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Source: Journal of Coastal Research, 36(sp1) : 622-633

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/1551-5036-36.sp1.622

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Journal of Coastal Research	SI 36	622-633	(ICS 2002 Proceedings)	Northern Ireland	ISSN 0749-0208

Monitoring and Management of the Northern Ireland Sea Defences using a Risk Based Apppoach

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ABSTRACT

This paper describes the development of a monitoring and management system for designated sea defences in Northern Ireland, which are managed by the Rivers Agency of the Department of Agriculture and Rural Development. The system developed was termed a "Management Response System" and includes a comprehensive monitoring regime combined with proposals for assessing the condition and performance of the sea defences.

The designated sea defences are at various locations in Lough Foyle, Belfast Lough, Strangford Lough, and at Killough, on the Irish Sea coastline. These defences protect extensive areas of low lying agricultural land, residential properties, and other various assets such as airports, the Belfast to Londonderry railway line and an army base. The study indicated that a breach of these sea defences would cause extensive flooding.

The long-term objective of Rivers Agency is to monitor, maintain, upgrade, and strengthen their sea defences. The development of this monitoring and management system aims to adopt "Best Practice" in terms of sea defence asset management.

Monitoring is often seen as an activity that is supplementary to managing sea defences. In fact, monitoring is a primary means of managing flood risk. In undertaking this study the aim was to ensure that the need for monitoring was based on an appreciation of flood risk. Moreover, monitored information should not just be collected but should be used to inform management decisions regarding flood risk. It is often this feedback loop that is missing when monitoring is considered in isolation to the overall management of sea defences.

The study assessed the flood risk associated with the sea defences and also defined how this risk is managed, the 'Management Response'. This information was then used to define a comprehensive monitoring regime including visual inspections, structural surveys, site surveys, and environmental monitoring. The system recommends that an annual review report should be completed to summarise the results obtained and recommend further monitoring and remedial works for the following year's monitoring programme. This annual review will also inform management decisions on the need to upgrade the sea defences.

During the short period for which the system has been implemented to date, the conclusions drawn indicate that the management response system does provide an effective means of managing the designated sea defences within Northern Ireland. The monitoring has been targeted based on flood risk, and the monitoring results are used to assess the need for capital and maintenance works. Comparison of the system with published monitoring recommendations from agencies in the UK, Europe and the USA indicate that the system represents "Best Practice".

ADDITIONALINDEXWORDS: *Sea defence Monitoring, Management Response System, Drainage (Northern Ireland) Order 1973,*

INTRODUCTION

Northern Ireland Sea Defences

The Rivers Agency of the Department of Agriculture and Rural Development for Northern Ireland is responsible for the operation and management of the sea defences, which are designated under the Drainage (Northern Ireland) Order 1973.

The designated sea defences comprise four earth embankment structures located along the southern shoreline of the Lough Foyle Estuary and six defences located at various locations around the County Down coastline.

The Lough Foyle sea defences, (Figure 1), comprise some 20km of earth embankments located at two distinct locations along the southern shoreline of the Estuary. The Black Brae and Longfield defences are located at the

