example, lower/higher than expected risk associated with any of the catchment drainage areas?) What do you think might be responsible for any discrepancies in your catchment understanding vs that of the model prediction?
5	Catchment 22 has the highest percentage of areas identified as risky (highest percentage of risk values >= 0.9 within the catchment), does this align with your views and knowledge?
6	Looking at catchments 39/40 and 29/30, why do you think that this particular pattern of fine sediment risk is so focused in a particular location in the catchment? Do you trust the model prediction here? Is that a fair reflection of reality in your opinion?
7	Were the model outputs easy to understand/read? Is the colour ramp produced by SCIMAP the most appropriate?
8	How could the model be improved? For example, do you feel there are additional data layers/missing information that would add further value to the modelled outputs?

3.2.3. Qualitative Analysis

While interview transcripts were not coded, some elements of thematic analysis (TA) were utilised. TA was not ‘pure’, but analysis followed some aspects of the 6 Phases of TA (Braun and Clarke, 2006; Braun and Clarke, 2022). This allowed the identification of recurring themes, issues and debates raised by experts. Interview recordings were reviewed to explore these themes and document relevant answers, quotes and comments. Themes were checked to ensure they did not implicitly contradict each other and related to study aims and objectives.

3.3. Additional Datasets and Documentation

After interviews were completed, additional catchment datasets, identified in question 8, were sourced from a variety of open data platforms. Datasets identified included geology, soil type and more detailed land use classes. A full list of suggested datasets can be found in Table 6. However not all datasets identified were utilised due to relevance and availability. Selected datasets were downloaded and processed in QGIS. Full data acquisition, processing, styling and outputs can be found in A1. These datasets were combined with expert opinion further facilitated the ‘verification’ of the SCIMAP model, as well as attempting to identify possible pollution sources and transfers on Arran. Details of additional forestry documentation can be found in A2 and S1.

4. Results

4.1. Model Outputs

4.1.1. Standard SCIMAP Outputs

SCIMAP simulations were run for 41 drainage basins on Arran, 37 of those returned successful outputs. Simulations produced figures detailing a channel's accumulated risk to in-stream fine sediment pollution (Figure 7) for each catchment on Arran.

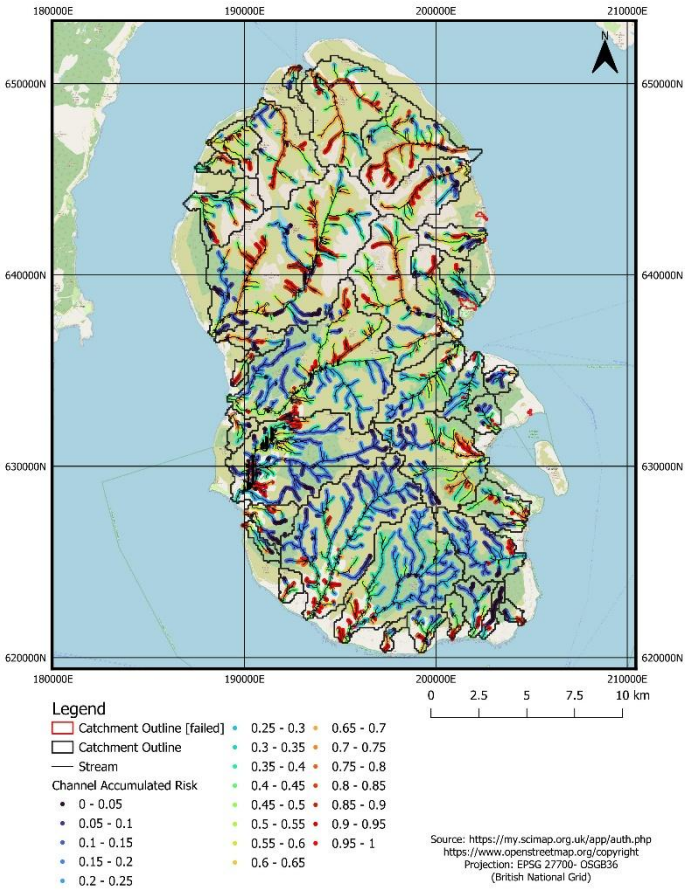


Figure 7. Channel accumulated risk of fine sediment for each successful SCIMAP simulation (catchments returning failed simulations are outlined in red). Areas highlighted in red are where there is most likely to be the source of a problem. There are potentially more problem areas in the north and in southern coastal zones.

4.1.2. 'High Risk Zones'

The percentage of each catchment identified as a 'high risk zone' (values ≥ 0.9) was calculated (see 3.1.3) (Table 5) and displayed at both catchment (Figures 16, 18, 20, 22 and 24) and island (Figure 8) scale. These figures were presented to experts to highlight the predicted highest risk areas in each catchment.

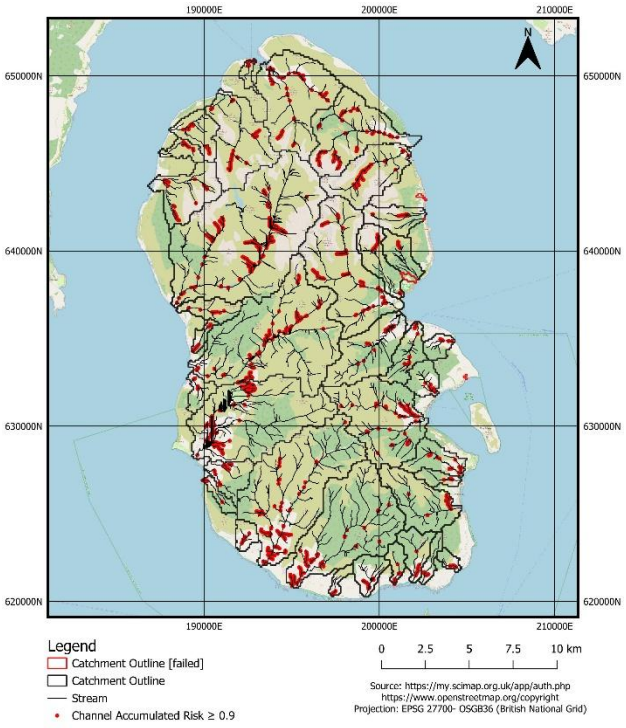


Figure 8. Channel accumulated risk of fine sediment ≥ 0.9 for each successful SCIMAP simulation (catchments returning failed simulations are outlined in red). There are potentially more problem areas in the north and in southern coastal zones.

Out of 37 successful catchment simulations, 12 returned SCIMAP outputs that signalled risk values ≥ 0.9 for over 10% of the catchment (Figure 9). One of these 12 catchments, catchment 22, indicated values ≥ 0.9 for over 20% of the catchment (see 4.2.3).

Table 5. The percentage of each catchment predicted channel accumulated risk values ≥ 0.9. Rows highlighted in yellow show percentages greater than 10%. The row highlighted red shows a percentage greater than 20%.

Catchment Number	Percentage of datapoints ≥ 0.9 (2.d.p)	Catchment Number	Percentage of datapoints ≥ 0.9 (2.d.p)	Catchment Number	Percentage of datapoints ≥ 0.9 (2.d.p)
1	5.42	15	6.18	27	7.52
2	6.25	16	6.43	28	9.69
4	5.79	17	11.49	29	16.67
5	6.03	18	8.92	30	7.42
6	6.13	19	10.62	31	10.98
7	6.46	20	7.16	32	13.69
8	5.72	21	5.69	34	8.23
9	13.78	21B	6.63	36	5.48
10	6.84	22	23.53	38	11.64
11	9.10	23	9.00	39	8.88
12	17.06	24	10.34	40	6.05
13	7.88	25	9.04		
14	17.51	26	14.48		

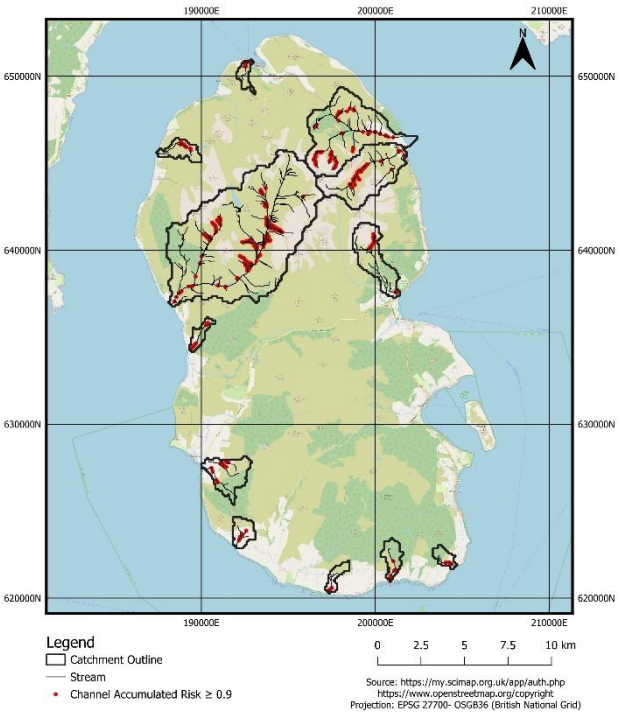


Figure 9. Catchments on Arran with 'high risk zones' comprising more than 10% of the catchment. Catchments vary in size and location with no obvious distribution trends.

4.1.3. Failed Catchments

While most catchments on Arran undertook successful SCIMAP simulations, catchments 3, 33, 35 and 37 (Figures 11, 12, 13 and 14 respectively) returned failed simulations (Figure 10).

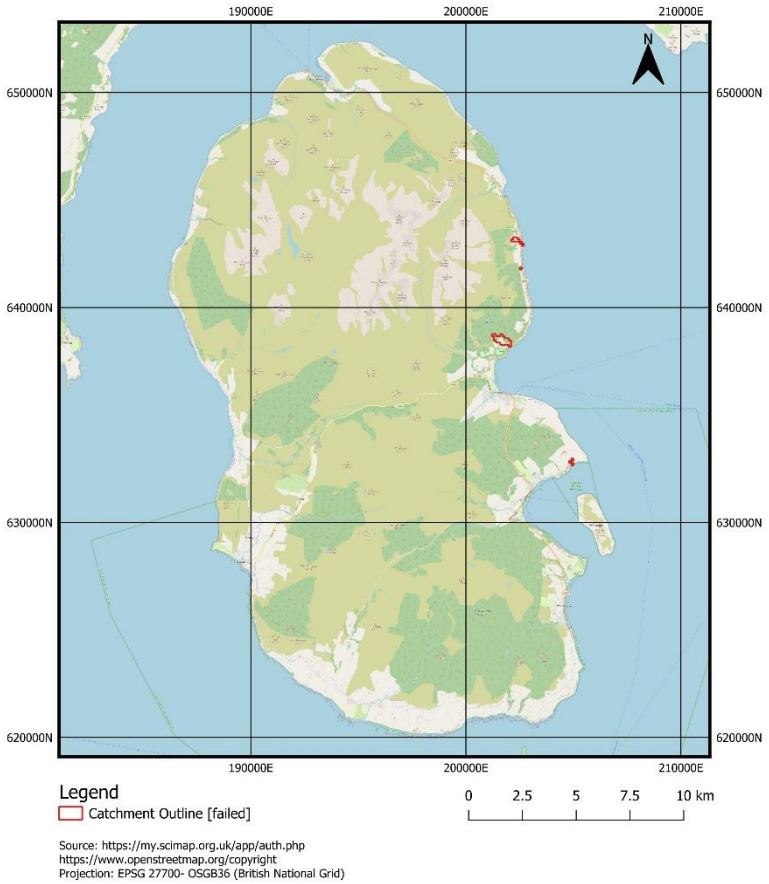


Figure 10. The location of each of the four catchments returning failed simulations on Arran. These catchments are distributed on the east of Arran, mainly in the north.

