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Environmental risk assessment; a case study of the Colhuw Beach revetment on the Glamorgan Heritage Coast, Wales

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Abstract. A newly constructed coastal revetment at Colhuw Beach in the Glamorgan Heritage Coast, Wales, UK, was analysed using a recently developed environmental risk assessment package (ERA). Conflict with Heritage Coast conservation objectives is apparent and the act of building such a structure is questioned for a location where maintenance of *natural* beauty is an axiom of the coastal management philosophy. The likelyhood of revetment related environmental consequences of significant magnitude was analysed using estimated probability values derived from Bayesian theory. The damaging impact of the structure on the natural environment is out of all proportion to the level of storm protection afforded to the site. Analyses, such as carried out via ERA, would have shown planners, engineers and environmentalists, the inadequacies of such an investment and management strategy. The ERA approach can help to introduce greater clarity and consistency into decision making processes.

Keywords: Coastal revetment; Conservation; Effectiveness.

Introduction

A revetment of questionable scale, location and performance has been constructed at Colhuw Beach within the Glamorgan Heritage Coast (GHC) in Wales, UK (Fig. 1). The Heritage Coast concept for England and Wales was first proposed in 1973/1974, and the Countryside Commission set up three pilot schemes (Glamorgan, Dorset and Suffolk) to introduce low cost, non statutory schemes based upon areas of high *natural* scenic quality. The Glamorgan Heritage Coast (GHC) is still one of the 'Flag Bearers' of this management philosophy which has now been applied to 45 coastal sections of England and Wales, (Williams 1992).

The revetment scheme is in conflict with some of the conservation objectives of Heritage Coasts i.e.:

- To conserve scenic quality
- To foster leisure activities which rely on natural scenery and not on man made activities.

Management principles for such environments revolve around the following:

- Determination of acceptable levels and intensity of use.
- Zonation land use policies (to include : Remote, Transitional/Intermediate and Intensive; the latter are also termed 'Honeypot' sites).
- Control of development.
- Access regulation e.g. judicious siting of car parks, foot paths, etc.
- Landscape improvement.
- Diversification of activities: 'passive' rather than 'active' e.g. walking and angling rather than e.g. motor cycling.
- Provision of interpretation services with the aim of promoting an understanding and interest in the coastal environment.

Colhuw Beach is located in the centre of the GHC ca. 1.5km from the small town of Llantwit Major. It is one of four 'honeypot' sites within this Heritage Coast where site management is geared to recreational activities. Such areas and facilities can reduce visitor pressures on adjacent sections of the coast but they can be in conflict with the conservation objectives of Heritage Coasts if they are inappropriately located and designed. Typically 'honeypot' areas have a range of visitor facilities and Colhuw is no exception with its car park, cafe, toilets and lifeguard station.

The scenic quality of the GHC, like other Heritage Coasts, is exceedingly high. Nevertheless, anthropogenic structures, often associated with coastal protection, sea defence or sewage works can impinge on the natural environment. It is axiomatic that any engineering structure built on the coast will interfere with natural processes. Revetment structures are often chosen as solutions to coastal erosion problems since they can dissipate wave energy and slow down/stop erosion at the immediate site. However their effectiveness has been questioned and Tait & Griggs (1990) in a review of > 40 seawall/revetment papers found that few included sufficient information on field conditions and most provided little assessment of the post-construction effectiveness of the structures. Uda (1991), in a

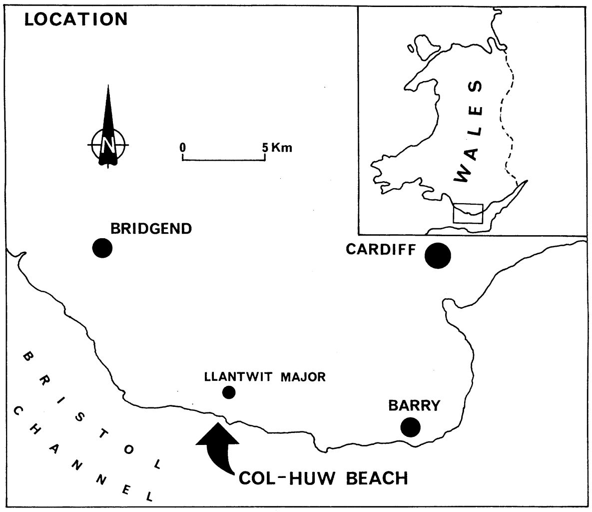

Fig. 1. Location of Colhuw Beach.

