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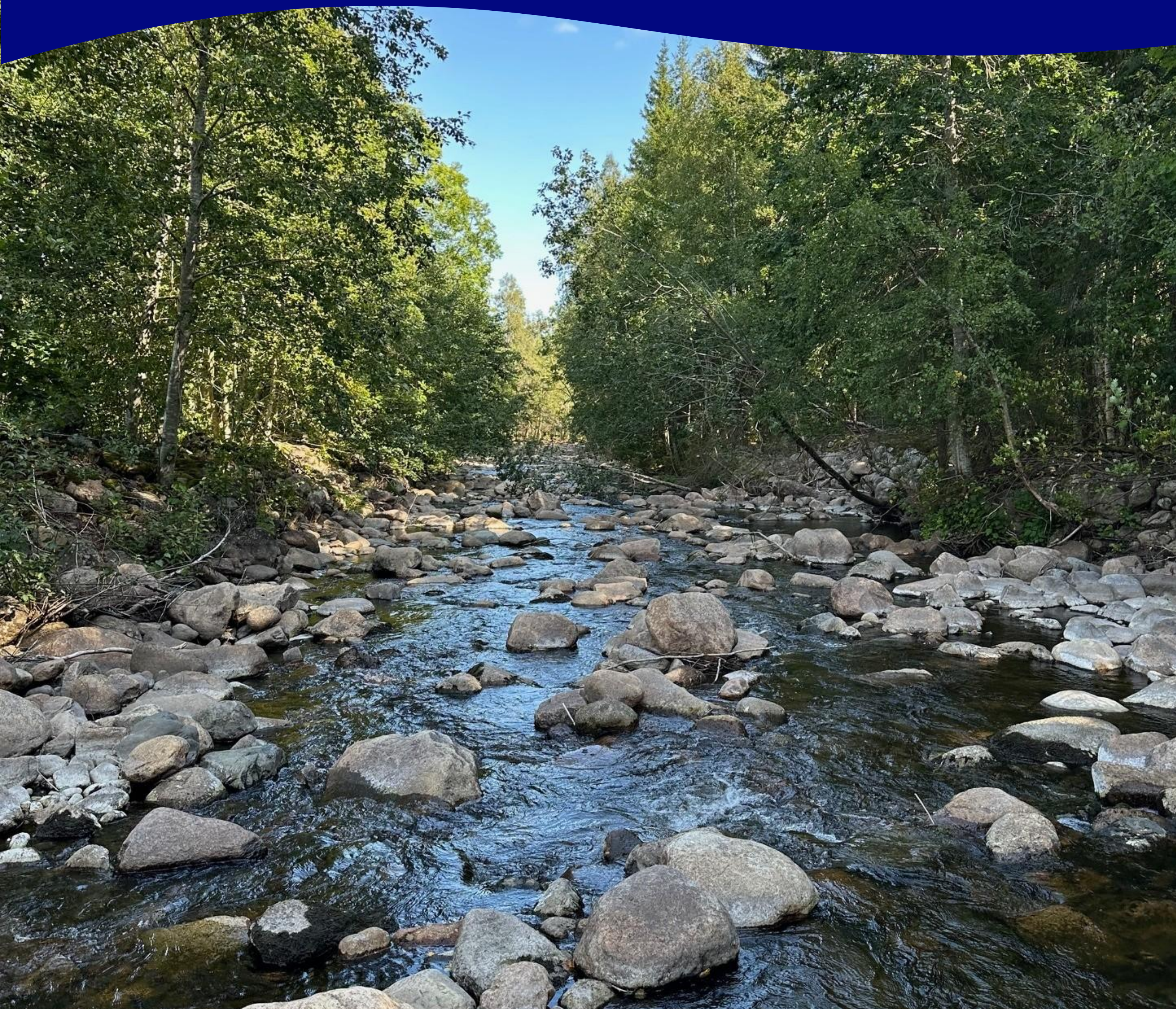
Risk and vulnerability analysis, including an update of the restoration plan for the Hegga river



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Abstract
NIVA, in collaboration with CBEC, was commissioned by the Hurdalsvassdraget/Vorma River Basin Sub-district to assess restoration options for the lower River Hegga in Nannestad, Hurdal, and Gran municipalities, Norway. The river has Moderate Ecological Status under the EU Water Framework Directive due to limited trout spawning and juvenile habitats caused by channel modifications.The project aimed to (1) develop restoration plans and (2) model hydraulic impacts. Work included data review, LiDAR drone survey, and field surveys. Findings show the river, once a multi-thread system, is now a straightened single channel with embankments, disconnected from floodplains. This has increased transport capacity, caused bed armouring, and eliminated key habitats. The most effective measure is selective embankment breaching along the south bank to reconnect floodplain and side channels. Modelling confirmed that targeted breaches can redistribute flows, reduce shear stress, stabilize spawning substrates, and create low-velocity habitats. Larger boulders (>0.5 m) should be reintroduced to enhance roughness and habitat complexity.
While beneficial, these measures will not fully resolve habitat or flood risk issues. The report recommends reconsidering reactivation of the historic southern channel, which could reduce flood risk and restore wet woodland, subject to landowner consent and detailed design.

Keywords: Floodrisk assessment, restoration plan, river restoration, habitat improvement meassures
Emneord: Flomrisikoanalyse, restaureringsplan, elverestaurering, habitatforbedrende tiltak

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Preface

The report presents the results from the risk and vulnerability analysis, including an update of the restoration plan for the Hegga river. The project was carried out by NIVA in collaboration with CBEC on behalf of the Hurdalsvassdraget/Vorma River Basin Sub-district. The contact person at the client has been the Hurdalsvassdraget/Vorma River Basin Sub-district coordinator, Helge B. Pedersen & Steffen F. Hestnes, Hurdal municipality. Johnny Håll has been the project manager for NIVA and Colm M. Casserly for CBEC.

CBEC led on fieldwork, reporting and design development, NIVA together with SpectroFly have been responsible for the UAV LiDAR survey, while NIVA has been responsible for the project. The field survey was undertaken by Colm M. Casserly & Johnny Håll, while the UAV LiDAR survey was undertaken by Trygve Heide (NIVA) and Robert Nøddebo Poulsen (SpectroFly). The report and concept designs were authored by Alberta Edwardes, Colm M. Casserly and Siofra Handibode, with additional design feedback from Hamish Moir. Åse Åtland (NIVA), Jeremy Bunn & Dan Piggott (CBEC) have quality assured the report and Johnny Håll has translated the English summary into Norwegian.

The following individuals participated in meetings, discussions, field visits, and contributed input to the report: Stig Nordli and Fredrik Rølsåsen (Mathisen Eidsvold Værk), Kjetil Finngarden, Ove Bakken, and Harald Hagen (landowners), Christian Juel (Hurdalssjøen Fiskeadministrasjon) Pernille Aker (Hurdal municipality) and Bjørn Otto Dønnum (Hafslund AS). Bjørn Otto and Hafslund AS have also assisted with water flow simulations in order to estimate flood return intervals.

We would like to thank the Norwegian Water Resources and Energy Directorate (NVE) and the Hurdalsvassdraget/Vorma River Basin Sub-district (Huvo) for their financial support for this survey.

All are gratefully acknowledged for their support and collaboration.

Oslo, 15.02.2026

Summary

NIVA, in collaboration with CBEC, was commissioned by the Hurdalsvassdraget/Vorma River Basin Sub-district to evaluate restoration opportunities for the lower River Hegga, located in Nannestad, Hurdal, and Gran municipalities. The river currently holds a Moderate Ecological Status under the EU Water Framework Directive, primarily due to limited spawning and juvenile habitats for native trout caused by extensive channel modifications.

The project aimed to (1) develop restoration plans to improve ecological conditions and (2) to undertake hydraulic modelling to assess the risks and benefits associated with these proposed measures. Work included a desk-based review of historical and geological data, a LiDAR drone survey (June 2025), and field reconnaissance and walkover surveys (July–August 2025). The desk-based review also included an assessment of the report prepared previously by NaturRestaurering (2019) and the options proposed by them, specifically in light of the storm Hans and damage caused to local property. These assessments revealed that the river, once a dynamic multi-thread system, has been straightened into a single-thread channel with embankments, disconnecting it from floodplains and paleo-channels. This confinement has increased transport capacity, leading to bed armouring, loss of hydraulic diversity, and elimination of critical trout habitats.

The most effective intervention identified is selective embankment breaching along the south bank to reconnect floodplain and side channels. Hydraulic modelling of various flood scenarios confirmed that targeted breaches can safely redistribute flows, reduce shear stress, stabilize spawning substrates, and create low-velocity habitats for juvenile trout. Larger boulders (>0.5 m) from breaching should be reintroduced to enhance in-channel roughness and habitat complexity.

Although these measures will improve conditions, they will not completely solve the problems of limited habitat for trout or flood risk under future climate scenarios. The report therefore recommends reconsidering the possibility of reactivating the historic southern channel alignment, which could significantly reduce flood risk and restore wet forest habitat. This requires the consent of the landowners and the development of a detailed design to ensure a culvert of sufficient size under the FV 120 road and a defined channel at the outlet to the lake, so that no homes or properties are put at risk.

Sammendrag

NIVA, i samarbeid med CBEC, ble engasjert av Hurdalsvassdraget/Vorma Vannområde for å vurdere restaureringsmuligheter for nedre del av Hegga, som ligger i kommunene Nannestad, Hurdal og Gran. Elven er i dag vurdert til moderat økologisk status i henhold til EUs vannrammedirektiv, hovedsakelig på grunn av begrensede gyte- og oppvekstområder for ørret som følge av omfattende fysiske inngrep.

Prosjektet har hatt som mål å (1) utvikle restaureringsplaner for å forbedre økologiske forhold og (2) gjennomføre hydraulisk modellering for å vurdere risiko og fordeler ved foreslåtte tiltak. Arbeidet omfattet en gjennomgang av historiske og geologiske data, LiDAR-dronekartlegging (juni 2025) samt feltbefaringer (juli–august 2025). Den skrivebordsbaserte gjennomgangen omfattet også en vurdering av rapporten som NaturRestaurering publiserte i 2019, og de løsningsalternativ som ble foreslått der, spesielt i lys av stormen Hans og skadene den forårsaket på lokal eiendom. Analysene viste at elven, som opprinnelig var et dynamisk forgreinet elvesystem, er rettet ut til et enkelt elveløp med steinvoller, noe som har frakoblet elven fra flommark og eldre elveløp. Denne innskrenkingen har økt transportkapasiteten, ført til fortetting (armering) av bunnsubstratet redusert hydraulisk variasjon og eliminert viktige habitater for ørret.

Den mest effektive tiltakspakken er selektiv åpning av seksjoner av steinvollene langs sørbredden for å gjenopprette forbindelsen til flommark og sidekanaler. Hydraulisk modellering av ulike flomscenarier bekreftet at målrettede åpninger av steinvollene kan fordele vannføringen i elven på en sikker måte, redusere skjærspenning, stabilisere gytesubstrat og skape lavhastighetsområder godt egnet for ungfisk. Større steiner (>0,5 m) fra åpningene bør føres tilbake til elveløpet for å øke variasjonen i strukturen i elvebunnen (ujevnheten) og habitatkompleksitet.

Selv om disse tiltakene vil forbedre forholdene, vil de ikke fullstendig løse problemene med begrenset habitat for ørret eller flomrisiko under fremtidige klimascenarier. Rapporten anbefaler derfor å vurdere muligheten for å reaktivere det historiske elveløpet sør for nåværende elveløp, da dette kan redusere flomrisikoen betydelig og gjenopprette flomskogsmark. Dette vil kreve samtykke fra grunneierne, i tillegg til at det bør utarbeides en detaljprosjektering for å sikre en kulvert av tilstrekkelig størrelse under veien FV 120, og et definert elveløp ved utløpet til innsjøen, slik at ingen boliger eller eiendommer utsettes for fare.

1 Introduction

NIVA, in partnership with CBEC (hereafter referred to as the project team), was commissioned by the Hurdalsvassdraget/ Vorma River Basin Sub-district to assess risks and opportunities for restoration works along the lower River Hegga. Located in the municipalities of Nannestad, Hurdal, and Gran within Akershus and Innlandet counties, the river is currently classified as having Moderate Ecological Status under the EU Water Framework Directive (WFD), primarily due to impacts on the recruitment of native trout populations. Spawning and juvenile rearing habitats are believed to be limited, largely as a result of significant physical alterations to the river. These include historic timber floating practices and various forms of river engineering such as canalisation, straightening, and bed armouring, along with infrastructure built in and adjacent to the channel (Colman et al., 2019). These cumulative modifications have led to an unstable river channel with low physical diversity and poor habitat quality for trout and likely other aquatic species. For instance, the channel's instability promotes the downstream transport of gravel and cobble-sized material, leading to bed coarsening, armouring, and a net loss of suitable habitat for spawning and 0+ (juvenile) trout. This situation is worsened by a reduced upstream sediment supply, due to trapping behind dam and weir structures. Fish passage is also hindered by a natural migration barrier (waterfall) approximately 2 km upstream from the outlet (Colman et al., 2019). The river's current uniform morphology offers few pool habitats, which are vital as holding areas for adult trout and as refuges for juveniles. Additionally, historical engineering works have exacerbated local flooding in places and contribute to unpredictable and destructive ice flows in winter (Colman et al., 2019).

1.1 AIMS AND OBJECTIVES

The overall objective of this initiative is to implement a comprehensive set of restoration measures that will improve the river's physical and ecological condition, with the ultimate objective of achieving Good Ecological Status under the WFD. The aim therefore of this report was to (1) develop restoration plans for improving ecological condition, and (2) to undertake hydraulic modelling to assess the risks and benefits associated with these proposed measures.

Building on an initial options report by Colman et al. (2019), the project team have applied a 'nature-based' approach in developing suitable restoration plans. This approach seeks to find sustainable interventions that work with the river's natural processes and that are appropriate given physical and socio-economic/ infrastructure constraints at the site (e.g. agricultural productivity, land-use and embankments, etc.). As part of this design philosophy, the project team's restoration proposals aim to re-establish natural process as much as is practicable within the constraints imposed on the site. This approach aims to promote a self-sustaining river system that requires minimal long-term management.

1.2 APPROACH

A desk-based review of data on the River Hegga was undertaken, building on the desk-based assessment and concept options report prepared previously by Colman et al. (2019). The purpose of this supplementary assessment was to ensure that the design development is based upon up-to-date information regarding the physical form and catchment characteristics of the watercourse and to consider the applicability of sustainable 'nature-based' restoration/ management options. Data sources that were consulted include historic maps (1818-1882), soil (Norwegian Geological Society, 2025), geology (Norwegian Geological Society, 2025), land use data (CORINE, 2018) and available reports (Vann-Nett, 2025 and Colman et al., 2019). As the basis for design, the project team then undertook a

LiDAR survey of the study reach using YellowScan LiDAR (at red and green wavelengths) on 16. June 2025. This data was used as the basis for design development and subsequent hydraulic modelling.