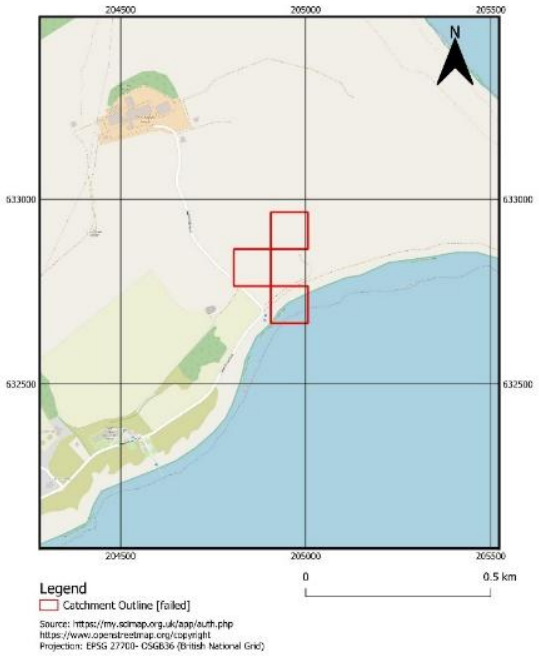


Figure 12. Outline for catchment 3.

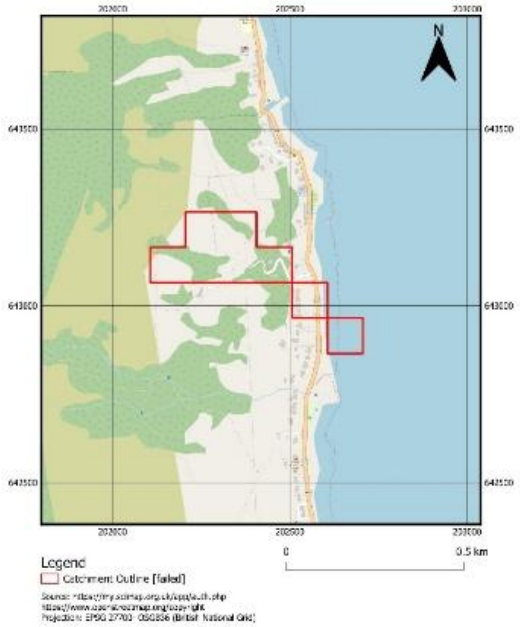


Figure 11. Outline for catchment 33.

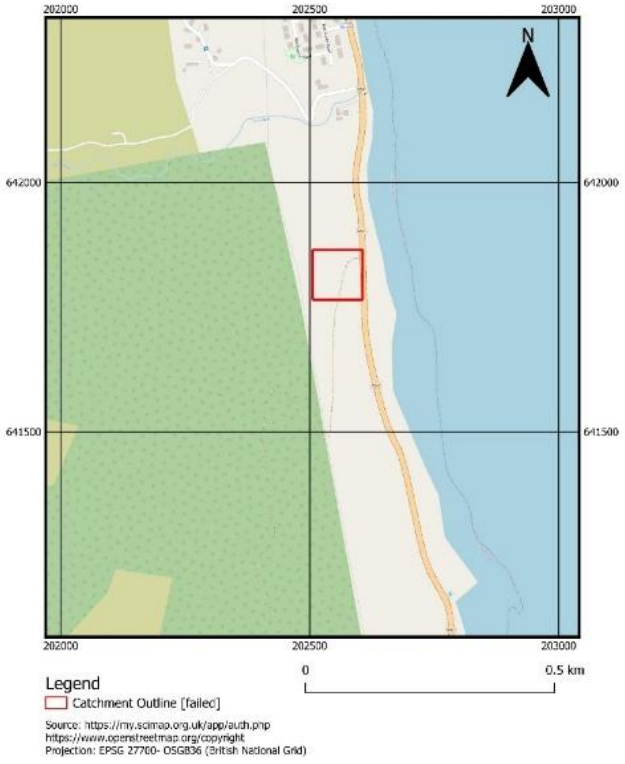


Figure 14. Outline for catchment 35.

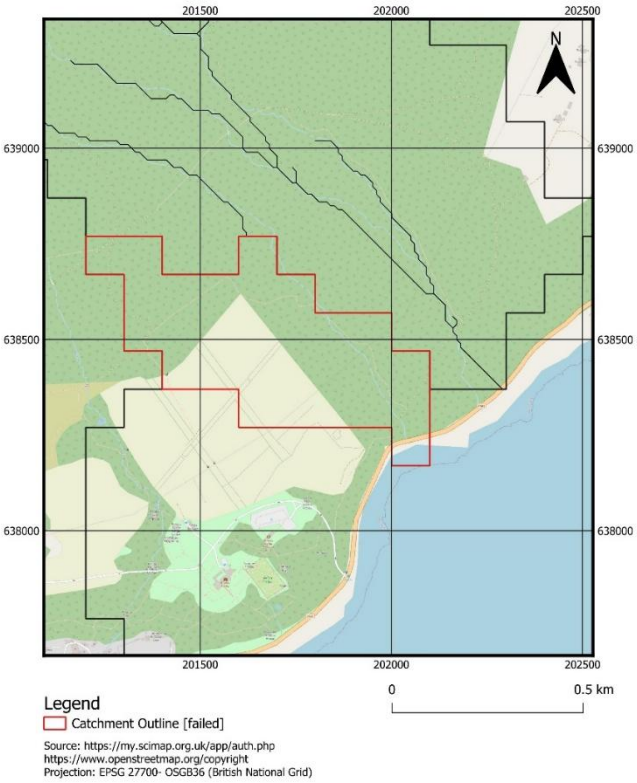


Figure 13. Outline for catchment 37.

4.2. Model vs Expert Opinion

Model outputs were presented to experts during individual interviews allowing discussion, comments, reasoning and validation.

4.2.1. Expert Predictions

From their own knowledge of Arran, experts predicted forestry ("*I think the areas most adjacent to active forestry sites are the most at risk*" (E1)), peatland ("*...certain areas from the uplands where you've got degraded peatland*" (E2)) or agriculture "*...issue with farmland*" (E4)) as areas creating the greatest risk of in-stream fine sediment pollution. Arran has a range of forestry blocks with the bulk "*in the central part of the southern half of the island"* (E8) with many having "*watercourses that will flow into catchments in one way or another*" (E8). Full forestry blocks and their locations on Arran can be found in A2 with corresponding LMPs (containing felling maps) in S1. Other small villages such as Lamlash, Brodick Bay, Whiting Bay, Blackwaterfoot and Glen Rosa were predicted as potential contributing areas, but for localised disturbances and catchment specific dynamics.

4.2.2. Experts in Agreement

Only 50% of experts directly stated whether the predictions in Figure 7 reflected their own views and understanding. These experts agreed that the model outputs are broadly in line with what they expected, "*I think it's fairly well representative… of kind of the areas that I would expect there to be some issues*" (E6).

4.2.3 Where SCIMAP and Experts Disagree

Experts disagreed with numerous geographical areas, at varying scales. Main areas of surprise and disagreement were the possible north-south (N/S) divide in predicted risk across the island, Glen Rosa and Machrie (further details in 4.2.3).

The possible N/S divide between catchments (Figure 7) separated expert opinion with 5/8 disagreeing, *"...I would have expected the south to have more fine sediment pollution than the north to be honest*" (E4), 2/8 remaining impartial and only E8 agreeing stating there is less turbulence in the south with the forestry stabilising the soil "*except when we're going in to do any operations and that's only going to be for a very short period of time*" (E8).

Glen Rosa was a hugely surprising area for many experts (Figures 15 and 16).

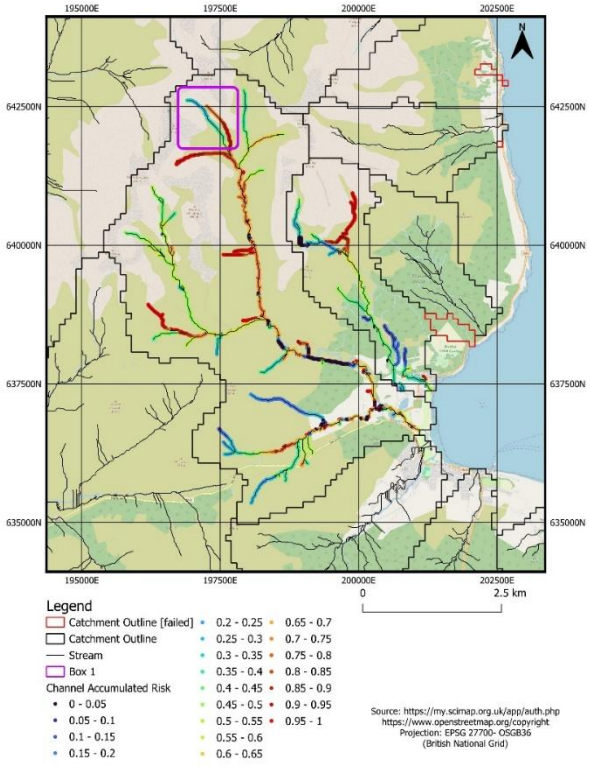


Figure 15. Channel accumulated risk of fine sediment for catchments 38 and 39. Box 1 highlights two parallel streams, identified by experts as an area of interest.

