OPERANDUM

OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks

Intervention proposals in phase 3

Salix

naturalea

GCU Glasgow Caledonian University

University for the Common Good

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Short Description
This document reports information needed for the set-up and operationalisation of Nature Based Solutions (NBSs) at OAL-UK. It includes the description of the OAL, a conceptual approach for NBSs selection at the OAL level, a description of the selected NBSs, a botanical description of the selected NBSs, and a conceptual approach for monitoring the performance of the selected NBSs.

Dissemination level		
PU	Public	
CO	Confidential, only for Members of the Consortium, including the EU Commission Services	

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DOCUMENT I. Memory

1. Study site

OAL-UK is adjacent to Catterline Bay. OAL-UK represents a small-scale (i.e. 0.4 km^2), culturally significant OAL due to its scenic beauty, portrayed by renowned Scottish painters in the past. The site lies close to the Fowlsheugh coastal nature reserve, known for its high cliff formations and habitat supporting prolific seabird nesting colonies.

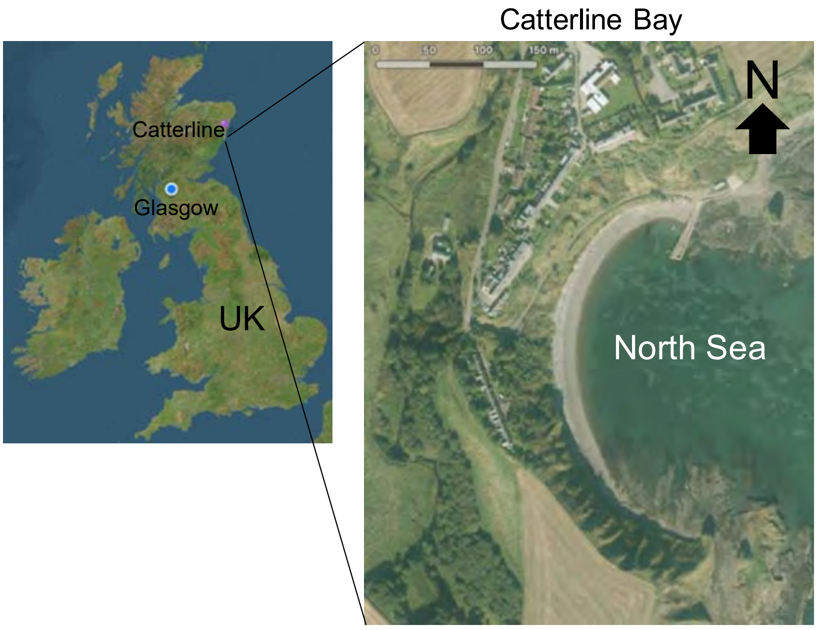


Fig 1: Location of OAL-UK, Catterline Bay.

2. OAL Characteristics

Location and Socio-economic features

OAL-UK is located approximately 7 miles south of Stonehaven, Aberdeenshire (WGS84 Long: -2.21 Lat: 56.90 Fig. 1). Catterline Bay hosts a small residential community (ca. 150 inhabitants) which includes a primary school. The community is settled atop the cliffs and slopes adjacent to the bay. Catterline's residents use the slopes, cliffs, beach and shores for minor fishing activities and for recreational purposes. There is a divers club (https://www.montrosesubaquaclub.co.uk/about-us/) that is operative during the summer months, and it maintains an access road to the beach. Paddleboarding activities also take place at Catterline Bay during the summer. Catterline's residents are actively involved in the implementation of Nature-based Solutions (NbSs) against landslides and coastal erosion hazards through the Catterline Braes Action Group –i.e. CBAG https://www.cbag.org.uk/.

Climate

OAL-UK is located within the temperate humid climate zone (Cgc: subpolar oceanic climate; Köppen, 1884). The mean annual temperature at the site is 8.9ºC and the mean annual rainfall is 565.13 mm (2011-2014; Gonzalez-Ollauri and Mickovski, 2016). The precipitation at the site is characterised by frequent, low- intensity rainfall events (Gonzalez-Ollauri and Mickovski, 2016).

Geology and Edaphology

The basement geology of the area is Devonian age conglomerate, similar to that seen beneath Dunnotar Castle, although are dipping much more gently in Catterline. A detailed description of the Catterline Conglomerate Formation from the BGS website *(http://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=CATC*) is: “A bimodal, clast-supported conglomerate with clasts mainly of lava, but also containing psammite, quartzite, vein-quartz and feldspar porphyry in a mediumgrained lithic sandstone matrix, with single flows of andesite and three sandstone members.”Quaternary glacial deposits of unknown composition and thickness are expected to uncomfortably rest upon the basement rocks.

With regard to soil features, well-drained (saturated hydraulic conductivity (Ks): $5.82x10^{-05}$ m s^{-1}), shallow (ca. 600 mm), sloped (25-50º), and landslide-prone silty sands (sand: 79.82%; silt: 5.85 %; clay: 3.08%) overlie the conglomerate rock. The topsoil at the site (0-400 mm below ground level, b.g.l.) has a mean dry bulk density of 0.86 g cm^{-3}, a drained cohesion of 33.4 kPa, a mean angle of internal friction of 22º and a mean organic matter content of 5.57 %.

Topography

The site topography is dominated by sloped (25–50º) terrain and cliffs dropping into the North Sea (Fig. 2). These are combined with a flatter inland area that is crossed by a stream leading to the formation of inclined riverbanks

Land Cover

The vegetation of the study site is characteristic of temperate humid climates, comprising herbaceous weeds and grasses associated to disturbed grounds (Gonzalez-Ollauri and Mickovski, 2017b) intermixed with areas dominated by riparian trees and shrubs (e.g. willow, sycamore, ash, hawthorn), where oak and beech individuals can be also found. Agricultural crops of wheat, barley and potatoes surround the study site. There is also a 2 km-long stream within the OAL. Other land covers comprise urban and artificial land with a minor area covered by transport infrastructure, which represent 11 % of the OAL’s total area.

Fig 2: Study site

Location: name: Catterline **(UK)** coordinates: 56.9°N 2.2°W scale[1] (NBS): micro scale[1] (impact): watershed	**Hydro-meteorological risks** ✓ flood ✓ landslide ✓ storm surge ☐ drought	**Existing NBS** ☐ green ☐ blue/grey/hybrid ✓ unsystematic	**Intended NBS** ✓ green ✓ blue/grey/hybrid
Innovation ✓ definition ✓ co-design ☐ deployment ☐ monitoring/modeling ✓ KPI ☐ market development ☐ co-benefit			**Stakeholders** ✓ statutory authorities ✓ local government ✓ resident ✓ land owner/managers ☐ business ☐ research institutions ☐ civil protection ☐ cultural associations
Economic assets ✓ tourism/recreation ☐ biodiversity ☐ manufacturing industries ✓ agriculture/fishery ☐ cultural heritage	**Links to EU initiatives** ✓ Natura 2000 ☐ WFD ☐ EU-LIFE ☐ other EU Projects	**Major strategies to maximize impact** ✓ replication ✓ dissemination ☐ exploitation ✓ capacity building ☐ shifting policies	

Fig 3: Main chacateristics of the area. *From Glasgow Caledonian University*

3. Hydrometeorological hazards at OAL-UK

Three main hydrometeorological hazards act on OAL-UK. These are shallow and deep landslides, surface erosion, and coastal erosion. The soil materials comprising the slopes and cliffs at OAL-UK present silty sand texture. As a result, the mechanical strength of the slope forming materials is subject to changes under wetting and drying cycles, which make the OAL-UK prone to rainfall-induced landslides and surface erosion. These natural hazards are worsened in some sections of the OAL as a result of an overpopulation of rabbits and the outflow of a natural spring from which the local community used to retrieve water for consumption. Once the spring was closed, the water begun to outflow diffusively, saturating the slope-forming materials and thus reducing their mechanical strength. Currently, there are a number of active, and interlinked, shallow landslides and surface erosion processes at the OAL. Yet, historic records from pictures, photography, local testimonies, and news suggest that the former natural hazards have occurred at the OAL over time. Moreover, past spring tides in combination with storm surges have led to severe erosion episodes of the toe of the OAL's slopes and cliffs. This, in turn, weaken the slope forming materials further, becoming even more prone to rainfall-induced landslides and erosion. To our knowledge, there only is one major landslides episode reliably reported by the OAL's residents, and recorded at the meteorological station deployed *in situ* at the OAL (https://www.pedrox.com/weather/index.html). This occurred in October 2012 after two periods with prolonged rainfall occurring in the summer and October, respectively. From local testimonies, it seems that this episode was concurrent with spring tides and a storm surge episode, which worsened the landslides event. Through the examination of rainfall time series retrieved at the OAL for this period, we observed total rainfall amounts comprised between 30 and 40 mm, with durations comprised between 11 and 16 hours, and intensities ranging between 1.9 and 3.9 mm h^{-1}. With this, we established that an extreme hydrometeorological event likely to trigger severe landslides at OAL-UK could be selected on the basis of daily rainfall depths beyond 30 mm d^{-1}, which corresponds to ca. 5 % of annual rainfall concentrated in one event. Meteorological time series for the OAL-UK are available from late 2011 to present, so the examination of longer time series is not possible. The examination of these time series indicate that between 2011 and late 2018, five extreme episodes of have occurred at the OAL-UK (Table 1). The study of meteorological time series from nearby weather stations (e.g. Stonehaven) could be helpful but not meaningful, as Catterline presents a marked micro-climate (e.g. Gonzalez-Ollauri and Mickovski, 2016). In fact, through the study of meteorological records for Stoneheaven, where other landslide episodes have been recorded by local media (e.g. https://www.bgs.ac.uk/products/geohazards/landslide.html), suggest that extreme events with rainfall depths of 150 mm d^{-1} would be more representative. As for extreme events related to the storm surge episode allegedly occurring in October 2012, monthly extremes from Aberdeen's offshore sea monitoring station were examined (https://www.bodc.ac.uk/data/bodc_database/nodb/). From this dataset we retrieved the maximum records for wave height, tidal level, and surge recorded. These resulted in the following extremes: (i) Wave height > 4.0 m; (ii) tidal level > 4.815 m ; and (iii) surge > 0.59 m. We believe the combination of both prolonged period with rainfall and high sea levels represent the worse-case scenario at the OAL. In addition to the above-mentioned hydrometeorological hazards, riverbank erosion and flooding hazards are also contemplated at the OAL-UK. There is a small-size stream at the OAL-UK which flow and water level does not experience substantial seasonal changes. The size and length of the stream and its flow conditions do not impose major hazards or risks to the OAL's community. However, we have observed some minor episodes of riverbank erosion and flooding at specific points of the riparian zone. We do not have records yet on river flow and height, but considering the small size of the catchment (i.e. ca. 0.4 km^2), we could assume that the same extreme events described above could potentially trigger changes in the river hydrodynamics with potential to lead to minor episodes of riverbank erosion and flooding.

Rainfall extremes	Start	End	Rainfall intensity (mm h^{-1})	Total rainfall per event (mm)	Duration (h)
2012-07-18	2012-07-18 3:00	2012-10-12 18:00	1.93	30.8	16
2012-10-12	2012-10-12 5:00	2012-10-12 15:00	3.76	41.4	11
2015-07-04	2015-07-04 04:00	2015-07-04 14:00	2.78	30.6	11
2016-06-25	2016-06-24 23:00	2016-06-25 12:00	2.52	35.4	14
2017-06-06	2017-06-05 23:00	2017-06-07 06:00	1.27	40.8	32

Extreme rainfall events recorded at OAL-UK

4. Project rationale and approach

Humans have transformed the Earth's landscapes over time. This transformation has overall improved welfare in human communities but also has created conflicts with the environment. Some of these conflicts are worsen by pursuing the creation of static elements in a dynamic world. In addition, landscape transformations may derive into situations in which humans cannot benefit from Nature anymore. Currently, humans are subject to the consequences derived from climate change. This creates extreme environmental conditions related to the occurrence of natural hazards, which provoke serious damages to human life and property. To mitigate natural hazards, humans have gained insight into hydrology, edaphology, meteorology, etc. Yet, we need comprehensive and multi-disciplinary approaches to be able to mitigate natural hazards derived from climate change. These approaches should take into account the dynamics and functioning of ecosystems. Integrated, ecology-based approaches to tackle natural hazards should work along with Nature. Nature-Based Solutions (NBS) are born with this idea in mind. NBS should enable human communities to mitigate natural hazards while retrieving additional benefits or services -i.e. ecosystem services. Examples of NBS can be found in the techniques related to soil and water bioengineering. With NBS employing soil & water bioengineering techniques, the following environmental problems can be addressed:

- Landscape degradation
- Water recharge and pollution
- Drought
- Nutrient retention and cycling
- Runoff management and erosion control
- Slope stabilisation
- Diffuse pollution reduction
- Reduction of flood risks
- Regulation of temperature and humidity (i.e. climate regulation)

A key objective of OPERANDUM is to show the capacity of NBS to manage hydro-meteo hazards by involving local communities, authorities and other stakeholders within the decision and implementation processes (i.e. co-design and co-deployment). Hazards such as shallow landslides and erosion can be effectively addressed with soil bioengineering techniques that combine the use of plants, especially shrubs, with conventional civil engineering approaches.

One key feature to implement NBS effectively and sustainably is the use of local, natural materials. Natural materials, such as logs and plant cuttings, are less rigid than steel and concrete, and so they can evolve adapting to changing environmental conditions. NBS also need management and maintenance, but these are less costly and easier to implement than in conventional engineering projects.

Effective NBS that employ soil bioengineering techniques should use local and native plant materials. Sometimes other plant species can be introduced when there are not foreseen invasive issues. Newly introduced species should present features that enable the overlap of the ecological functions with respect to the local species. This will maintain the persistence of the ecological and structural functions and features of the host ecosystem in spite of climatic or environmental changes while increasing biodiversity. In fact, more diverse plant assemblages tend to be more resilient towards natural hazards and environmental change.

We propose below a conceptual approach illustrating the steps to follow from the identification of hydro-meteo hazards to the deployment and monitoring of specific NBS at a given OAL.

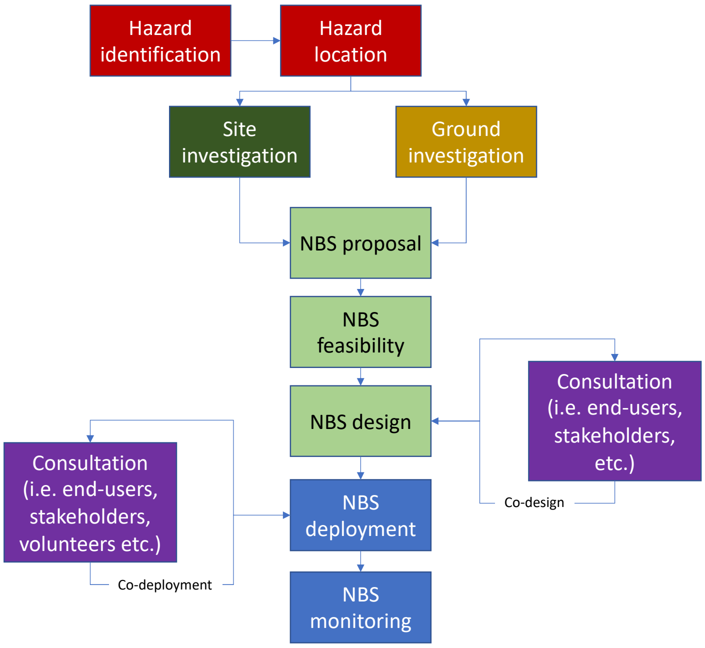


Figure 4. Conceptual model illustrating the steps to follow in the implementation of specific NBS at a given OAL.