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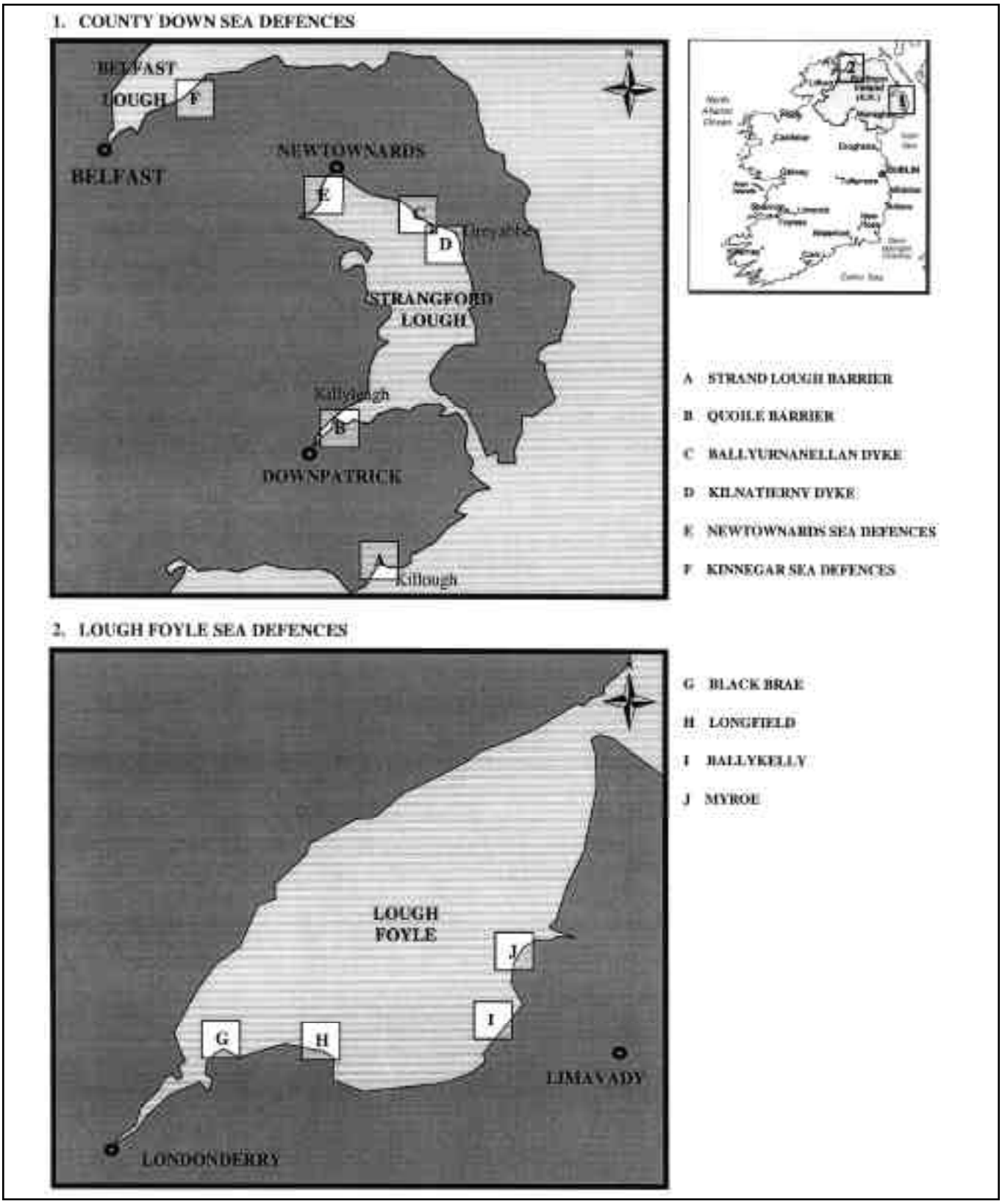


Figure 1 Study area locations.

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southern end of the estuary close to the mouth of the River Foyle. The Ballykelly and Myroe defences commence at a distance of approximately 6km to the east of the Longfield defence and are located at the northern end of the estuary, close to estuary's narrow mouth to the open seas of the Atlantic Ocean. Lough Foyle is tidal and the defences are subject to storm surges and locally generated waves.

The County Down sea defences vary significantly in construction form and are more dispersed around the coastline, refer to Figure 1. The longest of the County Down sea defences is located at the northern end of the Strangford Lough estuary and extends from Newtownards to Island Hill, near Comber, a distance of 4.6km. This defence is principally an earth embankment of up to 4m in height, but includes a number of differing construction forms. The northern 1.6km section, which protects the town of Newtownards, has recently been upgraded with new rock revetments and sheet piled cut-off walls.

Two sea defences are located at Greyabbey on the eastern shoreline of Strangford Lough, which is an internationally recognised and designated marine nature reserve. These defences comprise two separate rock protected earth embankments, which extend for a total distance of approximately 1 km and protect low lying farmland and bird habitats.

The Quoile Pondage is located at the southern end of Strangford Lough and provides flood protection to the town of Downpatrick, the Quoile Pondage and Nature Reserve and the surrounding low lying land. This sea defence comprises two principal elements viz, a stone pitched earth embankment at the eastern side of Hare Island and a reinforced concrete barrier structure with sixteen tidal flap gates to the west of Hare Island.

The Strand Lough Barrier is located between Killough Harbour and Strand Lough and provides flood protection to the town of Killough. The structure is constructed as a reinforced concrete barrier with four structural steel counterbalanced flap gates to prevent tidal flooding.

The final designated sea defence in County Down is located at Kinnegar on eastern shores of Belfast Lough. This defence protects a small low lying residential area and comprises a sloping armoured rock revetment.

Background to this Study

During the past two decades the Rivers Agency have undertaken a number of feasibility studies and capital upgrading works for their designated sea defence stock. Monitoring programmes have been developed and implemented for some defences. For example at Lough Foyle the Rivers Agency has previously implemented monitoring programmes aimed at scheduling maintenance works and providing management information for the capital works programme.

In April 1999 the Rivers Agency appointed WS Atkins to undertake a monitoring feasibility study for all of the designated sea defences within Northern Ireland. The key objectives of this study were to review the existing condition of the sea defences and develop a common Monitoring and Management Response System. The aims of this monitoring and management system were to provide a management tool for scheduling monitoring and maintenance through to programming capital upgrading works.

STUDY METHODOLOGY

Approach to the Study

The principal aim of the study was to develop a comprehensive monitoring and management system, which was common to all of the designated sea defences, and provided information for the effective management of the sea defence assets.

In keeping with the recommendations from the Department of the Environment, Food and Rural Affairs (DEFRA) in their publication (MAFF, 2000) FCDPAG4, Flood and Coastal Defence Project Appraisal Guidance – Approaches to Risk, the management system for the Northern Ireland sea defences was developed using a risk based approach.

