Recent improvements to Fairbourne flood protection. (above) Rock armour added to the storm beach at Friog. (below) New tidal gate at the mouth of the Afon Henddol.

Fairbourne - an adaptive engineering approach to flood protection

Graham Hall **August 2022**

1. Origins of the current flood strategy

In 2011, the civil engineering company Royal Haskoning was commissioned to carry out surveys around the Welsh coast and produce the West of Wales Shoreline Management Plan. The initial version of this report, published in November 2011, discussed flood risk to Fairbourne and recommended a policy of 'Hold The Line':

> *"As there is no significant increase in flood risk expected as a result of climate change, a policy 3 has been selected. This means we will continue to maintain the channels and local flood defences to ensure the current level of risk is sustained. Stopping or reducing the existing flood risk management actions would allow existing flood defences to fall into a state of disrepair and would put more than 850 people in the policy unit at a greater risk of flooding than at present."*

Within a few weeks, a revised version of the report was published, in which the policy for Fairbourne had been changed to 'Managed realignment'.

> *"This would involve relocation of property owners and businesses from Fairbourne."*
>
> Haskoning (2011).

The decision to abandon Fairbourne had apparently been taken by Gregor Guthrie, a civil engineer employed by Royal Haskoning. Gwynedd Council seems to have accepted the recommendation to demolish Fairbourne without questioning this decision.

In February 2014, the BBC broadcast an edition of the program 'Week in Week Out' entitled 'Sea level threat to force retreat of communities in Wales'. The program focussed on Fairbourne, stating that Gwynedd Council was planning to 'decommission' the entire village, dismantling all homes, roads, shops, and infrastructure and turning it back into marshland.

The intention to abandon Fairbourne was picked up more widely by journalists, leading to a series of newspaper articles often carrying sensational headlines:

'This is a wake-up call': the villagers who could be Britain's first climate refugees

As sea levels rise, Fairbourne, sandwiched between mountains and the beach, is being returned to the waves. But where will its residents go?

The Welsh village being abandoned to the sea because of climate change

UK Disappearing Village Told It's Beyond Saving

Figure 1: A selection of newspaper headlines following the 2014 BBC programme announcing the plans to abandon and demolish Fairbourne.

Over the period from 2013 to 2018, effective flood protection schemes were carried out around Fairbourne by Natural Resources Wales and Gwynedd Council. These included: reconstruction and strengthening of a section of sea wall at Friog; reconstruction of sections of the Mawddach estuary embankment to the north of the village; and improvements to the course of the Afon Henddol which flows around Fairbourne and discharges into the estuary through a new tidal gate (see illustrations on the title page).

Despite Fairbourne now having good flood defences, and the fact that houses in the village have not been flooded at any time within living memory, Gwynedd Council have continued with an inflexible policy to demolish the village:

> *“Fairbourne is a community at risk from various sources – coastal storms, rising sea levels, a river that carries mountain run off and a high groundwater table,” says Gwynedd Council senior project manager, flood and coastal erosion risk management, Lisa Goodier. “The village can be defended sustainably for the next 40 years but from 2045 it will have to be decommissioned and from 2055 it will not be possible to defend.”*
>
> *(New Civil Engineer, 2018).*

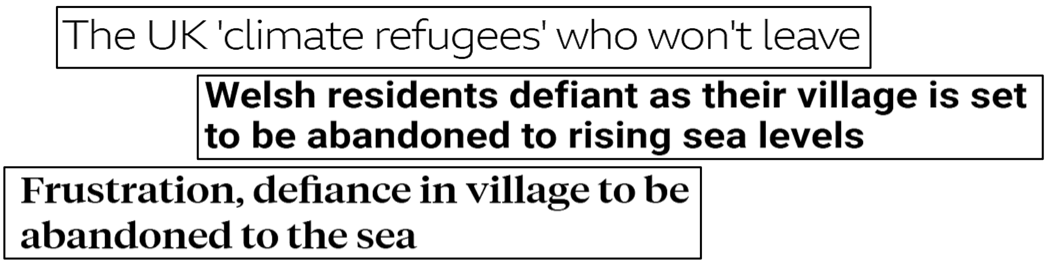
The date of 2054 by which the village should be abandoned and demolished appears to have been decided by Gregor Guthrie of Royal Haskoning, and is based on predictions of sea level rise:

> *‘Referring to the source-pathway and receptor model, the work compiled within this overview reviews the various sources of flood risk. A key date in the timeline is 2054. This is the projects’ current planning horizon which was set back in 2014, and reflects the point in time where there is no longer a need to manage the defences.’*
>
> Royal Haskoning Technical Group Overview Report. Gregor Guthrie, principal author.
> (Haskoning, 2018).

Very little information has been provided by Gwynedd Council as to how the proposed decommissioning of Fairbourne would take place. In April 2021, the *Independent* newspaper published an article:

> *‘Without legislative guidelines or access to a national funding stream, Gwynedd council has made it clear that the costs of decommissioning will fall on private householders. There will be no compensation. Decommissioning a village is hard work; gas pipes and electricity pylons would need to be carefully dismantled and all structures completely flattened. To add insult to injury, residents have been told they may well have to contribute £6,000 to the cost of demolishing their homes to make way for the salt marshes that will serve as buffer against future flooding.’* Independent (2021).

The situation which has developed in Fairbourne is clearly causing enormous concern to local residents. A more belligerent tone of headline is now appearing in the press:


The UK 'climate refugees' who won't leave

Welsh residents defiant as their village is set to be abandoned to rising sea levels

Frustration, defiance in village to be abandoned to the sea

Figure 2: A selection of newspaper headlines published since 2018.

In 2022 Arthog Community Council, which represents the people of Fairbourne, voted to reject plans to abandon and demolish the village. The motion to reject the decommissioning of the village was unanimously passed at a meeting of the council on 4 May.

> *“Arthog Community Council requests a thorough review and ultimately a reversal of the decision to decommission Fairbourne in 2054”. But Gwynedd Council said it “does not have a formal plan to decommission Fairbourne”.*
>
> Cambrian News (2022).

It is evident that planning for the future of Fairbourne has been handled very badly. Local residents have understandable serious concerns. This is an extremely serious matter involving hundreds of residents losing their homes and businesses with apparently no prospect of compensation and rehousing. **Such a course of action should not be undertaken unless there is absolute certainty that it is necessary and all possible alternatives have been considered.**

2. Justification presented for abandoning Fairbourne

The decision to abandon and demolish Fairbourne is clearly based on cost. The report by Royal Haskoning implies that flood defences could be provided to protect the village until at least the end of the current century, but that it would not be economically worthwhile to do so. In July 2018, the Fairbourne Preliminary Coastal Adaptation Masterplan was published. This states:

> *'The Technical Overview Report (Haskoning, 2018) shows that maintaining the defences will cost around £10,000,000 up to 2055 (subject to additional works potentially required in relation to the embankment, estimated as being in the order of £4,000,000). The present value cost (Pvc) for such works would be in the order of £6,500,000.*
> *Beyond 2055, the costs increase significantly. The initial tranche of improvements (including the potential need to address tidal locking issues associated with fluvial and ground water), amounts to an additional cost in the order of £53,000,000, with further costs in the order of £51,000,000 to maintain defences over 100 years. The combined works to provide protection over 100 years have been estimated to be in the order of £115,000,000.'*

Costs of flood defences appear to be modest up to the year 2055. Beyond this time, an enormous increase is predicted. This prediction is based on computer modelling: firstly by agencies estimating possible sea level rise; and secondly by Royal Haskoning in using the estimated sea level rise to determine the future flood risk to Fairbourne.

It must be said that computer modelling is an imprecise science, having the status of little more than an educated guess. In particular, estimates of possible sea level rise and storm intensity are dependent on predicting a wide range of events which may affect the future climate, including: changes to industrial and agricultural production in different parts of the world, innovation and adoption of new energy technologies, along with unforeseeable events such as wars or volcanic eruptions. Climate scientists generally give predictions as a range of probabilities, rather than precise values. As prediction moves further into the future, the reliability decreases and the range of possible outcomes grows wider. It appears that Royal Haskoning have used a worst case scenario for sea level rise in their modelling, leading to a worst possible prediction of flooding for Fairbourne, and consequently the maximum possible cost of flood defence works.

However, the reliability of the computer modelling for Fairbourne is affected by more than just the accuracy of the predicted sea level and storm wave values input to the model. It is crucially dependent on a full and accurate understanding of the physical processes which are being modelled, and correctly representing these processes mathematically when simulating flood events.

It is stated that the major risk to Fairbourne comes from overtopping of the Ro Wen shingle spit by storm waves, or a catastrophic breach of the shingle spit during a storm. A series of flood models have been presented in the publication 'Fairbourne Preliminary Coastal Adaptation Masterplan' to illustrate these scenarios (Fairbourne Moving Forward Partnership, 2019a).

The first two models (fig.3) indicate that Fairbourne village would have been flooded in 2018 by overtopping waves during a storm with a magnitude occurring once in 50 years (T50), or once in 100 years (T100).