5. Projected NBSs at OAL-UK

Naturalea, in partnership with GCU, is looking into the implementation of 8 original NBSs against shallow landslides and surface erosion at OAL-UK. The selection of the different NBSs and actions was done in agreement with the conceptual model shown in Fig. 4.

The projected NBSs will be distributed over 11 different actions (Fig. 5). These will be deployed at different locations within the OAL to explore the performance of the projected NBSs under changing edaphological and topographical conditions (e.g. slope, aspect, curvature, etc) with the aim of upscaling the planned NBSs in the future. In addition, each planned NBS will be vegetated using different plant species combinations and densities to explore performance differences in the mid and long terms with respect to plant diversity and establishment. The 11 NBS actions are planned to be deployed along the beach access road within Catterline Bay. With this, our intention is to create an open-air NBS exhibition which both residents and tourists will have the opportunity to interact with along the walk to the beach. This will enable the visitors to gain insight into NBSs, overall promoting and improving their public acceptance and perception. A brief description of each NBS is provided below.

Fig 5: Zones where NBS actions are planned or already executed at OAL-UK.

5.1. Brush layers

A brush layer consists of a series of steps excavated on the slope, which are then reinforced with plant cuttings, bundles, stacks, and loose earth materials. The aim of a brush layer is to reduce the slope gradient as in terraced systems while ensuring long-term stability and resilience with the establishment of a dense vegetation cover. This technique is applied to slopes with a gradient less than 40°. Branches and cuttings from plant species with the ability to propagate from stems and cuttings (e.g. willow) are placed crosswise on terraces of at least 50 cm in width and with a counter-fall towards the main slope. The branches should cover at least 50% of the area and are filled up with material excavated from the terrace above. To secure the counterscarp from fallings, the branches are placed onto the backwards incline base; then the filling operation is continued.

5.2. Live fascine

A live fascine is a technique that consists in the installation of faggots made of bushes and tree branches of riparian species that are able to reproduce from branches and cuttings (i.e. vegetative propagation). The brushwood faggot or fascine is built by disposing all the branches in the same direction. With this technique, we can use vegetal waste coming from the implementation of other bioengineering techniques, in which bigger bushes and logs are used. The material used to build the fascines is, generally, the leftovers from the preparation of live stakes. It is important that some of the employed branches are at least 3cm wide, as the wider sections are more prone to regrow, while the thinner branches will provide a structural function, retaining soil until a resilient root tissue is fully grown. It is important and preferable to use local species, as well as building the fascines during the dormant season. In zones with hard weather conditions, these structures are established by burying completely a first layer of fascines. Then, one or more layers can be added depending on the zone's conditions and the erosion control needs. When more than two layers are installed, the technique is called *Fascine with brushlayers Ribalta*.

5.3. Fascine with brushlayers

This technique is used with the objective to apply an immediate protection of the slope toe. It uses different stratums overlapped by live fascines. These are placed longitudinally at the slope or terrace toe combined with live stakes, normally of willow, placed transversely at the edge over the medium water level. Fascine with brushlayer enables the installation of 3+ levels/terraces of fascines, while two levels are only possible with the technique described in 5.2.

5.4. Live cribwall

A live cribwall is a gravity wall made of a cellular structure with logs and living stakes or plants in container with the objective that the future development of the plant substitutes the logs structure following its natural degradation or decay (Fig. 12). This technique is used as a retention wall in the stabilisation of slopes with gradients up to 60º.

The cribwall structure is made of timber logs (i.e. logs of peeled conifer, chestnut...) deployed perpendicularly and horizontally with respect to the slope. The space between the logs is filled with compacted earth materials and living stakes, cuttings or plants in container are planted on the front part in high density to retain and reinforce the soil materials. Plant fascines can be also deployed within the front part, which will contribute to retain moisture and foster the establishment of vegetation within the cribwall. The structural logs are secured with nails or steel bars to ensure that the cribwall structure works as a block. A minimum amount of anchorage points is advisable, as places in which nails are installed are prone to rapid degradation.

Live cribwalls can use any type of wood, yet hardwoods with a slow degradation are recommended, as enough time for the establishment of vegetation within the cribwall must be allowed. The diameter of the logs can be highly variable. We recommend the use of logs with diameters comprised between 20 and 30 cm in diameter. It is worth noting that in many instances, timber logs are supplied/sourced with heterogeneous and uneven diameters. To circumvent this issue, it is important to establish even horizontal levels. The live cribwall should have a gentle slope towards the inner part. At the inner cribwall section, the perpendicular logs have a very important anchorage role to the original slope section. The cribwall structure always needs a certain foundation depending on its location and the load it is supposed to stand. In water courses, for instance, it is advisable to protect the cribwall base with stones, rock roll gabions or resistant materials and to level the base below the transitory erosion level. Part of the cribwall foundation must be directly linked to the upper structure and must allow root colonisation. The cribwalls should not have more than 2 m in height. If the height of the slope to protect is higher, a system of cribwalls deployed in terraces should be considered.

5.5. Slope lattice

A slope lattice is a structure made by the union of timber logs deployed perpendicular to each other, creating a grid or lattice structure seated on the slope to be protected (Fig. 14). The structural logs are secured to the ground with nails. A minimum amount of anchorage points is advisable, as places in which nails are installed are prone to rapid degradation. The entire slope lattice structure is secured to the ground with steel nails, anchors with wooden sticks anchored to the ground, which will reinforce the soil mechanically over time. The internal part of the slope lattice is filled with earth materials, rooted plants, cuttings and seeds in high density. Slope grids can be deployed for the protection of relatively stable slopes with severe problems of soil consolidation and on slopes with a slope gradient greater than 45-50º. The number of horizontal logs is calculated in relation to the slope and cohesion of the soil. As with other NBS, the evolution of the structure depends on the plant species, so plant selection is paramount.

5.6. Live palisade

Live palisades are vertical or slightly inclined wooden structures used to retain the ground on embankments and at slope toes (Fig. 15). Live palisades tend to increase the power of the soil or its inner depth. When the wooden structure decays, vegetation roots will reinforce the non-stabilised interspaces of the palisade. This structure is formed by living poles or stakes, which are driven into or buried in the ground horizontally with respect to the slope or wall, forming an array of stakes with gaps in between equal in width to the diameter of the employed stakes. As the structure is built, it is backfilled progressively with soil to level it up the top part of the structure. The latter step is not needed when the palisade is designed for retaining sediment naturally contained in the runoff. Wooden stakes of 8 to 12 cm in diameter are used as vertical posts. These are deployed with a space of 1 to 1.5 meters, depending on the amount of plant material available. After backfilling the wooden structure, it is convenient to sow seeds of native herbaceous or planting native shrubs.

5.7. Loricata cribwall

The Loricata cribwall is a constructive technique based on the creation of a wooden, durable structure that maintains its structure for a large period of time until the vegetation cover develops. It comprises a metal frame holding a series of frontal logs deployed horizontally. The structure is anchored to the ground through a central metallic piece located at the gravity centre. Using basic principles of structural mechanics, the standing force and length of the structure used to anchor the whole structure at the gravity centre can be easily determined. The frontal appearance of a Loricata cribwall is very similar to any cribwall. It can be easily vegetated for landscaping purposes but the stability of the structure no longer depends on the vegetation. The structure has a known, stable and permanent resistance from the moment of its construction and allows the vegetation to develop without any impediment. It should be noted that this system avoids drilling holes in the wooden logs, which grants a longer durability of the logs. In addition, loricata cribwalls are low cost, quick to install and provide an immediate stabillisation effect.

5.8. Live pole drain

A live pole drain (LPD) is composed of a bundle of cuttings and fascines placed horizontally on the ground and oriented in the downslope direction (Fig. 6. Live drains thus facilitate the movement of water off the slope. Hence, live drains can provide ground stability where excess moisture has created instability. Live drains may also allow for vegetation establishment, by reducing earth slumping as a result of improved drainage and root reinforcement. Moreover, the vegetation slows down water movement, reducing erosion, and preventing gully formation. The live drain should comprise a main or principal drainage path in along the flow path to which drainage branches flow into. The main drainage path and branches should be built from ca. 20-30 cm cylindrical bundles of live cuttings and fascines. The main drainage path should be oriented in the direction of the slope and the branches or lateral drain fascines should be deployed in a way that flow into the main drainage is ensured. The lateral drain fascines should be smaller than the main drainage cuttings (e.g. 10-20 cm in diameter). In some instances, it is advisable to cover the live pole drain with earth materials to ensure an adequate contact of the employed plant materials with the soil, promoting the development of roots.

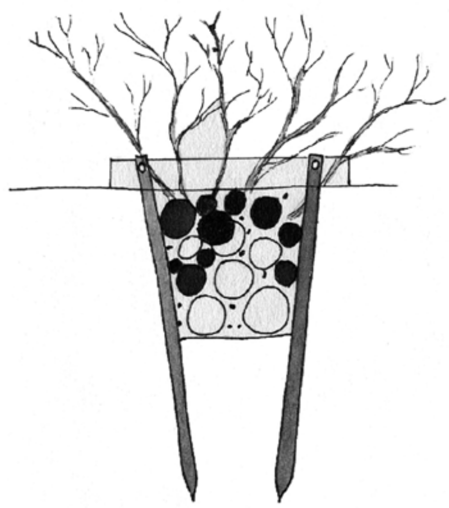


Fig 6. Illustration of a live pole drain. Source: Norris et al. (2008).

5.9. Krainer cribwall

This technique has the same functionality as the live cribwall (Section 5.4) but it is employed for the protection ofsteeper slopes withhigher soil surcharge. This can be achieved by deploying a second line of logs within the cribwall structure. The second line of logs is located behind the first one horizontally and against the slope gradient (see Figure 21).

5.10 Live ground anchors

Earth anchors in combination with substrate+seed bags can be rapidly deployed in most displaceable ground conditions. This type of NBS can improve the stability conditions of the slope at the same time that can lead to a fast development of a vegetated ground cover able to prevent erosion. This NBS should be deployed at locations presenting steep slopes and clear landslide and erosion signs in which the implementation of other mechanical plant operations are not feasible due to the topographical and ground conditions. Earth anchors can be deployed with the use of portable, manual augering equipment and usually require low to no maintenance at locations free from severe coastal erosion episodes. With this technique bags containing earth materials and seeds are filled and deployed on the ground surface attached to the anchors cap. Earth materials should be chosen according to the soil type present at the OAL. If possible, earth materials from landslide deposits can be employed to fill the bags to be seeded. The addition of organic substrates and fertilisers will aid in the germination and development of the seeded vegetation. Plant materials should be selected in agreement with the environmental conditions of the OAL. In general, native fast growing and frost resistant plant species should be preferred. The intervention can be finished with the deployment of a synthetic geogrid or an organic blanket made from coir.

6. Botanical characteristics of the projected NBS at OAL-UK

The proposed original NBS at OAL-UK will employ soil bioengineering techniques contemplating the use of local and pioneer plant species. It is worth noting that pioneer plant species have the capacity to colonise degraded and disturbed land (e.g. landslide-prone landscapes). Yet, not all plant species have these mechanical capacity to stabilise slopes and provide effective erosion control. As a result, careful plant selection is mandatory to ensure intervention success. Plant species useful in soil bioengineering should present the following features:

- Adventitious root emission capacity
- Rooting ability of cuttings and branches
- Sufficient Mechanical tensile strength of roots and shoots
- Resistance to falling stones
- Dense canopy to intercept rainfall and foster evapotranspiration
- Survival capacity after planting
- Resistance to soil wet conditions and good water uptake capacity
- Mechanical tensile strength
- Soil consolidation
- Ground soil improvement
- Aboveground architectural traits that reduce the concentration of precipitation around the tree bole (i.e. stemflow).
- Resistance to overturning and toppling

- Balanced allometric relationship between above and belowground plant parts

Willow species have been traditionally used in soil bioengineering interventions due to their fast-growing nature, to their outstanding ability to propagate from shoots and branches, to their adaptation to wet soils and environments, and to their water (and pollutants) uptake capacity. The presence of willow species such as *Salix viminalis* at OAL-UK make willow a great species candidate to be employed within the planned interventions at the OAL. In addition, there is clear supporting evidence suggesting that willow leads to increased slope stability at the OAL (e.g. Gonzalez-Ollauri and Mickovski, 2017). Other local candidate plant species to be employed within the planned NBS interventions are: sycamore (*Acer pseudoplatanus* L.), silver birch (*Betula pendula*), wild cherry (*Prunus* sp.), gorse (*Genista falcata* L.), broom (*Cytisus scoparius*), hawthorn (*Crataegus monogyna* L.) together with some pioneer herbs such as red campion (*Silene dioica* L.), blue fleabane (*Erigeron acris*) and clover (*Trifolium sp.*), which are expected to colonise the intervention site spontaneously. Plant species from which fruit and fibre can be retrieved could be interesting, too, yet our aim is to employ plant species that can be sourced within the OAL. A brief description for each plant species is provided below.

6.1. Basket willow (Salix viminalis L.)

It is a multistemmed shrub growing to between 3 and 6 m. It has long, erect, straight branches with greenish-grey bark. The leaves long and slender, 10–25 cm long but only 0.5–2 cm broad. The flowers are catkins, produced in early spring before the leaves; they are dioecious, with male and female catkins on separate plants. It is commonly found by streams and other wet places. Along with other related willows, the flexible twigs (called withies) are commonly used in basketry, giving rise to its alternative common name of "basket willow". *Salix viminalis* is a known hyperaccumulator of heavy metals and other pollutants.

*6.2. Sycamore (*Acer pseudoplatanus L.*)*

It is a large deciduous, broad-leaved tree, tolerant of wind and coastal exposure. It is native to Central Europe and Western Asia. The sycamore establishes itself easily from seed. The sycamore can grow to a height of about 35 m (115 ft) and the branches form a broad, rounded crown. The bark is grey, smooth when young and later flaking in irregular patches. The leaves grow on long leafstalks and are large and palmate, with 5 large radiating lobes. The flowers are greenish-yellow and hang in dangling flowerheads called panicles. They produce copious amounts of pollen and nectar that are attractive to insects. It readily invades disturbed habitats. It is tolerant of a wide range of soil types and pH, except heavy clay, and is at its best on nutrient-rich slightly calcareous soils. The roots of the sycamore form highly specific beneficial mycorrhizal associations with the fungus Glomus hoi which promotes phosphorus uptake from the soil. Sycamores make new growth from the stump or roots if cut down and can therefore be coppiced to produce poles and other types of small timber. Sycamore is planted in parks for ornamental purposes, and sometimes as a street tree, since its tolerance of air pollution makes it suitable for use in urban plantings.