Given that the sea defences generally protect farmland and rural assets the Rivers Agency do not operate a formal flood warning system. The management system therefore only considers wider issues of monitoring and management actions, whilst implementing "best practice" in terms of sea defence asset management.

Monitoring is an essential tool for managing coastal and flood defences. As a minimum it is used to identify defects and hence schedule further monitoring and maintenance works. Monitoring can also be used to measure the performance of flood defences and to inform decisions concerning the need and priority for capital upgrading works. In this respect, it may be regarded as a means of managing flood risk.

The requirements for the monitoring system are to:

- Inform management decisions regarding emergency, maintenance and capital works
- Provide early warning of failure so that appropriate emergency action can be taken
- Measure the performance of the existing defences
- Provide information concerning environmental conditions

The detailed methodology for the study is presented in Figure 2 and details are outlined below.

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Asset Review

The asset review comprised the detailed assessment of each sea defence in the terms of:

- Structural form and construction history
- Detailed condition assessment of the sea defences at the present time
- Coastal Processes – Tidal levels and extreme water levels, wave climate and joint probability analysis of waves and water level occurrence
- Lough morphology and historical changes
- Defence backpond drainage
- Ground conditions
- Geotechnical and structural failure mode
- Potential flooded areas and assets protected

The principal aim of the asset review was to establish detailed information for each sea defence to allow the risk management and monitoring system to be developed. This information would also provide the baseline data by which all future assessments are measured.

The asset review was conducted in two principal stages, viz site based visual assessment and a desk study review of the existing feasibility reports (WS ATKINS, 2000; RIVERS AGENCY, 1996; FERGUSON MCILVEEN, 1995, MOTT MACDONALD, 1994; WDR and RT TAGGART, 1993) and historical records.

Structural form and construction history

The assessment of the structural form of each sea defence and the construction history is the essential first stage of the assessment. This information was generally collected from the previous Feasibility Study reports (WS ATKINS, 2000; RIVERS AGENCY, 1996; Ferguson McIlveen, 1995, MOTT MACDONALD, 1994; WDR and RT TAGGART, 1993) and provides outline engineering information for the following stages of the study, risk assessment and the monitoring and management system.

Knowledge of the construction history was essential, as it set the context for building the defences and highlighted problems with the original construction in terms of flooding potential, defects and overtopping risk. In particular, knowledge of the construction history was important for the Lough Foyle sea defences as the earth banks were constructed on thick layers of soft alluvial silts and clays, which are liable to long term consolidation settlement.

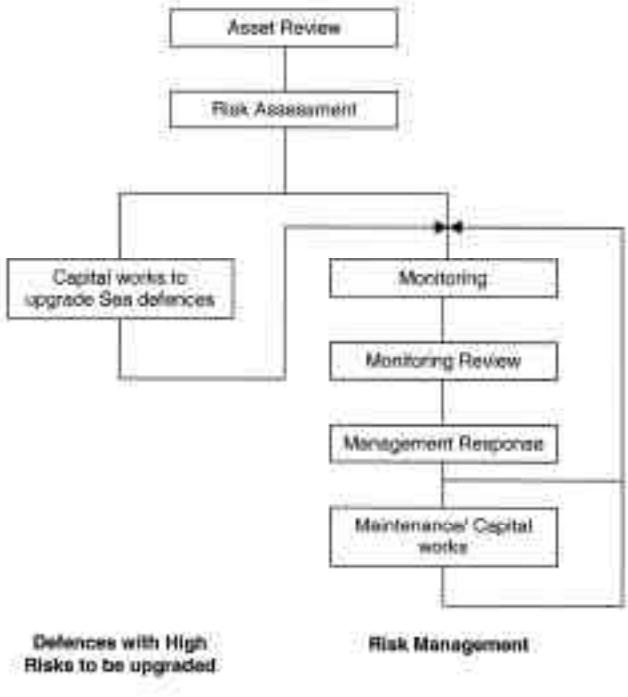


Figure 2. Feasibility Study Methodology Flowchart

Detailed condition assessment of the sea defences at the present time

A detailed visual assessment of the general condition of each sea defence was undertaken at the commencement of the project. This information was vital as it provided detailed information on the current condition of the defences, current defects and information on the general degradation of the structure with respect to time.

Detailed geometric and level surveys and some structural surveys were also undertaken at the most of the defences.

This information would be used as the baseline for future surveys and was recorded on standard asset survey sheets. Figure 3 presents a typical cross section for the Kinnegar sea defence in County Down, which was included on the asset record survey sheet for this defence.

