# Beach Nourishment Assessment Cullipool Beach, Luing

## Report for the Isle of Luing Community Trust

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# 1 Introduction

This report has been prepared by Martin Hurst and Jim Hansom, School of Geographical and Earth Sciences, the University of Glasgow on behalf of the Isle of Luing Community Trust. The overarching aim of the report is to establish whether existing spoil at the abandoned Cullipool slate quarry and its environs, together with any new spoil generated from the re-opening of the slate quarry, is sufficient for the purpose of artificially nourishing the eroding beach that fronts parts of the Cullipool village.

The detailed focus of the work aims to:

1. Establish past coastal planimetric change to inform rates of lower-, mid-, upper beach, cliff/vegetation edge change over a series of time periods (dependent on available data sources).
2. Establish anticipated rates of future change based on projected past rates of change modified for the potential effects of future sea level rise.
3. Undertake a morphological survey of the beach and intertidal area between MHWS and MLWS using a surveying drone backed by DGPS ground control points, to produce a Digital Terrain Model (DTM) for comparison with an earlier survey conducted by GWP (2022) of the slate quarry and environs which captured part of the beach area.
4. Produce cross-shore topographic transects from the DTM to allow estimates of the enhanced beach levels that would be anticipated to reduce both the rate and extent of upper beach erosion and inform the sediment replacement volumes required to achieve this level of protection.
5. Outline possible management options: A range of management options exist at any given location depending on the context and availability of funding to action these. The report aims to outline:
    a. Standard options for managing coastal erosion (including adaptation).
    b. Erosion management using beach replenishment, minimum sediment volumes and their likely residence time.
    c. Preferred combined management actions at Cullipool to reduce the future risk of erosion and overtopping.

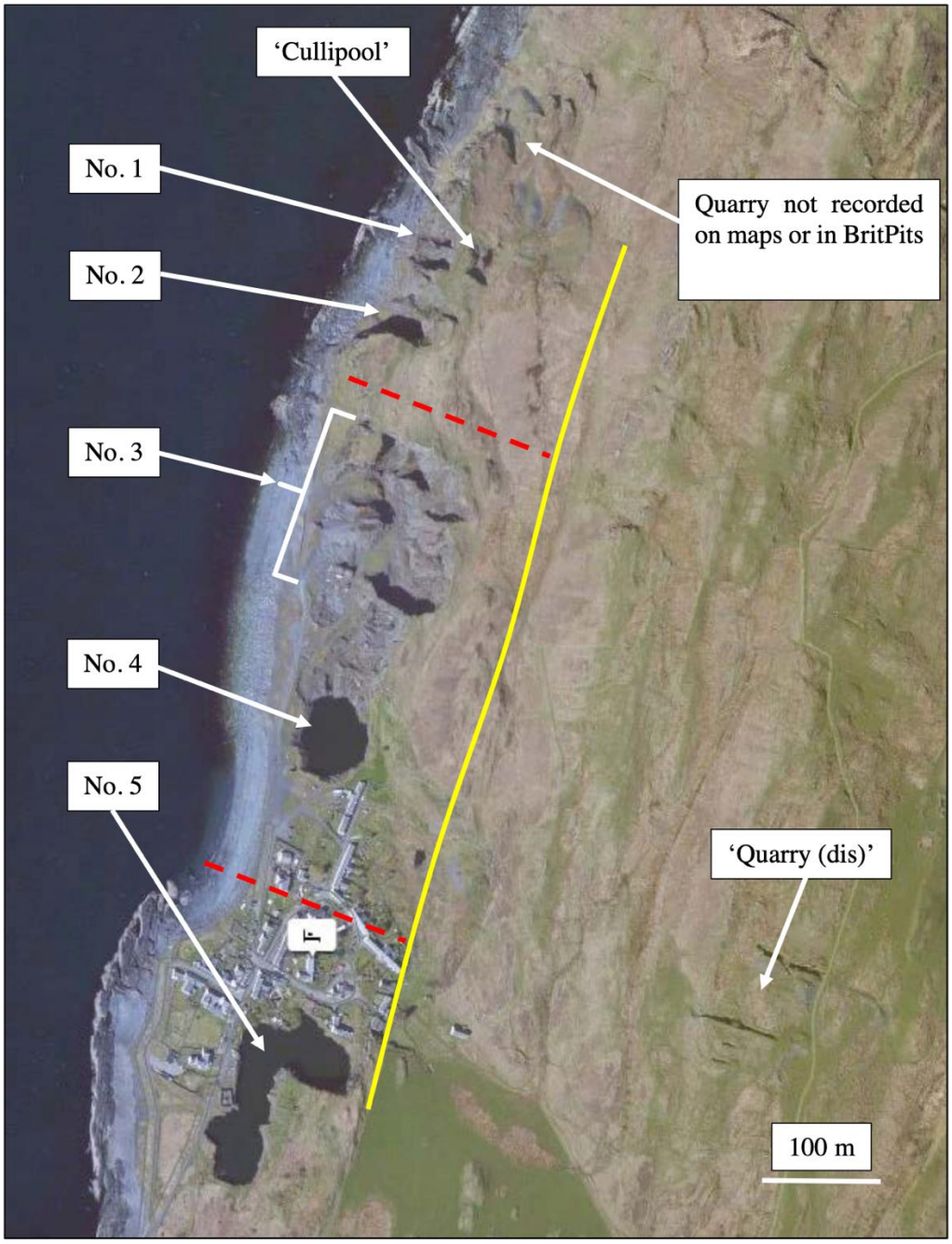


*Figure 1: Location of Cullipool Quarries (from BGS, 2020). The yellow line indicates the orientation of the main slatey cleavage, the red lines indicate geological faults.*

# 2 Background

Quarrying for slate on Luing started in 1751, continuing in the vicinity of Cullipool, on the northwest coast of Luing, until 1963 after which West Highland Slate production ceased. However, there is now a demand for distinctive Scottish slate products largely for the conservation of existing historical properties. In the environs of the village of Cullipool a thick

workable slate unit, known as the ‘70 foot’ slate-rock, has been worked in several places some of which have been excavated into the emerged marine rock shore platform that fronts the now abandoned early Holocene-aged (6.6-7 ka BP) cliffs (Dawson, 1984) that skirt the coast of western Luing. A series of 5 quarries, numbered 1 to 5 moving from north to south, make up the Cullipool Quarries (Richey & Anderson, 1944) with Cullipool 4 and 5 excavated into the emerged rock platform with 1 to 3 excavated into the abandoned cliff face. By 1938, all but Quarry 3 had ceased working (BGS, 2020) and in 1963, it too ceased operation (Fig 1).