Early in the design process, CBEC's Design Director undertook an initial one-day reconnaissance site visit on the 10. July 2025. This visit was then followed by a more comprehensive walkover survey undertaken by a CBEC geomorphologist and NIVA ecologist on the 19. August 2025. Field data and stakeholder input collected while on site was integrated with information from the earlier desk-based assessments to develop a broader understanding of the river's processes and stakeholder concerns.

This combined analysis was later used to support the development and evaluation of sustainable, nature-based restoration approaches for the study reach. The aim of this approach is to identify the key, large-scale river processes that have been disrupted by past human activities and, where feasible given site constraints, to restore a more naturally functioning and stable river system. This iterative refinement process included hydraulic modelling, which was undertaken by CBEC to rigorously assess the benefits and predicted outcomes of the new proposal.

Following initial modelling outputs, the project team, led by CBEC, presented the proposed designs and model outputs at a stakeholder meeting on the 22. September 2025, with feedback then being incorporated into the final proposed design. This work concluded with the development of construction drawings for the final preferred design, along with some suggestions for future investigations.

1.3 REVIEW OF EXISTING DATA

1.3.1. Background Information and Status

The Hegga River (Water Body ID: 002-1735-R) is a medium-sized river located in the Hurdalsvassdraget/Vorma River Basin Sub-district within the Glomma watercourse region, spanning the municipalities of Nannestad, Hurdal, and Gran in Akershus and Innlandet counties (Vann-Nett, 2025). Coordinated by Østfold Fylkeskommune, within the Glomma water region, Hegga is approximately 6.7 km in length and lies within the Eastern Norway ecoregion at a medium elevation (200–800 m) (Vann-Nett, 2025) (Figure 2). The river belongs to water type R206 and is characterized by low calcium levels, high humus content, and low turbidity (Vann-Nett, 2025). The catchment area has been designated watercourse 002.DAB2A, and no precipitation data is provided (Vann-Nett, 2025) The Hegga river catchment is ca. 81 km^2, and consists of 86% forest, 7% lake and 6% mires/bogs.

The River Hegga is located within two Protected areas. The PA5670 The Halden watercourse to the Glomma watercourse – Oslofjord, and the PA5671 Eastern Norway. They are listed as being protected areas under the "The Nitrates Directive" and the "The Wastewater Directive" respectively (Vann-Net, 2025). The bedrock data taken from the Berggrunn N250/Bedrock 1:250.000 shows that the bedrock is predominantly composed of Alkali feldspar granite and quartz (Norwegian Geological Society, 2025).

The dominate soils type of the upstream section of River Hegga, near Lake Øyangen is reported as "Moraine material, discontinuous or thin cover over bedrock", the middle section of the river is reported as having soils type of "Moraine material, continuous cover, in places of great thickness". The downstream section of the channel are reported as being River and creek deposits (Fluvial deposits) and Glacial sediment (Glaciofluvial deposit) (Norwegian Geological Society, 2025).

As the river flows from Lake Øyangen, it initially traverses areas classified under CORINE Land Cover code 324 (Transitional Woodland-shrub). The river then predominantly passes through land classified as code 312 (Coniferous Forest), indicating a largely forested landscape along its course. Nearing its confluence with the Lake Hurdalssjøen, the surrounding land use transitions to code 243, which represents land principally occupied by agriculture, with significant areas of natural vegetation (CORINE, 2018). The Hegga River currently has a moderate ecological status and an undefined chemical condition. Environmental pressures are generally low, including impacts from acid rain, agricultural runoff, forestry, and scattered buildings, with moderate impact from physical changes related to historic timber floating (Vann-Nett, 2025). Restoration efforts reported in July 2024 include physical rehabilitation of the river, clean-up of dispersed sewer systems, and habitat improvements to support trout populations. The river is part of two protected areas: the Halden to Glomma watercourse and Eastern Norway region, with set environmental targets aiming for a “good” ecological and chemical status (Vann-Nett, 2025).

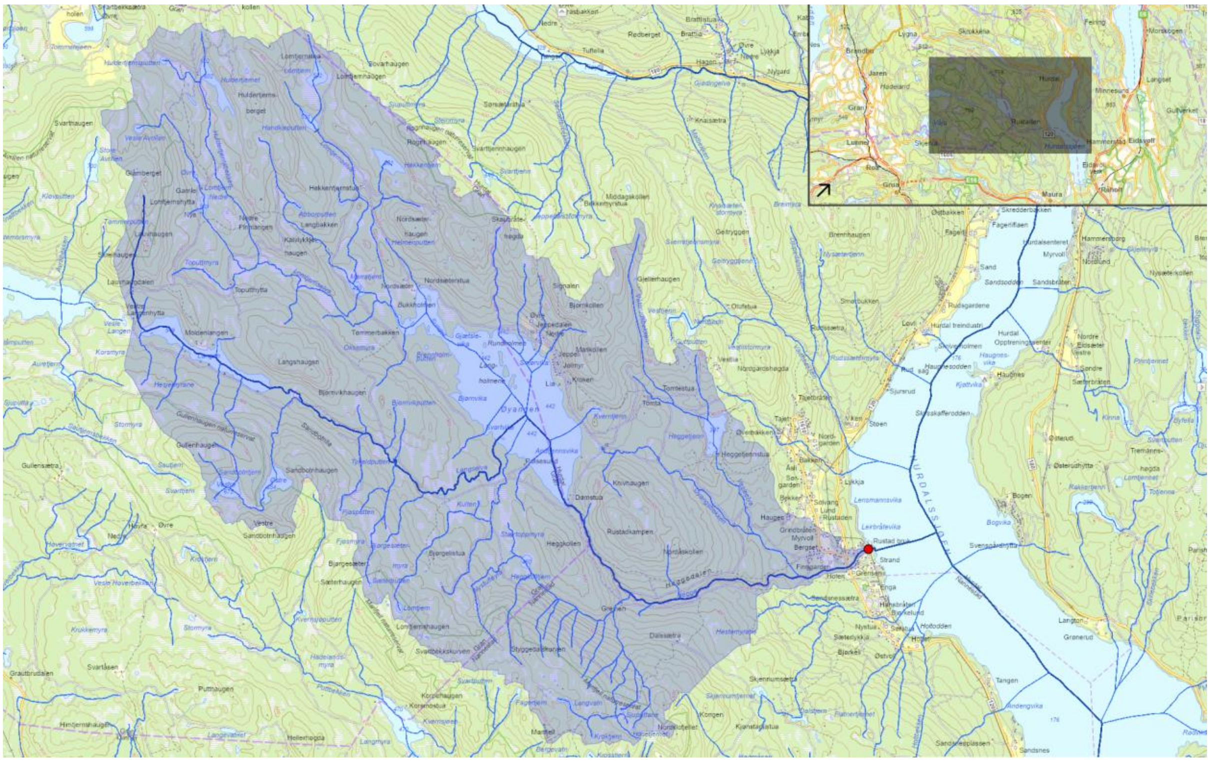

Figure 1. The Hegga river catchment (source: nevina.nve.no)

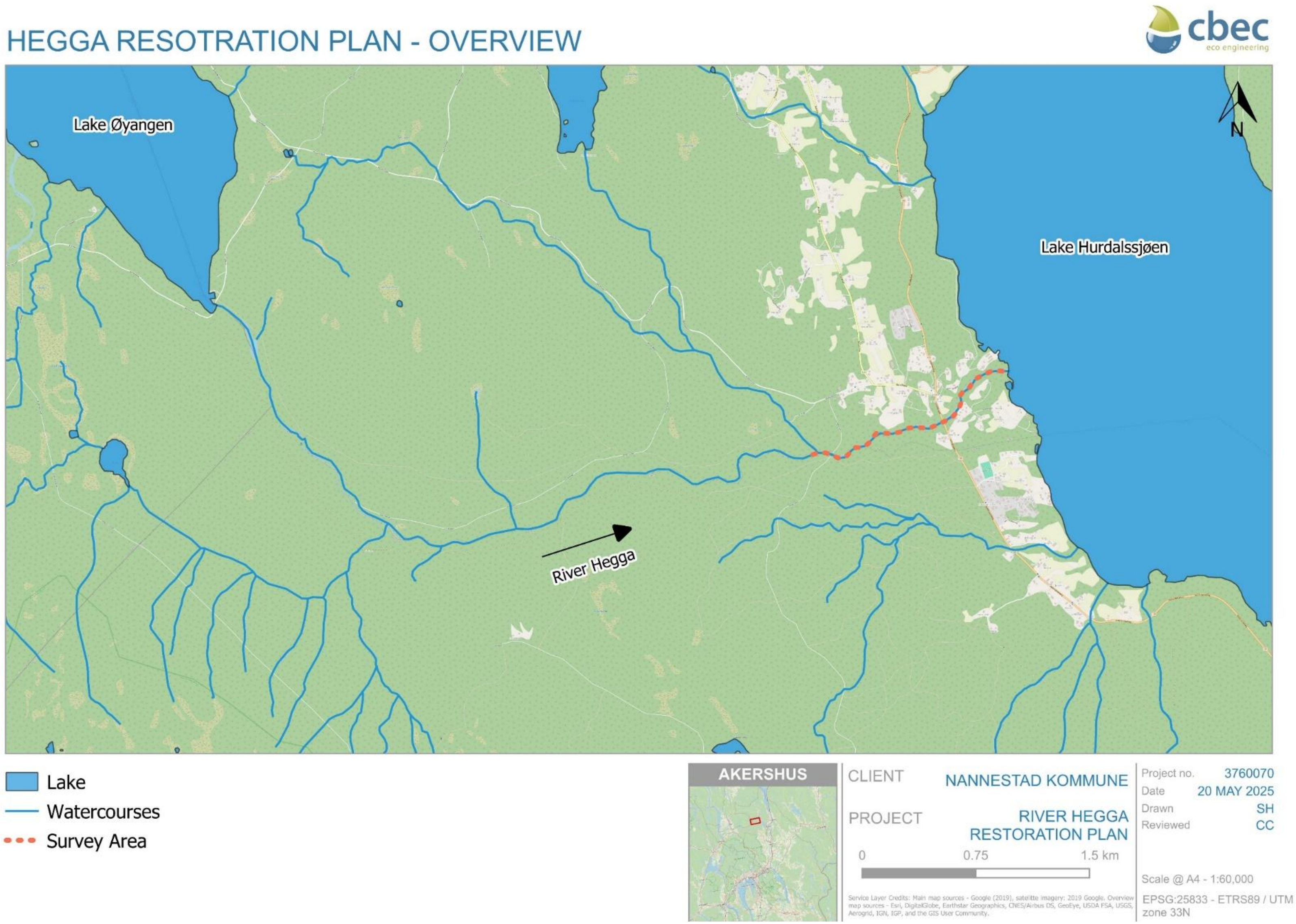

Figure 2. Overview of the River Hegga and survey area.

1.3.2. Historic Context

Background information on the River Hegga's historical context was received from a local historian and landowner[1]. Around 10,000 BP, when the last glacial era ended, meltwater rivers could convey large volumes of coarse sediment. At this time there was a meltwater river flowing in from the west which eventually deposited the material in the areas that are now Sandsnesseter in Nannestad and southern Rustad in Hurdal. In the subsequent millennia, the River Hegga incised into this flat depositional plain. There is evidence to suggest that the River Hegga has changed its course, particularly from the upper part of the plain towards Lake Hurdalssjøen. West of the county FV 120 road (FV 120), the river has both carved out and deposited masses within an area that expands to 200 m at its widest. At its outlet by the lake, three main courses are discernible, including the river's current alignment. The flat terminal regions associated with these primary channels, located around the lake's greatest water level today, show that all three channels saw substantial water flow during later developmental periods.

The River Hegga's current channel alignment has been maintained for at least 250 years (Figure 3). This is corroborated by documentary evidence, such as a 1765 lease agreement between the owner of Sørgarden Rustad and Hans Moe, in which Moe leased the waterfalls in the Hegga to erect a sawmill near the present location of the Rustad estate (Tveter 1958, p. 320). Following this industrialization, the river's management shifted towards making the watercourse suitable for timber floating (Tveter 1958, p. 314). Interventions included the construction of a weir in 1852 to collect timber, the remains of which are visible near the waterfall at Rustad Mill, until its destruction by flooding in 1927 (Cultural Heritage Plan for Hurdal Municipality, 2003, p. 73).

The most important recent changes and disruptions to the riverbed most likely occurred between 1950 and the end of log driving in the early 1960s. Machines were used to straighten the riverbed and make it easier for logs to flow into the lake. Current data and observations suggest a natural geomorphic inclination for the river to alter its route southward, possibly reverting to one of its historical confluences with Lake Hurdalssjøen. This older, southernmost river course coincides with the boundary line between Hurdal and Nannestad (Figure 3).

[1] *Information is based on a presentation at a meeting on 15 May 2025 by the local historian and landowner, Ove Bakken.*

Figure 3. Historical Channel Alignment 1818-2025. Kartverket Historical map of survey area from 1818. Source: oldmapsonline.org

1.3.3. Naturrestaurering Report

With the aim of improving the river's physical and ecological condition, a report by Colman et al. (2019) was commissioned by Hurdalsvassdraget/ Vorma River Basin Sub-district. The report characterised the river, its history and challenges it faces.

The report also proposes a number of potential physical measures that could be implemented to enhance the aquatic habitat quality of the river. Their key proposals to improve habitat are illustrated in Figure 3. The project team was tasked with assessing their feasibility of these measures. The key measures included[2];

1) Setting Back Assets/ Infrastructure: Relocation of current structures, buildings and assets outside the areas of flood/erosion concern. This would reduce risk while also providing the river freedom to perform its natural physical functions.
2) Embankment Breaching/ Widening: The selective excavation of existing channel margins and removal of embankments. This would improve lateral connectivity (with the floodplain), while also reducing the channel's transport capacity and erosive power under elevated flows.
3) Increasing Channel Roughness; Adding boulders or large wood structures to the channel to increase channel roughness and flow heterogeneity. This would diversify the riverbed and create essential shelter and velocity refuges for juvenile fish.
4) Gravel Augmentation: Introducing a significant volume of aggregates of appropriate sizes for spawning habitat.
5) Pool Excavation: The creation of pools through excavation. This could be used in combination with the placement of large (immobile) boulders.
6) Fish Passage Mitigation: To ensure a manageable jump height for trout at the base of the waterfall, steps or sufficiently deep pools could be created.

