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Assessing the impact of forestry on water quality in Scotland: A review of modelling capabilities

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Project Aims

This study aims to evaluate current evidence of impact of forestry on water quality and identify the modelling needs of stakeholders for assessing the impact of forestry on water quality in Scotland. By understanding these needs, the study sought to ensure that the models used are relevant and effective in addressing the specific concerns and requirements of those involved in forest management and environmental protection.

The project objectives were:

1. To evaluate current evidence on the impacts of commercial forestry activities on water quality and identify high risk parameters and conditions where commercial forestry activities could adversely impact water quality.
2. To determine the modelling needs of stakeholders for assessing the impact of commercial forestry operations on water quality in Scotland.
3. To review relevant literature on hydrological modelling tools used to assess commercial forestry operations.
4. To evaluate the suitability of available hydrological models based on water quality and key criteria such as development purpose, model design and structure, processes, accessibility, usage, support, and data.

Background

Forests play a critical role in global hydrological, nutrient, and carbon cycles, influencing water dynamics, runoff generation, groundwater recharge, and water transport to rivers and lakes. They are also key in carbon exchange between the atmosphere and terrestrial biosphere, holding about 80% of global aboveground biomass and offering crucial opportunities for soil carbon sequestration and storage in standing biomass and wood products. Consequently, changes in forest ecosystems, such as felling, restocking, wildfires, and pest infestations, can significantly impact water quality and aquatic carbon fluxes. There is a real concern that, although impacts are often localised, the additional impact contribution from forestry could magnify existing pollutant contribution from other non-forestry (e.g., agriculture) sources.

Concern about the effects of commercial forestry on water quality is a persistent issue in managing water catchments in Scotland. Over the past few decades, forest management practices have significantly shifted towards reducing environmental impacts. These efforts are guided by standards like the UK Woodland Assurance Standard and the UK Forestry Standard (UKWAS and UKFS, 2023), which are independent certifications verifying sustainable forest management in Britain. Although there are detailed practical field guides based on these standards to help foresters plan operations considering water discharge levels and quality, the risk of operational errors remains. Therefore, it is crucial to identify when these instances occur.

Forestry operations impacting water quality can have significant off-site effects if practices are non-compliant. The main risks of diffuse pollution from forestry are linked to nutrient, sediment, and carbon input to rivers and lakes. This may result in increased risks to aquatic habitats and drinking water abstractions. This can come from fertilizers used during tree planting or soil disruption when planting or felling trees, leading to increased algal growth in lochs, reducing light and oxygen levels, and harming aquatic ecosystems. Other forestry practices such as cultivation, drainage, and road construction can also affect water quality.

Although many negative effects associated with forest harvesting can be significantly reduced by using low-impact harvesting systems now widely adopted internationally in commercial forestry, it is essential to evaluate, monitor, and predict changes in forest water quality due to commercial forestry practices. This study thus aimed to describe current evidence regarding forestry's impact on water quality and to identify the modelling research needed to support environmental decision-making in management practices to improve forest water quality. Hydrological models can estimate environmental impacts, but results have been inconsistent due to a lack of appropriate models and data to evaluate forestry activities for planning.

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To access the outputs for this project, please visit: crew.ac.uk/publications/assessing-impact-forestry-water-quality

Improving modelling approaches is therefore crucial for understanding and predicting risks to water quality so that management plans and mitigation strategies can be improved.

This was achieved by examining available models and considering necessary inputs for forest water quality and related watershed forest management practices. We identified critical water quality parameters in forest environments, such as dissolved organic carbon (DOC), sediment, and carbon. We assessed the models' capability to predict outcomes based on diverse management practices, encompassing factors influencing forest hydrology (e.g., land use, soil properties) and specific forest operations (e.g., planting, logging). This evaluation aimed to understand the data requirements necessary to represent these factors accurately as inputs. Finally, we examined each model's potential for scaling up to assess impacts at larger catchment or watershed scales, ensuring their suitability for comprehensive environmental assessments across broader geographical areas.