The area fronting Quarries 3 and 4 is a flat-topped terrace of made ground, composed largely of slate waste produced over the lifetime of the quarrying operations. Close to the abandoned cliff, the terrace is punctured by excavations that include Quarries 5 and 4, both now flooded with 5 reported to be 30m deep and 4 reaching an unknown depth but likely to extend beyond 10m below sea level (GWP, 2022). The village of Cullipool itself, and the tramways which once linked the quarries to the quay, are in places built on the slate waste produced by quarrying activities. A by-product of this is that the village has been historically protected from the impact of erosion and wave-overtopping by tipping slate waste onto the fronting beach at Cullipool. This both enhanced the beach volume and prevented the base of the made ground terrace behind being accessed by all but the severest of wave events (Figure 2).

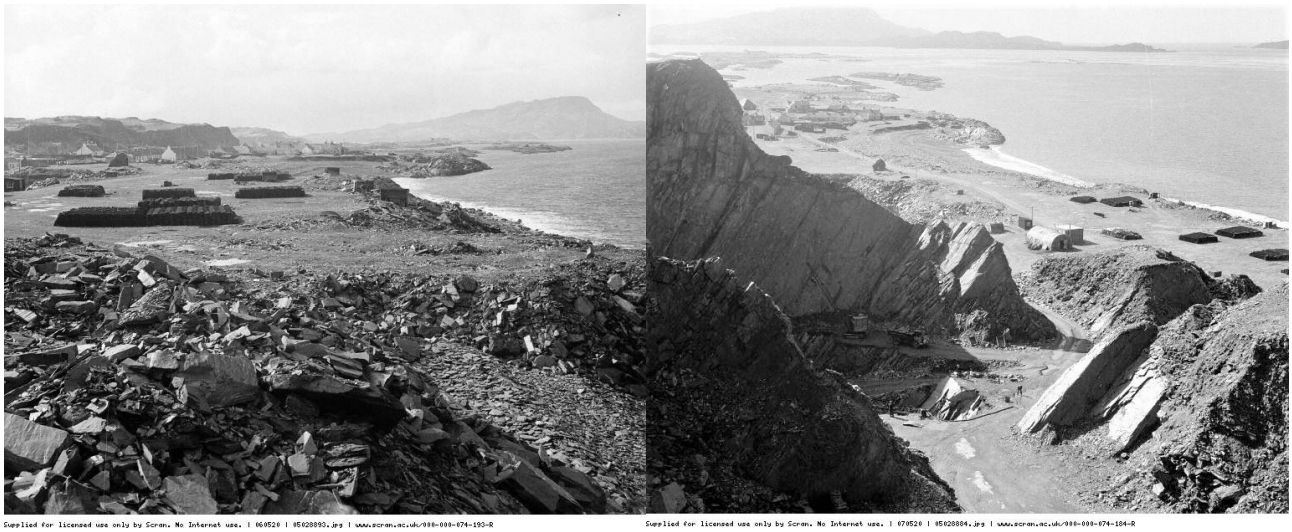
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*Figure 2: Photographs showing the extent of made ground fronting Cullipool 3 in the 1940’s. Both taken looking towards the south (copyright Scran, used with permission).*

The outcome of cessation of quarrying is that the supply of slate waste to the beach has ceased with the beach undergoing progressive erosion, leading to a progressive loss of volume, associated beach lowering and undermining of the made ground terrace edge behind. Google Earth images show 3 to 4m of erosion of the backing terrace edge over the 10 years between 2010 and 2020 (GWP, 2022). Prior to this in 2000, and in response to concerns over ongoing erosion, the intertidal was remodelled using heavy plant and a boulder rip rap wall was constructed along the foot of the then eroding made ground terrace edge at the rear of the beach. The boulder armour was shallow-sunk into the upper foreshore and then built at a steep, sub-vertical, slope landward up to the elevation of the terrace edge using boulders from both the quarry and the foreshore. A section of the boulder armour was repaired in 2015 and, after storm erosion and overwash in 2019, the gaps in the wall were filled with rubble but this replacement material was washed away during subsequent storms. By 2022, several sections of the boulder rip rap wall had failed with the undermined boulders now littering the upper foreshore and the exposed made ground behind subject to failure at the gaps in the boulder armour (Figure 3).

*Figure 3: Cullipool Beach looking north in April 2022 on a falling tide, showing extensive failure of the boulder armour and undercutting of made ground to the rear. Copyright James Hansom.*

It is almost certainly the case that the health and viability of the beach at Cullipool has been sustained in the past by the supply of quarried waste from the slate quarries (see Fig 2). The cessation of quarrying has resulted in this supply being greatly reduced to a level that is insufficient to sustain the beach in its current position. The result is recession of the coastal

edge and progressive lowering of the fronting beach that has served to undermine parts of the boulder rip rap that was constructed to slow recession of the backshore. Since there now exists the possibility of future quarry development that will require disposal of quarried waste, then reinstating a direct feed of waste to the foreshore offers a viable route to sustain the beach as it did in the past. This should reduce, if not arrest, the current rate of beach lowering and slow erosion of the made ground backshore edge.

*Figure 4: Wave Overtopping Impacts of Storm Aiden at Cullipool Bay. Copyright Colin Buchanan*

Two modern properties lie close to the landward edge of the backshore at the south end of the beach, landward of an access track to the disused Quarry 3. These properties have been constructed on made ground which is itself currently at risk from coastal erosion. Wave overwash during Storm Aiden in 2019 resulted in substantial undercutting of the made ground edge and deposition of beach sediment that buried the track on top of the made ground terrace. The same event resulted in destruction of part of the garden stone wall of the northernmost house (Scaraben) and flooding of its garden area (Figure 4) The overwashed beach sediment (Figure 5) has since been cleared, the garden wall reinstated and strengthened and a flood gate installed (Figure 6).

The extent to which made ground underlies some of the older houses of the village is unknown, but some are underlain by undulating bedrock outcrops of the emerged shore platform, similar to the outcrops on the current shore platform. If some of these older houses sit atop made ground then they are also potentially at risk from coastal erosion in the future, particularly given any anticipated rises in sea level and an increase in the delivery altitude of waves expected on that higher sea level. See Dynamic Coast (https://www.dynamiccoast.com/cop26), where RCP8.5 (95%) High Emissions Scenario

(our current path) predicts 0.92m of sea level rise by 2100; whereas RCP 2.6 (50%) Low Emissions Scenario (ultra-conservative path) predicts 0.25m of sea level rise by 2100.

