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The Effect of Riparian Woodland Cover on Ecosystem Service Provision from Small Streams along the Oslofjord

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Lastly, I want to thank my family for their continued support and encouragement throughout my studies.

This thesis has deepened my belief in the vital connection between people and the rest of nature. I hope this work contributes, in some small way, to fostering greater recognition of this connection and thoughtful ways of valuing the ecosystems on which we all depend.

Robin Renz

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Abstract

This study quantifies the benefits of ecosystem services provided by three small streams and their riparian corridors discharging into the Oslofjord and models three alternative management scenarios to test the impact of land-use changes. An analytical cascade framework was applied, using publicly available land-use data and stream morphology in GIS and monetary proxies to monetarily estimate 13 services. The estimated annual sums of ecosystem services per hectare ranged from NOK 2327 to NOK 3609, with cultural and provisioning services contributing most. Forest cover was the strongest driver, with forest-based services contributing up to 65%. The *"Biodiversity first"* scenario yielded the highest summed value estimates per hectare, while *"Production first"* caused a decline. The intermediate scenario, *"Ambitious Oslofjord plan implementation"*, with increased protection and restoration of riparian woody buffers, led to a moderate increase in summed value. The results support the contention that riparian woodland cover is a key landscape element for maintaining functional riparian zones and ecosystem service capacity. The findings are an argument for the inclusion of riparian zones in landscape planning and ecosystem accounting, and the study offers a replicable method for local and regional ecosystem service valuation in Norway.

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Abbreviations

AR5	Arealressurskart AR5
CICES	Common International Classification of Ecosystem Services
DBCA	Department of Biodiversity, Conservation and Attractions
EPSG	European Petroleum Survey Group
ESS	Ecosystem Service(s)
FTEM	Forest Trends' Ecosystem Marketplace
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
MEA	Millennium Ecosystem Assessment
MINA	Faculty of Environmental Sciences and Natural Resource Management
NCP	Nature's Contributions to People
NGO	Non-Governmental Organisation
NIBIO	Norwegian Institute of Bioeconomy Research
NVE	Norwegian Water Resources and Energy Directorate
PEFC	Programme for the Endorsement of Forest Certification Schemes
QGIS	Quantum Geographic Information System
S1	Scenario 1 "Production first"
S2	Scenario 2 "Ambitious Oslofjord plan implementation"
S3	Scenario 3 "Biodiversity first"
SSB	Statistics Norway
SSP	Shared Socioeconomic Pathway(s)
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
US EPA	United States Environmental Protection Agency

1 Introduction

Norway's ecosystems are under pressure, and attention has been brought to the build-down of nature, which often happens in small quantities but adds up to a significant area in total (Breidenbach et al., 2017). The conversion from forested areas to agricultural land (including pastures) accounts for almost a third of the total forest conversion in Norway (ibid.). Public attention and media articles increasingly voice concern over ecosystems facing challenges due to human development, with the Oslofjord being one of the most prominent examples in Norway (Fiksdal, 2024). The public and scientific community attest a concerning ecological state to one of the most inhabited regions in Norway, the Oslofjord and have put ecosystem protection on the political agenda (Frigstad et al., 2024; Ministry of Climate and Environment, 2021).

However, there is currently a lack of tools and knowledge to estimate trade-offs between landscape development and the capacity of ecosystems to provide us with the essential goods and services that we depend on every day (Norwegian Environmental Agency, 2022). The Norwegian Environmental Agency has planned to develop a national ecosystem service accounting system to better understand the current state of ecosystem services and their benefit to the Norwegian population (ibid.). As of today, such a system and its necessary information are lacking at all decision-making levels, and planners, stakeholder representatives and interested NGOs are often confronted with decision-making processes which ignore several services and values that functioning ecosystems provide.

Streams are one of the ecosystems that impact our landscape and the Oslofjord in numerous ways, including serving as spawning habitats for fish, influencing water quality, and material transport. Riparian vegetation is shown to be an integral part of the stream ecosystem (Sweeney & Newbold, 2014), yet it competes for space against agriculture developed in the fertile floodplains of lowland streams. This conflict is also discussed in Norwegian media (Aasdalen, 2025), debating whether the Oslofjord should be protected against nutrient runoff through increased redevelopment of riparian vegetation along its streams, or if food production from agriculture is more critical.

While agricultural land produces tangible benefits, which are easily quantifiable in monetary terms (e.g. value of agricultural yield), the value of streams and riparian vegetation is less tangible, and the quantity of benefits provided is often unknown. This knowledge imbalance makes it necessary to assess the Total Economic Value (TEV) of all ecosystem services provided by different land-use forms in the landscape. This could serve as a better basis for decision-making, weighing in all the benefits that humans utilise from a landscape and its various ecosystems.

The assessment of ecosystem services (ESS) has been done in several studies in Europe for riparian vegetation on a catchment or floodplain scale (Immerzeel et al., 2023; Immerzeel et al., 2021; Vermaat et al., 2020; Vermaat et al., 2021). This earlier work showed that publicly available data could be used to estimate the ESS of riparian zones and found that forest cover, stream morphology and population density were important factors for ESS provision. Earlier scenario assessments found that humans as landscape stewards have a clear impact on how ESS provision could change depending on landscape management and other socio-economic changes (Immerzeel et al., 2023; Vermaat et al., 2020; Vermaat et al., 2021). This study aims to apply a similar ESS framework at the local scale of three streams in the Oslofjord to assess how different land-use categories and ESS contribute to the TEV. The second objective is to create potential scenarios for alternative forms of land management in the riparian zones and to investigate how they could influence different ESS and their summed TEV. Currently, this is the first study to apply the ESS framework to riparian zones in the Oslofjord.

Based on the main objectives of this study, the following research questions have been formulated:

1. How do the studied streams differ in ESS contribution to TEV in relation to the land use of their riparian zones?

2. To what extent does riparian woodland cover contribute to the relative importance of final services?

3. How do different land-use scenarios alter the TEV and composition of ESS?

The initial hypotheses for the three research questions are:

I. The relative importance of final ESS contributing to TEV depends on the land use of their riparian zones.

II. Riparian woodland cover is the major driver of ESS provision in the riparian zone.

III. Future policy and different land-use scenarios change the TEV and economic importance of different ESS in the riparian zone.

2 Background and Theory

2.1 The Riparian Zone

The basis for any spatial analysis is the definition of what area exactly is to be analysed. In the case of the study objective – studying the riparian zones of various streams discharging into the Oslofjord – one must answer what a riparian zone is. Defining the riparian zone is not straightforward, and definitions might vary significantly (National Research Council, 2002; Verry et al., 2004). In the functional and theoretical context, the approach by the National Research Council (2002, p. 33) is used in this thesis:

> *"Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect waterbodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence)."*

The emphasis on "influence" and exchanges between the terrestrial and aquatic ecosystems also corresponds with an Australian management interpretation (Department of Biodiversity, Conservation and Attractions [DBCA], 2000). When it comes to structural components of the landscape, the DBCA (2000) states that the riparian zone includes "the immediate vicinity of the stream, which consists of the bed, banks and adjacent land, as well as the floodplain, which carries large floods" (p. 1).

To operationalise the above-mentioned definitions and properties of the riparian zone, this thesis defines the riparian zone spatially as a zone of a minimum of 30 m from the stream's channel (as immediate vicinity) plus the flood-prone area of the stream. This demarcation of a spatial analysis is also in line with Vermaat et al. (2021), who studied the effect of riparian woodland on ESS provision in European streams.

The riparian zone serves many functions in the interplay between the aquatic stream ecosystem and the adjacent terrestrial ecosystems of the valley floor and its nearby higher grounds. Primary functions include the maintenance of habitats and food web integrity, the uptake and cycling of nutrients and the transport and accumulation of sediments (National Research Council, 2002). For the woodland cover in a riparian zone, also referred to as "woody buffer strips" or "streamside forest buffer" (Sweeney & Newbold, 2014; Vermaat et al., 2021), several assessments have identified and quantified direct benefits to society from various functions of intact riparian woodland (Kail et al., 2022; Sweeney & Newbold, 2014; Vermaat et al., 2021). Such ecological benefits can be water quality enhancement through nutrient retention, protection against erosion and sediments, and temperature regulation through shading and function as a habitat (Sweeney & Newbold, 2014). In this thesis, the term “woody buffer strips” includes the forest cover in the above-defined riparian zone (30 m buffer around stream + flood-prone area). Kail et al. (2022) divide the ecological functions of woody buffer strips into retention, shadowing, delivery of organic matter and habitat functions. Still, the existence of trees themselves also has functions not directly associated with the adjacent area, like carbon sequestration to mitigate global climate change. Since some of these functions vary and are highly dependent on local stream and landscape properties (Sweeney & Newbold, 2014), the scale and trade-offs of such benefits in the landscape need to be studied on a stream level, which has not occurred in the Oslofjord area yet. An overview of all identified functions and corresponding ESS for the local context of this study is provided in Chapter 4.

2.2 Ecosystem Service Evaluation Framework

The concept of ESS first gained vast global attention after the historical publication by Costanza et al. (1997), being mainstreamed by the Millennium Ecosystem Assessment (MEA, 2005). This has defined ESS as the services or values that nature provides us directly or indirectly through the ESS categories “provisioning”, “regulating”, “cultural”, and “supporting”. This concept has since come a long way and has been adjusted while gaining traction in political decision-making (Gómez-Baggethun et al., 2010; IPBES, 2019). The framework's core refers to valuing nature in a (often monetary) way to inform decision-making better and shine a light on the fact that some aspects of nature and its ecosystems are not yet well included in most of society’s decision-making and spatial planning. This can be metaphorically expressed as: “Nature does not send us a bill, but destroying ecosystem functions might result in us having to bear high costs”. For example, streams flood and destroy infrastructure because of the altered morphology by humans. The stream morphology provided flood protection in its original state, an ESS that humanity did not pay for in the first place. From an evaluation perspective, this concept was further operationalised to calculate the monetary values of specific ecosystems and natural capital on a national and global scale (Bateman et al., 2011; TEEB, 2010).

The scientific community also criticises the economic evaluation of ecosystems and nature, mainly for its anthropocentric perspective on nature as a “service provider”, the bias of the Western knowledge system and the potential to commodify nature (Gómez-Baggethun & Muradian, 2015; Muradian & Gómez-Baggethun, 2021). The critique against the original ESS approach has led to further development of the concept of Nature's Contributions to People (NCP) (Díaz et al., 2018). This development marks a rift within the scientific community, and the concepts of ESS and NCP continue to be debated (Braat, 2018; Costanza, 2024; Farley et al., 2024; Kenter, 2018).

However, this thesis applies the ESS framework because it presents a quantifiable and relevant approach for policymakers (Norwegian Environmental Agency, 2022) that can be applied to publicly available data. It is understood that monetary evaluation cannot put an accurate value on ecosystems, but instead gives policymakers an indication and compares alternative land-use scenarios. Thus, the scope of this thesis is not to achieve an accurate market-similar pricing of every individual ecosystem function but rather to reasonably approximate the final benefit they provide to society (some of them without being noticed or considered if such estimations were not made).

The Common International Classification of Ecosystem Services (CICES) provides an extensive list of ESS used in this thesis to categorise service flows to final services (Haines-Young, R., Potschin, M.B., 2018). This has been done in the context of river restoration (Vermaat et al., 2016) or evaluation of ESS in the catchment or riparian zone (Immerzeel et al., 2023; Immerzeel et al., 2021; Vermaat et al., 2020; Vermaat et al., 2021). The challenge for land-use-based ESS evaluations is to lead from specific landscape and stream features to final quantifiable service values that constitute the social benefit of the specific ESS. This has been attempted by adopting an ESS cascade model to structure the value generation of ESS (Boerema et al., 2017; Mononen et al., 2016).

The cascade adopted by Mononen et al. (2016) and developed by Haines-Young and Potschin (2012) includes four initial steps from biophysical structures to societal value. The cascade is divided into the steps of structure, function, benefit and values. The ecosystem structure entails the biophysical properties that make the ecosystem function (Mononen et al., 2016). This can be expressed as the spatial perspective. The ecosystem function describes what is needed to produce the ESS, and this was also coined as the ESS supply (Boerema et al., 2017). An example of a function can be the production of berries (function) in a forest (structure). Transitioning to the socio-economic system, the next step is the benefits provided to humans by the ecosystem. Mononen et al. (2016) describe benefits as the share of the potential ESS that is utilised. At the last step of the cascade stands the value. These can be economic, social, related to health or intrinsic values (Mononen et al., 2016). For berry picking, values could mean the market value of harvested blueberries or the recreational value of picking them.

Vermaat et al. (2020) and Vermaat et al. (2021) introduced the concept of merging function and benefit to measurable services in biophysical flows, keeping the function implicit. This is, according to Vermaat et al. (2020, 2021), because these functions are required for the final benefit to be generated and therefore not measured separately. An overview of the ESS cascade is given in Figure 1. This thesis aims to adopt a similar cascade approach in the local context, focusing on the final provided ESS, which excludes “supporting services” or “intermediate services” to avoid double counting as these are interpreted as functions determining the capacity of the ecosystem to deliver the final ESS (Haines-Young, R., Potschin, M.B., 2018, p. 4).

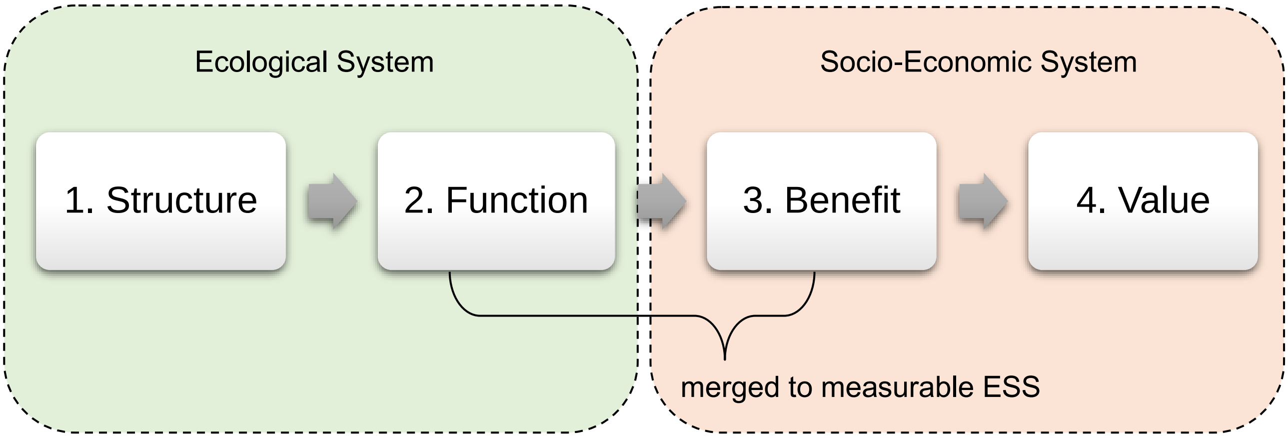

Figure 1. Ecosystem Service Cascade based on Mononen et al. (2016), Boerema et al. (2017) and Vermaat et al. (2020,2021)

2.3 Policy Situation in the Oslofjord Area and Potential Scenarios

Several laws and different local and national authorities manage and address streams and their riparian vegetation in Norway (Norwegian Water Resources and Energy Directorate [NVE], 2021). While the Planning and Building Act acknowledges a 100-meter zone along streams and lakes, which is of special interest for nature, culture, and outdoor activities, it does not give specific instructions for protecting riparian woody vegetation. The Land Act, on the other hand, protects streams with yearly regulatory runoff in the sense that a minimum of 6 meters of vegetation must be guaranteed when new fields or pastures are established along streams (NVE, 2021). However, this mainly includes grassland and is already currently subject to subsidies from the county governor in the Oslofjord region. A rate of NOK 20 per meter grassland buffer between agriculture and a stream, with the grassland having a minimum width of eight meters, is currently subsidised (County Governor, 2025, p. 23).

The Water Resource Act §11 in Norway focuses more on the ecological function of riparian vegetation buffers and states that “along the banks of watercourses with year-round water flow […] a limited natural vegetation buffer shall be maintained to counteract runoff and provide habitat for plants and animals [translated]” (Vannressursloven, 2001). There is no further explanation on the width or composition of the riparian buffer, and the municipalities are responsible for determining an adequate buffer regulation for their territory. The Norwegian PEFC forest standard defines a riparian vegetation buffer for streams over one meter in width or year-round water flow as a 10 m to 15 m wide zone without active management and wild growth (Bjørnstad, 2024).

Access to nature and the streams investigated in this thesis is usually free for everyone, as described in the Outdoor Recreation Act (Friluftsloven, 1957), but limitations for specific forms of usage, like hunting and fishing, may apply (Forskrift om fiske etter anadrome laksefisk i vassdrag, 2021)

The Oslofjord and its streams have gained increasing public attention in the last decade due to the alarming condition of the fjord (Fiksdal, 2024; Frigstad et al., 2024). The "Oslofjord plan" is the latest coordinated policy aiming to manage the Oslofjord better, including land use, pollution and stream health. It will potentially change the current management regime (Ministry of Climate and Environment, 2021). The Oslofjord plan aims to specifically address seven focus areas in the fjord, which are (translated):

1. Reduce discharges from municipal wastewater and sewage in scattered settlements
2. Reduce runoff from agriculture
3. Reduce inputs of environmental toxins and marine litter
4. Protect vulnerable species, selected habitat types, and cultural heritage sites
5. Restoration of natural values
6. Measures to Promote Active Outdoor Recreation
7. Cross-cutting Measures for a Holistic Management of the Oslofjord

The most relevant focus area for establishing scenarios on how land use regarding streams and riparian vegetation could change in the Oslofjord is focus area 2. Several recommendations within focus area 2 are concentrated on riparian buffer strips and recommend implementing stricter enforcement of environmental protection laws regarding riparian buffers, increased restoration and protection of riparian zones (Ministry of Climate and Environment, 2021, p. 19).

The scenarios developed in this thesis aim to portray possible management alternatives in the future and will, therefore, include considerations from the Oslofjord plan. Other studies have also adopted locally adapted Shared Socioeconomic Pathway (SSP) scenarios (O'Neill et al., 2017) for the effect of land-use change in ESS studies of rivers (Vermaat et al., 2020; Vermaat et al., 2021).