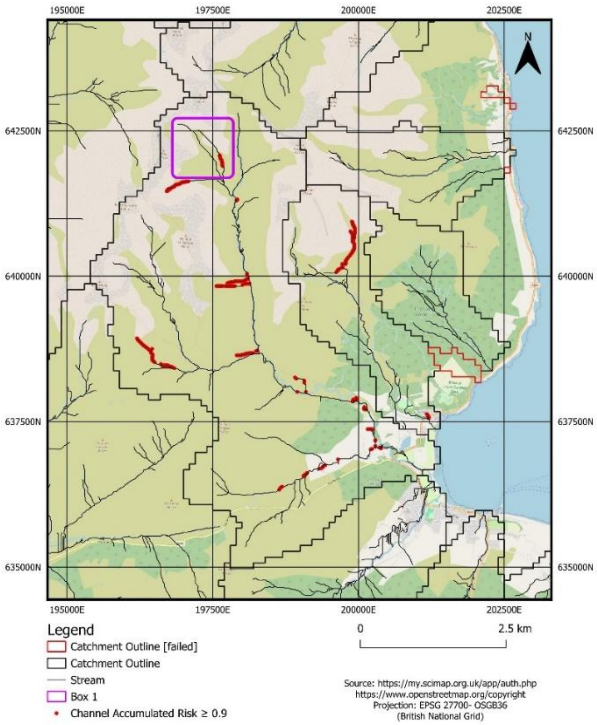


Figure 16. Channel accumulated risk of fine sediment values ≥ 0.9 in catchments 38 and 39, with no obvious trend in distribution of high-risk zones. Box 1 highlights two parallel streams, identified by experts as an area of interest.

E2, 3, 4 and 7 (50% of experts) all stated they did not think the model outputs either accurately represented, or were correct for, this catchment. "*Glen Rosa didn't seem quite right somehow, it didn't fit with what I know of the Glen"* (E4). Experts further noted two parallel watercourses, with identical terrain, displaying very different predicted risk ratings (Figures 15 and 16 box 1), causing confusion, "*In Glen Rosa… you've got two almost parallel channels, and one is bright red, and the other is the other end of the spectrum…. I'd be interested to know why that is*" (E2).

4.2.3. Catchment 22 - An Area of Surprise

Catchment 22 (Figures 17 and 18) was identified as having the highest percentage of predicted 'high risk zones' (Table 5) which caused surprise amongst most experts.

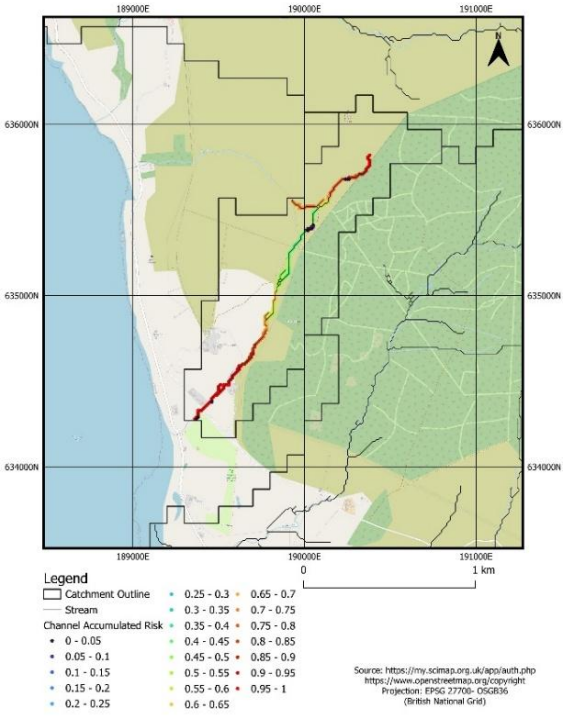


Figure 17. Channel accumulated risk of fine sediment for catchment 22, with the upper and lower courses of the river as predicted risky areas.

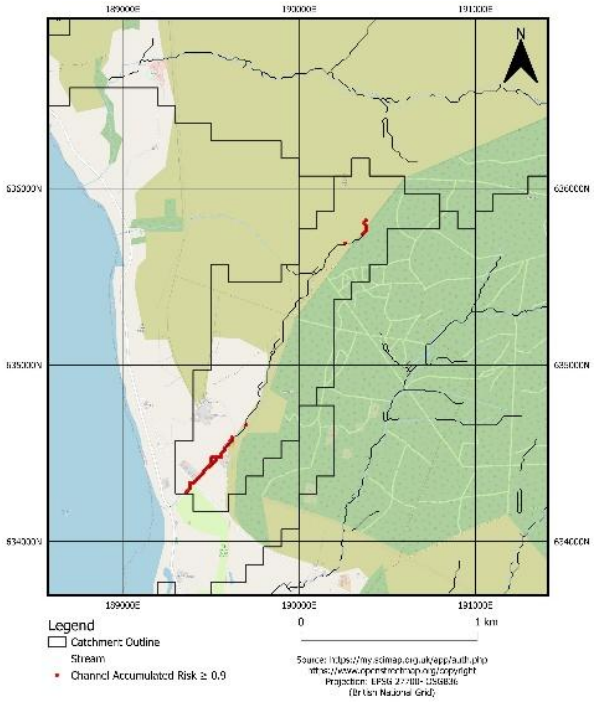


Figure 18. Channel accumulated risk of fine sediment values ≥ 0.9 in catchment 22, with high-risk zones predicted in the upper and lower course only.

Catchment 22 was described by four experts as having relatively uniform land use, level terrain, accommodating a golf course and containing some rough grazing from patches of agriculture. Most experts could not clarify why this catchment was predicted such high levels of fine sediment risk, "*It doesn't lend itself to an immediate understanding of why that would be like that*" (E1). Most experts had limited knowledge of this area meaning comments or suggestions were not independently verified.

4.3. Three Further Catchments of Interest

As well as areas of surprise and disagreement, experts commented on three additional areas at catchment scale.

4.3.1. Lochranza (catchments 29 and 30)

Experts were presented Figures 19 and 20 to provide catchment scale insight in the north where urbanisation has occurred within a region lacking other diverse land use.

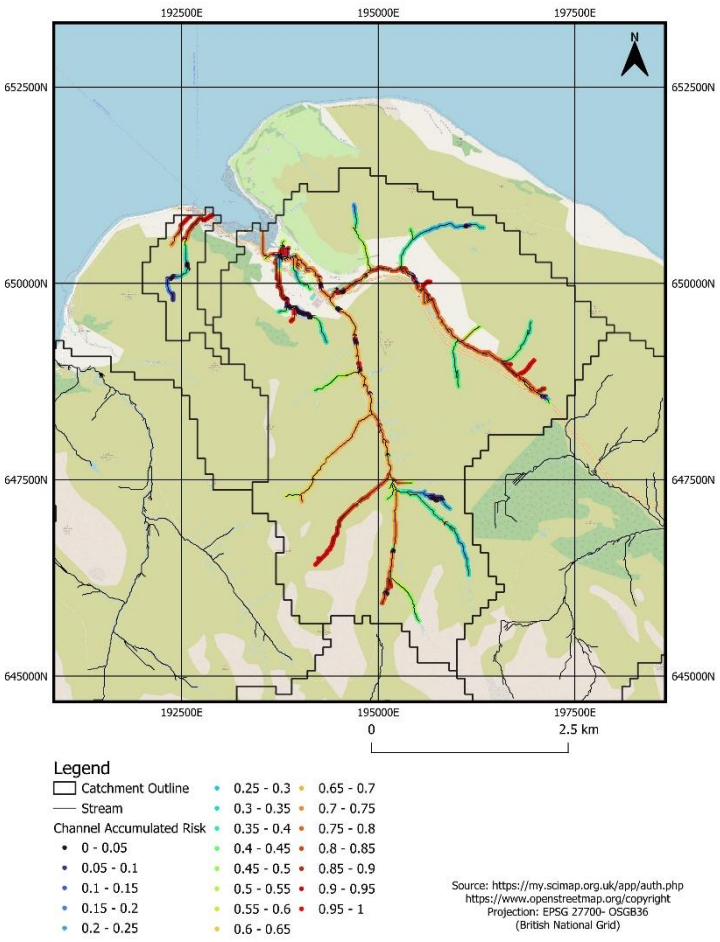


Figure 19. Channel accumulated risk of fine sediment for catchments 29 and 30, with particular focus on the north/right hand watercourse.

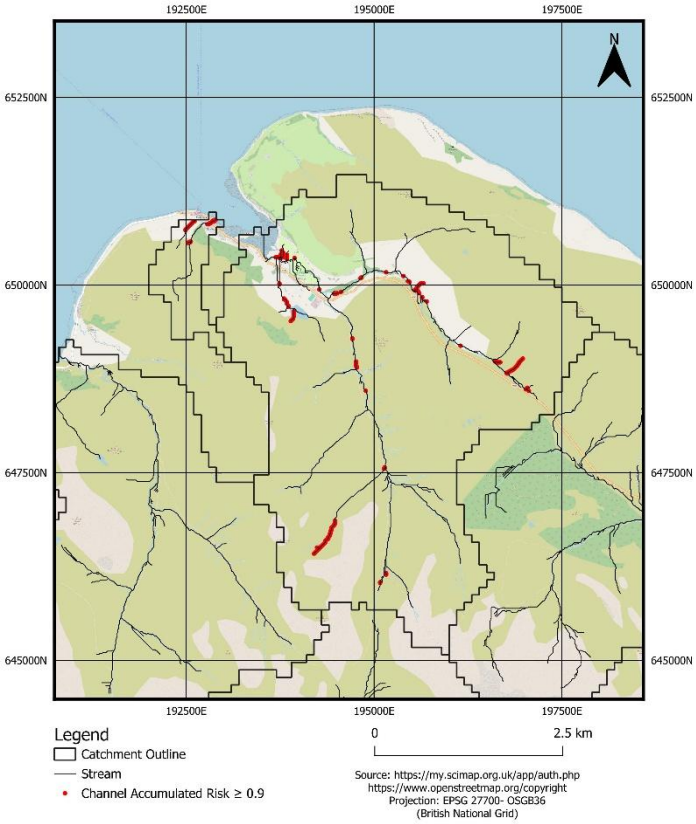


Figure 20. Channel accumulated risk of fine sediment values ≥ 0.9 in catchments 29 and 30, with no visible trend in distribution of high-risk zones.

Experts described Lochranza as having steep terrain, thin soils, some peatland restoration and no forestry. The watercourse (running through Gleann Easan Biorach) is notorious amongst experts and residents for being 'mucky and boggy'. The area is prone to landslips, "*There seems to be a lot of instability in that glen at the moment*" (E3).

4.3.2. Brodick (catchments 39 and 40)

Experts were displayed Figures 21 and 22 which show the largest settlement on Arran in the southeast of the island.