[2] *As the original report was written in Norwegian, we have used here English-language terminology that we feel best illustrates what we understand the original authors intended.*

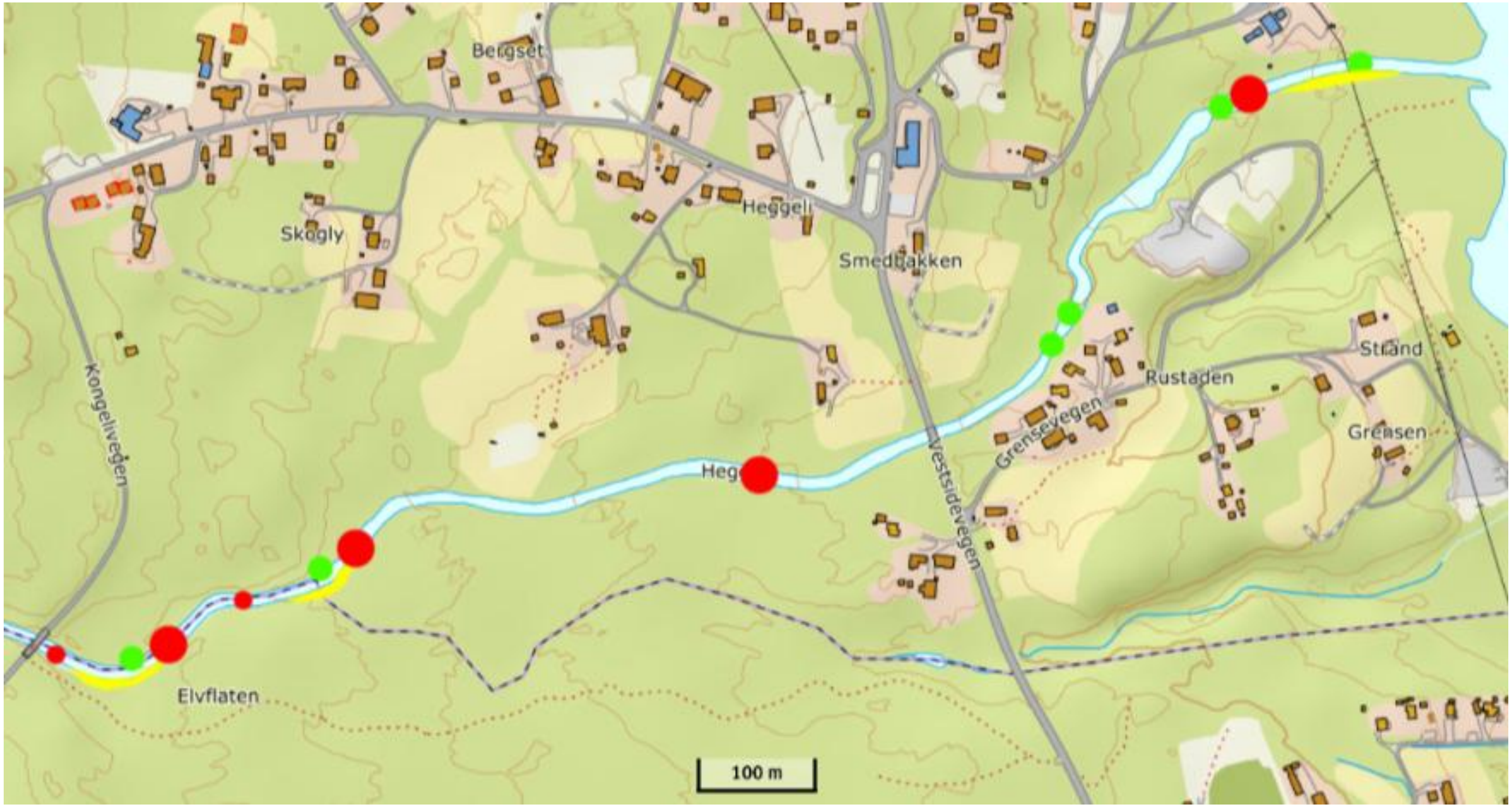

Figure 4. Measures proposed by Colman et al., 2019. Yellow areas indicate the proposed modifying of the riverbank. Green circles indicate the proposed excavation and stone reinforcement of pools. Red circles indicate proposed locations for spawning gravel placement. The size of the red circle (large/small) indicates the amount (high/low) of spawning gravel. Map base: Kartverket 2019 (WMS). Source: Colman et al., 2019.

2 Data collection

2.1 LiDAR data

A UAV LiDAR survey was undertaken by NIVA over the River Hegga on 16th June 2025. The primary objective was to capture high-resolution topographic data to support CBEC's design process and hydrological modelling applications. This field log documents work carried out by Trygve Heide (NIVA) and subcontractor Robert Nøddebo Poulsen (SpectroFly). The purpose was to survey the lower reach of the Hegga River in Hurdal municipality, Akershus, using YellowScan LiDAR at red and green wavelengths.

In total, an area of 42.4 ha was surveyed. Of this, 8.15 ha along the river were covered with green LiDAR for bathymetry and adjacent topography, while 34.25 ha were measured with red LiDAR to improve penetration in vegetation-rich areas. Turbidity samples were taken at four points in the river. Mean turbidity was 1.18 FNU. Sample 3 likely had a higher particulate load (2.34 FNU) and raised the average. Samples 1, 2 and 4 ranged between 0.73 and 0.84 FNU, indicating low particulate content and good conditions for green LiDAR (Table 1).

Table 1. Results from turbidity measurements (FNU).

Time	FNU	GPS
14:55	0.73	60°20'42.2"N 11°00'24.4"E
15:00	0.79	60°20'41.9"N 11°00'21.8"E
16:24	2.34	60°20'53.2"N 11°01'04.2"E
16:28	0.84	60°20'54.1"N 11°01'06.9"E

Turbidity measurements (FNU) do not register air bubbles, which can reduce the penetration depth of green LiDAR. In sections with churning water/rapids, air entrainment yields lower point density in the LiDAR data (Figure 5 & Figure 6).

Figure 5. Ground control point near a rapid, marked with environmentally friendly chalk spray.

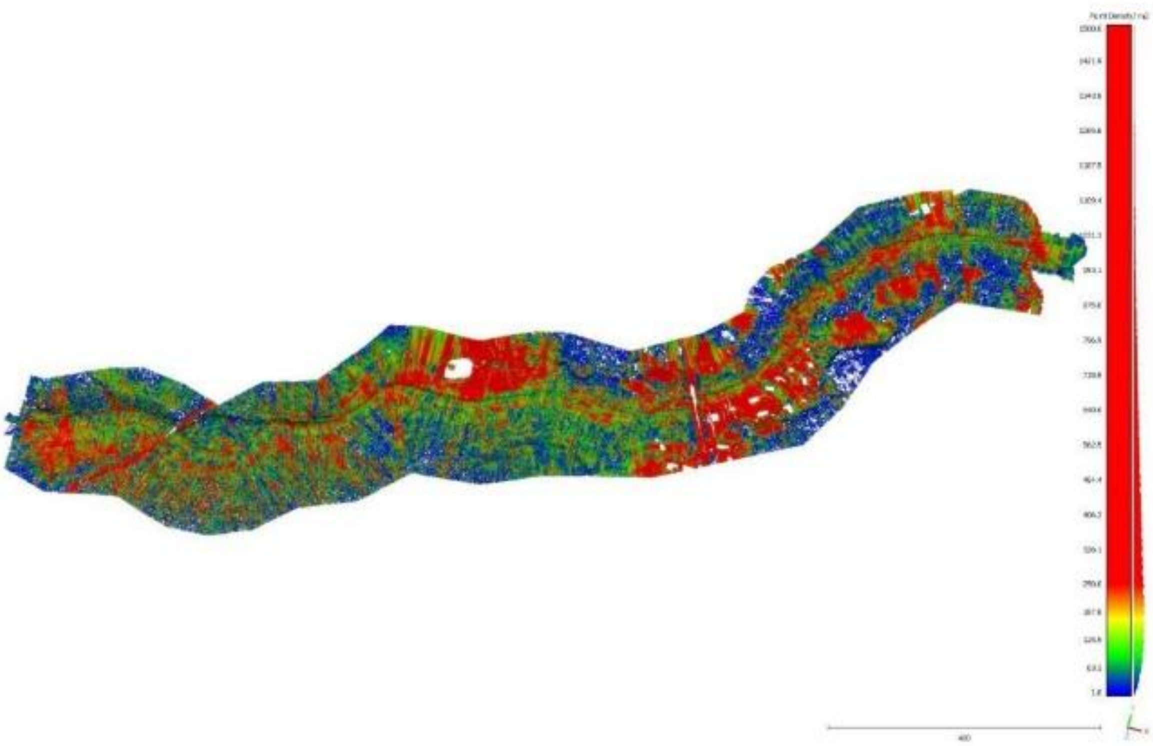

Figure 6. Point-density map for green and red LiDAR.

Green and Red LiDAR (Light Detection and Ranging) systems are often employed for specific environmental sensing applications. Red LiDAR, typically operating at wavelengths around 905 nm or 1550 nm (near-infrared), is widely used in terrestrial and atmospheric sensing due to its strong performance in clear air and lower cost for some components. In contrast, green LiDAR utilizes a shorter wavelength, commonly near 532 nm, which is strongly favoured for bathymetric (underwater depth) surveys as this wavelength penetrates the water column much more effectively than red or near-infrared light. The selection between the two depends primarily on the medium being surveyed-air/land for red, or water for green.

The drone survey utilized a dual-wavelength LiDAR approach, employing Green (TopoBathy) and Red (Topography) LiDAR sensors (YellowScan Navigator and Explorer) on a Hexadrone Tundra 2 platform. The acquisition, conducted on 16-06-2025 at an altitude of 40-80 meters AGL, covered a total area of 34.25 hectares using a corridor flight pattern. The Green LiDAR specifically targeted the riverbed and immediate banks, covering 8.15 hectares, while the Red LiDAR covered a larger area to supplement topography, essential due to dense bank vegetation. Data processing included PPK correction of GNSS trajectory using Hexagon SmartNet data and point cloud processing in Yellowscan CloudStation for strip alignment, ground/water mapping, automated classification, and colorization. A significant Quality Assurance (QA) stage involved calculating the alignment and merging of the Red and Green point clouds, followed by semi-automated/manual filtering and reclassification to address noise and misclassifications. The final topobathymetric point cloud (Classes 02 and 40) contained 68,004,809 points, yielding a mean point density of 210 points/m² (for a grid). Final deliverables included two LAZ point clouds (all classes and topobathy only) and a 50 cm resolution Topobathy Digital Elevation Model (DEM) in GeoTIFF format. Limitations included reduced point density in areas with dense vegetation and turbulent water containing air bubbles. The data was collected within the extent of 60°20'38.07"N, 10°59'57.24"E upstream to 60°20'55.35"N, 11° 1'18.80"E, downstream where the River Hegga flows into Lake Hurdalssjøen. The Green and Red LiDAR combined was collected within a buffer 200 m across of surrounding the floodplain and the channel itself. The Green LiDAR was collected in a buffer of 15m around the channel.

2.2 Field assessment

The geomorphological field assessment phase commenced with an initial one-day reconnaissance site visit conducted by CBEC's Design Director on July 10th, 2025. This preliminary investigation was subsequently followed by a more extensive geomorphic walkover, which was performed collaboratively by an experienced CBEC geomorphologist and NIVA ecologist. This walkover facilitated a familiarisation of local geomorphic and hydrological processes and provided a basis for evaluating the feasibility of implementing nature-based solutions. This included the assessment of option proposals originally put forward by Colman et al. (2019) – see Section 1.3.3 and Figure 4.

On the walkover undertaken 19th August 2025 during atypically low flow conditions[3], the channel was wadable and bed material visible in most locations. For reporting purposes, the study reach can be divided into two sub-reaches; The upper sub-reach extends from the Kongelivegen Road Bridge (Figure 9) to the shore at Hurdalssjøen.

Locations and characteristics of fluvial features and pressures were recorded on tablet computers using a mobile GIS platform (QField) with integral GPS capability. Georeferenced photographs were taken throughout the survey reach to capture significant natural features and infrastructure, and to illustrate the general character of each sub-reach. This process allows accurate determination of the position and

[3] *Local landowners described flow conditions on the day of survey as being uncharacteristically low.*

extent of key features (e.g. length of bank erosion, engineering pressures). Recording the data digitally allows outputs (shapefiles) to be viewed immediately following the conclusion of the survey in GIS. The types of features recorded are listed below:

- Reach-scale channel morphology using a classification scheme that draws on aspects of other recognised procedures (Montgomery and Buffington 1997, Brierley and Fryirs, 2000).
- Floodplain morphology and land use, for example, drainage channels/ditches, relict natural secondary channels, wetland areas and swales.
- Sediment sources and storage such as tributaries and bank erosion. Within-channel storage (i.e. the extent of alluvial bar features) were recorded, noting dominant and sub-dominant sediment sizes; fines (<2 mm), gravels (2-64 mm), cobbles (64 -256 mm) and boulders (>256 mm).
- River engineering pressures and abstraction such as embankments, culverts, bank protection, canalisation/realignment, embankments, hydraulic structures, historic monuments, water intakes, outfalls and bridge crossings were categorised in terms of their extents and severity of impact(s) to river process and options for restoration.
- Fish passage and barrier assessment, including collection of geometry and site constraint information to aid the development of mitigation options.

A summary map showing the presence of geomorphic features and pressures can be seen in Figure 8 and representative photographs are presented in Figure 9 to Figure 20. Field observations indicated a relatively steep single-thread, boulder-bedrock channel (Figure 9, Figure 11, Figure 14, Figure 15, Figure 19 & Figure 20). Over the entire 3,400 m survey extent, the river displayed a longitudinal slope of 2% (Figure 8). This gradient facilitates a notable elevation drop from c. 240 m (ASL) at the upstream extent, to an elevation of c. 180 m(ASL) at the lakeshore. The upper sub-reach is largely unconfined on the right bank, while the left bank is initially confined, this decreases with distance downstream (Figure 7). Below the FV 120 road Bridge, the channel is mostly confined on both sides where the channel flows through a steep bedrock gorge. Below the waterfall section the valley opens up before reaching the outlet to the lake. Riparian land use on both sides of the channel predominantly comprises mature coniferous forest.

The composition of the bed surface material varies along the profile, reflecting changes in stream power, gradient, and local geology. The upper sub-reach is dominated by mobile boulder/cobble assemblages (Figure 11), with localised sections of exposed bedrock (e.g. at the bridge, see Figure 9), indicating high stream power or strong structural control. Apart from localised clusters, only the section above the FV 120 road bridge exhibited the presence of significant amounts of finer bed material, with increasing proportion of cobble sized material. This section coincides with an area on the north bank that floods episodically[4], but also the presence of active side channels off the south bank – suggesting preferential deposition under high flows, relative to the stretch upstream. The lower sub-reach, however, showed an increase in the extent of exposed bedrock (Figure 20) and valley confinement. At the lowermost extent of the sub-reach the gradient drops off suddenly as the river meets the Lake Hurdalssjøen. Here the channel bed was characterised by a significant depositional zone (comprising coarse cobble/boulder size material).

Other significant features along the system included the presence of two natural waterfalls in the lower sub-reach (Figure 18 and Figure 19), one of which is acknowledged as a barrier to fish migration upstream. The presence of bank erosion (Figure 13), which locals partially attribute to the transport of ice flows and boulders during high-flow events, was recorded along isolated sections of both banks, with the most significant examples seen along a 150 m section below the FV 120 road Bridge. Given the

[4] *Information provided by local landowners and confirmed by hydraulic modelling results (See Section 4.9).*

presence of adjacent properties (specifically on the south bank) this also coincides with the presence of hard bank protection. Other localised sections of hard bank protection were associated with a disused mill race (Figure 17) which showed evidence of breaching on the day of survey (attributed to storm Hans – 7th August 2023). The dominant man-made pressure however was the presence of extensive boulder embankments which were observed to line much of the channel on both banks. Although originally constructed as part of management practices to better facilitate the floating of logs, these also now act as flood embankments, disconnecting the channel from its floodplain.