3 Study Area

The wider marine and geological background of the investigated streams is the Oslofjord. The Oslofjord is approximately 100 km long and reaches from the Skagerrak arm of the North Sea into the Norwegian capital, Oslo. It is the most populated fjord in Norway, and approximately 1.6 million people live in the municipalities adjacent to the Oslofjord as of 2024 (Thorsnæs & Halleraker, 2024). The Oslofjord is divided into several parts, and the main parts are (from north to south) the inner Oslofjord (adjacent to Oslo), the middle Oslofjord (beginning at Drøbak) and the outer Oslofjord (beginning around Larkollen, Saltkopp) (Frigstad et al., 2024). Three small streams (first to third Strahler order) were sampled according to the criteria outlined below and serve as case study streams for this thesis. All three discharge into the middle Oslofjord and flow through forested and agricultural land (Figure 2). The streams are Odalsbekken (Frogn municipality, mouth: 59°38'N, 10°38'E), Solbergbekken (Vestby municipality, mouth: 59°36'N, 10°39'E) and Knattvollbekken (Akershus municipality, mouth: 59°31'N, 10°28'E). Odalsbekken is the stream with the largest population in the vicinity since it is close to the peri-urban edge of Drøbak, while Knattvollbekken and Solbergbekken flow through less populated areas.

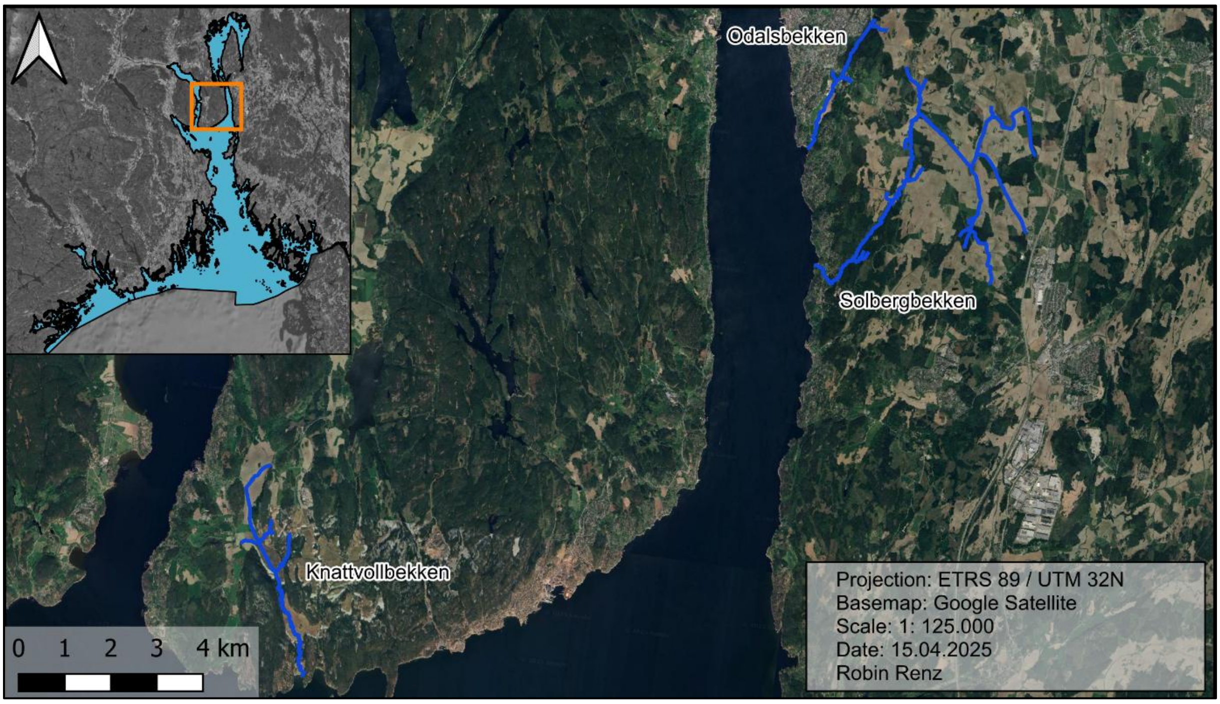

Figure 2. The Oslofjord (upper left) and the study area with the investigated streams (Data source for the Oslofjord: Norwegian Environment Agency, 2010.)

All three streams had to fulfil the following requirements to be included in this study: (1) low Strahler order of 1–3, (2) direct discharge into the Oslofjord, (3) no disturbance from other large water bodies within the stream (4) encompass different land-use forms, including agriculture and forest.

4 Methodology

4.1 General Approach

To operationalise the frameworks and theoretical background outlined in Chapter 2, this study is based on a five-step process (Fig.3). The first methodological step consists of the gathering of raw data in the form of publicly available datasets to create a riparian buffer zone around the streams and calculate the land use of these areas. This happened in the second step, the spatial analysis of the sampled riparian zones. Steps 1 and 2 of Figure 3 quantify the ESS structure from the ESS cascade concept (section 2.2). The next step was the identification and classification of ESS into the CICES framework and an assessment of monetary valuation approaches that could be applied (step 3 in Figure 3 and the function/benefit, value components from the ESS cascade). This was done spreadsheet-based, and the final delivery value of every ESS was estimated as the product of land use (ha), a biophysical flow (e.g. kg ha^{-1} yr^{-1}) and a monetary value estimate (e.g. NOK kg^{-1}). The TEV is the sum of all ESS value estimates in a stream (NOK yr^{-1}, NOK ha^{-1} yr^{-1}). The final step of the methodology involved a scenario analysis, where different fictitious but plausible management alternatives were simulated as changes in land use to assess how the contribution of riparian woodland to the TEV may potentially change with future landscape development. A simplified workflow is depicted in Figure 3. In addition to the main steps, a partial sensitivity analysis was performed on selected parameters to highlight their impact on the TEV in the three streams.

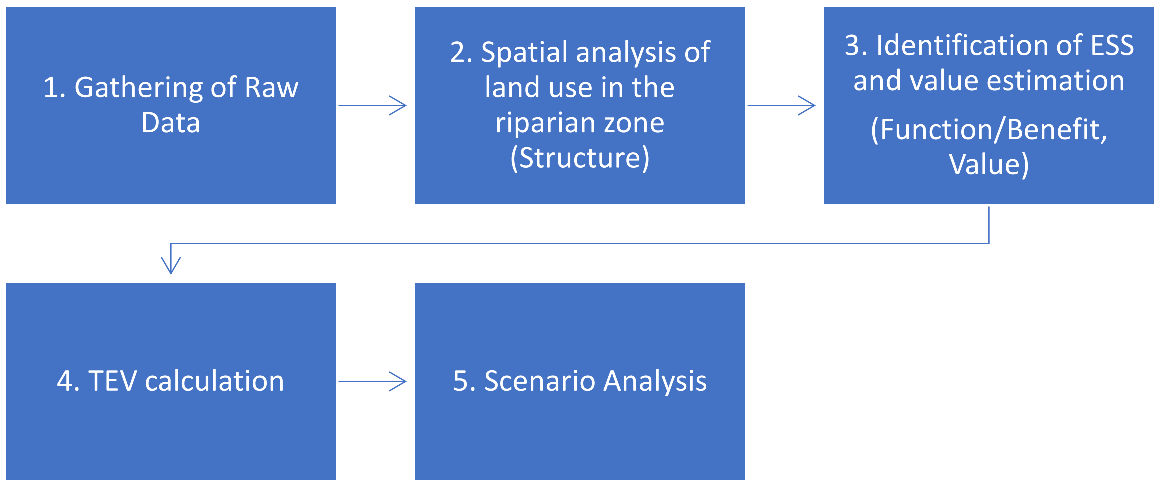

Figure 3. Workflow of the Methodology

4.2 Spatial Analysis of Land Use in the Riparian Zone

Data Assumptions and Sources

To operationalise the proposed spatial method, the following assumptions were made about the available data and stream properties:

The riparian zone of each stream was generally estimated as a minimum of 30 meters from each streamside (Vermaat et al., 2021) plus the potential floodplain defined by the NVE map "aktsomhetskart for flom" (Table 1). This is not the actual historical flood area, but rather the potential floodplain of the streams, and was used in this thesis to demarcate an area that had a functional connection to the stream due to elevation (NVE, 2020).

Land use was defined by the "Arealressurskart AR5" (AR5). This map consists of a mix of land cover classification methods to assign the current potential use of areas in Norway (Alhstrøm et al., 2019; Norwegian Forest and Landscape Institute, 2014). It is the most detailed map available in Norway. An important distinction is that this map reflects potential use rather than the actual land use in some surfaces (e.g. agricultural surfaces). A field that is currently not in use can still be classified as arable land (Alhstrøm et al., 2019). In this thesis, the resource potential is assumed to reflect the actual resource use, assuming an efficient agricultural system and therefore using the terms "land use" and "land cover" interchangeably for all AR5 classifications.

Table 1. Data sources for the land-use calculation in the riparian zone

Dataset	Description	Source
Aktsomhetskart for flom	Map of potentially flood-prone areas in Norway	NVE (2020)
Elvenett	Stream network in Norway	NVE (2025a)
Arealressurskart AR5	The most detailed land resource map available for Norway	Norwegian Institute of Bioeconomy Research (NIBIO), provided via MINAs recognised AR5-user, Roar Økseter

Spatial Pre-Processing

The software used for the spatial analysis was QGIS version 3.34.13. After obtaining the shapefiles for all streams in the study area, the AR5 classification and the "aktsomhetskart for flom", all layers were reprojected to the coordinate reference system ETRS89/UTM zone 32N (EPSG code: 25832) to match the geographical area in which the study area lied and to create measurement units in meters. In the next step, a 30 m buffer was created around the data source "elvenett" (*eng. river network*) to ensure a minimum buffer of 30 m around the stream defined as a riparian zone and then "dissolved" to create a unified output layer. This buffer layer was merged with the shapefile "aktsomhetskart for flom" with the geoprocessing tool "merge", and the "dissolve" tool was applied to create a unified shapefile. The merge function ensured that a minimum buffer of 30 m around the stream on each side was maintained, even if the "aktsomhetskart for flom" shapefile covers an area with less than 30 m around the riverbanks.

The final operation within the spatial pre-processing was to create a layer which entailed the above-described riparian zone and the land-use information from the AR5. This was done with the QGIS tool "intersect" for the entire Oslofjord. The classification of this final layer was done according to Alhstrøm et al. (2019) with the attribute "arealtype" representing the different land-use classes. The full workflow of spatial methods for creating the riparian zone and land-use calculations is shown in Figure 4.

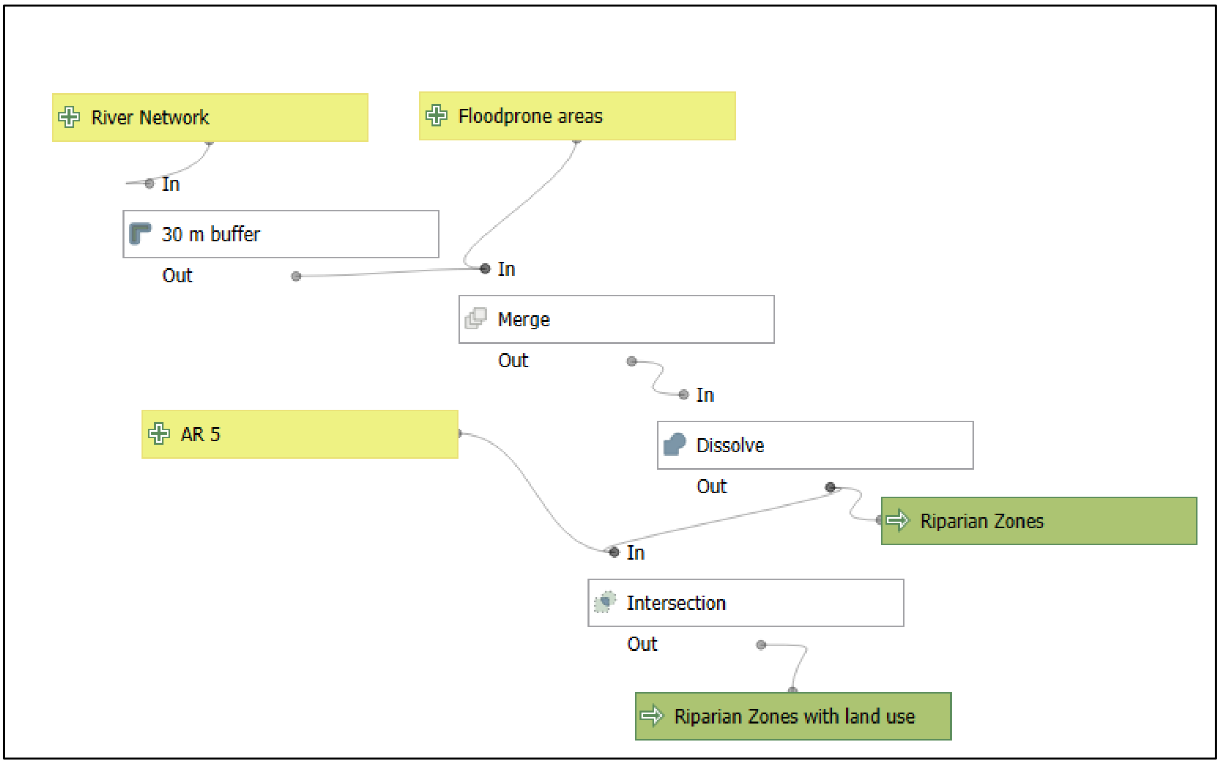

Figure 4. QGIS model to produce riparian zones with land-use information

Land-Use Calculation

Individual streams were selected by creating a mask layer in QGIS and using the geoprocessing tool "clip". This separated the individual streams of interests and their riparian zone for further analysis. The last step before the spatial data could be exported was calculating the area for each "arealressursflate" (*eng. land resource polygon*), which is the unit in which AR5 expresses spatial information about land resources. This was done using the field calculator in QGIS with the function "area($geometry)" to obtain the results in square meters. The measurement tool in QGIS was used to spot-check the different land resource polygons to ensure the approach was accurate and plausible. The shapefile's attribute table, containing the key information (area size, area ID, area type) of the individual streams' riparian zones, was exported to a Microsoft Excel Spreadsheet format for further evaluation. All following calculations were based on QGIS or Microsoft Excel, and charts were designed with the programming software R (version 4.2.1)[1].

4.3 Ground-Truthing

To verify the spatial data used as input for calculating land use, a field trip was undertaken on 22 March 2025, with spot checks along all three streams. These spot checks were used to partially verify the remote sensing data with the real world in a "ground-truthing" approach, which is common in remote sensing (Steven, 1987). Special attention was paid to whether parts of the stream were piped, blocked, or not holding water in the spring period. This allowed several corrections along Solbergbekken and Knattvollbekken. For example, the field trip ensured that woody buffers would not be simulated where the stream was severely piped in the landscape, hence avoiding creating unfit scenarios. One day of spot-checks was not a complete tracking of the whole stream length, but it helped remove certain parts from the data models or confirm them. The most removals were done at Knattvollbekken (Figure 5). The removals for Solbergbekken are displayed in Appendix 1, and no removals were done in Odalsbekken. Additional photos of the three streams are included in Appendix 2.

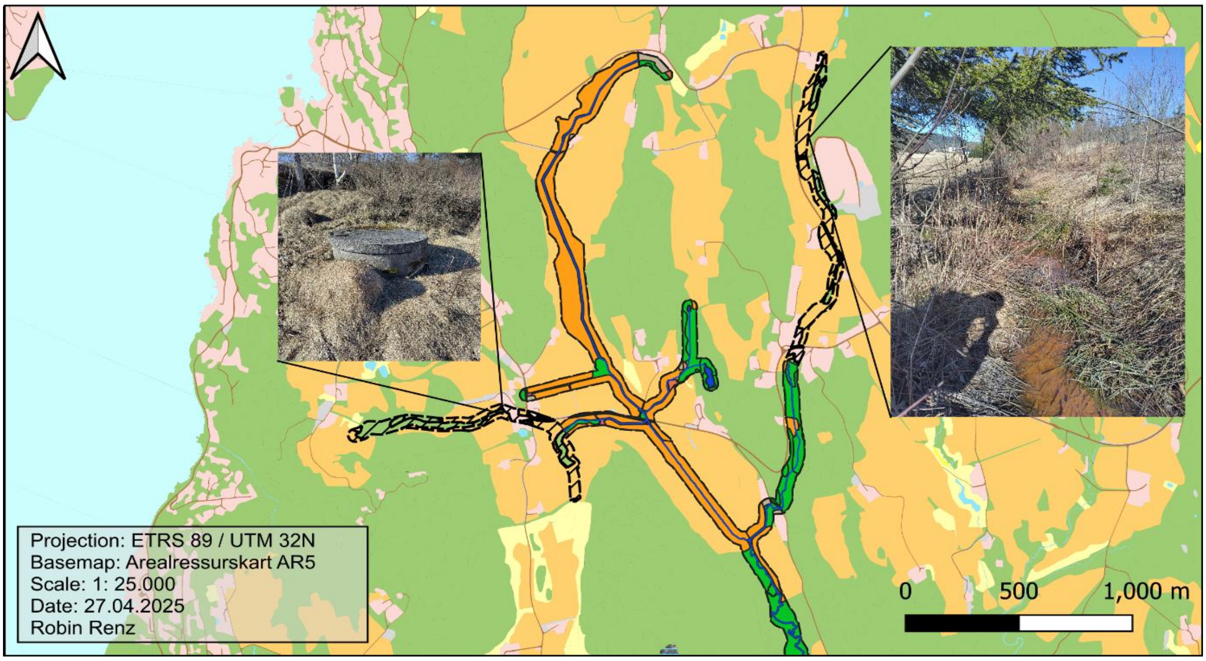

Figure 5. The upper reach of Knattvollbekken is displayed in land-cover classes of AR5. Removed parts are shown in black. Photos display piping or false stream classification (drainage ditch instead of flowing stream). The removed part in the east was piped and disturbed several times; the removal continued until the stream was continuously visible from the surface.

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[1] Artificial Intelligence transparency disclaimer: ChatGPT (model GPT-4o) was utilised for code polishing in accordance with section 3.2 of the guidelines for use of AI at NMBU. It was used to generate and improve code for the data visualisations in R for Chapter 5.

4.4 Ecosystem Service Evaluation

This thesis simplified the ESS cascade by Mononen et al. (2016) by representing the ESS structure through land-use categories and stream properties, and merging the steps function and benefit together (Vermaat et al., 2020; Vermaat et al., 2021) (section 2.2). Different approaches to arrive at the final value were used, and it is acknowledged that predominantly monetary values were considered. The final value was not always derived by a direct link to a specific biophysical unit, but could also be derived directly from values produced by a specific area type, like farmgate revenue per ha of arable land (Immerzeel et al., 2021). In this example, the biophysical benefit (e.g. harvested product) and function of the ecosystem are implicit in the monetary value of the product that is the final service, such as crops or fodder.