Coastal Processes – Tidal levels and extreme water levels, wave climate and joint probability analysis of waves and water level occurrence

The detailed assessment of the tidal levels and prediction of the extreme water levels, including an allowance for sea level rise, was undertaken for each sea defence. This assessment was essential to provide information for the assessment of the potential structural and geotechnical

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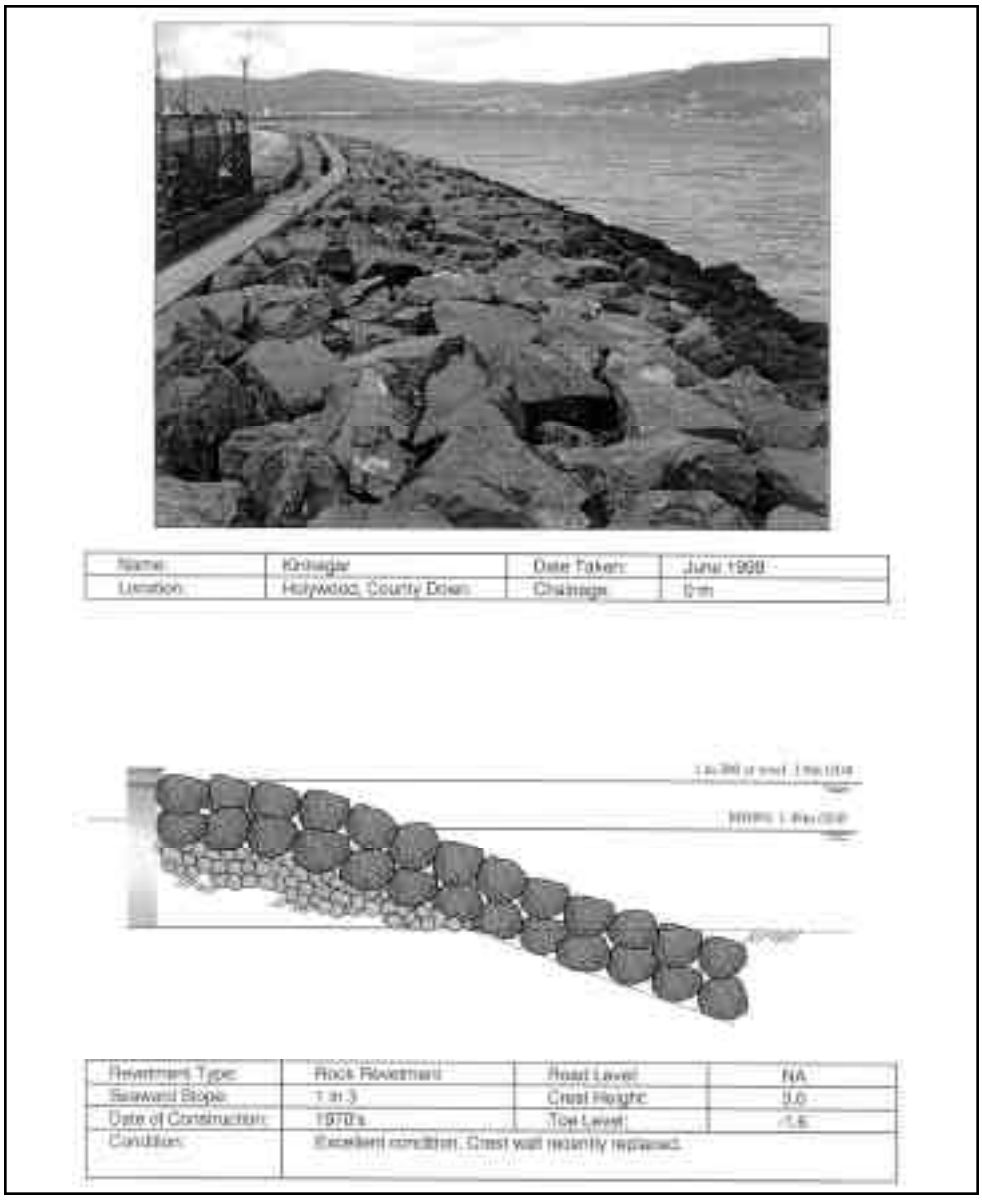


Figure 3. Typical Asset Data Sheet

failure modes and hence the assessment of the performance of the defence and the standard of protection provided.

Historical tidal records were not available for each sea defence and therefore had to be estimated from the closest standard port with the appropriate corrections being applied. This assessment provided a good first order estimate of the anticipated levels and led to the recommendation to undertake tidal monitoring at sites where overtopping or structural instability may be a concern.

In addition, the wave climate was assessed at the location of each sea defence using hindcasting techniques from extreme wind speeds. The wave climate data was used both directly and within the joint probability analysis for the assessment of overtopping and the potential structural and geotechnical failure modes of each defence.

Lough morphology and historical changes

Given the general nature of the sea defences, earth embankments and reinforced concrete barriers, the structures are sensitive to erosion of sea bed levels which could cause undermining of the front toe of the defence.

The asset review therefore included an investigation of historical mapping of the foreshore area to assess previous variations in the sea bed level. In addition, the relevant coastal processes were investigated to determine the likelihood of future toe erosion at each defence.