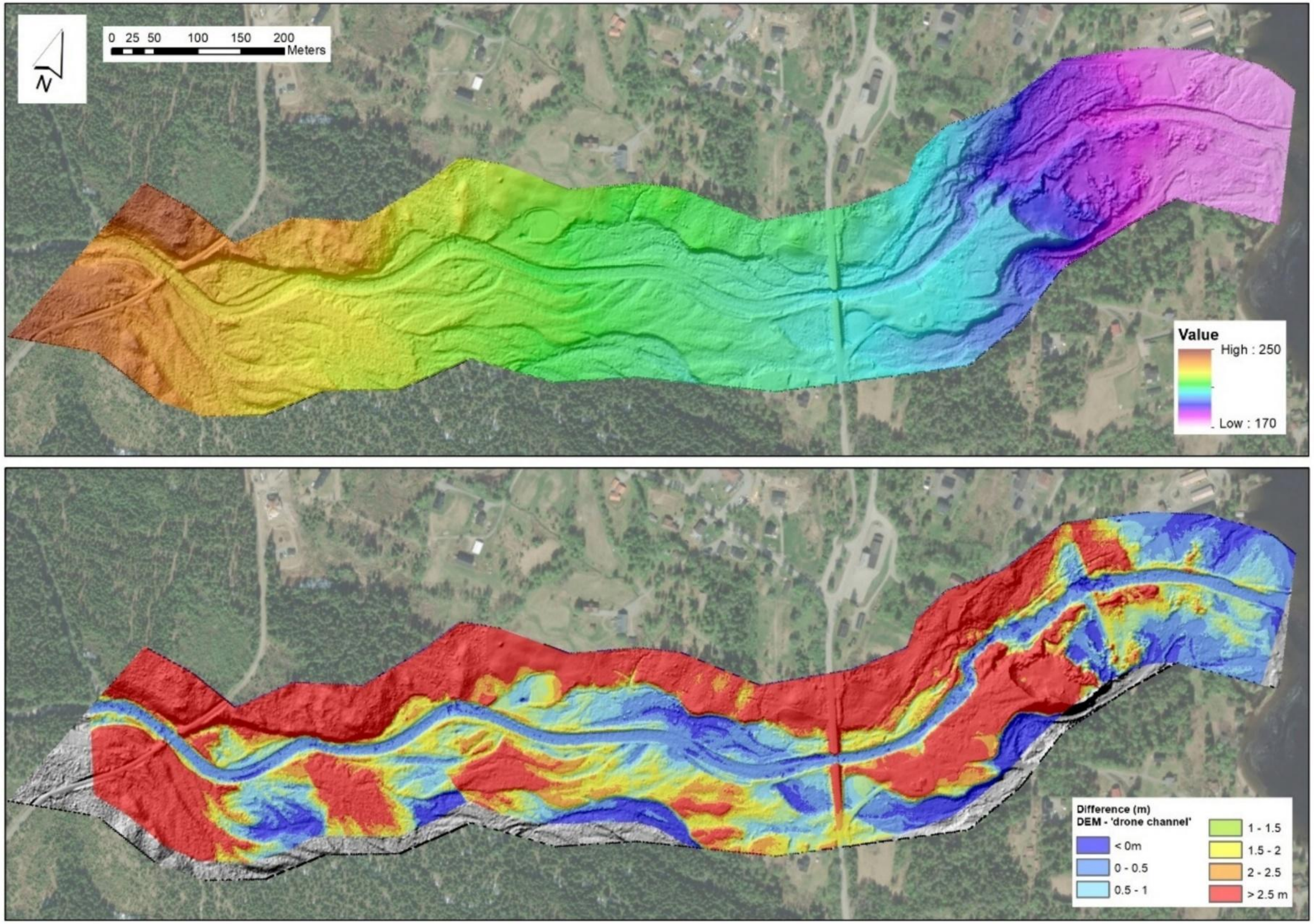

Figure 7. Digital Elevation Model (DEM) created for the study site. Note extent of lateral confinement and presence of disconnected paleochannels to the south.

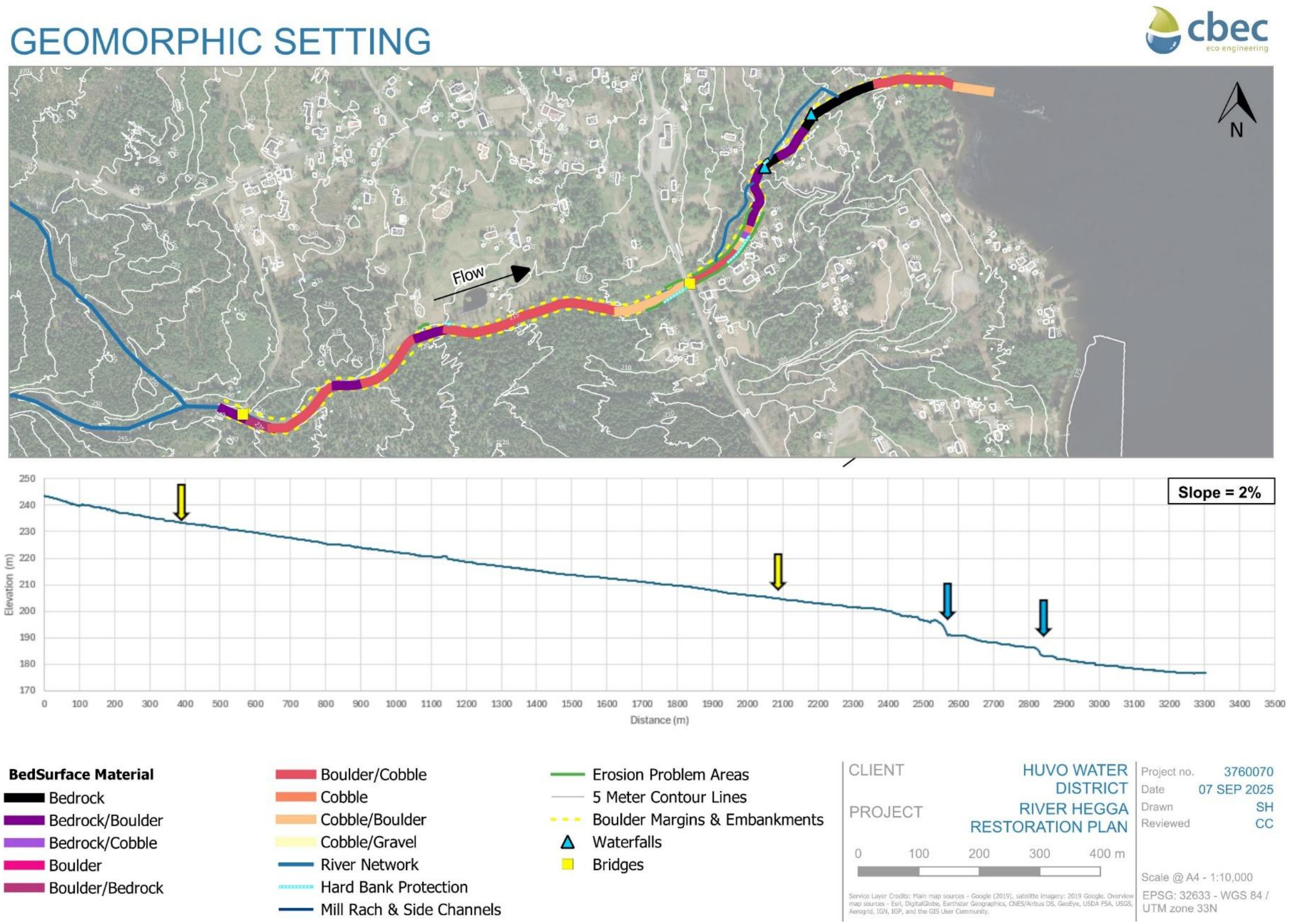

Figure 8. Geomorphic setting.


Figure 9. Bridge at the upstream extent of the survey area.


Figure 10. Example of vegetated boulder embankments that line much of the channel on both banks.


Figure 11. Example of boulder dominated surface materials along the upper sub-reach.


Figure 12. Note presence of bedrock outcrops. Looking towards left bank


Figure 13. Example of an undercut bank with leaning trees.


Figure 14. FV 120 road Bridge approximately mid-way along the study site. Looking downstream.


Figure 15. Typical steep boulder dominated channel. Note densely wooded channel banks.


Figure 16. Properties located in close proximity to channel on South bank.


Figure 17. Example of hard bank protection. Note breached section on right side of photograph.


Figure 18. First waterfall is likely a barrier to fish.


Figure 19. Second waterfall along survey area.


Figure 20. Exposed bedrock channel typical of the lower sub-reach.

3 Design development

3.1 Interpretation of historic setting and pressures

The Hegga River flows for approximately 6.7 km from Lake Øyangen through the municipalities of Nannestad, Hurdal, and Gran to Lake Hurdalssjøen. Before anthropogenic modification, the Hegga likely exhibited a dynamic multi-thread planform characterized by multiple active channels, including to a former lake outlet to the south. This older, southernmost river course coincides with the boundary line between Hurdal and Nannestad. This natural configuration would have facilitated periodic inundation of adjacent areas, with flow energy being dissipated across multiple pathways during high discharge events. Straightening and confinement of the channel, undertaken primarily to facilitate timber floating operations and enhance agricultural land drainage, occurred most intensively between 1950 and the early 1960s. These modifications involved comprehensive clearing of in-channel boulders (which provided natural hydraulic roughness) and the construction of extensive embankments along both banks using material excavated from the channel itself (Figure 21). The embankments effectively disconnected the river from its historical flow paths and relict paleo channels, particularly those visible in LiDAR data (Figure 7) on the southern floodplain where three distinct former outlets remain discernible in the landscape.

Confinement of flow within a single, straightened channel has fundamentally altered the river's hydraulic regime and geomorphological behaviour. The concentration of discharge through one constrained cross-section has increased unit stream power, particularly during flood events, resulting in elevated boundary shear stresses that promote the downstream transport of gravel and small cobble substrates essential for trout spawning. This enhanced transport capacity has led to progressive bed coarsening and armouring in downstream reaches, a process exacerbated by reduced sediment supply from upstream due to trapping behind dam and weir structures. The loss of hydraulic diversity associated with the multi-thread planform has eliminated pool habitats that function as holding areas for adult trout and refuges for juveniles during high flows. Despite the embankments providing necessary flood protection for adjacent agricultural land and infrastructure, sections of unprotected banks continue to exhibit instability. The river's energy, no longer dissipated across multiple channels and the natural floodplain, is now concentrated within the main channel, driving localized erosion problems along vulnerable reaches. The increase in larger boulders being transported by the river, which ultimately end up being deposited at the outlet to the lower lake, is in large part a function of the cessation of boulder removal practices locally.

Figure 21. Example of boulder embankments that disconnect the channel from its historic floodplain.

3.2 Proposed measures

As part of this project, designs have been assessed and developed based on those already identified during the initial options appraisal (Colman et al., 2019). These designs also take account of local constraints, both natural and anthropogenic, including property, land use and utilities information provided by the client (Figure 22). Applying a 'nature-based' approach, the project team have sought to develop a suite of restoration measures that provide a synergistic benefit to the physical process regime, ecological health and infrastructure of the wider Hegga system. Below we have identified which of the originally proposed measures (i.e. from (Colman et al., 2019) are still appropriate, which require modification, and which should be descoped.

1) **Setting Back Assets/ Infrastructure:** The relocation of current structures and buildings away from the river was recommended by Colman et al. (2019). The NIVA-CBEC project team would also advocate for setting/ moving back nonessential buildings, assets and infrastructure outside of the river's natural floodplain where possible. However, stakeholder discussions suggest this option is not feasible, and alternative options should be considered instead.
2) **Embankment Breaching / Widening:** The single most beneficial measure that can be implemented at the site is the selective removal of embankment sections to facilitate hydraulic reconnection of the floodplain and relict paleo channels located on the south bank.

   This approach is predicated on the principle of working with, rather than against, the river's natural geomorphic tendencies. Under the current single-thread configuration, all discharge is conveyed through one constrained cross-section, generating elevated shear stresses that mobilize and transport spawning substrates, leaving a channel bed dominated by bedrock and large boulders. Through strategic embankment breeching, the intervention seeks to reintroduce flow pathways that align with the system's natural hydraulic propensities, thereby establishing a more sustainable and resilient morphological configuration. Redistributing a proportion of the discharge across reactivated channels will lower boundary shear stress in the main channel, causing a reduction in sediment size transported, promoting substrate stability and enabling the retention of gravel and cobble-sized material necessary for successful spawning. Concurrently, the reactivated channels themselves will provide alternative hydraulic environments characterized by lower velocities and increased structural complexity, offering essential habitat for juvenile trout and functioning as refugia during high flow events.

A major constraint to wholesale removal of embankments is that these put at risk adjacent properties which currently rely on the embankments for flood protection. Rather than full embankment removal, the option proposed by the NIVA-CBEC project team employs targeted breaching at locations where geomorphological evidence indicates historical channel activity and where topographic conditions favour controlled flow distribution (Figure 23). In order to be confident in the functionality of breaching the embankment at specific places along the south bank of the Hegga, the proposed option and design were modelled. To be confident in the sustainability of the approach, the modelling utilized scenarios representing various flood events, specifically Qmean, 1 in 5 year, 1 in 10 year, 1 in 50 year and 1 in 100 year flood event. This initial stage of modelling was essential for precisely evaluating flooding patterns downstream and across the floodplain after the embankments had been breached in specific places, providing the fundamental hydraulic data for the design and construction. Given local constraints (natural and anthropogenic), the locations where embankment breaching could be safely implemented are presented in Section 4.2.

3) **Increasing Channel Roughness:** The reintroduction of large boulders or large wood structures (LWS) into a stream channel is a technique used to enhance hydromorphic diversity and encourage the retention of sediment. Also proposed in the report by Colman et al. (2019), the strategic placement of boulders along the Hegga would induce localized scour and deposition patterns, creating variations in water depth and velocity. However, there is a local motivation to continue the removal of boulders from the channel for the perceived benefits to flood risk. Such a practice is not sustainable and would further impact the physical condition of the river, therefore negatively affecting trout spawning and juvenile rearing habitats. We propose that boulder reintroduction is undertaken in parallel with the removal of selected sections of embankment. Although the river would benefit from the introduction of boulders of all diameters, we recommend clasts that are 0.5m in diameter or greater. Following the modelling results (Section 4.9.4), a sediment size mobilisation analysis was performed to refine the overall understanding of the intervention's impact. This sediment mobility modelling revealed a significant finding of a reduction in the amount of bed material being moved down the main channel of the River Hegga after breaching of the embankment at specific locations. This reduces the likelihood of boulder transport (but may not eliminate it) and increases channel roughness locally. The use of LWS for this same purpose has now become a routine part of river enhancement projects in other settings (e.g. UK). However, the high flow velocities and risk of ice debris catching on the LWS make their use in this context less optimal.