After creating the riparian zone and calculating the information about the land use of the riparian zone, potential ESS were identified based on Immerzeel et al. (2021), Vermaat et al. (2021) and own considerations for the local context. The ESS have been translated into the CICES classification and were all based on the calculated land use and the floodplain characteristics of the streams. Figure 6 gives a complete overview of the ESS cascade adapted for this thesis and its subsequent steps. The calculations were carried out in spreadsheet form, and supplementary material is available upon request to the author or supervisor of this thesis.

An attempt was made to use local values for the estimation of the ESS value where possible. If local statistics were unavailable, Norwegian values were used as a proxy, and if Norwegian data were unavailable, Scandinavian or European values were used to calculate final values. A more detailed synopsis of land use, floodplain characteristics and the estimation of ecosystem benefits and their subsequent values is given in Table 2. All values were calculated in Norwegian Krone (NOK), and market values older than 2010 were inflation-adjusted. It needs to be mentioned that the areas of open water (fjords, lakes, ponds) in AR5 have been excluded from the analysis.

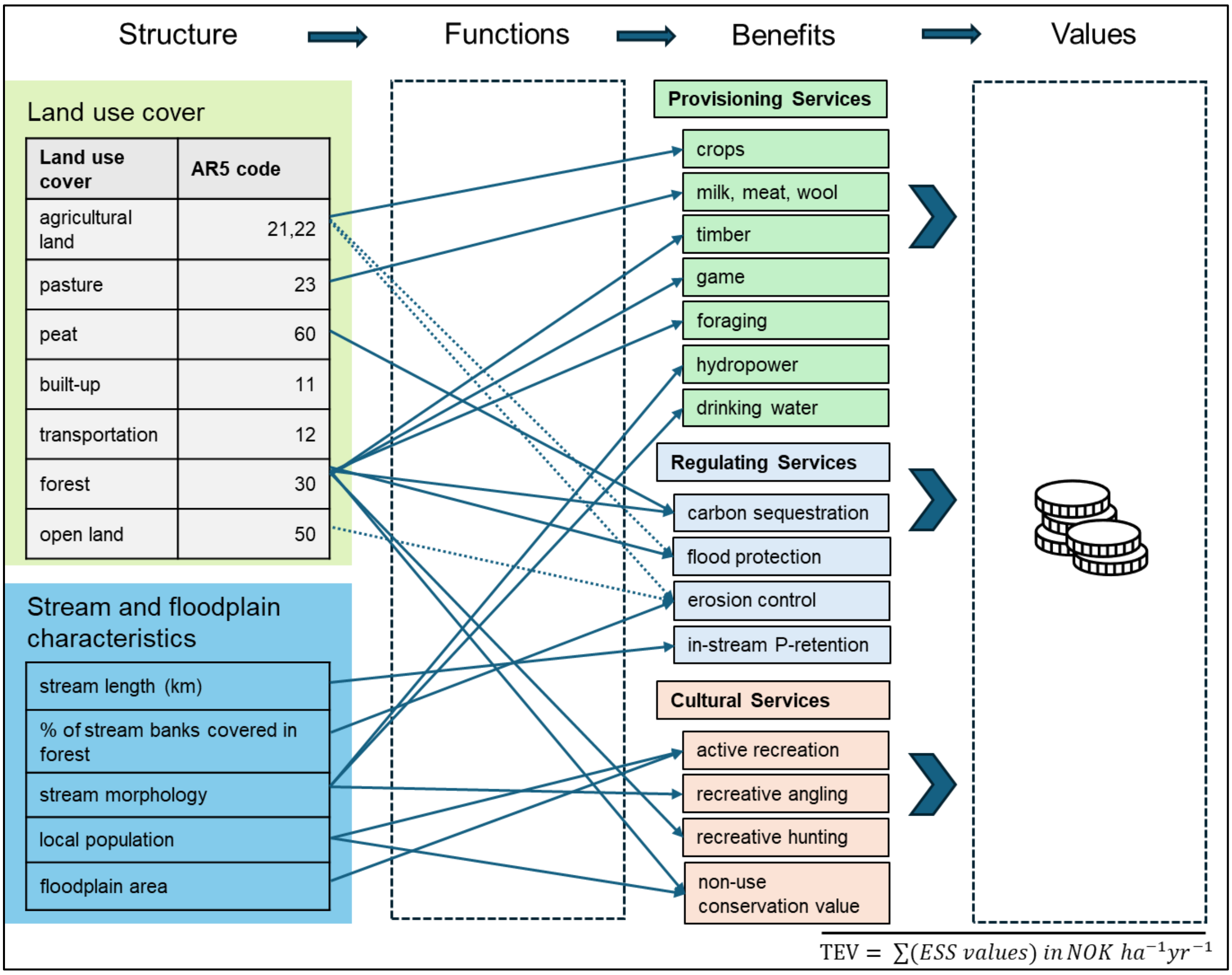

Figure 6. Ecosystem service assessment cascade (own design based on Vermaat et al. (2020, 2021). Arrows depict the relations between ecosystem structure and final ESS; dotted arrows symbolise indirect influence on ESS calculation.

Table 2 shows that most identified services were based on the forest cover in the riparian zone, while no services were identified for open land as a category. However, the latter was treated as grassland in the erosion control calculation. Some ESS, which were initially identified in Figure 6, appeared not applicable to the studied streams. These were: “hydropower”, “angling”, and “drinking water”. These services were taken to have zero value because of local regulations (angling is not allowed in these streams) or because the potential is not used (drinking water and hydropower) in the studied streams. This does not imply, however, that there is no potential for these ESS. Adjustments to results or values identified in the literature are transparently stated in the last column of Table 2. Differences in data quality and weaknesses of individual value estimates are discussed in Chapter 6. After all individual values for each stream were calculated, the TEV was summed up for each stream and normalised to annual NOK per ha riparian zone (NOK ha^{-1} yr^{-1}).

Table 2. Relevant ecosystem services and quantification assumptions, the full spreadsheet with calculations can be made available upon request

Land use class *(AR5 in English)*	**Service, (CICES code)**	**Measurement, unit**	**Short description, sources**
Provisioning Services			
Agricultural land	Crops 1.1.1.1	Long-term average gross income from field crops adjusted with an ESS contribution factor. (NOK×ha^{-1} [agricultural land]×yr^{-1})	The initial approach is similar to Immerzeel et al. (2021). The local 3-year averaged revenue from field crops was divided by the average crop area size per farm of the county to reach an approximate value per ha. An ESS contribution factor of 0.222 for Sweden (Vallecillo et al., 2019) was applied to avoid accounting for value chain production factors. Viken county farm holdings: Statistics Norway (SSB, 2025b) county farm income: SSB (2025c)
Pasture	Milk, meat, wool 1.1.3.1	Long-term average gross income from grazing livestock adjusted with an ESS contribution factor. (NOK×ha^{-1} [pasture]×yr^{-1})	The initial approach is similar to Immerzeel et al. (2021). The local 3-year averaged revenue from grazing livestock was divided by the average pasture size per farm of the county to reach an approximate value per ha. An ESS contribution factor of 0.387 for Sweden from (Vallecillo et al., 2019) was applied to avoid accounting for value chain production factors. Viken county farm holdings: SSB (2025b) county farm income: SSB (2025c)
Forest	Timber 1.1.5.2	Long-term average value of wood removal normalised per ha and adjusted with an ESS contribution factor. (NOK×ha^{-1} [forest]×yr^{-1})	The 10-year average gross value of commercial roundwood removals was normalised per ha for each stream's municipality and then modified by an ESS contribution factor of 0.92 for Sweden from Vallecillo et al. (2019). municipality data on commercial roundwood removals: SSB (2024a) municipality forest cover: SSB (2024b)
Forest	Game 1.1.6.1	Value based on average hunted weight and value of big game and small game of each municipality, and fraction of municipality forested land in the riparian zone. (NOK×ha^{-1} [forest]×yr^{-1})	The initial approach to break down game value into big and small game on a municipality basis is based on Immerzeel et al. (2021). Big game is represented by deer and moose hunting, and small game is represented by pigeon hunting. The average meat weight per hunted animal was then multiplied by meat values and normalised to the municipal forested area. felled animals: SSB (2025e) weight of big game: Norwegian Agriculture Agency (2025) weight of small game: Søraker (2024) price big game: Statskog (2024) price small game: TRIDGE (2025)

Land use class ***(AR5 in English)***	**Service, (CICES code)**	**Measurement, unit**	**Short description, sources**
Forest	Foraging of Berries & Mushrooms 1.1.5.1	Nationwide foraging rates with average picking weight and market value of berries are adjusted to municipality population and ha forest area. The result was adjusted to the forested riparian zone. ($NOK \times ha^{-1}$ [forest]$\times yr^{-1}$)	Nationwide foraging rates from SSB (2024d) were assumed for the municipalities, and the average annual quantity of berries and mushrooms taken from Schulp et al. (2014). This is multiplied by the market values for berries and mushrooms from Turtiainen and Nuutinen (2012). All values were converted to NOK[2]. municipality population: SSB (2025a) **Result adjustment**: A factor of 0.5 was applied because the source data aggregates berry and mushroom picking into one activity.
Stream morphology	Hydropower 4.2.1.3	No hydropower production within the studied streams.	Source: NVE (2025b)
Stream morphology	Drinking water 4.2.1.1	No drinking water extraction from any of the streams.	Source: Geonorge (2017)
Regulating Services			
Peat	Climate regulation 2.2.6.1	The average uptake of CO_2 by peatland multiplied by a carbon credit market price, normalised to peatland in the riparian zone. ($NOK \times ha^{-1}$ [peatland]$\times yr^{-1}$)	The carbon uptake of peatlands is taken from (De Wit et al., 2015) and converted to CO_2 uptake with the US EPA (2024). An international CO_2 market price of NOK 108 for forestry carbon credits was used for price calculation (Forest Trends' Ecosystem Marketplace [FTEM], 2024).
Agricultural land, pasture, forest	Flood protection 2.2.1.3	Expressed as the avoided cost of flooded agriculture due to forest land cover. ($NOK \times ha^{-1}$ [forest]$\times yr^{-1}$)	Damage curves for flooded land use were taken from a European study (De Moel & Aerts, 2011). An inundation depth of 1 meter was assumed in the floodplain, and the damage value was divided by 500 since the floodplain data is based on 500-year flood intervals. It was decided that only the avoided damage to agricultural land and pasture is seen as a service (NOK 82/ha and NOK 19/ha). This is due to the lack of a flood model, and to keep the service estimation conservative.
Stream morphology	Water quality improvement 2.2.5.1	In-stream retention of phosphorus per stream km. ($NOK \times$ stream kilometer^{-1})	The approach is based on Vermaat et al. (2021) to account for in-stream phosphorus retention, with a conservative value of 100 kg/ stream km. The P-price is based on the international average Triple phosphate prices (IndexMundi, 2025) and the chemical formula of YARA fertiliser (YARA Norge, 2025).
Forest	Climate regulation 2.2.6.1	The average uptake of CO_2 by the forest multiplied by a carbon credit market price, normalised to the forest in the riparian zone. $NOK \times ha^{-1}$ [forest]$\times yr^{-1}$)	The average CO_2 uptake of Norwegian forests is taken from Framstad et al. (2011). An international CO_2 market price of NOK 108 per forestry carbon credit was used for price calculation (FTEM, 2024).

[2] Exchange rates for the entire study are NOK/€ = 11.694 and NOK/$ = 11.061 from 03/25

Land use class *(AR5 in English)*	Service, (CICES code)	Measurement, unit	Short description, sources
Forest	Erosion control 2.2.1.1, 2.2.1.2	Avoided P-loss through phosphorus retention from woody buffers adjacent to the stream and agricultural land or grassland, normalised to the floodplain. NOK×ha^{-1} [floodplain]×yr^{-1})	This service estimates the retention of phosphorus load from agriculture and grassland in the riparian zone with a function based on Vermaat et al. (2021), reducing potential P-loads by forested area adjacent to the stream in buffer zones between agriculture and stream. The logic is: If there is a forested buffer around the stream, retention = 1, one-sided/partial = 0.5, and no forest buffer = 0 load retention. P-price based on ESS 2.2.5.1.
Cultural Services			
Forest	Non-use 3.2	Willingness to pay in Norway per household for increased forest conservation. Adjusted for municipality population and floodplain forest area. NOK×ha^{-1} [forest]×yr^{-1})	The willingness to pay per Norwegian household is from a representative study from Lindhjem et al. (2014), based on 2007 NOK, and adjusted up to NOK prices for 2024. The survey concerned the willingness to pay per year for additional forest conservation. data for the municipality population: SSB (2025a) data for household size: SSB (2024c)
Forest	Recreational hunting 3.2	The value of hunting licences in the municipality, normalised for floodplain forest area. NOK×ha^{-1} [forest]×yr^{-1})	Recreational hunting is separated from game value. Forests are assumed to be the main hunting ground, and the local annual value of hunting licences is normalised to the forest area. value of hunting licences: SSB (2025e)
Stream	Recreational angling 1.1.6.1	No service identified	Angling for anadromous salmonids is forbidden in all three investigated streams. No additional sales of fishing licenses could be identified for the stream areas. source fishing ban:Forskrift om fiske etter anadrome laksefisk i vassdrag (2021) source fishing licences: inatur (2025)
Population	(local) Active Recreation 3.1	Estimation of travel costs for the local population in a 700 m buffer around the streams. Normalised to the non-urban floodplain or the riparian zone. NOK×ha^{-1} [non-urban floodplain]×yr-1)	National statistics on recreation in nature (SSB, 2024d) were used to estimate the behaviour of the local population within a 700 m buffer around the stream (including no other streams). The local population was calculated in QGIS with population density maps (SSB, 2025d). The value of trips and frequency of local recreation were taken from a Norwegian study in Haldenvassdraget (Juutinen et al., 2022). **Result adjustment:** 1. To remain realistic, the population that only recreates at the streams was multiplied by a factor of 0.5 to account for other recreation choices 2. The travel cost was multiplied by factor 0.5 to reduce the applied car expenses in Juutinen et al. (2022), which are less relevant for the local population within the 700 m buffer.
Open land	none defined	none	none

4.5 Land-Use Scenarios

Three scenarios were simulated to assess the potential development of land use in the riparian zone of the investigated streams. Three models were developed in QGIS to automate the workflow of scenario output and ensure a simple, transparent, and replicable representation of scenario functions and assumptions. The time horizon for the scenarios was defined as 2040, which I assume to be the time required for ecosystems to adjust their structure and ESS flow. This horizon also appears plausible for potential implementations of the Oslofjord plan (Ministry of Climate and Environment, 2021) to show measurable effects. Table 3 gives an overview of the scenario narratives and data manipulations in QGIS. Scenario S1 is similar to the pessimistic scenario in Vermaat et al. (2021), while scenario S3 of this thesis aligns with the ambitious scenario (ibid.). The scenarios S1 and S2 also correspond to SSP3 ("regional rivalry – a rocky road") and SSP1 ("sustainability – taking the green road"), formulated by O'Neill et al. (2017). SSP3 assumes environmental degradation, deforestation and the expansion of agriculture, while SSP1 assumes strong regulations regarding land use, improving environmental conditions and the diffusion of best practices in agriculture (ibid.). Articulation of these three scenarios was discussed with fellow master student Eline Ziener Antonisen, who works on a parallel project on scenarios and ecosystem services for the Inner Drammensfjord, which is part of the Oslofjord system.

Table 3. Scenario assumptions

Scenario name	Description	Model choices
Baseline	The current situation reflects the ESS structure and prices as of 2025.	-
S1: *"Production first"*	No measures are taken to protect riparian woody buffer zones along streams, and conventional agriculture is intensified in southeastern Norway.	Removal of all woody buffers along agricultural land.
S2: *"Ambitious Oslofjord plan implementation"*	Measures to protect streams from nutrient loads and the restoration of stream biodiversity are in the political focus. Riparian woody buffers are protected and subsidised.	In addition to all current woody buffers and forests, a minimum woody buffer of 10 m is established around the streams.
S3: *"Biodiversity first"*	Sustainability, conservation and a biodiverse landscape are prioritised, woody vegetation is redeveloped in the riparian zone.	All agricultural land, pastures, and open areas in the riparian zone are developed as woody vegetation, so that the full potential of this "Nature-Based Solution" (Cohen-Shacham et al., 2016) is deployed.

To operate the scenarios with minimum assumptions and investigate the research hypothesis, forest cover was the main input for the scenarios. A combination of some manual geoprocessing and modelling was necessary. As scenario 1 implied full agriculture along riparian buffers, the riparian buffers were identified and marked first before the model could be applied. Model 1 for scenario 1 is exemplified in Figure 7 to illustrate the general QGIS workflow; models 2 and 3 for the other scenarios are attached as Appendices 3 and 4. The precise forest coverage along the stream was recalculated for each scenario to produce an accurate output for total forest land use in the riparian zone and forest coverage along the stream banks.

