

Barrow Borough Council  
& West Lakes Renaissance

## Barrow-In-Furness Strategic Flood Risk Assessment: Phase 1

Date: July 2005

Project Ref: R/3521/1

Report No: R.1189



*JOHN YOUNG Associates*

**Barrow Borough Council  
& West Lakes Renaissance**

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<b>Version</b>	<b>Details of Change</b>	<b>Authorised By</b>	<b>Date</b>
1	Draft for Comment	N J Cooper	30/03/05
2	Final – minor edits to address comments	N J Cooper	18/07/05

<b>Document Authorisation</b>		<b>Signature</b>	<b>Date</b>
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## Executive Summary

This report presents the findings from Phase 1 of a Strategic Flood Risk Assessment that is being undertaken in the borough of Barrow-in-Furness. The present phase of works involves a review of publicly available information, consultation with appropriate organisations about flooding issues and available data holdings, and makes recommendations for further data collection or investigation in subsequent phases of work.

It has been identified that flooding within the borough can be due to tidal inundation, fluvial flooding, 'fluvio-tidal' flooding (i.e. flooding due to tide-locking of fluvial discharge) or sewer flooding. The greatest flood risk exists in the town of Barrow-in-Furness, where approximately 1,875 properties lie within the Environment Agency-defined flood risk zone. Here, the potential causes of flooding include:

- Inadequacy in the hydraulic capacity of open channel sections and lengths of culverts conveying a Main River, named Poaka Beck, through the town;
- Hydraulic restrictions associated with bridges and other structures spanning the Poaka Beck;
- The condition and operation of the bifurcation sluices on the Poaka Beck;
- High fluvial flows in conjunction with high impoundment levels within Cavendish Dock preventing discharge of fluvial flood flows to the sea;
- Breaching of dock/sea walls or flood embankments leading to tidal inundation;
- Overtopping of the dock/sea walls or flood embankments leading to tidal inundation; and
- Sewer flooding as a result of possible inadequacies in the storm water sewerage system and or pumping plant.

The report identifies a number of available data sources relating to topography, fluvial hydrology and hydrometrics, tidal levels and surges, waves, flood risk mapping, development plans, flood and coastal defence assets, and future 'strategic' shoreline or catchment management policies.

Despite the available information, it is considered that some flooding issues are in need of further consideration in subsequent phases of the Strategic Flood Risk Assessment. Recommendations for further work include:

- Mapping the location and type of flood and coastal defence assets;
- Obtaining further details relating to the crest levels of existing defences around Barrow Island and the Dock Estate;
- Confirming the extreme tidal water levels that should be applied to flood risk assessments;
- Assessing the present standard of service offered by flood and coastal defence assets, particularly in zones of highest flood risk such as areas of Barrow-in-Furness and Barrow Island, taking into consideration extreme water levels, overtopping due to wind-wave generation, sea level rise and the design freeboard allowance;
- Assess the consequences of failure or breaching of these defence assets;
- Establish a river model of the lower reaches of Poaka Beck through urban Barrow-in-Furness;
- Assess the consequences of high fluvial flows through the Poaka Beck with high impoundment levels in Cavendish Dock reservoir;
- Assess the structural condition of the seaward embankment along Cavendish Dock; and
- Prepare a flood risk assessment for any development proposals within the Environment Agency's flood risk zone 3.

Several of the recommended activities have benefits beyond the production of a Strategic Flood Risk Assessment alone and will provide useful information to:

- the flood and coastal management activities of the Environment Agency and Barrow Borough Council;
- the implementation of recommendations made to Associated British Ports, Barrow under the Reservoirs Act; and
- the preparation of a development-specific Flood Risk Assessment for the Barrow Port Master Plan.

It is recommended that the findings of Phase 1 of the Strategic Flood Risk Assessment, as reported herein, be further discussed between interested parties, including the Environment Agency, before progressing with subsequent phases of investigation.



## Acknowledgements

The following are thanked for their valuable contributions to the present phase of the study:

ABP Barrow	David Carpenter and Bob Phillips
BAE Systems	Ian Gowans
Barrow Borough Council	Robin Gawlik, Phil Huck and Claire Savage
Bullen Consultants	Kevin Keating and Sam Wingfield
Capita Symonds	George Clement and Mark Ellis
Environment Agency	Gary Clark, Philippa Hodgkins, Iwan Lawton, Steve Russell, Paul Swain and Sarah Taylor
Owen Williams Group	Andrew Taylor and Ian Wardlaw
United Utilities	Ian Bird, Mike Dickson, Roger Fisher and John Nelson
University of East London	Dominic Hames
West Lakes Renaissance	David Humphrey

## Acronyms and Abbreviations

ABP	Associated British Ports
ABPmer	ABP Marine Environmental Research Ltd
AOD	Above Ordnance Datum
BBC	Barrow Borough Council
BODC	British Oceanographic Data Centre
CEUK	Coastal Engineering UK Limited
CFMP	Catchment Flood Management Plan
CIRIA	Construction Industry Research and Information Association
COW	Critical Ordinary Watercourse
CPS	Coast Protection Survey (of England and Wales, by MAFF)
Defra	Department for Environment, Food and Rural Affairs
DEM	Digital Elevation Model
DETR	Department for Environment, Transport and the Regions
EFO	Extreme Flood Outline
FARL	Flood Attenuation by Reservoirs and Lakes
FCDPAG	Flood and Coastal Defence Project Appraisal Guidance
FEH	Flood Estimation Handbook
FRA	Flood Risk Assessment
GEV	Generalised Extremes Variable
GPS	Global Positioning System
HAT	Highest Astronomical Tide
IFM	Indicative Floodplain Map
IFSAR	Interferometric Synthetic Aperture Radar
JBA	Jeremy Benn Associates Consulting Engineers Limited
JPA	Joint Probability Assessment
JPM	Joint Probability Method
JYA	John Young Associates Consulting Engineers Limited
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
LPA	Local Planning Authority

MAFF	Ministry of Agriculture, Fisheries and Food (now part of Defra)
Met. Office	Meteorological Office
MHWN	Mean High Water, Neap Tides
MHWS	Mean High Water, Spring Tides
MLWN	Mean Low Water, Neap Tides
MLWS	Mean Low Water, Spring Tides
MWL	Mean Water Level
NFCDD	National Flood and Coastal Defence Database
NRA	National Rivers Authority (now part of Environment Agency)
ODN	Ordnance Datum, Newlyn
OS	Ordnance Survey
RADAR	Radio Detection and Ranging
REFDIF	Refraction-diffraction (wave model)
PAR	Project Appraisal Report
POL	Proudman Oceanographic Laboratory
POT	Peak Over Threshold
PPG	Planning Policy Guidance
RPG	Regional Planning Guidance
SAAR	Standard Annual Average Rainfall
SDS	Sea Defence Survey (by NRA)
SFRA	Strategic Flood Risk Assessment
SFRT	Sequential Flood Risk Test
SMP	Shoreline Management Plan
SRJPM	Spatially Revised Joint Probability Method
SUDS	Sustainable Drainage Systems
TUFLOW	Two-dimensional Unsteady Flow (flood simulation model)
UKHO	United Kingdom Hydrographic Office
West Lakes	West Lakes Renaissance (urban regeneration company)

## Glossary of Terms

<b>Astronomical tide level</b>	The tidal level resulting from the gravitational effects of (mainly) the moon and the sun.
<b>Brownfield site</b>	Any land or site that has previously been developed.
<b>Catchment</b>	The area contributing flow or runoff to a particular point on a watercourse.
<b>Catchment Flood Management Plan</b>	A strategic planning tool through which the Environment Agency seeks to work with other key-decision makers within a river catchment to identify and agree policies for sustainable flood risk management.
<b>Coastal flooding</b>	Flooding from the sea.
<b>Critical ordinary watercourse</b>	A watercourse that is perceived as being 'critical' since it is known to have caused flooding or has the potential to put at risk from flooding large numbers of people and property.
<b>Culvert</b>	Covered channel or pipe that forms a watercourse below ground level.
<b>Design event</b>	An historical or notional flood event of a given annual flood probability, against which the suitability of a proposed development is assessed and mitigation measures, if any, are designed.
<b>Design flood level</b>	The maximum estimated water level during the design event.
<b>Development</b>	The carrying out of building, engineering, mining or other operations in, on, over or under land or the making of any material change in the use of any buildings or other land.
<b>Discharge</b>	Rate of flow of water.
<b>Estuarial flooding</b>	Flooding from an estuary, where water level will be influenced by river flows and tidal conditions.
<b>Field drainage</b>	System of drains to control the water table in agricultural land.
<b>Flood defence</b>	Flood defence infrastructure, such as flood walls and embankments, intended to protect an area against flooding, to a specified standard of protection.

<b>Flood defence level</b>	The level to which flood defences are constructed, that is the level of the top of flood walls and embankments, expressed relative to Ordnance Datum.
<b>Flood event</b>	A flooding incident characterised by its peak level or flow, or by its level or flow hydrograph.
<b>Flood plain</b>	Area of land that borders a watercourse, an estuary or the sea, over which water flows in time of flood, or would flow but for the presence of flood defences where they exist.
<b>Flood probability</b>	The estimated probability of a flood of given magnitude occurring or being exceeded in any specified time period.
<b>Flood risk</b>	An expression of the combination of the flood probability and the magnitude of the potential consequences of the flood event.
<b>Flood risk assessment</b>	A study to assess the risk of a site or area flooding, and to assess the impact that any changes or development in the site or area will have on flood risk.
<b>Flood storage</b>	The temporary storage of excess run off or river flow in ponds, basins, reservoirs or on the flood plain during a flood event.
<b>Fluvial flooding</b>	Flooding from a river or other watercourse.
<b>Formal defence</b>	A flood defence asset that is maintained by the Environment Agency.
<b>Freeboard</b>	The difference between the flood defence level and the design flood level.
<b>Hydrograph</b>	A graph, that shows the variation with time of the level or discharge in a watercourse.
<b>Indicative floodplain map</b>	A map that delineates the areas estimated to be at risk of flooding during an event of specified flood probability. "Indicative" acknowledges that such maps give an indication of the areas at risk but, due to the scale of the exercise, they are not reliable for precise information in relation to individual sites.

<b>Informal defence</b>	A structure that provides a flood defence function, but is not owned or maintained by the Environment Agency.
<b>Inspecting Engineer</b>	A Chartered Engineer who has been appointed to the 'All Reservoirs Panel' and is competent to undertake inspections in accordance with Section 10 of the Reservoirs Act, 1975.
<b>Local planning authority</b>	Body responsible for planning and controlling development, through the planning system.
<b>Main river</b>	A watercourse designated on a statutory map of main rivers, maintained by Defra.
<b>Mitigation measure</b>	A generic term used to refer to an element of development design which may be used to manage flood risk to the development, or to avoid an increase in flood risk elsewhere.
<b>Ordinary watercourse</b>	A watercourse, which is not a private drain and is not designated a main river.
<b>Return period</b>	A term sometimes used to express flood probability. It refers to the estimated average time gap between floods of a given magnitude, but as such floods are likely to occur very irregularly, an expression of the annual flood probability is to be preferred.
<b>Runoff</b>	The flow of water, caused by rainfall, from an area.
<b>Sea defences</b>	Engineered structure designed to prevent coastal flooding.
<b>Sequential flood risk test</b>	A risk-based approach to flood risk assessment, applied through the use of flood risk zoning, where the type of development that is acceptable in a given zone is dependent on the assessed flood risk of that zone.
<b>Sewer flooding</b>	Flooding caused by the blockage or overflowing of sewers or urban drainage systems.
<b>Shoreline Management Plan</b>	Non-statutory plan to provide sustainable management policies against tidal flood and coastal erosion risk.

<b>Standard of protection</b>	The estimated probability of a design event occurring, or being exceeded, in any year. Thus it is the estimated probability of an event occurring which is more severe than those against which an area is protected by flood defences.
<b>Strategic flood risk assessment</b>	A study to examine flood risk issues on a sub-regional scale, typically for a river catchment or local authority area during the preparation of a development plan.
<b>Supervising Engineer</b>	A Chartered Engineer who is competent to undertake inspections and prepare annual statements in accordance with Section 12 of the Reservoirs Act, 1975.
<b>Tidal surge</b>	An increase in tidal water level above the astronomical tide level caused by low barometric pressure and/or wind acting on the surface of the sea.

# Barrow-In-Furness Strategic Flood Risk Assessment: Phase 1

## Contents

	Page
Executive Summary.....	i
Acknowledgements .....	iii
Acronyms and Abbreviations .....	iv
Glossary of Terms .....	vi
1. Introduction.....	1
1.1 Background to the Study.....	1
1.2 Aims and Objectives .....	2
1.3 Consultation .....	3
2. Synopsis of Flooding Issues.....	4
2.1 General .....	4
2.2 Barrow-in-Furness.....	6
2.2.1 General .....	6
2.2.2 Flooding of Barrow-in-Furness from Poaka Beck .....	6
2.2.3 Tidal Inundation of Barrow-in-Furness.....	7
2.2.4 Sewer Flooding in Barrow-in-Furness.....	8
2.3 Tidal Inundation.....	9
2.4 Fluvio-Tidal Flooding.....	10
2.5 Fluvial Flooding.....	11
2.5.1 General .....	11
2.5.2 Rampside.....	11
2.5.3 Dalton-in-Furness .....	11
2.5.4 Askam-in-Furness.....	12
2.6 Sewer Flooding.....	12
3. Review of Data and Information .....	12
3.1 Background.....	12
3.2 Topography.....	12
3.2.1 Background.....	12
3.2.2 Remote Sensing .....	13
3.2.3 Land-Based Survey .....	13

3.3	Fluvial Hydrology and Hydrometrics.....	14
3.3.1	Introduction .....	14
3.3.2	Poaka Beck.....	15
3.3.3	Sarah Beck .....	18
3.3.4	Deep Meadow Beck.....	19
3.3.5	Blea Beck.....	19
3.3.6	Mere Beck.....	20
3.4	Tidal Levels, Surges and Waves.....	20
3.4.1	Background.....	20
3.4.2	Tidal and Surge Data .....	21
3.4.3	Wave Data .....	24
3.4.4	Joint Probability of Waves and Water Levels.....	25
3.5	Flood Risk Mapping .....	26
3.5.1	Background.....	26
3.5.2	Environment Agency Indicative Floodplain Mapping .....	26
3.5.3	Coastal Flood Risk Mapping .....	26
3.5.4	Environment Agency Flood Risk Zones.....	27
3.6	Barrow Borough Council Local Plan Review.....	27
3.7	Flood and Coastal Defence Assets .....	28
3.7.1	Background.....	28
3.7.2	Location and Type .....	28
3.7.3	Condition Assessments and Standards of Service .....	32
3.8	Strategic Studies .....	40
3.8.1	Catchment Flood Management Plans.....	40
3.8.2	Dalton-in-Furness Pre-feasibility Study.....	41
3.8.3	Shoreline Management Plans.....	41
3.8.4	Walney Island Strategy Study.....	42
3.8.5	Roa Island Shorelink Sustainability Study.....	43
4.	Conclusion and Recommendations .....	43
4.1	Prioritisation of Tasks for the SFRA .....	43
4.2	Opportunities for Defra Grant-in-Aid.....	44
4.3	Application of the Sequential Flood Risk Test (SFRT) .....	45
4.4	Responsibilities for Implementing the Recommendations.....	54
5.	References .....	56