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Sea defence backpond drainage

The land protected by the Lough Foyle sea defences is generally located below the mean high spring tide level (MHWS) and in many cases is located at approximately mean tide level. Rainfall run-off from the protected lands and the upland areas beyond the Belfast to Londonderry railway line is collected in the backpond drains, which are located directly behind the defence.

These backponds are considered to be critical as the water level will have a significant influence on the stability of the rear slope of the earth embankment. Additionally, the backpond outfalls could provide a potential backflow route for tidal flooding and locally generated waves within the backponds have caused minor erosion of the pond side slopes.

Similar backpond conditions exist at the Greyabbey and Quoile sea defences in County Down. However the water level is not considered to be as critical to the overall stability of these defences given the relative levels of the earth embankment and the backpond water level.

Ground conditions

The nature of the sea defence construction, environmental loading (tidal and wave conditions), recent upgrades to the construction and operation of the defences, results in the assessment of the ground conditions being critical.

The programme of sea defence study and upgrading undertaken by the Rivers Agency has resulted in an extensive database of ground investigations for each sea defence. A desk study assessment of these reports was undertaken.

Assessment of the ground condition data indicated that the Lough Foyle sea defences were constructed from locally available material and that the upgrading works of the 1950's used material excavated from the backpond to reinforce the rear slope of the defence. The defences are therefore generally constructed from very soft to soft silty clayey alluvial soils, which would be susceptible to erosion by water, tidal and wave action.

These soft alluvial soils extend for a considerable depth below the structure and as such the defence may be susceptible to long term consolidation settlement.

Given the dispersed locations of the County Down sea defences, the ground conditions vary considerably. The assessment identified that similar ground conditions to those experienced at Lough Foyle exist at the Newtownards sea defences. However, the sea defences at Strand Lough and Quoile are founded on inter bedded layers of firm to stiff clays and medium dense to dense sands and gravels.

The results from this assessment are utilised in the geotechnical and structural failure mode assessment.

Geotechnical and structural failure mode

Identification of the potential geotechnical and structural failure modes was undertaken for each sea defence. The purpose of this assessment was to analyse the structural form of the defence using the detailed information outlined above. This assessment highlighted that the following failure mechanisms could potentially occur:

- Frontal Erosion and loss of armour/ stone pitching protection
- Piping/ internal erosion
- Pore water pressure build up
- Settlement, including consolidation
- Slope stability, including gravitational slips of both the front and rear slopes
- Overtopping
- Sliding/ overturning failure
- Toe erosion/ undermining
- Structural failure
- Tidal flap gate failure
- Backpond drainage levels variation causing some of the stability problems noted above

Once identified, these potential failure modes could be assessed in terms of the risk of their occurrence. Details of this assessment are presented below.

Flooded areas and assets protected

The designated sea defences typically protect low lying farmland and other rural assets. However urban population centres are protected by the Newtownards and Quoile sea defences and the Lough Foyle sea defences protected assets which include the Belfast to Londonderry railway line, an army base and an airport. The Quoile sea defences also protect the Quoile Pondage, which is an area of significant conservation interest

As part of the study the potential flood areas were mapped on the basis of a significant breach of the defence. This flood mapping was based on the results of topographic surveys, Ordnance Survey mapping and mapping included within the previous Feasibility Study Reports (WS Atkins, 2000; Rivers Agency, 1996; Ferguson McIlveen, 1995, Mott MacDonald, 1994; WDR and RT Taggart, 1993). Table 1 summarises the assets protected by each of the designated sea defences.

The flood mapping and asset review, as presented in Table 1, demonstrates that the sea defences in Lough Foyle and at Newtownards and Quoile protect high value assets.

RISK ASSESSMENT

In keeping with the recommendations from the Department of the Environment, Food and Rural Affairs

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(DEFRA) in their publication (MAFF, 2000) FCDPAG4, Flood and Coastal Defence Project Appraisal Guidance – Approaches to Risk, the management system for the Northern Ireland Sea Defences was developed using a risk based approach.

The principal objective of the risk assessment was to identify the hazards and prioritise the risks for each defence, hence allowing the sea defence monitoring strategy to be developed to address the areas of highest concern. The risk assessment process reviewed the likelihood of the hazard occurring and the potential consequences of its occurrence. Risk is defined as likelihood multiplied by consequences of the hazard occurring.

The first stage of the risk assessment process used all of the data collected within the asset review to assess the applicability of the potential failure modes for each designated sea defence. To demonstrate this a summary of this first stage assessment for the County Down sea defences is presented in Table 2.

The second stage of the risk assessment process was to identify the likelihood, or probability, of the failure mode (hazard) occurring. Given that the principal aim of the overall study was to develop a sea defence monitoring strategy, it was decided to use a simplified hazard assessment matrix to allow a qualitative assessment of low, medium and high risks. This qualitative assessment was based on information obtained from the asset review on the present condition of each sea defence. Table 3 presents the hazard assessment results for the County Down sea defences.