6.3. Silver birch (Betula pendula Roth)

Tree species native to Europe and parts of Asia. The silver birch is a medium-sized deciduous tree, typically reaching 15 to 25 m height, that owes its common name to the white peeling bark on the trunk. The twigs are slender and often pendulous and the leaves are roughly triangular with doubly serrate margins and turn yellow in autumn before they fall. The flowers are catkins and the light, winged seeds get widely scattered by the wind. The silver birch is a hardy tree, a pioneer species, and one of the first trees to appear on bare or fire-swept land. The silver birch has an open canopy which allows plenty of light to reach the ground. This allows a variety of mosses, grasses and flowering plants to grow beneath which in turn attract insects. Successful birch cultivation requires a climate cool enough for at least the occasional winter snowfall. As they are shallow-rooted, they may require water during dry periods. They grow best in full sun planted in deep, well-drained soil.

6.4. Hawthorn (Crataegus monogyna L.)

It is a native shrub to temperate regions of the Northern Hemisphere in Europe. Mostly growing to 5–15 m tall, with small pome fruit and (usually) thorny branches. Hawthorns provide food and shelter for many species of birds and mammals, and the flowers are important for many nectar-feeding insects. Many species and hybrids are used as ornamental and street trees. The common hawthorn is extensively used in Europe as a hedge plant. Hawthorns are among the trees most recommended for water conservation landscapes. Hawthorn can be used as a rootstock in the practice of grafting. Although it is commonly stated that hawthorns can be propagated by cutting, this is difficult to achieve with rootless stem pieces. The wood of some *Crataegus* species is hard and resistant to rot.

6.5. Broom (Cytisus scoparius L.)

it is a perennial leguminous shrub native to western and central Europe. Plants of *C. scoparius* typically grow to 1–3 mtall, rarely to 4 m, with main stems up to 5cm. The shrubs have green shoots with small deciduous trifoliate leaves 5–15 mm long, and in spring and summer are covered in profuse golden yellow flowers 20–30 mm from top to bottom and 15–20 mm wide. *C. scoparius* is found in sunny sites, usually on dry, sandy soils at low altitudes, tolerating very acidic soil conditions.

6.6. Gorse (Ulex europaeus L.)

It is a perennial leguminous shrub native to much of western Europe, where it grows in sunny sites, usually on dry, sandy soils. It is also the largest species, reaching 2–3 metres. Gorse thrives in poor growing areas and conditions including drought; it is sometimes found on very rocky soils, where many species cannot thrive. Moreover, it is widely used for land reclamation (e.g., mine tailings), where its nitrogen-fixing capacity helps other plants establish better.

Gorse is a valuable plant for wildlife, providing dense thorny cover ideal for protecting bird nests. Gorse readily becomes dominant in suitable conditions, and where this is undesirable for agricultural or ecological reasons control is required, either to remove gorse completely, or to limit its extent. Gorse stands are often managed by regular burning or flailing, allowing them to regrow from stumps or seed.

6.7. Blue fleabane (Erigeron acris L.)

Blue fleabane is a common native annual or occasional perennial growing to a height of about 20 – 50cm. Blue fleabane is a plant of skeletal environments on well-drained neutral or calcareous soils particularly on warm southing facing slopes. Habitats include sand dunes, quarries, waste areas, walls and rock outcrops. Grows readily from seed sown at any time of the year.

6.8. Red campion (Silene dioica L.)

It is a herbaceous flowering plant in the family Caryophyllaceae, native throughout central, western and northern Europe, and locally in southern Europe. It is a biennial or perennial plant, with dark pink to red flowers, each 1.8-2.5 cm across. The flowering period is from May to October. The plant grows to 30–90 cm, with branching stems. Red campion grows in roadsides, woodlands, and rocky slopes. It prefers to grow on damp, non-acid soils.

6.9. Clover (Trifolium spp.)

It belongs to the legume or pea family Fabaceae. The genus has a cosmopolitan distribution with highest diversity in the temperate Northern Hemisphere. They are small annual, biennial, or short-lived perennial herbaceous plants with the ability of fixing atmospheric nitrogen.

7. Technical specification of the planned NBS actions at OAL-UK at phase III

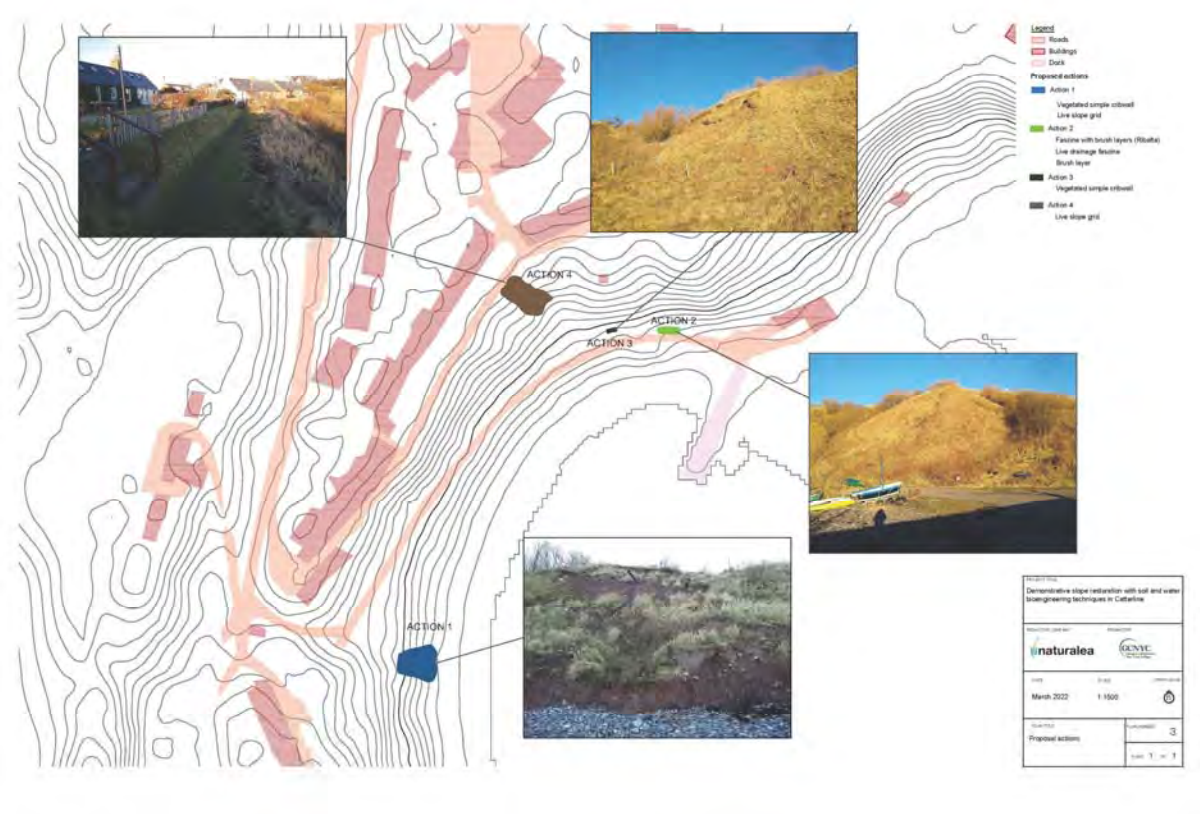


Fig 7. Prposal action for 2022.

7.1. Action 1: Stabilisation of slope affected by drainage of the road

The road drain pipe is broken and water is flowing all over the slope. There are several points where water gushes down the slope. The probability of new landslides is high so machinery can't be circulated along the slope without much additional action to consolidate the land. Access from the top is also not possible without affecting an already stabilized plant mass. The current slope, if continuous, would have a slope of between 30-40º, but currently there are several terraces with greater slopes.

The proposal is to do a 10 m (8m) 4-level cribwall and making a live slope grid of 10 x 1,5-meter. Create a 15 meters lines of live drainage fascine to drain the area. Creation at the top of 16 metres of 2 levels fascine with brush layers (Ribalta). to manage land slopes.

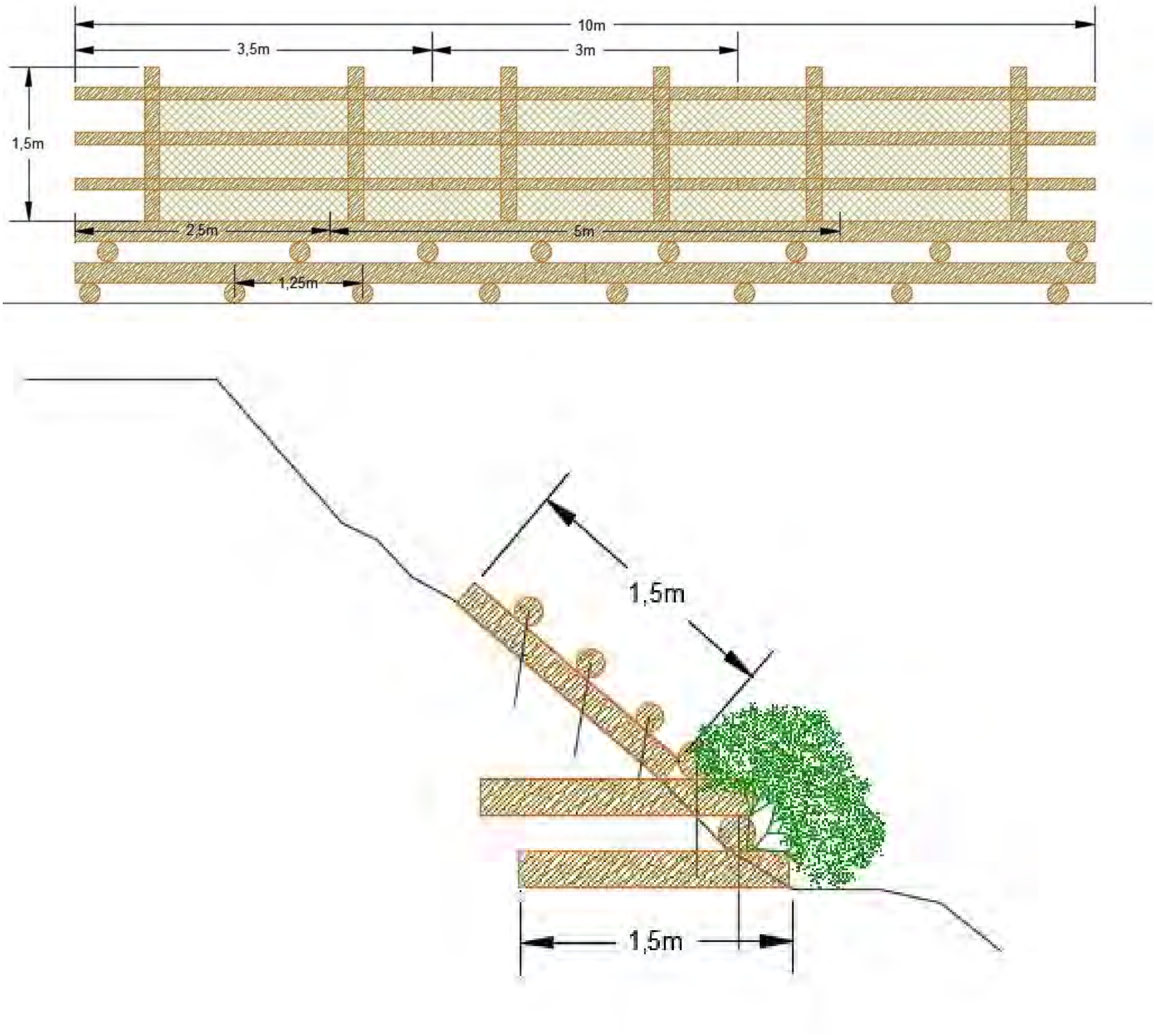


Fig 8. Crib wall and life slope gride

Plants of the Crib wall:

	1st level	2nd level	Unites / species
Hawthorn (*Crataegus monogyna*)	6	10	16
Broom (*Cytisus scoparius L.*)	2	5	7
Gorse (Ulex europaeus L.)	2	7	9
Basket willow (*Salix viminalis L.*)	30	18	48
Unites/levels	40	40	80

Plants of the Life slope gride:

	1st level	2nd level	3rd level	Unites /species
Hawthorn (*Crataegus monogyna*)	4	7	4	15
Broom (*Cytisus scoparius L.*)	5	10	12	27
Gorse (Ulex europaeus L.)	4	10	12	26
Basket willow (*Salix viminalis L.*)	20	6	6	32
Unites/levels	33	33	34	100

Description	Measurements
Live simple cribwall (0,8 m tall)	10 m
Live slope grid on the top de 4 x 4 m	1 un
Plantation of vegetation in AF (Slope grid A)	60 un
Live drainage fascine.	15 m

7.2. Action 2: Stabilisation of slope's toe with brush layers and drainage and stabilisation of the upper slope section with live fascine

The zone where this action has been planned presents a slope gradient comprised between 40 and 55º. This zone has suffered a landslide event in the past and in these last years (Fig. 7). At present, an active drainage system consisting of a corrugated pipe collects surface water from the upper slope. The water collected by the pipe then flows into a gravel channel located in the internal margin of the access road to the beach (Fig 8). Soil wetness is evident in this zone, which encourages further slope movement and surface erosion. Thus, the zone must be drained to ensure adequate stabilisation. The slope's toe also presents clear signs of instability. Yet, the slope's toe has dryer soil conditions than the upper counterpart. The dimensions and access to the slope's toe make feasible the implementation of a brush layer. Both interventions are intended to work complementary. On the one hand, the brush layer intended for the slope's toe will confer stability to the slope system by reducing the slope gradient and by fostering the development of a vegetation mat contributing to the mechanical and hydrological stability of the slope forming materials. On the other hand, the live fascine intended for the upper slope part will collect and withdraw surface water. This will help to improve the hydromechanical stability of the zone in which the live fascine is deployed at the same time that reduces the amount of water received by the slope's toe. As a result, the live fascine will also contribute towards the stabilisation of the slope's toe.