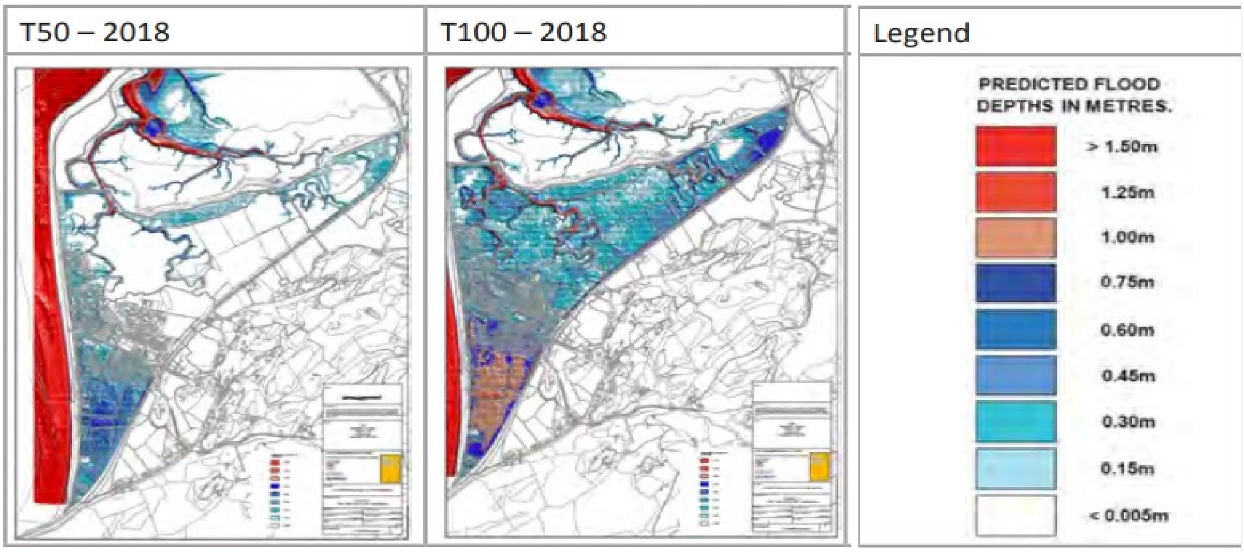


Figure 3: Computer models for flooding of Fairbourne in 2018 for storms of 50 year and 100 year frequency.

In both cases, the village is shown as flooded to a depth of around 0.45m, which is about knee deep. This is similar to flooding which occurred in Towyn, near Abergele (fig.4).

Figure 4:

Flooding at Towyn.

Major storms have actually occurred in North Wales during the period specified for the models. Storm Clara in February 2020 and Storm Eunice in February 2022 both caused extensive flooding and damage to property across North Wales. These storms were at the limit of storm magnitude possible for the Welsh coast, taking into account the geometrical configuration of the Irish Sea basin and the maximum wind force produced in the Atlantic. They therefore count as close to 100 year events. **However, no flooding at all occurred in Fairbourne during either storm, and no damage was done to any of the sea defences** (fig.5).

Figure 5: Fairbourne beach and Friog sea defences a few hours after Storm Eunice, February 2022.

Both flood models are clearly incorrect, and have been based on invalid assumptions or data. We need to consider why the models failed.

The Ro Wen shingle spit in front of Fairbourne has a wide flat crest. Indeed, in the south of the village the top of the shingle spit is sufficiently wide to be used as a car park. Modelling has shown that wave overtopping along the length of the Ro Wen spit in front of Fairbourne village is negligible (Hall, 2022a). This is confirmed by observations made by local residents. Water washing onto the top of the storm beach generally dissipates into the porous surface of the shingle bank. Any small amount of water flowing over the embankment is directed into the village drainage system and will flow back to the estuary.

It is likely that the original modellers made the error of assuming that all water overtopping the seaward crest of the storm beach continued across the full width of the embankment, and then flowed onto the ground surface in Fairbourne village where it accumulated to cause flooding.

It is asserted that Fairbourne is at imminent risk of a catastrophic breach of the Ro Wen shingle spit during a storm, leading to immediate inundation of the village and danger to life (Fairbourne Moving Forward Partnership (2019a). This scenario is shown in the third computer model (fig.6).

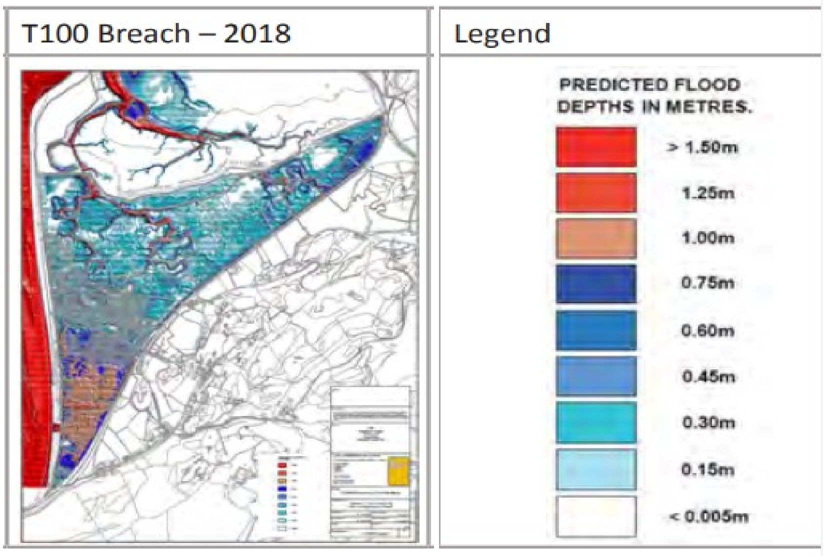


Figure 6 :

Computer model for flooding of Fairbourne due to a breach of the Ro Wen shingle storm beach.

The breach which has been simulated appears to be a gap of around 50m cut through the Ro Wen spit at a location just north of the Friog mobile home park. The sequence of photographs in fig.7 show the line of the simulated breach. The model simulates a breach extending down to a level close to the sandy beach in order to allow water to flood through the gap.

Figure 7:

Sequence of images across the Ro Wen spit. The foreground represents the location of the simulated breach of the storm beach.

(a) beach and face of the storm beach.

(b) upper surface of the storm beach

(c) landward slope of the storm beach

Data has been collected by Professor M. Phillips to record changes in the volume of the Ro Wen storm beach over the period since 1991 (Phillips et al., 2017). Accurate measurements show that there is a slight loss of shingle occurring at the southern end of the spit near Friog, whilst the spit is stable or gaining shingle further north (fig.8).

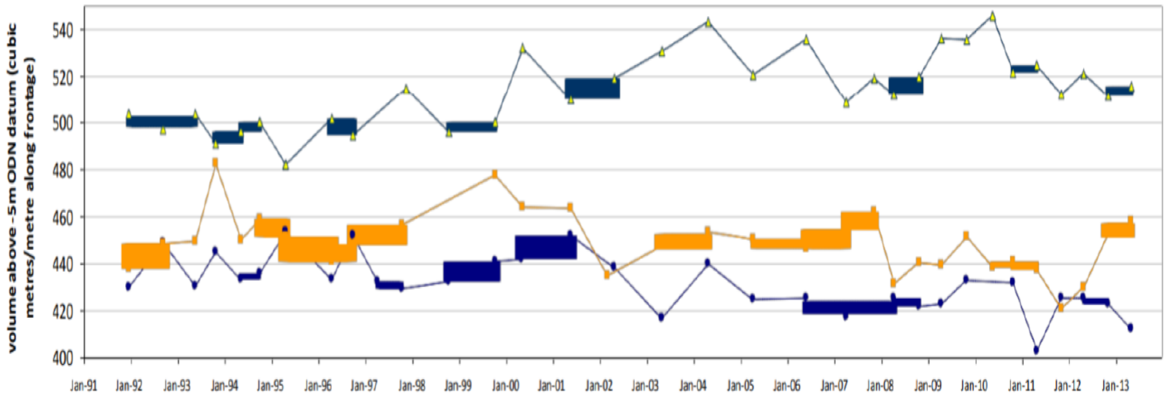


Figure 8: Volume of storm beach shingle over the period 1991-2013. The storm beach is seen to be slightly losing shingle at Friog corner (blue), stable at Fairbourne village (yellow) and slightly gaining shingle at the northern end of the spit (green).

A concrete wall was emplaced along the centre of the shingle spit to strengthen the structure when Fairbourne was first developed as a seaside resort in Victorian times (fig.9). The wall is approximately a metre in thickness and extends to a depth of about 3 metres.

Figure 9:

Photograph about 1913 showing the sea wall constructed by Solomon Andrews to protect the newly established seaside resort of Fairbourne.

A breach of the Ro Wen spit could conceivably occur by one of two mechanisms (fig.10):

- Erosion of the front face of the storm beach cutting back to reach the sea wall, which then fractures, allowing erosion to continue through the landward embankment.
- Erosion working downwards from the upper surface, washing shingle in both directions away from the sea wall, which finally fractures.

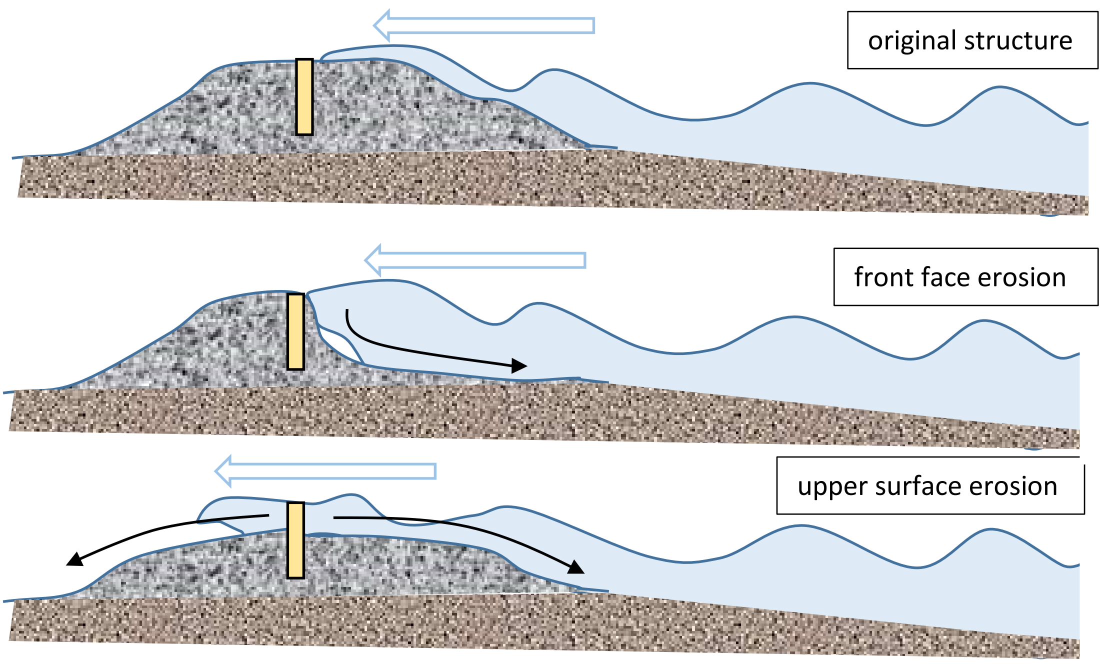


Figure 10: Conceivable mechanisms by which a breach of the shingle spit could occur.