*Figure 5: Overwashed beach sediment in the aftermath of Storm Aiden, 2019. Copyright Colin Buchanan*

*Figure 6: March 2022 showing the road cleared and new wall and floodgate protecting Scaraben. Damage to the riprap seawall remains. Copyright James Hansom*

# 3 Information and data sources

The following sources of information have been consulted as part of the survey field preparation, subsequent analysis, and compilation of this report:


1. Dynamic Coast: online digital resource which maps the changes in positions of MHWS and MLWS over the historical period. www.dynamiccoast.com
2. GWP (2022), “Geological and Geotechnical Assessment to Determine the Focus for Future Site Investigation in the Vicinity of the Cullipool Quarries and Outline Quarry Development Design” GWP, 10pp.
3. Digital Land Surveys (2022), UAV topographic survey of the Cullipool Quarry Nos. 1 to 4 area. Digital Land Surveys Limited, January 2022.
4. British Geological Survey (BGS) (2020) “Potential for renewed quarrying of West Highland Slate: a preliminary assessment of the island of Luing and the Ballachulish district” Decarbonisation & Resource Management Programme. Open Report, OR/20/016, 2020.
5. Richey, J E, and Anderson, J G C. (1944), Scottish Slates. Wartime Pamphlet No. 40. (London: Geological Survey of Great Britain).
6. Dawson, A.G (1984) Quaternary sea-level changes in Scotland. Quaternary Science Reviews, 3 (4), 345-368.


# 4 Methodology

1. UoG carried out a pre-survey assessment on 4 March 2022 followed by a UAV drone survey team visit on 19 April 2022.
2. In order to assess the viability and volume of potential beach feed from quarry waste, it was necessary to establish the geometry of the existing foreshore and backshore in comparison with previous geometries derived from past mapping, aerial and satellite images, together with Digital Terrain Models (DTMs) derived from more recent UAV drone overflights.
3. A further UAV drone survey with DGPS control point ground survey on 19 April 2022 was timed to coincide with a low spring tide (to give maximum beach extents) and

good weather conditions for drone survey (light winds and good light conditions). This drone survey captured all of the terrain from Quarry No 3 south to the village limit (the adopted roadway) and east from MLWS to some way beyond the quarry access road. This fully captured the intertidal area at Cullipool and the made ground comprising the backshore edge. The drone and DGPS survey also captured the ground control points from an earlier drone survey conducted by Digital Land Surveys in January 2022, allowing the 2 surveys to be pinned together for direct comparisons. The drone data were analysed within Pix4D to allow DTMs and representative cross-shore topographic profiles to be constructed and beach and backshore sediment volumes to be derived.

4. The beach cross-profiles were then compared with the historical positions of MHWS and MLWS from the Dynamic Coast GIS mapping to permit an estimate of historical changes in positions and volumes. These changes were extrapolated forward in time, taking into account the potential effects of sea level rise exacerbating erosion.
5. The UAV-derived topography was used to generate an estimate of the volume of beach material required to reinstate the beach to a former geometry and volume.
6. This permits the volume of beach material required to reinstate the beach to a former level to be compared with the volume of existing available quarry waste and that to be generated in the future by quarry re-opening. The annual added volume required to maintain the beach at this geometry can be also matched with the annual waste production volume from quarry workings. Together this produces a target initial beach feed volume and an annual beach replenishment volume. Noting that the position of MHWS and MLWS changed little between 1970 and 1995, the volume required to restore the beach to its 1995 position was assessed.

# 5 Historic beach changes, transects and volumes

## 5.1 Historic Shoreline Change

There have been very clear changes to the coastal positions over the years as defined by the shifts in MHWS and MLWS locations (Figure 7).

The position of MHWS in 1890 (Figure 7, grey lines) is instructive with its position in the north substantially landward of its current position and dates from before the input of quarry waste onto the foreshore, since Quarry 3 had not commenced at that time or was not fully operational. In the south the 1890 MHWS lies well seaward of its current position.

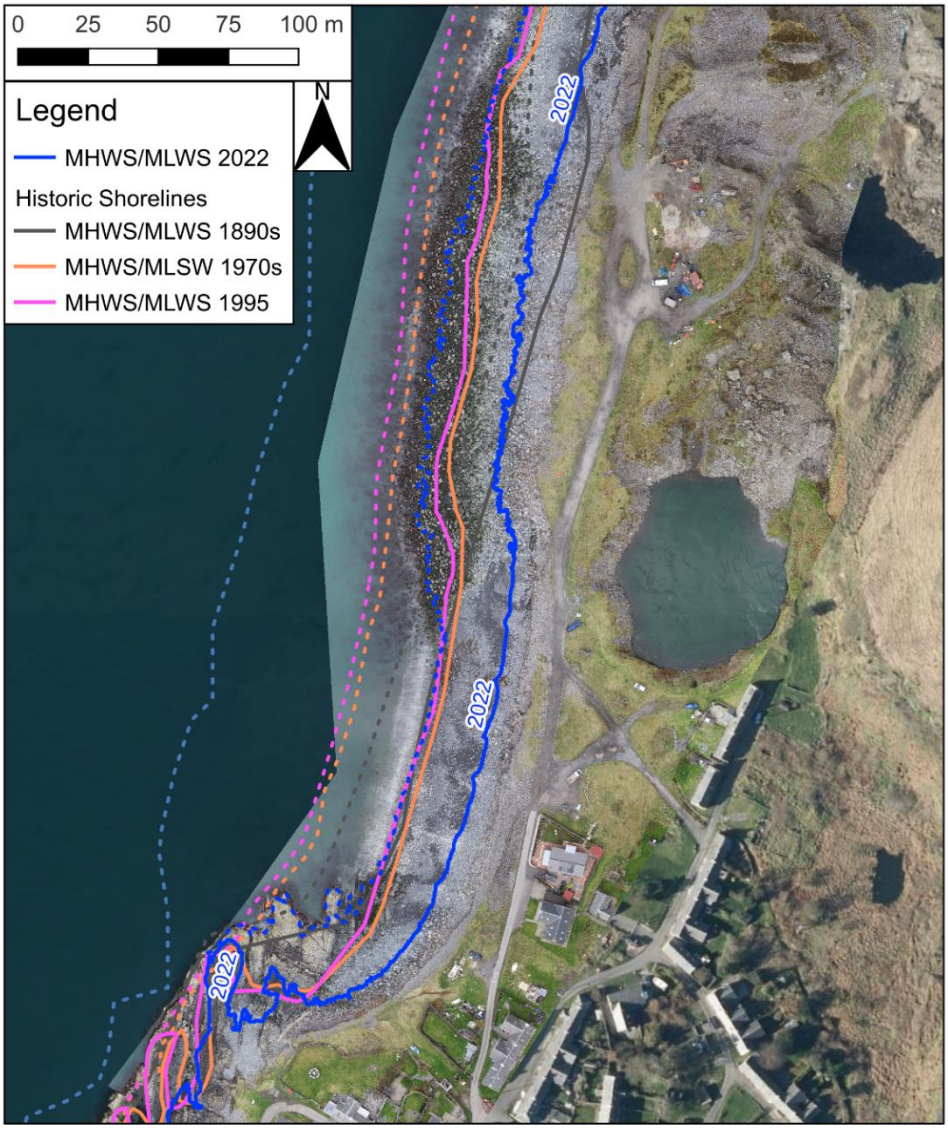


*Figure 7: Historical positions of MHWS (solid) and MLWS (dashed) from Ordnance Survey maps and recent survey by University of Glasgow in April 2022. Light blue dashed line is the –10m depth contour. Shorelines superimposed on April 2022 aerial imagery and Bing aerial imagery.*

Similarly in the north, MLWS in the 1890s lay well landward of its current position, and in the south MLWS lies seaward of its current position. The beach was steep, with slope varying from 0.17 in the south to 0.26 m/m in the north as measured between MLWS and MHWS.