Fig 9 Landslides suffered in the study area

Fig 10 Location and proposal for action 1

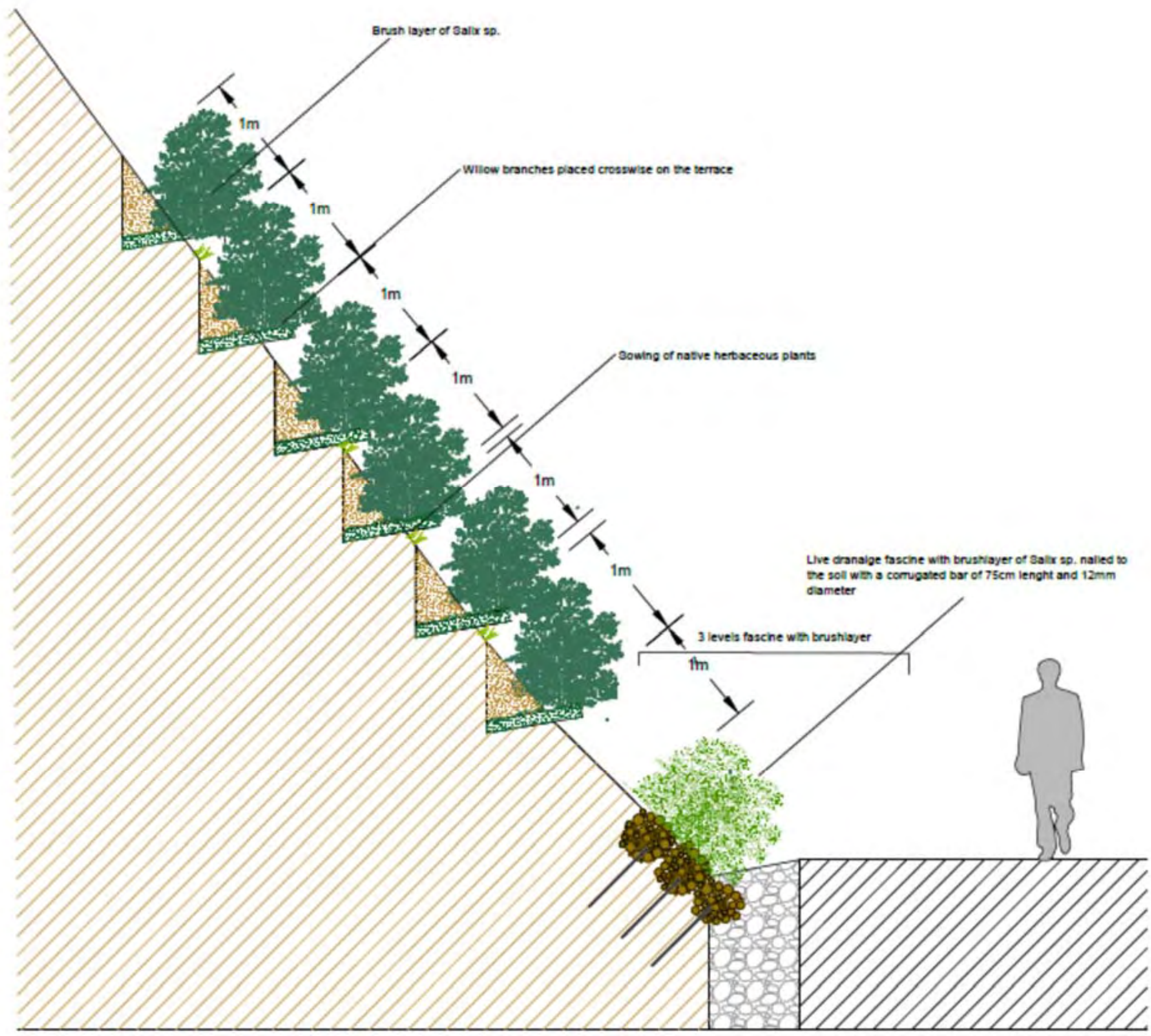


Fig 11: Transverse section of a brush layer. Support plants per level

	1st level	2nd level	3rd level	4th level	5th level	6th level	Unites/species
Hawthorn (*Crataegus monogyna*)	5	5	5	5	5	5	30
Broom (*Cytisus scoparius L.*)					5	5	10
Gorse (Ulex europaeus L.)			5	5	5	5	20
Basket willow (*Salix viminalis L.*)	20	20	15	15	10	10	90
Unites/levels	25	25	25	25	25	25	150

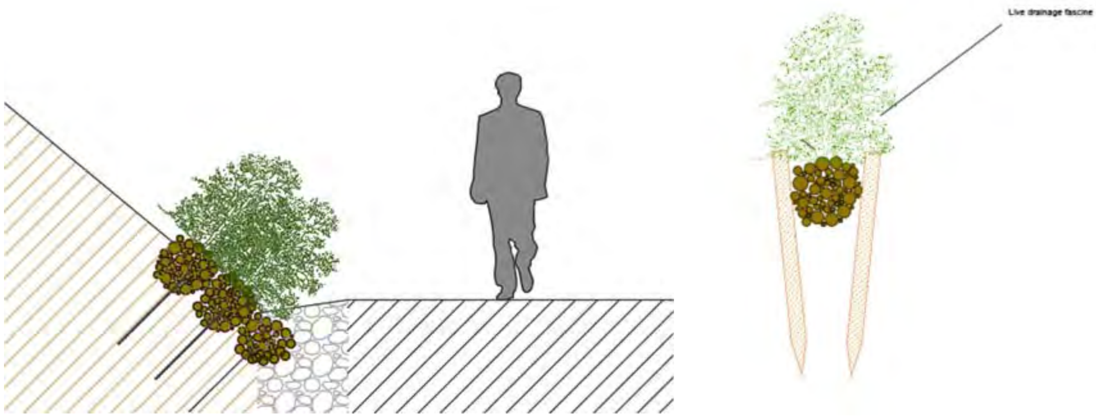


Fig 12: Details of the fascine *Ribalta and live drainage fascine*

Description	Measurements
Brush layer (6x10m)	60 m^2
3 levels fascine (Ribalta)	10 m
Live drainage fascine.	20 m

7.3. Action 3: Simple Live cribwall to stabilise and protect a slope crest section

The zone in which action 2 is planned shows clear evidence of slope failure. This is clearly seen in the lower slope gradient of the bottom section with respect to the top (Fig. 11), as a result of the accumulation of sliding soil materials. A live cribwall (Fig. 12) is intended in this zone. A live cribwall consists of a wooden frame built with superposed timber logs (generally peeled pine). To form the cribwall structure, the timber logs are deployed orthogonally (Fig. 12). Three rows of logs are deployed and anchored facing the slope, while another three rows of logs are deployed against the slope gradient. The logs deployed against the slope gradient are nailed to the logs inserted into the slope. The inner part of the frame is then backfilled with earth and plant materials. As the timber logs within the frame structure decay, the action of the established vegetation will take over, conferring mechanical and hydrological stability to the intervention in the long term. To encourage the long-term stability of this intervention further, the soil materials located at the crest of this section are removed and used to fill the cribwall structure (Fig. 12). The designed cribwall is intended to be 1.4 m high.

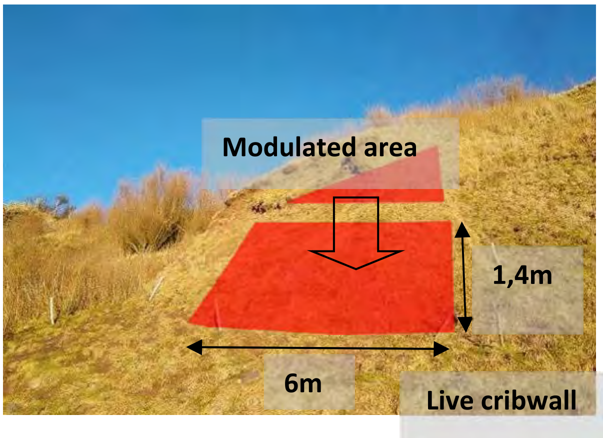



Fig 13: Location and proposal for action 2

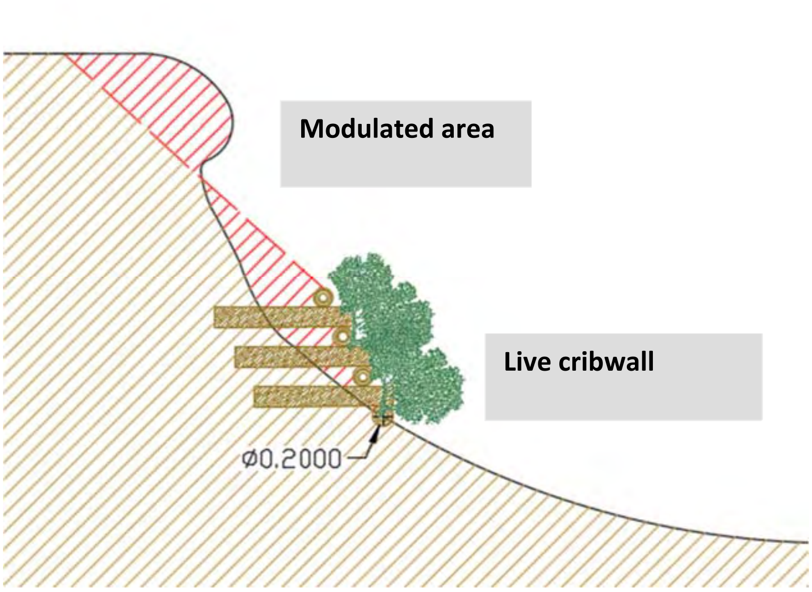


Fig 14: Details of the action 2

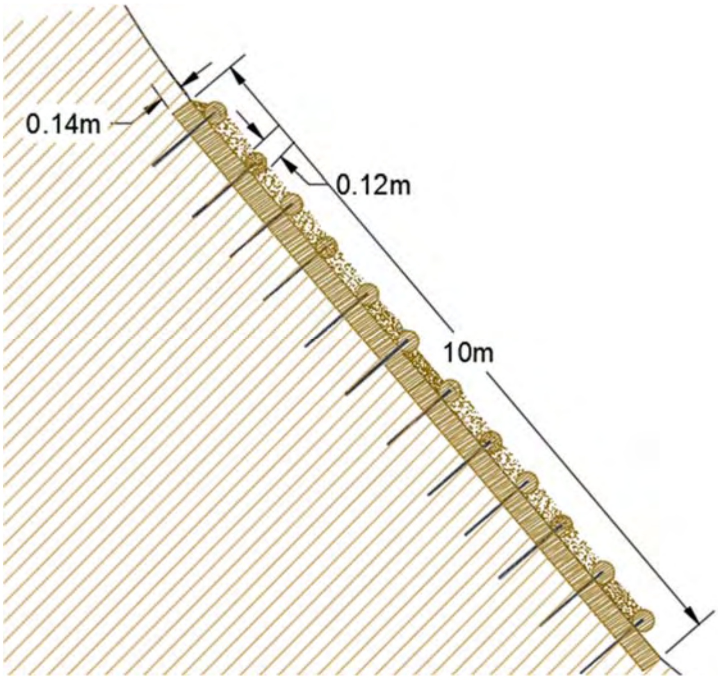
	1st level	2nd level	3rd level	Unites/species
Hawthorn (*Crataegus monogyna*)		6		6
Boom (*Cytisus scoparius L.)*			6	6
Gorse (*Ulex europaeus L.)*		5	5	10
Basket willow (*Salix viminalis L.*)	10	5	5	20
Sycamore (*Acer pseudoplatanus L.*)	6			6
Unites/levels	16	16	16	48

Description	**Measurements**
Live cribwall (1,4m tall)	6 m

7.4. Action 4: Scenic footpath stabilisation with slope lattice

Action 4 is proposed to stabilise a scenic footpath showing evident signs of instability and surface erosion due to the slope gradient present underneath the path. A slope lattice will provide a robust wooden skin to the slope below the path, reducing the tension of the slope and creating stable conditions for the establishment of a dense vegetation cover.