Neither of the mechanisms seems plausible:

Waves approaching the coast have a rotational motion and may break on a shore in different ways (fig.11):

If the storm beach face has a gentle slope, rotational energy is removed gradually from the approaching wave and the wave motion is predominantly in a forwards direction as it breaks. This produces a spilling breaker. The wave can pick up and transport sediment, encouraging deposition of sediment at higher levels on the storm beach.

If, however, the storm beach face slopes steeply, then waves will have lost less rotational energy by the time they break, creating a plunging breaker. The rotational energy of the water can carry sediment back down the storm beach face and erosion may occur.

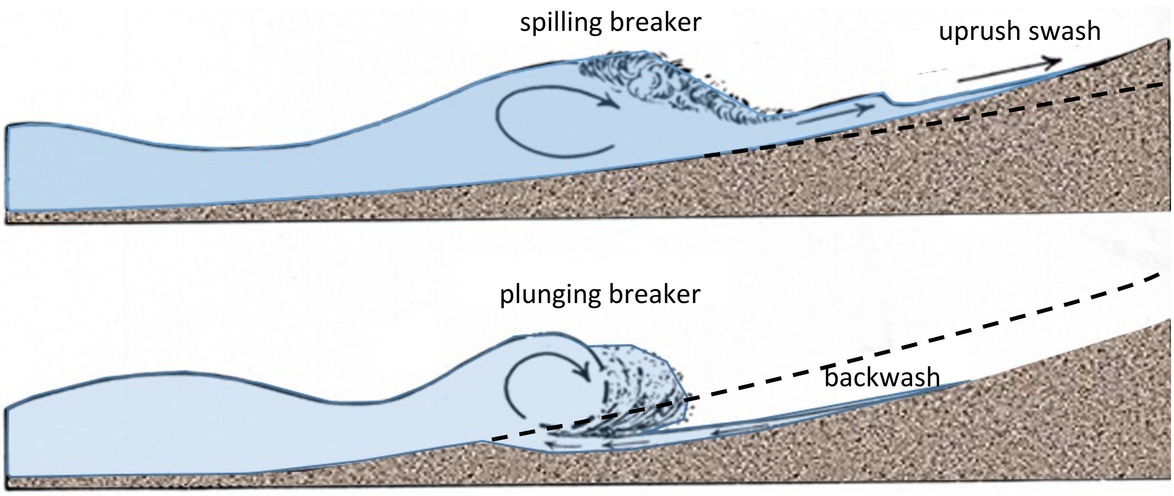


Figure 11a: (above) Constructive spilling breaker. **b**: (below) Erosional plunging breaker.

Storm waves would only be of a sufficient height to affect the upper half of the storm beach face for about one hour on either side of high tide. During this time, waves are most likely to break on the front face by a spilling mechanism due to the relatively gentle angle of the face, with no erosion occurring. Furthermore, much of the incident wave would be absorbed into the permeable structure of the shingle bank, where the water would drain downwards inside the shingle mass without causing any erosional effect (fig.12).

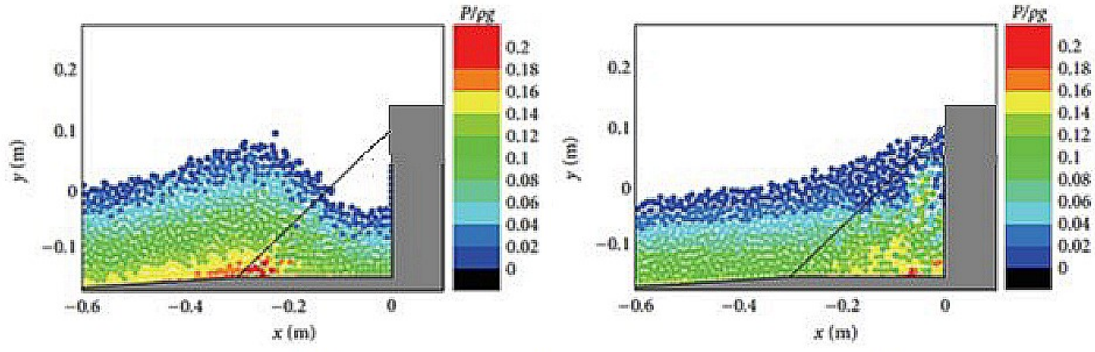


Figure 12: Model for the impact of storm waves on a permeable structure (Pu & Shao, 2012).

Storm waves would only be of sufficient height to overtop the crest of the shingle bank for about one hour around high tide. The effect of waves washing over the top surface of the storm beach is to arrange the shingle into a closely packed structure, with smaller gravel filling the surface cavities. This has the effect of armouring the surface, preventing subsequent waves from easily picking up material. Furthermore, any shingle carried back seawards down the front face of the storm beach would have the effect of further reducing the slope angle of the face. This in turn would promote the breaking of waves by a spilling mechanism which will deposit shingle onto the storm beach.

We are left with the problem of how the concrete core wall could be fractured to allow ingress of water. In the case of upper surface erosion, there would simply not be sufficient time for this to occur before the tide fell and the flood risk receded. In the case of front face erosion, the large inland embankment behind the wall would provide support and prevent mechanical fracturing of the concrete due to wave impact.

Measurements by Phillips (fig.8) indicate that the storm beach embankment in the area of the simulated breach has a volume of approximately 420 cubic metres of shingle per metre along the spit. It is possible that some plunging breakers could cause erosion, but surveying has never identified more than 30 cubic metres/metre of erosion during any storm event, leaving 390 cubic metres/metre of shingle still in place. Furthermore, it was found that the lost shingle was normally replaced by constructive marine processes in the few weeks following a storm.

We must conclude that there is no plausible mechanism for the breaching of such a massive structure as the Ro Wen spit during a storm event. Any small amount of erosion which might occur on the front face of the storm beach would present no risk to Fairbourne. This erosion would be repaired naturally by coastal processes, or could easily be repaired artificially by the replacement of the shingle.

The computer model for breaching of the shingle spit is based on invalid assumptions and data, and should be discounted as evidence of a flood risk to Fairbourne.

We should finally look at the effects of sea level rise on the Ro Wen shingle spit.

To understand the formation and continued evolution of the Ro Wen spit, it is necessary to consider the mechanism by which storm waves approach and break on the shore. During a storm, the bulk of sea water at depth is stable, but waves develop by rotational movement of water near the surface. Energy is transferred to the waves from wind blowing over the sea surface. This energy maintains the rotational motion of the upper layers of sea water, with the extent of the rotation reducing with depth (fig.13). As waves approach the shore, the lowest layer of rotating water makes contact with the shelving beach.

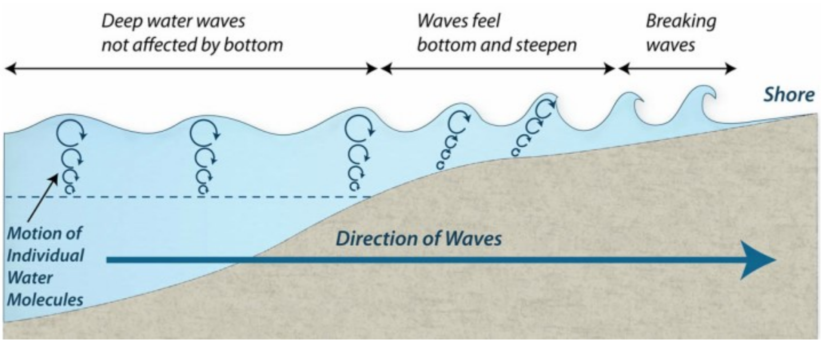


Figure 13:

Mechanism by which waves ground and break on reaching a shelving beach.

Sediment can then be picked up from the sea bed and transported by approaching waves. The maximum grain size which can be picked up depends on the amount of rotational energy stored below the waves, and the depth to which the rotating cells of water are able to reach. During moderately windy conditions the sea water may be able to pick up and transport inshore sand, whilst during the most powerful storms it may be able to pick up both sand and coarser pebbles from deeper sea bed deposits.

As storm waves break on the shore, the transported load of sand and pebbles will be thrown up the beach (fig.14). After breaking, the gravity return flow of sea water is able to carry sand back down the beach, but the heavier shingle is left behind. Over a period of time, a large shingle storm beach can be constructed.