Assessment of Table 3 indicates that the sea defences at Greyabbey are classified as having high risk for all potential failure modes. However, when the degree of risk is considered in parallel with the consequences of a breach, i.e. flooding of poor quality farmland, the overall risk assessment allocates a low priority in terms of future monitoring and management. Contrary to this is the risk assessment for the sea defences at Newtownards, which have been recently upgraded, and Quoile and Strand Lough where the hazards are assessed as generally low to medium risk. The significance of the consequences of potential failure resulted in these defences being designated as medium to high. Hence, the proposal to implement higher levels of monitoring at these defences.

The risk assessment process outlined above was also undertaken for the Lough Foyle sea defences. The results of the hazard assessment indicated that most results were in the medium to high band and when combined with the more significant consequences of a breach, the risks assessment determined a moderate to high risk. Hence, the proposal to implement a more comprehensive monitoring system across all of the Lough Foyle sea defences.

This approach gives a good appreciation of the potential problems associated with the sea defences, their general standard of protection and provides a simplistic means of targeting the monitoring programme to the areas of most concern.

It is however possible to extend this hazard and risk assessment to a more detailed analysis and fault tree approach such as that recommended in the UK DEFRA publication (MAFF, 2000) "FCDPAG4 - Approaches to Risk". This more detailed assessment could be considered in five - seven years when a sufficient databank of monitoring results has been collected.

MONITORING SYSTEM

Review of Existing Monitoring Regime

The monitoring programme previously implemented by the Rivers Agency for all of the designated sea defences generally varied for each sea defence and consisted primarily of regular (weekly – annual) inspections. The principal aim of these inspections was to schedule maintenance works, but it also provided management information for capital upgrading works.

A previous feasibility study developed a more detailed monitoring regime for the Lough Foyle sea defences. This programme was principally designed to measure the performance of the upgraded sea defences at Myroe, where there was a particular concern with post construction settlement and slope stability.

At the present time an environmental monitoring contract is also in progress at Newtownards in Strangford Lough, where the sea defences are being upgraded. This programme was designed to measure both pre and post construction impact on the highly designated foreshore.

Monitoring Recommendations

The results of the asset assessment and particularly the sea defence risk assessment process identified the need for general monitoring and in particular the locations where more detailed monitoring should be targeted.

The feasibility study identified that the key monitoring tasks were:

- Visual walkover condition assessments (including weekly to 10 yearly assessments)
- Structural assessments (Rock armour and structural assessments of barriers)
- Geometric survey and sea bed level monitoring
- Environmental monitoring

The recommended monitoring programme for the County Down sea defences is presented in Table 4

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Table 1. Northern Ireland Sea Defences - Assets Protected

Location	Assets Protected	
Lough Foyle Sea Defences		
All Defences	Belfast to Londonderry Railway City of Derry Airport Army base Farmland Residential housing	
County Down Sea Defences		
Greyabbey	Farmland	
Kinnegar	Residential housing	
Newtownards Ards airport Recreation and leisure Agricultural land	Housing, schools, retail and manufacturing	105ha 63 ha 2 ha 96 ha
Quoile Barrier Quoile Pondage Nature Reserve	Downpatrick town	
Strand Lough Barrier	Farmland and Killough town	

Table 2. Potential Failure Modes for the County Down Sea Defences

Failure Mechanism	Strand Lough	Quoile Barrier	Quoile Causeway	Greyabbey	Newtownards	Kinnegar
Frontal erosion, loss of armour protection			•	•	•	•
Piping/ internal erosion			•	•	•	
Pore water pressures					•	
Settlement					•	
Slope stability	•	•	•	•	•	•
Overtopping			•	•	•	•
Sliding/ overturning failure	•	•				
Toe erosion/ undermining	•	•	•	•	•	•
Structural failure	•	•				

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Table 3. Hazard Assessment for the County Down Sea Defences

Failure Mechanism	Strand Lough	Quoile Barrier	Quoile Causeway	Greyabbey	Newtownards	Kinnegar
Kinnegar						
Frontal erosion	-	-	L	H	L	L
Piping/ internal erosion	-	-	?	H	L	-
Pore water pressures	-	-	-	-	L	-
Settlement	-	-	-	-	L	-
Slope stability	-	-	?	H	L	L
Overtopping	M	M	L	H	L	H
Sliding/ overturning failure	M	M	-	-	-	-
Toe erosion and undermining	?	H	L	L	L	M
Structural failure	L	M	-	-	-	-
(note " ?" indicates insufficient information)						

Table 4. Recommended Monitoring for the County Down Sea Defences

Defence	Recommended Monitoring	Purpose of monitoring
All Defences	Visual inspection Condition survey Asset review Annual reporting Post storm appraisal	General condition and appraisal of performance. Scheduling maintenance/upgrading. Need for capital improvement works.
Strand Lough Barrier	Structural survey Geometry Bed levels Water levels	Structure soundness Movement Scour in tidal channel Estimation of extreme tidal levels
Quoile Barrier	Structural survey Geometry Bed levels Water levels	Structure soundness Movement Scour in tidal channel Estimation of extreme tidal levels
Greyabbey	Lough shore levels	Foreshore movement/stability
Newtownards	Rock armour condition Geometry	Rock armour performance Settlement, slope stability Foreshore movement/stability
Kinnegar	Lough shore levels Rock armour condition Lough shore levels	Rock armour performance Foreshore movement/stability

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Visual Walkover Condition Surveys

Visual condition inspections are considered to be the primary and most important aspect of the monitoring system, as they assess the general condition of every aspect of the sea defences. The proposed monitoring programme includes weekly surveys by the Rivers Agency's staff, six monthly and annual surveys by qualified coastal defence Engineers and a ten yearly survey by a suitably experienced Consulting Engineer.