Fig 15: Location and proposal for action 11



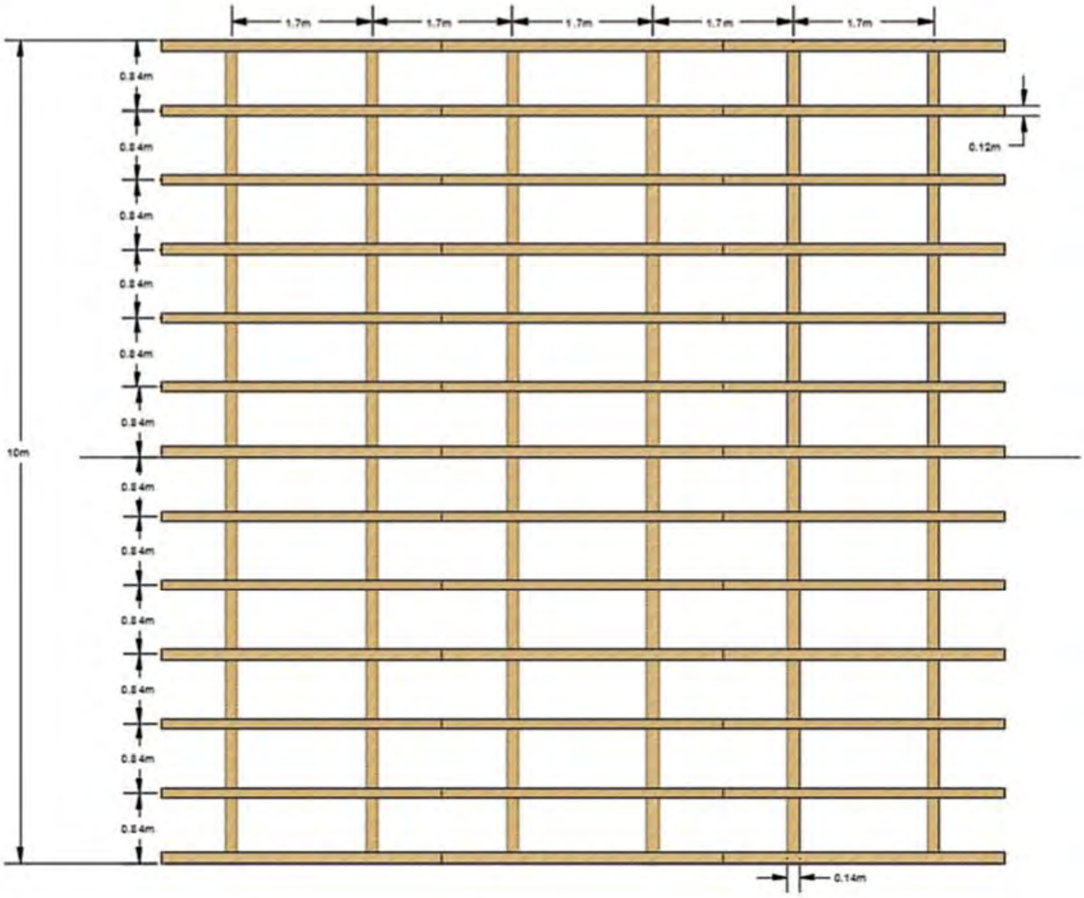


Fig 16: Constructive details of the live slope grid proposed in action 11

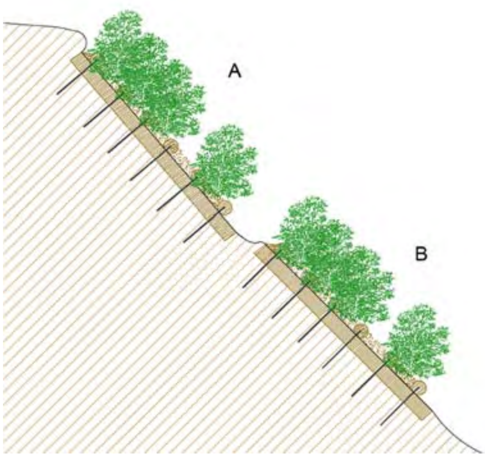


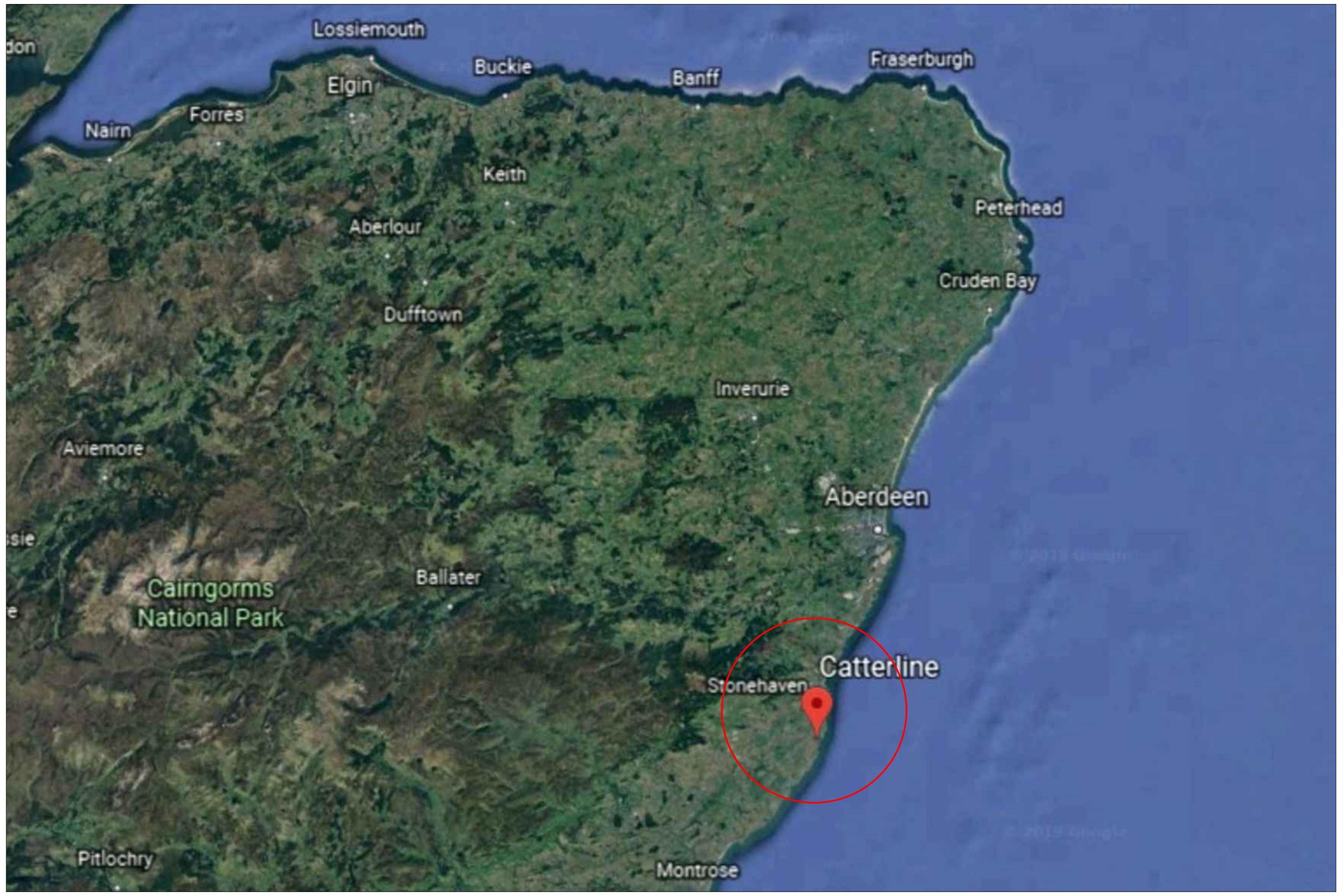
Fig 17 A: Profile section in case that the two lines are not continuous

I

	1st level	2nd level	3rd level	4th level	5th level	6th level	1 line Units / species	2 line Units / species
Hawthorn (*Crataegus monogyna*)	5	5	6	6	3	10	35	70
Broom (*Cytisus scoparius L.*)	2	4	6	6	5	9	32	64
Gorse (Ulex europaeus L.)	2	2	6	6	15	9	40	80
Basket willow (*Salix viminalis L.*)	22	22	15	15	12	7	93	186
Sycamore (*Acer pseudoplatanus L.*)	4	2						
Unites/levels	35	35	33	33	35	35	200	400

Description	Measurements
Live slope grid (10x10m)	1 un

DOCUMENT II. Maps



PROJECT TITLE

Demonstrative slope restoration with soil and water bioengineering techniques in Catterline

REDACTOR COMPANY: naturalea

PROMOTOR: GCNYC

DATE	SCALE	ORIENTATION
March 2022	N/S	

PLAN TITLE	PLAN NUMBER
Location	1
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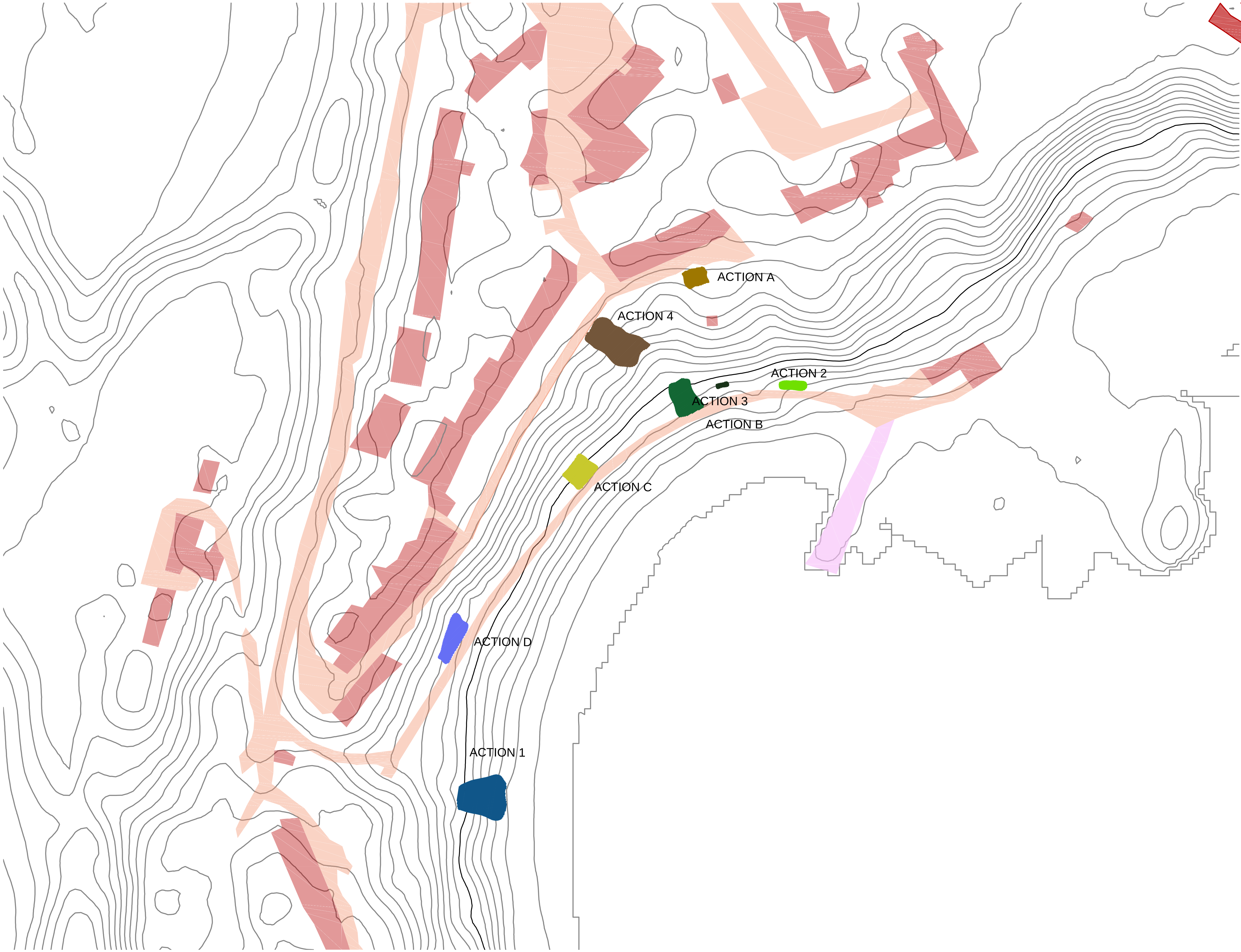


Legend

- Roads
- Buildings
- Dock

First phase executed actions

- Action A
  Ground anchors
- Action B
  Live drainage fascine
- Action C
  Double cribwall
- Action D
  Double cribwall slope grating and palisade

Proposed actions

- Action 1
  Vegetated simple cribwall
  Live slope grid
- Action 2
  Fascine with brush layers (Ribalta)
  Live drainage fascine
  Brush layer
- Action 3
  Vegetated simple cribwall
- Action 4
  Live slope grid

PROJECT TITLE Demonstrative slope restoration with soil and water bioengineering techniques in Catterline		
REDACTOR COMPANY naturalea	PROMOTOR GCNYC Glasgow Caledonian New York College	
DATE March 2022	SCALE 1:900	ORIENTATION
PLAN TITLE Executed actions	PLAN NUMBER 2	PAGE 1 OF 3

Legend

- Roads
- Buildings
- Dock

Executed actions

- Action A
  Ground anchors
- Action B
  Live drainage fascine
- Action C
  Cribwall
- Action D
  Cribwall, live slope grid and palisade

PROJECT TITLE Demonstrative slope restoration with soil and water bioengineering techniques in Catterline	
REDACTOR COMPANY naturalea	PROMOTOR GCNYC
DATE March 2022	SCALE 1:900 ORIENTATION
PLAN TITLE Executed actions	PLAN NUMBER 2 PAGE 2 OF 3

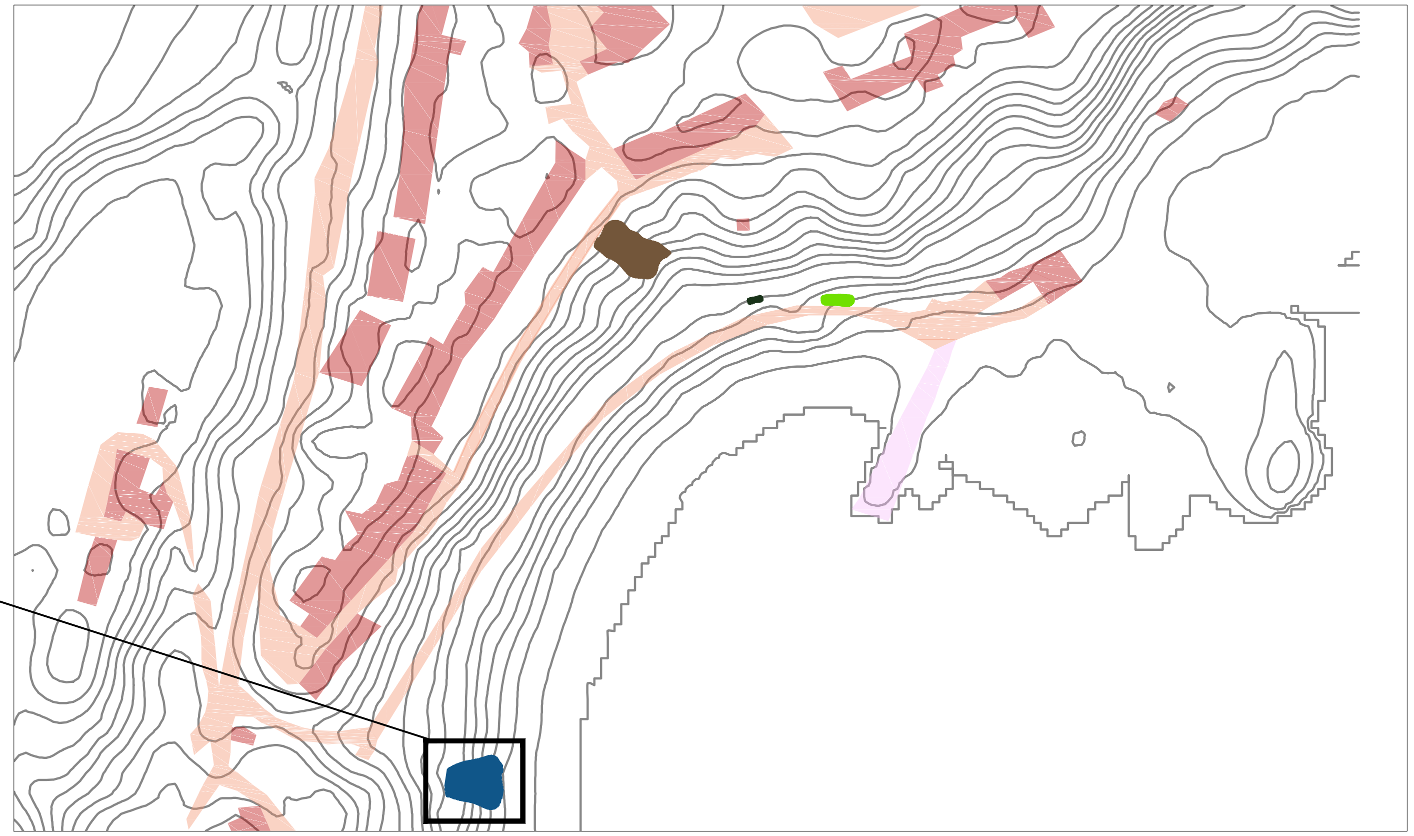
Legend

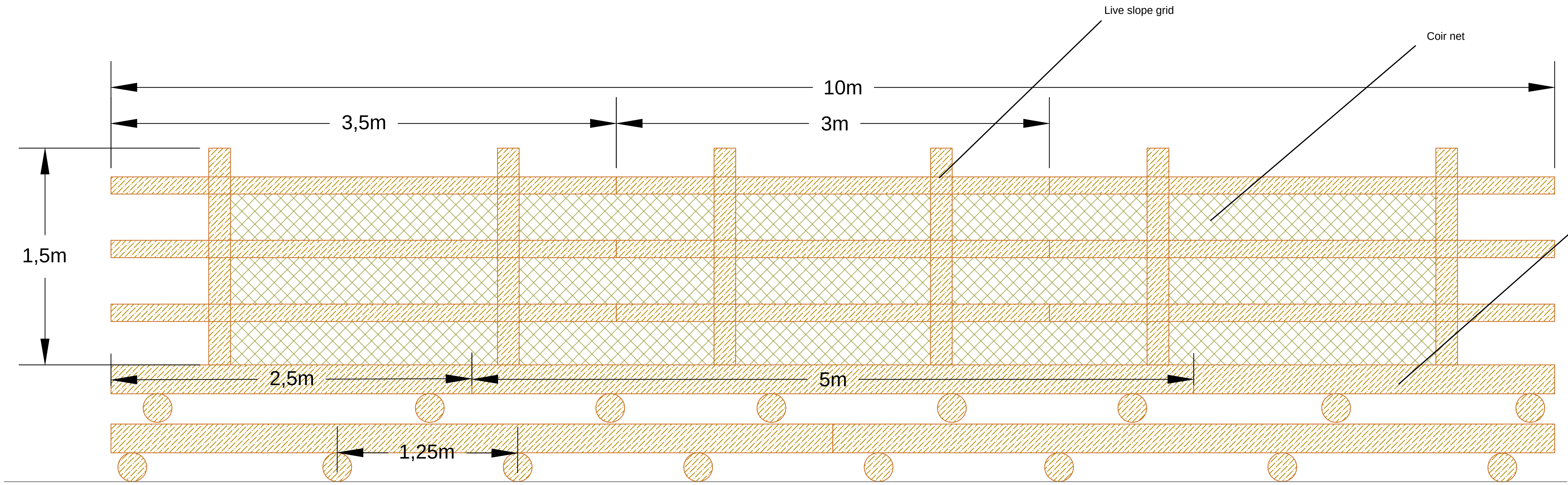
- Roads
- Buildings
- Dock

Proposed actions

- Action 1
  - Vegetated simple cribwall
  - Live slope grid
- Action 2
  - Fascine with brush layers (Ribalta)
  - Live drainage fascine
  - Brush layer
- Action 3
  - Vegetated simple cribwall
- Action 4
  - Live slope grid