4) **Gravel Augmentation:** Currently the River Hegga lacks the quantity and calibre of suitably sized gravels needed for salmonid spawning. This is in part due to the current transport regime, but also the absence of roughness elements in the channel that would encourage their retention (addressed in part by measures 1 and 2). However, gravel augmentation if implemented without

addressing the root cause of the problem will only be a temporary solution, as gravel will inevitably be transported away. Although not counter-productive, thought should be given to whether this approach will constitute a good use of resources.

5) **Pool Excavation:** The proposed creation of pools through excavation by Colman et al. (2019), is not a recommended measure for the following reasons. Field reconnaissance indicated that many of the locations where pool excavation was proposed would be unfeasible given the presence of bedrock. In such sections where current bed composition may allow mechanic excavation, it is very unlikely that these pools would be sustainable in the long-term, as prevailing sediment and transport regimes indicate they would quickly be infilled.

6) **Fish Passage Mitigation:** Colman et al. (2019) proposed that the mitigation of the lower waterfall as a fish passage barrier was by blasting steps or sufficiently deep pools at its base to better facilitate fish passage. Although such an approach may prove successful, the NIVA-CBEC project team do not recommend blasting as means of mitigating a natural passage barrier.

DESIGN CONSTRAINTS

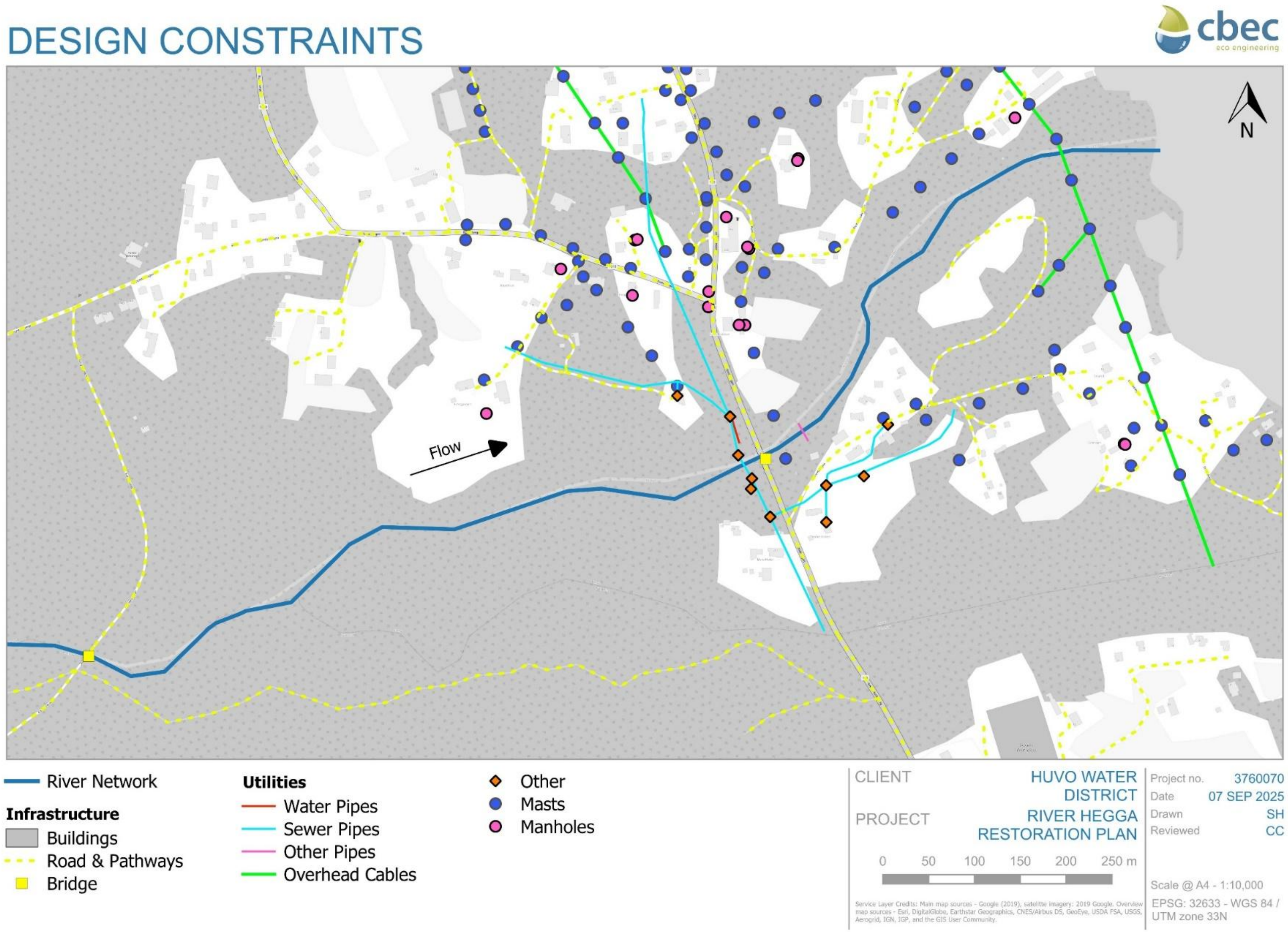

Figure 22. Design constraints.

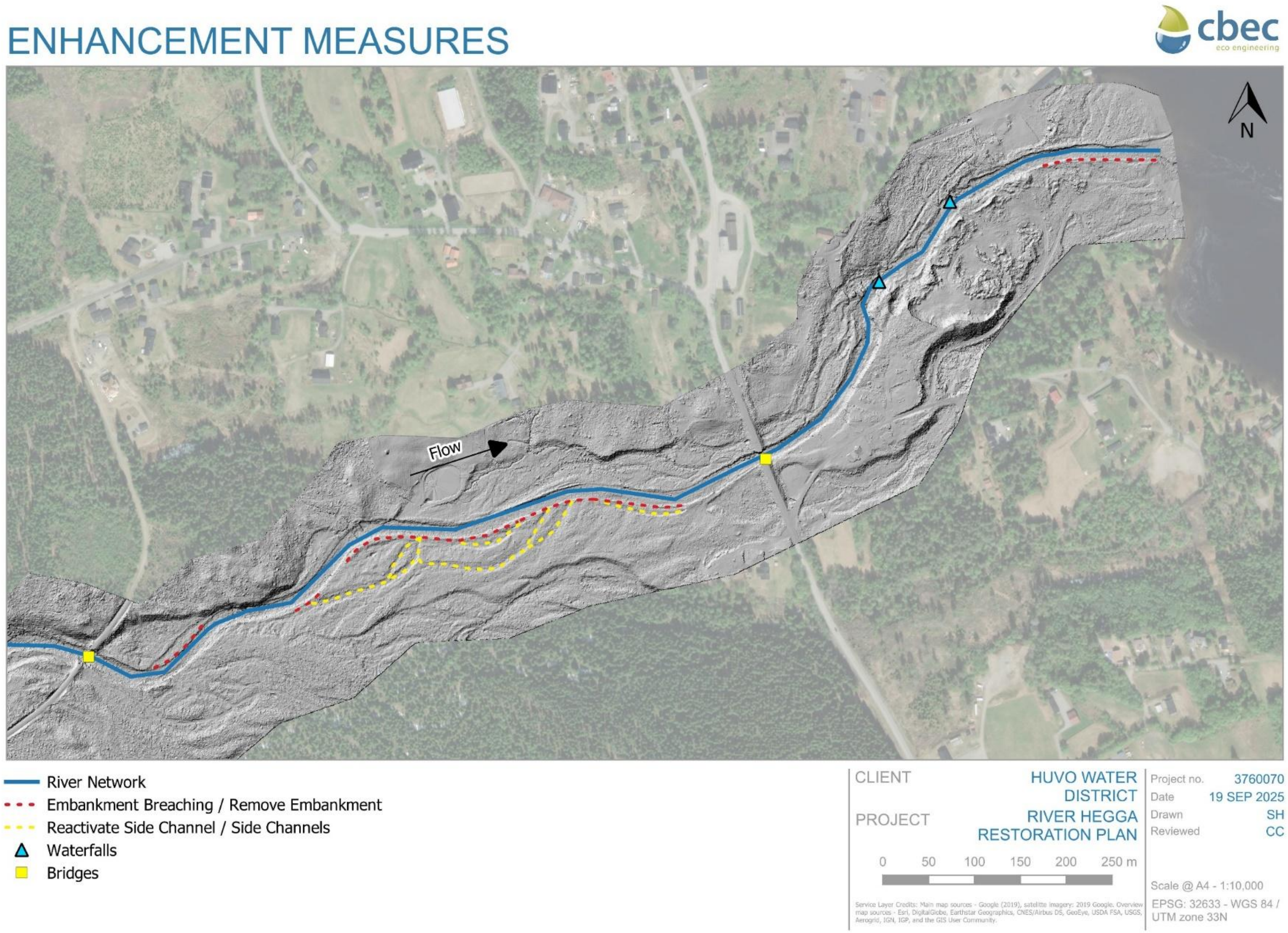

Figure 23. Concept design, showing candidate locations for targeted embankment breaching. Note that not all breaching points shown here were deemed worthwhile.

4 Hydraulic modelling

4.1 Aims and objectives

This section of the report details the hydrology used and hydraulic modelling approaches and processes used to support this project.

The aim of the hydraulic modelling is to support the assessment of flood risk associated with the restoration designs, alongside demonstrating when and where ecological goals are being met.

4.2 Design proposals

Figure 24 shows the key physical works proposed as part of the options discussed in Section 3.2. These involve the strategic removal of short sections of embankment and high ground to promote activation of paleo-channels during high flows. The design was refined to minimise the amount of excavation required to get the most benefit possible.

4.3 Hydrology

Hydrological input for the model was provided by the client. A summary of the peak flows used in the model is shown in Table 2. Qmean is the mean annual flood, which normally has a return period of approximately 2.33 years. As only the peak flow values were provided, events were run to simulate steady state flows at the peak value.

Table 2. Peak flows provided by the client.

Return Period	Peak Flow (m^3/s)
Qmean	13.2
Q5	19.4
Q10	22.8
Q50	30.6
Q100	33.6

The client also provided data for the body of water which the River Hegga flows into; Hurdalssjøen. Hurdalssjøen is regulated between 172,69 and 176,29 m (Above Sea Level) however in flood events the water level exceeds the upper regulation limit. A graph was provided by the client which includes statistical data on the water levels between 1995 and 2024. It shows the maximum and minimum values for this period dependent on month. The maximum recorded water level is approximately 178m (ASL), this was used as the elevation for the stage hydrograph downstream boundary for the model in order to represent a conservative scenario in regard to the water level of Hurdalssjøen.

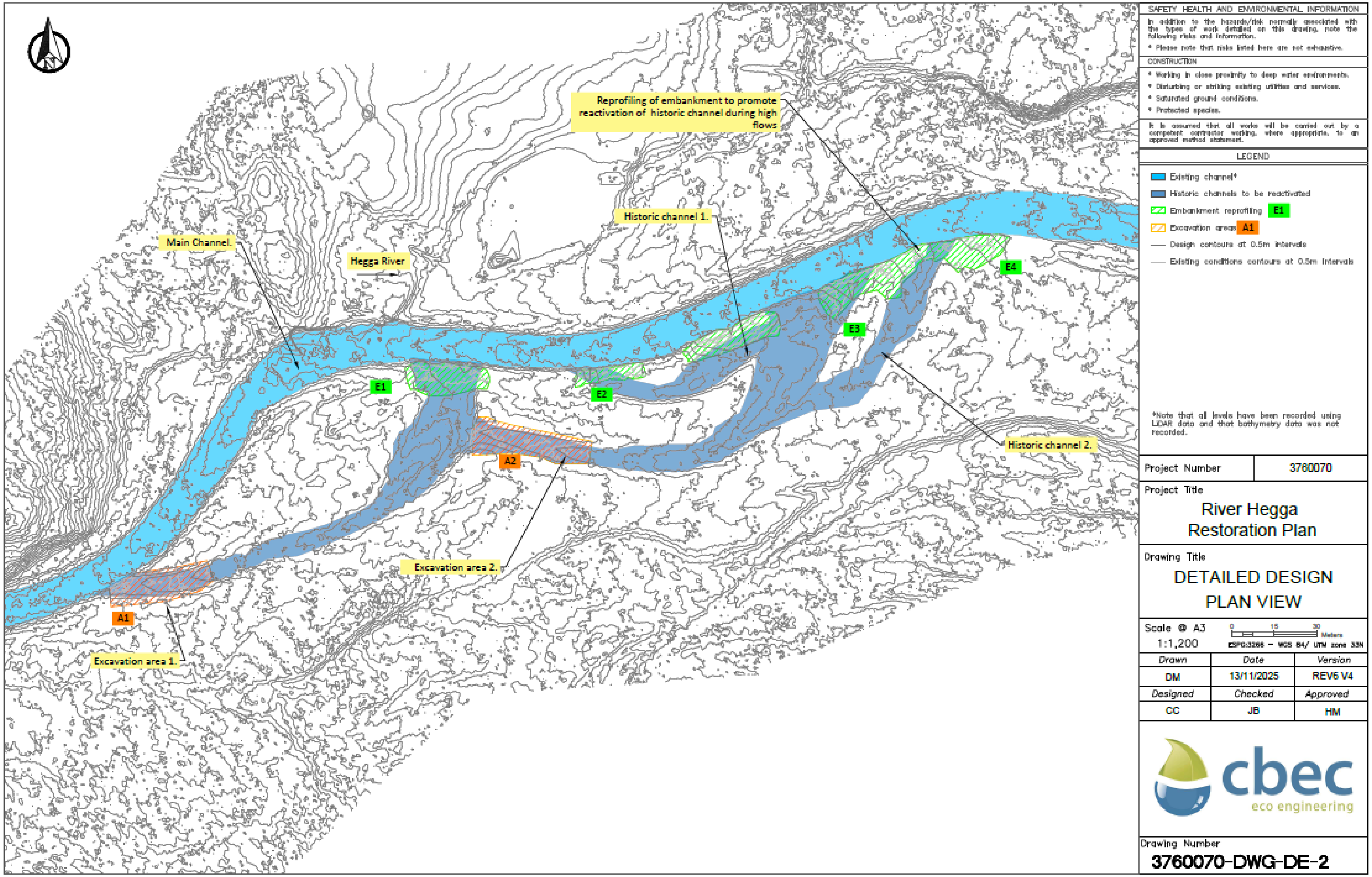

Figure 24. The preferred design proposal for embankment breaching.

4.4 Modelling rationale

Hydraulic modelling was carried out in HEC-RAS- version 6.3.1. This code has been benchmarked by HEC against the current DEFRA/EA 2D flood model benchmarking tests for hydraulic models in the UK[5]. It is a fully 2D model and is capable of rapidly and effectively modelling in-channel depths, velocities and shear stresses and the effects of meandering or realignment and channel floodplain interaction. The model solver can be run in a variety of modes; for the River Hegga the full momentum shallow water equations solver was selected to capture the effects of super-elevation at the outside of bends and to compute time-accurate hydrographs.