## Appendices

- A. Review of National and Regional Guidance Documents
- B. Catchment Descriptors

## Tables

### Section 2:

2.1	Summary of known flooding problems.....	5
-----	-----------------------------------------	---

### Section 3:

3.1	Poaka Beck catchment descriptors .....	16
3.2	Top 20 ranked 'peak over threshold' (POT) events (Little Fields level station).....	17
3.3	Sarah Beck catchment descriptors .....	19
3.4	Blea Beck catchment descriptors .....	20
3.5	Astronomical tidal levels (source: UKHO).....	21
3.6	Measured tidal level data.....	22
3.7	Extreme water levels (in mODN) at Barrow .....	23
3.8	Nearshore wave statistics extracted from Futurecoast .....	25
3.9	Information on coastal defence type and location (as collated and kindly provided by Capita Symonds).....	30
3.10	First-order assessments of standard of service provided by existing defences against flooding (Source: Atkins, 2000) .....	33
3.11	Crest levels of dock walls in the outer dock system (Sources: ABP Barrow drawings).....	34
3.12	Summary of coastal defence inspection assessment at Roa Island and causeway (Source: ABPmer, 2003).....	39
3.13	Summary of most recent asset assessments .....	40
3.14	Relevant shoreline management plans .....	41
3.15	Management units and management policies .....	42

<b>Section 4:</b>	
4.1	Locations ranked by number of properties at risk ..... 44
4.2	Hierarchy of flood risk assessment studies (from CIRIA, 2004)..... 54
4.3	Summary of mutual benefits in executing the key study recommendations..... 55

## Figures (see separate pdf)

### Section 1:

1.1	Barrow Port Master Plan
1.2	Study Area
1.3	Key Areas of Interest in the Vicinity Barrow-in-Furness

### Section 2:

2.1	Environment Agency Flood Risk Mapping (south of borough)
2.2	Environment Agency Flood Risk Mapping (north of borough)
2.3	Flooding Problems Identified during Consultation (south of borough)
2.4	Flooding Problems Identified during Consultation (north of borough)
2.5	Environment Agency Flood Risk Mapping (Barrow-in-Furness)

### Section 3:

3.1	LiDAR Data Availability
3.2	Watercourses of the Furness Peninsula
3.3	Catchment Mapping: Poaka Beck
3.4	Poaka Beck Catchment Hydrology
3.5	Poaka Beck Ranked 'Peak Over Threshold' Data
3.6	Catchment Mapping: Sarah and Deep Meadow Becks
3.7	Sarah Beck Catchment Hydrology
3.8	Catchment Mapping: Blea and Mere Becks
3.9	Blea Beck Catchment Hydrology
3.10	Location of Tide Gauges at Roa Island, Halfway Shoal and Barrow's Ramsden Dock
3.11	Tidal Characteristics for Three Tide Gauge Stations
3.12	Tidal Curves for the Spring and Neap Tidal Cycles for the Three Tide Gauges

## 1. Introduction

### 1.1 Background to the Study

ABP Marine Environmental Research Limited (ABPmer) and John Young Associates Consulting Engineers (JYA) were appointed jointly by Barrow Borough Council (BBC) and West Lakes Renaissance (West Lakes) to undertake a Strategic Flood Risk Assessment (SFRA) in the borough of Barrow-in-Furness. This is being undertaken in accordance with Planning Policy Guidance Note 25 (PPG25): *Development and Flood Risk*, which recommends the application of a Sequential Flood Risk Test (SFRT).

Following consultation with the Environment Agency's North West Region, it was decided to take the study forward in a phased manner. This report presents the findings from Phase 1 and it is intended that further consultation be undertaken with the Environment Agency before proceeding with subsequent phases. The overall study may ultimately comprise the following phases:

- Phase 1 (presented in this report): review publicly available information; consult with the local planning authority (Barrow Borough Council) and flood defence agency (Environment Agency); and identify, in broad terms, the key issues associated with flood risk within the borough that need to be considered further;
- Phase 2: undertake a strategic assessment of flood risk within the borough via application of the SFRA; and
- Phase 3: undertake a detailed assessment of the flood risk issues at key sites within the study area.

It is possible that Phases 2 and 3 could be combined under the auspices of a single, more detailed study.

The need for the present study arose initially because of West Lakes' re-development proposals, as contained within the Barrow Port Master Plan (these are schematised in Figure 1.1). The Master Plan intends to regenerate large areas of Barrow Port and Barrow Island through waterfront and marine development including, amongst other aspects, a cruise ship terminal, a water wildlife reserve, sculpture and heritage trails, and a marina village. Some areas of the planned re-development lie within flood risk zones, as defined by Environment Agency flood risk mapping. Further details of the re-development proposals can be found at the following web page:

[www.westlakesrenaissance.co.uk/barrowprojectdetails.asp?strNewsID=50](http://www.westlakesrenaissance.co.uk/barrowprojectdetails.asp?strNewsID=50)

Whilst the study area initially focused on the Barrow Port Master Plan area, it was subsequently extended by Barrow Borough Council to additionally include all areas covered by the *Local Plan*. The study area is presented in Figure 1.2, whilst Figure 1.3 highlights some key features of interest in the vicinity of Barrow-in-Furness.

## 1.2 Aims and Objectives

The overall aim of the flood risk assessment process is to identify locations within a defined study area that are at risk from flooding, and to propose measures to mitigate such risk. In the context of a borough-wide SFRA, this may be through informing the relevant statutory development plans of flood risk issues so as to avoid inappropriate development and to ensure that any proposals for development would not increase flood risk elsewhere. In the context of a specific development, it may be through the incorporation of measures that mitigate risk through the scheme design process (e.g. provision of flood defence structures, specification of appropriate flooring levels or roofing design of buildings, or the use of sustainable drainage systems).

The aim of Phase 1 of the present study is to identify relevant data and knowledge, assess its suitability for use in subsequent phases and, where gaps exist, make recommendations to fill these gaps.

Specific objectives of Phase 1 of the study are to:

- Provide a description of the study area, including:
  - Identification of existing defences, their state of maintenance and performance;
  - Sources of potential flooding;
  - Main Rivers, Critical Ordinary Watercourses (COWs) and drainage;
  - Relevant land usage and policy documents;
  - Past flood events including depth of flooding;
  - Hydrology and drainage of study area.
- Review information sources, including:
  - Barrow Borough Council's Local Plan Review 1996 to 2006;
  - Barrow Local Plan – Alteration to Chapter 3 Housing;
  - Planning Cumbria – Cumbria and Lake District Joint Structure Plan 2001-2016 – proposed changes June 2004;
  - Environment Agency's Indicative Flood Risk Maps; and
  - Information on waves and tides held by ABP Barrow.

Detailed analysis of relevant data, where necessary, and preparation of a more detailed assessment of flood risk issues are to be undertaken in subsequent phases of the study.

### 1.3 Consultation

Early consultation with the Environment Agency revealed that the following guidance documents are of principal relevance to the present study:

- Planning Policy Guidance 25 (PPG25): *Development and Flood Risk* (DETR, 2001);
- Regional Planning Guidance 13 (RPG13); and
- Meeting the Sequential Flood Risk Test: Guidelines for the North West Region (JBA, 2004).

In addition, CIRIA has recently published industry guidance on flood risk (CIRIA, 2004) and this includes a flood risk assessment toolkit. Also in progress is a Research and Development study by HR Wallingford on *'Flood risk assessment guidance for new development'*.

Following a review of the available guidance documents (Appendix A), a further series of consultation meetings were held between the Project Team and key staff members from a range of organisations with responsibility for flood defence, coast protection, land use planning and development control, or data collection. The aim of these meetings was to identify key flood risk areas and principal flooding mechanisms, and to review data availability.

Meetings were held on the following dates:

- 3<sup>rd</sup> February 2005, Meeting with Barrow Borough Council;
- 3<sup>rd</sup> February 2005, Meeting with Capita Symonds;
- 4<sup>th</sup> February 2005, Meeting with Environment Agency and West Lakes Renaissance.

Furthermore, a series of telephone discussions have been conducted with key staff from other organisations with responsibilities and interests in the study area. These have included:

- ABP Barrow;
- BAE Systems;
- Bullen Consultants;
- Mott MacDonald;
- Owen Williams Group;
- United Utilities; and
- University of East London.

In addition to these consultation activities, the Project Team also undertook a site visit, particularly focusing on those areas of the borough that were identified as key flood risk areas during the consultation meetings.

## 2. Synopsis of Flooding Issues

### 2.1 General

Following discussions with Barrow Borough Council, the Environment Agency and Capita Symonds, and a review of the available documentation, several areas and a large number of properties within the study area have been identified as potentially being at risk of flooding. The majority of the sites tend to be in urban areas but it is also recognised that there are large areas of sparsely populated or agricultural land within the borough that are at risk.

Flooding issues in Barrow-in-Furness have been considered separately in Section 2.2 because of the multi-modal nature of flooding within the town. Flooding issues elsewhere within the borough-wide study area can be grouped by the following flooding mechanisms:

- Tidal inundation;
- Fluvio-tidal flooding;
- Fluvial flooding; and
- Sewer flooding.

Each of these mechanisms is discussed in more detail in the Sections 2.3 to 2.6, respectively.

Figures 2.1 and 2.2 show the Environment Agency flood risk mapping for the south and north of the borough respectively and Figures 2.3 and 2.4 summarise flooding problems that have been identified during the course of the present phase of study. However, it should be noted that the information provided in this document may be incomplete due to under-reporting by organisations or individuals who have suffered flooding in the past. The numbered locations shown on Figures 2.3 and 2.4 can be cross-referenced against Table 2.1.

Table 2.1 Summary of known flooding problems

Ref.	Location	Nature of Flooding	Comments
1	North Scale, Walney Island	Sewer	Unknown sewer flooding problem.
2	Earnse Point, Walney Island	Tidal	Possible breach of defensive wall near static caravan park.
3	Promenade, Vickerstown, Walney Island	Tidal	Pub called the Ferry on the promenade is flooded every few years. The promenade is also flooded between Central Drive and Mill Lane. North of Central Drive could potentially be cut off.
4	Nr. Vickerstown, Walney Island	Tidal	The road (Cistercian Way) floods and there is potential for properties to flood. The A590 and Carr lane also flood.
5	Saltmarsh Caravan Park, Walney Island	Tidal	Shown on Tidal Indicative Floodplain Mapping.
6	Biggar, Walney Island	Tidal	Embankment often breached north of Biggar village, thus cutting off the village.
7	Cavendish Dock, Barrow-in-Furness	Tidal	Flood risk to south Barrow as a result of breaching to Cavendish Dock (reservoir).
8	Roa Island Road, Barrow-in-Furness	Tidal	Flooding of the causeway cuts off the Island.
9	Rampside, Barrow-in-Furness	Fluvial / Tidal	Flooding from the Beck and/or overtopping blocks the A5087 and limits access to Rampside.
10	Rape Haw, South End, Walney Island	Tidal	Tidal inundation cuts off South End threatening the caravan park.
11	Flass Lane/Yarlside Road, Barrow-in-Furness	Fluvial / Sewer	Carriageway flooding and poor drainage can result in external flooding to houses.
12	Old Rampside Road, Barrow-in-Furness	Fluvial	Several drives / gardens flooded.
13	Frederick Street Area, Barrow-in-Furness	Sewer	Flooding to several nearby properties due to pumping station failure on Frederick Street.
14	Abbey Road Area, Barrow-in-Furness	Sewer	Various sewer capacity/flooding problems in Barrow Town Centre.
15	Furness Abbey, Barrow-in-Furness	Fluvial	
16	N. Barrow-in-Furness	Sewer	Various sewer capacity / flooding problems in Northern Barrow-in-Furness.
17	Dalton-in-Furness	Fluvial	Undersized culvert at Goose Green and various other fluvial problems in Dalton-in-Furness.
18	Lousy Point	Tidal	Settlement often flooded and cut off.
19	Askam-in-Furness	Fluvial / Sewer	Various fluvial and drainage problems in Askam-in-Furness.
20	Marsh Grange	Fluvial / Tidal	Tidal inundation of some cottages and fluvial flooding of the railway line at crossings.
21	Kirkby-in-Furness, Sandside	Tidal	Tidal flood risk. Railway-embankment frequently overtopped.

## 2.2 Barrow-in-Furness

### 2.2.1 General

The Environment Agency flood risk mapping shows that Barrow Island and parts of Barrow-in-Furness are at risk of flooding (Figure 2.5). Within the town there are approximately 1,875 residential properties are at risk of flooding. Information obtained for this study has established that the town is vulnerable to sewer flooding, fluvial flooding and tidal inundation.

There are no formal flood or sea defences protecting Barrow-in-Furness, although some dock/sea walls and embankments in the Dock Estate fulfil an informal flood defence function. A number of possible specific flooding mechanisms affecting the town have been identified during the course of this study and these include:

- Inadequacy in the hydraulic capacity of open channel sections and lengths of culverts conveying a Main River, named Poaka Beck<sup>1</sup>, through Barrow-in-Furness;
- Hydraulic restrictions associated with bridges and other structures spanning the Poaka Beck;
- The condition and operation of the bifurcation sluices on the Poaka Beck;
- High fluvial flows in conjunction with high impoundment levels within Cavendish Dock preventing discharge of fluvial flood flows to the sea;
- Breaching of dock/sea walls or flood embankments leading to tidal inundation;
- Overtopping of the dock/sea walls or flood embankments leading to tidal inundation; and
- Sewer flooding as a result of possible inadequacies in the storm water sewerage system and or pumping plant.

### 2.2.2 Flooding of Barrow-in-Furness from Poaka Beck

Poaka Beck enters Barrow-in-Furness from the north-east, adjacent to the Yarlside district of the town, and is classified as a 'Main River' within the urban area (see Figure 2.5). The watercourse flows southwards and then adjacent to the railway before entering Cavendish Dock via a rail underbridge. In common with many other urban rivers, the Poaka Beck has been gradually walled and culverted to accommodate residential, commercial and dock development. ABP has confirmed that their responsibilities extend to rail underbridge and no further. In addition, a second beck, Low Level Beck, exists which has its own outfall to Morecambe Bay.

No records of flooding from Poaka Beck affecting residential or commercial properties in the town have been identified and the risk and extent of flooding is not well

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<sup>1</sup> Also known as Mill Beck in its downstream reaches.

understood. Flooding in extreme events could be caused by tidal locking (discussed below) or hydraulic restrictions at bridges, culverts and other structures impeding the flow. However, without detailed witness information associated with past flood events it is not possible to identify these hydraulic restrictions.