PROJECT TITLE Demonstrative slope restoration with soil and water bioengineering techniques in Catterline		
REDACTOR COMPANY naturalea	PROMOTOR GCNYC Glasgow Caledonian New York College	
DATE March 2022	SCALE 1:1500	ORIENTATION
PLAN TITLE Proposal actions	PLAN NUMBER 2	PAGE 3 OF 3





PROJECT TITLE

Demonstrative slope restoration with soil and water bioengineering techniques in Catterline

REDACTOR COMPANY: naturalea

PROMOTOR: GCNYC

DATE: March 2022

SCALE: Details: 1:30, Location: 1:2000

ORIENTATION

PLAN TITLE: Details actions: Action 1

PLAN NUMBER: 3.1

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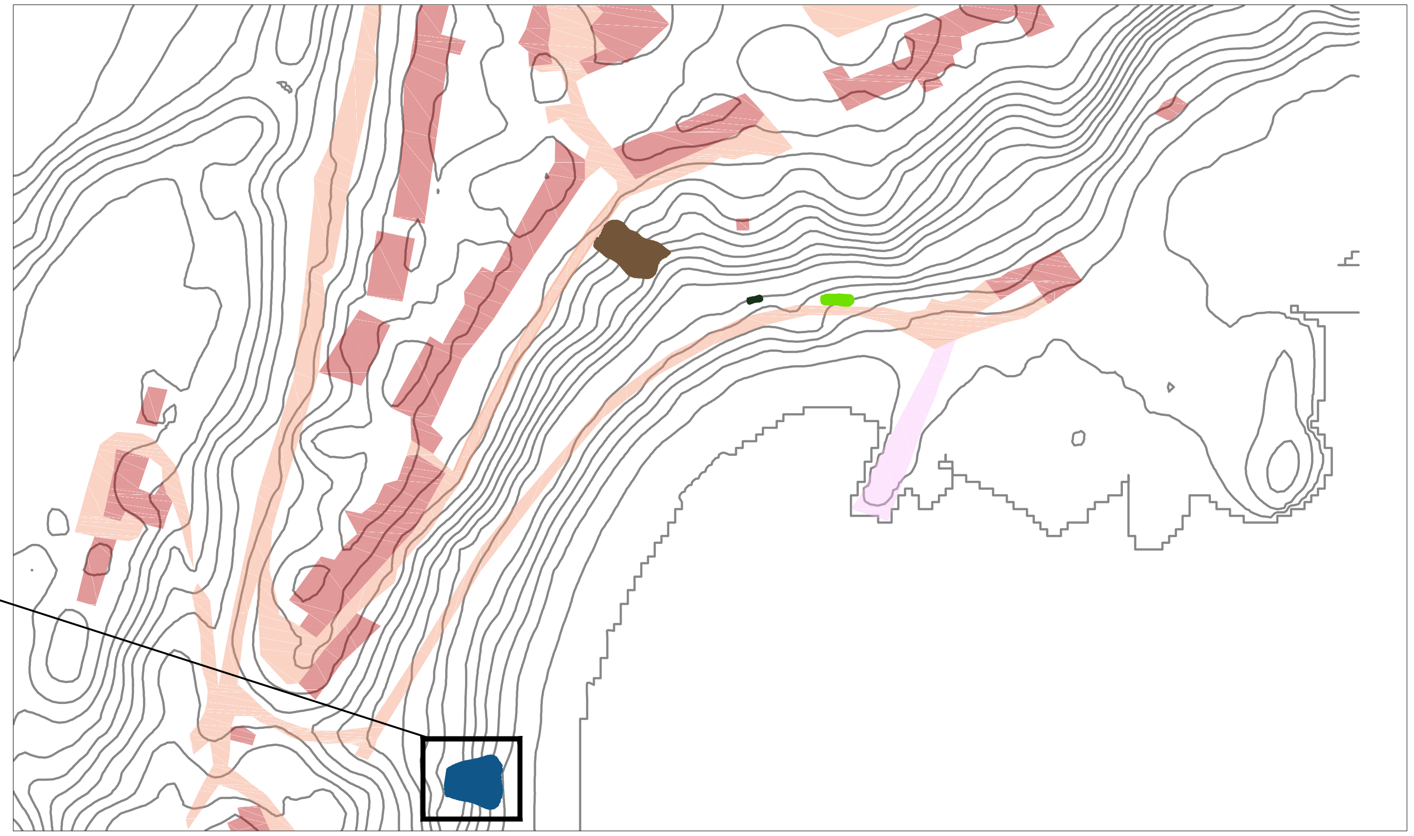

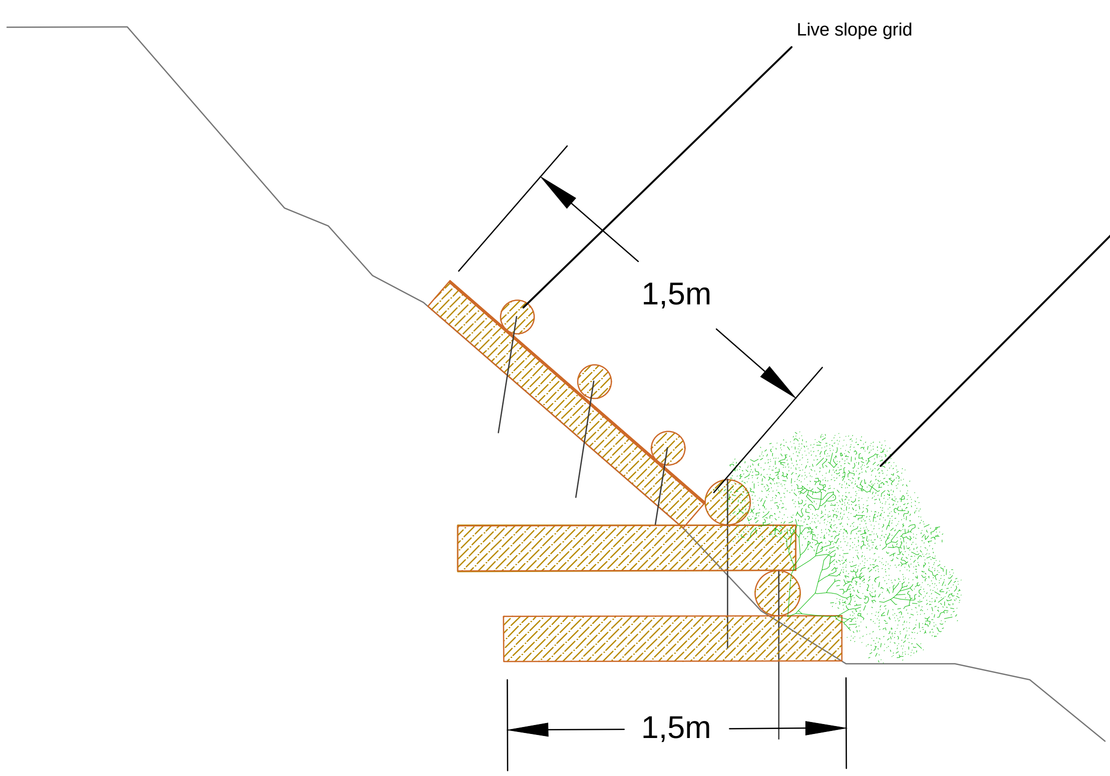

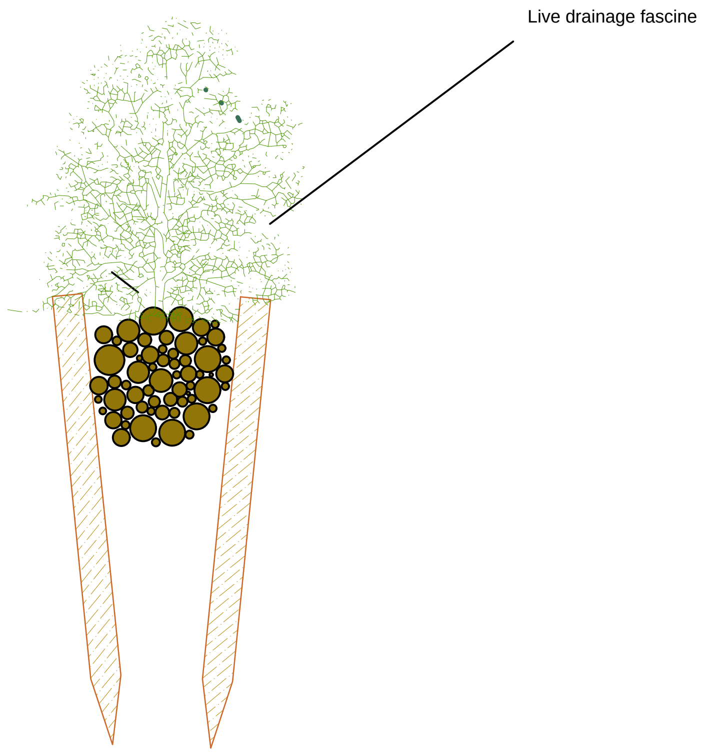

PROJECT TITLE

Demonstrative slope restoration with soil and water bioengineering techniques in Catterline

REDACTOR COMPANY

naturalea

PROMOTOR

GCNYC

DATE	SCALE	ORIENTATION
March 2022	Details: 1:30 Location: 1:2000	

PLAN TITLE

Details actions: Action 1

PLAN NUMBER

3.1

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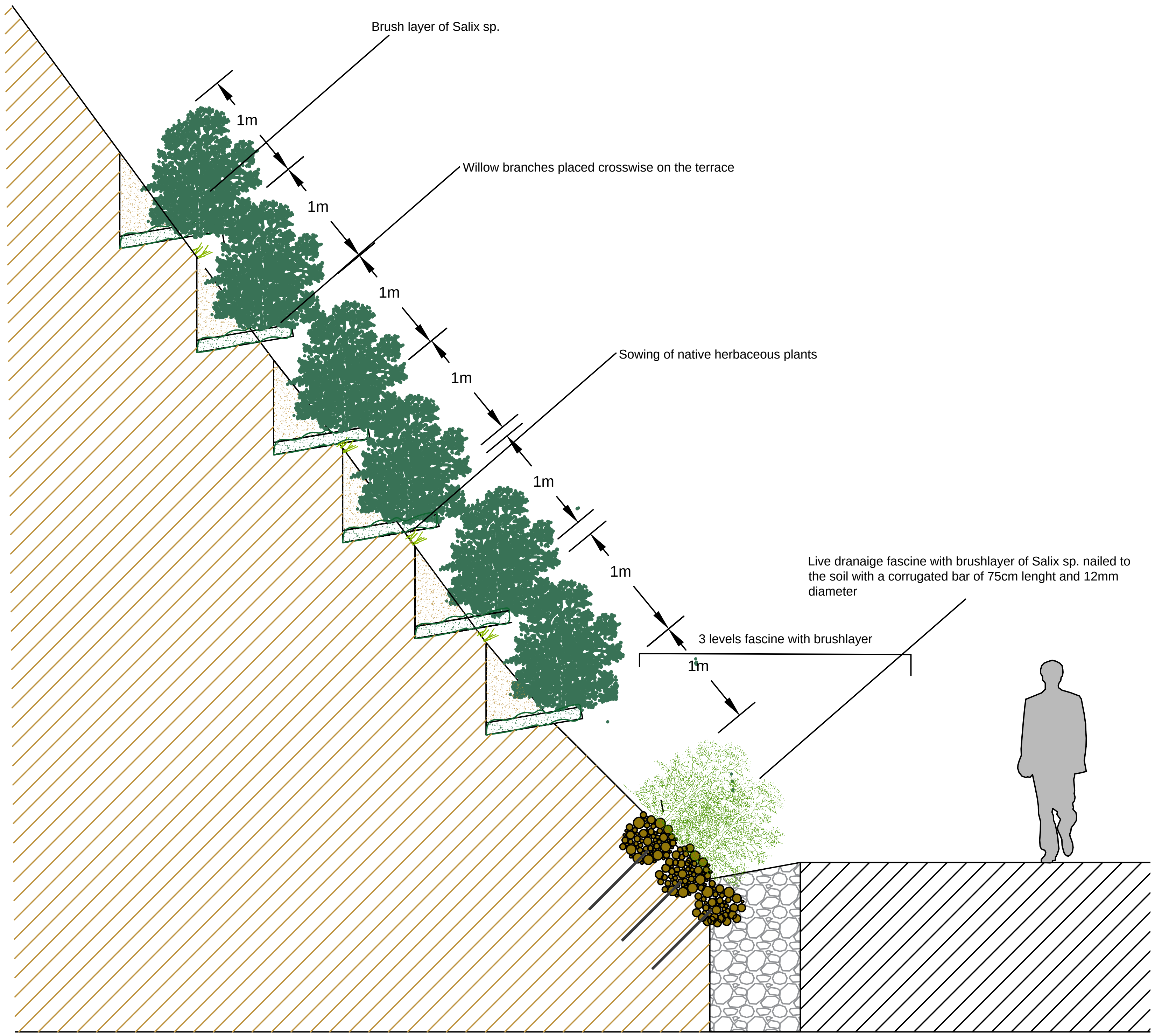