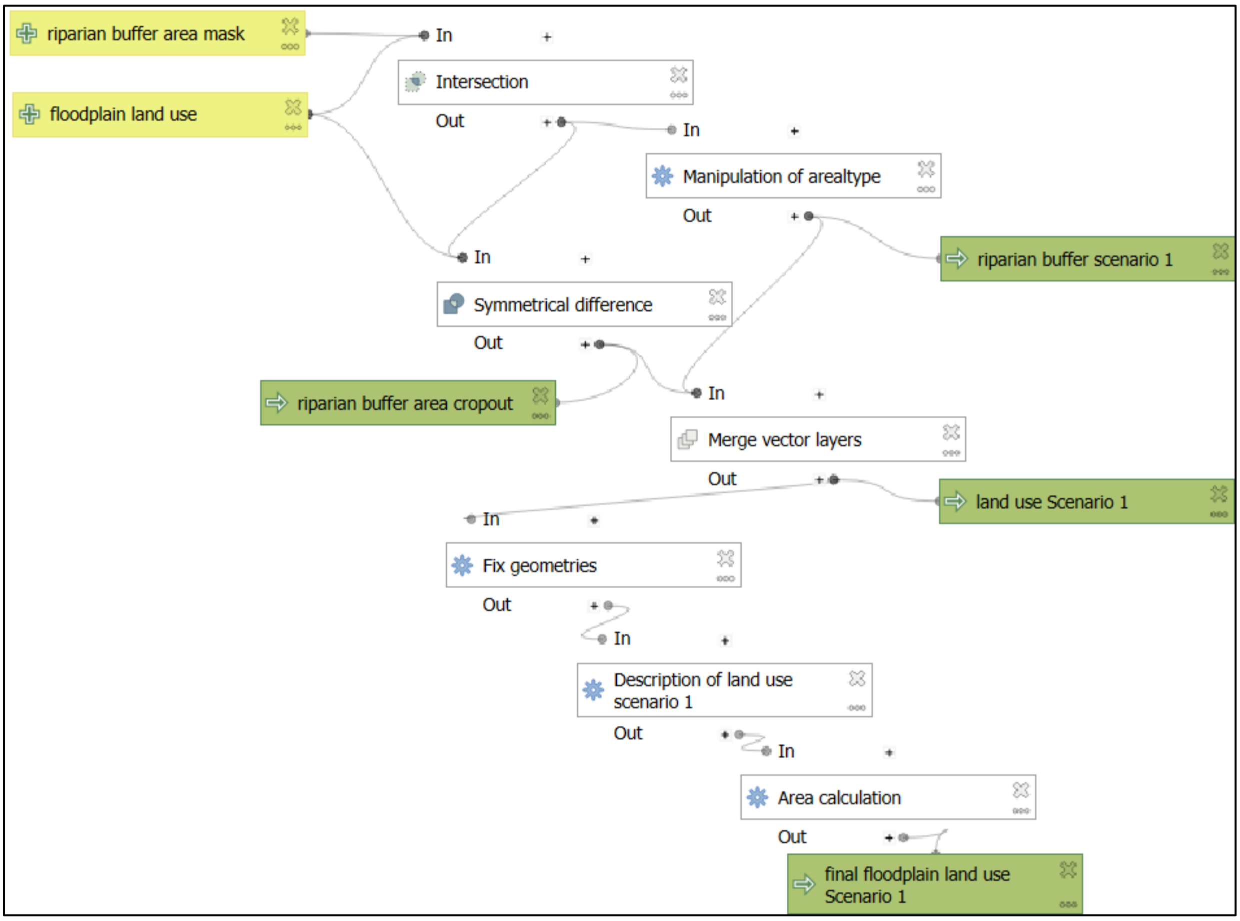

Figure 7. QGIS model to create Scenario 1

4.6 Sensitivity Analysis

The data availability and quality of datasets varied across different ESS, which caused higher confidence in data that was locally available. Values like the carbon price, on the other hand, differ in several ESS studies (Immerzeel et al., 2021; Vermaat et al., 2021; Vermaat et al., 2016). No formal standardised CO_2 price has been formulated for forest carbon sequestration. A partial sensitivity analysis was conducted to showcase the insecurities with selected services. Four ESS were changed in the proportion of -50% or +50% to ensure comparability. The baseline for the sensitivity analysis was the monetary ESS values in NOK ha^{-1} yr^{-1}. The following ESS were included in the sensitivity analysis:

1. *Value of carbon (+50%)*

   The price used in this thesis implies a low-end real market value of international carbon credits. Future carbon credit prices are hard to predict, varying depending on the standard and region, but the sensitivity analysis presents the effect of rising carbon prices.

2. *Value of agriculture (+50%)*

   A Swedish ESS contribution factor was used to estimate how much of the final market value of agricultural land is provided by the ecosystem; no data were available for Norway. To account for the potential undervaluation of this service, this ESS was increased by 50%, similar to Immerzeel et al. (2021).

3. *Value of timber (-50%)*

   Timber prices fluctuate (Steinset, 2024), and predictions cannot be made for the scope of this thesis. Because it was a main provisioning service, opposing the agricultural provisioning services, the timber value was down-adjusted for the sensitivity analysis.

4. *Value of non-use (-50%)*

   The non-use ESS was based on the willingness to pay for non-use/restoration of forests, which was taken from the study Lindhjem et al. (2014), and based on NOK values from 2007. The values were inflation-adjusted in the calculation of this ESS. Adjusting the values of willingness to pay with inflation might overestimate the overall ESS, which cannot be confirmed unless respondents are asked again. More importantly, contingent valuation methods like the willingness-to-pay method are also known to overestimate environmental values, called the “hypothetical bias” (Nilgen et al., 2024, p. 4). Therefore, the value of non-use was down-adjusted in the sensitivity analysis.

5 Results

5.1 Land Use of the Riparian Zone

The investigated streams and their subsequent riparian zones differ in stream length and size, with Solbergbekken being the longest stream with the largest riparian zone, followed by Knattvollbekken (approx. ¼ in size) and Odalsbekken as the shortest stream with the smallest riparian zone (approx. ½ of Knattvollbekken). The streams differ slightly in coverage of woody vegetation buffers adjacent to the stream, but heavily in the local population living within a 700 m vicinity of the stream. Odalsbekken is by far the most populated, followed by Solbergbekken and then Knattvollbekken (Table 4).

Table 4. Stream properties

Stream	Riparian zone [ha]	Stream length [m]	Fraction of banks fully wooded	Population in a 700 m vicinity
Odalsbekken	26.5	4346	68%	4501
Solbergbekken	211.4	20545	43%	488
Knattvollbekken	51.9	8234	63%	241

The land-use classes present in the three studied streams were open land, built-up land, agriculture, peat, pastures, transportation and forests. Table 5 shows that the three streams had a different land-use composition. The intra-stream composition also varied and can be seen for all streams in Appendices 5–7. The riparian zone of Odalsbekken included the most forest (66%) and the most built-up land (5%) while having the lowest share of agricultural land (20%). Solbergbekken and Knattvollbekken were somewhat similar regarding forest cover (40% and 42% respectively). Still, Knattvollbekken had more built-up land than Solbergbekken, despite having a significantly smaller riparian zone. Knattvollbekken was also the only riparian zone with land classified as pasture (<1%), while Solbergbekken had the only share of peat (<1%) among all three streams. With the share of roads being relatively similar (between 1–2%) and open land varying between 2–6%, the balance between agriculture and forest was the main denominator for different land use coupled ESS deliveries (besides stream length and population as in Table 4).

Table 5. Land use characteristics of the three streams

Land-use category (AR5)	Odalsbekken		Solbergbekken		Knattvollbekken	
open land	1.7 ha	6%	4.2 ha	2%	2.0 ha	4%
built-up	1.4 ha	5%	1.2 ha	1%	1.4 ha	3%
agriculture	5.3 ha	20%	120.1 ha	57%	26.2 ha	50%
peat	0 ha	0%	1.1 ha	0%	0 ha	0%
pasture	0 ha	0%	0 ha	0%	0.2 ha	0%

Land-use category (AR5)	Odalsbekken		Solbergbekken		Knattvollbekken	
transportation	0.6 ha	2%	1.2 ha	1%	0.4 ha	1%
forest	17.6 ha	66%	83.6 ha	40%	21.8 ha	42%
Grand Total	26.5 ha	100%	211.4 ha	100%	51.9 ha	100%

The balance of agricultural land cover and forest land cover in the riparian zone also differed among the different municipalities of the three streams (Figure 8). All riparian zones in Vestby had a forest cover of approx. 40% and 45% agriculture. This was the municipality with the highest share of agriculture in the riparian zones, followed by Frogn (30%) and then Asker (12%), which had the highest share of forest in the riparian zones (70%). The investigated streams did not represent the land-use balance of the municipalities. Odalsbekken had more forest cover than the other riparian zones in Frogn (+11%) and a lower share of agriculture (10% less). The riparian zone of Solbergbekken represented the municipality of Vestby precisely in terms of forest cover but had a higher cover in agriculture (+12%). Knattvollbekken was the least representative of its municipality, Asker, and had lower forest cover (-28%). The riparian zone of Knattvollbekken also entailed more agriculture (+38%) than the other riparian zones in the municipality (Figure 8). For the share of all land-use classes in the municipalities, see Appendix 8.

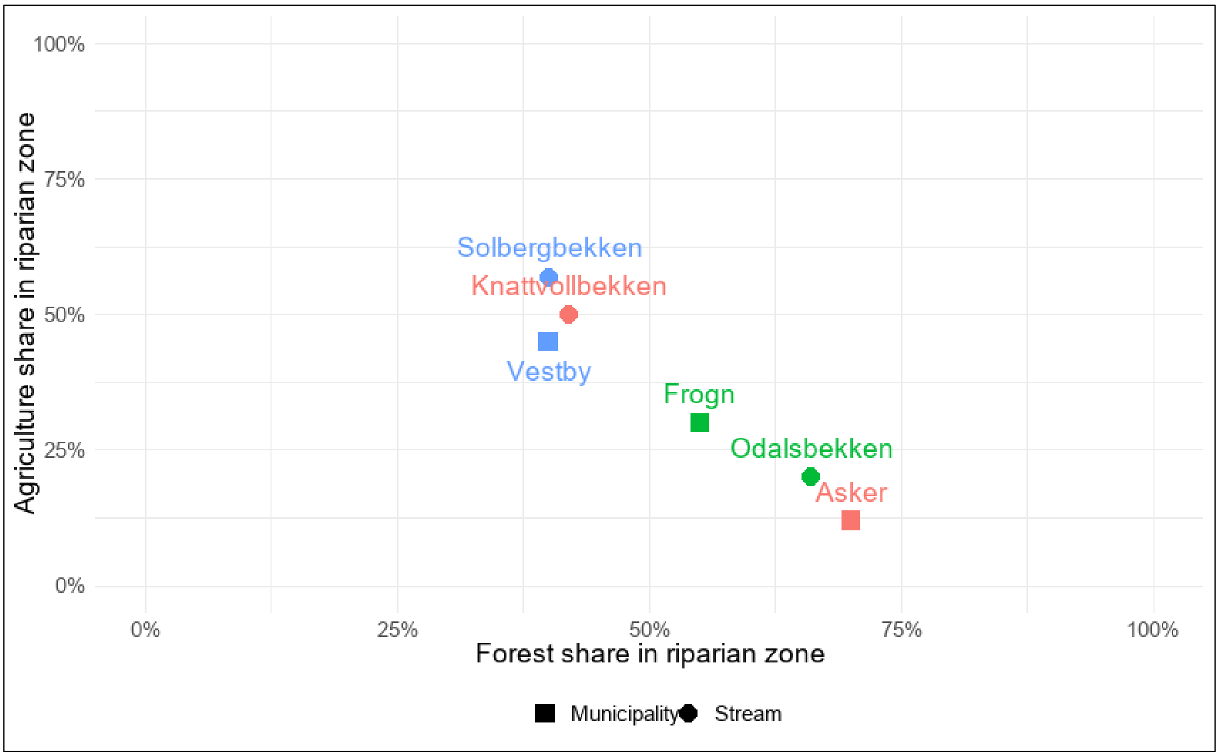

Figure 8. Share of forest cover and agricultural cover in the three streams and their relevant municipalities (colours indicate the relevant municipality to the stream)

5.2 Ecosystem Service Contribution to Total Economic Value

The TEV of the three streams ranged between approx. NOK 95,600 and NOK 499,400 per year. The shortest stream with the smallest riparian zone (Odalsbekken) had the lowest TEV, followed by Knattvollbekken (approx. NOK 120,900) and Solbergbekken (Figure 9).

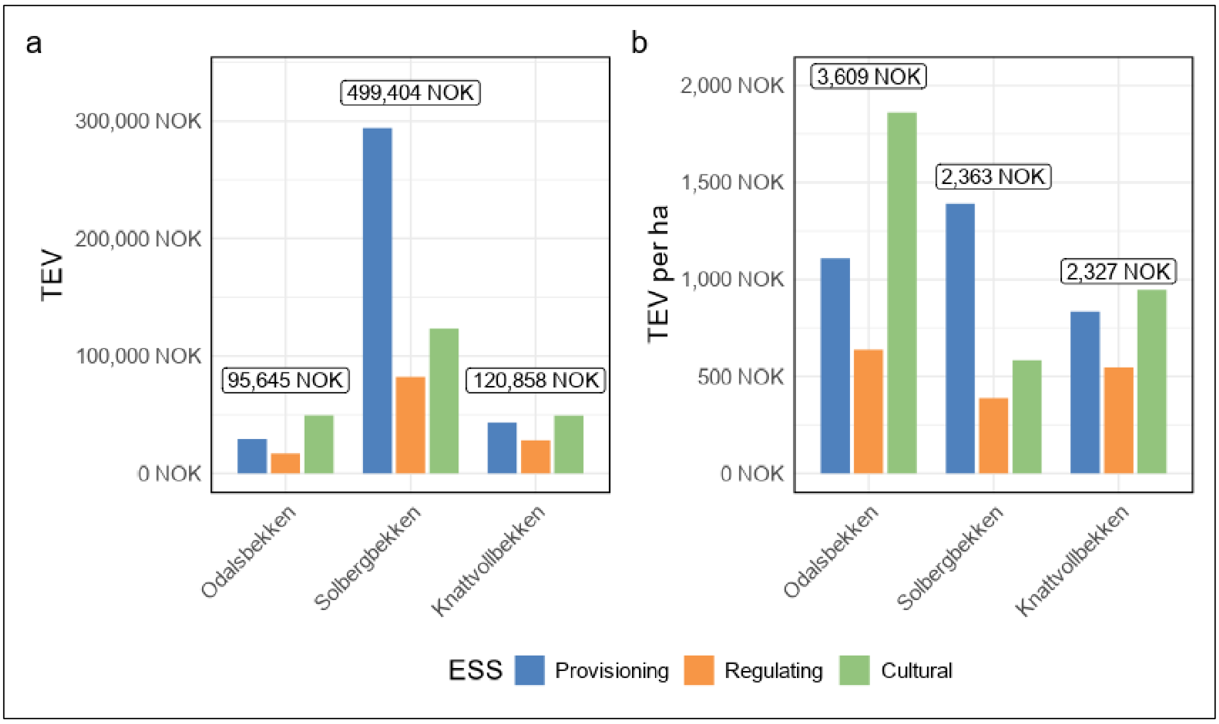

Figure 9. Annual TEV per stream and service category (sum of all services per stream in text boxes). a. TEV of the riparian zones, b. TEV per ha riparian zone

In the riparian zone of Odalsbekken, cultural ESS were contributing most to TEV, followed by provisioning ESS and regulating ESS (Figure 9a). In Solbergbekken, provisioning services were the predominant contributor, followed by cultural and regulating services. Knattvollbekken had a similar pattern to Odalsbekken, except that cultural ESS and provisioning ESS contributed relatively similarly to TEV. A more nuanced per-area comparison is provided in Figure 9b, displaying the ESS contribution of the three ESS categories and the final TEV normalised to ha^{-1} yr^{-1}. This showed a different order in stream TEV, with Odalsbekken having the highest TEV ha^{-1} yr^{-1}, and Knattvollbekken and Solbergbekken having a similar TEV ha^{-1} yr^{-1}. This indicates that the high TEV of Solbergbekken (9a) was observed due to the total size of the riparian zone.

Cultural ESS differed most among the three streams (Figure 9), with Odalsbekken having the highest TEV ha^{-1} yr^{-1} (approx. NOK 1900, compared to NOK 600 and NOK 900). This was due to the high contribution of active recreation to the cultural ESS in Odalsbekken (NOK 640), compared to values under NOK 20 ha^{-1} yr^{-1} in the other streams (Table 6). The ESS active recreation was dependent on the local population around the riparian zone, and the high local population around Odalsbekken is therefore likely to be responsible for this high ESS value (section 5.1). However, this is a constant factor and did not change in the following land-use scenarios. At the same time, the ESS non-use was tied to forest cover and the municipality's population density. The municipality's population density did not appear to substantially affect the cultural service category since Asker had the highest population density of the three streams, but not the highest non-use ESS value (Table 6). To compare individual ESS across streams with different land use, all TEV values per ESS were normalised per total riparian area (Table 6). From the 13 identified ESS, eight were directly forest-related, while “crops”, “milk, meat & wool”, “carbon sequestration peat”, “water quality improvement” and “active recreation” were not or not solely linked to forest cover.

Table 6. Value of all ESS normalised to annual NOK/ha and percentage of TEV for the three streams (forest-related ESS are highlighted in green). Means and standard deviations are displayed in the last column.

ESS (CICES Code)	*Odalsbekken (NOK ha^{-1} yr^{-1})*	*Solbergbekken (NOK ha^{-1} yr^{-1})*	*Knattvollbekken (NOK ha^{-1} yr^{-1})*	*Mean (SD) (NOK ha^{-1} yr^{-1})*
Crops (1.1.1.1)	215 (6%)	609 (26%)	541 (23%)	455 (211)
Milk, meat, wool (1.1.3.1)	0.0 (0%)	0.0 (0%)	24 (1%)	8 (14)
Timber (1.1.5.2)	780 (22%)	722 (31%)	195 (8%)	565 (322)
Game (1.1.6.1)	39 (1%)	22 (1%)	11 (<1%)	24 (14)
Foraging (1.1.5.1)	76 (2%)	38 (2%)	63 (3%)	59 (19)
Climate regulation (2.2.6.1)	178	107	113	133 (40)
Carbon sequestration forest	178 (5%)	106 (4%)	113 (5%)	132 (40)
Carbon sequestration peat	0.0 (0%)	0.4 (<1%)	0.0 (0%)	0.1 (0.2)
Flood protection (2.2.1.3)	54 (2%)	32 (1%)	34 (1%)	40 (12)
Water quality improvement (2.2.5.1)	399 (11%)	237 (10%)	386 (17%)	341 (90)
Erosion control (2.2.1.1, 2.2.1.2)	6 (<1%)	13 (1%)	13 (1%)	10 (4)
Recreation (3.1 pooled)	718	53	83	284 (376)
Active recreation (local)	640 (18%)	15 (1%)	18 (1%)	224 (360)
Recreational hunting	78 (2%)	38 (2%)	65 (3%)	60 (20)
Non-use (3.2 pooled)	1144 (32%)	531 (22%)	865 (37%)	847 (307)
Sum	**3609**	**2363**	**2327**	**2766**

The three most relevant services per hectare riparian zone for Odalsbekken were “non-use”, “timber” and “active recreation”. At the same time, for Solbergbekken they were “timber”, “crops” and “non-use” and for Knattvollbekken “non-use”, “crops” and “water quality improvement” (Table 6). Notably, the non-material ESS “non-use” was an essential service in all three streams, with an estimated proportion of the TEV ha^{-1} yr^{-1} of 22–37% across all streams. Forest-linked services constituted most of the TEV ha^{-1} yr^{-1} in all three streams (Odalsbekken: 65%, Solbergbekken: 64%, Knattvollbekken: 58%). Since most services in all three service categories were linked to forest cover, a general increase of TEV with increasing forest cover in the riparian zone is expected. The only exception to this observation was the category of provisioning services for Knattvollbekken. The ESS, “crops”, and “milk, meat & wool” made up 24% of the TEV ha^{-1} yr^{-1} of Knattvollbekken, while the other (forest-related) provisioning ESS only accounted for approx. 13% of TEV ha^{-1} yr^{-1}. All original ESS before normalisation to the floodplain area are displayed in Appendices 9–11. Appendix 9 exemplifies that the ESS value per hectare for crops in Odalsbekken is NOK 1072 ha^{-1} yr^{-1} of agricultural land. This is in comparison to NOK 215 ha^{-1} yr^{-1}, normalised to the riparian zone (Table 6).