Cavendish Dock acts as a balancing reservoir to the wider Barrow docks system. Loss of water from the Devonshire, Buccleuch and Ramsden Docks during locking operations is compensated by water flowing in from Cavendish Dock. There are two inlet/outfalls structures in Cavendish Dock. The main sea sluice to the south west of the impoundment allows water into and out of the dock from the sea. The sill of the sea sluice is understood to be set at 4.56m AOD and this defines the top water level in the reservoir under normal tidal conditions. A penstock on the sluice can be adjusted to control overflow from the dock into Walney Channel and is closed during extreme sea storm surge and elevated water levels in order to prevent sea water flowing into the dock and raising water levels to an unacceptable level above 4.56m AOD.

Ramsden Dock is connected to Cavendish Dock via twin culverts with an invert level of 3.23m AOD. The culverts are regulated by lifting sluice gates and control the level of water in the rest of the dock system. The 'All Reservoirs Panel' Inspecting Engineer for Cavendish Dock has stated that during extreme conditions when the sea sluice is closed and the water in the Ramsden Dock is at a high level, thus preventing discharge from Cavendish Dock, then the volume of flow entering Cavendish Dock from Poaka Beck combined with any wind-generated waves moving across the dock, could result in overtopping to the north eastern embankment. Bob Phillips of ABP (Engineering Manager, North West) has confirmed this scenario and has stated that under certain circumstances water levels in Ramsden Dock are kept at a higher level than in Cavendish Dock with a highest maintained level of approximately 5.07m AOD.

In addition, the 'All Reservoirs Panel' Inspecting Engineer has also suggested that high levels in the dock combined with hydraulic restrictions associated with the rail underbridge could cause flooding of the Poaka Beck upstream of the dock, which would affect Barrow-in-Furness. It is considered that the development of a detailed hydrological and hydraulic model would resolve these issues and allow the risk of flooding and the extent of the flood risk from Poaka Beck to be assessed.

### **2.2.3 Tidal Inundation of Barrow-in-Furness**

Cavendish, Devonshire, Buccleuch, Ramsden Docks and Barrow Island are situated to the south and west of Barrow-in-Furness. The Cavendish Dock embankments, caisson lock structures and vertical sea walls on Barrow Island all currently provide flood protection from tidal inundation and act as informal sea defences (see Figure 2.5). It is assumed that the Environment Agency flood risk mapping for Barrow Island and Barrow-in-Furness has been based upon tidal inundation caused by a catastrophic breach failure or overtopping of these informal flood defences during extreme storm surge conditions on the Cumbrian coast.

Bob Phillips of ABP has stated that in his opinion there are three main issues in relation to the dock system:

- The condition of the long embankment;
- The caisson lock gate structure which acts as an informal flood defence at the entrance to the dock; and
- The level of the walls adjacent to the Walney Channel.

The long embankment which forms the southern limit of the Cavendish Dock is vulnerable to damage during storm conditions. Bob Phillips has indicated ABP inspect the condition of the embankment and make repairs as necessary following all significant storms. Unfortunately there is very little geotechnical data pertaining to the embankment and the risk of breach failure is an unquantified risk, which should be further addressed.

The integrity of the informal flood defences for Barrow-in-Furness and Barrow Island rely upon the closure of the caisson lock gate to the dock system (see Figure 2.5). A failure to close the caisson during extreme storm surge conditions may mean that the line of flood defence is pushed inland to the inner dock wall. This could be a significant operational risk if the inner dock wall is at a significantly lower level than the informal flood defences adjacent to Walney Channel.

Walney Island provides a high degree of protection to wave attack and overtopping of the informal flood defences adjacent to Walney Island. However, in 2002 it has been reported that there was limited wave overtopping to the walls on Barrow Island primarily because of elevated water levels due to storm surge. The return period associated with this event has not been determined for this study, but it is considered that overtopping could be an important factor for subsequent phases of the SFRA to consider.

The evaluation of extreme water levels, the level and structural integrity of informal sea defence structures are therefore critical in quantifying the risk and consequence of flooding from tidal inundation.

#### **2.2.4 Sewer Flooding in Barrow-in-Furness**

The sewage network was originally built for the old town encompassing southern Barrow-in-Furness. The north end is higher up and the sewerage network has evolved around new developments. As a result of this, the sewerage at the southern end of Barrow has capacity problems. Most of low-lying Barrow, near to the docks, is affected.

United Utilities has confirmed that there are sewer flooding issues in Barrow-in-Furness. Barrow Borough Council and United Utilities have provided information relating to the location of properties affected by flooding. The most recent flooding

events in August 2004 (3<sup>rd</sup>, 5<sup>th</sup>, 8<sup>th</sup>, 10<sup>th</sup>, 12<sup>th</sup> and 23<sup>rd</sup>), 14<sup>th</sup> September 2004 and 4 October 2004 affected approximately 30-40 houses in Salthouse Road and Frederick Street. Flooding at this location has been attributed to a failure of the Salthouse pumping station, which was disabled during the storm and resulted in surcharging to the storm sewers. It is assumed that this can be classified as a maintenance failure rather than an inadequacy in the sewer infrastructure requiring capital investment.

United Utilities has a capital programme of works in Barrow-in-Furness to address sewer flooding problems. Work is currently being undertaken at Hollow Lane to install a storage tank to mitigate flooding to one property. It is also understood that two large storage tanks are programmed to be installed to mitigate the risk of flooding to Barrow-in-Furness town centre. The timing of the works has not been established.

A number of other non-flood related capital schemes are being proposed by United Utilities in Barrow-in-Furness. These projects involve increasing storage capacity at a number of pumping stations to reduce the volume of effluent discharged to the Walney Channel in storm conditions. The sites include Palace Nook and Ramsden Dock pumping stations.

## 2.3 Tidal Inundation

There are several locations within the borough-wide study area that are potentially at risk from tidal flooding. This can be caused by any one, or any combination, of the following factors:

- High astronomical tidal levels;
- Tidal surge;
- Wave action.

Generally, much of the study area is relatively well protected against wave action, with the exception of the seaward-facing coast of Walney Island. Elsewhere, tidal flood risk is largely determined by the still water level with respect to the crest level and structural condition of existing flood and coastal defence assets.

Aside from Barrow-in-Furness and Barrow Island, which have already been discussed in Section 2.2, the principal areas that are potentially at risk from tidal inundation include:

- Sections of Walney Island;
- Roa Island and its shore-linking causeway; and
- Strips of largely rural/agricultural land, *e.g.* at Rampside, Roosebeck, around Scarth Bight and north from Askam-in-Furness to the borough boundary.

Walney Island has historically experienced a number of flooding events, primarily caused by:

- Wave overtopping and/or breaching of defences on the seaward (western) side of island, where defences front low-lying hinterland; and
- Overtopping of defences that have a relatively low crest level on the eastern side of the island, along the promenade that runs northwards from the bridge connecting Walney to Barrow-in-Furness.

These events have led to cessation of access until the tide recedes and hence caused temporary disruption to residents and emergency services. There is also a tidal flood risk from potential overtopping and/or breaching of defences on the eastern side of the island, such as the Biggar Dyke, although here wave action is very low and tidal flood risk is dominated by the still water level.

Roa Island, its shore-linking causeway and the area around Rampside, including the A5087 road, have also suffered from localised flooding due to overtopping of existing defences, although perhaps to a lesser degree than at Walney Island. Appendix F of the *Roa Island Shoreline Sustainability Study* presents photographs of wave overtopping during an event in February 2002, when a surge level of 1.4m was calculated. This event led to flooding of the western and southern sides of the island and the causeway. Where causeway pitching was absent or in poor condition, erosion of the underlying softer material occurred, exposing the water and telephone services. This damage was later repaired.

## 2.4 Fluvio-Tidal Flooding

The coastal margins of the Barrow peninsula to the west and south east (south of Newbiggin) are characterised by flat agricultural land where ground levels vary between 0m AOD and 10m AOD. The watercourses in these areas are typical of intensively drained land and are aligned with field patterns. The flood risk mapping reflects the low lying nature of the land and, assuming that the mapping is accurate, flooding will be the result of high fluvial flows in conjunction with high tidal levels which prevents or restrict the discharge of water through the stream or river to the sea.

Frequently water levels on flat agricultural land are controlled by sluices, non-return valves and other hydraulic control structures. In order to understand the mechanisms of flooding to these areas knowledge of farming practices and a comprehensive asset survey is required to determine the hydraulic characteristic of the area. Watercourses which drain these marginal areas include:

- Sarah Beck;
- Deep Meadow Beck;
- Blea Beck;
- Mere Beck;
- Cross Beck; and
- Soutergate Beck.

With the exception of Blea Beck, no historical records of flooding have been identified and it is expected that the human impact of fluvio-tidal flooding will be comparatively small given the lower density of dwelling in these areas. Properties at risk are located on the majority of the aforementioned watercourses but it should be noted that some could be at risk of tidal inundation alone. It should be noted that past flooding to Blea Beck has not been attributed to fluvio-tidal flooding but to blockage.

## 2.5 Fluvial Flooding

### 2.5.1 General

The objective of this section is to identify particular flooding problems associated with ordinary watercourses, Critical Ordinary Watercourses and Main Rivers. It is accepted that flooding will occur within the natural floodplains of the rivers. These areas are delineated by the Environment Agency flood risk mapping (see Figure 2.1 and 2.2).

Figures 2.3 and 2.4 show the properties at risk of fluvial flooding within the Environment Agency's flood risk mapping and a collection of specific flooding problems which have been highlighted by Barrow Borough Council and other agencies during the consultation process associated with this study. Fluvial flooding in Barrow-in-Furness from the Poaka Beck has been discussed in Section 2.2 and is not repeated here. Other locations where there have been reported fluvial flooding problems which affect residential and commercial property include:

- |   |                   |              |                      |
|---|-------------------|--------------|----------------------|
| ▪ | Rampside          | Unnamed Beck | (No. 9, Figure 2.3)  |
| ▪ | Old Rampside Road |              | (No. 12, Figure 2.3) |
| ▪ | Furness Abbey     | Poaka Beck   | (No. 15, Figure 2.3) |
| ▪ | Dalton in Furness | Poaka Beck   | (No. 17, Figure 2.3) |
| ▪ | Askam in Furness  | Blea Beck    | (No. 19, Figure 2.4) |
| ▪ | Dunnaholme        | Mere Beck    | (No. 20, Figure 2.4) |

Some limited information relating to the reasons for flooding has been obtained from Barrow Borough Council and other sources. These are discussed in following sections.

### 2.5.2 Rampside

Flooding at Rampside has been attributed to an unnamed beck which floods the A5087 and places adjacent properties at risk.

### 2.5.3 Dalton-in-Furness

Flooding here has been attributed to insufficient channel capacity in the Poaka Beck. A numerical model through Dalton-in-Furness has been developed as part of a *Pre-feasibility Study* to assess flood risk from the Poaka Beck in Dalton. In addition, it is

also understood that there are problems associated with the capacity of culverts and blockage on an ordinary watercourse (Hag Gill), which is a tributary of the Poaka Beck. Two properties have been reported to be prone to flooding.

#### **2.5.4 Askam-in-Furness**

Blockage to Blea Beck and problems with highway drainage result in flooding. No properties are reported to have been flooded.

### **2.6 Sewer Flooding**

In 1998/1999 United Utilities installed an interceptor sewer tunnel in the promenade in Vickerstown on Walney Island. It is understood that the interceptor sewer has surcharged since installation and this has resulted in one property being internally flooded and a second externally.

## **3. Review of Data and Information**

### **3.1 Background**

Application of the SFRT requires data and information about the following:

- Topography of the land (which determines levels and gradients);
- Physical pressures, such as the location of rivers, and physical processes, such as hydrology, hydrometry, tides, surges and waves;
- Flood risk zones (as defined by the combination of the above factors);
- Development pressures and constraints (as identified in Development Plans);
- The location, type, condition and standard of service of existing defences (which potentially can reduce flood risk);
- Planned flood and coastal management policies (to identify whether these may change over time).

The following sections discuss each of these aspects in turn.

### **3.2 Topography**

#### **3.2.1 Background**

The topography of the study area is important to define accurately since this is key to the identification of flood risk areas. Topographic data can be captured using either remote sensing techniques (such as stereoscopic aerial photography, LiDAR, IFSAR or satellite imagery) or land-based techniques (such as conventional surveying). Typically, remote sensing techniques are best-suited to national or regional studies

where the rapid coverage of a wide area is required, whilst land-based techniques are best-suited to more local studies where greater precision in topographic levels is required (i.e. development-specific FRA).

### 3.2.2 Remote Sensing

- Barrow Borough Council possesses vertical aerial photographs in digital format covering the study area. Although these were provided to the Project Team for purposes of the present study, there was a problem with the digital data that meant that they could not be used. Barrow Borough Council is further investigating this issue and this section of the report will be updated once further information is available.
- During the preparation of the Walney Island Strategy Study, vertical aerial photographs (presumably those mentioned above) were subjected to photogrammetric analysis in order to yield wide-area topographic data covering the island. These data were 'ground truthed' and further supplemented by GPS survey (see Section 3.2.3).
- The Environment Agency possesses LiDAR data that covers the majority of the study area (Figure 3.1): gaps in coverage exist at the southern end of Walney Island and at Roa and Foulney Islands, but there exist plans to fill these gaps with further LiDAR collection imminently. LiDAR typically has a vertical accuracy of the order of  $\pm 0.15\text{m}$  and this resolution is suitable for mapping flood risk zones, although where detailed land-based survey is available this should be used in preference. During the course of the present study, the Environment Agency has confirmed that these LiDAR data have been 'ground truthed' against field data in certain selected areas, and that the data could be made freely available for use in subsequent phases of the study.
- During the course of the present study, the Project Team was directed towards Environment Agency-held IFSAR (Interferometric Synthetic Aperture RADAR) data as a potential means of filling gaps in topographic data. Further discussion with the Environment Agency's Science Group, based in Twerton, revealed that a U.S. company named Intermap undertook the acquisition of IFSAR data across England and Wales in 2002 and the Environment Agency has purchased an 'off the shelf' digital elevation model (DEM) known as NEXTMap Britain™. This model has been used in the development of Flood Zone Maps (see Section 3.5.4). Further investigations have revealed that the vertical accuracy of IFSAR data is of the order of  $\pm 0.5\text{m}$ - $1.0\text{m}$ .

### 3.2.3 Land-Based Survey

- As previously mentioned in Section 3.2.2, a land-based GPS survey was undertaken, by Survey Operations Ltd., in order to 'ground truth' topographic

data derived from photogrammetric analysis of aerial photographs during the *Walney Island Strategy Study*. This land-based survey was also extended to incorporate areas of the island that became inundated during a storm surge event during the project in February 2002.

- Prior to the preparation of the *Roa Island Shorelink Sustainability Study*, Barrow Borough Council carried out a topographic survey of levels on the island and causeway, with additional spot levels recorded across the surrounding inter-tidal zone.