4.5 Data sources

The accuracy of a 2D hydraulic model is highly dependent on the accuracy and spatial resolution of topographic data of both the channel bed and floodplain. For the River Hegga area, the terrain data was surveyed by the client using a green and red LiDAR sensor with a Hexadrone – Tundra 2 drone platform. The survey was completed in mid June 2025 (Section 2.1). A green and red LiDAR drone can collect both bathymetric and terrain data. The merged topographic and bathymetric digital elevation model (DEM) was provided at 0.5 metre resolution.

Orthoimagery from the drone flight was also provided for the site, this was used to provide extra details about the site such as floodplain types, bank vegetation and identification of channel features such as waterfalls and boulder characteristics. These were used to develop a site friction map.

4.6 Modelling methodology

An existing conditions model was built initially using the existing conditions DEM (Digital Elevation Model) as the baseline surface for the model runs. The results of the existing conditions model were used to guide the design process. An iterative process (i.e. iterating on channel alignment, width, slope) was implemented to satisfy design objectives.

The model domain, shown in Figure 25, was set up using a 4 m cell size for the floodplain and a 2-metre cell size for the channel. HEC-RAS uses a pre-processing phase of sub-grid sampling at the terrain resolution. This creates a look up table of rating curve for each grid cell and allows lower mesh resolution than a non-sub-grid sampled model. The model extent has been designed to include the entire functional floodplain at highest flood return modelled. i.e. the 1 in 1000 year. The floodplain outflow boundary is included to prevent glass- walling (build-up of water at the model boundary) as at the time of modelling the boundary was limited by the LiDAR drone DTM extents.

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[5] *Developed by the US HEC. Benchmarking of this code has been undertaken by the code authors: Brunner, G., Report RD-51, Benchmarking of the HEC-RAS Two-Dimensional Hydraulic Modeling Capabilities, US Army HEC, Davis CA, April 2018*

Figure 25. 2D model extents including Inflow and Outflow Boundaries.

The inflow boundary seen in Figure 25 is located at 610303, 6691363. The downstream boundary (611621, 6691991) was defined using a stage hydrograph set at 178 (masl). This value is the highest water elevation recorded at Hurdalssjøen since 1995. The floodplain outflow also uses normal depth boundary conditions and is placed to prevent significant glass- walling in the model domain. The slope value has been estimated at 0.01 by calculating the gradient of the terrain in the area. Spatially varying Manning's n roughness values were applied to the floodplain, using land cover classification polygons. Values were estimated from a range of sources including literature (e.g. Chow 1959) and UK CES/AES roughness advisor software compared to aerial images and site photographs and OS mapping. The Manning's n values are summarised in Table 3. Figure 26 shows the location of the friction polygons used for design modelling.

The model was run at an adaptive timestep based on courant values. The mass volume accounting error was below 1% for all the planned runs.

Table 3. Spatially varying Manning n friction for existing and design.

Feature	Manning's number	Colour in map
Heavily Vegetated Floodplain	0.08	
Existing Channel, high boulder frequency	0.05	
Waterfall Uplift	0.20	

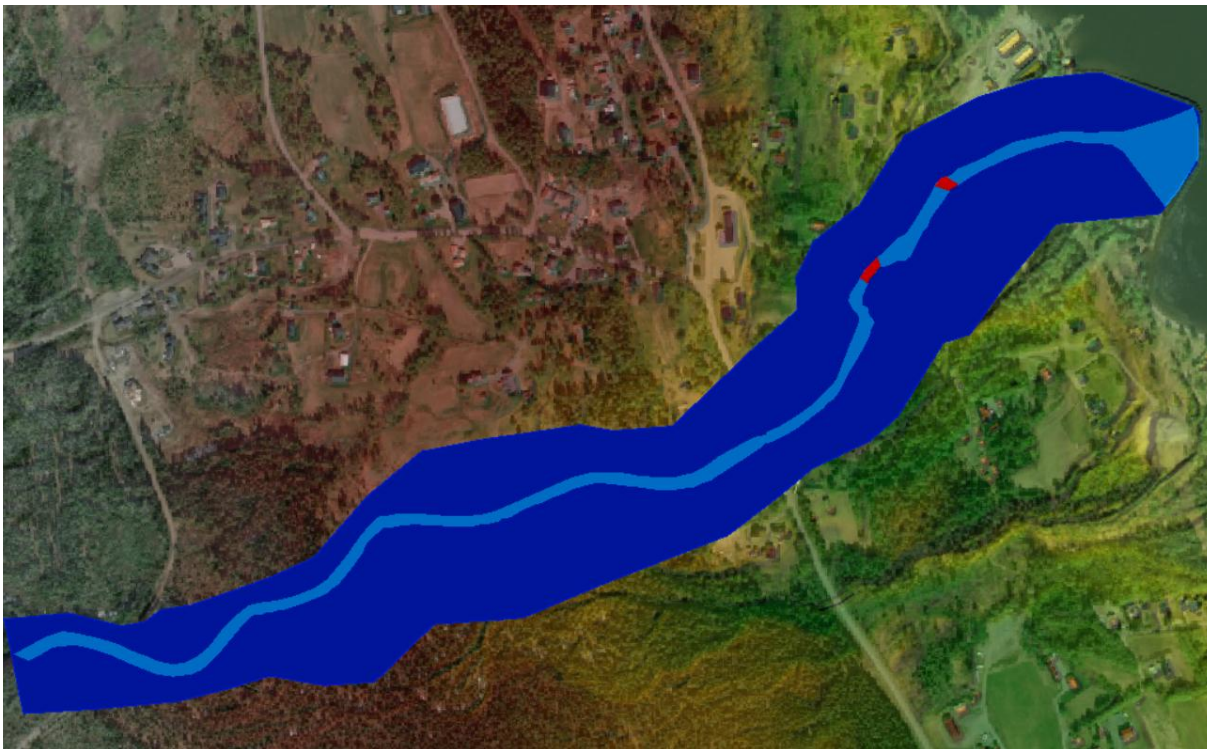


Figure 26. Location of Manning's polygons.

There are two waterfalls located at the red polygons above in Figure 26, a Manning's friction of 0.2 has been used to help stabilise the model at these areas of high gradient. Additionally, weir equations have been included at the top of the waterfalls, using an SA 2D connection in HEC- RAS with a broad-crested weir and coefficient of 1.66.

There are two road bridges in the model domain shown in Figure 27, these bridges were not included in the model as the soffit of the bridge decks was estimated from the LiDAR drone data to be above that of the initial 1 in 100 year model run water surface elevation results as demonstrated in Table 4. Therefore, the bridges are not anticipated to interact with the flow. The western bridge does have piers but as there was no topographic survey of these they have not been included in the model.

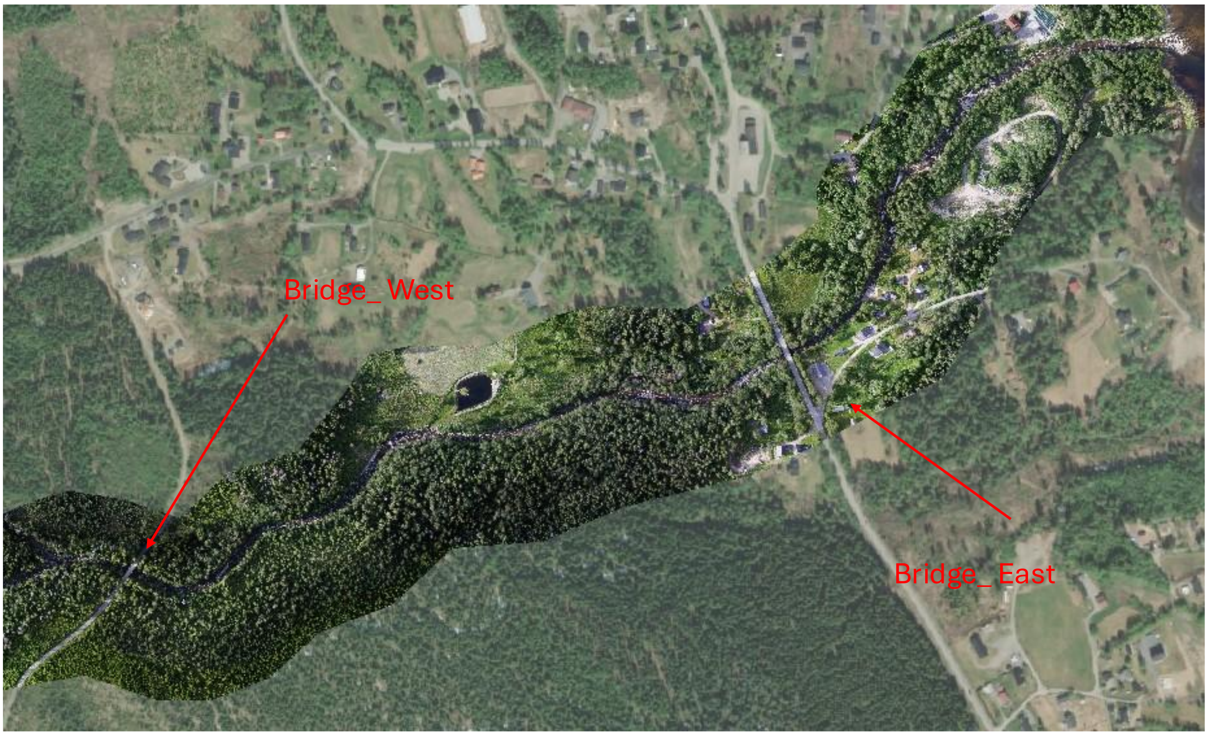


Figure 27. Structure Locations.

Table 4. Bridge soffits compare to 1 in 100 year WSE.

Bridge	Location	Soffit (metres)	1 in 100 year WSE (metres)
Bridge_West	610422, 6691364	238	234.20
Bridge_ East	611146, 6691607	210	206.15

4.7 Model limitations

There are some model limitations given lack of data or other factors:

- As there is no topographic available for the piers at the western upstream bridge, the model does not represent these. It has been assumed that they would not have a significant effect on the model results in this area.
- The model has only been run with the stage boundary at set to the highest recorded water surface level at Hurdalssjøen in order to show conservative, 'worst- case' flood scenarios. The model does therefore not represent conditions with the Hurdalssjøen at lower levels.
- As only the peak values were provided by the client the models have not been run with hydrographs but instead with steady peak flows. This means there is no rising and falling limbs in a flow hydrograph, which would show the progress of flood inundation.

4.8 Model verification

No calibration or verification of the model has been completed as there was no calibration data available.

4.9 Modelling results

4.9.1. Map outputs

Figure 28 to Figure 32 show the maximum depth outputs compared between design and existing conditions for the Qmean, 1 in 5 year, 1 in 10 year, 1 in 50 year and 1 in 100 year flood event.

They show that from the Qmean and above the design activates the paleo channels on the south bank and in all cases the flow rejoins the main channel. Inundation extents and depth patterns elsewhere in the model are not significantly changed by the design.

In the 1 in 50 and 1 in 100 year result at the downstream extent on the north bank the existing results show the activation of a mill lade (611292 ,6691822) It is understood that this will be blocked by farmers and is not included in the official design. However, an embankment was added to the design surface at the entrance of the mill lade with an elevation increase of 0.51 metres and a length of 4 metres.

The 1 in 50 year design results show that this embankment is effective in blocking the activation of the mill lade however in the 1 in 100 year results it is still activated in design conditions. It is therefore recommended that any embankment be larger than the one included in the model in order to block the lade during the 1 in 100 year flood event.

4.9.2. Maximum Mobilised Sediment Size

Figure 33 shows a difference in Dcrit (the sediment size at which mobilisation starts to occur) between the design and existing conditions for the peak of the 1 in 5 year event. This illustrates the effect of the design on maximum mobilised particle size along the channel in the model area.

It shows the Dcrit in the area of the main channel parallel to the activated paleo channel to be reduced by up to 100mm, as a result of flow being diverted into the paleo channels. For the remaining reaches of the channel, further from the design changes, differences in Dcrit are minimal, i.e. between 1 and 20 mm.

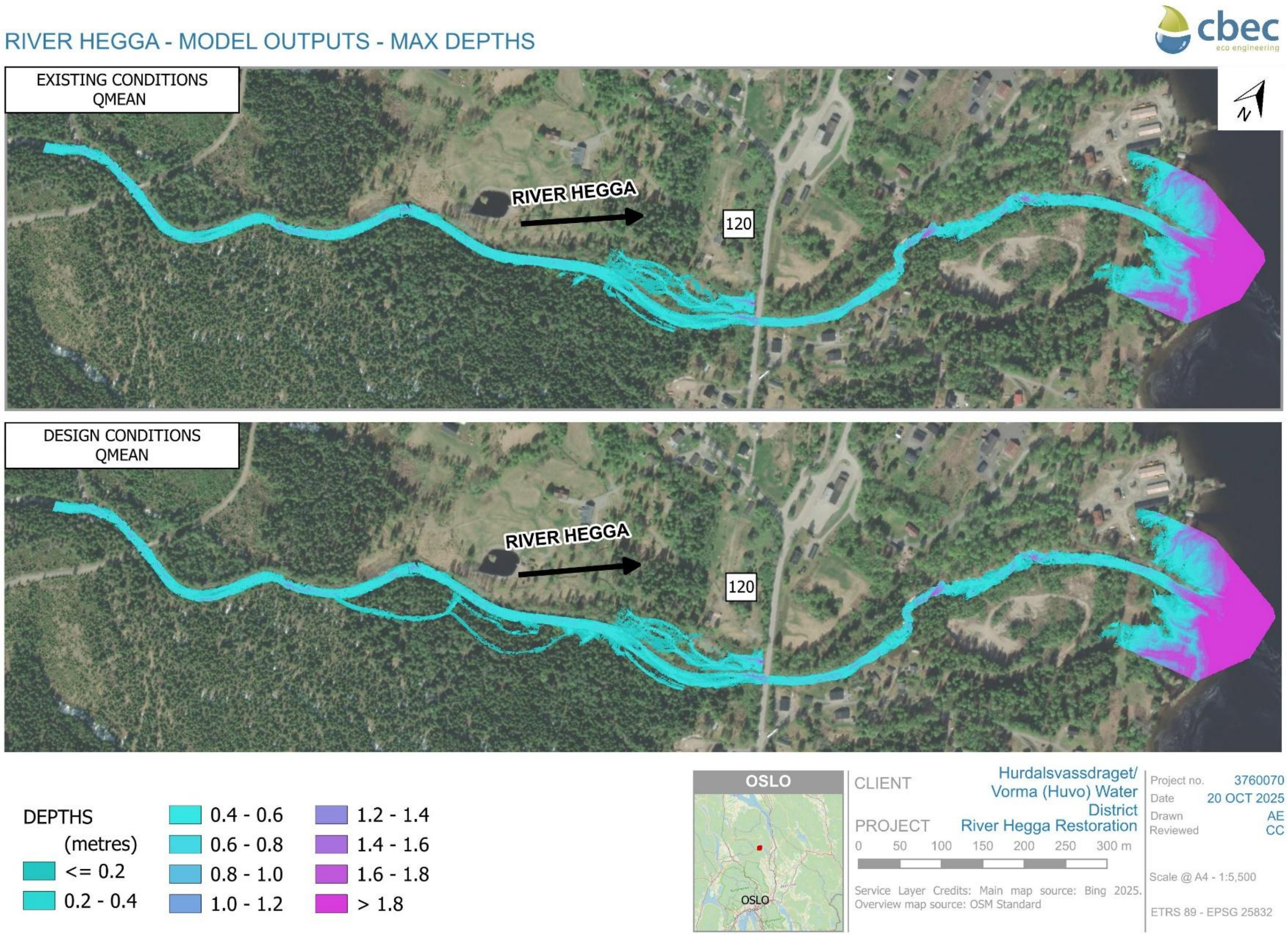


Figure 28. Qmean depth comparisons.