comprehensive analysis of beach erosion in Japan, concluded that revetments, seawalls and other wave dissipating works resulted in the creation of an artificial coast with significant changes to beach conditions and loss of the original beach material. However, sea walls and revetments are necessary in certain conditions. They have been blamed, sometimes wrongly, as a cause of erosion though Basco (1990) for example, showed that the presence of a seawall for the last 50 yr at Virginia Beach, USA produced no significant increase in recession rates. Here recession from the wall was due to a steep offshore bathymetry and high wave energy rather than the existence of the seawall.

A further factor which may influence the coastal environment is that, after construction, many 'protection' works can suffer damage structurally and/or functionally. For example:

1. Structural failure will take place if the construction is not designed with sufficient attention to the external and internal wave induced loads on the component elements of the revetment i.e. cover, filter and base layer. The physical mechanisms associated with the breaking wave and tidal range, plus the response of the more or less permeable rock revetment, all contribute to the development of an extremely complex domain and special attention has to be paid to the limits of the design parameters. A stochastic approach is often necessary to understand the behaviour of revetment structures and time dependent changes in the structural parameters, e.g. block strength (residual strength) and changing permeability parameters have roles to play.

2. Functionally, the structure is likely to have an adverse impact on its own and adjacent beaches due to accelerated loss of sediment This has been well-documented in the literature e.g. the four-year study of the beaches of Monterey Bay, California, USA, by Griggs et al. (1990). Downdrift loss of sediment is common and is a function of the end section, wave approach angle, wave height and period (Bottin & Acuff 1990). In addition, Kim et al. (1998), using 1-D and 2-D numerical models, have shown that rubble mound seawalls in Korea have suffered deformation of the structural cover layers due to scouring at the base of the structure. Balas & Hapoglu (1995) and Balas (1998), have also pointed out that the question of risk management and models associated with breakwater construction, is of a very recent origin.

In addition developers and/or local authorities often propose coastal structures in spite of a lack of scientific evidence of long-term changes within the coastal system. In particular, there may be deficiencies in information on the nature of morphological and/or sea level change and clear criteria to judge the *long-term* success of a scheme are rarely stated. The quest for an integrated approach to coastal management remains an elusive practical goal and little formal assessment of the success of procedures and structures exist.

In spite of this range of uncertainties, engineering schemes are being introduced, even within Heritage Coasts, which can have a severe impact on scenic quality and which do not necessarily provide a long term solution to the initial environmental problem. Given the scale of many intervention schemes some effect is inevitable and this appears to be the case at Colhuw where a revetment has been constructed on the western edge of the upper beach in an attempt to halt coastal recession and protect two buildings and an adjoining car park, (Fig. 2). It has had a catastrophic effect on beach morphology, scenic quality and visitor facilities. This paper uses a newly designed on-line environment risk assessment system in a retrospective study to assese whether the impact of the revetment could have been forecast more clearly and it questions the appropriateness of such a construction project at this site.

Physical location of Colhuw Beach

Colhuw Beach, at its landward limit, is 200 m wide and extends seaward for some 400 m. The beach consists of a thin veneer of pebbles and a shallow depth and small area of sand overlying a late glacial outwash delta and with a well developed pebble ridge in the back beach zone. The inter-tidal slope is 1:50 and the beach is bounded to the west and east by cliffs 5 - 30m in height. There is historical evidence of recession of the cliff, platform and beach systems.

The near vertical cliffs are mainly developed in the

Fig. 2. Western alongshore view of the Colhuw revetment.

bucklandi zone of the lower Lias, a system consisting of nodular limestone layers up to 1.0m thick, interbedded with shales/mudrocks up to 0.5m thick. The cliff base rocks of the eastern side and the shore platforms are composed of lower Lias, *angulata* zone strata. This material is weaker, consisting of fissile shale/mudrocks with thin, interbedded limestone strata.