### 3.3 Fluvial Hydrology and Hydrometrics

#### 3.3.1 Introduction

The rivers within the study area are characterised by the geology and topography of the peninsula which is bounded to the west by the Duddon Estuary, Morecambe Bay to the east and a catchment divide in the north. The moors and fells in the north of the Furness Peninsula, which also form its backbone, dominate the hydrology of the area isolating the Lakeland catchments in the north from those on the peninsula. As a result, the Furness Peninsula has a series of short comparatively steep catchments that flow east, west and south. Figure 3.2 has been extracted from the FEH CD Rom and shows the watercourses of the peninsula. The larger of these catchments are:

- Poaka Beck;
- Sarah Beck;
- Deep Meadow;
- Mere Beck; and
- Blea Beck.

These catchments are discussed in more detail in the following sections. In addition, there are a number of other small catchments which drain the comparatively flat coastal margins to the west and south east of the borough. This includes the watercourses and lakes associated with the mines (quarries) to the north west of Dalton-in-Furness, a small catchment to the south of the mines (quarries) catchment, and the unnamed beck at Rampside which has been reported as causing flooding to the A5087. The flood risk mapping for the small catchments on the west side of the peninsula indicate that there are no properties at risk and that flooding is possibly the result of tidal inundation to agricultural land. The Rampside catchment is not delineated on the FEH CD Rom and would require further study to evaluate the extent of the catchment.

Poaka Beck has a small percentage of its area within the neighbouring Local Authority, Mere Beck forms the borough boundary and the majority of Deep Meadow Beck is within the adjacent Council area. It should be noted that the development and

planning policy of adjoining authorities could impact on Barrow Borough Council, and *vice versa*.

The Environment Agency has supplied details of the extent of Main Rivers and Critical Ordinary Watercourse. Poaka Beck, Sarah Beck and Deep Meadow Beck are classified as Main Rivers. Poaka Beck is maintained for approximately 13 km from its discharge point at the sea to just north of Dalton-in-Furness. The mapping also indicates that sections of Sarah Beck have been reclassified as a Main River.

Hag Gill (Dalton in Furness) and Roose Beck (Barrow in Furness) are classified as Critical Ordinary Watercourses. It is also understood that Blea Beck is a Critical Ordinary Watercourse, but this is not shown on the Environment Agency Mapping supplied for this study.

### 3.3.2 Poaka Beck

#### (a) General

Poaka Beck is the longest river on the peninsula and flows from the north to the south of the borough through Dalton-in-Furness and Barrow-in-Furness (see Figure 3.3). The hydrology of the river is influenced by the presence of three reservoirs, namely Poaka Beck Reservoir, Harlock Reservoir and Pennington Reservoir, and the two urban areas. Topographically, the latter reservoir is not within the Poaka Beck catchment but water is transferred by pipeline between the Dragley Beck and Poaka Beck catchments as necessary to service the water supply requirements of United Utilities.

The Environment Agency has confirmed that there is no impoundment licence for the reservoirs and it is assumed that they were originally constructed under a specific Act of Parliament for the supply of potable water to Barrow-in-Furness. The storage provided by the reservoirs serves to attenuate flow and abstraction reduces the volume of water entering the fluvial system downstream of the reservoirs. The *Flood Attenuation by Reservoirs and Lakes Index* (FARL) for the Poaka Beck catchment is a value of 0.937, reflecting the attenuation provided by the reservoir system.

Water is abstracted from the reservoir system and fed to the water treatment works (EA abstraction licence 2674814005). Mike Dickson (Works Controller), John Nelson (Reservoir Engineer) and John Sanders, all of United Utilities, have been contacted with respect to the operation of the reservoir system. It is understood that the daily abstraction to the water treatment works varies according to demand up to approximately 16 Ml/day. Although large in supply terms, this amount of abstraction has a comparatively small impact on the overall hydrology of the catchment. United Utilities has completed analyses relating to the maximum possible flood (approximate return period of 1 in 30,000 years) to assess the adequacy of the spillway structures, but has not made any other assessments for lower return periods.

United Utilities also retains data for the reservoir systems including process volumes and retained water levels. These details could be made available for the present study but they are not considered to be critical. The catchment descriptors obtained from the FEH CD Rom indicate that 9% of the catchment is urban, although development since 1972 may have increased this proportion.

(b) Hydrology

Figure 3.3 shows the extent of the Poaka Beck catchment, which is approximately 25.25 km<sup>2</sup> with a standard annual average rainfall (SAAR) of 1,140 mm. Table 3.1 shows the principal catchment parameters including area, SAAR, FARL and URBTEXT1990 for the full catchment shown in the above figure. Details of the abbreviations used in this table can be found in Appendix B. A preliminary rainfall run-off analysis has been undertaken using the methodology contained in the Flood Estimation Handbook (FEH), named *“Restatement and Application of the Flood Studies Report Rainfall-Runoff Method”*.

Figure 3.4 shows the results of the analysis in the form of flood hydrograph for probabilities of annual flooding of 0.1% (1 in 1,000 years), 1% (1 in 100 years), 2% (1 in 50 years), 3.3% (1 in 30 years), 10% (1 in 10 years) and 50% (1 in 2 years) respectively. The hydrograph shows flood flows at the discharge point to the sea. It should be noted that the rainfall run-off method generally returns higher flow rates by comparison to the FEH statistical method. Accordingly, it is recommended that hydrological analyses for hydraulic modelling be based upon the FEH statistical method and calibrated against the hydrometric information for Little Fields Level Station (see below for details).

**Table 3.1 Poaka Beck catchment descriptors**

Descriptor	Value	Descriptor	Value	Descriptor	Value
AREA	25.16	DPLBAR	7.86	SAAR4170	1162
FARL	0.937	DPSBAR	79.5	SPRHOST	37.6
PROPWET	0.53	LDP	16.43	URBCONC	0.775
ALTBAR	77	RMED-1H	10.8	URBEXT1990	0.092
ASPBAR	178	RMED-1D	38.5	URBLOC	0.566
ASPVAR	0.26	RMED-2D	49.3		
BFIHOST	0.545	SAAR	1140		

(c) Hydrometric Data

Figure 3.2 shows the location of Little Fields Level Station. Data for Little Fields was obtained from Susan Taylor at the Environment Agency, and extends from 1999 to 2005, giving approximately five years of records as indicated below. Figure 3.5 shows the ‘peaks over threshold’ values since 1999 categorised by rank.

Table 3.2 shows the top 20 ranked events since 1999. The sewer flooding incidents in Barrow-in-Furness for the 14<sup>th</sup> September 2004 and 4<sup>th</sup> October 2004 were commensurate with fluvial flood flows at Dalton-in-Furness for the previous day, which ranked 55<sup>th</sup> and 62<sup>nd</sup> respectively. It is recommended that a stage discharge relationship for the Level Station at Little Fields be developed. Assuming that this has not already been undertaken then this would allow direct calibration of the hydraulic modelling within Dalton-in-Furness.

- Auth. Ref. 8350
- Station Name Little Fields
- Loc. Description Poaka Beck
- Grid Ref SD22897386
- Parameter Stage
- Gauge Zero 0.000 MAOD
- Units metres
- Period 01/01/1999 to 31/12/2005
- Start of Day 09:00 GMT
- Threshold 0.400 metres

Table 3.2 Top 20 ranked 'peak over threshold' (POT) events  
(Little Fields level station)

Rank	Time	Date	POT (m)
1	17:45:00	25/10/01	0.401
2	00:30:00	10/02/02	0.402
3	05:15:00	29/09/02	0.402
4	05:30:00	16/09/03	0.402
5	13:45:00	10/10/00	0.405
6	09:30:00	25/10/02	0.406
7	01:30:00	16/07/03	0.406
8	20:00:00	12/12/00	0.408
9	10:30:00	05/12/01	0.408
10	16:30:00	31/01/02	0.409
11	04:30:00	05/08/03	0.41
12	14:45:00	27/09/01	0.411
13	23:30:00	01/09/02	0.411
14	07:00:00	25/09/02	0.412
15	21:00:00	23/01/01	0.417
16	05:00:00	26/08/02	0.419
17	07:15:00	17/09/04	0.419
18	08:30:00	06/02/01	0.425
19	03:45:00	16/07/02	0.426
20	04:15:00	03/08/03	0.427

(d) Hydraulic Modelling

It is understood that a *Pre-feasibility Study* has been undertaken by Babtie Group (now Jacobs Babtie) to assess possible problems with flooding in Dalton-in-Furness. The study has been reported to include some hydraulic modelling and an economic assessment. Iwan Lawton of the Environment Agency has stated that the study output is not in the form of a conventional report, but rather a collection of spreadsheets and other digital information.

The Environment Agency has confirmed that this information can be made freely available during subsequent phases of the SFRA and it is therefore recommended that this information is obtained and reviewed during Phase 2. Apart from the model mentioned above, no other models have been identified within the study area.

### 3.3.3 Sarah Beck

(a) General

Sarah Beck is a small catchment discharging into Morecambe Bay on the east side of the Furness Peninsula (see Figure 3.6). The catchment area is approximately 7km<sup>2</sup>. There is comparatively little development within the catchment with the villages of Newton and Leece being the only main settlements. The catchment has a maximum elevation of approximately 90m, but a large proportion of the catchment area that is at risk of flooding is on marginal coastal agricultural land at a level of between 0m and 10m AOD (see Figure 2.1). Accordingly, there are very few properties at risk from flooding directly from Sarah Beck. There are however a number of properties and caravans adjacent to the A5087, which are shown as being at risk of flooding. It is assumed that this relates to either tidal inundation or fluvio-tidal flooding where high sea levels prevent the discharge of floodwater from Sarah Beck, thus resulting in flooding.

(b) Hydrology

The catchment has a standard annual average rainfall (SAAR) of 1,032mm. Table 3.3 shows the principal catchment parameters including area, SAAR and URBTEXT1990 for the full catchment shown in Figure 3.5. A preliminary rainfall run-off analysis has been undertaken using the methodology contained in the Flood Estimation Handbook (FEH), *“Restatement and Application of the Flood Studies Report Rainfall-Runoff Method”*.

Figure 3.7 shows the results of the analysis in the form of flood hydrograph for probabilities of annual flooding of 0.1% (1 in 1,000 years), 1% (1 in 100 years), 2% (1 in 50 years), 3.3% (1 in 30 years), 10% (1 in 10 years) and 50% (1 in 2 years) respectively. The hydrograph shows flood flows at the discharge point to the sea. It

should be noted that the rainfall run-off method generally returns higher flow rates by comparison to the FEH statistical method.

**Table 3.3 Sarah Beck catchment descriptors**

Descriptor	Value	Descriptor	Value	Descriptor	Value
AREA	6.92	DPLBAR	3.25	SAAR4170	1052
FARL	1	DPSBAR	53.8	SPRHOST	27.8
PROPWET	0.52	LDP	7.33	URBCONC	-
ALTBAR	32	RMED-1H	10.5	URBEXT1990	0.004
ASPBAR	138	RMED-1D	36	URBLOC	-
ASPVAR	0.25	RMED-2D	46.7		
BFIHOST	0.683	SAAR	1032		

(c) Hydrometric Data and Hydraulic Modelling

The Project Team has not identified any hydrometric data or hydraulic models for this catchment.

### 3.3.4 Deep Meadow Beck

Deep Meadow Beck is adjacent to Sarah Beck and also discharges into Morecambe Bay (see Figure 3.8). The catchment area is approximately 25.5 km<sup>2</sup>, but there is only a small proportion of the upland catchment within the present study area. The villages of Marton and Lindal-in-Furness are located in this catchment. There are a number of small streams and flooded quarries in the catchment but the flood risk mapping does not show any areas within the present study area that are at risk of flooding. The Project Team has not identified any hydrometric data or hydraulic models for this catchment that would be relevant to the present study area.

### 3.3.5 Blea Beck

(a) General

Blea Beck discharges into the Duddon Estuary, on the western side of the Furness Peninsula (see Figure 3.8). The catchment area is approximately 5.5 km<sup>2</sup>, draining the western slopes of Hare Slack Hill, and includes part of Askam-in-Furness. The flood risk mapping indicates that there are no properties at risk of flooding, however Capita Symonds has reported there have been problems with blockage to a culvert and flooding to the highway.

(b) Hydrology

The catchment has a standard annual average rainfall (SAAR) of 1,149 mm. Table 3.3 shows the principal catchment parameters including area, SAAR and URBTEXT1990

for the full catchment shown in Figure 3.5. A preliminary rainfall run-off analysis has been undertaken using the methodology contained in the Flood Estimation Handbook (FEH), *“Restatement and Application of the Flood Studies Report Rainfall-Runoff Method”*. Figure 3.9 shows the results of the analysis in the form of flood hydrograph for probabilities of annual flooding of, 0.1% (1 in 1,000), 1% (1 in 100 years), 2% (1 in 50 years), 3.3% (1 in 30 years), 10% (1 in 10 years) and 50% (1 in 2 years) respectively. The hydrograph shows flood flows at the discharge point to the sea. It should be noted that the rainfall run-off method generally returns higher flow rates by comparison to the FEH statistical method.

**Table 3.4 Blea Beck catchment descriptors**

Descriptor	Value	Descriptor	Value	Descriptor	Value
AREA	5.48	DPLBAR	2.61	SAAR4170	1209
FARL	0.98	DPSBAR	86.3	SPRHOST	34.1
PROPWET	0.52	LDP	5.55	URBCONC	0.538
ALTBAR	71	RMED-1H	10.5	URBEXT1990	0.029
ASPBAR	283	RMED-1D	41	URBLOC	0.629
ASPVAR	0.58	RMED-2D	52		
BFIHOST	0.57	SAAR	1149		

### (c) Hydrometric Data and Hydraulic Modelling

The Project Team has not identified any hydrometric data or hydraulic models for this catchment.

### 3.3.6 Mere Beck

Mere Beck is located at the north of the study area on the west coast of the Furness peninsula and has a catchment area of 2.31 km<sup>2</sup>. The borough boundary follows the line of the river at the seaward end of the catchment (see Figure 3.8) but there is very little of the catchment within the present study area. Marsh Grange falls within the Mere Beck catchment and flooding problems have been reported at this location but there are very few other properties within the present study area. The Project Team has not identified any hydrometric data or hydraulic models for this catchment.

## 3.4 Tidal Levels, Surges and Waves

### 3.4.1 Background

Coastal flooding occurs when water passes over the crest of existing flood or coastal defences in large volumes, or when such structures become breached and then water flows through the breach. There are three main coastal flood risks and, most

commonly, it is a combination of two or more of these that leads to flooding events (Institute of Hydrology, 1999):

- High astronomical tide level;
- Tidal surge;
- Wave action.

Data relating to these processes are discussed in following sub-sections.

### 3.4.2 Tidal and Surge Data

The UK Hydrographic Office presents annual tide tables for the relevant 'primary port' of Barrow Ramsden Dock and 'secondary ports' of Halfway Shoal, Haws Point and Roa Island. Summary astronomical tidal levels for each station are presented in Table 3.5, including the highest astronomical tide (HAT) level which will occur once a year.