5.3 Scenario Analysis

5.3.1 Land-Use Change under the Scenarios

After applying the scenario models and landscape assumptions formulated under 4.5, the changed land use for each AR5 class has been recalculated. Since the land-use classes “built-up” and “transportation” are constant under all defined scenarios (S1–S3), “agriculture” and “forest” were the land-use classes that changed most under the scenarios (Figure 10). Forest was maximised under S3, while agriculture was maximised under S1, which minimised forest cover. S2, which implied a ten-meter riparian buffer between streams and agricultural land, was between S1 and S3. Riparian buffers covered close to 100% of the stream banks under S2 and S3, while being significantly reduced under S1 (-19% stream bank coverage at Odalsbekken, -7% at Solbergbekken, and -20% at Knattvollbekken).

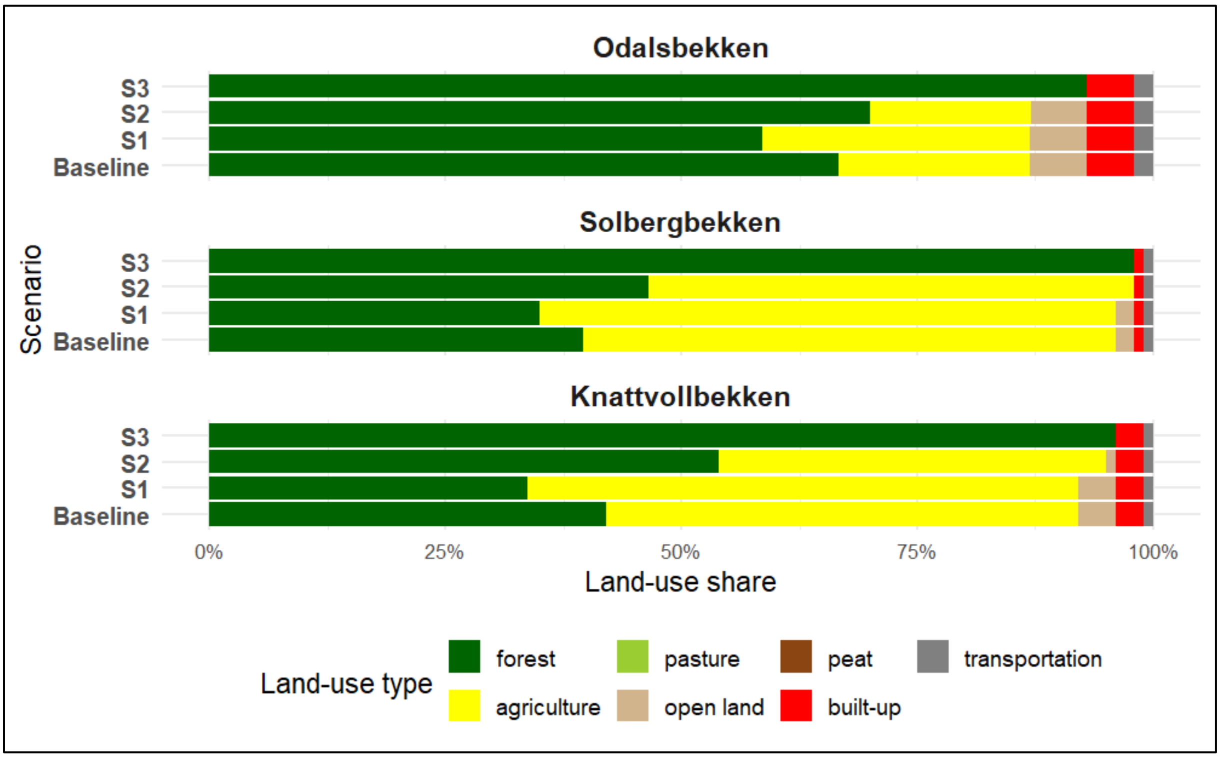

Figure 10. Land use of the three streams under the defined scenarios

Figure 11 demonstrates the implementation result of the land-use change methodology on Odalsbekken. Not only does the total land use differ for each scenario, but riparian buffer strips have also been identified, removed, and replaced by agriculture under S1, or widened to a minimum of ten meters under S2. This precise land-use change within the riparian zone led to a shift in the balance between agriculture and forest, and affected the regulating ESS of erosion control through varying woody streambank coverage.

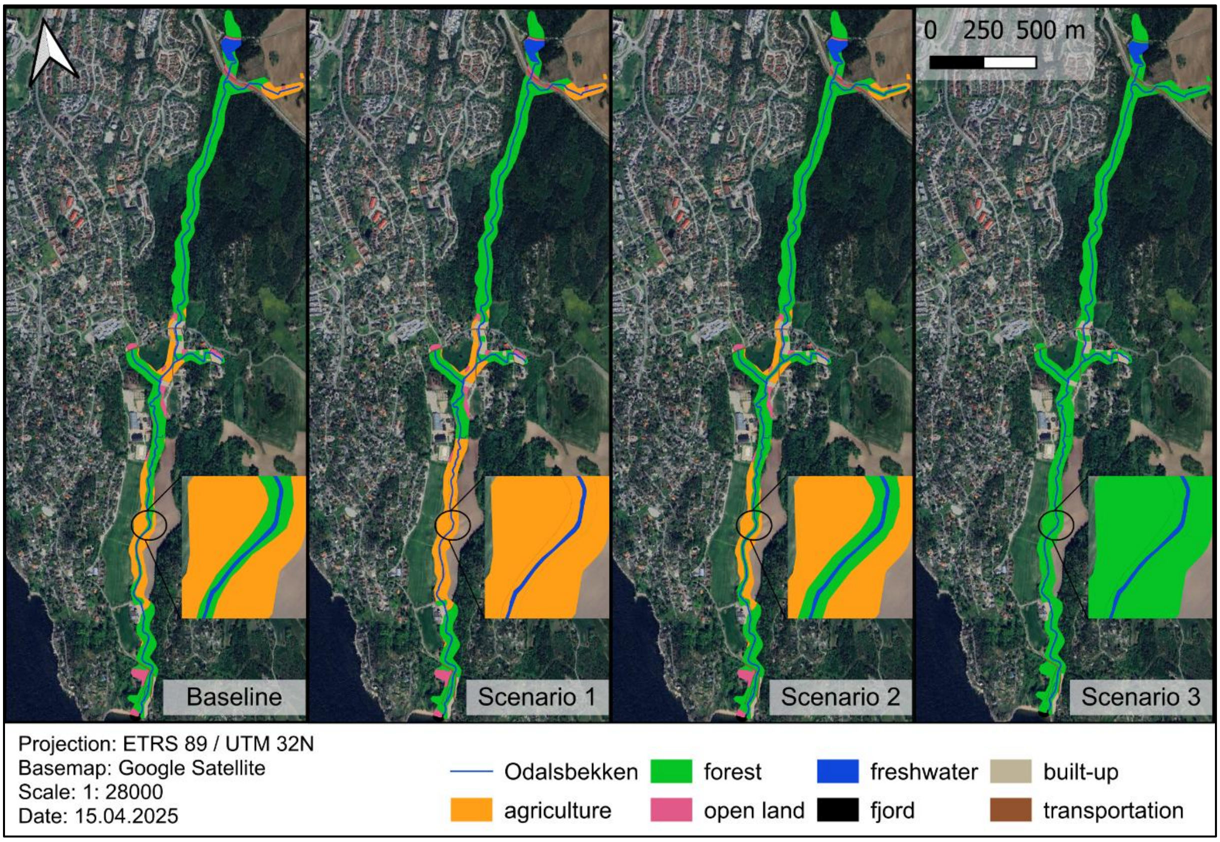

Figure 11. Map of land-use change under the three applied scenarios in Odalsbekken. The zoomed-in map for scenario 1("Production first") shows that the riparian buffer was exchanged with agricultural land, scenario 2 ("Ambitious Oslofjord plan implementation") displays the widened 10 m buffer, and the zoomed-in map for scenario 3 ("Biodiversity first") shows the full forest cover in the riparian zone.

5.3.2 Ecosystem Service Change under the Scenarios

The land-use changes affected the flow of ESS (Figure 12). The Scenario "Biodiversity first" (S3) yielded the highest TEV ha^{-1} yr^{-1} for the riparian zone in all three streams. The TEV surplus from "Biodiversity first" ranged from approx. 20% (Odalsbekken) to 67% (Knattvollbekken), as displayed in Appendix 12. S1, estimating the removal of all riparian buffer strips, demonstrated the lowest TEV ha^{-1} yr^{-1}, which decreased between approx. 5% and 8% across the streams. S2 yielded a marginally higher TEV than the baseline in all three streams, with the lowest surplus in Odalsbekken (3%) and the highest in Knattvollbekken (12%).

In absolute numbers, the scenario analysis affected the TEV as follows: For Knattvollbekken, TEV changed from -NOK 9,300 (S1) to +NOK 61,100 (S3) annually, compared to a baseline of NOK 121,000 (Appendix 12). Odalsbekken exhibited a narrower range, from -NOK 5,200 (S1) to +NOK 18,900 (S3), compared to a baseline TEV of NOK 95,600. Solbergbekken, with a TEV of NOK 499,400, was the most sensitive to the scenarios, with the potential impact on TEV ranging from -NOK 26,600 (S1) to +NOK 336,400 (S3) per year (Appendix 12).

Investigating the changes in more granularity showed that regulating and cultural ESS demonstrated an increased TEV ha^{-1} yr^{-1} with increased forest cover under S2 and S3 for all streams (Figure 12). Cultural ESS had a stronger growth than regulating ESS (Table 7). The surplus of regulating services was less than 10% for S2 in all streams and between 14% and 50% for S3. Cultural services increased between 4% and 28% in S2 and between 26% and 145% in S3.

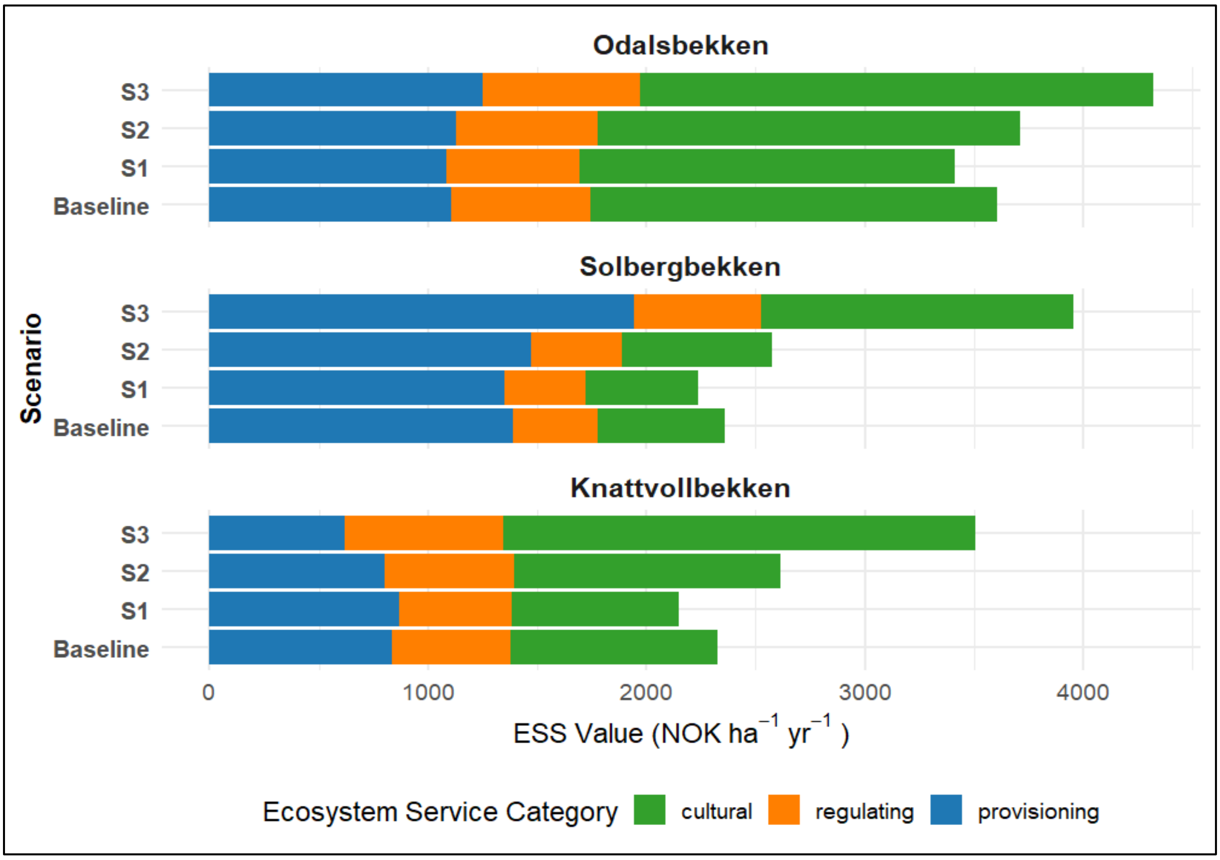

Figure 12. Overview of scenario impact on the ecosystem service categories

The pattern of increased value per hectare with increasing forest cover did not hold for provisioning ESS in all three streams. While the value from provisioning ESS increased under S2 and S3 for Odalsbekken and Solbergbekken, provisioning ESS declined with increasing forest cover in Knattvollbekken by 4% (S2) and 26% (S3). Provisioning services increased by 4% under S1 in Knattvollbekken (Table 7).

Table 7. Detailed change of ecosystem service categories for all scenarios

Stream	ESS Category	S1 Change (%)	S2 Change (%)	S3 Change (%)
Odalsbekken	provisioning	-2	+2	+13
Odalsbekken	regulating	-4	+2	+14
Odalsbekken	cultural	-8	+4	+26
Solbergbekken	provisioning	-3	+6	+40
Solbergbekken	regulating	-5	+8	+50
Solbergbekken	cultural	-11	+17	+145
Knattvollbekken	provisioning	+4	-4	-26
Knattvollbekken	regulating	-6	+8	+33
Knattvollbekken	cultural	-19	+28	+128

The observation that the provisioning ESS of Knattvollbekken increased with declining forest cover was mainly caused by a high ESS value of crop production in comparison to forest-related provisioning ESS for Knattvollbekken (approx. NOK 540 ha^{-1} yr^{-1} vs. approx. NOK 270 ha^{-1} yr^{-1}). The value of timber was especially low compared to the other two streams (difference of approx. factor 3–4). Although provisioning ESS in Knattvollbekken did not follow the pattern found in the three streams for the scenarios, Figure 13 gives the first indication of a potential trend of increasing TEV ha^{-1} yr^{-1} with increasing forest cover and decreasing TEV ha^{-1} yr^{-1} with growing cover of agricultural land. This trend was apparent in the three case study streams and cannot be generalised to other geographies with a small sample size of n=3, but indicates a pattern that could be a basis for further research. Looking at individual services, the value of crops as an ESS increased the most for Odalsbekken under S1, with a surplus of approx. 40% (Appendix 13).

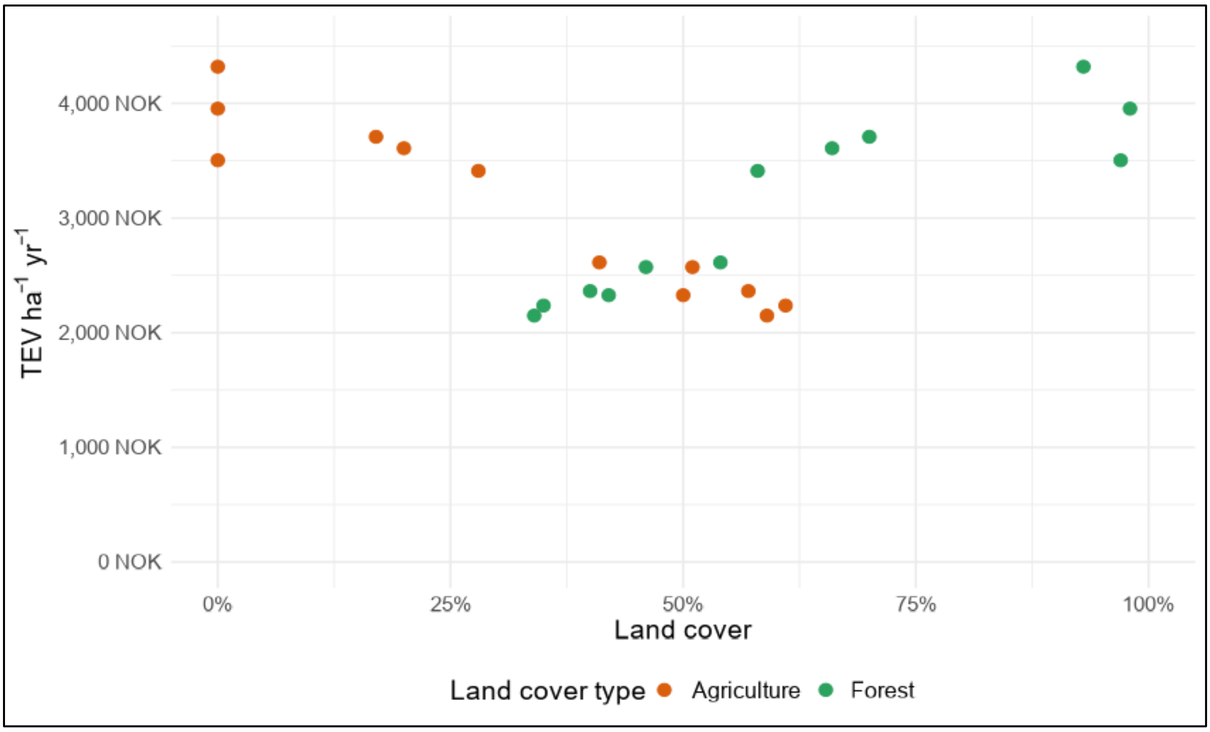

Figure 13. Agricultural land cover and forest land cover to TEV ha^{-1} yr^{-1} across all scenarios and streams

Forest-based ESS declined similarly in Odalsbekken and Solbergbekken under S1 (-12%), and strongly in Knattvollbekken (-20%). The scenario implementing a ten-meter woody buffer along the streams (S2) benefited forest-based ESS most in Knattvollbekken (+29%) and least in Odalsbekken (+6%). This could be because Odalsbekken had an already better-developed riparian woody buffer in comparison to Solbergbekken (section 5.1). S3, on the other hand, led to the highest forest-based ESS surplus in Solbergbekken (approx. 149% surplus), a high surplus of 130% in Knattvollbekken and a moderate surplus of around 40% in Odalsbekken. The two agriculturally dominated streams, Knattvollbekken and Solbergbekken, profited most from maximised forest cover in the riparian zone, since they had less baseline woody vegetation. In other words, there is more potential for ESS value improvement. Appendix 13 gives a comprehensive overview of the changes to all individual services under the scenarios.