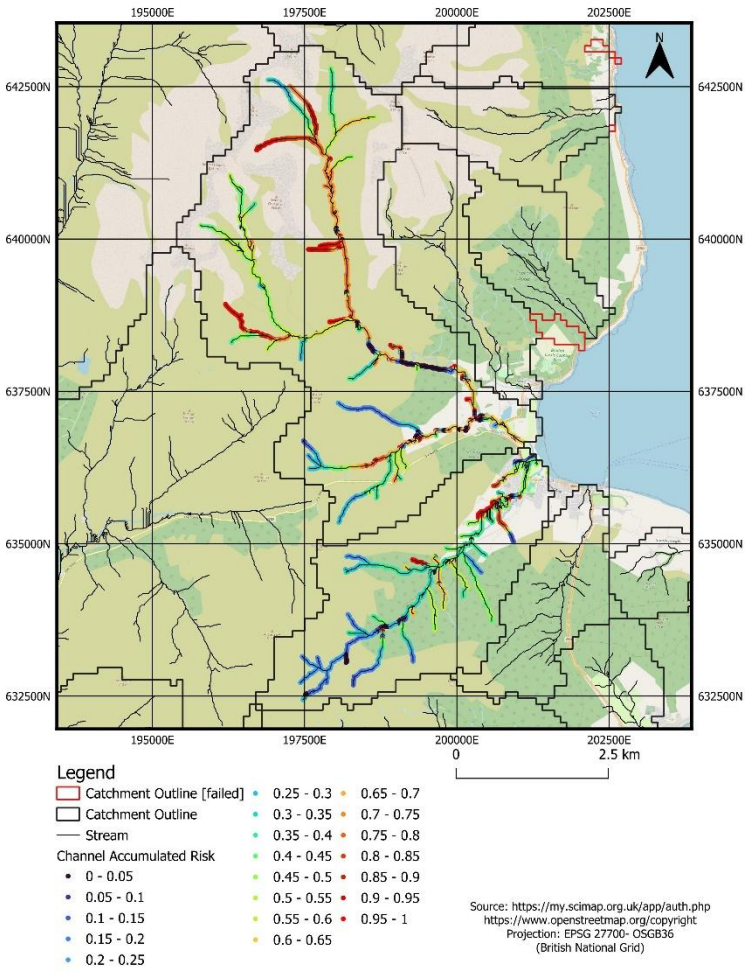


Figure 21. Channel accumulated risk of fine sediment for catchments 39 and 40, with particular focus on the highly mountainous and elevated areas.

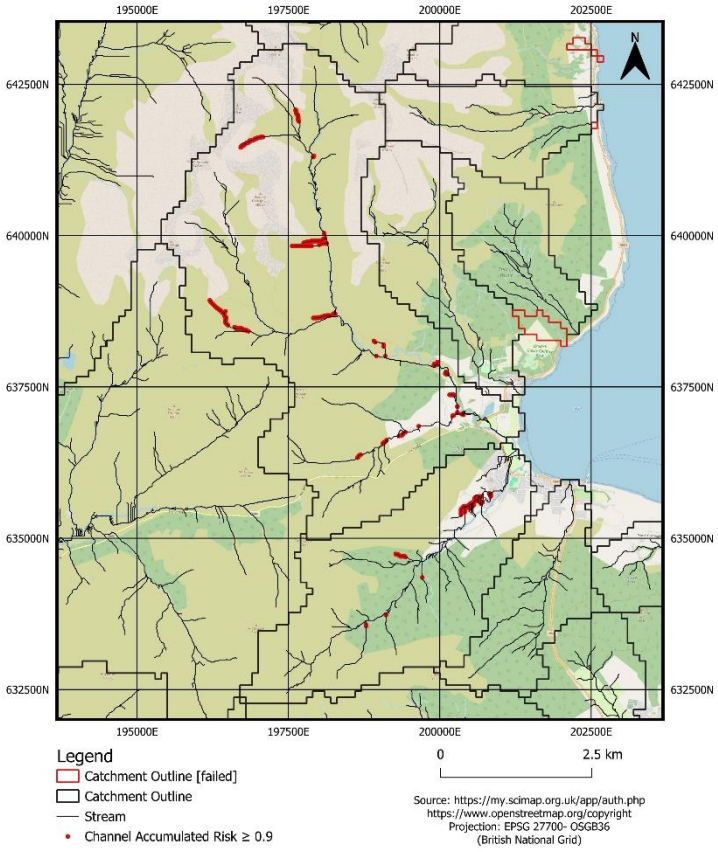


Figure 22. Channel accumulated risk of fine sediment values ≥ 0.9 in catchments 39 and 40, with no visible trend in distribution of high-risk zones.

Most experts agreed with the generic outputs for Brodick other than Glen Rosa (detailed in 4.2.3), with confusion in coastal areas *"Where there's very limited opportunity for land management to occur, the model seems to indicate a higher risk and I can't understand that for love nor money*" (E1).

4.3.3. Lamlash (catchments 3 [failed], 4 and 5)

Lamlash (Figures 23 and 24) was briefly spoken about with E4. She explained how "*Lamlash does have a particular issue with farmland"* but acknowledged that "*it happens to be that I live here, so I'm much more super aware of it*".

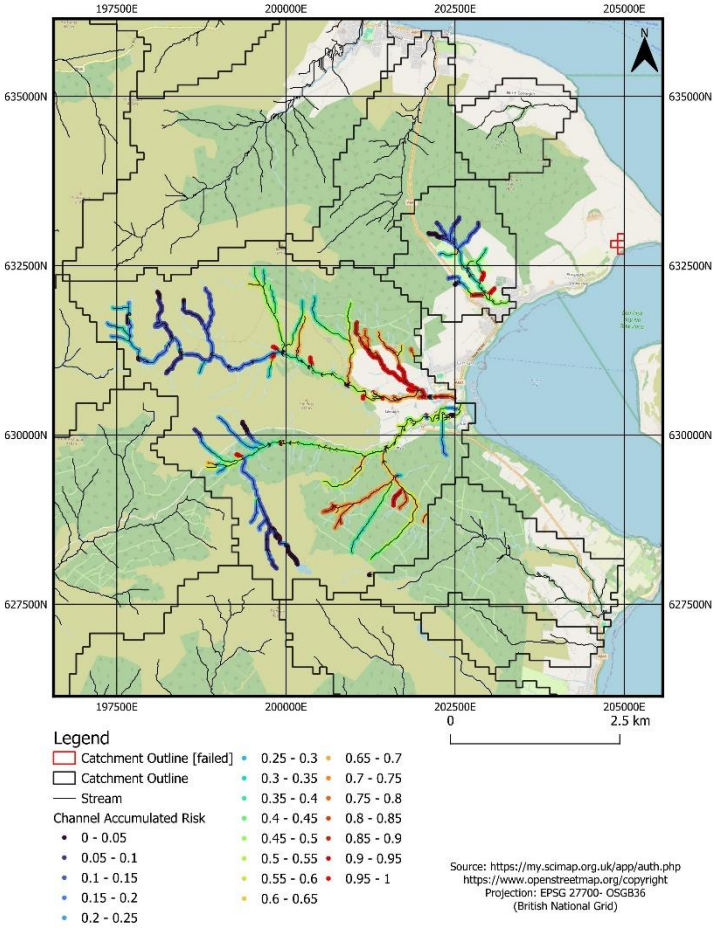


Figure 23. Channel accumulated risk of fine sediment for catchments 4 and 5, with particular focus on the settlement of Lamlash.

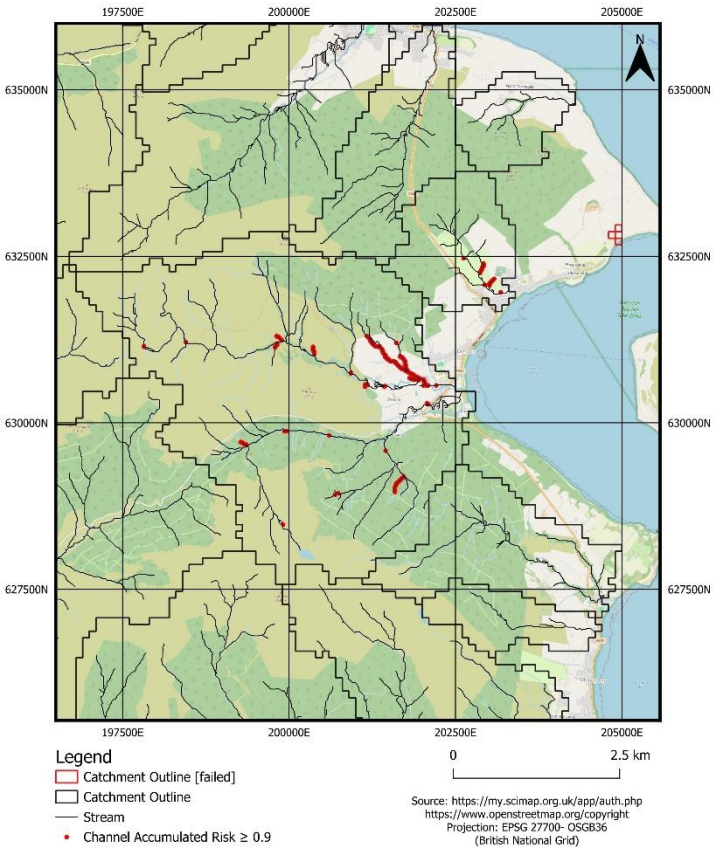


Figure 24. Channel accumulated risk of fine sediment values ≥ 0.9 in catchments 4 and 5, with high-risk zones concentrated in the lower courses in predominately coastal and urban areas.

4.4. Themes, Patterns and Additional Observations

As well as commenting on maps predicting fine sediment risk, experts were asked to explore additional topics surrounding the SCIMAP model.

4.4.1. Dynamic Nature

SCIMAP outputs display an annual average of in-stream fine sediment risk. Experts were asked if they thought fine sediment dynamics would vary across a temporal scale, with most stating they would be generally similar, "*I think it'll be broadly kind of similar throughout the whole year*" (E6). Some seasonal and localised variations were identified, but only visible at catchment scale.

4.4.2. Visual Outputs of the SCIMAP Model

All experts found the model outputs easy to read and had no immediate issues. "*As a visual aid, as a rough and ready tool, it really helps you get a clear idea of where the pressures may lie and then you can delve into that data"* (E1), "*Visually it's easy to understand"* (E4). Many agreed that the colour ramp was appropriate for a first glance. Red was associated as "*alarming*" or "*danger*" which experts felt matched the riskiest areas it was representing, while blue was viewed as more "*passive*". A "l*ow, medium, high*" (E1) categorised scale was suggested to simplify model outputs and reduce clutter, however the expert acknowledged that "*you can hide a lot of detail in a few categories…"* (E1).