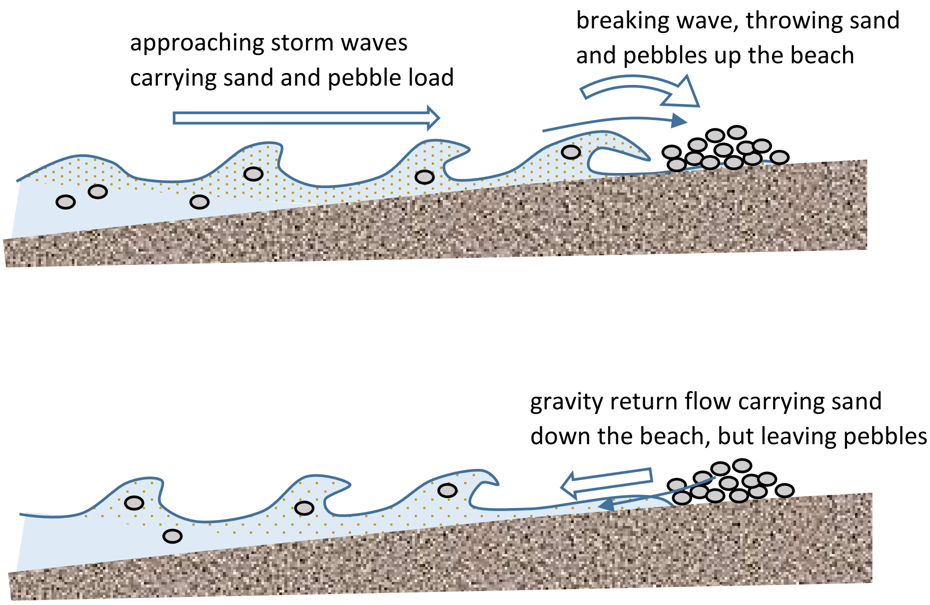


Figure 14:

Formation of a shingle storm beach by wave action during a storm.

The Ro Wen storm beach near Friog is shown in fig.15, looking from the edge of the sandy foreshore at the level of a calm high water spring tide. The shingle embankment extends to a height of 5.5m above the sand beach. This height is not by chance, but represents very closely the maximum height reached by breaking storm waves along this shore.

Figure 15:

Shingle storm beach near Friog, looking upwards from the sandy foreshore marking the level of calm water at high spring tide.

The storm beach is a dynamic structure in equilibrium with marine processes. There is every indication that the height of the storm beach will adjust naturally to slow sea level rise over a number of decades, maintaining a height equal to maximum storm wave height. This will occur through storm waves throwing shingle onto the top of the existing structure if sea level rises and makes this possible.

Figure 16:

Upper surface of the storm beach, showing the accumulation of shingle thrown up by storm waves.

It is known that the Ro Wen storm beach has been very stable for thousands of years since its formation at the end of the Ice Age, and that its profile has changed little in the past century (Hall, 2022b). This is due to the ability of the shingle spit to adapt naturally to changing sea conditions.

The change in sea level of 1 metre used in the modelling by Royal Haskoning for the period up to the end of the current century is probably an over-estimate, and the change will take place very gradually over many decades. This will provide plenty of time for the storm beach height to adjust naturally to the prevailing wave heights.

We can conclude that the risk of flooding in Fairbourne from storms at sea is very small:

- Wave overtopping is currently negligible, and the risk will remain small.
- There is no possibility of a catastrophic failure and breach of the shingle spit at any time in the foreseeable future.

The enormous costs which have been budgeted by Royal Haskoning to protect against these events are therefore unnecessary.

A further very large cost estimate by Royal Haskoning is related to the discharge of drainage water into the Mawddach estuary. The Afon Henddol and other small rivers between Fairbourne and Arthog enter the estuary through tidal gates, which open at low tide to allow the rivers to discharge, but close with the rising tide to prevent inflow of water from the estuary (fig.17).

Figure 17:

Tidal gate at Arthog, allowing drainage water to discharge into the Mawddach estuary at low tide.

During each month there is a natural variation in the tidal range between higher spring and lower neap tides (fig.18).

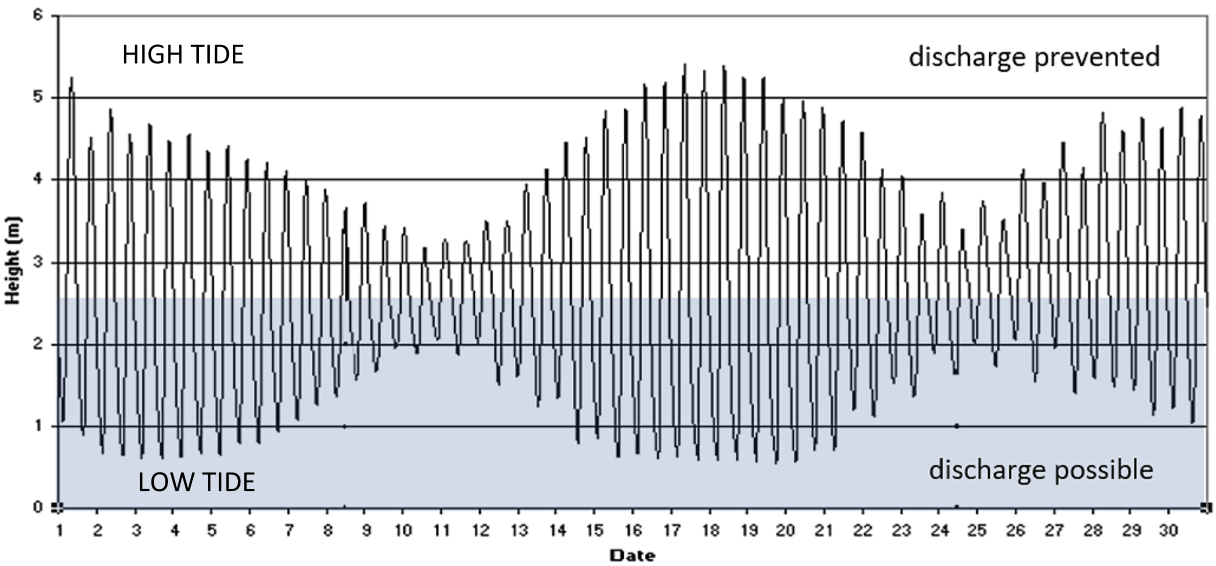


Figure 18: Typical tidal data for Barmouth

If sea level rises, the time available for rivers to discharge through the tidal gates will be reduced. By the end of the century It may become impossible for discharge to occur at neap tides by simple gravity flow, as the estuary water level will not fall sufficiently low. Pumping may then be required for a few days each month.

If pumping is necessary, it would be an advantage if this could be carried out by means of electricity generated locally from renewable sources. An on-shore wind turbine would be a relatively cheap and reliable option, although there may be a reluctance to allow a wind turbine due to intrusion on the landscape. An off-shore wind turbine may be an acceptable alternative; the sea bed is fairly shallow offshore from Fairbourne and Barmouth so construction should not be a problem. An opportunity also exists to site an electric generator on the sea bed around the mouth of the Mawddach estuary. Water flows reach high velocities at the period of maximum inflow on a rising tide.

A number of designs of tidal generator are available or being developed (fig.19) which could be secured to the sea bed at a depth where they would not present a hazard to boats using the estuary.

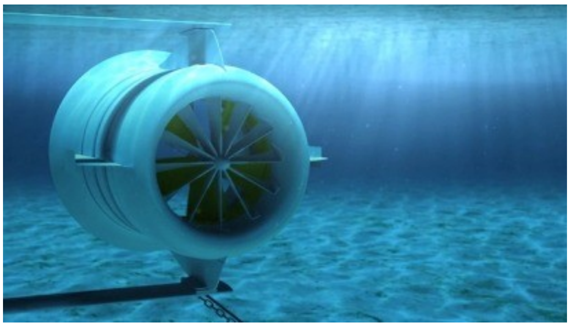


Figure 19(a)

Fixed underwater turbine for electricity generation.

Figure 19(b)

Underwater turbine tethered to the sea bed by cable and free to move in the water current.

Power generated by whichever renewable method is preferred would then be stored in batteries for use at the times required for pumping during the tidal cycle. It is likely that an economical system can be installed using readily available technology, which will have low running costs.

It appears that decommissioning of Fairbourne has been recommended due to a perceived need for huge expenditure after 2055. This is mainly allocated to:

- preventing wave overtopping and storm breaches of the Ro Wen spit by storm waves,
- handling the pumped discharge of river water into the Mawddach estuary.

Whilst a budget of £14 million for flood defences up to the year 2055 appears reasonable, the amount of £115 million after 2055 seems to be an enormous over-estimate. Much of the expenditure included in this sum will be unnecessary, or a more economical solution is readily available.

3. An adaptive engineering approach

An evaluation of the basis on which the decommissioning of Fairbourne was recommended (Haskoning, 2018) indicates that:

- The decision to abandon Fairbourne is based on a worst case prediction of sea level rise. The actual sea level rise is likely to be lower.
- The decision is based on computer modelling of events after the year 2055. This is sufficiently far into the future that considerable uncertainty exists.
- Computer models presented as evidence for the need to abandon Fairbourne can be shown to be incorrect. The persons carrying out the modelling lacked understanding of coastal geomorphology. For example: it was not realised that the shingle storm beach is a dynamic system in equilibrium with marine processes. As sea level rises, the height of the storm beach will also rise naturally as waves throw pebbles onto the upper surface.
- There has been no effort to check the validity of computer models against actual events. The model prediction of flooding due to storm wave overtopping of the Ro Wen spit did not actually occur during major storms in 2020 and 2022.
- Estimates of flood protection costs for the period after 2055 appear to have been massively exaggerated. This is of particular importance, since the main argument for decommissioning Fairbourne is that the cost of flood defences will be unaffordable after this date.

It is of great concern that Gwynedd Council is intending to destroy in excess of 420 homes and businesses and to make over 800 people homeless on the basis of demonstrably unreliable scientific advice. It is stated that no compensation will be paid, but this will clearly be unacceptable to the people affected. It is expected that the matter will be taken to court, and Gwynedd Council is likely to be compelled to pay compensation and reasonable expenses incurred by persons forced unnecessarily to relocate elsewhere. The total cost could be substantial, perhaps in excess of £100 million. There would be very serious consequences if this money had to be taken out of other areas of vital expenditure in Gwynedd, such as health, education or social care.

In view of the unsatisfactory situation which has developed, it seems sensible for the decision to decommission Fairbourne by 2054 to be set aside, and for a new approach to the flood protection of Fairbourne to be considered.

Problems have arisen because the decision to decommission Fairbourne was based on a single worst case flood scenario, which was then deemed unaffordable to defend against. The only solution offered was to demolish the village. The matter has been made worse because much of the modelling, which covers years well into the future, is unreliable.