By the 1970's MHWS and MLWS in the north had moved substantially seaward due to quarry spoil input from Quarry 3 over the intervening period 1890s to 1970s (Figure 7, orange lines). In the south, fronting the northernmost houses, MHWS remained in a similar location but MLWS had moved seaward, likely reflecting the southward movement of spoil-derived beach accumulating on the lower intertidal. This suggests that the entire foreshore in the south widened and flattened over this period due to quarry spoil deposition. Intertidal beach slope in the south is 0.11-0.12 (compared to 0.17-0.19 in the north). This period predates the insertion of a boulder wall along the seaward edge of the made ground so that the intertidal beach slope was largely unconstrained by artificial structures.

The most recent OS MHWS and MLWS has a survey year of 1995 (Figure 7, pink lines). In both the north and south MHWS and MLWS lie slightly seaward of their previous position in the 1970's. This offset occurs both along the beaches but also on sections of rocky shore, suggesting a systematic error in the mapped shorelines. Subsequently the made ground edge at the backshore had been stabilised and its position fixed by insertion of the rip rap boulder wall in 2000. The positions of MHWS and MLWS in 1995 lay at their most seaward locations since the 1890's, likely reflecting the accumulation of beach materials removed from the upper intertidal by wave activity moving MLWS seaward and movement in MHWS unconstrained by any obstruction (ie. the boulder wall).

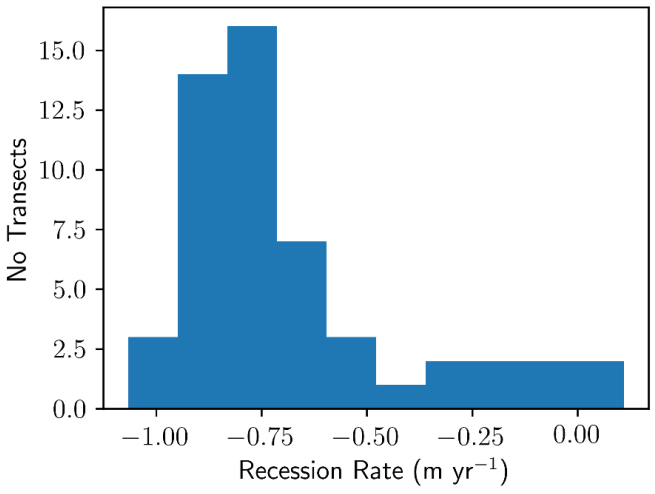


*Figure 8: Distribution of rates of change in the position of MHWS from 1995-2022 on cross-shore transects at Cullipool*

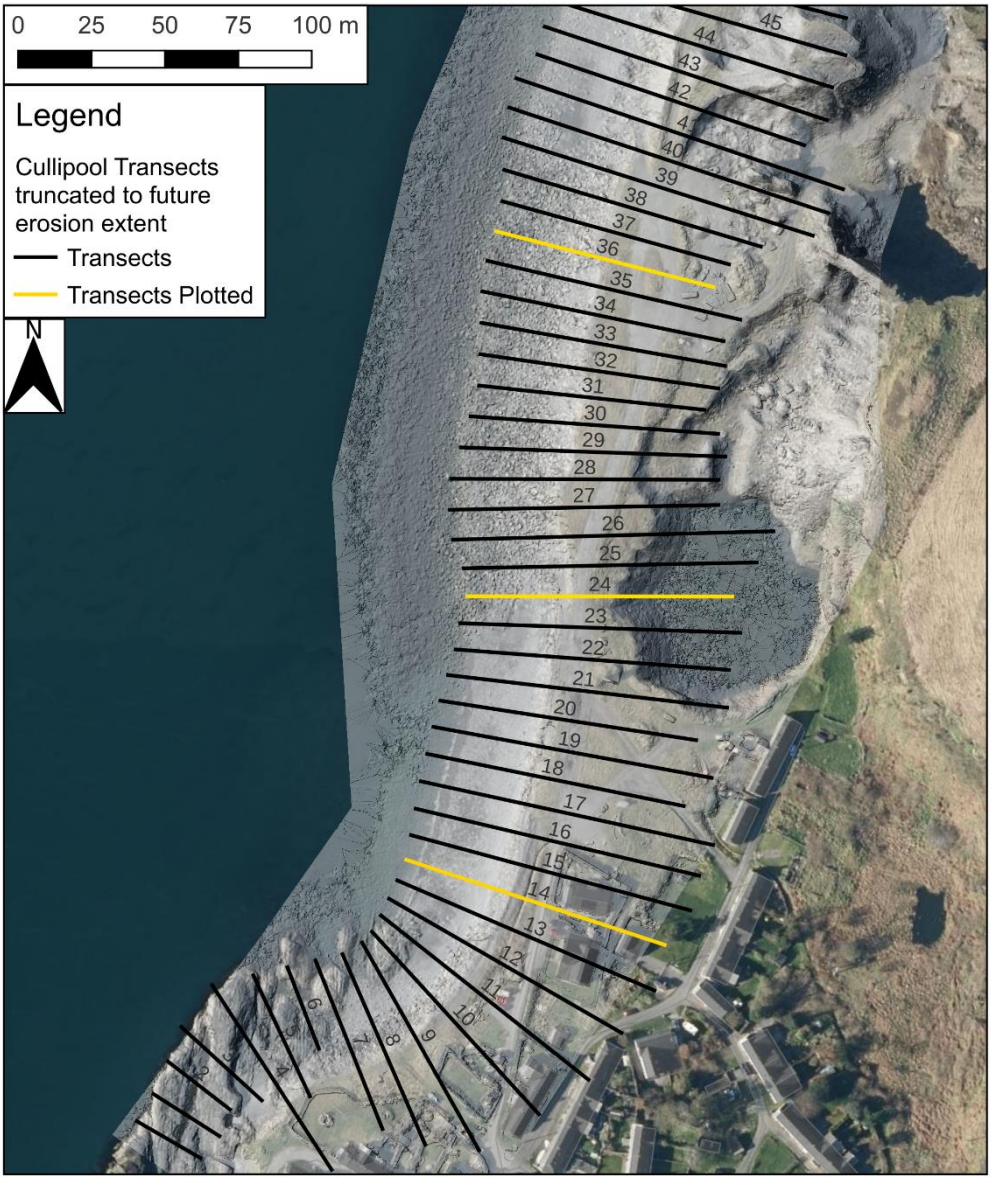


*Figure 9: Transects used for shoreline change analysis. Transects are numbered sequentially from south to north. Transects 14, 24 and 36 highlighted were selected to visualise cross-shore topographic profiles as shown in Figure 10.*