The cliff mass strength of the gently dipping rocks is further reduced by the presence of well developed, near vertical joints. The combination of interbedded sedimentary rocks with contrasting geotechnical properties and the presence of abundant discontinuities results in a cliff system which is inherently unstable (Williams & Davies 1984). This failure tendency is compounded by location of the site in a high energy marine environment with strong wave action from the SW (wave fetch of 5000km). The mean height of the highest one third of the waves is > 3m though rarely exceeds 3.5m Typical wave energy densities calculated for the Pierson-Moskowitz spectrum of $H_s = 1.65$ m and $T_z = 6.0$s were $2m^2$/Hz at a frequency of 0.1Hz (Williams et al. 1996) and the Bristol Channel has the second highest tidal range in the world (16.4m at Avonmouth; >6.0m at Colhuw Point), together with a storm surge, calculated as 3.5m in a 100-yr time period. There is a powerful and efficient eastward longshore drift in the surf zone, with pebble movements of up to 40m/day recorded at the Colhuw site (Williams & Davies 1980). The resultant of this dynamic wave environment and weakness in rock mass strength, is an average cliff recession rate of 6-9cm per annum. The combination of cliff recession caused by translation, toppling and joint-block failures and rapid sediment loss to the east has proved to be of great concern the local planning authority and their most recent response (1996) saw the construction of the revetment.

The revetment at Colhuw Beach

As stated above, coastal protection in this area has been problematic because of the destructive power of storm wave erosion and weakness of the cliff mass materials. However no integrated coastal management plan exists for the area with respect to coastal erosion and the main element of the coastal plan has been to identify ‘honeypot’ and remote zones for visitor usage. The issue of coastal erosion and beach management has been tackled in a piecemeal and reactive manner. Various strategies (sea wall construction at the western side of the upper beach as early as the 1880s; cliff blasting undertaken in 1969 and a number of beach nourishment and beach scouring projects in the early 1970s;) have been tried at different times at Colhuw with the objectives of:
1. Limiting the rate of cliff failure/recession;
2. Reducing the related threat to life and property;
3. Maintaining the small sand beach;
4. Protecting visitor facilities from storm damage, (Williams & Davies 1980; Williams et al. 1998).

These strategies have had very limited success and the problem of coastal protection and maintenance of visitor facilities was brought to a halt in January/February 1990 with the occurrence of the most destructive of recent storms. Southwest, onshore wind velocities reached 140km and a storm surge of 3.1m was recorded. This event damaged the existing sea wall on the western side of the upper beach, destroyed the lifeguard station located immediately inland and undermined the foundations of the car park. It also cast tonnes of storm beach debris onto the car park surface, (Fig. 3). The car park and buildings were some 7m above OD. This is 1m above mean high water springs but, as described above, wave run-up is sufficiently strong to cause erosion at elevations > 3 m above this height.

In response to this high energy event, a new protection scheme was initiated in 1996. A revetment was

Fig. 3. Storm overwash, Colhuw Beach February 1990.

constructed along the western edge of the upper beach and the lifeguard station rebuilt at a combined cost of 750000 GBP. The structures were placed on almost the identical locations of the sea wall and lifeguard station affected by the 1990 storm. The revetment is large scale within the context of the local environment, measuring some 80m in length, 20m in width and 6m in height. It is built with 7 tonne, roughly rectangular, Carboniferous limestone blocks (Figs. 2 and 4). It extends from the western cliff edge and covers approximately half the beach width. However, in November 1996, just at the point of completion of the project, an onshore south-westerly gale at high tide caused damage to the new lifeguard building, severe downdrift upper beach erosion and undermining of the foundations of the eastern side of the car park, (Figs. 5 and 6).

Following these almost immediate problems, a moratorium was placed on further work on the revetment by the Welsh Office, the arm of government with overall responsibility for coastal planning and protection in Wales, but which was not involved in the decision making process for the Colhuw revetment scheme. However, remedial repairs had to be undertaken on inland buildings and car park (Fig. 7). Currently, the large gaps between the revetment blocks are being filled with pebbles and litter, further reducing the planned permeability of the structure.

As outlined earlier, in conventionally designed coastal structures, there is a measure of uncertainty concerning structural capacity and potential load intensities. Application of the Hudson Equation (Deterministic Design) to the structure, has indicated that whilst it can be

Fig. 4. Beach side view of the Colhuw revetment.