**Table 3.5 Astronomical tidal levels (source: UKHO)**

Tidal Parameter	Barrow Ramsden Dock <sup>2</sup>		Halfway Shoal <sup>2</sup>		Haws Point <sup>3</sup>		Roa Island <sup>2</sup>	
	Level (mCD)	Level (mODN)	Level (mCD)	Level (mODN)	Level (mCD)	Level (mODN)	Level (mCD)	Level (mODN)
HAT	10.30	5.55	9.85	5.10	10.45	5.75	10.15	5.40
MHWS	9.30	4.55	8.90	4.15	9.40	4.70	9.20	4.45
MHWN	7.10	2.35	6.80	2.05	7.10	2.40	7.10	2.35
MWL	5.00	0.25	4.88	0.13	5.15	0.45	5.08	0.32
MLWN	3.00	-1.75	2.80	-1.95	3.00	-1.70	3.00	-1.75
MLWS	1.10	-3.65	1.00	-3.75	1.10	-3.60	1.00	-3.75
LAT	0.00	-4.75	-0.04	-4.79	0.00	-4.70	-0.06	-4.91

The astronomical tidal levels presented above are generated by the gravitational forces of the moon and, to a lesser extent, the sun and these levels are regular and predictable. Superimposed on these effects are irregular meteorological effects, such as atmospheric pressure or winds, which can influence the predicted astronomical tidal levels by either elevating or suppressing them.

The deviation of the observed tide from the predicted astronomical tide that would otherwise occur with no meteorological influence is called a 'surge'. A surge is positive if the water level is higher than the tide caused only by astronomical forces, and negative if lower. Positive storm surges primarily have implications for flooding (e.g. overtopping of defences), whilst negative storm surges primarily have implications for

2 Chart datum for Barrow, Halfway Shoal and Roa Island lays 4.75m below Ordnance Datum, Newlyn (ODN).  
3 Chart datum for Haws Point lays 4.70m below Ordnance Datum, Newlyn (ODN).

navigation (e.g. grounding of vessels). Phillips and Rollinson (1971) observed positive tidal surges of between 0.3 and 1.1m in their analysis of water levels in the study area.

Measured tidal data captures both the astronomic tidal levels and any surge effects that may be experienced. Within the study area, measured tidal data are available at three relevant locations, namely Barrow Ramsden Dock, Roa Island and Halfway Shoal, as depicted in Figure 3.10. Details of these data are presented in Table 3.6.

**Table 3.6 Measured tidal level data**

Location	Data Available	Source	Measurement Period
Barrow, Ramsden Dock	Digitally at two gauges every 4 mins	ABP	01/05/92 - Jan 05
Roa Island	Digitally at two gauges every 4 mins	ABP	01/05/92 - 16/02/00
Halfway Shoal	Digitally at two gauges every 4 mins	ABP	22/08/92 - 31/05/01

Note: Whilst all three stations have now been decommissioned, it should be noted that ABP Barrow is presently in the process of commissioning a replacement network at these same three locations.

ABPmer has previously collated all of the available tidal data from Roa Island and Halfway Shoal and possesses tidal data from Barrow Ramsden Dock covering the period up to 31<sup>st</sup> December 2002. The remaining data from Barrow Ramsden Dock (January 2003 to January 2005) can be obtained from Alan Fowler of the UKHO (based in Taunton, Somerset).

These data were used by ABPmer in the *Roa Island Shorelink Sustainability Study* (ABPmer, 2003) to illustrate a slight increase in tidal range as the tide propagates from the open Irish Sea into Morecambe Bay and further inland through to the Ramsden Dock at Barrow (Figure 3.11). In addition, the landward propagation of the tide through the restricted channel also introduces a time lag in the phasing of the tide (Figure 3.12).

The quality of datasets from these tide gauges has been investigated as part of a Cumbrian-wide study undertaken by Hames *et al* (2004). This has involved the comparison of data between the two gauges operational at each location and its comparison with data from the POL gauge at Workington. The analysis suggests the following conclusions:

- Water levels at Roa Island are under-recorded by, approximately, 0.05 to 0.07m;
- Water levels at Barrow Ramsden Dock are reasonably accurate. However, the tide gauge has been subject to periods of siltation, and it is considered that from 2004 onwards the data should be rejected;
- Water levels at Halfway Shoal are accurate to, approximately, 0.02m; and
- Further processing and quality assurance is recommended before any further analysis is undertaken.

Work has previously been undertaken to investigate the extreme water levels (combining both astronomical tide and surge components) that are associated with events of various return periods. Whilst there is variability in the results, particularly over the longer return periods, this is to be expected due to the different statistical approaches adopted and variations in the length, quality and frequency of the datasets used. For example, a relatively recent study by JBA (1998) utilised a dataset ending in 1998, whilst the dataset used in a study by Lennon (1963) expired in 1962. The Lennon study also scaled a value for Barrow from the data at Liverpool and Gladstone Dock. These extreme water levels are given in Table 3.7 and show considerable variability in values derived from different studies. There are three columns showing results from the JBA study. This is because alternative statistical methods were compared and a preference was indicated for the Generalised Extremes Variable (GEV) method since it showed the best fit to the measured data. The relevant column showing these extreme water levels is highlighted in grey shading. Such differences between various previous studies are worthy of further investigation since extreme water levels are the principle cause of tidal flooding in the study area.

**Table 3.7 Extreme water levels (in mODN) at Barrow**

Return Period (yrs)	Lennon (1963) <sup>4</sup>	Graff (1979)	Coles & Tawn (1990) <sup>5</sup>	JBA (1998) <sup>4</sup>	JBA (1998) <sup>6</sup>	JBA (1998) <sup>7</sup>	Hames (2005) <sup>6</sup>
1	5.55	5.41	-	5.13	5.63	-	-
5	5.88	5.67	-	5.66	-	-	-
10	5.96	5.80	5.79	5.80	6.18	6.04	6.31
20	6.03	5.92	-	5.94	-	-	-
25	-	-	-	5.99	6.40	6.16	6.53
50	6.11	6.09	-	6.15	6.54	6.24	6.67
100	6.16	6.22	6.39	6.33	6.76	6.32	6.89
250	6.22	6.40	-	-	6.99	-	7.12

Note: JBA (1998) compared various statistical approaches to determining extreme water levels at Barrow (Ramsden Dock) and indicated a preference for the application of the GEV approach. These results are highlighted in grey shading.

To provide further context, Atkins (2000) report that major surges occurred in recent decades, leading to extreme water levels of:

- 6.15m AOD (an event with a 1 in 50 year return period) in November 1977;
- January 1983 (no tidal record);
- 5.95m AOD (1 in 20 year return period) in February 1990; and
- 6.33m AOD in February 1997 (1 in 100 year return period).

<sup>4</sup> Based on Generalised Extremes Variable (GEV).

<sup>5</sup> Based on Joint Probability Method (JPM).

<sup>6</sup> Based on Spatially Revised Joint Probability Method (SRJPM).

<sup>7</sup> Based on Revised SRJPM.

Extreme water level values will increase in future with sea level rise. The recommended design allowance for sea level rise in the North-West Region is 4mm per year (MAFF, 1999).

### 3.4.3 Wave Data

With the obvious exception of the western-facing shore of Walney Island, much of the study area is generally protected against direct wave approach by inter-tidal and sub-tidal features, such as the various sand flats and channels, as well as by the presence of Walney Island itself. This means that whilst it is important to consider the propagation of waves from offshore to nearshore close to Walney Island, local wind-generated waves are more important to consider elsewhere in the study area. When waves act on an elevated water level (e.g. at times of the highest astronomical tides, or during surge events), there exists the potential for overtopping of flood or coastal defences and possible flooding. Under severe conditions wave action can also lead to structural damage and, ultimately, collapse and breaching.

As part of the *Cumbrian Coastal Study*, the then National Rivers Authority (a predecessor authority of the Environment Agency) commissioned data collection from an inshore wave recorder situated off the southern end of Walney Island, in the Piel Channel, between 8<sup>th</sup> October 1992 and 31<sup>st</sup> March 1993. These data were used to calibrate a coarse grid numerical model that predicted the inshore wave climate at various locations around Morecambe Bay, of which South End, Bent Haw Scar and Earnst Point (all along Walney Island) were within the present study area (ABP Research, 1994). This revealed that the predominant approach directions were in the sectors 210-270°N and typical wave heights were between 0.5-2.5m, although events of up to 3.5m can be observed (ABP Research, 1994). In addition, the SMP for sub-cell 11d provided an inshore wave climate at the north end of Walney Island, based on a similar transformation of offshore Met Office data. All of these data sources have been collated and neatly summarised in the Walney Island Strategy Study (Atkins, 2000).

In addition, Atkins (2000) report that video recording of specific storm conditions at four sites on Walney Island, namely Earnse Bay, Sandy Gap, Hillock Whins and Hare Hill was undertaken on fourteen separate occasions between March 1992 and April 1994 to provide a visual assessment of wave conditions applying.

As part of Defra's *Futurecoast* study (Defra, 2002), a number of 'nearshore wave analyses' were performed. This involved the transformation of time series of wave data from 24 offshore positions to a series of 68 nearshore positions around England and Wales, one of which was at Walney Island. The offshore data sets were purchased from the UK Met Office wave model and contained both wind-waves and swell-waves. The wave transformation was achieved through use of a backtracking wave ray model based on linear wave theory. The model had the capability to

incorporate processes of wave refraction, breaking, shoaling, wave-wave interaction and dissipation due to bottom friction. The model incorporated the effect of tidally varying water levels, as predicted using tidal harmonic analysis, but did not incorporate non-tidal effects, such as surges due to atmospheric pressure. The resultant nearshore wave data for Walney Island are presented in Table 3.8. These indicate that waves approach Walney predominantly from the sectors between 210°N and 270°N and whilst typically wave heights in the nearshore are around 0.5 to 2.0m, occasional heights of up to 3.5m can be reached. This supports the results of the earlier Cumbrian Coastal Study and Sub-cell 11d SMP.

Table 3.8 Nearshore wave statistics extracted from Futurecoast

Wave Height (m)	Direction (deg)											
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360
3.25 - 3.5	0	0	0	0	0	0	0	0	7	0	0	0
3 - 3.25	0	0	0	0	0	0	0	1	3	0	0	0
2.75 - 3	0	0	0	0	0	0	0	0	20	0	0	0
2.5 - 2.75	0	0	0	0	0	0	0	17	60	0	0	0
2.25 - 2.5	0	0	0	0	0	0	1	71	116	0	0	0
2 - 2.25	0	0	0	0	0	0	2	251	279	1	0	0
1.75 - 2	0	0	0	0	0	0	5	555	634	6	0	0
1.5 - 1.75	0	0	0	0	0	0	18	828	913	53	0	0
1.25 - 1.5	0	0	0	0	0	0	53	1249	1136	112	0	0
1 - 1.25	0	0	0	0	0	0	138	1496	1114	253	1	0
0.75 - 1	0	0	0	0	0	0	391	1527	1107	608	22	0
0.5 - 0.75	0	0	0	0	0	0	611	1607	826	920	154	0
0.25 - 0.5	0	0	0	0	0	0	1063	2039	937	1302	393	0
0 - 0.25	305	686	1175	914	340	78	373	719	575	464	400	126

Both the Cumbrian Coastal Study and Futurecoast involved the transformation of offshore waves to nearshore locations using numerical modelling techniques. In contrast, the Roa Island Shorelink Sustainability Study incorporated an assessment of locally-generated wind-waves as a function of wind direction, speed and fetch using empirical calculations based on the methods of McConnell (1988). This revealed significant wave heights of 0.8-1.0m were possible around the island.

#### 3.4.4 Joint Probability of Waves and Water Levels

In the *Roa Island Shorelink Sustainability Study* (ABPmer, 2003) calculations were made of the overtopping potential around both the island and the shore-linking causeway due to prescribed combinations of water level and wave conditions. Although this was not a true 'joint probability assessment' (JPA) it nonetheless provides useful information on flood risk due to waves and water levels. Results indicate that under a 1 in 1 year water level with a 1 in 1 year wave height, all sections of the coastal defences would potentially become overtopped, although mean discharges would be unlikely to cause damage and both vehicle and pedestrian access to the island via the causeway would not be deemed unsafe. It is only when 1 in 10 year water levels are combined with 1 in 10 year wave events that vehicle and pedestrian access via the causeway is deemed unsafe and some damage to property floors and floor coverings may be anticipated.

Work is presently being undertaken by Dominic Hames of University of East London as part of a PhD Thesis investigating 'The joint probability of waves and water levels along the Cumbrian coast from Barrow to Silloth'. This will involve wave modelling using REFDF (refraction-diffraction) to generate output conditions relating to wave and tide combinations. However, output has not been available in time for input to the present phase of the SFRA.

### 3.5 Flood Risk Mapping

#### 3.5.1 Background

The Environment Agency has a duty to provide advice to LPAs on the suitability, or otherwise, of formal planning applications with respect to consideration of flood risk. In pursuance of this, the organisation has undertaken or commissioned a number of flood risk mapping initiatives over recent years. Key aspects are discussed in following sub-sections.

#### 3.5.2 Environment Agency Indicative Floodplain Mapping

The Environment Agency has published indicative floodplain maps (IFM) as part of a national flood hazard mapping exercise. These maps show the areas that are indicative of the general zones that could be affected by flood events, overtopping or breaching of flood defence structures. The mapped flood plains nominally relate to the 1% (1 in 100 year) fluvial event floodplain and the 0.5% (1 in 200 year) tidal event floodplain. These maps are a valuable source of readily available information and can allow a rapid assessment of the likelihood of flooding. However, the accuracy of the maps is limited due to the scale of the activity that was undertaken. The maps do not differentiate between those areas that are presently undefended and those that are protected against floods up to the effective level of an existing flood defence. The IFM have now been replaced by the Environment Agency's Flood Risk Zone Maps (see Section 3.5.4).

#### 3.5.3 Coastal Flood Risk Mapping

In 2001, Posford Duvivier (now Royal Haskoning) and Mott MacDonald prepared a report on behalf of the Environment Agency on *Coastal Flood Risk Mapping* in the Northern Area of the North West Region (PD-MM, 2001). The tidal flood plain was defined by the water levels reached by a 1 in 200 year return period tidal event and took into consideration an assessment of the plausible extent and duration of breach failure in existing defences (details of the 'Breach Method' used are presented in Worth and Cox, 2000 and this approach has recently been recommended as industry 'best practice' by CIRIA, 2004). The tidal floodplain was classified as 'defended' if the defences were considered to be secure against still water level overtopping or damage due to wave action during a 1 in 200 year return period event.

Extreme water levels for various ports were taken from a previous analysis by Jeremy Benn Associates (JBA, 1998)<sup>8</sup>. Interpolation was then applied to establish values at 1km intervals along the coast. Consideration of wave action, where relevant, was made with reference to the appropriate Shoreline Management Plan and, for some locations, fetch calculations. Topographic data was derived from 1:25,000 OS maps, OS Landform PROFILE data and unfiltered LiDAR data. The extent of resulting tidal flooding was presented on 1:10,000 scale Ordnance Survey maps.

Various extracts from this report were provided to the Project Team by the Environment Agency, but it would remain a valuable exercise to view the entire document due to its high relevance to the present study.