Understanding model outputs caused some issues but this was not due to the colour ramp, "*The hardest bit for me to get my head around was the idea that it's almost kind of like a relative figure, so it's hard to compare one catchment with another*" (E4).

4.4.3. Suggested Improvements and Datasets From Experts

All experts acknowledged that no model could contain every contributary factor and that increasing data inputs can decrease model accessibility. Despite this, many additional datasets were suggested to improve the model's predictions, specifically for Arran (Table 6). Geology and land use type datasets were utilised (A1).

Table 6. All additional datasets suggested by experts during interview.

Habitat type	Soil type	Geology	Prevalent wind direction
Land use type (more detailed)	Soil pH	Forestry felling	Susceptibility to freeze thaw
Terrain	Fish habitat quality	Peatland	Geology
Forestry type	OS base and contour map	Peatland restoration	Areas of intensive agriculture

4.4.4. Experts' Additional Comments About Arran

Additional comments by experts described spatial trends in geology and agriculture, as well as general island dynamics on Arran. E2 explained how geology on Arran is split by the Highland Boundary Fault with older rock in the north and younger rock in the south (Arran Geopark, 2024) (Figure 25).

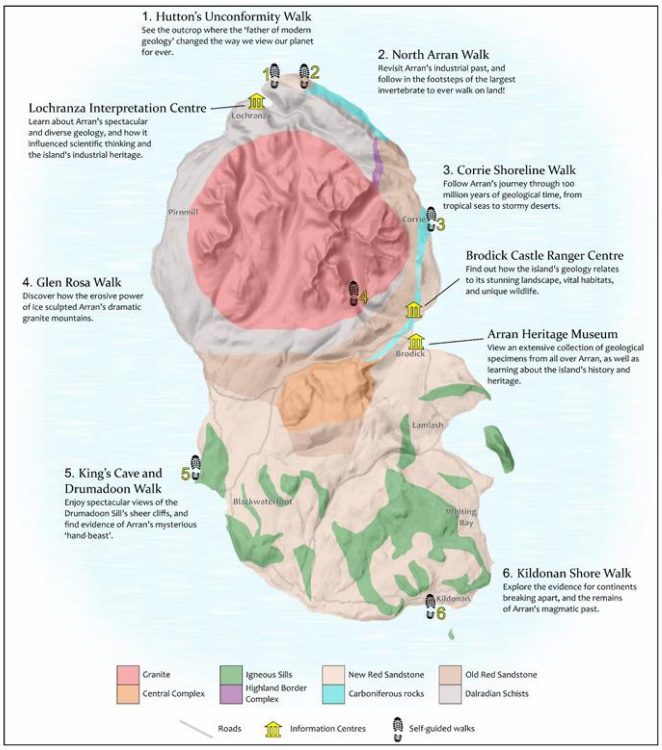


Figure 25. Geology on Arran (Arran Geopark, 2024).

Experts explained that Arran does not contain large amounts of agriculture, but what is present is concentrated in the south, specifically the southwest. This agriculture is mainly permanent pasture with limited cultivation for cereal crop rotation.

General island trends include the north being wetter and steeper, as well as land in the north having less landowners. Experts also stated that most of the north is ‘wild’ land with agriculture, forestry and urbanisation concentrated in the south.

5. Discussion

For the first time, an assessment of fine sediment risk has been conducted across the entire island of Arran. This assessment utilised the SCIMAP model which mapped 41 catchments across the island, with 37 catchments producing outputs detailing possible areas at high risk to fine sediment pollution. To further 'verify' these outputs, additional expert elicitations were sought through a series of online interviews. The model outputs and expert insights were combined with additional catchment datasets to identify possible contributing pollution pressures to poor water quality. This information will be presented to COAST to guide future research and mitigation methods when evaluating coastal water quality and bathing water status.

SCIMAP outputs predicted potentially higher risk values in northern catchments and the coastal zones of southern catchments. 'High risk zones' in each catchment were quantified but show no significant distributions at either catchment or island scale. Within specific catchments, predicted risk values varied with some offering more obvious reasoning for these values than others. Failed simulations occurred in four catchments, all located on the east of Arran. Experts had varying levels of agreement with these trends, model outputs and each other. Levels of agreement were influenced by scale (both spatial and temporal), land use type and the expert's role. Agreement at catchment scale was lowest, with most experts surprised and/or unable to explain displayed trends in a variety of different catchments.

5.1. Scale

SCIMAP produced a range of outputs across different land use areas, catchments and geographical points detailing channel accumulated risk to fine sediment pollution. There was some broad agreement with model outputs at island level, this could be due to the annual timestep and temporal scale of the model generating first approximation, general predictions. These predictions facilitate discussion and knowledge exchange between experts, researchers and policymakers. However, at a more localised catchment level, agreement with the model outputs was lower. This is to be expected, with stakeholder participation often causing conflict and disagreement (Stosch et al., 2022a; Stosch et al., 2022b).

5.1.1. Spatial: Island Wide

The four failed catchments could be due to source or transfer pathways being unidentifiable (within each catchment). For there to be a risk to fine sediment pollution, both need to be identified otherwise the diffuse pollution continuum or CSAs cannot occur (Haygarth et al., 2005; Sharpley, 1985). Possible gaps or errors in DEM or drainage network data could have caused this. These simulations could be re-run with varying scales of DEM data to examine possible causes.

Channel accumulated risk predictions for each catchment on Arran appear to display a split between northern and southern catchments with higher risk predicted in northern and coastal southern zones. This did not meet expert expectations with 7/8 experts surprised by these predicted patterns who collectively commented on limited land use activities that would disturb sediment and create pollution. Experts had predicted areas of forestry and agriculture to contribute most risk to fine sediment pollution which on Arran, are concentrated in southern catchments. However, E8 (from forestry) was not surprised by this, explaining how

he believes long established forestry would stabilise the soil in the south and how northern soils are more turbulent. This theory aligns with model predictions, as well as the CSA concept (Sharpley, 1985) and diffuse pollution continuum (Haygarth et al., 2005). Source accumulation and transfer pathways will be prevented, halting the movement of sediment within these areas.

One possible alternative explanation for the high predicted risk values in the north is geology. While bedrock in the north is predominantly (more resistant) granite, superficial geology mainly comprises of poorly sorted sand and gravel of a range of clast sizes. This class of rock is more prone to erosion (Menzies, 2022) and could contribute higher source risk in these catchments. Although SCIMAP does not consider geology when calculating source risk or erosion potential, it does consider the amount of time there is bare soil throughout the year within each land class (Wells and Reaney, 2014). Superficial geology could contribute to this erosion risk. The northern catchments on Arran are predominately classed as heather, with associated risk weightings 0.05 (Table 2). This could indicate a 'medium' probability of both bare soil and erosion risk. This coupled with the loose sedimentary soils could be generating a high source risk in these catchments. This potential high source risk, combined with higher levels of rainfall and steeper elevation (than the south) indicate a higher likelihood of CSAs within northern catchments, as well as having more prominent source, mobilisation and transfer pathways.

Conversely, in the south SCIMAP predicted low channel accumulated risk other than in extremely coastal zones. One possible explanation for this finding is land elevation in the southern coastal areas. The south of Arran was described during interviews as having a relatively flat coastal road but then with a steep drop between the road and the sea. This drastic change in elevation over a small spatial scale could generate higher connectivity risk

and well as potentially higher accumulation and less dilution of fine sediment through hydrological pathways, thus increasing channel accumulated risk predictions.

Experts, LCM data and FLS LMPs denote most of Arran's forestry in the central southern catchments. Both broadleaved and coniferous forestry are assigned an associated risk weighting of 0.05, indicating (again) a 'medium' level of risk. However, forestry areas have less bare soil as well as tree roots increasing soil stability (Oades, 1993). This would reduce erosion risk potential and thus, source risk. Furthermore, the south of Arran receives less annual rainfall and has flatter terrain. These would reduce connectivity values within these catchments. This apparent mismatch of trends in model outputs and expert observation suggest potential issues surrounding fit between these two factors.

5.1.2 Spatial: 'High Risk Zones'

SCIMAP does not allow comparisons between catchments, therefore calculations beyond model outputs were carried out in order to identify high risk zones. The catchments on Arran with 'high risk zones' comprising more than 10% of the catchment follow no obvious spatial distribution and vary in size. This infers the model is not skewing these percentages due to catchment size (small catchments could have higher percentages due to containing less datapoints) or scale.

5.1.3. Spatial: Catchment Level

The use of catchment spatial scale within this study facilitated expert engagement but masked specific detail (Rollason et al., 2018). Experts disagreed most with model outputs at catchment scale, particularly Glen Rosa (catchments 38 and 39) and Machrie (catchment 22).

Within Glen Rosa, experts believed that model outputs were not an accurate reflection, noting two streams of interest (box 1, Figures 15 and 16). There seems to be no logical explanation for the discrepancies identified in these [reportedly identical] parallel channels. Here experts noted identical data for LCM, DEM and rainfall. However one possibility is DEM data may be at different spatial resolutions within the catchment due to a lack of data availability or possible pixel gaps/overlaps, leading to disjointed data and subsequent hydrological transfer pathways and risks. However, these explanations do not account for the source pathway identified by SCIMAP to generate this high risk.

Experts could not suggest definitive reasoning for the large number of 'high risk zones' within catchment 22. This is a further example of discrepancies between model fit and expert observation.

5.1.4. Spatial and Temporal: Model Outputs vs Expert Observations

Discrepancy between scale of model datasets and scale of expert knowledge became apparent throughout interviews and analysis. While interviewing experts for their elicitation was useful, this did not take place in the field. It is therefore possible that experts were not in a place to compare SCIMAP outputs with their own immediate observations.

SCIMAP uses datasets at different resolutions with DEM at 5m, LCM at 25m and rainfall at 1km (Table 1). The catchments' specific detailed nuances described by experts are likely to be at smaller resolutions (approximately 1-5m). The 5m DEM resolution may consider these processes, but the 25m LCM and 1km rainfall likely will not. These resolutions will also not consider distinctions in hydrology or morphology in the landscape such as subsurface flow pathways, artificial drainage networks and complete hydrological routing or landscape flow pathways. Additionally, experts' temporal scale is more likely to operate in days, weeks or

months and not necessarily annual, as SCIMAP does. The SCIMAP framework was tested for variation in performance due to seasonality in the context of FIOs (Porter et al., 2017). While there was some variance in model performance, further research is required to determine whether fine sediment dynamics vary seasonally in the same way as FIOs (Oliver, 2014; Porter, 2018) and whether this will impact model performance.