5.4 Partial Sensitivity Analysis

As Figure 14 shows, the TEV ha^{-1} yr^{-1} was nearly unaffected by the adjustment of the carbon price. After the 50% increase, TEV ha^{-1} yr^{-1} increased by approx. 2%. This indicates the comparably small relevance of the carbon price and sequestration rates, as other services contributed more to the TEV (carbon price accounted for 4–5% of the TEV ha^{-1} yr^{-1} in all streams).

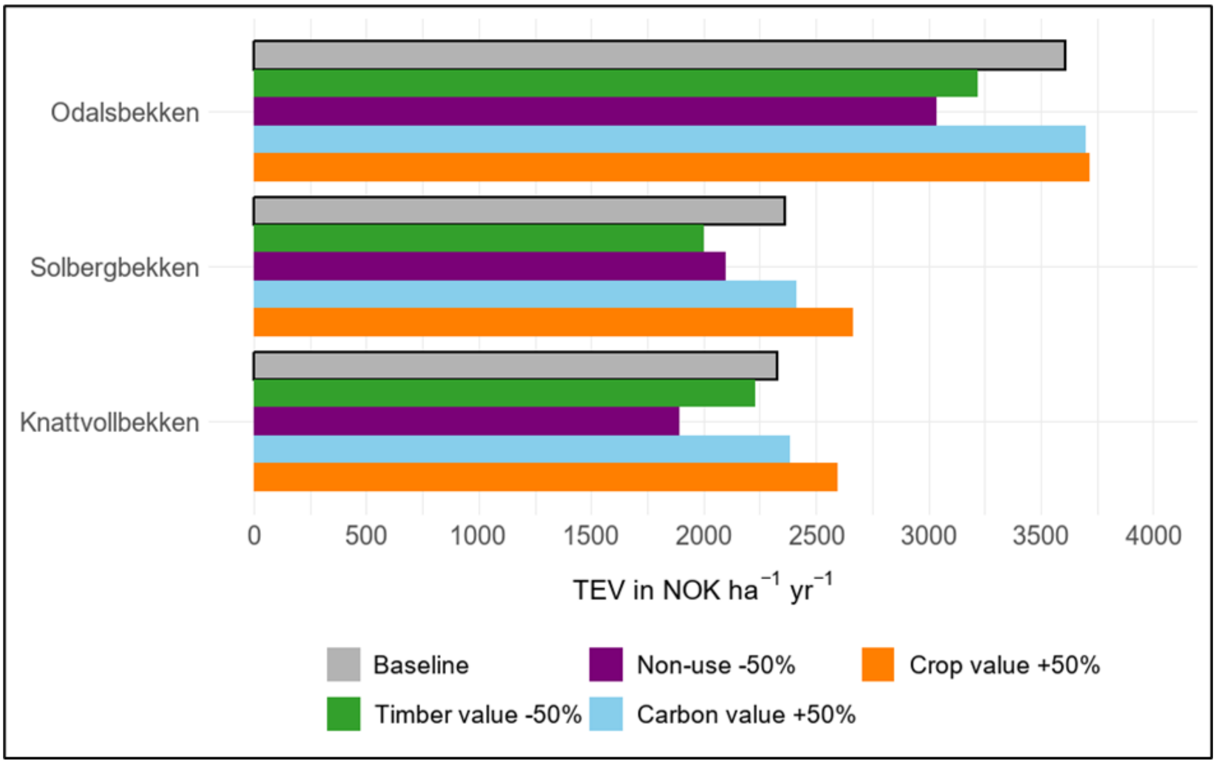

Figure 14. Sensitivity Analysis in all three streams over four variables and the baseline

The most significant changes in TEV ha^{-1} yr^{-1} of all investigated parameters in the partial sensitivity analysis were caused by the down adjustment of monetary non-use value (Figure 14). This mainly affected Odalsbekken (-16%) and Knattvollbekken (-19%). Solbergbekken was the only stream in which non-use did not rank first in ESS value order (Table 6), which reflects in lower sensitivity (-11%). Increasing the value of crops by 50% showed strong positive effects on TEV ha^{-1} yr^{-1} in the agricultural streams Knattvollbekken (+12%) and Solbergbekken (+13%). In Odalsbekken, where agriculture only constituted 19% of total land use, the TEV ha^{-1} yr^{-1} increased by 3% with a 50% crop value increase. Halving the value of the ESS timber showed the strongest effects in Odalsbekken and Solbergbekken (-11% and -15%) but only a comparably weak impact on Knattvollbekken (-4%), which had the lowest timber value of all three streams (Table 6).

One interesting aspect was the change in overall dominance of forest-related ESS if the sensitivity scenarios were to apply simultaneously. Neglecting the carbon price due to the low sensitivity and applying +50% crop value, -50% non-use value, and -50% timber value would lead to a share of forest-related ESS of 51% (Odalsbekken), 43% (Solbergbekken) and 40% (Knattvollbekken) from TEV ha^{-1} yr^{-1}. This means that the overall pattern of increasing TEV ha^{-1} yr^{-1} with increasing forest cover would only hold for Odalsbekken, while for Knattvollbekken and Solbergbekken, crops would yield the highest share of TEV ha^{-1} yr^{-1}, and agriculture would be the driving force of TEV. The next chapter discusses the implications of these observations and comparisons with other literature.

6 Discussion

6.1 Interpretation of Results

Land Use and Ecosystem Service Contribution

The findings in Chapter 5 made clear that it is possible to quantify ESS values on a first-order stream basis in Norway, mainly using local statistical data. Most ESS were linked to the existence of forests and riparian vegetation in the three studied stream valleys. This relatively small sample of three streams indicates support for the results from Immerzeel et al. (2021), who found that a larger local population size contributes positively to the TEV (especially via cultural ESS). In comparison to other ESS quantification studies in Europe, the TEV ha^{-1} yr^{-1} of Odalsbekken, Solbergbekken and Knattvollbekken were in the lower end of the ranges from Vermaat et al. (2021) and Immerzeel et al. (2021), who include a total of ten other streams studied in Europe (Table 8).

Comparing individual ESS showed a similar pattern, with the ESS ha^{-1} yr^{-1} in this study being on the lower end of the range of observations, despite different assessment methodologies (Table 8). Some locally induced differences were not taken into consideration for this comparison. For example, provisioning ESS like "drinking water", "milled peat", and "hydropower" are difficult to compare since they are tied to context-specific extraction and infrastructure and not utilised in any of the investigated streams of this study. The investigated streams might also have the potential to generate local hydropower, but this ecosystem structure (combination of flow, slope, and morphology of the stream) was not utilised as an economic service as of 2025.

Another context-specific example was angling: The value of angling in this assessment was zero due to the law prohibiting in-stream fishing (Forskrift om fiske etter anadrome laksefisk i vassdrag, 2021). However, the stream still provides a spawning habitat for several species that are attractive for fishing (e.g. sea trout). These can be fished in the fjord, and therefore the streams have most likely a benefit for fishing, which was just not quantifiable for this study and thus conservatively assessed as zero. The assessment of flood protection was especially low compared to Immerzeel et al. (2021) and Vermaat et al. (2021), most likely due to the relatively unrobust and simple value assessment applied for this study, which is based on potential flood damage to (only) agricultural land. The studies differed strongly in flood protection methodology, which complicates comparisons. Another ESS value comparison that should be highlighted is recreational value. This value was also low in this study (Table 8). This is due to the assessment excluding any form of national or regional tourism and just estimating the recreational value of locals with adjustments in travel cost value.

Generally similar services have been identified in the two other studies and this assessment, except for Immerzeel et al. (2021), who did not include “non-use”, “water quality improvement” and “erosion control”. Comparing Knattvollbekken from this study with Haldenvassdraget, a Norwegian catchment, showed a rather similar estimation of annual TEV ha^{-1} yr^{-1} (Immerzeel et al., 2021). Although it must be stated that Immerzeel et al. (2021) researched on a catchment basis, not only the riparian zone.

*Table 8. Comparison of this study's ecosystem service value range with the European studies Immerzeel et al. (2021) and Vermaat et al. (2021). *Vermaat et al. (2021) only explicitly reported values >5€ ha^{-1} $yr^{-1,}$ so if no value was given but the ESS was assessed, <5€ were assumed.*

Ecosystem Service (CICES)	This study, n = 3 (NOK ha^{-1} yr^{-1})	This study, (€ ha^{-1} yr^{-1})	Immerzeel et al. (2021), n = 6 (€ ha^{-1} yr^{-1})	Vermaat et al. (2021), n = 4 (€ ha^{-1} yr^{-1})
Crops (1.1.1.1)	215–609	18–52	0.25–118 *(Halden: 11)*	42–464
Milk, meat, wool (1.1.3.1)	0–24	0–2	4–99 *(Halden: 7)*	50–168
Timber (1.1.5.2)	195–780	17–67	9–130 *(Halden: 60)*	<5 –63*
Game (1.1.6.1)	11–39	1–3	0–8 *(Halden: 8)*	<5*
Foraging (1.1.5.1)	38–76	3–6	0–2 *(Halden: 0.37)*	<5*
Peat (1.1.5.2)	0	0	0–65 *(Halden: 0)*	—
Hydropower (4.2.1.3)	0	0	0–4 *(Halden: 4)*	<5*
Water use (4.2.1.1/4.2.2.1)	0	0	0–109 *(Halden: 26)*	<5–353*
Flood protection (2.2.1.3)	32–54	3–5	0–15 *(Halden: 1)*	279–487
Carbon sequestration (2.2.6.1)	107–178	9–15	2–260 *(Halden: 85)*	5–10
Water quality improvement (2.2.5.1)	237–399	20–34	—	<5–13*
Erosion control (2.2.1.1, 2.2.1.2)	6–13	~1	—	<5*
Recreation (3.1 pooled)	53–718	5–61	31–7,080 *(Halden: 181)*	85–185
Recreational hunting (separate from game)	38–78	3–7	0.1–5 *(Halden: 1)*	—
Recreational angling	0	0	0–19 *(Halden: 0.26)*	13–70
Active recreation (Travel value)	15–640	1–55	30–7,079 *(Halden: 180)*	72–115
Non-use (3.2 pooled)	531–1144	45–98	—	17–73
TEV	**2,327–3,609**	**199–309**	**183–7,199 (*Halden: 384*)**	**538–1,590**

Notable exceptions from the general lower-end estimations of this study in comparison with Immerzeel et al. (2021) and Vermaat et al. (2021) were “timber”, ”water quality improvement”, “foraging”, and “non-use”, where results fell more in the medium-high part of the range. The ESS “timber”, “foraging”, and “non-use” were mainly connected to Norwegian data sources, which might indicate a higher ESS provision of the local riparian zones in comparison with the riparian zones from other geographical contexts, but methodologies also varied.

Other international studies also found relatively high estimates compared to this study. Natho and Hudson (2024) report an average TEV of €4355^{2015} ha^{-1} yr^{-1} across 14 studies focused on floodplains in Germany, with 50% of TEV being contributed by flood regulation. A meta-study from De Groot et al. (2012) across 320 ESS publications with ten assessed biomes found values between \$1446^{2007} and \$7757^{2007} ha^{-1} yr^{-1} (mean \$4267^{2007}) for rivers and lakes. Values ranging between \$1373^{2007} and \$2188^{2007} ha^{-1} yr^{-1} (mean \$1588^{2007}) were reported for woodlands (De Groot et al., 2012). The authors stated that generalisation from the meta-study is difficult due to the large value range and context-specificness of ESS estimations on the case-study scale. Still, comparing De Groot et al. (2012) and the other peer-reviewed literature mentioned in this chapter, with the results from this thesis, indicate that it is unlikely that this thesis significantly overvalues individual ESS or the TEV ha^{-1} yr^{-1}.

Regarding the generalisability of the results in the municipal context, Figure 8 shows that the selected streams were not all representative of the other riparian zones in the municipality regarding land use. Solbergbekken was the most representative in the combination of forest cover and agriculture. Nevertheless, many of the ESS valuations were based on municipality data and could therefore be used for further assessments of other streams and their riparian zones in the Oslofjord.

Scenario Analysis

The findings did not confirm the exact pattern found in Vermaat et al. (2021), that the increase in cultural services and riparian forest cover would be at the expense of provisioning services. This study aligns with the findings from Felipe-Lucia et al. (2014), in estimating a general increase in provided ESS with the increase of forest cover in the riparian zone. However, it must be noted that this thesis did not include feedback loops/ knowledge rules, as in Vermaat et al. (2021), since they were either not applicable or not suited for the scale of the studied streams. This means that the grade of complexity is lower. The increase in ESS value from provisioning services with rising forest cover was mainly due to the high timber value compared to agriculture, as reported in this study. Both values were based on local statistics of the actual monetary value extracted from agricultural land or forest. The discrepancy with Immerzeel et al. (2021) could lie in the aspect of a less productive agricultural system in Norway, with western European countries like France and Germany having amongst the highest crop yields in Europe due to good climatic conditions (Schils et al., 2018). Although being a speculative indication, three out of four streams researched had lower timber values per hectare than crop value in Vermaat et al. (2021).

Another important factor for the different behaviour of provisioning services with maximised woodland between this thesis and Vermaat et al. (2021) could be the near-absence of dairy farms and pastures in the three riparian zones of the Oslofjord. These are assessed with a comparably high ESS value (Immerzeel et al., 2021; Vermaat et al., 2021). Hence, they are strongly contributing to the value of provisioning ESS. Pastures were only present to a small degree in the riparian zone of Knattvollbekken (<1% land cover).

Besides the valuation itself, it is relevant to look at the question of who benefits from the ESS provision and potential land-use changes (Immerzeel et al., 2021). A maximum TEV with full forest cover might be the maximum benefit to the general society, according to this thesis. Still, individual stakeholders might have to take net losses in such scenarios. An example could be farmers, taking a net loss with increasing forest cover and increasing TEV, because agricultural yield declines with declining agricultural land use. When discussing ESS and TEV, policymakers must address and moderate these issues. In the study area, this is already done through financial incentives and subsidies for farmers in all three municipalities, if they implement grass buffers around streams (County Governor, 2025). The results of the scenario analysis support the idea of developing similar schemes for woody vegetation along agricultural streams as well.

Felipe-Lucia et al. (2014) raise the question of scale when investigating ESS in the landscape. They found that riparian forests have a particularly high value on the local scale, but other ESS-providing land uses might be more relevant on the municipal scale. A concrete example would be cropland. This work focused on the riparian zone (small scale), but if one extends the TEV to municipal scale, crop production could likely become a more relevant ESS in comparison to the other ESS provided in the riparian zone, simply due to the size of the total agricultural area (Felipe-Lucia et al., 2014). This highlights that the question of scale is vital to consider for landscape management utilising the ESS approach.

Partial Sensitivity Analysis

The partial sensitivity analysis (section 5.4) revealed that the assessment methods were particularly sensitive to the change in “non-use” in all three streams and, to a limited extent, sensitive to value changes for timber and agriculture. The partial sensitivity analysis was not exhaustive enough to create any concrete future predictions or robust statistical relationships between different variables, which is also due to the small sample size. Still, it revealed that future price changes have the potential to alter the trends between land use and TEV found in this study. For timber and agriculture, long-term averages were used in the ESS estimation to average out the value fluctuations from wood or agricultural goods, which were visible in the raw data (SSB, 2024a, 2025c). However, if timber value would for some reason decline in southeastern Norway and the value of the agricultural land rises (e.g. due to price increases or more efficient farming methods), agriculture could take over most of the value generation from provisioning services in the riparian zones. This study does not allow for a prediction of price factors, and it is not possible to say if one price scenario is more likely than the other. However, it is to be expected that price changes will have a higher influence in the short-term future on changing the ESS value than a change of land use might have, since prices of traded goods can be subject to sudden market changes. In contrast, land use in Norway (particularly in riparian zones) is under regulatory oversight (section 2.3), long-term planned, and often tied to private or public ownership.

The assessment of non-use has varied in Vermaat et al. (2021) and this study, Immerzeel et al. (2021) did not assess non-use, and non-use as an immaterial ESS is challenging to quantify (Natho & Hudson, 2024; Small et al., 2017). Despite the uncertainty lying in the assessment of non-use, it is included here to reflect the importance of the non-material relationship that humans have with nature.

6.2 Hypotheses

Reverting to the initial objectives of the thesis, each hypothesis is briefly evaluated in the light of the results.

Hypothesis I

The relative importance of final ESS contributing to TEV depends on the land use of their riparian zones.

The first hypothesis can be partially confirmed. A positive relationship between forest cover and TEV was observed, and the balance between forest cover and agriculture was found to have the most significant influence on the estimated TEV. However, the results indicate that land use is not the only relevant variable. The local population density, for example, had a strong impact on cultural ESS provision. Immerzeel et al. (2021) also suggest that other stream parameters have an effect on TEV (e.g. geology, stream slope, accessibility). This could not be assessed in this study.

Hypothesis II

Riparian woodland cover is the major driver of ESS provision in the riparian zone.

The results of this thesis support Hypothesis II. Among all land-use classes, most ESS in the riparian zone were connected to riparian woodland cover (even if not all are material). This was true for all investigated streams, and TEV increased in all streams with increased woodland cover. This holds true for both the baseline scenario and the price levels used, although its validity is to be seen in light of the limitations explained in the sensitivity analysis.

Hypothesis III

Future policy and different land-use scenarios change the TEV and economic importance of different ESS in the riparian zone.

The results support the third hypothesis. As the scenario analysis showed, humans as landscape stewards can change the capacity of ESS provision of riparian zones. If riparian buffers are protected and established, the dominance of forest-related ESS is likely to increase in the landscape. However, if society were to choose a more intensive agricultural management, this could lead to an increase in different values of riparian buffers, such as pest control and flood protection value. The TEV and TEV ha^{-1} yr^{-1} also changed with the application of the three different scenarios, which supports the hypothesis as well. The scenario analysis has only covered land-use scenarios, while the sensitivity analysis revealed that the economic yield of agricultural land had an effect on the TEV of agriculturally dominated lowland streams. Hence, the intensity and pricing of food in the future, which could be policy-driven, could change the balance of economic importance towards the agricultural landscape and away from forest-linked ESS.

6.3 Methodological Limitations

Spatial data quality

The assessment of the different ESS can only be as accurate as the spatial data input for the land use of the riparian zones. With the AR5 dataset, a high resolution and precision for the Norwegian land use was chosen, but there are still shortcomings in remote sensing compared to the reality on the ground. AR5 is technically a “land-resource” map. That means that the AR5 class does not always correspond to the actual land use on the ground. Arable land, for example, can also remain as an unused meadow and will still be classified as agriculture, to name only one example (Alhstrøm et al., 2019). Operating with the assumption that the agricultural system works as efficiently as possible and utilises all possible areas is a potential error source of this study. Other spatial data quality issues lay in the misalignment of the two datasets, “elvenett” (NVE, 2025a) and the floodplain area (NVE, 2020). This was mitigated through methodological adjustments (section 4.2) and a field trip to identify falsely classified stream water bodies (section 4.3). Still, the extent of the ground-truthing field trip was not enough to confirm all parts of the stream as correctly classified.