#### 3.5.4 Environment Agency Flood Risk Zones

The Environment Agency published Flood Zone Maps in 2004 to replace the IFM. These have been prepared in a consistent manner across the UK, providing an estimate of fluvial flooding under the 1% (1 in 100 year) and 0.1% (1 in 1000 year) events. The 0.1% flood event is called the Extreme Flood Outline and this is being adopted by the Environment Agency to define the extent of the PPG25 Low to Medium risk zone on Flood Zone Maps, whilst the 1% event is being adopted to define the extent of the PPG25 High Risk Zone for fluvial flooding.

These fluvial flood zones have been calculated on the basis of hydrology, determined in accordance with the *Flood Estimation Handbook* (IoH, 1999), and flood routing defined by topographic information from the nation-wide NEXTMap Britain™ digital elevation model (which was derived using IFSAR data). The Environment Agency intends to update the 1% fluvial flood extent on a quarterly basis as part of the Strategic Flood Risk Management Framework as and when more accurate mapping and modelling results for Main Rivers and COWs becomes available.

Within tidally affected areas, the PPG25 High Risk Zone is defined by those areas that are potentially at risk from the 0.5% (1 in 200 year) tidal event, without the benefit of defences. The *Coastal Flood Risk Mapping* work undertaken by Posford Duvivier (now Royal Haskoning) and Mott MacDonald was used to inform delineation of this boundary within the present study area.

### 3.6 Barrow Borough Council Local Plan Review

Barrow Borough Council's *Local Plan Review 1996 - 2006*, contains detailed policies and proposals for the use and development of land for the whole of the present study area. Relevant information from this has been included on Figures 2.1, 2.2 and 2.5, which also show the existing flood risk zone mapping. It is vital to note that whilst

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<sup>8</sup> Values from application of the GEV approach were used (see Section 3.3.2 for further details).

these maps have been prepared using the information available for download from Barrow Borough Council's website, they do not contain the latest amendments contained in the First and Second Deposits relating to *Proposed Alteration to Chapter 3 - Housing*. As such, Figures 2.1, 2.2 and 2.5 **do not** accurately represent the very latest situation since some of the housing areas shown on these figures have now been de-allocated. Further details of these changes can be found at the following web pages:

First Deposit [www.barrowbc.gov.uk/pdf/CHAPTER%203%20-%20Alteration.pdf](http://www.barrowbc.gov.uk/pdf/CHAPTER%203%20-%20Alteration.pdf)

Second Deposit [www.barrowbc.gov.uk/pdf/LocalPlan2ndDeposit.pdf](http://www.barrowbc.gov.uk/pdf/LocalPlan2ndDeposit.pdf)

Notwithstanding the above, Figures 2.1, 2.2 and 2.5 demonstrate that there are a number of locations where development areas shown on the Local Plan Review are within the existing flood risk area (zones 2 and 3).

The most important area of conflict between the existing flood plain mapping (zones 2 and 3) and the *Local Plan Review* is in Barrow-in-Furness and relates to fluvial flooding from the Poaka Beck and possible tidal inundation as a result of overtopping or breaching of Cavendish Dock (reservoir) and wider dock system. It is considered that the LPA has responsibilities under PPG25 to undertake an assessment, commensurate with the requirements of the sequential test, to establish whether the proposals contained in the *Local Plan Review* for the above sites are viable in relation to flooding.

In addition, West Lakes Renaissance, an urban regeneration company, has been appointed to develop Master Plans for three areas identified on the *Local Plan Review* as E1, E7 and E8. Zone E1 is not within the flood risk area but the Master Plan incorporates adjacent areas. Sites E7 and E8 fall within the flood risk mapping area for Barrow-in-Furness. Under these circumstances the developer will be required, under the terms of PPG25, to submit a flood risk assessment for development within these sites.

## 3.7 Flood and Coastal Defence Assets

### 3.7.1 Background

In terms of assessing flood and erosion risk, it is the location and type of coastal defence assets, and their present condition and standard of service that are the key aspects. These are discussed further in following sub-sections.

### 3.7.2 Location and Type

Information on the location and type of flood and coastal defence assets is available from a number of sources. In theory, the most up to date and authoritative source

would be the National Flood and Coastal Defence Database (NFCDD). The aim of the NFCDD is to provide a single easily accessible and definitive store for all data on flood and coastal defences in England and Wales, and its development is a requirement under the MAFF 'High Level Targets' for flood and coastal defence operating authorities (see MAFF, 1999 - note: these are soon to be updated by Defra). The Environment Agency is leading the development of the NFCDD, but is working in partnership with local authorities and internal drainage boards to ensure the successful delivery of the database. However, due to the 'in progress' nature of the NFCDD, relevant information is unlikely to become available in time for subsequent phases of the present SFRA.

Consequently, attention must turn instead to existing available sources of information and, in the absence of the NFDCC, this presently comprises:

- MAFF<sup>9</sup> Coast Protection Survey of England and Wales (1994); and
- NRA<sup>10</sup> Sea Defence Survey (1991).

Both of these data sources were used in the preparation of the relevant SMPs and the Walney Island Strategy Study and relevant information has also been mapped as part of Defra's Futurecoast study (although not for the eastern-facing shore of Walney Island or the mainland shore in the lee of Walney Island) and, for Walney Island in its entirety, as part of the *Strategy Study* (Atkins, 2000). Whilst the content of these databases must now be considered somewhat dated, it can still be considered as providing useful information on the location and type of defence assets that are in existence. However, this information can be supplemented with other known sources and, most notably, Capita Symonds has kindly provided a spreadsheet containing a compilation of details from the MAFF and NRA surveys, supplemented with other useful information, such as the crest level and inspection frequency. This spreadsheet is reproduced here as Table 3.9.

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<sup>9</sup> Now part of Defra.

<sup>10</sup> Now part of Environment Agency.

Table 3.9 Information on coastal defence type and location (as collated and kindly provided by Capita Symonds)

CPS/SDS Code	Location	Owner	Start Easting	Start Northing	End Easting	End Northing	Type	Sub-type	Material	Length (km)	Crest Level (mAOD)	Min. Residual Life (yrs)	Worst Cond.	Year Constructed	Inspection Frequency (months)
010/0368/1	Tummer Marsh	Not Known	318074	467496	308226	467844	TE	EM	BK	0.43	6.00		Poor		12
010/0369/1	Biggar Dyke	Barrow Borough Council	318468	466253	319090	467011	TE	EM	BK	0.98	7.00		Fair		12
010/0370/1	Creepshaw Marsh	Not Known	319626	465262	319815	465462	TE	EM	BK	0.34			Poor		12
010/0371/1	Wylock Marsh	Not Known	319932	463970	320389	464134	TE	EM	BK	0.52	5.80		Fair		12
010/0372/1	Rape Haw	Not Known	320996	462330	321298	462721	TE	EM	BK	0.52	6.00		Good		12
010/0373/1	South Haws - Shelley Bars	Not Known	322115	462086	322974	462631	TE	EM	BK	1.58	6.70		Good		12
210/8001/1	Near Peasholmes Lane	Cumbria County Council	324314	466412	324934	467034	RV	WL	CN	0.89	7.20	<5	Class 4	1930	12
210/8001/2	Near Peasholmes Lane	Cumbria County Council	324314	466412	324934	467034	RV	RW	CN	0.89	7.20			1930	12
210/8001/3	Near Peasholmes Lane	Cumbria County Council	324314	466412	324934	467034	GR	NA	TM	0.89				1930	12
210/8002/1	North East of Rampside	Private	324119	466267	324247	466366	RV	WL	CN	0.16	8.50	5-10	Class 3	1900	12
210/8003/1	Concle	Private	323500	465979	323703	466047	RV	WL	CN	0.21	8.10	5-10	Class 3	1900	12
210/8004/1	Roa Island Road	Railtrack	323227	465090	323382	465868	GB	NA	OT	1.50	6.80	<5	Class 4	1890	12
210/8005/1	Roa Island	Barrow Borough Council	323171	464965	323309	464926	RV	EM	CN	1.07	7.50	5-10	Class 3	1950	12
210/8006/1	Piel Island	English Heritage	323241	463529	323369	463830	RV	EM	ST	0.39	7.10	5-10	Class 3	1950	12
210/8007/1	Concle Bank	Barrow Borough Council	323235	465868	323358	466121	SH	NL	SC	0.28	7.00				12
210/8008/1	Beacon Hill	Barrow Borough Council	322817	466123	323234	466460	SH	NL	SC	0.54					12
210/8009/1	Pike Stones Bed	Barrow Borough Council	322623	466460	322813	466627	SH	NL	SC	0.25					12
210/8010/1	Ridding Head Scar	North West Gas	322466	466628	322623	466828	SH	NL	SC	0.26					12
210/8011/1	Westfield Point	North West Gas	322218	466830	322694	468230	RV	AL	RK	1.62			Class 1		12
210/8011/2	Westfield Point	North West Gas	322218	466830	322694	468230	SH	NL	SC	1.62					
210/8012/1	Cavendish and Ramsden Docks	Associated British Ports	320298	467251	322163	468333	RV	EM	MS	2.17	7.10	5-10	Class 3	1870	12
210/8012/2	Cavendish and Ramsden Docks	Associated British Ports	320298	467251	322163	468333	SW	WL	MS	2.17	7.10			1870	12
210/8012/3	Cavendish and Ramsden Docks	Associated British Ports	320298	467251	322163	468333	RV	EM	MS	2.17	7.10			1870	12
210/8013/1	Ramsden Dock Entrance	Associated British Ports	320076	467103	320187	467126	RV	EM	RK	0.30	7.00	>10	Class 3	1992	12
210/8014/1	Belfast Berth	Associated British Ports	319719	467099	320032	467360	SW	WL	CN	0.20	7.00	>10	Class 2	1870	12
210/8015/1	Deep Water Berth	Associated British Ports	319439	467358	319721	467818	RV	EM	ST	0.59	7.00	<5	Class 4	1870	12
210/8015/2	Deep Water Berth	Associated British Ports	319439	467358	319721	467818	RV	EM	RB	0.59	7.00			1870	12
210/8015/3	Deep Water Berth	Associated British Ports	319439	467358	319721	467818	RV	EM	RB	0.59	7.00			1870	12
210/8015/4	Deep Water Berth	Associated British Ports	319439	467358	319721	467818	RV	EM	ST	0.59	7.00			1870	12
210/8016/1	Barrow Island	Associated British Ports	319404	467818	319527	467942	RV	EM	MS	0.20	7.00	>10	Class 2	1870	12
210/8017/1	BAE Systems	BAE Systems	319160	467900	319401	468155	RV	EM	BK	0.38		>10	Class 2	1980	12
210/8018/1	BAE Systems	BAE Systems	319105	468155	319159	468185	SW	AP	MS	0.06		>10	Class 2	1986	12
210/8018/2	BAE Systems	BAE Systems	319105	468155	319159	468185	SW	WL	CN	0.06				1986	12
210/8018/3	BAE Systems	BAE Systems	319105	468155	319159	468185	GB	WB	ST	0.06				1986	12
210/8019/1	BAE Systems	BAE Systems	319033	468187	319103	468359	SW	AP	MS	0.19		>10	Class 2	1920	12
210/8020/1	BAE Systems	BAE Systems	319019	468361	319034	468407	SW	AP	MS	0.05		>10	Class 2	1986	12
210/8020/2	BAE Systems	BAE Systems	319033	468364	318989	468515	GB	WB	ST	0.05				1986	12
210/8021/1	Former BAE Systems West Shop	Barrow Borough Council	318989	468515	318932	468715	RV	EM	RK	0.32		>10	Class 2	1950	12
210/8022/1	North of Jubilee Bridge	Barrow Borough Council	318892	468732	318933	468919	SW	WL	CN	0.19		>10	Class 2	1986	12
210/8023/1	Jubilee Bridge to Crook Scar	Private	318830	468921	318935	469480	SW	WL	MS	0.67		>10	Class 2	1920	12
210/8024/1	Crook Scar	Private	318725	469478	318829	469721	SW	WL	MS	0.26		5-10	Class 3	1920	12
210/8025/1	Hindpool	Private	318711	469721	318740	470159	SH	NL	CC	0.44					12
210/8026/1	Hindpool North	Cumbria County Council	318741	470158	318782	470720	SH	NL	CC	0.57		>10	Class 1		12

CPS/SDS Code	Location	Owner	Start Easting	Start Northing	End Easting	End Northing	Type	Sub-type	Material	Length (km)	Crest Level (mAOD)	Min. Residual Life (yrs)	Worst Cond.	Year Constructed	Inspection Frequency (months)
210/8026/2	Hindpool North	Cumbria County Council	318741	470158	318782	470720	RV	AL	RK	0.57				1990	12
210/8027/1	Ormsgill	Cumbria County Council	318760	470600	318902	470720	RV	TE	RB	0.19		>10	Class 2	1930	12
210/8028/1	Promenade North	Barrow Borough Council	318319	468650	318664	469669	TE	EM	MS	1.13	5.80	5-10	Class 2	1930	12
210/8029/1	Hare Hill	Barrow Borough Council	320368	462672	320527	462960	SH	NL	CC	0.33	12.5	>10	Class 1		12
	South End Farm Landfill <sup>11</sup>	Barrow Borough Council					RV			0.30		>10	Class 1		
210/8030/1	White Horse Scar <sup>12</sup>	Barrow Borough Council	319482	463746	319951	464463	RV	AL	RK	0.86	6.50	>10	Class 1	1987	12
210/8031/1	Cow Leys Lane	Barrow Borough Council	318923	464754	319216	465229	AR	BD	RK	0.56	7.60	>10	Class 1	1988	12
210/8032/1	Middle Hill Lane	Barrow Borough Council	318555	465660	318642	465814	AR	BD	RK	0.18	7.60	>10	Class 1	1988	12
210/8033/1	Bent Haw	Barrow Borough Council	318190	466216	318339	466535	RV	AL	RK	0.35	9.10	>10	Class 1	1988	12
210/8034/1	Walk Haw Scar	Barrow Borough Council	317156	468841	317214	469234	RV	WL	MS	0.41	7.20	>10	Class 2	1950	12
210/8035/1	Walk Haw Scar North	Barrow Borough Council	317163	469236	317210	469492	RV	WL	MS	0.26	8.70	5-10	Class 3	1950	12
210/8036/1	Earnse Bay	Barrow Borough Council	317011	469492	317164	470003	RV	AL	RK	0.55	9.00	>10	Class 1	1993	12
210/8036/2	Earnse Bay	Barrow Borough Council	317011	469492	317164	470003	RV	AP	OT	0.55	9.00			1993	12
210/8036/3	Earnse Bay	Barrow Borough Council	317011	469492	317164	470003	GR	FT	RK	0.21				1993	12
210/8037/1	Isle of Walney	Barrow Borough Council	317214	468827	318188	466537	SH	NL	SH	2.51					12
210/8038/1	Lowsy Point	Barrow Borough Council	318466	473920	318564	474024	RV	AL	RK	0.15				1990	12
210/8039/1	Low Bank	Cumbria County Council	319960	463298	320188	463711	RV	AL	RK	0.47	8.40			1998	12
210/8040/1	Marsh Street Askam	Barrow Borough Council	320963	477821	320979	477984	RV	AL	RK	0.16	7.00			1999	12
210/8040/2	Marsh Street Askam	Barrow Borough Council	320963	477821	320979	477984	RV	EM	CC	0.16	10.50			1999	12
210/8041/1	Bent Haw Tip	Barrow Borough Council	318340	466214	318464	465991	RV	BD	ST	0.25	6.00			2000	12
210/8041/2	Bent Haw Tip	Barrow Borough Council	318340	466214	318464	465991	RV	EM	SH	0.25	8.00			2000	12
210/8042/1	Roa Island - Marine Terrace	Private	323200	464809	323261	464789	RV	EM	CN	0.07				1950	12
210/8043/1	Roa Island Belfast Pier (Boat Club)	Private	323209	465114	323237	465091	RV	EM	CN	0.00				1950	12

Type Codes		Sub-type Codes		Material Codes		Worst Condition	
RV	Revetment	EM	Embankment	BK	Block	Class 1	Condition as built.
TE	Tidal Embankment	WL	Wall	CN	Concrete	Class 2	Some signs of wear, needs to be kept under observation; returnable to Class 1 with simple maintenance, i.e. work advisable in order to prevent undue deterioration.
GR	Groynes	RW	Recurved Wall	TM	Timber		
GB	Gabion	NA	Not Applicable	OT	Other	Class 3	Moderate works required; probably limited to a maintenance operation to return to satisfactory condition, i.e. work needed to sustain adequate performance.
SH	Shore	NL	Natural	ST	Stone		
SW	Sea wall	AL	Armour Layer	SC	Sandstone Cliff	Class 4	Significant works needed; capital works probably required within 5 years.
AR	Armour	AP	Apron	RK	Rock		
		WB	Wire Basket	MS	Masonry		
		BD	Bund	RB	Rubble		
		FT	Fishtail Groyne	CC	Clay Cliff		
				SH	Shingle		

<sup>11</sup> This section of defence was constructed after the MAFF Coast Protection Survey and has been added with details from the SMP (SMP, 1999).