5.2. Specific Land Classes

Before viewing model outputs, experts stated their own predictions of areas they thought would create the greatest risk of in stream fine sediment pollution. However, their predictions are mainly relating to land use in a specific area given their geographical expertise. While SCIMAP does consider land use type, it does not consider nuances and activities that occur within each land use class. SCIMAP does consider the 'riskiness' of each land use type within the risk weighting parameters (Table 2) but not catchment specific activities. The 'lumped' nature of SCIMAP's assigned risk ratings would likely diminish these localised details, and such criticism of models has been reported previously (Bormann et al., 2009; Okiria et al., 2022). Specific land classes were where model output predictions and expert opinion differed most, particularly surrounding activity implications in areas of forestry and agriculture. This could be due to SCIMAP source attributions (derived from land cover type) or transfer pathways not quite conceptualising the landscape appropriately. Alternatively, the LCM data employed by SCIMAP is from 2007, whereas expert knowledge of landcover is from 2024. This could explain possible discrepancies and disagreements surrounding specific land use areas.

5.2.1. Forestry

One of the interesting observations made both through outputs and interviews was the role of forestry on Arran. The model predicted low risk values for areas of forestry. However this was contradicted by 7/8 experts who claimed that forestry felling and operations contribute to fine sediment pollution, but SCIMAP will not pick up these detailed activities and so does not register this as an issue. This is due to SCIMAP not distinguishing between land cover class and how the land within the class is used.

SCIMAP assigns risk weightings based on the amount of time soil will be 'bare' and susceptible to erosion (Wells and Reaney, 2014). It is unlikely that soil will be bare in areas of established forestry and additionally will be stabilised by tree root presence. This could explain the 'medium' risk weighting assigned to both forestry classes. Differing activities within land classes can cause variable levels of sources, transfers and ultimately risks to fine sediment pollution hence there is a need for experts to utilise model outputs to inform researchers, policy makers and environmental regulators.

Forestry as a land class is difficult to evaluate when assessing fine sediment pollution risk and water quality. This is due to the dynamic nature of the ecological, hydrological and sociopolitical environments. Areas of active forestry on Arran caused large debate with experts claiming to have witnessed sediment entering watercourses from forestry activity first hand and have expressed reservations about mitigation measures FLS employ.

FLS must comply with the UKFS (5th Edition) which has a section detailing the requirements for forests and water (Forestry Commission et al., 2023). Furthermore, in Scotland, all forestry operations must meet the relevant General Binding Rules (GBR) (Scottish Government, 2011). These rules help prevent sources and transfers of fine sediment but inevitably, not all sediment pollution can be mitigated and some will enter watercourses

(Picchio, Jourgholami and Zenner, 2021; Shah et al., 2022). There is an ongoing debate about the implementation and efficacy of such mitigation measures. This creates large uncertainty surrounding risk weightings in forestry land use areas. Conflicting opinion, information and observations substantially impacts SCIMAP's ability and validity when predicting channel accumulated risk in catchments with active forestry. No one expert's opinion can be considered 'correct' or more 'valid' than other, but models of this nature can provide a mechanism to open up debate and dialogue across stakeholder communities to discuss why a model might be wrong and to try to reach some sort of conflict resolution (Hodgson et al., 2021; Stosch et al., 2022a; Stosch et al., 2022b). The highly conflicting predictions displayed by SCIMAP outputs, the experts' opinion and scientific research make it extremely difficult to determine the fine sediment risk for areas of forestry on Arran. This uncertainty highlights areas requiring discussion, providing an opportunity to implement the favoured interdisciplinary and ICM approach (Lane et al., 2010; Stosch et al., 2019) and warranting further research into the impacts, operations, mitigations, sources and transfers of fine sediment pollution within FLS managed areas. One possible method to examine this is detailed in 5.6.1.

5.2.2. Agriculture

Experts predicted areas of agriculture as one of the most significant areas contributing to fine sediment pollution. However, catchments containing agriculture were not the focus of interviews, this was due to the lack of agriculture on Arran as well as time constraints and proposed interview questions. SCIMAP has previously worked well in large agriculture catchments (Porter, 2018). The lack of agricultural areas on Arran could provide a possible explanation for the higher levels of uncertainty surrounding model outputs.

Agriculture is a varied land class, with cattle and crop contributing vastly different sources and transfers (Zahoor and Mushtaq, 2023). While it is assigned the highest risk weighting within SCIMAP (1.00), this does not consider the type of agriculture or activity within the land use class. Further examination of agricultural catchments on Arran is recommended, one possible methodology is detailed in 5.6.1

5.2.3. Peatland

Experts also predicted areas of peatland as significant contributors to fine sediment risk within catchments. Again, these areas were only briefly examined due to interview constraints however the concept of land class homogeneity vs heterogeneity was discussed. Arran has a variety of peat types as well as varying levels of both degraded and restored peatland. The semi-distributed 'clumped' nature of SCIMAP land class data would assign all areas of peatland the same risk weighting. This does not consider the differing erosion risks, with degraded peat more prone to erosion then restored peat (Li et al., 2018; Lunt et al., 2010). Peatland restoration helps slow the diffuse pollution continuum by reducing source, mobilisation and transfer risk. Further research into areas of peatland, both degraded and restored, is advised. A recommended approach is detailed in 5.6.1.

5.4. The Power of Disagreement

SCIMAP as a model is not designed to give absolute values of diffuse pollutants or consider management practices within land use areas. This is not necessarily a limitation, simply the trade-off of using a risk-based model for spatial targeting instead of a process-based model for absolute values.

While the above discussions raise a lot of uncertainty, both surrounding SCIMAP (as a catchment model) and expert agreement, this is incredibly useful. We learn most when models are wrong. This uncertainty should be acknowledged and further explored (Beven, 1996; Beven, 2007).

SCIMAP as a modelling tool created a collaboration on Arran, facilitating a discussion (around the proxy of fine sediment) that hadn't previously occurred and opening avenues of discussion and possible conflict resolution (Hodgson et al., 2021; Stosch et al., 2022a; Stosch et al., 2022b). It brought multiple viewpoints together to be assessed, as well as informing COAST on areas potentially most at risk to in-stream fine sediment pollution and subsequent degradation of water quality and bathing water status. While expert opinion may not have been entirely positive, their engagement reinforced the benefit of expert elicitation in debating SCIMAP outputs (Oliver et al., 2012; Reaney, 2014b) and inclusion in environmental management decisions, as promoted by the WFD (2000/60/EC). By disagreeing with model outputs, experts were able to suggest and guide recommendations and future research. This, by nature, is an interdisciplinary and ICM approach to water quality issues on Arran, favoured in current management (Lane et al., 2010; Stosch et al., 2019).

The 'best guess' provided by SCIMAP gives an educated starting point on where pollution pressures may occur throughout Arran. While experts may disagree with these predictions, the information provided by both the model and the experts provides guidance for mitigation measures and future research, preventing ineffective campaigns and allowing effective spatial targeting of areas most in need of research.

5.5. Limitations

5.5.1. Model Limitations

Catchment anomalies identified could be due to the 5m scale of DEM data used within the SCIMAP WebApp. It is possible either DEM data was not available at the required resolution at this point, or the DEM grid squares did not directly match up. These could be possible explanations for the anomalies in the stream networks, thus causing failed simulations.

While island-wide trends (such as the N/S divide) seem visually obvious, channel accumulated risk values are relative to each catchment. This does not completely devalue or disprove the observation but should be considered when drawing conclusions. This is a limitation of the SCIMAP framework but is transparently stated to users; it is the nature of the model. Users need to consider the trade-off between transparent limitations and the ability to involve a wider range of stakeholders due to simplicity.

Furthermore, data utilised by SCIMAP is somewhat outdated with DEM and LCM data from 2007 and average annual rainfall averaged over the 1980-2010 period. This could explain some of the disagreements between model outputs and experts as expert knowledge is from 2024.

5.5.2. Study Limitations

Calculated percentages of ‘high risk zones’ allowed some comparison between catchments. However, they were not statistically sound or significant so limited conclusions can be drawn from these values.

Experts put significant weighting on land use practice when considering fine sediment pollution. This could be due to the nature of their roles on Arran and current knowledge.

However this led to some difficulties when encouraging experts to consider alternative factors. It may have been useful to incorporate a wider range of interview questions to remind experts to view model outputs through the lens of fine sediment, allowing broader perspectives.

Additional discrepancy occurred when considering land use surrounding scale. LCM data in SCIMAP is at 25m scale, whereas expert predictions are likely to be between 1-5m. Alternatively, experts may have focused on this due to misunderstanding of the processes the SCIMAP model incorporates as well as minor miscommunications between experts and the interviewer surrounding model terminology. While experts were presented some information explaining the datasets and process that SCIMAP uses to generate channel accumulated risk predictions, the underpinning CSA concept was not presented.

5.6. Recommendations and Future Research

5.6.1. Modelling Recommendations

The main recommendation for this study is for modelling to be repeated but with adjusted risk weighting parameters for land use, reflective of Arran's land use activities. This would allow potential sources and transfers from activities occurring within land use classes to be considered. For example, areas of agriculture containing cattle could have their risk weightings increased compared to areas of agriculture containing crop cultivation. These Arran specific risk weightings could be determined through a more robust method of expert elicitation, allowing for a continuation of the collaborative mindset, ICM and interdisciplinary approach. However, this could cause potential conflicts between stakeholders as 'risk rating' disagreement of land use type could occur, especially surrounding areas of active forestry on Arran. To combat, a more formal robust framework to

determine these values would be required to consider stakeholder opinion as impartially as possible. This could be derived though probability density functions (Mzyece et al., 2024) through either the SHELF (O'Hagan and Oakley, 2022) or Cooke's (Colson and Cooke, 2018) frameworks (European Food Safety Authority, 2014). This could be combined with robust meta-analysis of existing studies and literature of fine sediment in each land use class. This methodology is recommended for areas of forestry on Arran as it would allow extensive examination of the impacts of forestry operations on fine sediment risk from a variety of perspectives.

Even with this extensive methodology, risk weightings would still be a 'best guess' of how land use management impacts risk weightings but gives a more detailed picture. This form of elicitation is incredibly time consuming. An evaluation between more specific risk weightings and the benefit of a first approximation 'best guess' needs to be assessed to determine if this method is beneficial. A survey approach, such as the Delphi method (Brown, 1968) could be considered but this may not provide the level of detail needed (European Food Safety Authority, 2014).