An alternative approach is to use an **adaptive engineering** methodology. Rather than plan for a single ***worst case*** scenario, adaptive engineering plans for the ***most likely*** scenario. However, a ***plan B*** (and perhaps ***plan C*** and ***plan D***) is held in reserve in case the situation develops in an unexpected way.

In the case of Fairbourne, levels of flood protection would be added as and when necessary. It is not impossible that the village might need to be abandoned at some time in the future if sea level rises by a very substantial amount, but all other reasonable courses of action would have been tried before that decision was finally taken.

The following notes set out a possible adaptive engineering strategy for the flood protection of Fairbourne.

3.1 Flood protection boundary for Fairbourne village

Flood defences for Fairbourne have been reinforced in recent years by Natural Resources Wales. The current defences consist of a series of embankments linking existing landscape features, to produce an enclosure around the Fairbourne and Arthog area. The boundary is marked in fig.20 below.

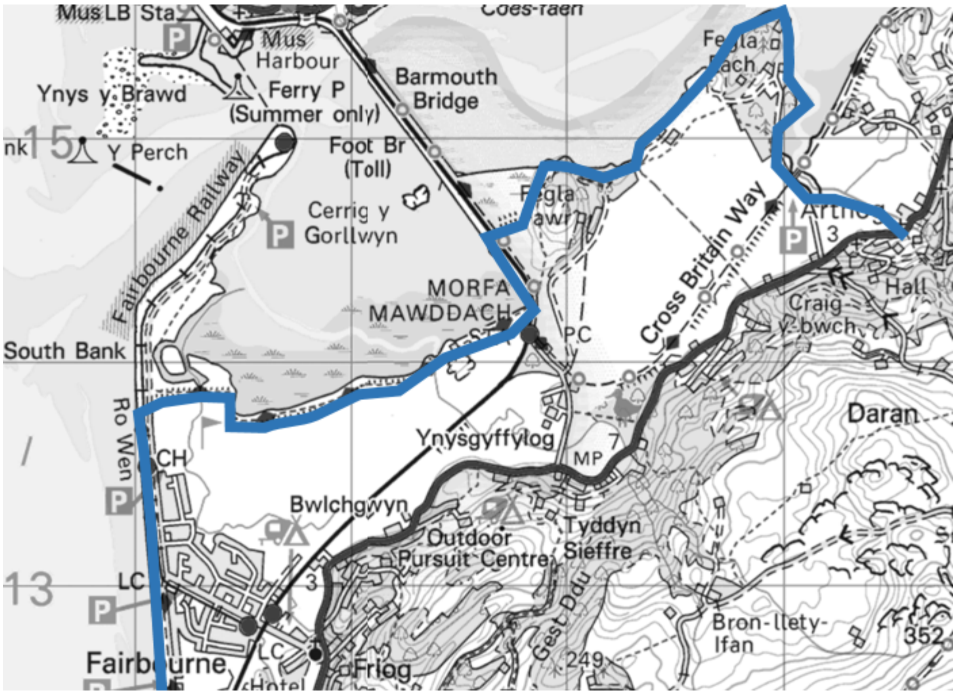


Figure 20: Current flood protection boundary for the Fairbourne and Arthog area.

The current defences are unlikely to adequately protect the village of Fairbourne in the future.

The enclosed area extends for a long distance eastwards to the mouth of the Afon Arthog. Within this enclosure are several streams draining from the hills between Friog and Arthog, the largest being the Afon Henddol at Fairbourne and the Afon Morfa near Morfa Mawddach. These streams must cross the flood protection area and discharge into the estuary through tidal gates.

Any major storm event threatening Fairbourne is likely to produce heavy rainfall over the surrounding mountains, leading to overbank flooding of the streams crossing the coastal lowland and a risk of surface water flooding to the village (fig.21).

Figure 21

Flooding at Arthog following a rain storm. River discharge from the hillside has exceeded the carrying capacity of the stream channel, causing overbank flooding.

An alternative flood protection scheme is proposed for the village of Fairbourne, as summarised in fig.22 below (Hall, 2021). A new and more restricted flood defence boundary would be created.

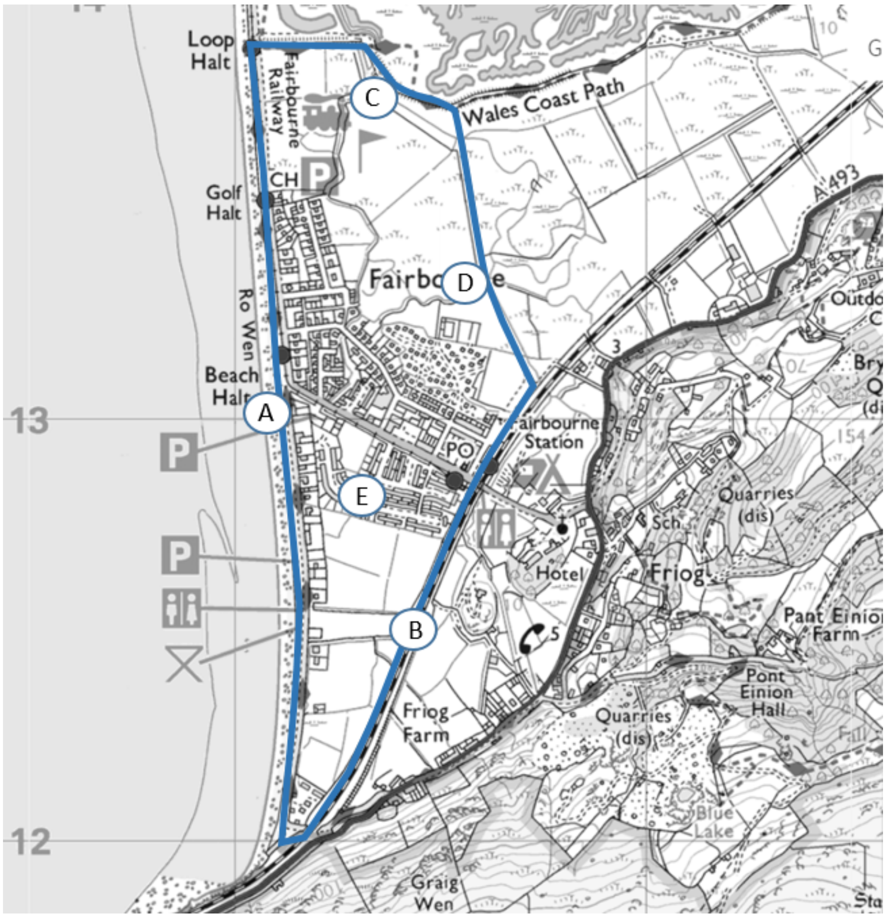


Figure 22

Proposed flood protection boundary for the village of Fairbourne.

- A new flood protection embankment approximately 3m in height (shown as D in fig.22) would be constructed across farmland to connect the existing estuary and railway embankments. This would eliminate any risk of surface water entering the village from farmland to the east. The approximate line of this embankment is shown in fig.23.

Figure 23: Approximate line of the proposed new flood protection embankment which would cross farmland to the east of the village.

- The northern flood protection boundary is formed by a short section of the existing estuary embankment (shown as C in fig.22). An advantage of the proposed scheme is that only this short section would need to be maintained and upgraded in order to provide ongoing flood protection for Fairbourne (fig.24).

Figure 24:

Estuary flood protection embankment north of Fairbourne (shown as C in fig.22 above).

- The Ro Wen shingle storm beach forms the seaward component of the Fairbourne flood protection boundary (shown as A in fig.22).
- The final component of the flood protection boundary is formed by the existing railway embankment, as it descends from the cliff at Friog to the railway station in Fairbourne village (shown as B in fig.22).

The main purpose of the new flood protection embankment to the east of the village is to exclude the Afon Henddol. This will remove any risk to the village during and after storms, when the river may be full and could overflow its banks.

The Afon Henddol currently reaches the estuary through a tidal gate near Fairbourne golf course (fig.25).

Figure 25:

Tidal gate alongside Fairbourne golf club at the mouth of the Afon Henddol, showing the outlet to the estuary

In the proposed scheme, the Afon Henddol would be re-routed eastwards across farmland to join the Afon Morfa, then discharge into the estuary through a shared tidal gate. The existing tidal gate at the golf course would remain in use only as the estuary outlet for the Fairbourne village drainage ditch network. The ditches will carry rainfall from within the Fairbourne flood protection boundary, and water from occasional storm waves overtopping the shingle spit at high tide during storms.

Discharge into the estuary through the tidal gate may not possible during periods of high tide. To avoid any risk of the village drainage ditches filling and overflowing at these times, a water retention pond will be created (fig.26). This will be developed around an existing wetland to the east of the village, and will be connected to the drainage ditch network by an existing river channel.

Creation of the water retention pond and construction of the new flood embankment would run in parallel. Clay excavated from the pond would be used in the construction of the embankment.