The most recent MHWS and MLWS lines have been derived from a DTM generated from the April 2022 UAV survey (Figure 7, blue lines). Both MHWS and MLWS are substantially landward of their previous 1995 positions. The median landward shift in MHWS position is 20.9 m, equating to a recession rate of 0.77 m/yr with the amount of change ranging up to 28.8 m, or 1.07 m/yr. The distribution of recession rates between 1995 and 2022 is shown in Figure 8. Furthermore, the intertidal zone is now narrower than it was in 1995, reflected in the steeper intertidal beach slopes of 0.13-0.15. These changes reflect a substantial amount of beach loss at Cullipool over recent decades, despite the installation of a rip rap

boulder wall in 2000. It can be assumed that these changes will continue if there are no further interventions, as reflected by recent damage to the sea wall during storm events.

The present beach morphology is illustrated by plotting topographic profiles along transects orientated perpendicular to the shoreline. The transects used to analyse historic and future shoreline change (see section below) are shown in Figure 9, and the cross-shore profiles included in Figure 10. See section 5.3 for explanation of proposed surface.

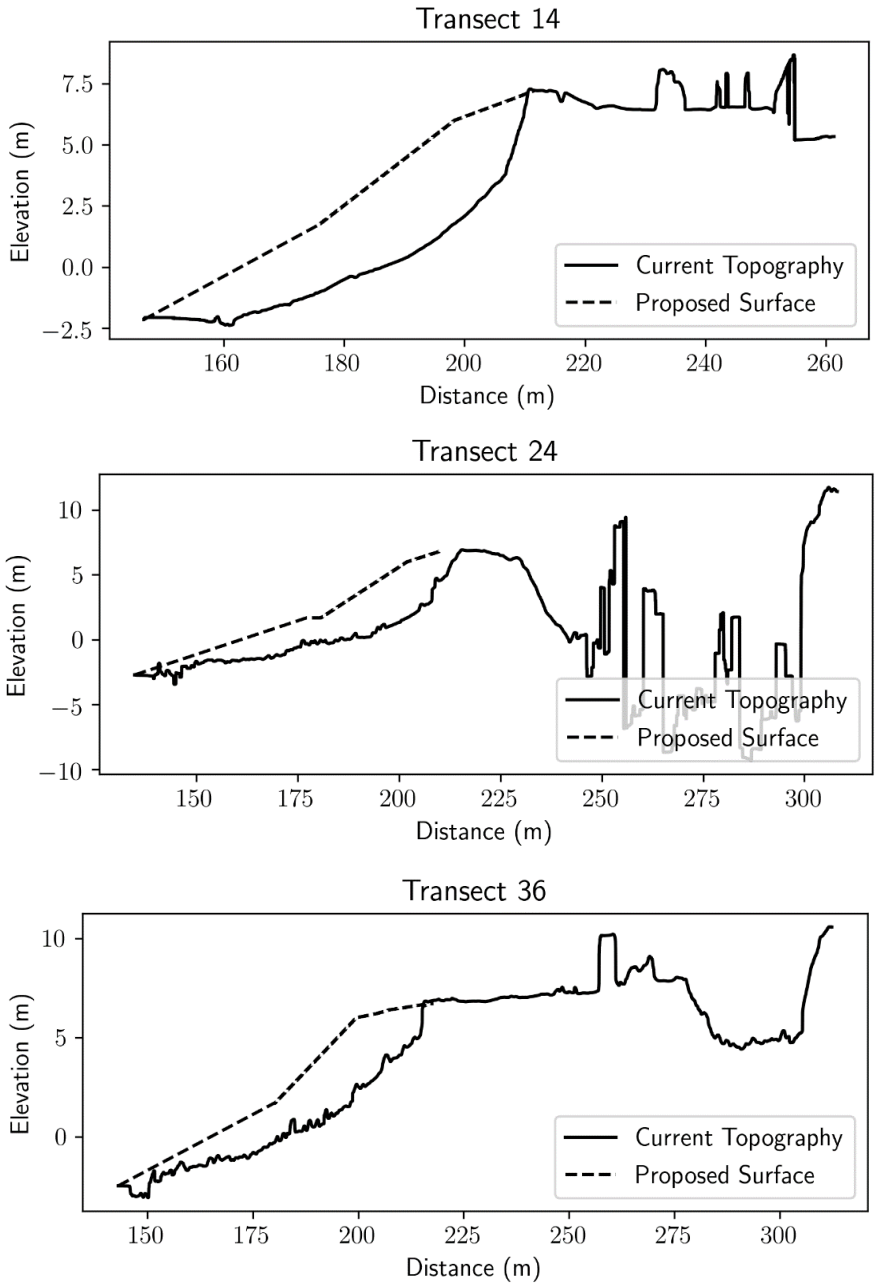


*Figure 10: Cross shore transects showing the current coastal topography at transects 14, 24, and 36 (see Figure 9 for location). Note that the high variability 250-300m along transect 24 reflects the presence of a horizontal water surface which the model (structure from motion) cannot resolve well.*

## 5.2 Future Erosion Projection

Using the same approach taken for the Dynamic Coast project, the most recent MHWS recession rates have been projected forward in time, with the anticipated decadal MHWS positions depicted to 2100 (Figure 11). These results could be considered as a “worst case scenario”, in that they assume that erosion can continue into unconsolidated material (not taking into account the presence of any bedrock or boulder wall), and that any existing or future defences are ineffective. They also adopt the most extreme UKCP scenario for sea level rise, but this may be assumed to be of secondary importance given the dominance of rapid recent recession in dictating erosion extrapolated into the future.