Fig. 5. View westwards at Colhuw showing the November 1996 storm damage.

described as safe, it will cause enhanced erosion of the adjacent, eastern section of the car park. In addition, application of the Reliability Based Design Model (Ergin & Balas 1997), suggested that a moderate damage level of 15% will be exceeded in the structure within 15 yr with an 80% probability and a damage level of > 30% with a 100% probability within the lifetime (assumed to be 50 yr) of the structure (Williams et al. 1998). The latter model evaluated safety and serviceability of the structure by modelling random variables using probability distributions at the limit state. The survival probability of the structure during any specified reference period and given environmental conditions, can then be specified.

Furthermore, for extreme conditions, where the design storm has a significant wave height in deep water of 3.5m, a wave period of 6 seconds, a high tide under a storm surge and with waves breaking at the revetment toe, the model predicted maximum wave overtopping of the structure by > 3.0m. In computation of this maximum wave overtopping, maximum breaker height H_b at the revetment toe for these conditions was calculated to have a value of 5m (Anon. 1984). This was used in the run-up equation:

$$R_u = H_b \cdot \alpha \cdot \xi \qquad (1)$$

where R_u is the wave run-up; H_b is the breaker height at the structure toe; α is a co-efficient (= 0.72), ξ is the Iribarren number, i.e.

$$\xi = \tan\beta / (H_b / L_o) \qquad (2)$$

where β is the revetment slope, and L_o is the deep water wave length. For Colhuw ξ was calculated to be 1.0.

Fig. 6. View eastwards at Colhuw showing the November 1996 storm damage.

Fig. 7. Remedial reconstruction undertaken at Colhuw in the summer of 1998.

The Iribarren number can be interpreted as the relative depth change across a wave length in the surf zone. Low values (< 0.23) indicate dissipative conditions and reflective conditions occur when values >1 are reached and the number is representative of the nearshore dynamics.

The run-up value for the extreme storm condition was computed to be 3.6m above the high tide storm surge. Since the height of the revetment crest above high tide and storm surge is only 0.5 m, the revetment will be overtopped during the design storm due to a height difference of 3.1m.The height of the maximum breaker at the revetment toe, $H_{b,}$ transformed to a deep water wave (Anon. 1984), gives a value of an individual wave height of H_o = 5m. The probability of exceeding this wave height for the extreme case is 2%.

This analysis for extreme conditions and structural damage suggests that further investment will be needed to maintain an already very expensive structure, the building of which was questionable, and against the advice of many local groups and expert opinion. Whilst it can be accepted that the structure offers a level of protection to the western zone of the upper beach (Fig.2) under moderate sea conditions, it is an example of constructive overkill at a cost of consequential morphological and structural damage (Figs. 5 and 6). Severe deterioration has occurred in the aesthetic quality of an environment originally regarded as having high scenic value.

Environmental Risk Assessment (ERA)

The problems described, should have been foreseen and if we are to improve the clarity and consistency of the decision making process, clear criteria for developers/ planners and some basis for judging the likely success or otherwise of the investment/project, should be provided. There is evidence that planners are beginning to use risk assessment techniques when faced with complex multidisciplinary problems which have to be solved in short periods of time (Anon. 1995). At present, environmental impact assessment in the UK may or may not be compulsory depending on the nature of the coastal project. Schedule 1 schemes for example port installations, refineries and power stations require an ERA study. Schedule 2 schemes, e.g. coastal protection works, *may* or *may not* submit an ERA, it is not mandatory, (Anon. 1990), though the latter is under review as a result of recent EU legislation.

The Research and Consultancy division of Associated British Ports (ABP) has developed an eight-step computer-based, risk assessment approach (the ERA package) to formally assess and document the most likely impacts of a development scheme on the coastal area (Anon. 1997). This on-line system has been applied to the Colhuw revetment. The ERA approach, formalizes and documents a process of using professional and expert judgement based upon knowledge, experience and previously published information. The ERA package was developed initially to assess the impact on species and habitats in Special Areas of Conservation and Special Protection Areas, particularly if a threat to site integrity was possible. Whilst the ERA package should be utilised *before* a proposed development is implemented, in the present analysis this was not possible and it has been applied in a retrospective fashion to the Colhuw revetment scheme. Nevertheless, it should establish whether most of the environmental consequences of the construction could have been reasonably predicted.