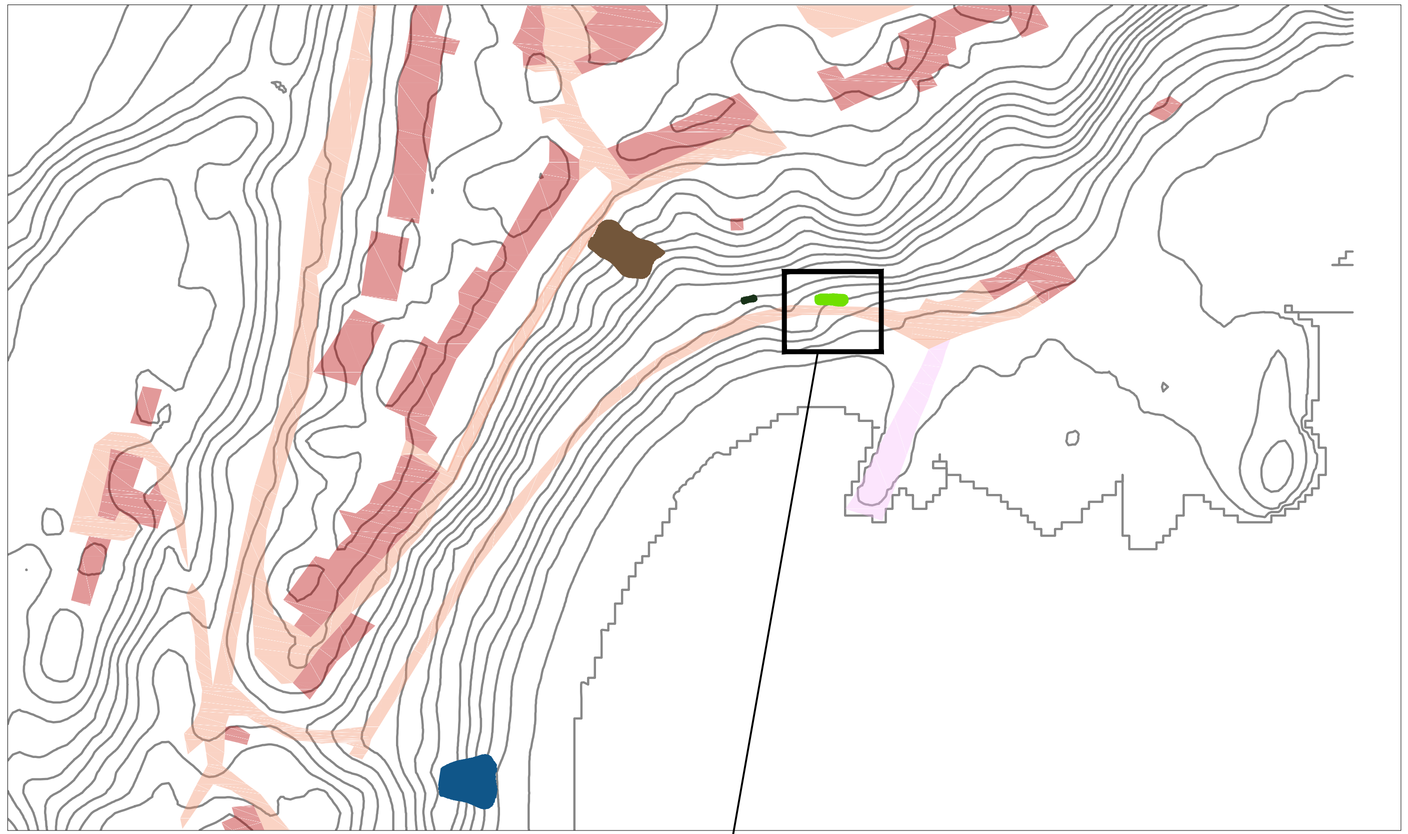

Soil to remove

Actual soil

PROJECT TITLE

Demonstrative slope restoration with soil and water bioengineering techniques in Catterline

REDACTOR COMPANY: naturalea

PROMOTOR: GCNYC

DATE: March 2022

SCALE: Details: 1:30, Location: 1:2000

ORIENTATION

PLAN TITLE: Details actions: Action 2

PLAN NUMBER: 3.2

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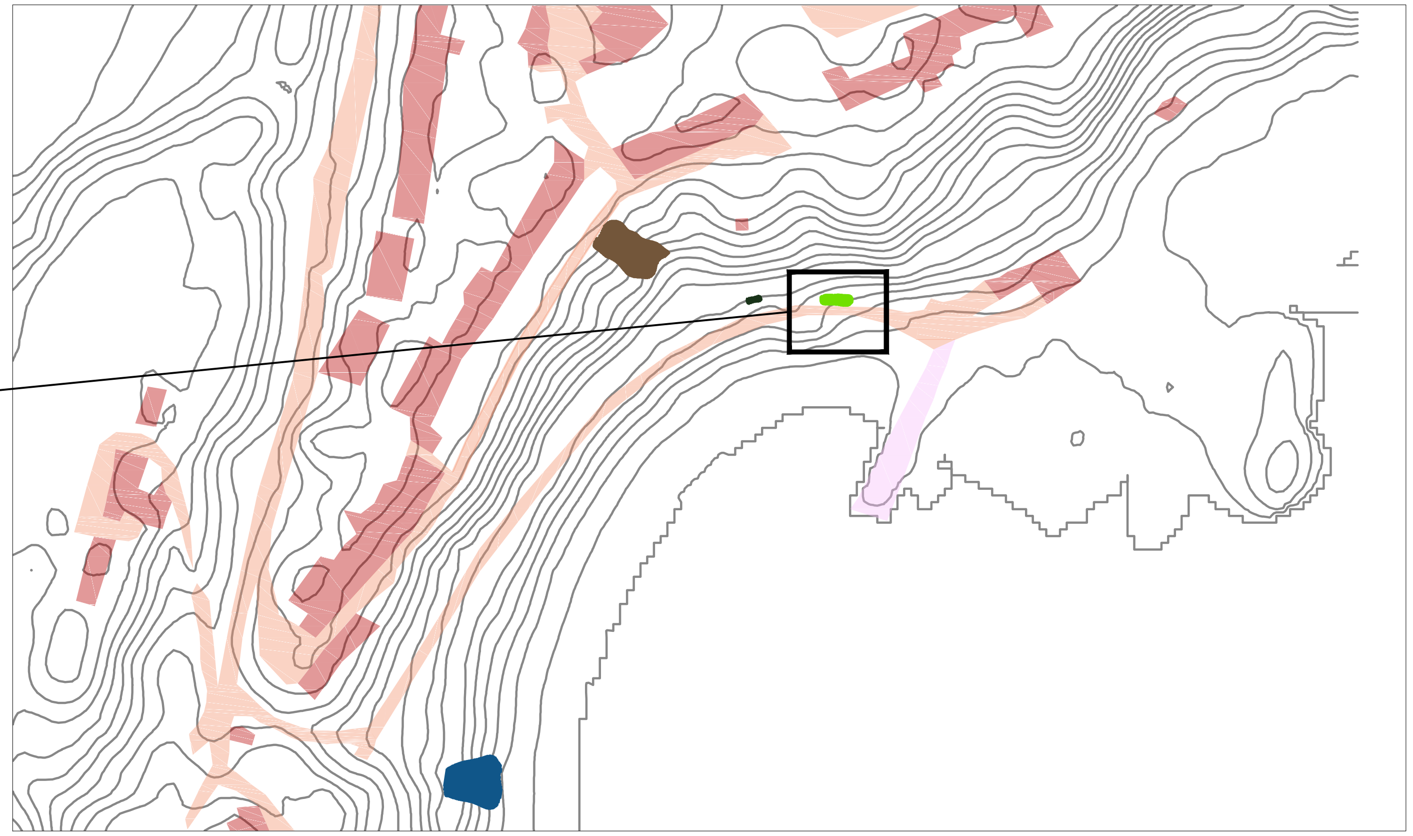

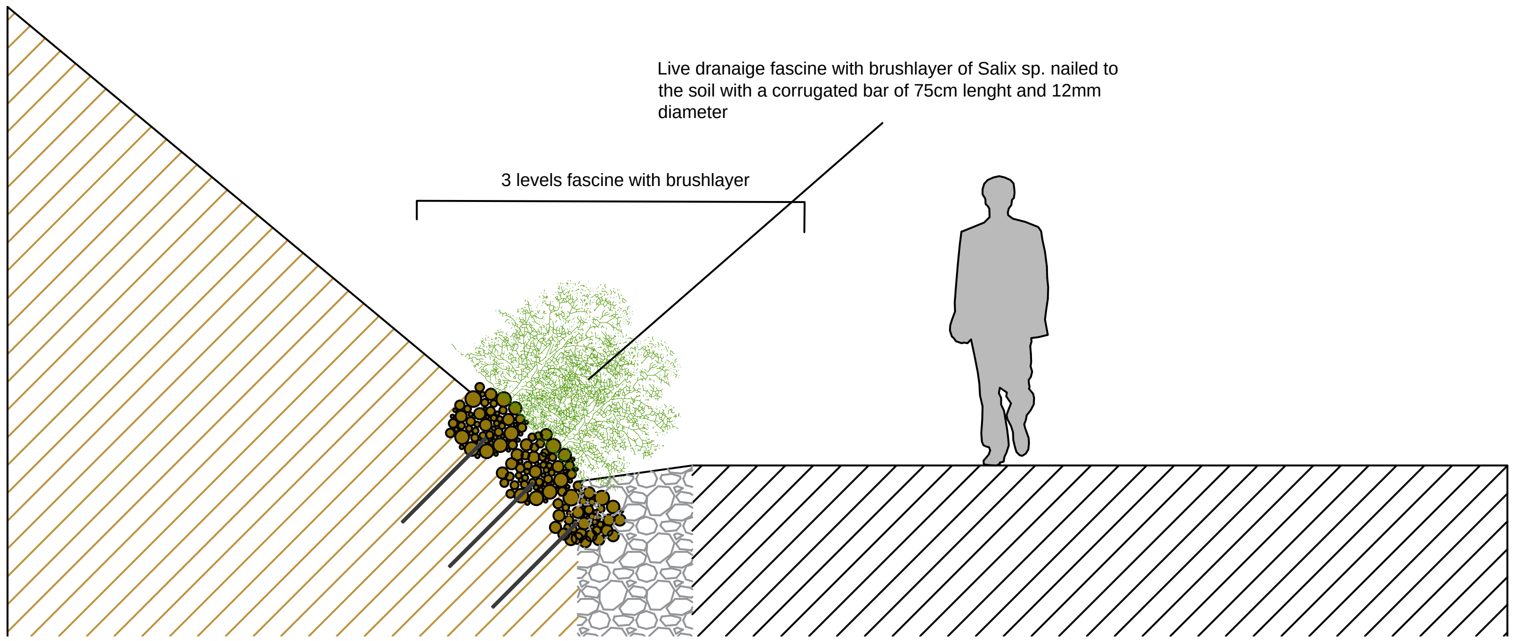

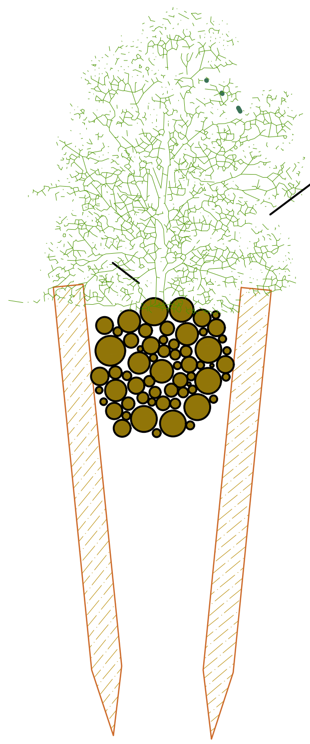

PROJECT TITLE

Demonstrative slope restoration with soil and water bioengineering techniques in Catterline