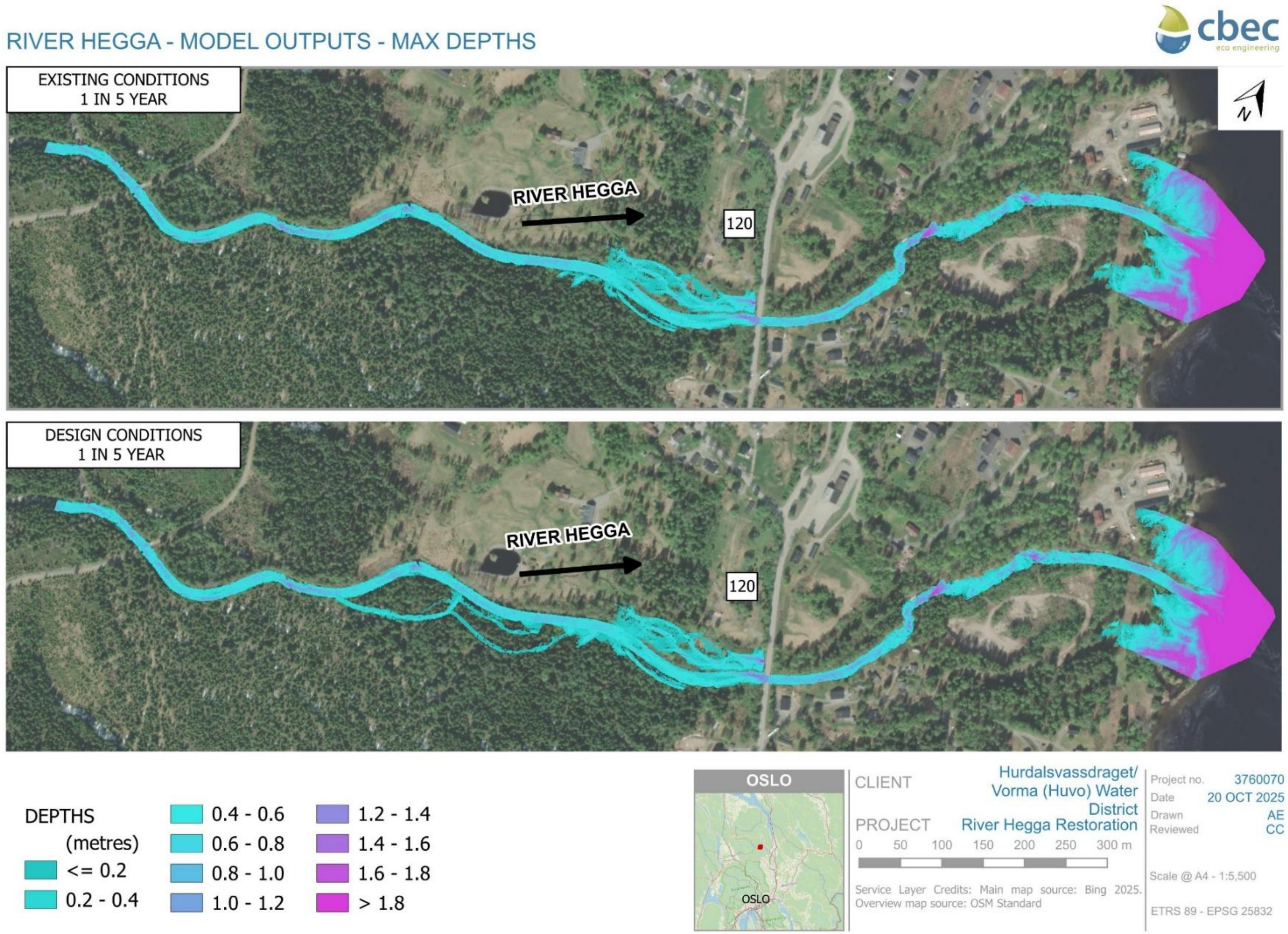


Figure 29. 1 in 5 year depth comparison.

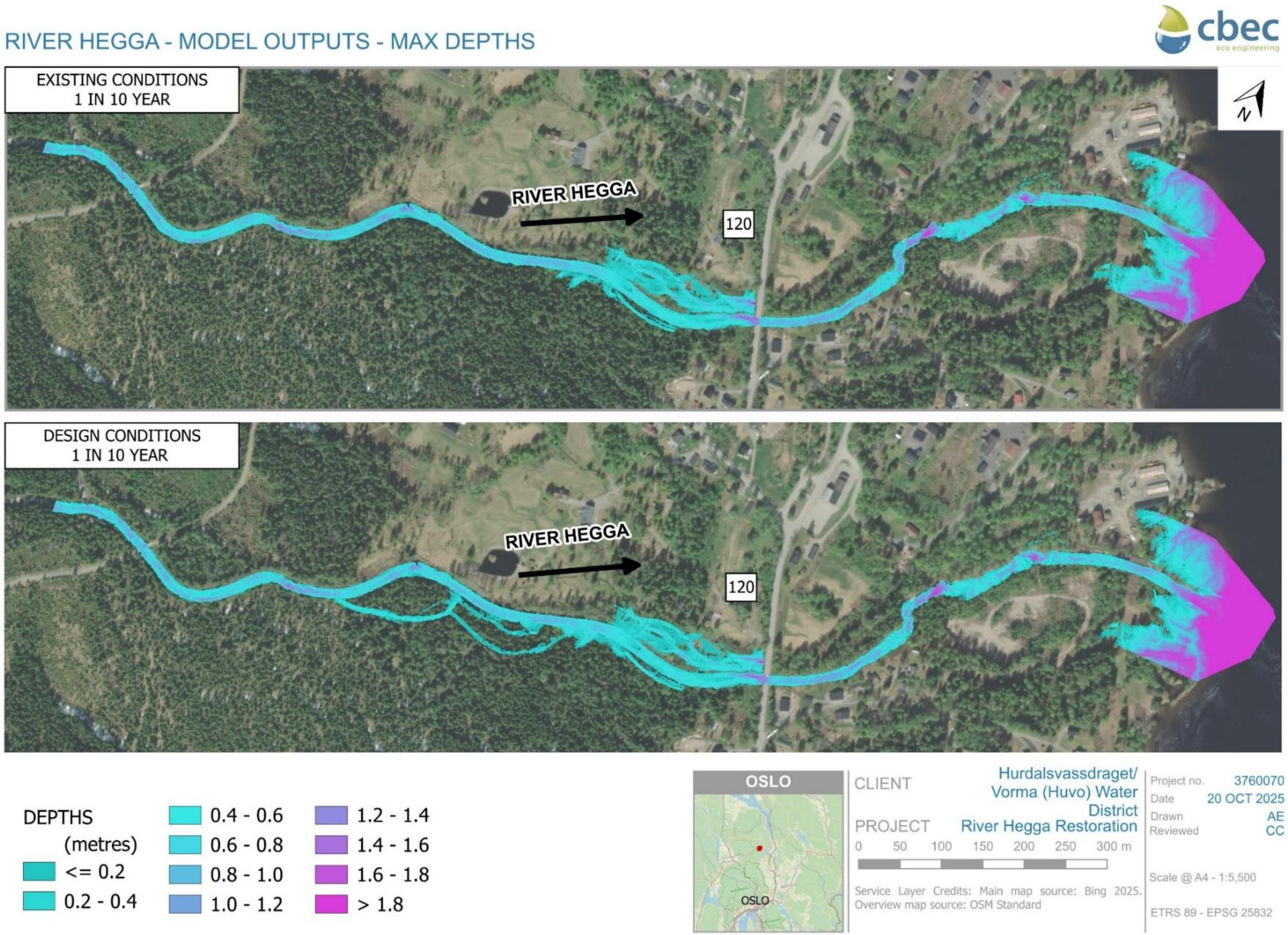


Figure 30. 1 in 10 year depth comparison.

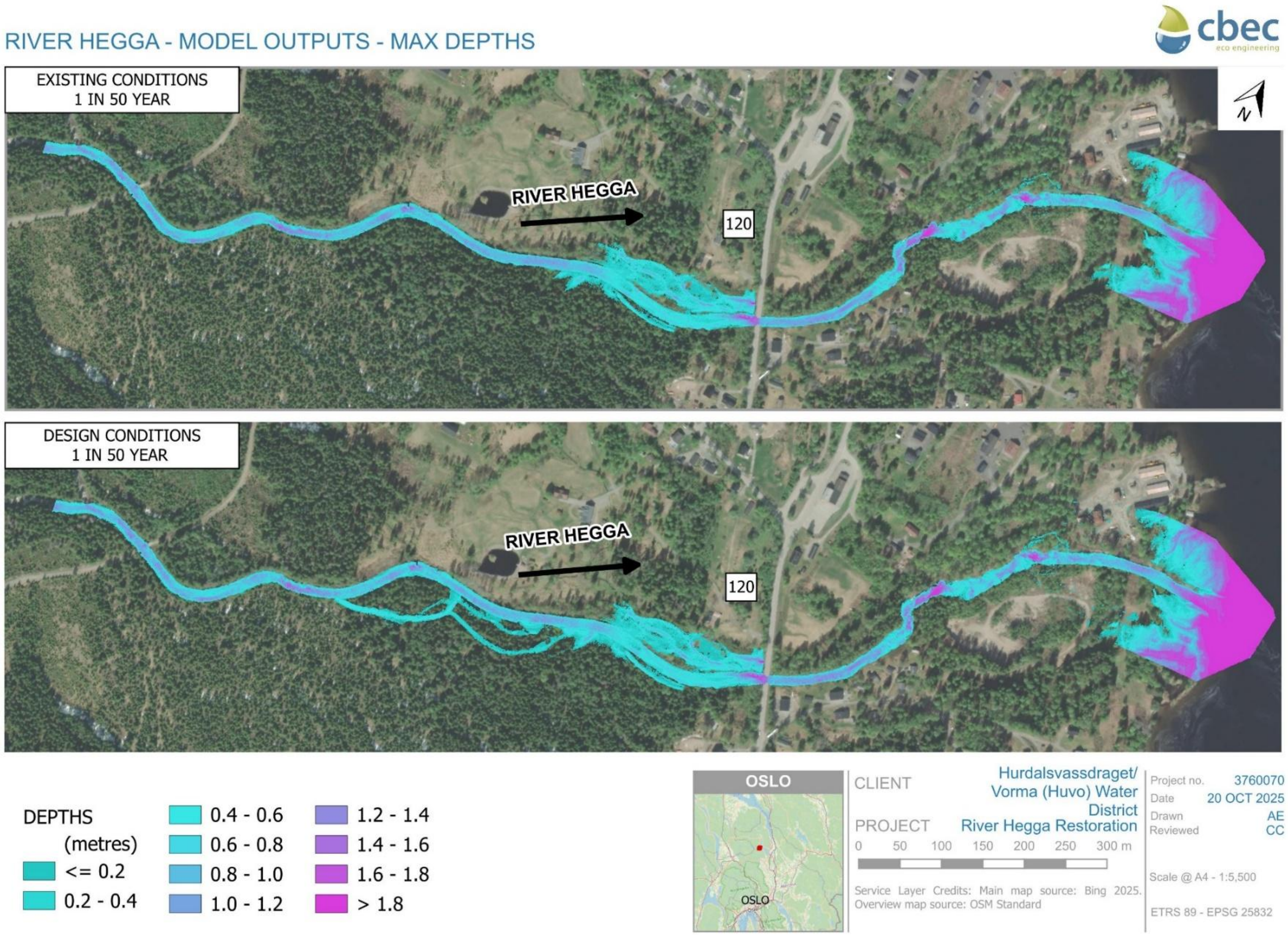


Figure 31. 1 in 50 year depth comparison.

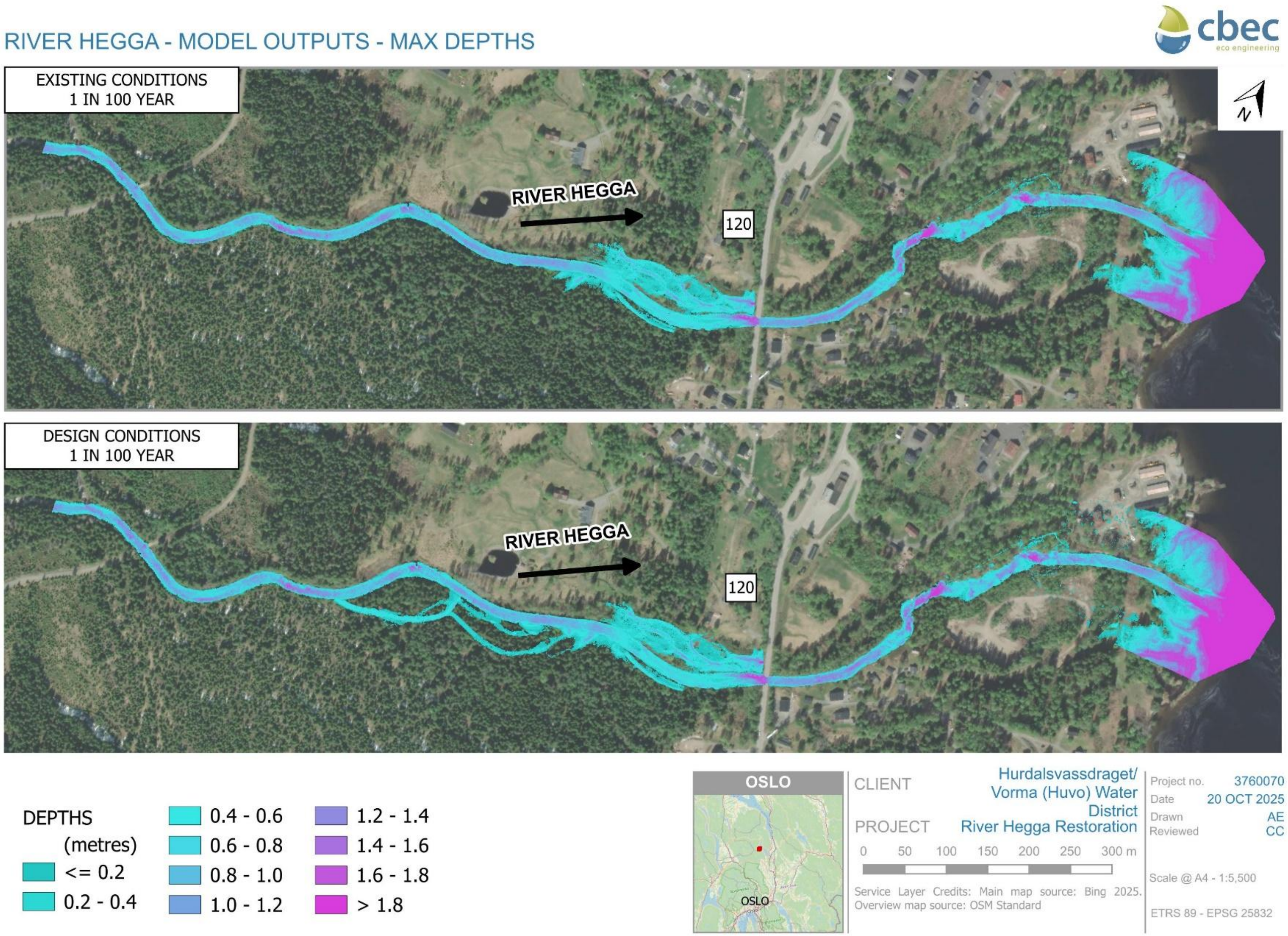


Figure 32. 1 in 100 year depth comparison.