The ERA package draws on the DoE (Anon. 1995) publication 'A guide to risk assessment and risk management for environment protection'. The eight steps within the package require:

- A project statement, including a comprehensive description of the site and surrounding area; the development proposal; the implementation plan; and post-development operations
- Identification of possible impacts
- Identification of consequences
- Estimation of consequence magnitudes
- Estimation of consequence probabilities
- Relevance of consequences
- Assessment of risk
- Overall assessment.

Assessment of consequences is clearly a key feature of the analysis and includes use of:

- A semi quantitative value for the magnitude of the consequences and an explanation
- A semi quantitative value for the probability of the consequences and an explanation
- Statistical weightings of the probabilities
- A matrix to assess the risk created by the magnitude and probability of the consequences.

In assessing the magnitude and probability of a consequence (Steps 4 and 5 above) a simple ranking is used ranging from negligible to high (see exemplar – 'Effects on geomorphology' below in Tables 1 and 2). The magnitude of a consequence is equivalent to a resultant state caused by the impact and since there will be some uncertainty in ascribing the most probable state, it could be difficult to assign a particular qualitative probability (i.e. high, medium, low, or negligible). If this is the situation, it is possible to give a probability value to each of the four states and Bayes' theory can be applied to estimate the most likely result due to all consequences, i.e.:

$$P\,[\mathrm{I}_j \backslash A] = P\,[A \backslash B_j].\,P[B_j] \,/\, P[A] \qquad (3)$$

where a set of mutually exclusive and collectively exhaustive states, $B1, B2, B3...Bn$, are given, the probability $P[A]$ of an event A can be written as:

Table 1. Impacts selected for assessment.

Possible impacts
Hydrodynamic change
Geomorphology
Inter-tidal communities
Landscape
Beach users
Cultural sites
Local economy

$$P[A] = P[A \cap B1] + P[A \cap B2] + \ldots P[A \cap Bn] \qquad (4)$$

and the total probability can be written as:

$$P[A] = \sum_{i=1}^{n} P[A \backslash B_i] \cdot P[B_i] \qquad (5)$$

Using Bayes' theory, the probability of a particular state for a given event can be obtained as follows:

$$P[B_j \backslash A] = P[A \backslash B_j] \cdot P[B_j] \big/ P[A] \qquad (6)$$

and the total probability derived from:

$$P[B_j / A] = P[A \backslash B_j] \cdot P[B_j] \bigg/ \sum_{i=1}^{n} P[A \backslash B_i] \cdot P[B_i] \qquad (7)$$

Every stage of the process in the ERA approach should be quantified as much as possible and it is recommended that where assumptions are made, they should be made explicit and recorded. Completion of the results allows the project impact assessment to be reviewed by all interested parties. It can form a useful addition to the decision making process, permitting a more informed assessment of consequences.

Results and Discussion

The possible environmental impacts of the revetment are identified in Table 1, and an example is given in Table 2 of the consequences, magnitudes and probabilities of one such impact i.e. the effects on the geomorphology of the site.

Summary descriptions of the results obtained for the impacts shown in Table 1 are as follows:

Impact 1: Hydrodynamic changes

Explanation: The revetment will alter the upper beach flow regime with wave run-up, reflection and turbulence likely to cause increased beach scour at the base of the revetment, especially under storm conditions. Over time, this will lower beach elevation and increase wave power at the site.

Impact 2: Effects on geomorphology (Table 2)

Explanation: As indicated (see Impact 1 above), increased wave power will scour sediments and lower beach elevation over time which will further enhance wave power at the revetment, especially at its base. Under high tide, oblique wave attack, longshore wave currents will be enhanced by the revetment structure and erosion will increase to the east of the construction both on the beach and at the base of the adjoining cliffs. This erosive effect will be accelerated by the reduction in sediment transfer from the landward edge of the upper beach caused by the presence of the 'fixed ' revetment.

Table 2. Environmental Risk Assessment Report.