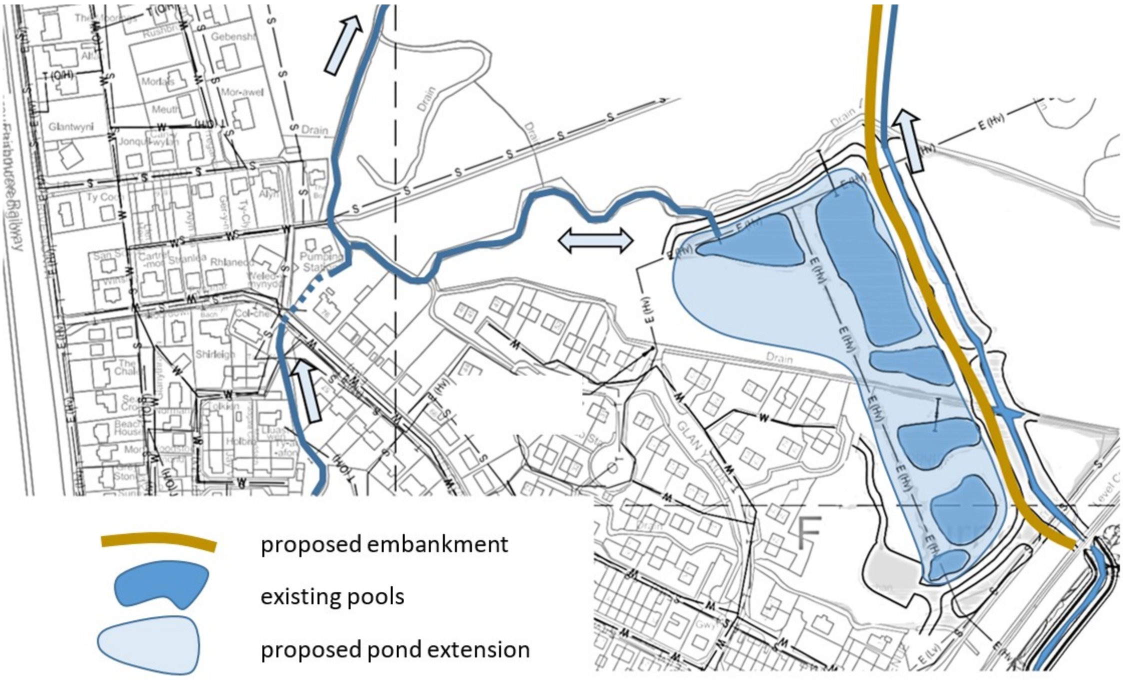


Figure 26: Water retention pond created to the east of the village.

Flood risk to Fairbourne is currently low, but it is recommended that the changes to the flood protection boundary for Fairbourne village outlined above are carried out by the year 2030 as a precautionary measure. The cost of the works is estimated at £10 million.

3.2 Precautionary works at Friog corner

It has been shown that the majority of the Ro Wen shingle spit is stable and at no risk of failure during a worst case storm at the present day. The only area of concern is a small section of the shingle spit in front of the mobile home park at Friog corner, where coastal erosion has taken place in recent years. This culminated in the failure of the concrete sea wall during a storm, inflow of sea water and shallow flooding of the mobile home park and adjacent agricultural land. However, no flooding occurred in Fairbourne village.

Effective repairs to the sea wall were carried out by Gwynedd Council and Natural Resources Wales, including the emplacement of sheet steel piles to prevent water inflow, and the addition of large boulders to dissipate wave energy (fig.27). This work should be very effective in preventing the future infiltration of storm water.

Figure 27

Recently reconstructed sea wall embankment at Friog.

A mechanism for coastal erosion at Friog can be suggested. Waves are refracted into the bay at Friog corner, approaching parallel to the shore. The water mass experiences a rapid change in direction northwards (fig.28). This creates a powerful current along the shore which carries smaller shingle towards Fairbourne, leaving only the larger and heavier material in situ.

Figure 28: Approach of waves at Friog corner, and redirection of the water mass along the spit.

Several years before the failure of the sea wall at Friog, measurements were made of the storm beach pebble sizes at points along the Ro Wen spit (fig.29). It was found that the pebble size at Friog corner was very substantially larger than at other locations.

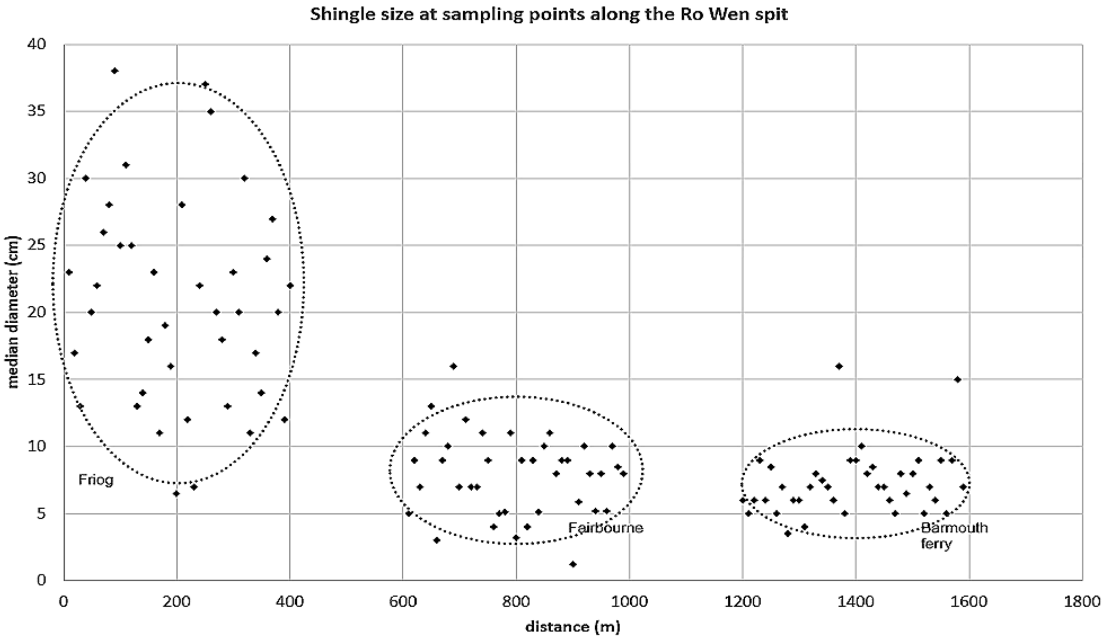


Figure 29: Sizes of random samples of storm beach pebbles at points along the Ro Wen spit.

The removal of smaller shingle caused a steepening of the remaining storm beach at Friog corner. This favoured the plunging type of breaking waves, leading to further storm beach erosion. Eventually, the sea wall was exposed, and this fractured during a storm.

Fracture of the concrete sea wall probably occurred because the wall was inadequately supported on the landward side against wave impact. Shingle had been removed at this point to create a flat area of ground for a group of huts (fig.30). This was probably done during the Second World War, to provide accommodation for troops manning the coastal defences.

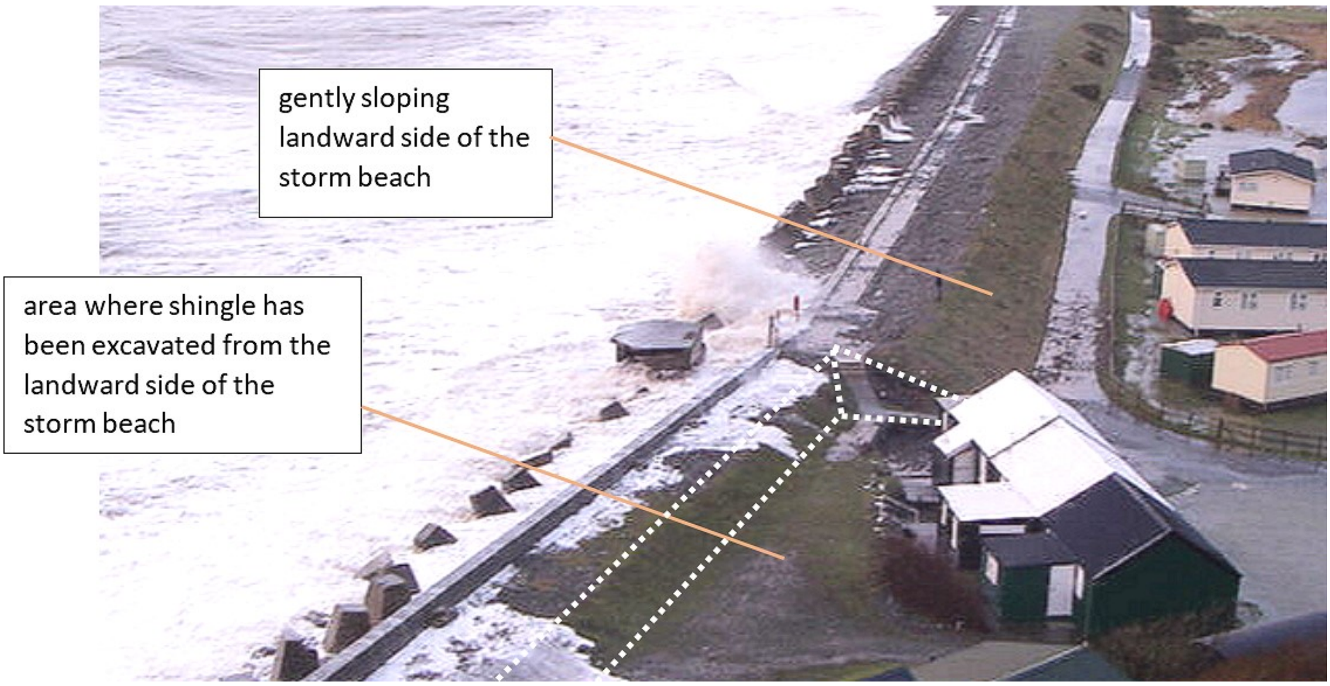


Figure 30: Friog corner under storm conditions, before reconstruction of the sea wall.

The damaged sea wall at Friog corner has been effectively repaired and reinforced, and there is currently no foreseeable danger of another failure occurring. The Ro Wen spit has been observed during and after a series of severe storms over the period from 2020 to 2022. There has been no damage or erosion at any point due to storm waves, and no significant wave overtopping occurred. At no time was there any flooding in Fairbourne village or at the Friog mobile home park. However, precautionary works are recommended at Friog corner to avoid future problems of coastal erosion.

A first step would be to prevent the direct impact of storm waves on the repaired sea wall, and to reduce the scouring action of storm waves as they are deflected towards Fairbourne. This can be done by the construction of a reef along the shore (fig.31). This might consist of boulders, concrete blocks, or other materials which would be stable against wave impact.