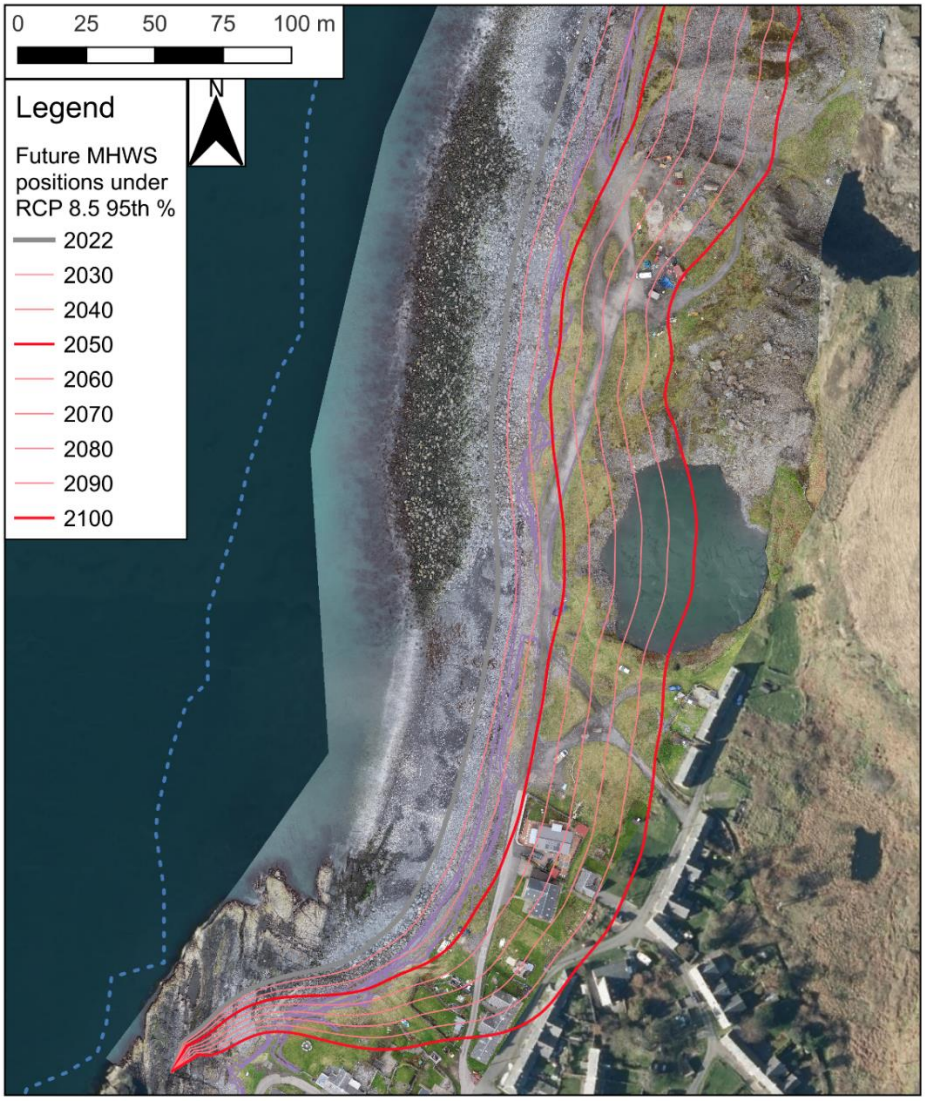


*Figure 11: Future positions of MHWS under RCP 8.5 95th percentile scenario, as calculated following the methods of the Dynamic Coast project. MHWS lines are plotted for each decade to 2100. This approach assumes that erosion occurs into unconsolidated substrate and is unabated by any coastal defences.*

Nevertheless, the recent changes and anticipated future projections combine to suggest that there is an enhanced risk of coastal erosion soon. Those risks are already evident with damage to the existing rip rap boulder wall which is currently undermined and collapsing onto the foreshore. If this structure has previously been effective in preventing erosion, there is a risk that erosion rates will accelerate if the structure is breached further.