The definition of the riparian zone was mainly based on data from NVE, but NVE acknowledges that the “Aktsomhetskart for flom” has significant methodological challenges and that the floodplain area (although based on a 500-year flood) might still be overestimated (NVE, 2020). Nevertheless, the data provided by NIBIO and NVE is the best publicly available spatial data for Norway that could be found and ensures that other scientific work can build on the data presented here.

Other methodological limitations

The data quality for the different service estimations varied greatly. While provisioning services were relatively straightforward to estimate and local data was often available even at the municipality level, regulating and cultural services were more challenging to estimate for the study area. The service flood protection, for example, was generated from damage values assessed in central Europe and not Norway (De Moel & Aerts, 2011), and while overall flood risk could be labelled as an ESS- disservice, a service component was isolated for this study. Only the component flood protection of agricultural land was included, while potential flood damage to structures and residential areas was ignored. This was mainly because no hydrological models were available for this study to estimate actual flood prevention. Consequently, flood protection was expressed as the avoided damage by the forest area not being used as agricultural land. This only reflects a fraction of the potential flood-regulating benefit to society: Barth and Döll (2016) identified six economic benefits and three social benefits of riparian forests regarding flood protection in a German catchment. They used water retention rates of a riparian forest to estimate the value of flood protection and found that in their case study, the riparian forest generated a flood protection ESS of €4300 ha^{-1} yr^{-1}, assuming a 10-year flood. It was a highly populated area; hence, the monetary evaluation is not to be compared with the three streams of this study. Still, these findings highlight that the value of flood protection can be comprised of more aspects than just the avoided damage to agricultural land. While reflecting a benefit to overall society from not having to compensate for flood damage, it likely represents a net loss for farmers and landowners if agricultural land is replaced with riparian vegetation to increase flood protection (see section 6.1).

Another aspect that needs to be discussed is the absence of recent and local surveys to assess the cultural ESS. Although value estimations were based on Norwegian surveys about travel behaviour and non-use value, the generalisability of other case studies to the study context in this thesis is uncertain. For the estimation of recreation, only local tourism estimates from Juutinen et al. (2022) were considered, while regional or international tourists were disregarded entirely. Field surveys could mitigate these methodological uncertainties.

Shortcomings of the Ecosystem Service Framework

It must be emphasised that comparisons between different ESS quantification studies can be challenging due to different assessment methodologies (Boerema et al., 2017). Regarding assessment data sources and value estimates, this thesis is aligned closest with the valuation methods of Immerzeel et al. (2021). In addition to problems of comparability, especially the estimation of cultural ESS and non-material ESS poses a challenge (Small et al., 2017). This is relevant since cultural ESS constituted 24–52% of TEV ha^{-1} yr^{-1} in the investigated riparian zones, and it is possible that the applied valuation methods did not cover some non-material values for specific stakeholder groups.

Apart from methodological insecurities that follow with the attempt to estimate ESS to quantify nature's functions into monetary “services” or “contributions”, some scholars, as shortly introduced in section 2.3, criticise the approach itself on principle (Muradian & Gómez-Baggethun, 2021). Ethical arguments critique the framing of nature as a contributor to humanity and an anthropocentric interpretation of the value of nature (Schröter et al., 2014). Evaluating ecosystems under a monetary ESS framework could also lead to the conclusion that some ecosystems provide disservices or are not generating “win-win” solutions for humanity and nature (McCauley, 2006). Hence, monetary valuation methods like those applied in this study should not be directly translated into market-based conservation regimes.

While acknowledging the ethical critique and shortcomings of the ecosystem framework, conventional conservation efforts have not solved the crisis of biodiversity and the overall deteriorating Earth system yet (Richardson et al., 2023). In this situation, one could argue that it can be considered ethically questionable *not to* value nature's benefits to humanity if frameworks like NCP or ESS are at our disposal to do so. After all, any comparison of alternatives, be it changes in land use or projected infrastructure against untouched nature, involves the weighing of criteria, and the choice of one alternative implies the rejection of another. The decisions in landscape management are made nevertheless, and the ESS concept can transparently communicate the value of functioning ecosystem services in these decision-making processes (Costanza, 2024). The concept of ESS or NCP can also be used as a line of thought to reconnect people with nature through highlighting our dependence on functioning ecosystems (IPBES, 2024; Schröter et al., 2014). Another argument for continuing the assessment of ESS on different geographical spheres is that states and international organisations are applying or planning to apply ESS accounting as a policy tool (Norwegian Environmental Agency, 2022; United Nations, 2024). Especially in Norway, where political focus has been put on pressured ecosystems and a national calculation of nature capital is intended (Norwegian Environmental Agency, 2022), it is essential to conduct scientific research on different scales. Equally important is an active discussion about the validity of various approaches for a just and accurate assessment of what ecosystems provide to the planet and especially to humanity.

6.4 Recommendations for Future Research

The following methodological recommendations can be given to address the limitations expressed in the discussion chapter:

a.) ***Local field studies or surveys*** should support estimations about human behaviour. This could lead to more validity, especially for cultural ESS, which are largely dependent on humans using the landscape to recreate, relax, or simply appreciate it. Knowing more about how people do so in the regional and local context will lead to more accurate value estimates and allow for better targeted management. A survey in the same study area of this thesis could be of great value to verify or correct the desktop approach.

b.) ***Better analysis of beneficiaries and stakeholder engagement*** could lead to a better understanding of the investigated area. Assessing who is benefiting to what extent from different ESS could bring an equity and justice component to more targeted landscape management. Local judgment and experience could contribute meaningfully to value estimations. Another potential benefit of intensified stakeholder engagement could be a better alignment of science with policy implementation.

c.) ***A more unified approach to assessing ESS*** is crucial to ensure comparability among studies. Boerema et al. (2017) suggest that subjective adjustments and ambiguous evaluation frameworks lead to dramatically different results. Producing more case studies with standardised assessment methods could reveal patterns in ESS provision and potentially help shape a national framework for assessing nature capital. This thesis and the applied methods, which lean on earlier work from Vermaat et al. (2021; 2016) and Immerzeel et al. (2021), can be used as an initial approach for such a framework.

d.) ***Automation of spatial processing steps*** and subsequent value modelling could enhance the assessment capacity of future studies, especially in the Norwegian context, where data is proven to be available. The generation of riparian zones and land-use information in geographical software should be automated based on the logic and workflow suggested in this thesis, to produce comparable results. Instead of three streams, the assessment could be scaled up to municipalities or counties with efficient programming.

7 Conclusion

This work evaluated the ecosystem services provided by riparian zones in three Oslofjord streams, applying an ESS framework to generate TEV and modelling land-use scenarios to explore potential trade-offs in future landscape management. It presents the first local-scale assessment of this kind in the Oslofjord region.

The small streams in the Oslofjord and their riparian zones provide a wide range of ESS. Using publicly available data, it was possible to estimate these values at the stream scale, though benefit transfers from other regions introduce some uncertainty. Increased forest cover consistently drove higher TEV ha^{-1} yr^{-1} across all streams, with the highest ESS values being linked to provisioning and cultural services, especially where the local population was high. Among the scenarios tested, a potential “Biodiversity first” scenario generated the highest TEV ha^{-1} yr^{-1}, while agricultural expansion under a “Production first” scenario led to reductions in TEV.

For policymakers, the findings suggest that riparian woodland provides quantifiable value to society and should be accounted for in regional or national ecosystem accounting methods. Land-use planning should acknowledge this value by integrating it into the current management regime. Expanding the existing financial incentives for landowners in the Oslofjord could be a tool for preserving or restoring riparian zones and their ESS.

With a sample size of three streams and 13 identified ESS, this work offers a reproducible foundation for scaling up ESS assessments to the municipal or county scale in Norway. Future assessments should focus on refining the valuation of cultural services and improving flood protection estimates.

Finally, the value of riparian zones, expressed through TEV, should not be treated as the market value of the ecosystem, but instead can be included as a conservative estimate of the value of riparian zones to society in landscape management decisions.

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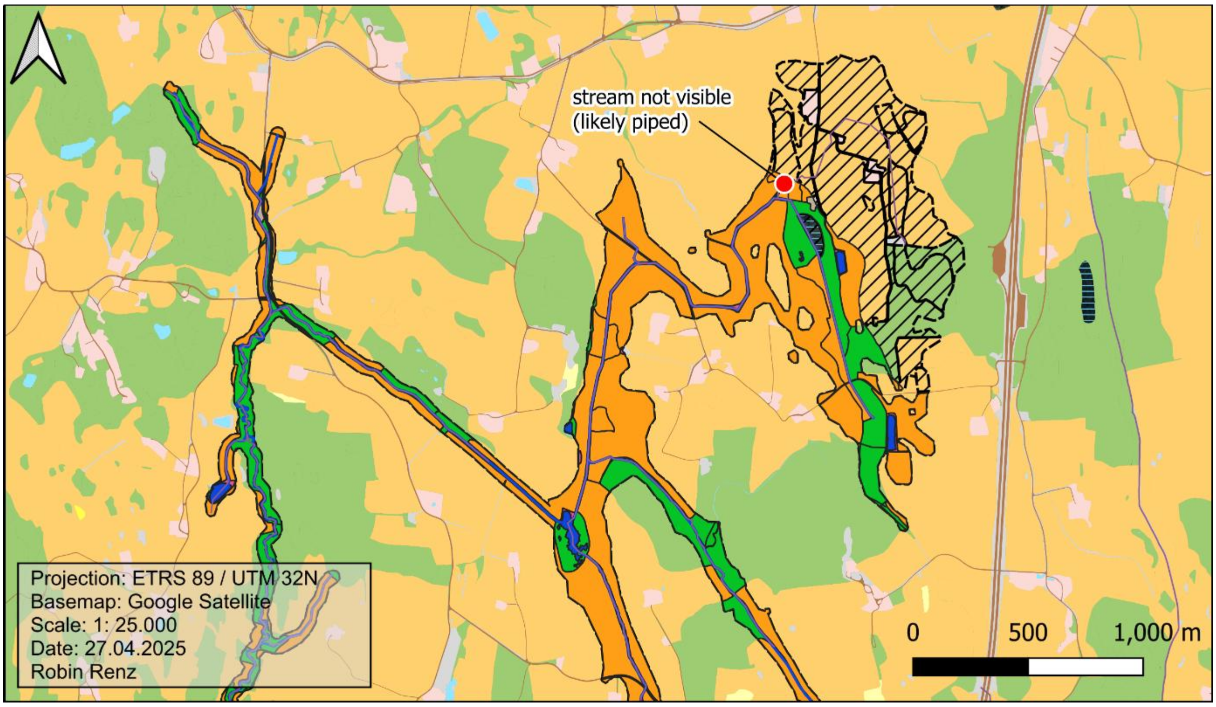
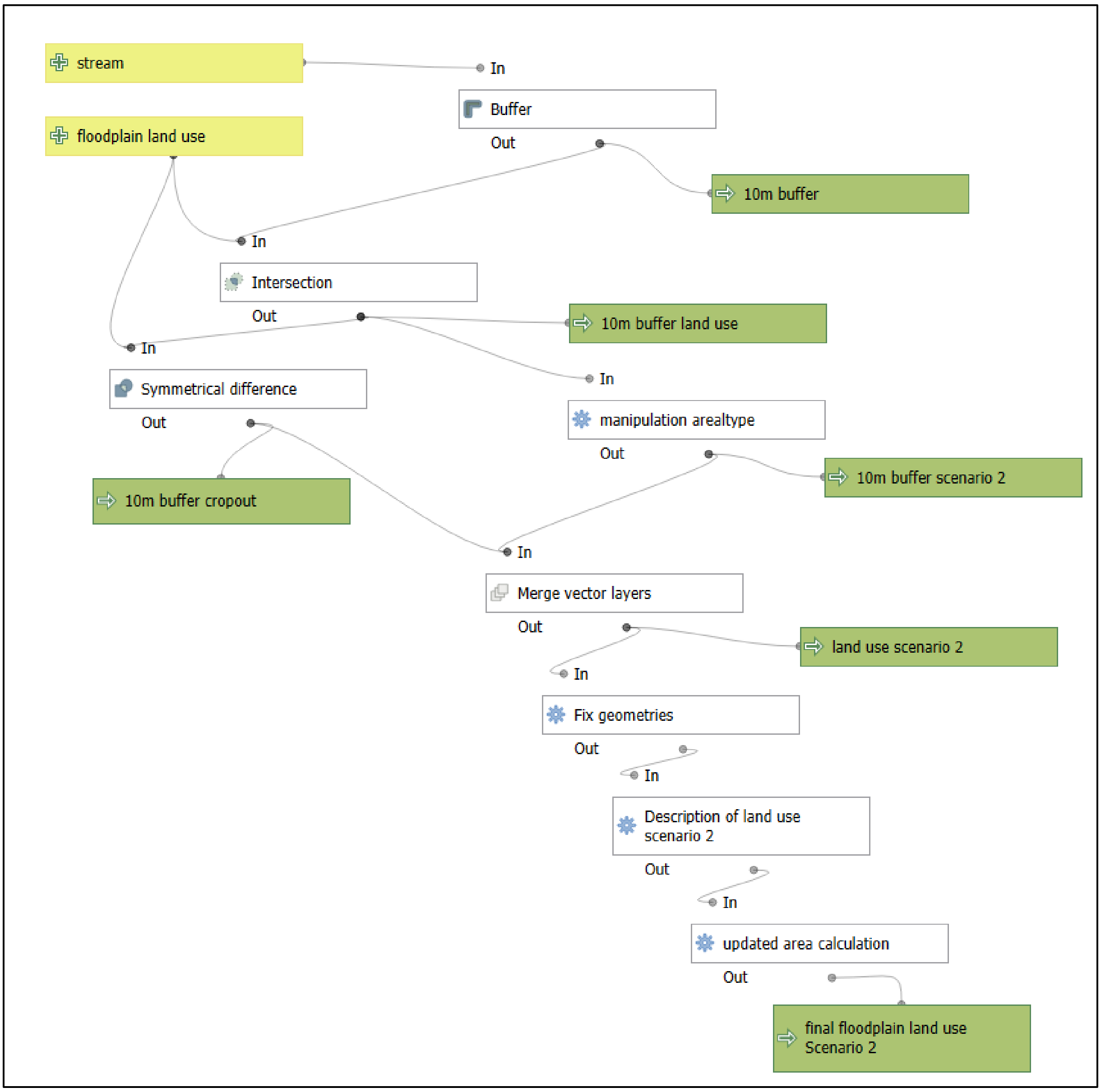
9 Appendix

Appendix 1. Excluded floodplain area of Solbergbekken (black stripes show area removed from the analysis)

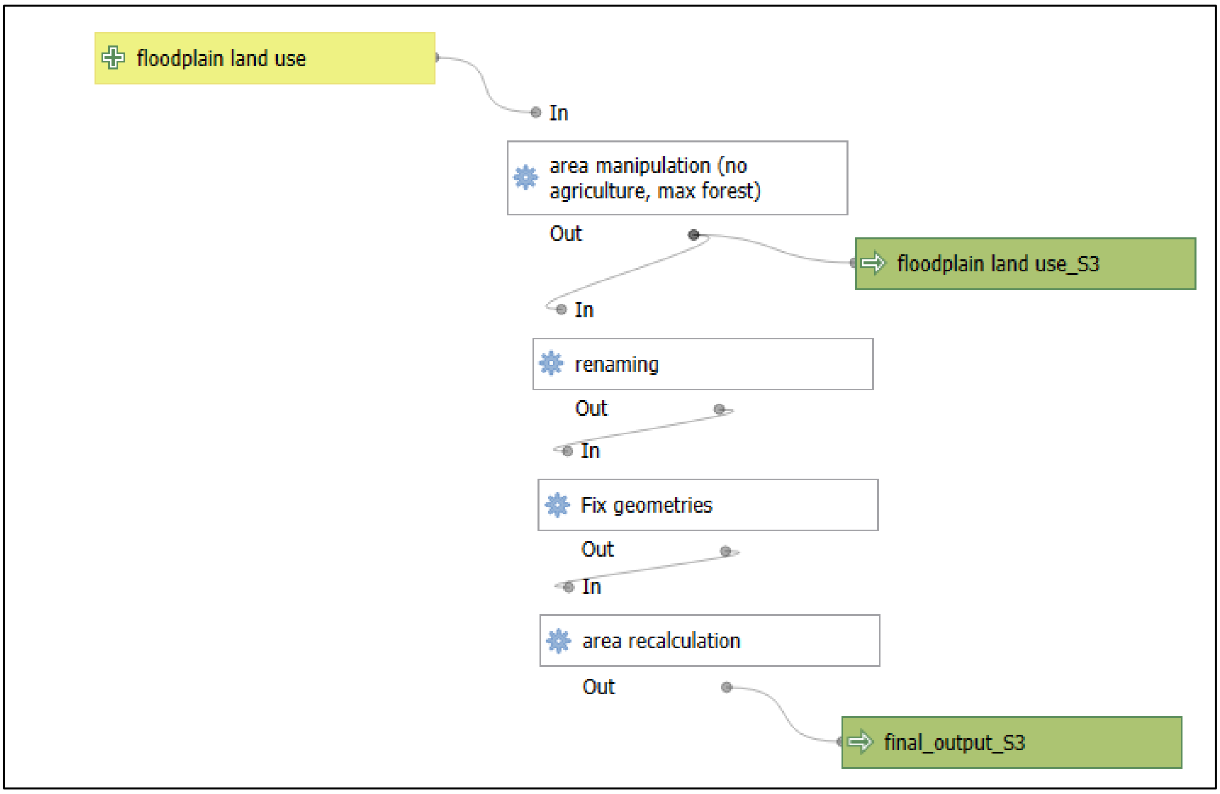


Appendix 2. The three investigated streams. Left to right: Odalsbekken (upper reach), Solbergbekken (middle of the stream), Knattvollbekken (mouth)