<sup>12</sup> The SMP (1999) reports that this section of defence deteriorated since the MAFF Coast Protection Survey.

### 3.7.3 Condition Assessments and Standards of Service

As previously identified, information on the location and type of coastal defences is available from the MAFF and NRA asset surveys. Whilst these also provide a degree of assessment of minimum residual life and worst condition of the defences (as included on Table 3.9), more recent condition assessments have been undertaken of many assets and these are now summarised.

#### (a) Walney Island Strategy Study

To assist with the preparation of the above study, Atkins (2000) evaluated the condition of the Walney Island defences and estimated their standard of service. It was identified that whilst the condition and age of existing defences varies considerably, the older defences tend to be located either in sheltered positions or where beach levels are reasonably stable, and therefore their active life is prolonged.

Defra's Project Appraisal Guidance for Strategy Studies requires an assessment of responses assuming a 'do nothing' option is applied. This is then used as the base case against which 'do something' options are evaluated. Atkins considered that under a 'do nothing' option:

- some sections of existing defence would remain effective without significant problems arising: these included the Earnse Point rock groyne and rock revetment (210/8036);
- some sections are presently considered to offer a lower residual life and/or be of a worse condition than that stated in the MAFF or NRA surveys: including the rock armour/broken concrete that has been tipped against eroding cliff face at Bent Haw (210/8033) and apparent low spots in the crest of defences at Middle Hill (210/8032) and Cow Leys (210/8031);
- some sections may become outflanked by continued erosion of the shoreline to either side: including isolated defences at Bent Haw, Middle Hill and Cow Leys;
- defences fronting the landfill tip between Hillock Whins and Honey Pot Lane (210/8030) appear either to have been set at too low a crest elevation or have settled due to insufficient filtering layers. This could lead to structural damage and eventual leaching of material from the rubbish tip; and
- in the absence of routine maintenance, defences on the eastern side of Walney could deteriorate.

Whilst many of the existing defences on Walney Island are intended to limit erosion, several are of relevance for assessing flood risk. These include the tidal flood embankments along parts of the eastern side of the island, such as Biggar Dyke (010/369), and revetments at Middle Hill (210/8032) and Cow Leys (210/8031) fronting low-lying land on the western side. The overtopping of these revetments in February 1997 led to extensive flooding that reached Biggar on the east side of the island.

Atkins also undertook a first-order assessment of the standard of service afforded by existing flood and coastal defence assets, taking into consideration a 1 in 200 year return period extreme water level of 6.50m AOD. For structures on the western side of Walney a nearshore wave height of 2.0m was assumed; for structures on the eastern side, wave activity is extremely limited and was excluded from the assessments. Results from the assessment are summarised in Table 3.10.

**Table 3.10 First-order assessments of standard of service provided by existing defences against flooding (Source: Atkins, 2000)**

CPS/SDS Code	Location	Exposure to Waves	Crest Level (m AOD)	Crest Level - Wave Height (m AOD)	Equivalent Water Level Return Period (yrs)
210/8036	Earnse Point	Yes	9.0	7.0	1000
210/8035	Walk Haw Scar (N)	Yes	8.7	6.7	250
210/8034	Walk Haw Scar (S)	Yes	7.2	5.2	2
210/8033	Bent Haw	Yes	9.1	7.1	1000
210/8032	Middle Hill	Yes	7.6	5.6	5
210/8031	Cow Leys	Yes	7.6	5.6	5
	Landfill Tip (N)	Yes	7.5	5.5	5
-	Landfill Tip (Low Bank)	Yes	8.4	6.4	150
	East coast, south of Biggar	No	6.0 <sup>13</sup>	6.0	25
010/369	Biggar Dyke	No	7.0	7.0	1000
210/8028	North of Jubilee Bridge	No	5.8	5.8	15

From this first-order assessment, it can be seen that some sections of defence provide quite a low standard of service, particularly between Middle Hill and Cow Leys and again at the northern end of the landfill site. It is, therefore, unsurprising that these areas have been notably vulnerable areas in recent years.

(b) Devonshire Dock Facility: Design Substantiation for the Astute Safety Case

Owen Williams Consultants undertook a condition survey of the Outer Dock System in 2001 on behalf of BAE Systems. This was part of the safety case for construction of *Astute* nuclear submarines at the Devonshire Dock complex. Whilst the resulting

<sup>13</sup> Assumed, rather than measured

report (Owen Williams Consultants, 2001) was kindly supplied to the Project Team by BAE Systems for use in the present study, it is not available for wider dissemination and consequently only broad findings are summarised here. Notwithstanding this, the report should be used in full in the subsequent phases of the study, if permissible, since it assesses the condition of each section of wall surrounding Devonshire, Buccleuch and Ramsden Docks (collectively referred to as the Outer Dock System), including both a schedule and photographic record of defects. Broad findings are:

- The Outer Dock System is formed predominantly of sandstone masonry gravity dock walls that were constructed in the Victorian era. In places these have been fronted/replaced by steel sheet piling.
- There exist a significant number of locations where the dock walls and quays have defects (due principally to their age and lack of maintenance);
- There are considered to be no areas where immediate collapse is threatened; and
- Whilst reference is made to a separate report on the overall integrity of the docks system, this report was never produced.

The report also includes a series of hand-drawings that were provided to Owen Williams Consultants by ABP Barrow. Crest level information has been extracted from these drawings, where possible, for the purpose of the present study and is summarised in Table 3.11.

**Table 3.11 Crest levels of dock walls in the outer dock system (Sources: ABP Barrow drawings)**

Location	Crest Level (mAOD)
Devonshire Dock North Wall	7.62
Buccleuch Dock North Wall	7.73

No crest level information is presented in the report for Buccleuch Dock Narrows, Ramsden Dock (main dock area) or Anchor Basin, and relevant information on the drawings for Buccleuch Dock South and Ramsden Dock Basin and Lock is not discernable.

(c) Cavendish Dock

Cavendish Dock is a water balancing reservoir for the wider docks system, intended to feed other docks, as necessary, with enough water to maintain them as operational under all tidal conditions. It was constructed around 1870, is rectangular in plan form and is bounded by embankments along all four sides.

Along the southern side of the Cavendish Dock runs the 'long embankment', which has a reported crest level of 7.1m AOD and a crest width of around 5m. The seaward side of the crest has a small masonry wall that is approximately 0.5m high that helps prevent wave overtopping. This embankment separates the water held in the dock from the sea; at low tide, water held in the dock is generally higher than the sea, but at high tide, the sea level can be higher than the dock water. There is a bi-directional sea sluice (single culvert) in the western end of this embankment through which water can enter or leave the dock when the vertical penstock is open, depending on tidal conditions. Under 'normal' conditions, the water in the dock is maintained at around 4.56mAOD (this is the invert level of the culvert) and it is understood that during extreme tidal conditions the penstock is closed by ABP in order to prevent sea water from flowing into the dock. A pair of timber paddles could be used as a back-up means of closing the culvert in the unlikely event of penstock failure. Both faces of the embankment are protected with open-jointed sandstone pitching and an unsurfaced track runs along its full length. In isolated areas, the voids between pitching stones have previously been sealed with concrete slurry discharged from the crest.

The western embankment separates Cavendish Dock from Ramsden Dock, which in turn connects to Buccleuch Dock. Twin culverts in this embankment are the means by which water can be released from storage in Cavendish Dock to Ramsden Dock. The culverts are pre-cast concrete units that each measure 1.37m in width and 1.22m in depth, with invert levels of 3.23mAOD. The embankment itself is relatively wide-crested and supports dock-serving infrastructure, namely both a single-track rail line and a surfaced road. Both faces of the embankment are protected with stone pitching.

The northern boundary is formed by a substantial railway embankment, which in turn is generally backed by higher ground. Similarly, in the south-eastern corner, the dock is formed through natural higher ground.

In the north-east corner, an embankment of around 150m in length retains the dock water from flowing across the lower ground that is situated immediately outside of the dock area. It is this short length of water-retaining embankment that classifies the dock as a reservoir. The crest and landward face of the embankment are grassed and whilst the seaward face is protected with open-jointed pitching in places, elsewhere rock, boulders and rubble have simply been dumped. A narrow footpath runs along the embankment crest, which has a total width of around 2.5m and a reported level of 5.6 to 5.7mAOD.

There is a gauge board in the dock and records are kept of weekly water level observations: these range from 4.26mAOD to 4.56mAOD.

The Poaka Beck (sometimes named Mill Beck at this location) discharges into Cavendish Dock close to its north-eastern corner via a small channel that runs beneath the railway embankment.

As Cavendish Dock is classified as a reservoir under the Reservoir Act 1975, it is inspected annually by a Supervising Engineer and on a 10-yearly basis by an 'All Reservoirs Panel' Inspecting Engineer. The most recent reports by these engineers have been reviewed for the present study, with key points highlighted below.

#### **Inspecting Engineer's Report (Airey, 2003):**

- The 'long embankment' was considered by the Inspecting Engineer to be an inherently stable structure, although there remains a need for targeted maintenance (continuous and ongoing) in order to repair the pitching on both sides of the embankment. In isolated patches, joints between the pitching on the seaward face had become exploited and the backing material washed out, resulting in some sinking of pitching stones. The crest was considered to be in satisfactory condition, although the masonry wall was, at the time of the inspection, considered to be in poor condition due to vandalism;
- The south-east corner of the dock was considered to be in satisfactory condition;
- The north-east water-retaining embankment was subject to regular maintenance at the time of the inspection to repair localised problems. It is an area of the dock defence system that is regularly observed since some leakages/damp patches have been observed on the landward side in key places and the crest levels are substantially lower than those along the 'long (seaward) embankment'. Crest level observations have been undertaken along this embankment since 1996 using ten permanent markers spaced at nominal 10m centres, and no settling of the embankment has been observed to date;
- The embankment separating Cavendish and Ramsden Docks was considered to be in good condition;
- The penstock in the sea sluice and twin culverts that serve to balance water levels between docks are regularly used and operational, but the timber paddles of the sea sluice were jammed in a partially opened position. It was recommended by the Inspecting Engineer that this issue be rectified or the paddles removed to avoid collecting debris; and
- In addition, the report notes that there was a rising main sewer newly constructed by United Utilities in 1998 along the northern boundary of the reservoir, and due to proximity of construction works to the reservoir, the proposed construction methods were reviewed by an 'All Reservoirs Panel' Inspecting Engineer. These works were successfully completed with no reported difficulties.

The Inspecting Engineer also made a recommendation which is key to the present study. He stated that the Poaka Beck inlet flood and discharge capacity should be reviewed and he presented the following argument for this:

- The reservoir was classified as 'Flood Category D' in accordance with the Institution of Civil Engineers' publication *Floods and Reservoir Safety* (ICE, 1996), *i.e.* a breach of the north-eastern water-retaining embankment would not lead to loss of life and would cause only limited flood damage since whilst there would be some inundation of the road and areas around railway bridge, the few properties in this area are slightly elevated and would probably avoid flooding;
- The design inflow condition for Flood Category D reservoir is 1 in 150 year flood event and, using the *Flood Estimation Handbook* (IoH, 1999), the peak discharge for such an event would be 50 cumecs, with a time to peak of 12 hours. This yields an estimated flood volume of 1Mm<sup>3</sup>, which is very much greater than the discharge capacity of Poaka Beck's inlet works beneath the railway embankment;
- Consequently, there is likely to be flooding along the Poaka Beck channel in the vicinity of railway underpass, but there is also likely to be an increase in water levels entering the dock from the inlet channel (of the order of 0.7m was estimated) and, potentially, surcharges due to wind-wave activity across the dock (up to 0.5m was estimated), resulting in implications on reservoir safety and potential minor overtopping of the water-retaining embankment.

The Inspecting Engineer's concluding recommendation was that there was a need to re-examine freeboard levels with respect to embankment overtopping potential under extreme flood conditions. This should be achieved through the following tasks to assess flood risk and flood water routing:

- Derive the 1 in 150 year flood hydrograph for the Poaka Beck catchment;
- Calculate the discharge capacity of the inlet channel to the dock;
- Assess the route for excess flow away from the dock and the discharge characteristics of this flow;
- Consider the sensitivity of the results to different operating regimes of the sea sluice, including the maximum potential period the sluice may be closed;
- Re-assess the wind-wave surcharge that may occur; and
- Re-assess the freeboard that exists.

The above tasks need to be completed before 7<sup>th</sup> August 2005, and a *Certificate of Satisfactory Completion* obtained under Section 10(6) of the Reservoirs Act, 1975.

#### Supervising Engineer's Report (Badley, 2004):

- Minor comments were made regarding the need to undertake continuous, ongoing maintenance of the 'long embankment' and repair the previously noted damage to the masonry wall along the seaward face of the embankment crest, but overall the condition was considered to be similar to the previous inspection;
- The report states that repair work on the north-eastern water-retaining embankment had been completed but that there remained the need for continuous and ongoing maintenance to repair damage to local areas, and some signs of leakage, similar in location and scale to those observed during the previous visit, were observed;
- The timber paddles in the sea sluice had been restored to working order.