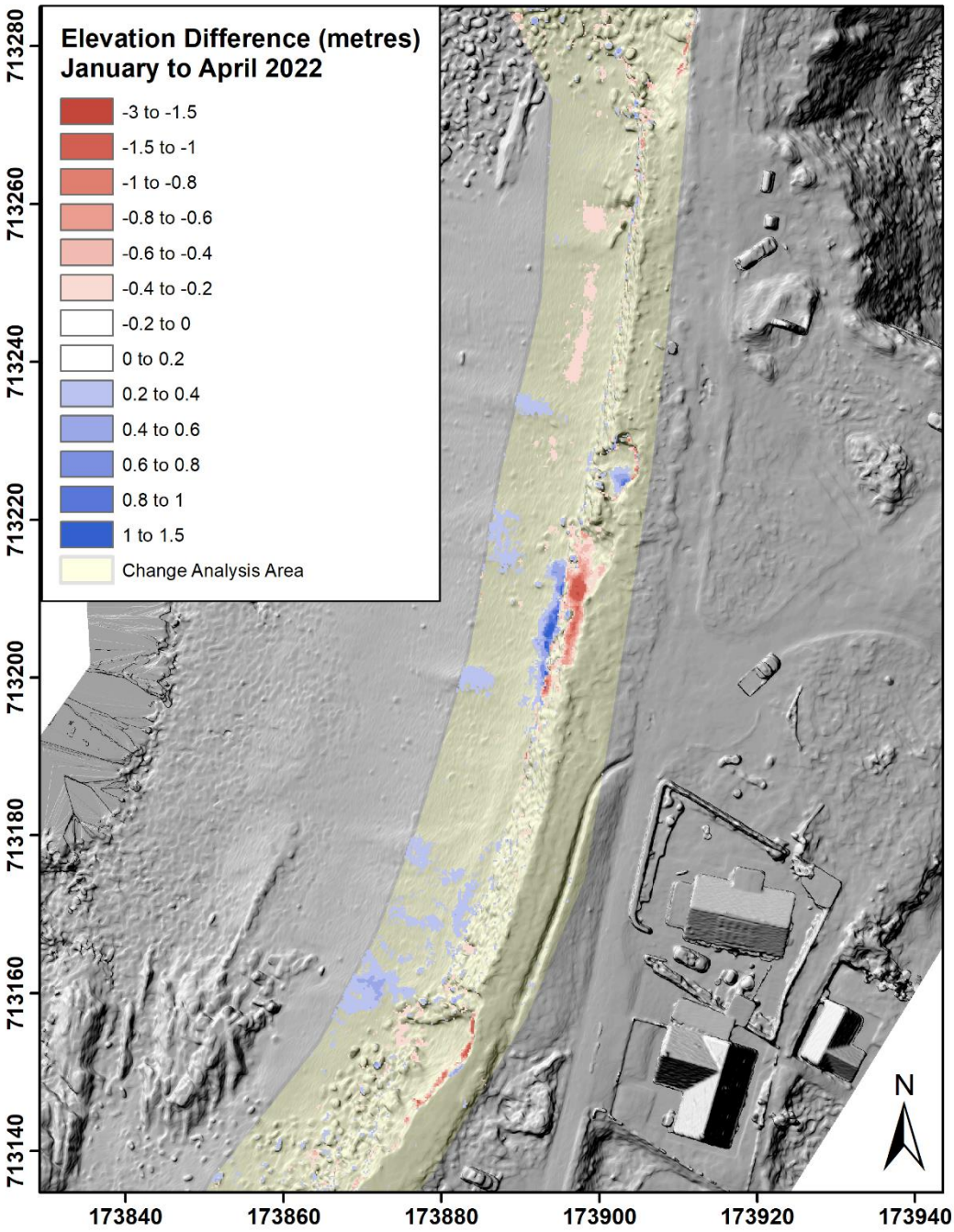


*Figure 12: Mapped differences in elevation between January 2022 DLS UAV Survey and April 2022 UofG Survey. Area of change analysis (transparent yellow) is limited to the upper foreshore due to high tide conditions during the DLS Survey. Superimposed on hillshade image of topography derived from April 2022 UofG UAV Survey. Coordinate system is British National Grid with spatial units in metres.*

## 5.3 Volume Change Analysis

Comparison of the two UAV-derived DTMs allows observation of recent changes on the foreshore. This analysis was limited to the supratidal area due to the January 2022 survey taking place during high tide conditions. The April 2022 survey was resampled so that both surveys were gridded at the same resolution allowing a direct differencing of elevations. Figure 12 shows the mapped elevation differences between the two surveys. Changes < 0.2m have been ignored as they are within the combined vertical uncertainty of the two datasets. The difference map shows limited change on the active beach, with areas of accumulation (blue) corresponding to transient beach cusps. However, the most obvious change is a section of the boulder rip rap wall that was damaged during the spring 2022, adjacent to an existing section of damage. The damage to the rip-rap wall highlights the need to intervene quickly as erosion and flood risk continue to be exacerbated by these ongoing changes. There is also a small area of recession of the cliff in the south, with up to 1 metre of cliff recession and over 1 m of vertical losses.

The thickness of sediment needed to replenish and reinstate the beach and intertidal slope to an approximation of its pre 1995 condition and construct a buffer in front of the riprap is shown in Figure 13. This surface has been created based on the April 2022 topographic survey down to the present position of MLWS, but additional sediment will also be required to raise the elevation of the current subtidal topography to recreate the pre-1995 beach slope. Factoring in the need to raise this subtidal area by 3.4 m, the total volume of sediment required to replenish and reinstate the beach is **91,300 m$^3$**. Erosion of the beach in recent decades indicates that there will be continued losses of material fed to the beach and thus a continuing plan of beach feeding is recommended. Based on the observed distribution of retreat rates (Figure 8) and the area of beach to be maintained, an annual top-up feed of at least **2,500 m$^3$** would be required to maintain the beach volume and geometry in its pre-1995 condition. However, continued monitoring of beach morphology and volume changes in the aftermath of any beach nourishment will be required to revise and update these figures.

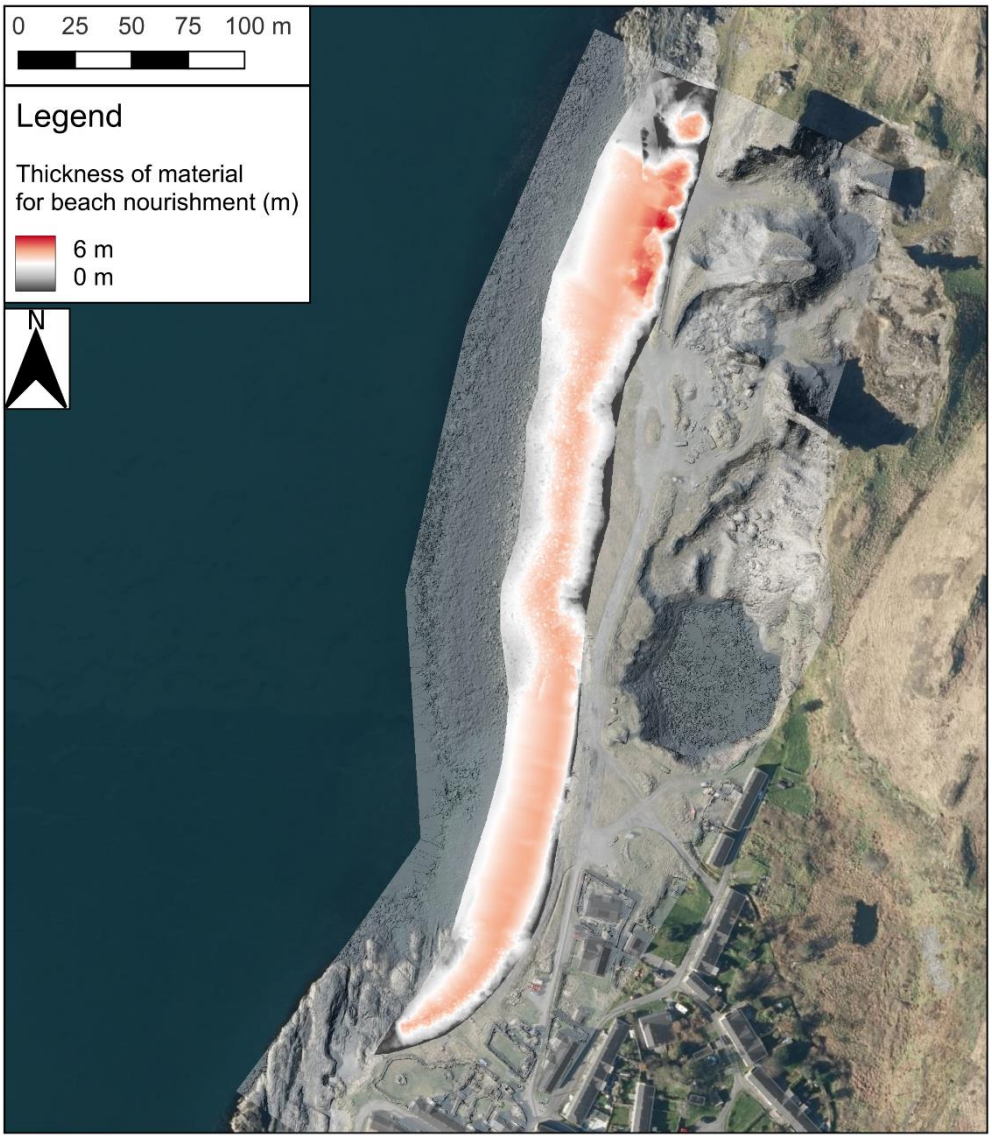


*Figure 13: Proposed thickness of beach nourishment in the current intertidal zone back to the made ground terrace edge/rip rap defences. This model assumes that the damage to the current rip-rap defences has been repaired and reinstated. In calculating the required volume of material, additional sediment has been factored in below the current low tide position that is not visualised in this image.*

# 6 Management options

Future management at Cullipool centres on one of four options.