The principal purpose of the weekly visual surveys is to monitor the condition of the defences and identify maintenance and repair requirements. The major benefits of weekly surveys are that minor defects can be monitored until a sufficient quantity of works can be scheduled to justify mobilising the required plant and labour resources or the repair becomes urgent. Additionally, the frequency of these surveys will provide early warning on any rapidly occurring defects which are likely to cause a breach of the defence.

The six monthly and annual walkover surveys should assess the defences in relation to the longer term aspects of larger maintenance works and upgrading programmes. The documented results should be accompanied by a comprehensive photographic record for future review.

The ten yearly walkover surveys should be undertaken by Consulting Engineer with experience of coastal defences. This inspection should represent a detailed review of the defences in terms of the points addressed as part of the asset review.

The monitoring feasibility study provided a detailed recording and reporting system for these walkover surveys. The results are recorded on a field sheet in terms of a priority score to represent the proposed course of action. Defects are to be classified using a traffic light system with emergency action, routine maintenance, and no action required. This system should provide early warning of failure and allow a timely response that may prevent further damage to the defences or possible breach.

Structural Surveys

The detailed structural surveys can be divided into the assessment of rock armouring quality and degradation and the structural assessment of the reinforced concrete barrier structures at Strand Lough and Quoile in County Down.

As part of the walkover survey programme, visual assessments of the rock armouring are undertaken at Myroe and Ballykelly sea defences in Lough Foyle and the Newtownards and Kinnegar sea defences in County Down. These inspections are targeted at fixed locations, which are representative of the overall armouring and are located in areas for which differing wave climates would be experienced.

At each assessment location stainless steel plates identify 200 rocks within the primary armour layer. This allows the area to be assessed for missing, broken or degrading armour. In addition, rock co-ordination assessments are undertaken on a representative sub sample to check for movement of the armouring.

Rip rap armour protection is used on the river banks at the Ballykelly sea defence. Annual assessment of this armour is completed by a visual inspection of size and degradation at 100m intervals.

The results of these surveys are presented on specially developed monitoring record forms.

The structural surveys of the Strand Lough and Quoile Barriers to be undertaken on an annual basis. It is recommended that in the early years of the monitoring regime the proposed detailed structural inspections, which should note all defects and crack widths, are augmented by a programme of underwater inspections, concrete and non destructive testing. Whenever sufficient base data has been collected, the period between subsequent supplementary investigations will be extended depending on the results obtained.

Geometric and Bed Level Surveys

The purpose of the geometric surveys is to assess the long term stability of the sea defences in terms of settlement and movement. In addition, monitoring of the bed levels at the front of each defence, by both beach and bathymetric surveys, is proposed.

Detailed geometric surveying using static and real time kinematic GPS in combination with Total Station theodolite and digital levelling will be undertaken on an annual basis. However, completion of the bathymetric surveys will be undertaken on a five yearly basis, unless events dictate a more regular survey programme.

To implement these surveys an extensive programme of permanent survey benchmarks, fixed survey points and chainage markers were established at all designated sea defences. As noted within the risk assessment, the concentration of survey markers was highest at the Lough Foyle sea defences where the highest risks occur. At the Greyabbey sea defences in County Down, where risks are low, only annual beach surveys are recommended.

Environmental Monitoring

The recommended environmental monitoring consists of three primary elements, *viz*:

- Tidal monitoring
- Backpond water level monitoring
- Salinity monitoring

Tidal monitoring is recommended for all of the sea defences in Lough Foyle and the defences at Strand Lough

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and Quoile. The principal reason for this recommendation is to allow accurate prediction of extreme tidal water levels to be undertaken at these locations to augment the existing overtopping and stability assessments. These factors are at present noted to be a medium or high level hazard at these locations.

The asset review highlighted that the backpond water levels could have a significant bearing on the geotechnical stability of the Lough Foyle sea defences. As such, weekly monitoring will provide a detailed assessment of the water levels and would provide valuable information for future detailed investigations.

The monitoring recommendations included a programme of salinity readings within the sea defence backponds at Lough Foyle. This monitoring has two objectives in that it provides an indication of seepage through the defence and outfalls and also allows the environmental assessment of the ecology of the ponds. These readings are generally taken at quarterly intervals.

MANAGEMENT RESPONSE

The purpose of looking at the wider management of the sea defences was to define how flood risk is managed and how management response is informed by the monitoring information.