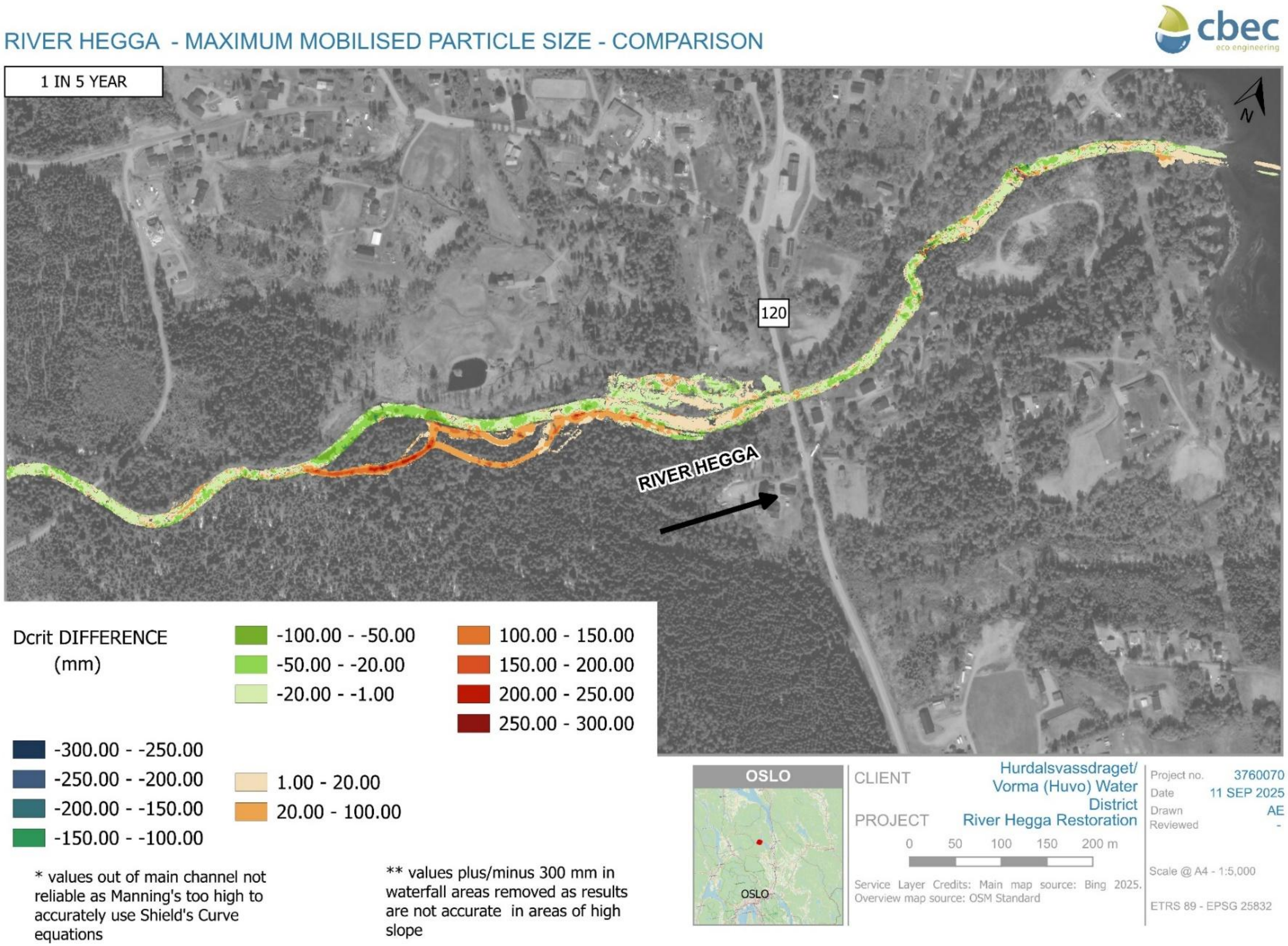


Figure 33. Dcrit difference between design and existing conditions at the 1 in 5 year flood.

4.10 Feasibility of reactivating old channel alignment

Early client discussions, including on site discussions as part of this project, dismissed the feasibility of possibly re-activating or realigning the historic channel to the south. On-going discussions as part of this project however suggest this option may be worth revisiting, given that options to manage both flood risk and improve ecological status are limited within the existing alignment. To investigate the initial feasibility of this option, CBEC used open sourced (1 m resolution) LiDAR that was available for the area.

This extended LiDAR data showed a network of paleo channels running to the south of the current main Hegga channel and flowing towards the Hurdalssjøen. CBEC ran a high-level model with an embankment breach (at grid reference 610515, 6691353) to activate this paleo main channel to determine the feasibility of a future more ambitious project to improve ecological habitat and reduce flooding from the current River Hegga flow path. Figure 34 shows the 1 in 100 year result, the FV 120 road has been daylighted. It shows the flow that has breached the embankment mainly stays central to the valley before joining the Hurdalssjøen and posing increased flood risk to the buildings in this area.

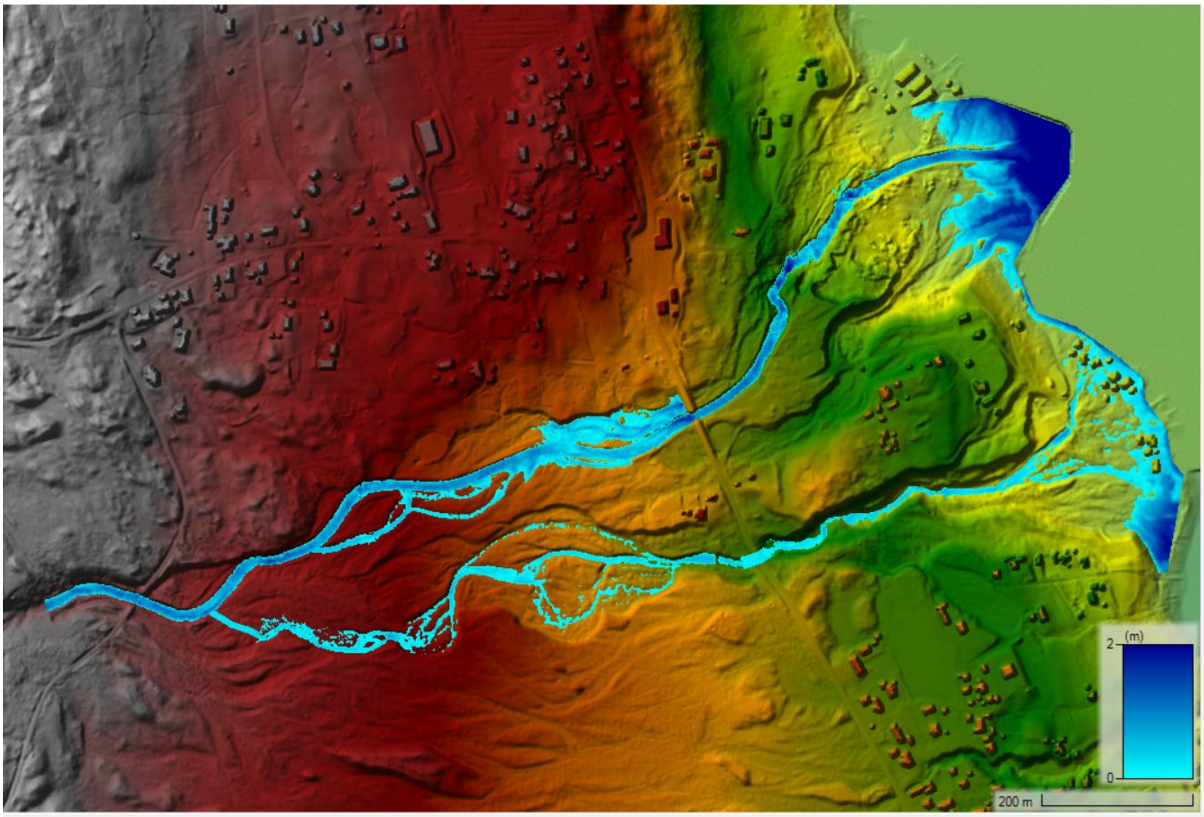


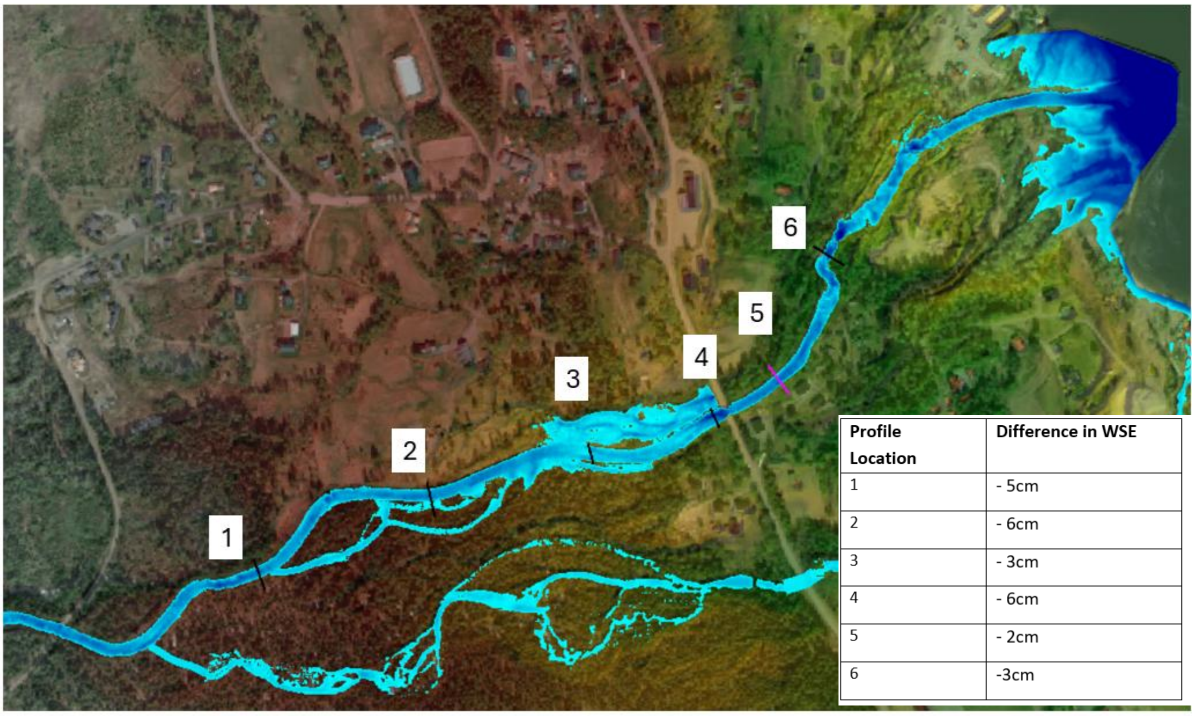
Figure 34. High level extended model results at the 1 in 100 year event. Note such an intervention would require careful design so that no properties at the outlet to the lake are put at risk.

The 1 in 5 year event for this scenario was also completed, Table 5 shows the percentage of flow diverted into this southern channel with the existing breach elevation.

Table 5. Percentage of flow diverted by breach.

Event	Flow Upstream of Breach (m^3/s)	Percentage of flow diverted
1 in 5 year	19.4	2%
1 in 100 year	33.6	6%

Figure 35 shows locations where water surface elevations were compared in the Existing 1 in 100 year conditions and the extension model with the southern breach. The table lists the amount the water surface elevation is reduced by in the extended model conditions in the 1 in 100 year event. It shows in all cases the water surface elevation is lowered by breaching the channel. The out of bank inundation extents are not significantly affected with the additional breach.



Profile Location	Difference in WSE
1	- 5cm
2	- 6cm
3	- 3cm
4	- 6cm
5	- 2cm
6	-3cm

Figure 35. Location of in channel WSE comparisons.

4.11 Hydraulic modelling conclusions

This section of the report has outlined the hydraulic modelling methodology for both the existing and design conditions for restoration of the River Hegga and the source and application for the hydrology used in this model. The model depth outputs demonstrate successful activation of paleo channels to the south of the River Hegga through a series of embankment breaches in the design conditions. The report also demonstrates how this design would reduce the maximum mobilised sediment size of the main channel in the design area.

Furthermore, an additional high-level model was completed at the 1 in 100 year event to demonstrate the potential feasibility of re-activating the historic channel to the south to enable future restoration and natural flood management projects in the area.

5 Conclusions and recommendations

The Hegga River, originally a dynamic multi-thread system, underwent significant anthropocentric alteration, resulting in its present-day configuration as a straightened, single-thread channel that has seen historic removal of boulders to the channel margins. These modifications have disconnected the river from its original floodplain, resulting in concentrated flows and a sediment transport regime capable of denuding the channel of the gravel-sized materials needed for trout spawning. The key restoration proposal that has emerged from this report is to attempt to reactivate a number of side channels on the south side of the channel wherever constraints allow. We also propose that larger boulders (>0.5 m) dislodged as part of the breeching process are reintroduced into the channel as a means of increasing in-channel roughness and providing greater flow and habitat heterogeneity. These measures, although beneficial, will not result in the wholesale transformation of trout habitat that is desired, nor will these measures address the local stakeholders concerns around flood risk, especially considering the expectation of larger and more frequent flood events in the future as a result of climate change. While the proposed interventions are still worthwhile, we also propose that the client revisits the option of reactivating the older channel alignment to the south, as our preliminary modelling suggest it would be feasible. However, such a project would require careful detailed design to ensure an adequately sized culvert under the FV 120 road, and a defined channel at the outlet to the lake so that no homes or property are put at risk. Such an intervention, if acceptable to local landowners, would reopen previously disconnected habitats (including the creation of wet woodland environments) and would function as a major release value under high-flow events, thus greatly reducing flood risk to those currently affected during large flood events. Furthermore, this would reduce the transport and erosive potential of the existing channel, thus increasing the retention time of gravels in the system.

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