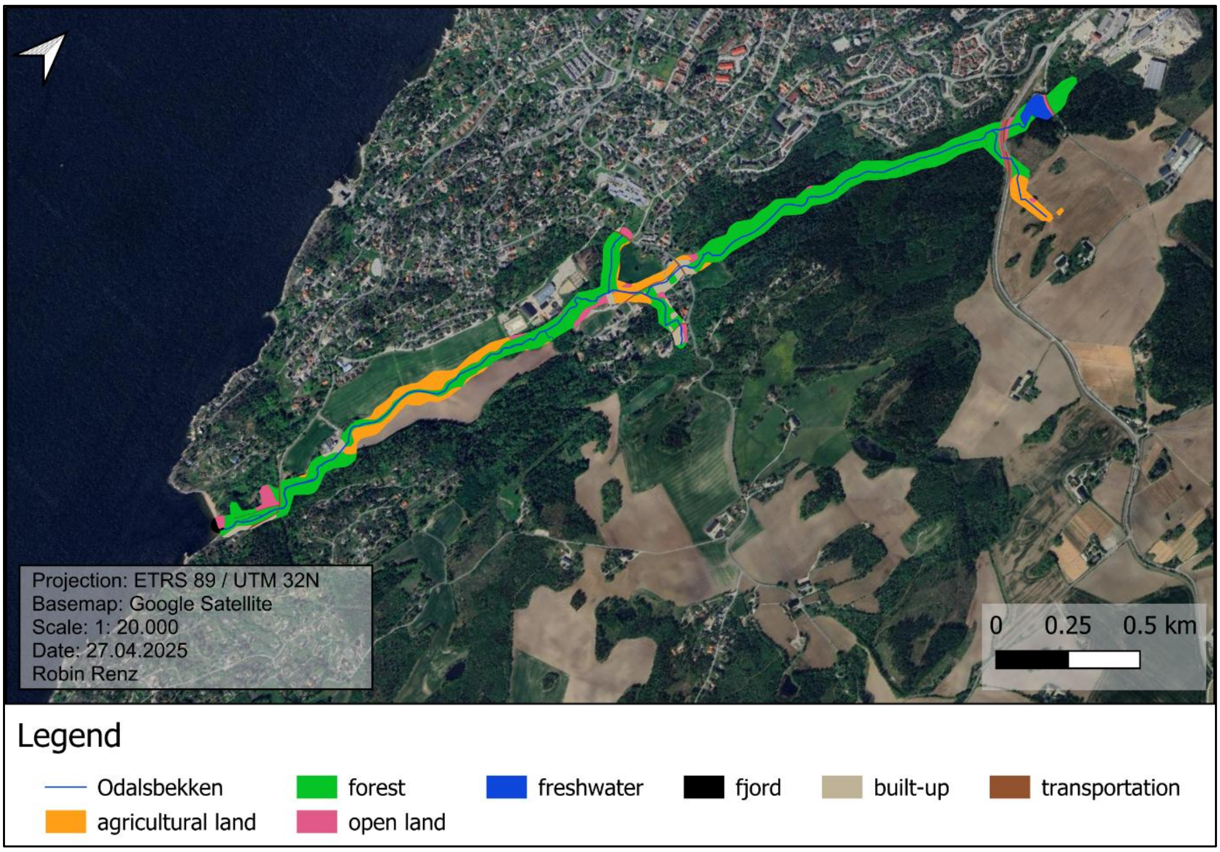
Appendix 3. Inputs in QGIS for the scenario 2 model



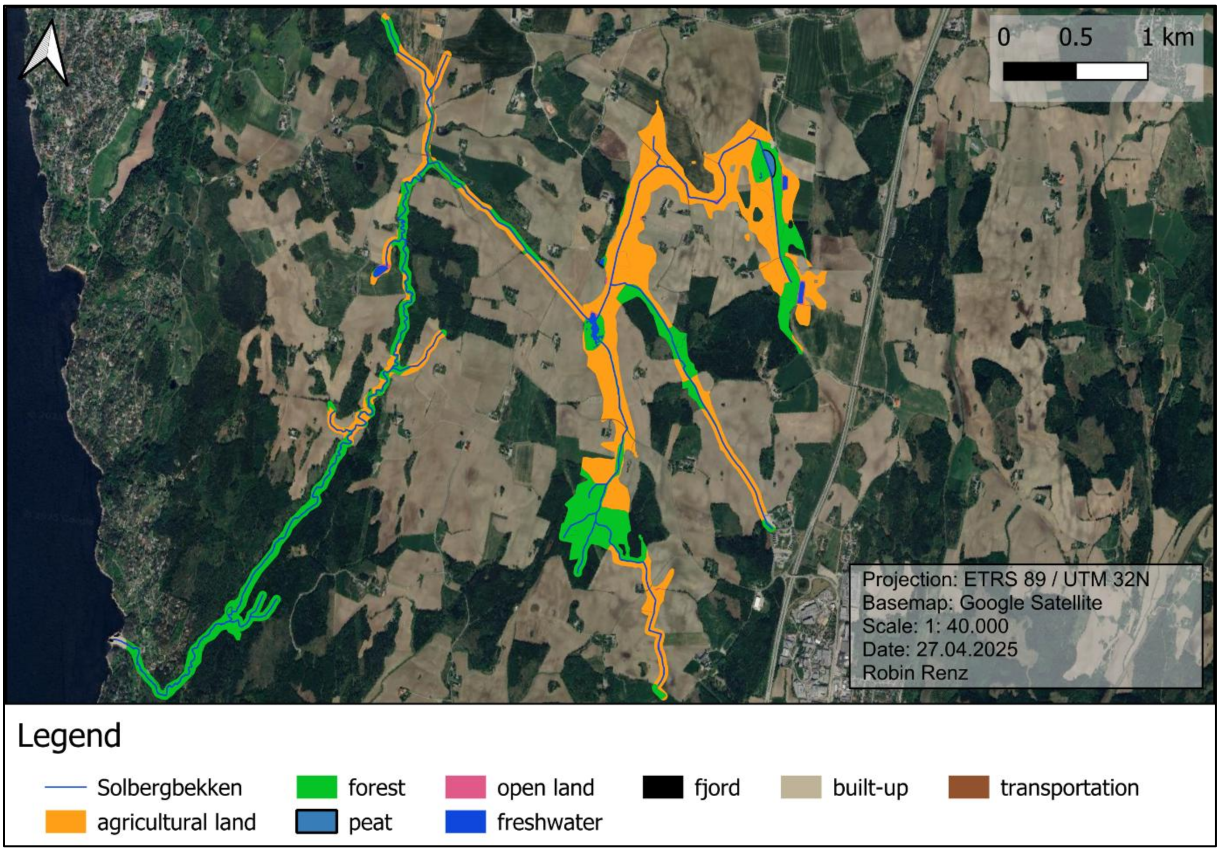
Appendix 4. Inputs in QGIS for the scenario 3 model



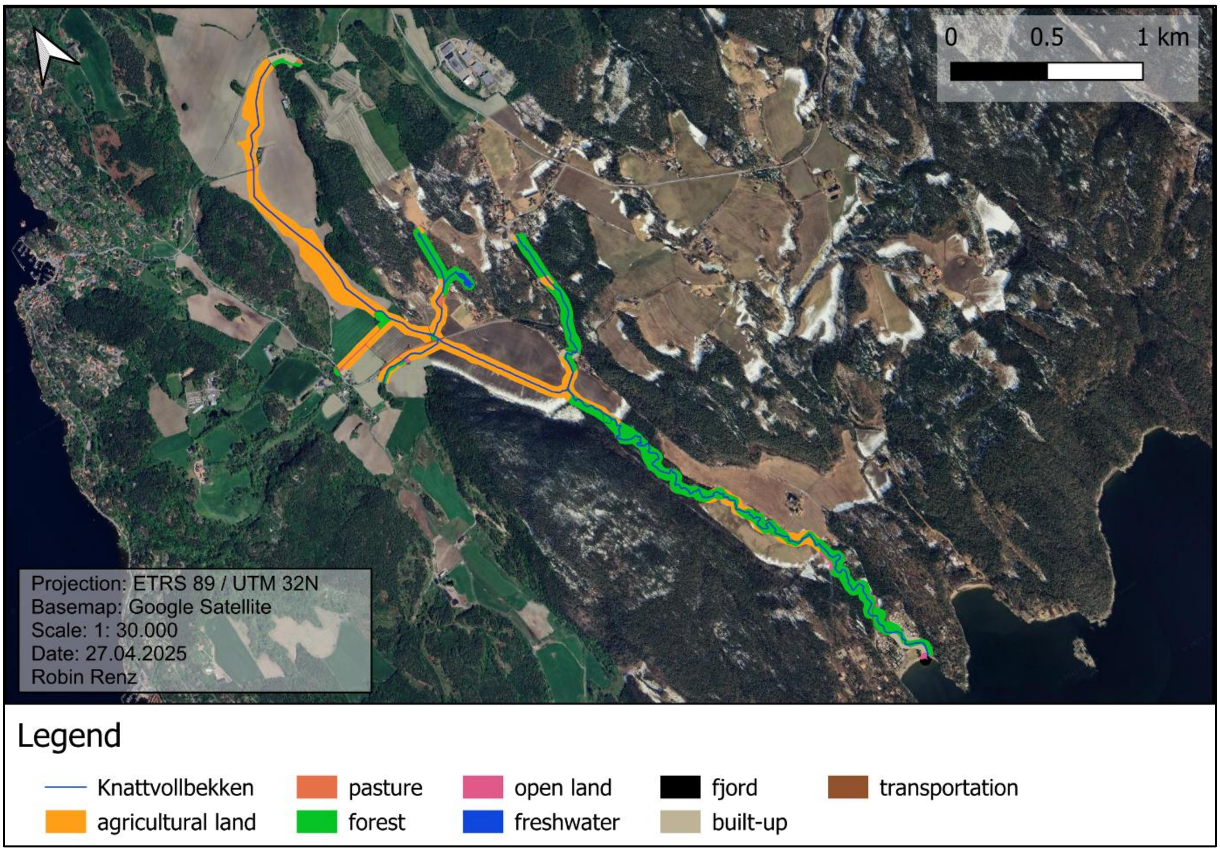
Appendix 5. Land use in the riparian zone of Odalsbekken



Appendix 6. Land use in the riparian zone of Solbergbekken



Appendix 7. Land use in the riparian zone of Knattvollbekken



Appendix 8. Land use in the riparian zones of Frogn, Vestby and Asker

Land-use category (AR5)	**Frogn**		**Vestby**		**Asker**	
open land	42.6 ha	6%	101.6 ha	7%	133.5 ha	4%
built-up	29.3 ha	4%	39.1 ha	3%	307.0 ha	8%
agriculture	212.0 ha	30%	659.0 ha	45%	466.2 ha	12%
peat	16.4 ha	2%	27.0 ha	2%	56.5 ha	1%
pasture	2.8 ha	0%	16.3 ha	1%	45.0 ha	1%
transportation	17.7 ha	2%	40.2 ha	3%	104.6 ha	3%
forest	396.7 ha	55%	589.8 ha	40%	2652.8 ha	70%
Grand total	717.5 ha	100%	1473.1 ha	100%	3765.6 ha	100%

Appendix 9. ESS values before normalisation to riparian zone (Odalsbekken)

Service Odalsbekken	category	CICES code	ESS (NOK ha^{-1} yr^{-1})	hectare area	total ESS value (NOK yr^{-1})	unit per yr
Crops	provisioning	1.1.1.1	1072	5.30	5685	ha/agriculture
Milk, meat, wool	provisioning	1.1.3.1	0	0	0	ha/pasture
Timber	provisioning	1.1.4.2	1175	17.58	20663	ha/forest
Game	provisioning	1.1.6.1	59	17.58	1030	ha/forest
Berries + Mushrooms	provisioning	1.1.5.1	115	17.58	2019	ha/forest
Carbon sequestration	regulating	2.2.6.1	269	17.58	4725	ha/forest
Flood protection	regulating	2.2.1.3	82	17.58	1439	ha/forest
Water quality improvement	regulating	2.2.5.1	2435	4	10582	unit stream kilometre
Erosion control	regulating	2.2.1.1, 2.2.1.2	6	26.50	150	ha/floodplain land
Non-use	cultural	3.2	1725	17.58	30325	ha/forest
Active recreation	cultural	3.1	691	24.55	16973	ha/non-urban
Recreational hunting	cultural	3.1	117	17.58	2054	ha/forest

Appendix 10. ESS values before normalisation to riparian zone (Solbergbekken)

Service Solbergbekken	category	CICES code	ESS (NOK ha^{-1} yr^{-1})	hectare area	total ESS value (NOK yr^{-1})	unit per yr
Crops	provisioning	1.1.1.1	1072	120.07	128779	ha/agriculture
Milk, meat. Wool	provisioning	1.1.3.1	0	0	0	ha/pasture
Timber	provisioning	1.1.4.2	1824	83.60	152507	ha/forest
Game	provisioning	1.1.6.1	55	83.60	4635	ha/forest
Berries + Mushrooms	provisioning	1.1.5.1	97	83.60	8137	ha/forest
Carbon sequestration forest	regulating	2.2.6.1	269	83.60	22471	ha/forest
Carbon sequestration peat	regulating	2.2.6.1	74	1.05	77	ha/peat
Flood protection	regulating	2.2.1.3	81	83.60	6799	ha/forest
Water quality improvement	regulating	2.2.5.1	2435	20.545	50024	unit stream kilometre
Erosion control	regulating	2.2.1.1, 2.2.1.2	13	211.37	2663	ha/floodplain land
Non-use	cultural	3.2	1342	83.60	112173	ha/forest

Active recreation	cultural	3.1	15	208.95	3142	ha/non-urban
Recreational hunting	cultural	3.1	96	83.60	7995	ha/forest

Appendix 11. ESS values before normalisation to riparian zone (Knattvollbekken)

Service Knattvollbekken	category	CICES code	ESS (NOK ha^{-1} yr^{-1})	hectare area	total ESS value (NOK yr^{-1})	unit per yr
Crops	provisioning	1.1.1.1	1072	26.19	28089	ha/agriculture
Milk, meat, wool	provisioning	1.1.3.1	5598	0.22	1235	ha/pasture
Timber	provisioning	1.1.4.2	465	21.78	10136	ha/forest
Game	provisioning	1.1.6.1	26	21.78	572	ha/forest
Berries + Mushrooms	provisioning	1.1.5.1	150	21.78	3258	ha/forest
Carbon sequestration	regulating	2.2.6.1	269	21.78	5853	ha/forest
Flood protection	regulating	2.2.1.3	82	21.78	1783	ha/forest
Water quality improvement	regulating	2.2.5.1	2435	8	20049	unit stream kilometre
Erosion control	regulating	2.2.1.1, 2.2.1.2	13	51.93	675	ha/floodplain land
Non-use	cultural	3.2	2063	21.78	44916	ha/forest
Active recreation	cultural	3.1	18	50.16	920	ha/non-urban
Recreational hunting	cultural	3.1	155	21.78	3372	ha/forest

Appendix 12. Aggregated change in annual TEV and TEV ha^{-1} yr^{-1} across all streams and scenarios. Relative changes in TEV ha^{-1} yr^{-1} for each scenario are highlighted in colour.

Stream	Baseline (NOK yr^{-1})	Baseline (NOK ha^{-1} yr^{-1})	S1 (NOK yr^{-1})	S1 (NOK ha^{-1} yr^{-1})	S2 (NOK yr^{-1})	S2 (NOK ha^{-1} yr^{-1})	S3 (NOK yr^{-1})	S3 (NOK ha^{-1} yr^{-1})
TEV Odalsbekken	95,645	3609	90,420	3411	98,304	3709	114,507	4320
	change to baseline (NOK/%)		-5225	-5.5%	+2658	+2.8%	+18,862	+19.7%
TEV Solbergbekken	499,404	2363	472,782	2237	543,725	2572	835,853	3954
	change to baseline (NOK/%)		-26,622	-5.3%	+44,321	+8.9%	+336,448	+67.4%
TEV Knattvollbekken	120,858	2327	111,578	2149	135,676	2613	181,953	3504
	change to baseline (NOK/%)		-9280	-7.7%	+14,818	+12.3%	+61,095	+50.6%

Appendix 13. Relative change of all ESS for the scenario analysis compared to the baseline

Stream	***Ecosystem Service***	***S1 Change (%)***	***S2 Change (%)***	***S3 Change (%)***
Odalsbekken	Crops	39.9	-14.5	-100.0
Odalsbekken	Milk, meat, wool	NaN	NaN	NaN
Odalsbekken	Timber	-12.0	+5.5	+39.7
Odalsbekken	Game	-12.0	+5.5	+39.7
Odalsbekken	Foraging	-12.0	+5.5	+39.7
Odalsbekken	Carbon sequestration forest	-12.0	+5.5	+39.7
Odalsbekken	Carbon sequestration peat	NaN	NaN	NaN
Odalsbekken	Flood protection	-12.0	+5.5	+39.7
Odalsbekken	Water quality improvement	0.0	0.0	0.0
Odalsbekken	Erosion control	-1.0	+19.6	-100.0
Odalsbekken	Active recreation	0.0	0.0	0.0
Odalsbekken	Recreational hunting	-12.0	+5.5	+39.7
Odalsbekken	Non-use	-12.0	+5.5	+39.7
Solbergbekken	Crops	8.1	-9.5	-100.0
Solbergbekken	Milk, meat. Wool	NaN	NaN	NaN
Solbergbekken	Timber	-11.6	+17.5	+148.7
Solbergbekken	Game	-11.6	+17.5	+148.7
Solbergbekken	Foraging	-11.6	+17.5	+148.7
Solbergbekken	Carbon sequestration forest	-11.6	+17.5	+148.7
Solbergbekken	Carbon sequestration peat	0.0	0.0	0.0
Solbergbekken	Flood protection	-11.6	+17.5	+148.7
Solbergbekken	Water quality improvement	0.0	0.0	0.0
Solbergbekken	Erosion control	-18.7	+58.6	-100.0
Solbergbekken	Active recreation	0.0	0.0	0.0
Solbergbekken	Recreational hunting	-11.6	+17.5	+148.7
Solbergbekken	Non-use	-11.6	+17.5	+148.7
Knattvollbekken	Crops	16.3	-18.9	-100.0
Knattvollbekken	Milk, meat, wool	0.0	-22.8	-100.0
Knattvollbekken	Timber	-19.6	+29.0	+130.3
Knattvollbekken	Game	-19.6	+29.0	+130.3
Knattvollbekken	Foraging	-19.6	+29.0	+130.3
Knattvollbekken	Carbon sequestration forest	-19.6	+29.0	+130.3
Knattvollbekken	Carbon sequestration peat	NaN	NaN	NaN

Stream	***Ecosystem Service***	***S1 Change (%)***	***S2 Change (%)***	***S3 Change (%)***
Knattvollbekken	Flood protection	-19.6	+29.0	+130.3
Knattvollbekken	Water quality improvement	0.0	0.0	0.0
Knattvollbekken	Erosion control	-23.3	+23.1	-100.0
Knattvollbekken	Active recreation	0.0	0.0	0.0
Knattvollbekken	Recreational hunting	-19.6	+29.0	+130.3
Knattvollbekken	Non-use	-19.6	+29.0	+130.3

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