Key findings

Although localised impacts can be profound, generalising impacts on different aspects of water quality from commercial forestry operations can be extremely challenging due to the large number of site-specific parameters and characteristics (for example, soil type, slope, precipitation levels following the activity etc.), that may interact and have a significant influence on the results. From the evidence available from primary literature, the impacts forest management activities on water quality tend to range from no significant impact to moderate levels. A review of over 1,700 papers identified 46 potential models that could be applied to assess water quality negative impacts from forestry. However, none of these models produced outputs that coupled forestry activities with key water quality parameters such as dissolved organic carbon (DOC), sediment, and carbon. Only four models considered both forest operations and forest hydrology impacts, but they lacked water quality outputs. Existing models also do not integrate small-scale point-source impacts typical of forestry to assess larger-scale risks. Despite these limitations, there is potential to develop a forestry water quality model for Scotland based on existing models, although challenges related to data requirements versus availability remain, as well as uncertainties on applicability of models across locations.

In assessing water quality impacts the following aspects need to be considered:

1. Forestry practices and compliance
2. Site specific risk factors (slope, soil type, rainfall)
3. Presence of sensitive receptors (naturally low nutrient waterbodies, habitats and drinking water supplies)
4. Pathways to sensitive receptors (drains, watercourses, run-off).

Conclusions and recommendations

Models are crucial tools in forest watershed management, addressing issues such as water supply, water quality, carbon sequestration, and biodiversity. They simulate physical systems using a set of equations or algorithms, tailored to specific technical problems by either applying existing models, modifying them, or developing new site-specific models. Effective models aid in decision-making and evaluating options, illustrating the dynamics of watersheds and waterbodies like lakes, rivers, and estuaries. Despite their long-standing use in environmental management, developing accurate models remains challenging due to practical and technical limitations. Current models often lack integration of forest management practices with water quality assessments, highlighting a significant gap in addressing the nexus between forest management and water quality. This comprehensive review identified potential models and underscored the need for models that can simulate the impacts of forestry operations on sensitive habitats and private water supplies, focusing on sediment and nutrient dynamics. With regards to forestry operational and compliance purposes the current process is deemed sufficient for identifying site level high risk area to inform mitigation. It should be noted that Forest Research expressed during the workshop that it does not think a water quality model is needed or useful, partly because considerable empirical data is available on the effects of forestry on water quality, but also due to the compounded uncertainties associated with a water quality model.

Nevertheless, SEPA feels there is a need for a modelling approach that allows SEPA to assess the contribution of forestry to wider scale water quality. The project team have restated that during the initial project proposal SEPA set out why a model would be useful: to include in source apportionment models which currently do not include forestry inputs, and to help identify potential areas at greatest risk from forestry to target audits. The project found that a quantitative model is not currently available and although potentially challenging to develop due to uncertainties, it should still be considered if uncertainties can be overcome. A qualitative risk model however could probably be developed more readily based on site specific risk factors and could help SEPA target audits. The main recommendations are addressed as follows:

- The deficit in available models and long-term comprehensive data tailored for assessing the impacts of commercial forestry on water quality limits the capacity to mitigate risk.
- Decision-making processes concerning forestry practices and land use planning should be driven by an understanding of the vital role of factors like soil type, slope, and precipitation in determining forest water quality. Current UKFS Guidelines and associated Guidance have been developed by considering such factors.
- Prioritising key activities such as watershed forest management, forest road networks, and harvest operations in future modelling efforts is crucial.
- Supporting the integration of both forestry activities and forest hydrology as inputs in modelling endeavours will lead to a better understanding of forest water quality dynamics and support informed decision-making.
- A better understanding of forest water quality dynamics will support informed decision-making by practitioners in Scotland. As a first step, a qualitative risk-based model should be developed, that would allow for the identification of high-risk areas and scenarios. Subsequently, a quantitative model, supported by long-term data, is ultimately needed in assessing these impacts and risks adequately.
- To develop a high-level model to qualitatively identify areas of high risk, it is possible that sufficient data and expert knowledge already exists. It is recommended that such a model is developed to provide a workable tool for stakeholders until a more robust quantitative model can be developed.