Figure 31: Proposed artificial reef to deflect storm waves at Friog corner.

The reef should be emplaced at an angle to the shore line, with the intention of causing storm waves to break and then deflect the water mass northwards along the shore.

A sheltered section of beach will be created behind the reef. It is recommended that shingle is brought from the northern end of the Ro Wen spit (fig.32) and deposited in this area, where wave action will carry it onto the shore and build up a new storm beach against and above the rock armour of the repaired sea wall. It is likely that any shingle removed from the end of the spit will be replaced naturally by longshore drift.

Figure 32: Shingle accumulations at the northern end of the Ro Wen spit.

Urgent attention should be given to restoring the landward profile of the storm beach at Friog corner, to provide mechanical support to the sea wall when impacted by storm waves. It is recommended that the huts at this point are relocated further from the sea wall, and the landward slope built up with rock material. Slate waste, available locally, would be suitable for this purpose as it contains a large amount of clay which would prevent any infiltration of sea water beneath the sea wall during high storm tides.

If these precautionary works are carried out, there should be negligible risk of a failure of the sea wall occurring within the next century. The cost of the proposed works at Friog corner is estimated to be £3.5 million.

3.3 Maintenance of the seaward boundary of the Fairbourne flood defence area.

The shingle spit between Friog and Fairbourne golf course should be monitored at regular intervals and after major storm events, looking particularly at the extent of wave overtopping during storms. If wave overtopping becomes a problem, this could be handled in two ways:

- The concrete cap wall (fig.33) along the affected section of the storm beach could be raised by perhaps 1m. This would prevent sea water travelling over the crest of the shingle bank, and would also encourage the accumulation of further shingle against the wall.

Figure 33:

Cap wall constructed alongside the original sea wall to provide extra protection from overtopping waves. Notice the accumulation of shingle against this structure.

- A French drain could be emplaced along the base of the landward embankment (fig.34). The drain would collect overtopping water and direct it into the village drainage ditch network.

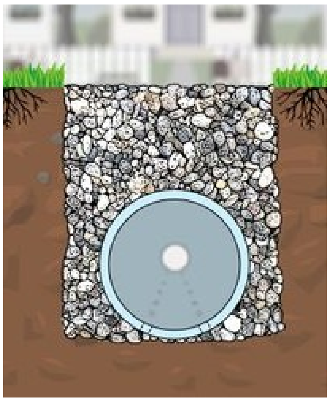


Figure 34: (left) French drain, constructed from a slotted pipe buried in a gravel filled trench. (right) Possible location for a drain, along the grass verge between the road and narrow gauge railway.

A contingency budget of £2 million should be allowed for possible works this century to control wave overtopping of the Ro Wen storm beach around Fairbourne village.

3.4 Estuary embankment and tidal gates

Computer modelling based on a worst case sea level rise and storm tidal surge for 2055 (Hall, 2021) indicates that the estuary flood embankment would not be overtopped. Beyond that date it may be necessary to raise the height of the short section of estuary embankment between the Ro Wen spit and the new flood embankment to the east of Fairbourne village. An increase in height of 1m is suggested.

A large expanse of salt marsh has developed behind the Ro Wen spit. This extends from the estuary embankment to the mouth of the Mawddach estuary. At some times of the year, the salt marsh is used for grazing sheep (fig.35).

Figure 35

Salt marsh on the seaward side of the estuary flood embankment.

The embankment can be seen in the left middle distance.

Wave energy is dissipated as water flows over the salt marsh vegetation, so that the estuary embankment is not subject to erosional wave action. The embankment is constructed from earth and clay, faced with grass, and shows no signs of wave damage. The height of the embankment could therefore be safely raised by the addition of earth or slate waste on the upper flat surface (see fig.24 on page 18 above).

The cost of raising the required section of the estuary embankment is estimated to be £1 million. This work would be required at some time after 2050, depending on the actual sea level rise which occurs.

The Fairbourne drainage ditch network and water retention pond will discharge into the estuary through the tidal gate at Fairbourne golf club (see fig.25 on page 18 above).

As sea level rises, the period during each tidal cycle when water can be released into the estuary by gravity flow will reduce. If sea level rise reaches 1m above present day levels, it is likely that drainage will be inhibited for several days each month during neap tides, when the water level does not drop as far as normal. Occasional pumping may become necessary by the end of the century. Electrical power could be generated locally from a renewable source such as a wind or tidal turbine. Power would be stored in batteries for use at the times required by the tidal cycle.

An electric pump of standard design would be installed alongside the tidal gate at the outlet of the Fairbourne drainage ditch network.

An amount of £2.5 million should be allocated for the installation of an electrical generating, power storage and pumping system. This work would be required at some time after 2090, depending on the actual sea level rise which occurs.

3.5 Modification of the flood protection boundary at Friog

For most of its length, there is no conceivable risk of the Ro Wen spit being breached by storm waves due to its massive width and considerable height above high tide level (fig.36).

Figure 36: View along the Ro Wen spit, Fairbourne showing the considerable width of the storm beach and landward embankment.

The only weak section of the shingle spit is at Friog, where repairs have recently been necessary. The rebuilding of the sea wall was completed successfully, and no further failure of the sea wall or shingle spit at Friog is expected. A contingency plan can, however, be put in place in the event of such a failure re-occurring. This would involve reducing the extent of the Fairbourne flood protection area to exclude Friog (fig.37).

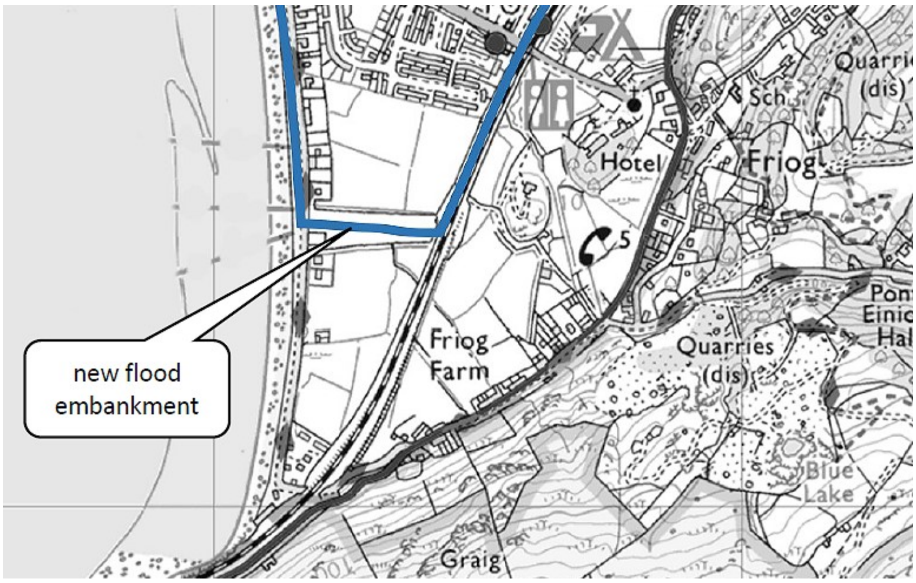


Figure 37

Reduction of the Fairbourne flood protection area by construction of a new embankment north of Friog.

The approximate location of the flood protection embankment is shown in fig.38. This would be an earth embankment approximately 3m in height which would connect the railway embankment to the shingle storm beach. The road is already above the level of the surrounding fields, so would only need to be built up with a small ramp to cross the flood embankment.

Figure 38: Location of a flood embankment which might be constructed in the event of further problems of coastal erosion at Friog corner.

It may be necessary to relocate the mobile home park and some agricultural buildings to land north of the new embankment, and several houses may need their own flood defences, but the principal objective of protecting Fairbourne village would be met.

An estimated cost for these works, if required, would be £2 million.

3.6 Tidal barrage

Tidal flooding currently affects a number of locations around the Mawddach estuary apart from Fairbourne, and is likely to increase in severity and frequency with climate change. This will threaten main roads and other vital infrastructure, and will present a significant risk to homes and businesses.

Figure 39: Tidal flooding of the A496 at Glyndwr, between Barmouth and Bontddu.

A suggestion has been made (Hall, 2022c) to construct a tidal barrage across the mouth of the Mawddach estuary between the Ro Wen shingle spit and Barmouth harbour. This would prevent the inflow of extreme high tides and eliminate tidal flooding in the lower Mawddach valley. The barrage would be equipped with turbines to generate electricity during the rising and falling tidal phases.

Figure 40: An impression of the tidal barrage linking the northern end of the Ro Wen shingle spit (right) to Barmouth harbour (left).

The Mawddach estuary forms the sea outlet for several large rivers (fig.41), and the water discharged from these rivers will increase the power generation potential of the tidal barrage.

Figure 41

Afon Mawddach in Coed y Brenin, north of Dolgellau.

Averaged over the long expected lifetime of the tidal barrage, electricity is likely to be produced at a cost comparable to wind generation and more cheaply than nuclear power.

A tidal barrage would eliminate any flood risk to Fairbourne from high water levels in the Mawddach estuary. It would also provide other benefits to the Fairbourne area by providing a direct road connection to Barmouth.

A cost benefit analysis, taking into account the generation of a large amount of renewable energy over a long period of time and the reduction in flood risk for the whole of the lower Mawddach valley, suggests that the project is worthy of consideration.

3.7 Flooding in Fairbourne

It is possible, despite one or more of the flood protection measures outlined above being implemented, that Fairbourne village does at some future date experience flooding. It is unlikely that this would occur during the current century, as a considerable rise in sea level and storm intensity would be necessary to overwhelm the current defences.

If Fairbourne were to flood, even the most extreme models presented in the publication 'Fairbourne Preliminary Coastal Adaptation Masterplan' only predict a maximum water depth of 0.6m within the village, which is a little over knee deep. Although obviously causing considerable property damage, this is unlikely to be the threat to life which some more sensationalist publications such as 'Fairbourne: A Framework for the Future' have suggested.