To develop this further, this study could be repeated using the SCIMAP 'Fitted' approach (Wells and Reaney, 2014) detailed in (Milledge et al., 2012). SCIMAP, as a tool, is most powerful when combined with the 'Fitted' approach (Porter, 2018). This approach would allow the spatial representation of source patterns within each individual catchment across varying land classes as well as facilitating the use of 'Correlation' and 'Uncertainty' features within the 'Observations' tab (Reaney, 2019). In a forestry context, fine sediment or water quality samples could be obtained before, during and after felling operations. Once inputted, these datasets could be run through 3 separate simulations and tested against the pre-defined risk weightings to see which stage of felling best matches this value. However, this methodology requires a spatial dataset of fine sediment concentration levels within

catchments across Arran that is distributed both spatially and temporally (Porter et al., 2017). This recommendation may be achievable as part of a larger scientific study or water sampling campaign but is not necessarily achievable by COAST.

Furthermore, the current study could be replicated at varying spatial and temporal scales, utilising alternative LCM, DEM and rainfall data available. This would facilitate more detailed and nuanced predictions of in-stream fine sediment pollution. This would be possible though the SCIMAP WebApp where datasets can be replaced with spatial extents provided by the WebApp to ensure data as at an appropriate scale and location for the selected catchment. Datasets could be replaced at varying spatial scales or by newer versions e.g. LCM 2023, providing more accurate temporal predictions. This approach is recommended for Glen Rosa, Machrie (catchment 22), areas of agriculture and areas of peatland. While this method is time consuming and requires a higher level of GIS knowledge (to correctly create, style and zip the required data), it could produce fruitful and beneficial results on specific problem areas and/or diffuse sources on Arran. This would allow COAST to examine these areas in more detail before targeting any mitigation or in field-sampling campaigns, conserving their limited resources.

5.6.2. Interview Recommendations

During interviews, experts sometimes put too much weighting on land management practices when discussing fine sediment patterns. If this study were to be repeated or adapted, the interviewer could guide the experts away from the topic of land use and foster other topics of conversation. Although study ethics must be considered to ensure experts are not being funnelled or coerced into a specific line of thought.

Furthermore, experts could have been presented information surrounding the CSA concept (the underpinning science of SCIMAP) and a glossary of key terms to aid both model output and interview question understanding. However this requires more in depth preparation for experts before interviews, which may not be possible based on the nature of their roles and subsequent availability. If this technique were to be utilised, the information presented would need to be succinct, easily understandable and accessible to streamline the process and prevent any disengagement from experts.

5.6.3. Recommendations for COAST

While COAST could utilise these modelling and expert recommendations, it is appreciated that they have limited time, money and resources making some the above unachievable. Therefore it is recommended that COAST focus on the land management lens of this study. Small scale water quality monitoring and subsequent evaluation of bathing water status could be focused in catchments within active forestry, agriculture and peatland as these were identified by both model outputs and experts (in varying degrees of agreement) and either most at risk to fine sediment pollution or warranting further investigation. This could be coupled with the previously detailed remodelling of catchment specific areas at varying spatial and temporal scales to build a picture of in-stream fine sediment risk on Arran through hydrological pathways and differing land activities. Discussions and stakeholder engagement surrounding this topic should continue to be fostered to promote an interdisciplinary and ICM approach to this problem, allowing the integration of varying hydrological, environmental and social viewpoints.

6. Conclusion

SCIMAP has given a best guess of areas on Arran most at risk of in stream fine sediment pollution. These predictions were then verified with varying levels of expert agreement. While predictions from either model outputs or experts may not be entirely accurate, they give a general idea of areas warranting further research. Areas of active forestry, agriculture and peatland were identified as areas of interest through both model outputs and expert elicitations.

To utilise COAST's resources effectively, small scale water sampling campaigns in these land use areas of interest are advised. This could be coupled with a more detailed modelling exercise of specific priority catchments of interest to synthesise risks to in-stream fine sediment risk on Arran from both hydrological and anthropogenic activities.

The discussion surrounding fine sediment pressures and pollution on Arran should continue to promote an interdisciplinary and ICM approach across the island, preventing the reliance on one particular method. Stakeholders should remain a key part of this process, allowing any future research or management strategies to holistically encompass the environmental and sociopolitical situation on Arran. This open communication, paired with a multi-method approach appreciates differing viewpoints, while providing the opportunity for conflict resolution between stakeholders, model outputs and hydrological processes.

7. Appendix

A1: Additional Datasets

A1.1 Additional datasets utilised, their styling and citations

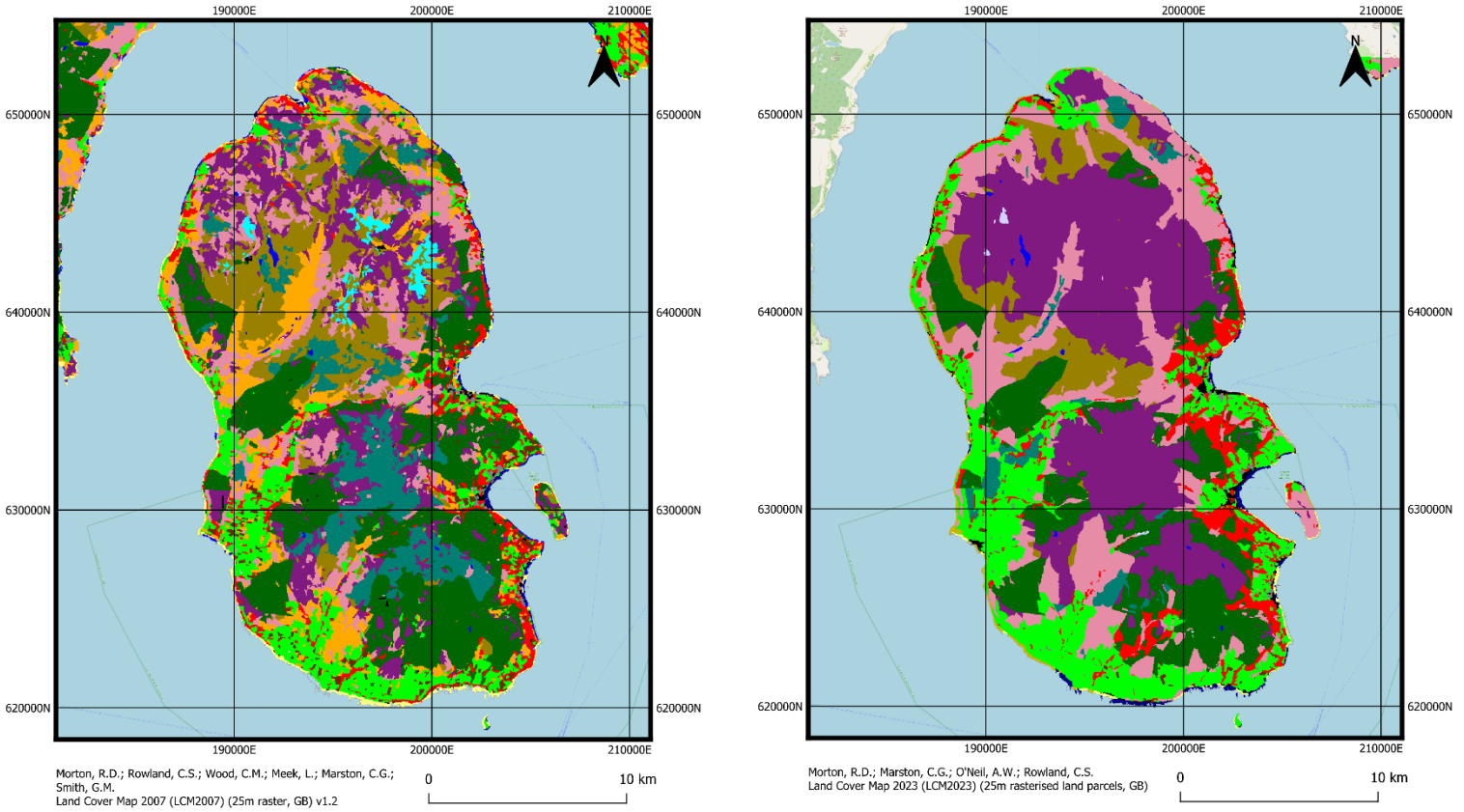
Dataset Name	Data Details	File Type	Available At	Citation	Attributes Used	Geoprocessing Process	Styling
Counties and Unitary Authorities (December 2023) Boundaries UK BFE	Arran Boundary	GPKG	Counties and Unitary Authorities (December 2023) Boundaries UK BFE - data.gov.uk	Office for National Statistics (2023). [online] Data.gov.uk.	CTYUA_DEC_2023_UK_BFE	'Select Features by Polygon'	No fill, black outline
BGS Geology 50K	Geology	ESRI Shapefile	Digimap Under the Geology Digimap Educational User Licence or Datasets - British Geological Survey	DiGMapGB-50 [SHAPE geospatial data], Scale 1:50000, Tiles: sc013_021. Updated: 30 November 2016, BGS, Using: EDINA Geology Digimap Service.	sc013_021_arran_superficial	Clipped by Arran boundary	sc013_021_arran_superficial.lyr Using the SLYR (community edition) Plugin
LCM 2007	Land Cover Class	GeoTiff	https://doi.org/10.5285/a1f88807-4826-44bc-994d-a902da5119c2	Morton, R.D.; Rowland, C.S.; Wood, C.M.; Meek, L.; Marston, C.G.; Smith, G.M. (2014). Land Cover Map 2007 (25m raster, GB) v1.2. NERC Environmental Information Data Centre.	25m Raster	Clipped by Arran boundary	Band 1, palleted/unique values styled with: LCMcolours_QGIS (.qml) or LCMcolours_QGIS_cb_friendly (.qml)
LCM 2023	Land Cover Class	GeoTiff	https://doi.org/10.5285/ab10ea4a-1788-4d25-a6df-f1aff829dfff	Morton, R.D.; Marston, C.G.; O'Neil, A.W.; Rowland, C.S. (2024). Land Cover Map 2023 (25m rasterised land parcels, GB). NERC EDS Environmental Information Data Centre.	25 m Rasterised Land Parcel Product	Clipped by Arran boundary	Band 1, palleted/unique values styled with: LCMcolours_QGIS (.qml) or LCMcolours_QGIS_cb_friendly (.qml)

A.1.2. LCM class map legends for 2007 (left) and 2023 (right).