Impact No. 2. Effects on geomorphology

Consequence No. 1. Erosion of upper beach deposits

Magnitude	high
Probability	high
Relevance	yes
Risk	high

Estimated probability values for each magnitude

Severe	High	Mild	Negligible
0.6	0.3	0.05	0.05

Consequence No. 2. Lowering of beach elevation

Magnitude	high
Probability	high
Relevance	yes
Risk	high

Estimated probability values for each magnitude

Severe	High	Mild	Negligible
0.6	0.3	0.05	0.05

Consequence No. 3. Erosion of cliffs on eastern side due to changes in sediment supply and wave currents

Magnitude	severe
Probability	high
Relevance	yes
Risk	high

Estimated probability values for each magnitude

Severe	High	Mild	Negligible
0.3	0.3	0.2	0.2

Consequence No. 4 . Erosion of cliffs on western side

Magnitude	medium
Probability	high
Relevance	yes
Risk	medium/low

Estimated probability values for each magnitude

Severe	High	Mild	Negligible
0.5	0.3	0.15	0.05

Consequence No. 5. Protection of landward sites in moderate sea conditions

Magnitude	severe
Probability	high
Relevance	yes
Risk	high

Estimated probability values for each magnitude

Severe	High	Mild	Negligible
0.5	0.3	0.2	0.1

Consequence No. 6. Erosion of down drift sites under severe high tide storms

Magnitude	severe
Probability	high
Relevance	yes
Risk	high

Estimated probability values for each magnitude

Severe	High	Mild	Negligible
0.5	0.3	0.1	0.1

Consequence No. 7. Erosion of deltaic deposits

Magnitude	mild
Probability	negligible
Relevance	yes
Risk	low

Estimated probability values for each magnitude

Severe	High	Mild	Negligible
0.3	0.3	0.3	0.1

Such sediment would have helped to 'rebuild' beach levels under constructive wave conditions. Erosion of the cliff along the western side could also be enhanced over time because the structure is likely to cause increased sediment transfer from the west along the face of the revetment under high tidal storm attack. This coarse clastic sediment will be used by storm waves to achieve erosion of the upper beach and cliff base immediately east of the structure.

Impact 3: Impact on intertidal communities

Explanation : The intertidal environment is already sediment starved and, for the reasons above, the revetment can only enhance this characteristic to the detriment of the intertidal faunal and plant communities.

Impact 4: Effect on landscape

Explanation: The revetment is a major, artificial 'intrusion' into the landscape of this Heritage Coast site (Figs 2 and 4). It is of a scale which dominates the beach and obstructs low level sea vistas. It will cause lowering of beach elevation and loss of upper beach sediments impairing the aesthetic quality of the existing Colhuw landscape. It will accelerate cliff erosion.

Impact 5: Effects on beach users

Explanation: Beach access has been inhibited by the construction of the revetment, particularly for young children and the handicapped. Sand sediment will be lost due to enhanced wave power under storm conditions and this is likely to reduce the size of the beach further limiting the attractiveness of this location for family users and surfers. Sea vistas from the car park have become severely restricted due to the height and scale of the construction and the aesthetic quality of the location has been impaired (see 4 above).

Impact 6: Effects on cultural sites

Explanation: Ca. 200 m offshore within the deltaic boulder/mud deposits are the remains of Colhuw port, probably destroyed during the climatic deterioration and storms/tidal maxima between the fifteenth and the sixteenth centuries (Davies & Williams 1990). The archaeologically important timber pile remnants are sufficiently offshore to be unaffected by changes along the upper beach associated with the revetment construction.

Impact 7: Effect on the local economy

Explanation: Due to the deterioration in the size of the sand beach, restricted beach access, restricted sea views from the car park, deterioration in general aesthetic quality of landscape and excessive erosion and loss of the car park surface immediately east of the revetment (Fig. 4), there is likely to be a reduction in numbers visiting Colhuw Beach with a consequent, if minor, effect on the local economy.

For the possible impacts listed above, Table 3 shows the count matrix for the relevant consequence magnitudes and shows a high probability of severe and high damaging effects for the environment.