Flood risk is controlled by a number of actions including:

- Capital works programme (upgrading of defences)
- Maintenance of existing defences and emergency works
- Monitoring of structural condition and environmental parameters

These actions are only taken when conditions exceed certain threshold values. For example, when the standard of protection of a defence is lower than would be expected.

Capital works includes upgrading of the existing defences to improve the standard of protection. The most recent upgrading work has been undertaken at Newtownards where 1.6km of the existing defences have been upgraded with new rock protection and sheet piled strengthening to the embankments. This work required a detailed assessment of flood risk and flood benefits in accordance with treasury guidelines for project appraisal (DEFRA FCDPAG). The Rivers Agency also plans to upgrade other defences where the existing standard of protection is lower than the required level.

Maintenance works are undertaken by the Rivers Agency direct works organisation. These works are usually scheduled for certain times of year and the need for maintenance is based on condition assessment made by visual inspection.

Emergency works are undertaken in response to events that cause defects which are likely to cause a breach or serious damage to the defences. The Agency has contingency arrangements to undertake such work using local materials. All the defences are accessible by road, which means that heavy plant can reach areas of breach.

Information from the monitoring programme provides the base data for all of these actions. To ensure that this information is properly used a number of feedback mechanisms were proposed:

- Reporting of survey results for action and future reference
- Post storm appraisal
- Annual review of monitored information

The results of the surveys are documented within short survey reports. The results of the survey are reviewed using the pre-determined response thresholds and where actions are required they are presented as an action recommendation statement.

When defects exceed threshold values then a response may be required comprising routine maintenance, emergency repair work, further inspection or investigation, increased frequency of monitoring, or all of these.

Operational threshold values and response activities were defined for all the sea defences. Table 5 presents a summary of the actions for the front face of flood defence embankments in County Down.

The monitoring and management response system also recommended that post storm appraisal be undertaken for events that are likely to exceed defined thresholds and as such put the stability of the defences at risk. The objective of the post storm appraisal is to identify any emergency remedial works and develop a record of the standard of service of the defences. This information can then be used in the future to assess the risk of failure of the defences and also provide the justification for upgrading.

The final element in the overall monitoring and management system is the annual monitoring review. The process of this review was accurately defined and includes the overall assessment of all monitoring results. This is presented in a report format summarising any recommendations with regard to changes in the monitoring programme and requirements for maintenance works or further studies which need to be undertaken within the following year.

IMPLEMENTATION AND OPERATION

The Rivers Agency has commissioned WS Atkins to implement and undertake the monitoring system. The programme to date has concentrated on the installation of the fixed assets required to complete the geometric and structural monitoring.

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Table 5. Examples of Operational Response for County Down Sea Defences.

Response Criteria **Front Face**	**Threshold Value**	**Response Activity**	**Priority**
Damage to armour layer, loss of stone	i) Minor loss of armour layer ii) Significant loss, or core layer exposed	i) Replacement of units ii) Emergency repairs. Post storm appraisal	M H H H
Movement or subsidence of front face	Visible movement, or +/- 50mm if survey point	Establish level survey if slippage is suspected and monitor daily. Post storm appraisal	
Undermining or damage to toe	Beach level below level of toe beam, or below other critical level	Undertake additional beach level surveys. Consider providing additional scour protection.	

Walkover condition surveys have been completed at all defences and the requirements for maintenance works have been reported to the Rivers Agency. All repairs have been completed by their direct labour organisation.

The outbreak of Foot and Mouth Disease in February 2001 resulted in monitoring programme being deferred due to agricultural land access restrictions. This has resulted in the geometric surveys being delayed until the present year and as such the efficiency of the systems operation cannot be fully assessed.

Monitoring of the efficiency of the system will be an ongoing process following the initial data collection phase. The annual monitoring review provides for system modifications and updates to be incorporated in response to the results obtained and also to include new developments within coastal management.

CONCLUSIONS

Implementation of the Monitoring and Management system commenced in 2000. To date progress has concentrated on the installation of the permanent survey instrumentation system which permits the geometric and structural survey to be completed.

Walkover surveys have been conducted at all sea defences and in some cases have highlighted the necessity to undertake localised maintenance works.

The programme of salinity monitoring has highlighted that variations in the salinity levels relate principally to the freshwater inflows from the land drainage systems. Further monitoring will be undertaken during the wet winter period and the results will be reviewed during the Annual Monitoring Review.

The current programme of monitoring includes for walkover, geometric and structural surveys to be completed in the spring 2002 period. Following this period an annual monitoring review will be undertaken and the results will feed back into the monitoring programme for 2002 – 2003.

During the short period of implementation the conclusions drawn indicate that the Monitoring and Management Response system provides an effective means of managing the designated sea defences within Northern Ireland. The monitoring has been targeted based on flood risk, and the monitoring results are used to assess the need for capital and maintenance works.

Comparison of the system with published monitoring recommendations from agencies in the UK, Europe and the USA indicate that the system represents "Best Practice".

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