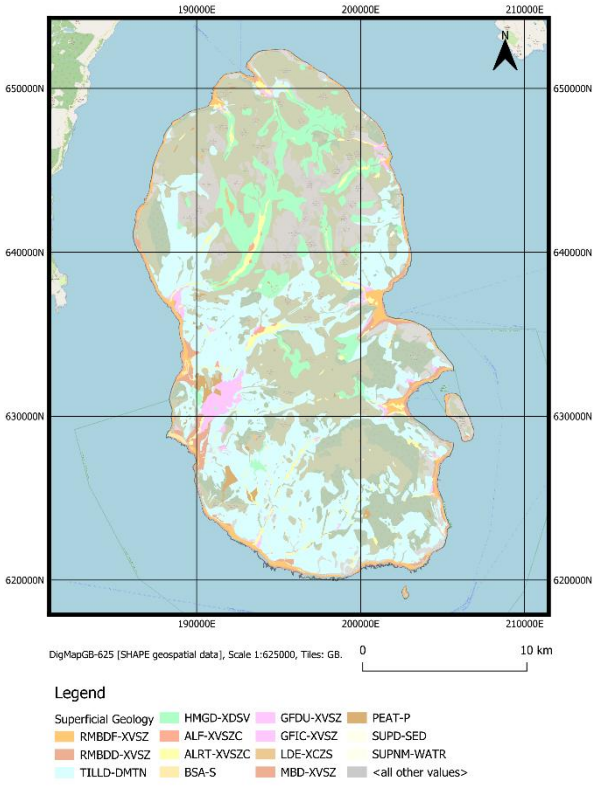
LCM2007 class	LCM2007class number
Broadleaved woodland	1
'Coniferous Woodland'	2
'Arable and Horticulture'	3
'Improved Grassland'	4
Rough grassland	5
'Neutral Grassland'	6
'Calcareous Grassland'	7
Acid grassland	8
'Fen, Marsh and Swamp'	9
Heather	10
Heather grassland	11
'Bog'	12
'Montane Habitats'	13
'Inland Rock'	14
Saltwater	15
Freshwater	16
'Supra-littoral Rock'	17
'Supra-littoral Sediment'	18
'Littoral Rock'	19
Littoral sediment	20
Saltmarsh	21
Urban	22
Suburban	23

UKCEH Land Cover Class	UKCEH Land Cover Class number
Broadleaved woodland	1
Coniferous Woodland	2
Arable and Horticulture	3
Improved Grassland	4
Neutral Grassland	5
Calcareous Grassland	6
Acid grassland	7
Fen, Marsh and Swamp	8
Heather	9
Heather grassland	10
Bog	11
Inland Rock	12
Saltwater	13
Freshwater	14
Supralittoral Rock	15
Supralittoral Sediment	16
Littoral Rock	17
Littoral sediment	18
Saltmarsh	19
Urban	20
Suburban	21

A.1.3. LCM cover maps for Arran from 2007 (left) and 2023 (right).



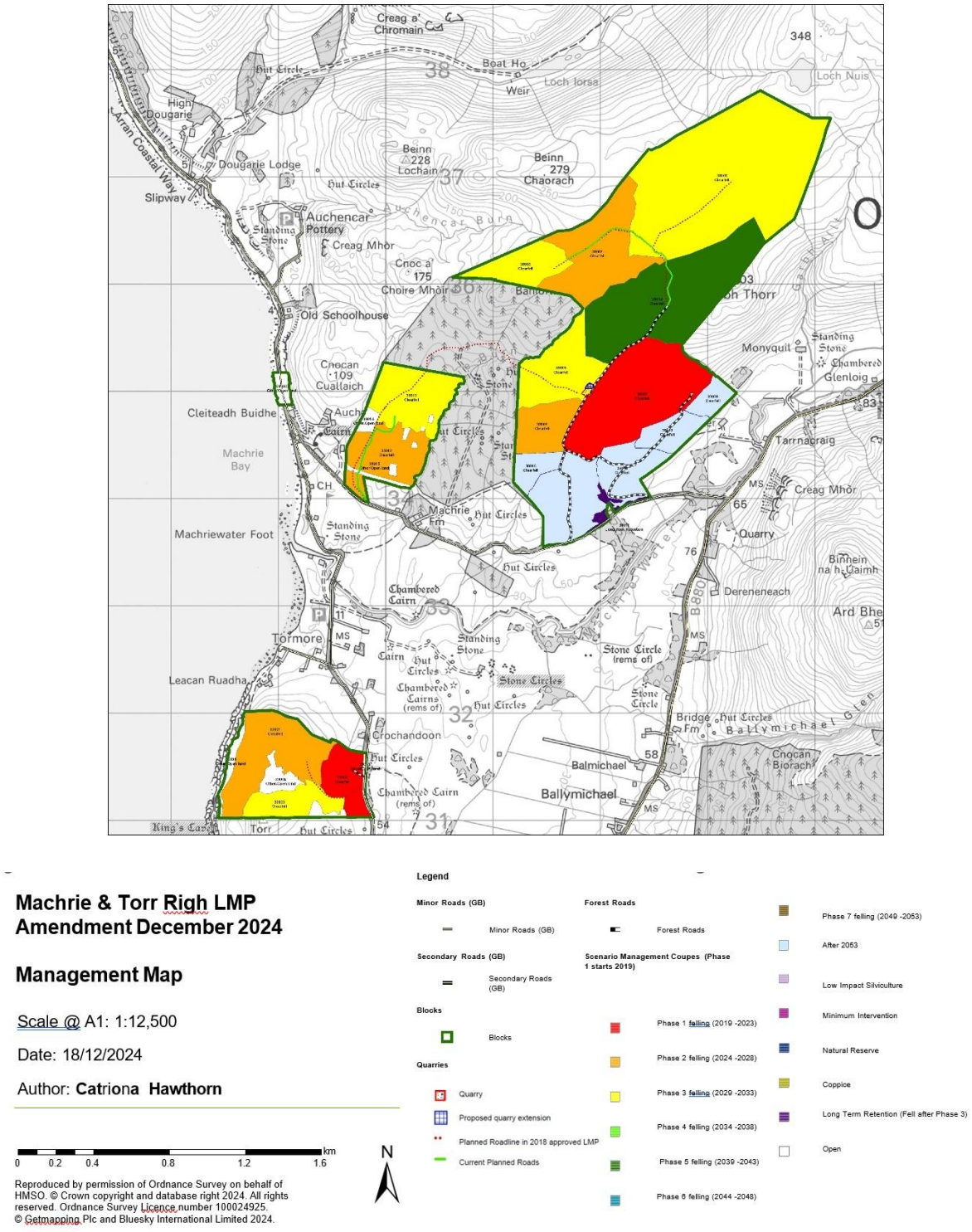
A.1.4. Superficial geology on Arran. LEX_RCS codes are searchable at https://www.bgs.ac.uk/technologies/bgs-rock-classification-scheme/



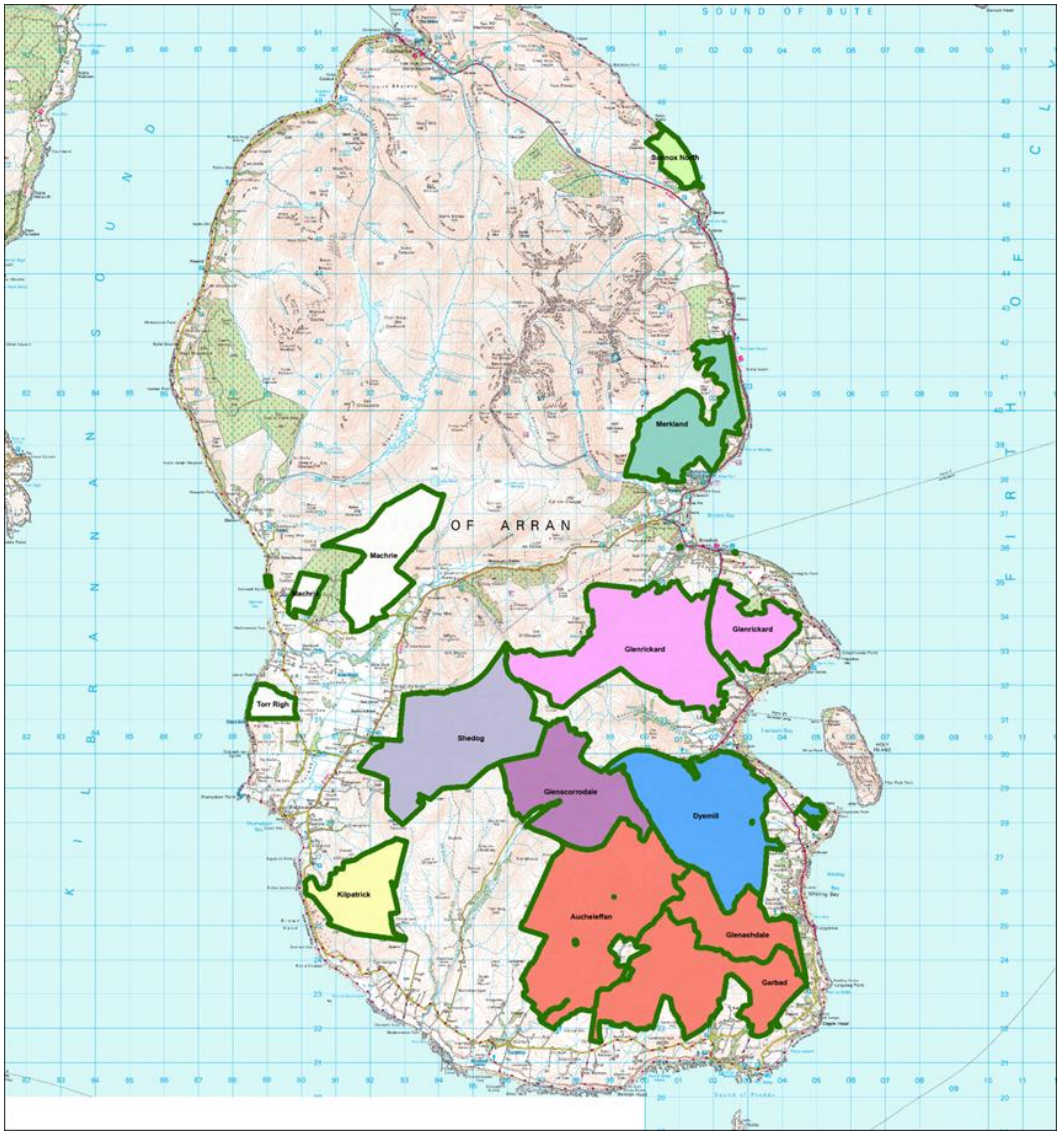
A2: Forestry Documents

All material from FLS was acquired through a freedom of information request. Permission was granted for these documents to be used in this study.

A.2.1. Felling map from the Machrie and Torr Righ LMP (FLS, 2025).



A.2.2. LMPs and their location on Arran (FLS, 2025).



8. Supplementary Information (S1)

Supplementary information for this study including can be found at the following link:

Sophie_Dennis_Supplementary_Information_(S1)

All material from FLS was acquired through a freedom of information request. Permission was granted for these documents to be used in this study. There are two management plans unable to be published due to being unapproved and under consultation. These are North Sannox and Glenrickard, however no significant felling is proposed in either plan.

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