The ERA technique has clearly identified geomorphological and landscape quality consequences for the Colhuw site which are particularly worrying, especially since the site lies within the GHC. Upper beach erosion will not be halted and the shoreward structures will not be protected with this scheme. The technique has confirmed what should have been evident to the planning agencies through the experience of repeated failure of all previous reactive, piecemeal projects which have attempting to halt recession at this site. It is virtually impossible to maintain the coastal boundary line at its present position at any sensible cost whilst conserving the scenic quality of this section of the Heritage Coast.

Failure to respond adequately to the behaviour of the natural system may have been a reflection of the difficulties of the Colhuw site, but there were alternatives. Observation of the natural behaviour of the shingle beaches in close proximity to Colhuw Beach could have suggested a different strategic response. If a policy managed retreat had been implemented and the existing natural, shingle beach allowed to migrate inland to establish a new equilibrium position, the probability of damaging effects on the environment would have been greatly reduced. The destruction of the lifeguard station in 1990 and the availability of an undeveloped site further inland should have resulted in a major review of strategic planning. At Southerndown, ca. 7km to the west an equilibrium pebble ridge has been allowed to develop and storm damage to the landward buildings and car park is negligible. The buildings and car park at Colhuw could have been relocated with respect to an appropriate set back line at much less cost than the existing scheme and the expense of constructing and maintaining the revetment would have been saved.

If this strategy had been implemented, preferable with a small amount of shingle beach augmentation, re-application of the ERA technique suggested a much more satisfactory outcome. The relevant summary assessment for the consequences and magnitude probabilities would have been:

Severe	High	Mild	Negligible
0.0	0.1	0.8	0.1

These values can be compared with those shown in Table 3, and clearly show that the strategy would have reduced the destructive effects on the environment and, it can be argued, would have produced a more satisfactory outcome on all counts, including costs.

Table 3. Count matrix for all relevant consequences.

Consequence	Consequence magnitude			
Probability	Severe	High	Mild	Negligible
high	4	4	1	0
medium	0	1	1	0
low	0	1	3	0
negligible	0	0	1	0

Probability of a relevant consequence magnitude occurring

Severe	High	Mild	Negligible
0.05	0.80	0.10	0.05

Conclusions

- Cliff failure and coastal recession is endemic to this area, and there are abundant mobile, pebble, storm beaches in the vicinity. All attempts to ‘fix’ the coastline at its present pre-determined line at Colhuw, including the 1996 revetment, have failed.
- The ERA technique is relatively easy to apply and has clearly highlighted the consequences of using a revetment solution to the erosion problem at Colhuw.
- If the ERA technique had been instigated prior to the start of the project it would have indicated that damaging changes to the environment were inevitable.
- The problem is further compounded by the inherent uncertainties in any structural design parameters and which in this case, is likely to experience a damage level of > 30% with a 100% probability within the lifetime of the structure.
- These conclusions and uncertainties should have required planners and decision makers to explore further the intervention strategies for this location and to search for alternative, possible ‘soft’ engineering solutions to the erosion problem. Several coastal landform indicators and tendencies exist in the GHC environment which could have provided a basis for an alternative strategy.
- ERA analysis suggested that a managed retreat policy, permitting the establishment of an equilibrium pebble ridge, could have provided a low cost and more effective solution.
- Whilst there would have been clear advantages in adopting a managed retreat and soft engineering strategy for the coastal problems of this location, partial completion of the existing project now represents a worrying case scenario. The planning authority faces a number of dilemmas: (1) total removal of the structure and buildings would be expensive and an admission of policy failure, (2) further extension of the revetment eastwards across the beach until it reaches the cliff line would also be expensive and compound the conservation and performance issues raised in this paper, (3) adoption of a compromise solution by retaining the

existing revetment, in spite of its problems, and adapting to downdrift erosion by permitting an equilibrium set back line to be established in this zone.

- The latter appears to be the current management policy (Fig. 7). It is once again reactive and will necessitate repeated damage repair costs to buildings and car park which the full set-back line approach would have reduced considerably. It also requires some pebble beach augmentation and may require the addition of an east side located groyne to reduce downdrift removal of sediment. However, it does not overcome the issue of deterioration in the aesthetic quality of this Heritage Coast site.
- The revetment strategy also raises an ethical question concerning the introduction of relatively large scale and costly man-made structure, of limited benefit, into a Heritage Coast area where the emphasis is on *natural* beauty and where a prime management objective, is the conservation of scenic quality.

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