REDACTOR COMPANY

naturalea

PROMOTOR

GCNYC

DATE

March 2022

SCALE

Details: 1:30
Location: 1:2000

ORIENTATION

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PLAN TITLE

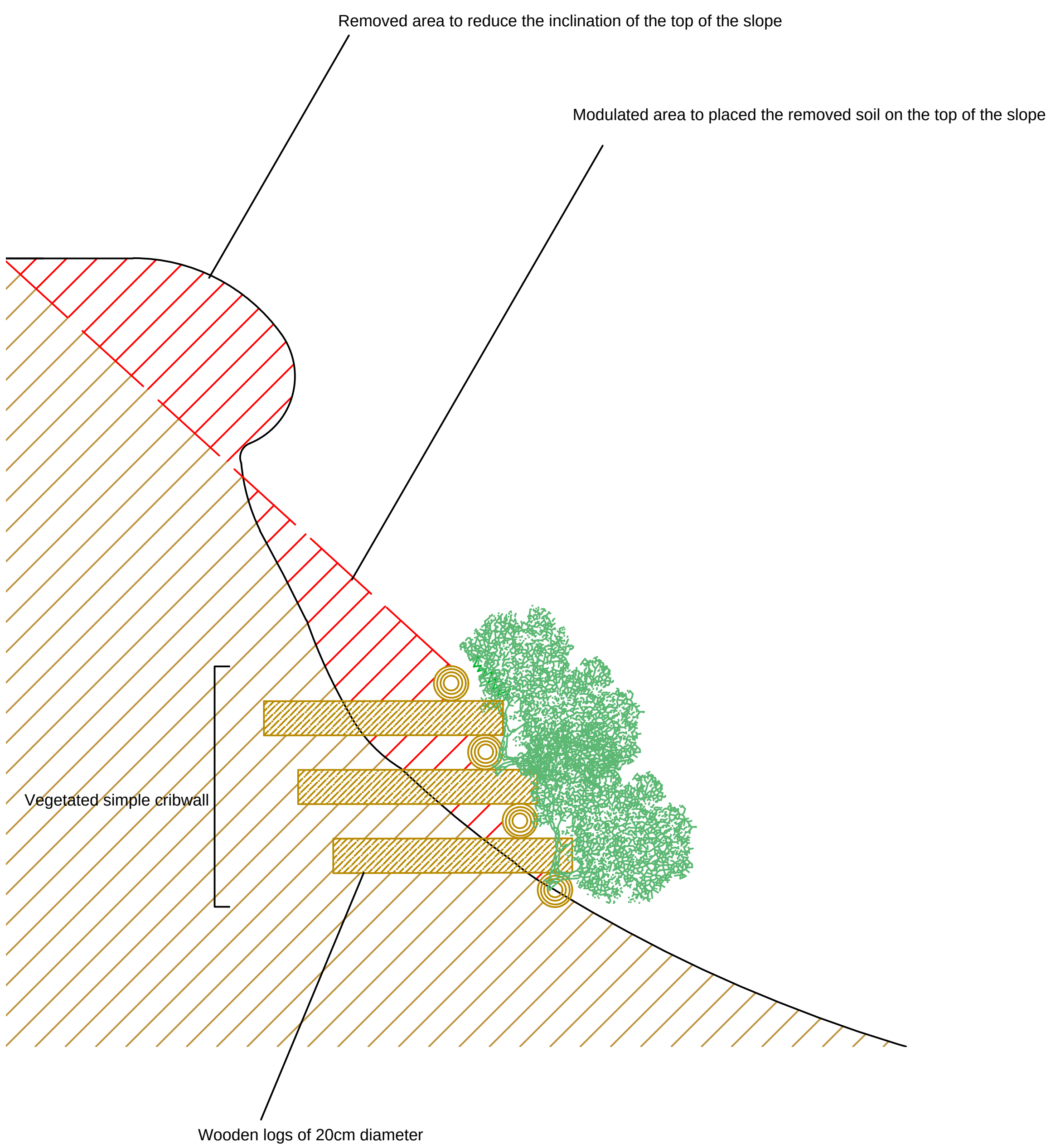
Details actions: Action 2

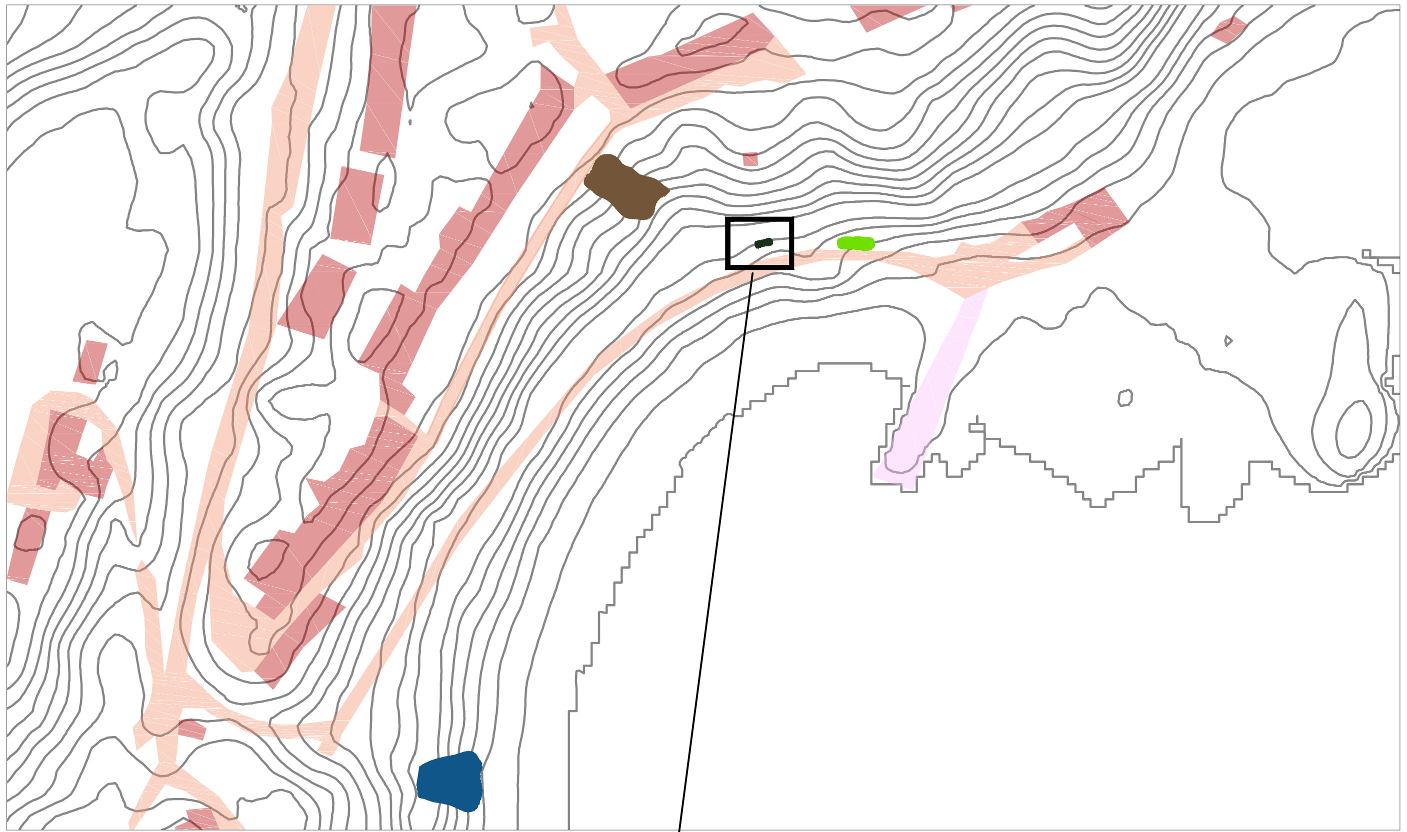
PLAN NUMBER

3.2

PAGE 2 OF 2

Vegetated simple cribwall executed by Naturalea





PROJECT TITLE		
Demonstrative slope restoration with soil and water bioengineering techniques in Catterline		
REDACTOR COMPANY: naturalea	PROMOTOR: GCNYC Glasgow Caledonian New York College	
DATE: March 2022	SCALE: Details: 1:40 Location: 1:2000	ORIENTATION: n
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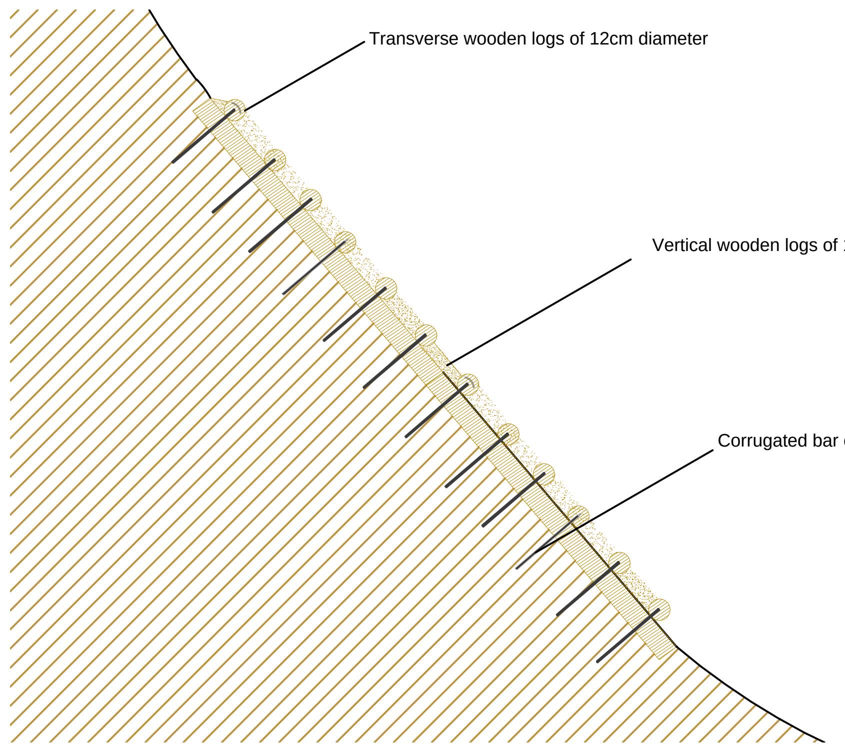

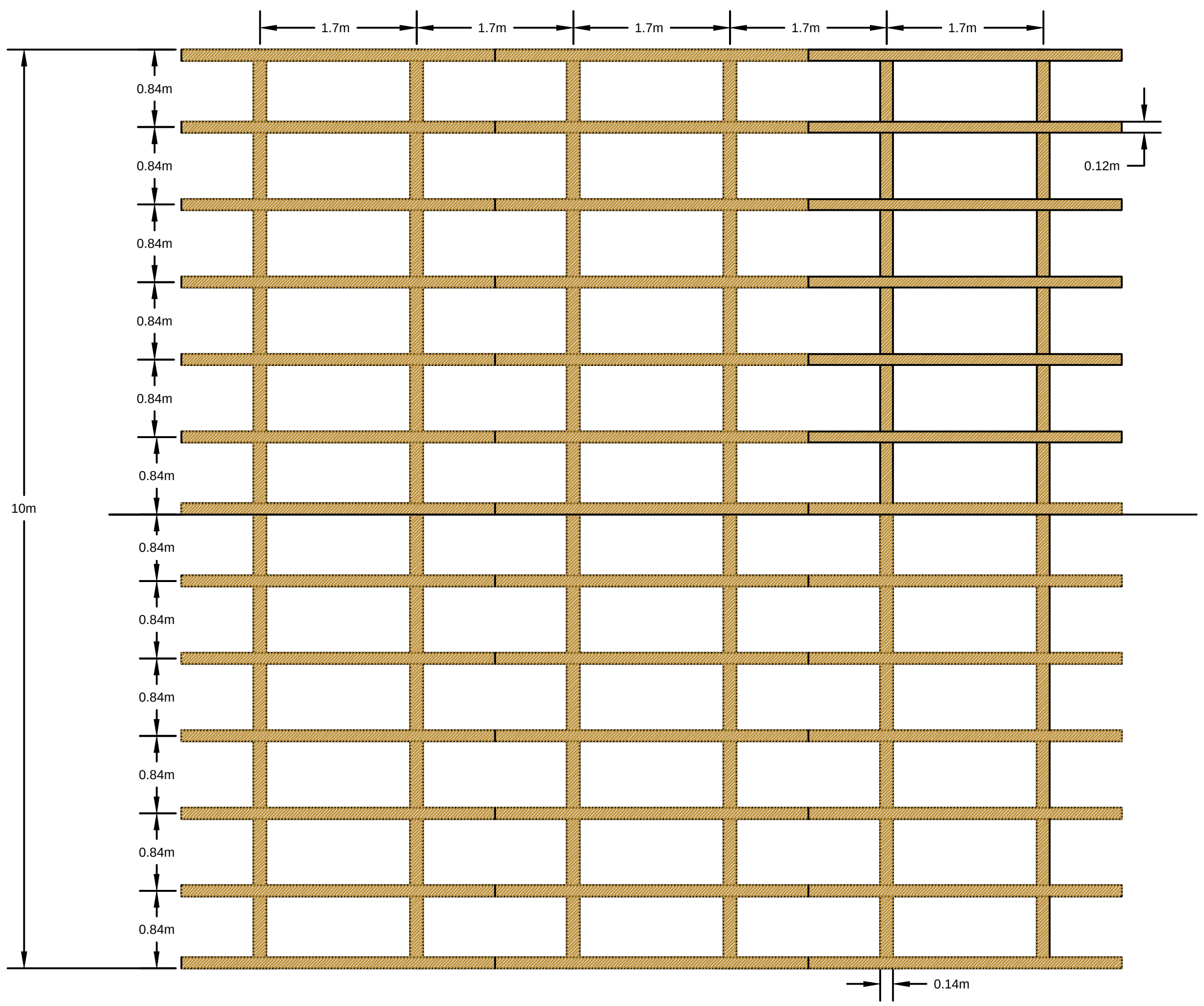

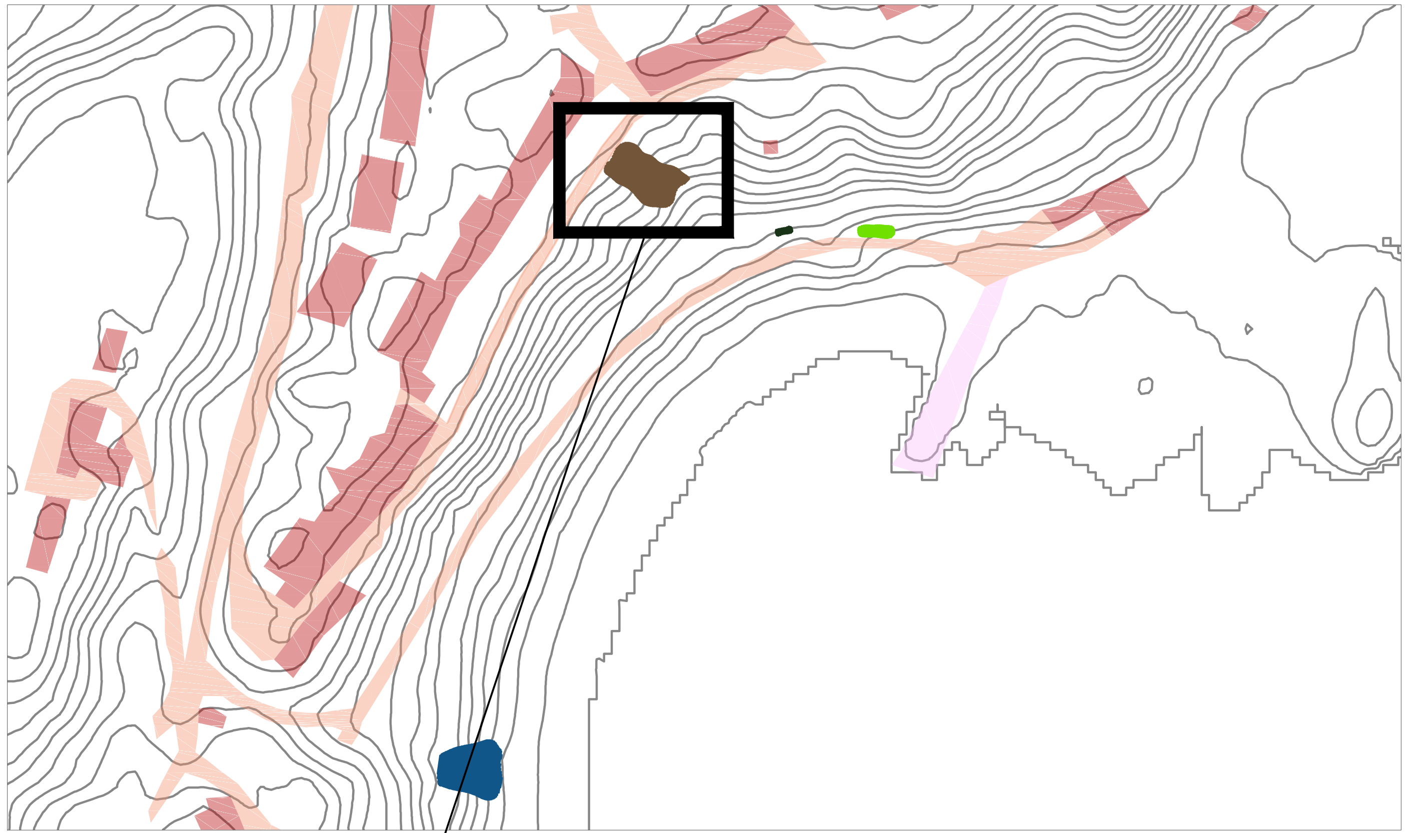

PROJECT TITLE Demonstrative slope restoration with soil and water bioengineering techniques in Catterline	
REDACTOR COMPANY naturalea	PROMOTOR GCNYC Glasgow Caledonian New York College
DATE March 2022	SCALE Details: 1:60 Location 1:2000 ORIENTATION
PLAN TITLE Details actions: Action 4	PLAN NUMBER 3.4 PAGE 1 OF 1