## 6.1 Option 1 – no further intervention

Accept progressive and ongoing retreat of the shoreline with no further artificial intervention. This involves the abandonment of the two modern houses closest to the shoreline. However, under this scenario recession over time will break through the made ground between the flooded quarry pool to the landward and place the northernmost part of Cullipool village beach at risk of erosion and flooding. For a village with a conservation designation, this outcome may be undesirable and will carry economic penalties for any displaced residents. The ongoing retreat of the made-ground terrace would also impact on the viability of the road to Quarry 3 which runs along the terrace surface close to the current artificial cliff edge. This option may be unacceptable to local residents and places the re-opening of Quarry 3 in jeopardy.

## 6.2 Option 2 – restoring existing defences

Inserting artificial coastal defences (boulder rip rap etc) to fix the shoreline in its 2022 position along the entire foreshore is an expensive option and would likely also require beach feeding to avoid wave reflection from the defence structure and associated beach lowering. Possibly unsustainable over the long term given anticipated sea level rise of almost 1m by 2100. Assumed to be financially unviable given the land and property value that would be provided with reduced risk.

## 6.3 Option 3 – beach replenishment

In the short to medium term a favoured method of sustainable coast defence is to maintain a full and mobile intertidal beach. This is because mobile beach sediments have the capacity to reconfigure their geometry under wave action to better dissipate that energy: under storm wave conditions beaches tend to flatten to better dissipate wave energy and reduce wave impacts on the upper beach. The efficacy of this process depends on sufficient sediment volumes being available in the intertidal to allow reconfiguration of beach geometry as well as the ability of the beach itself to relocate landward where possible. This is where beach feeding or nourishment can reverse any decline in beach sediment loss and indeed was the

situation at Cullipool when quarrying was in full swing and providing the beach with a ready supply of waste materials.

The type of material that has sustained the beach in the past (i.e. waste from Quarry 3, as well as earlier intertidal and subtidal feed from the older northern quarries, 1 and 2) is an excellent match with the existing comminuted slate material on the beach. One caveat is that fissile slate is not an ideal beach feed material since it slides easily and breaks down more rapidly than other rock types such as granite or quartzite. However, this disadvantage may be offset by the local availability of volumes of slate waste at Quarry 3 (and substantial volumes to the north at Port Mary) and the potential for an ongoing annual supply from any rejuvenated quarry workings. Indeed, there is no reason why, prior to any start-up of Quarry 3, substantial volumes of static waste adjacent to Quarry No 3, and at Port Mary to the north could not be immediately fed to the beach at Cullipool (Figure 14).

*Figure 14: Substantial volumes of suitable slate waste exist between MHWS and the abandoned cliff at Port Mary to north of Cullipool. A farm track provides access to this area and links by road to Cullipool. Copyright James Hansom.*

The GWP (2022) Geotech survey suggests that an initial volume of **23,000-25,000 m$^3$** of slate waste might be available to feed the beach, with an annual supplement from workings of **5,400 m$^3$** of waste over 25 years. This suggests that the volume of quarry waste at start-up of quarrying is insufficient to reinstate the beach to its 1995 condition but that subsequently the annual supplement of waste from quarry workings may maintain a healthy oversupply. Additional sources of sediments are thus required to fully reinstate the beach to 1995 levels. Extensive areas of slate waste exist adjacent to Quarry No 3, and at other

quarries to the north, including at Port Mary. If accessible and available these might be used to feed the beach at Cullipool in the meantime and spanning the start-up of Quarry No 3. If sufficient sediment cannot be sourced to replenish the beach to 1995 levels, the maximum obtainable volume of material should be used, but recognising that this will not afford the same level or duration of protection.

### 6.4 Option 4 - hybrid

Option 4 is a hybrid option combining options 2 and 3, that acknowledges that a fuller beach is needed and that beach feeding is a viable option here, but also that there also exists little scope to allow recession of the made ground edge landward. Any further recession places houses at greater risk than at present but also impacts on the viability of the trackway to Quarry 3, an essential route if the Quarry is to be reinstated and to allow waste feed to the beach. As a result, it makes sense in the short term to reinstate as much of the existing boulder rip rap wall as possible and as soon as possible in order to slow the recession of the made ground backshore edge and protect the access track.

The two large gaps in the central section of the boulder wall produced by recent storms should be urgently repaired with boulders harvested from the upper beach and backfilled with coarse materials, if possible, even before any formal quarry start-up. Any repair needs to rebuild where undermining has occurred and to reconnect with the rock platform at the south end. The height should reach at least the existing height of the made ground surface by harvesting any large boulders that have failed onto the beach, rebuilding with the heaviest and largest at the base, and working upward with smaller boulders as available. The footing of the wall should be set at least 1-2m below the beach surface (lower is better) and extend from the rock platform at the south as far north as the supply of rock allows, in the expectation that the north will be the site of the annual beach feed once the beach is reinstated. The longer-term stability of any reinstated boulder rip rap structure depends on sufficient volumes of beach sediment in front to be able to attenuate wave activity before it reaches the base of the wall. A wide and shallow beach is recommended since this dissipates wave energy more effectively, whilst the reinstated wall will help reduce risk and prevent overtopping. Indeed, a shallower angled wall will help dissipate wave energy even more and reduce run-up of waves.

# 7 Summary recommendation

The recommended management option at Cullipool is of a two-pronged hybrid approach to slow beach lowering and coast recession via recharging the intertidal beach, ideally to its 1995 volume, initially using locally available quarry waste and subsequently maintained on an annual basis by ongoing volumes of waste from the reinstated workings as well as reinstatement of the boulder rip rap wall where it has failed.

However, it is important to recognise that beach nourishment will only afford some extra time, alleviating the erosion and flood risk temporarily. The rapid rates of erosion and occurrence of overtopping during recent storms is illustrative of the long-term trajectory at this location. Coastal erosion and flood risk will become more precarious through time given anticipated sea level rise, and the low-lying nature of made ground on which Cullipool is situated. Ultimately in the coming years and decades, it will be inevitable that the relocation of some coastal assets will need to be considered, even if a large-scale nourishment intervention takes place in the shorter term.

Regardless of the management or adaptation strategy implemented, it is recommended that there is an ongoing monitoring programme to measure changes to the beach and made ground. The UAV topographic survey provided with this report should serve as a baseline for future surveys. However, another baseline survey should be conducted immediately following any works completed.

# 8 References

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