One single flood event should not necessarily require the village to be abandoned and demolished. If such a policy was implemented around the whole of the Welsh coast, the financial consequences would be catastrophic. Fairbourne could recover from an isolated flood event, although further emergency measures might be put in place to prepare for a future possible flood.

As a precaution, an emergency flood refuge could be constructed in a central location within the village, for example: adjacent to the village hall. The building could be of a modern architectural design similar to the newly constructed retail units in Borth shown in fig.42.

Figure 42

Possible design for a flood refuge.

The building would have an upper floor well above the height of any possible flood. The lower floor would house a garage for a rescue tractor which could tow a boat trailer.

In the event of a flood, an alarm would be sounded, and village residents could quickly move to the refuge. Elderly or disabled persons could be collected by the tractor and boat if required. Everyone would then remain in the safety of the refuge until the flood receded.

It is inconceivable that a flood could develop so quickly that there was insufficient time for residents to evacuate to the refuge.

There would be an opportunity for the upper floor of the building to be franchised to a commercial operator, for example: for use as a restaurant or café bar. This would have excellent panoramic views across Cardigan Bay, and would form an attractive tourist venue. The terms of the franchise would stipulate that the building would be made available immediately to the village in the event of a flood emergency.

Arrangements could be made for local volunteer flood wardens, who would assist village residents to the refuge during an emergency. An annual practice event could be held, to ensure that residents were aware of the actions to take if the warning alarm was sounded.

Various designs of flood barrier are commercially available for individual buildings, as for example in fig.43.

Figure 43

Removable flood barrier for a house doorway.

With adequate flood protection measures in place, the residents of Fairbourne might be prepared to live with the occasional flood every few years. Only if flooding became a regular occurrence, would abandoning the village be a preferred option.

4. Summary

A recommendation was made by the civil engineering company Royal Haskoning that Fairbourne village should be abandoned by the year 2054. This recommendation was made on the assumption that protection of the village from flooding after this date would require an expenditure of £115 million, which was not affordable.

Examination of the basis for Royal Haskoning's calculations showed that the estimated expenditure was based on a worst case scenario for sea level rise, and computer modelling had then been used to forecast the maximum extent of flooding possible in Fairbourne. However, it can be shown that the computer models are based on inaccurate data and a lack of understanding of the coastal processes affecting the Ro Wen shingle spit. Large amounts of money allocated to protect the village from storm wave overtopping and a catastrophic breach of the shingle storm beach are unnecessary. A further large sum has been allocated for pumped discharge of drainage water into the estuary. This appears to be a massive over-estimate, and a much more economical solution is available.

It is of great concern that Gwynedd Council is intending to destroy in excess of 420 homes and businesses and to make over 800 people homeless on the basis of demonstrably unreliable scientific advice. It is stated that no compensation will be paid to residents forced to leave their properties.

In view of the unsatisfactory situation which has developed, it seems sensible for the decision to decommission Fairbourne by 2054 to be set aside, and for a new approach to the flood protection of Fairbourne to be considered.

Problems have arisen because the decision to decommission Fairbourne was based on a single worst case flood scenario, which was then deemed unaffordable to defend against. The only solution offered was to demolish the village. The matter has been made worse because much of the modelling, which covers years well into the future, is unreliable.

An alternative approach is to use an **adaptive engineering** methodology. Rather than plan for a single ***worst case*** scenario, adaptive engineering plans for the ***most likely*** scenario. However, additional options are held in reserve in case events develop in an unforeseen way.

A suggested flood protection strategy is summarised in fig.44. Possible flood risks to Fairbourne come from the sea, the Mawddach estuary, surface water from the coastal lowland to the east of the village, and from the Afon Henddol which descends from the hills to the south.

The key component of the strategy is to reduce the size of the Fairbourne flood protection area by building a new embankment across agricultural land to the east of the village. This will exclude the Afon Henddol and prevent any risk from river flooding during a storm event over the mountains. A further benefit will be that only a short section of the estuary embankment between the Ro Wen spit and the new embankment will then need to be maintained and upgraded to order to protect Fairbourne.

Successful repairs have been carried out to the sea wall at Friog, and there is currently no risk of failure. However, precautionary works are recommended to reduce any further coastal erosion. An offshore reef would be constructed, and shingle replenished in the sheltered beach area behind the reef. Work should be carried out to reinstate the landward profile of the storm beach, which has been excavated to produce flat ground for a group of huts.

Monitoring of the Ro Wen spit should continue, particularly during storms. If problems of wave overtopping are identified, remedial action can be taken to prevent any risk of surface water flooding in the village. The concrete cap wall of the storm beach could be raised by 1m in affected areas, and a French drain may be installed to direct overtopping water into the village drainage network.

No overtopping of the estuary embankment is expected up to the year 2050. Beyond that time, depending on actual sea level rise, it may be necessary to raise the level of the embankment by 1m around the north of Fairbourne village.

Discharge of drainage water into the estuary should be possible by gravity flow alone until at least the year 2090. Beyond that time, depending on sea level rise, pumping may be necessary at some times of the month. An electric pump should be installed alongside the tidal gate, along with a wind or tidal generator and electrical storage battery.

At some time this century, there is the possibility that a major project might go ahead to construct a tidal energy barrage across the mouth of the Mawddach estuary. In addition to generating energy, the barrage would protect the whole of the lower Mawddach valley including Fairbourne from estuary flooding.

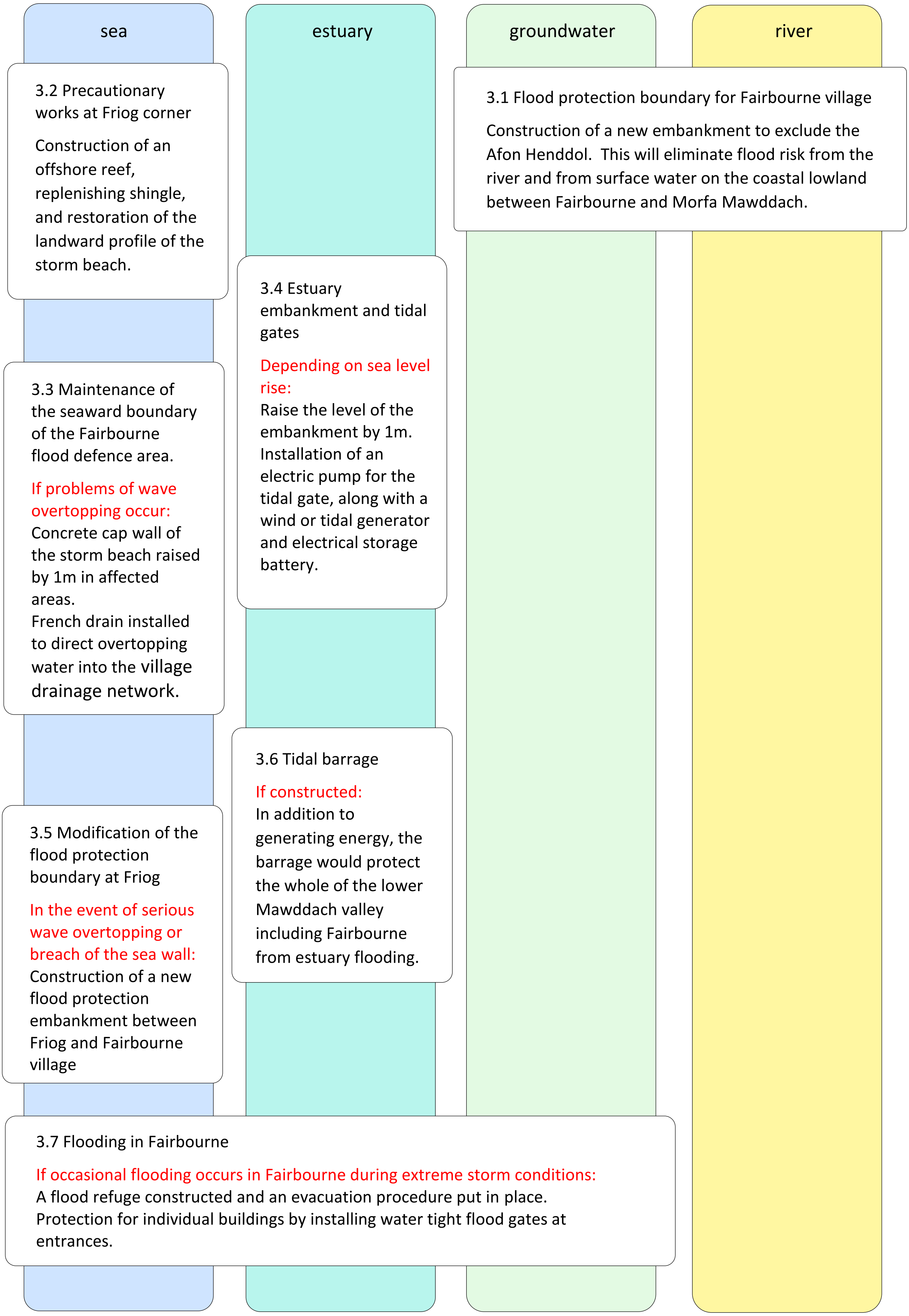


Figure 44: Adaptive engineering flood protection strategy for Fairbourne.

If, despite the flood control measures discussed above, flooding occurs in Fairbourne village then there are several actions which could be taken before abandonment of the village is considered.

There is a possibility that further coastal erosion at Friog could cause excessive wave overtopping or breach of the sea wall. If this problem should arise, a solution would be to construct a new flood protection boundary embankment across agricultural land between Friog and Fairbourne village, so that sea water entering at Friog cannot reach the village.

If occasional flooding occurs in Fairbourne during extreme storm conditions, several measures might be taken. A flood refuge could be constructed and an evacuation procedure put in place to transport people to the refuge if necessary during an emergency. Protection for individual buildings could be provided by installing water tight flood gates at entrances.

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