#### (d) Roa Island

JBA undertook a condition survey and damage risk assessment of the Roa Island causeway in 1999 on behalf of Rail Property Limited. Results are presented in detail, with accompanying photographic records, in JBA's report (dated May 1999). The intention of the study was to determine whether the causeway would be at risk of overtopping, failure of its protective facing and erosion of its clay core, or complete structural failure. At the time of the assessment, it was considered that certain sections of the causeway had little residual life and that urgent re-facing works were required to prevent erosion of the clay core. Certain works were implemented subsequent to issue of the report.

More recently, as part of the *Roa Island Shorelink Sustainability Study*, Coastal Engineering UK undertook a visual inspection of the condition of the defences along the causeway and around Roa Island. Results are presented in detail, with accompanying photographic records, in ABPmer Report No. R.1030 (dated June 2003) and are summarised in Table 3.12. The primary function of the defences around the island is to protect the shoreline from erosion, but they also serve a dual purpose by limiting overtopping and providing protection against flooding. The overtopping assessments that were carried out as part of that study suggest that all island and causeway defences provide typically the same level of protection and are estimated to be at risk of being overtopped from events with roughly a 10% annual probability of exceedence. Events with a 1-2% annual probability of exceedence can effectively temporarily cut off the island from the mainland at the height of the storm, as well as providing conditions that affect assets on the island.

Table 3.12 Summary of coastal defence inspection assessment at Roa Island and causeway (Source: ABPmer, 2003)

Code	Structure		Nature	Condition		Residual Life Expectancy (Without Attention)			Risk Level
	Name	Length (m)		Visual	CPSE Class	Min	Expected	Max	
210/8004a	Roa Island Causeway (Barrow Side)	730	Existing undamaged revetment	Fair	2	5	10	50	Medium
			New grouted stone revetment	Very Good	1				Low
			Grouted gabion revetment	Good	2				Low
			Damaged sections of revetment	Poor	4				High
			Concrete faced revetment	Fair	3				Medium
210/8004b	Roa Island Causeway (Morecambe Bay Side)	800	Southern section	Poor	4	5	10	20	High
			Car park area	Good	2				Low
			Northern section	Good	2				Low
210/8005a	Roa Island Boating Club House Spit/Jetty	400	North facing revetment	Fair	2	5	15	30	Medium
			Seaward end	Poor	3/4				Medium
			South facing revetment	Fair	3				Medium
210/8005b	Roa Island Boating Club House Spit to Watch Tower	125	Blockwork revetment	Poor	3	5	15	25	Medium
210/8005c	Roa Island South End (Watch Tower to Foulney St Slipway)	225	Concrete/masonry revetment	Fair	3	5	15	30	Medium
210/8005d	Roa Island Foulney St Slipway to Causeway South	200	Trinity Terrace revetment	Poor	3	5	20	30+	Medium
			Former Roa Island School frontage	Fair	2/3				Medium
			Boat Club frontage	Good	1/2				Low

(e) Summary

Table 3.13 presents a summary of the most recent information available relating to the condition and/or standard of service of the existing flood and coastal defences that are of key importance to management of flood risk within the study area.

**Table 3.13 Summary of most recent asset assessments**

Location	Source	Assessment	
		Condition	Standard of Service
Devonshire, Buccleuch and Ramsden Docks	<i>Devonshire Dock Facility Safety Case</i> (Owen Williams Consultants, 2001)	x	
Cavendish Dock	<i>Inspecting Engineer's Report</i> (Airey, 2003) <i>Supervising Engineer's Report</i> (Badley, 2004)	x	
Walney Island	<i>Walney Island Strategy Study</i> (Atkins, 2000)	x	x
Roa Island	<i>Roa Island Shorelink Sustainability Study</i> (ABPmer, 2003)	x	

### 3.8 Strategic Studies

Strategic studies are undertaken to identify appropriate policies to manage flood and coastal erosion risk in a sustainable manner that takes due consideration of technical, economic and environmental issues. This does not necessarily imply that all 'at risk' zones will be defended since it may be more sustainable in the longer-term to 'do nothing' or undertake 'managed re-alignment'. Consequently, when assessing flood risk via the SFRT it is important to know if any strategic policies will be altered from the present approaches. Relevant strategic studies include:

- 'High-level' Catchment Flood Management Plans (for policies to manage fluvial flood risk);
- 'High level' Shoreline Management Plans (for policies to manage tidal flood risk and coastal erosion risk);
- Further strategic studies as recommended by the 'high level' plans;
- Strategy Studies in accordance with PAG2 (MAFF, 2001) to identify options by which the 'high level' policies can be implemented.

#### 3.8.1 Catchment Flood Management Plans

A Catchment Flood Management Plan (CFMP) is a high-level policy document for the strategic, catchment-wide, management of flood risk, in a sustainable manner, over a 50-100 year horizon. Bullen Consultants Limited is presently undertaking the South West Lakes CFMP on behalf of the Environment Agency (North West Region) and, to

date, has produced an Inception Report (Bullen, 2005) which covers initial consultation and data collection/collation.

The South West Lakes CFMP includes the Barrow-in-Furness study area of the present SFRA and identifies that in this area the main flood risks are related to river flooding within the Poaka/Mill Beck sub-catchment and tidal and sewer flooding and Barrow-in-Furness sub-catchment. Note: tidal flooding is addressed within the SMP and Strategy Study processes, and not the CFMP process.

During the course of the present study, telephone discussions were held between the different Project Teams to ensure unnecessary duplication of effort was avoided and to provide mutual assistance between projects.

### 3.8.2 Dalton-in-Furness Pre-feasibility Study

It is understood that a *Pre-feasibility Study* has been undertaken by Babtie Group (now Jacobs Babtie) to assess possible problems with flooding in Dalton-in-Furness. The study has been reported to include some hydraulic modelling and an economic assessment. Iwan Lawton of the Environment Agency has stated that the study output is not in the form of a conventional report, but rather a collection of spreadsheets and other digital information.

The Project Team for the present study has not had sight of this data and is unable to pass comment on the hydrology, hydraulic modelling, calibration and results of the *Pre-feasibility Study*. It is recommended that these data are obtained and evaluated during the next phases of the SFRA, although it is noted that there would be an associated purchase cost from the Environment Agency.

### 3.8.3 Shoreline Management Plans

A Shoreline Management Plan (SMP) is a high-level policy document for the strategic, sediment subcell-wide, management of tidal flood and coastal erosion risk, in a sustainable manner, over a 50-100 year horizon. There are two SMPs of relevance to the study area (Table 3.14). There exists some overlap in boundary between these SMPs, with the northern end of Walney Island being covered in both plans.

**Table 3.14 Relevant shoreline management plans**

Sub Cell	Name	Date	Lead Authority	Consultant
11c	Morecambe Bay	March 1999	Lancaster City Council	Shoreline Management Partnership
11d	Earnse Point to St Bees Head	November 1998	Copeland Borough Council	Bullen Consultants

In both SMPs, the shoreline has been broken down into a number of Management Units (MU) and shoreline management policies are then selected for each MU in order to manage the risks due to coastal erosion or tidal flooding. Those MUs within the present study area are listed in Table 3.15, together with the selected management policies.

**Table 3.15 Management units and management policies**

SMP	MU	Location	Management Policy
11d	11	Dunnerholme Point to Sandscale Haws	Selective 'Hold the Line' and 'Do Nothing'
	12	North Walney Channel	'Do Nothing'
	13	North Walney Coast	'Do Nothing' (localised 'Hold the Line' at Earnse Bay to Mill Scar)
11c	1/1	North Walney	'Do Nothing'
	1/2	Earnse Bay to Mill Scar	'Hold the Line'
	1/3	Mill Scar to Nanny Point Scar	'Do Nothing'
	1/4	Nanny Point Scar to Hillock Whins	'Do Nothing'
	1/5	Hillock Whins to Hare Hill	Selective 'Hold the Line' and 'Do Nothing'
	1/6	Hare Hill to South End Haws	Selective 'Hold the Line' and 'Do Nothing'
	1/7	South End Haws to Biggar	Selective 'Hold the Line' and 'Do Nothing'
	1/8	Biggar to Walney Airfield (south)	Selective 'Hold the Line' and 'Do Nothing'
	1/9	Hindpool to Westfield Point	'Hold the Line'
	1/10	Westfield Point to Rampside	'Do Nothing'
	1/11	Piel Island	Selective 'Hold the Line' and 'Do Nothing'
2/1	Rampside and Roa Island	Selective 'Hold the Line' and 'Do Nothing'	
2/2	Rampside to Newbiggin	'Hold the Line'	

### 3.8.4 Walney Island Strategy Study

Atkins developed a Strategy Study for Walney Island in a number of stages between 2000 and 2004. This was aimed at further assessing the risk from tidal flooding and coastal erosion and proposing management options to mitigate those risks. A key conclusion of this study was that for the foreseeable future (of the order hundreds of years), Walney Island is not at risk of a 'permanent' breach caused by coastal erosion. Despite this, the island will continue to experience occasional 'temporary breaches', or flood water linkage caused by waves overtopping defences during extreme storms, but the problem abates as the tide recedes over a period of days. Nevertheless, it is appreciated that this is of great concern to isolated communities, particularly around Biggar and Tummer Hill. The study recommends a strategy for protecting Walney Island's human and environmental assets through "*Sustainable Selective Intervention*" (Atkins, 2004).

### 3.8.5 Roa Island Shorelink Sustainability Study

ABPmer, working in association with Coastal Engineering UK Limited (CEUK), undertook the Roa Island Shorelink Sustainability Study in 2003 (ABPmer, 2003). This included a walk-over condition assessment of the causeway and island coastal defences, together with assessments of the risk of flooding. The study concluded that with the coastal defences remaining adequately maintained, the principal flood risk would be through overtopping. Whilst, under the range of conditions investigated, physical damage to assets on the island would be limited, access to the island via the causeway could become temporarily prevented.

## 4. Conclusion and Recommendations

### 4.1 Prioritisation of Tasks for the SFRA

Although the study area is not large, there are a substantial number of issues associated with tidal inundation and fluvial flooding throughout the borough which could be addressed by more detailed hydraulic assessment. This includes a myriad of issues in the town of Barrow-in-Furness, which has a high population density, and issues along the southern parts of Walney Island, which by contrast is sparsely populated.

It is considered that some form of prioritisation be applied within subsequent phases of the SFRA, principally because of the time and cost of obtaining topographic data, information on defence crest levels, and undertaking condition surveys and in performing the appropriate hydraulic analyses for a large number of sites. Areas that, by virtue of the flood risk mapping, have a high number of properties at risk should be categorised as the highest priority, where further studies are considered 'very urgent'. Conversely, areas that are sparsely populated and contain fewer properties at risk should be classified as medium or low priority and here studies are considered to have somewhat less urgency. These criteria for prioritisation are commensurate with the definition of flood risk zones 3a, 3b and 3c in PPG25 and have the virtue of being comparatively simple. Thus, the approach is as follows:

- |                                                                                                                                                                   |                                                                                                                                                                                               |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>▪ 3a Developed areas</li> <li>▪ 3b Undeveloped and sparsely developed areas</li> <li>▪ 3c Functional floodplain</li> </ul> | <div style="display: flex; align-items: center;"> <div style="font-size: 2em; margin-right: 5px;">↓</div> <div> <p>High Priority</p> <p>Medium Priority</p> <p>Low Priority</p> </div> </div> |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Using this classification, Barrow-in-Furness, where approximately 1,850 properties are at risk of tidal inundation and fluvial flooding, is considered a high priority area where further investigations are deemed 'very urgent'. The other sites in the study area are considered to medium or low priority and Table 4.1 ranks these sites by the number of properties that are potentially at risk of flooding. The location numbering for these sites

can be cross referenced against Figures 2.3 and 2.4, which also highlight the properties at risk of flooding (in magenta).

**Table 4.1 Locations ranked by number of properties at risk**

Site Reference	Location
13 and 11	Barrow-in-Furness
3, 4 and 6	East coast of Walney Island, including Biggar and Vickerstown,
17	Dalton-in-Furness
8 and 9	Roa Island, Rampside and Sarah Beck
2 and 5	West coast of Walney Island, including Biggar Bank Road and Earnse Point
18 and 20	Duddon Estuary
20	Marsh Grange
19	Blea Beck, Askam-in-Furness
15	Poaka Beck, including Furness Abbey and Park House Farm

This philosophy of prioritising future effort based on the degree of risk has been encapsulated within the recommendations that have been made in Section 4.3 for subsequent phases of the SFRA.

## 4.2 Opportunities for Defra Grant-in-Aid

The recommendations made in Section 4.3 also incorporate discussions associated with Grant-in-Aid in accordance with "Flood and Coastal Defence Project Appraisal Guidance: FCDPAG 1 to 6" published by MAFF (now part of Defra) between 1999 and 2001. The objective of the FCDPAG series is to provide a sequential test for the implementation of flood alleviation schemes and it has three basic stages which are:

- Pre-feasibility Study;
- Project Appraisal Report (PAR); and
- Design and Construction.

A *Pre-feasibility Study* is the assessment of the cause, mechanism, frequency and consequences of a potential flood. Such a study also involves a preliminary evaluation of possible measures to mitigate flooding. A *Project Appraisal Report* (PAR) is the result of a more detailed supplementary study that includes engineering, economic and environmental assessments undertaken in accordance with FCDPAG, with a view to identifying a specific engineering option. A PAR may incorporate both preliminary and some detailed design.

For progression from Pre-feasibility Study to PAR, and then from PAR to design and construction, there needs to be a positive response to all of the following four questions.

- (a) *Is there a net benefit?*  
Demonstration that the savings achieved by eliminating or reducing the costs of flood damage are greater than the cost of the flood alleviation works themselves.
- (b) *Does it warrant priority?*  
Demonstration that this location warrants investment ahead of other proposals throughout England by ranking the respective Cost / Benefit ratios.
- (c) *Can it be done?*  
Demonstration that there are practical solutions to alleviate the flooding which do not simply move the problem elsewhere, or are less acceptable than the problem itself and demonstration that the potential solutions are achievable (difficulties may include Planning, Land, Environment, Local Support)
- (d) *Can it be funded?*  
Is Defra Grant-in-Aid and other funding available to pay for the works?

Defra Grant-in-Aid is awarded at some percentage of the cost of a Pre-feasibility Study, PAR and design/construction, but the precise amount varies around the country. It should also be noted that Defra's criteria for awarding Grant-in-Aid is dependent upon the results of the economic assessment and the total number of properties potentially affected by flooding. Again, the criteria changes from time to time but typically, in order to obtain Grant-in-Aid, benefit : cost ratios greater than 4.0 should be obtained, with more than 50 properties affected.

Given that there are approximately 1,850 properties within the flood risk mapping area for Barrow-in-Furness, it is considered that there is a good case for approaching Defra for the provision of Grant-in-Aid for a *Pre-feasibility Study* for Barrow-in-Furness. It is also noted that the process of undertaking the Pre-feasibility Study could benefit both West Lakes and Associated British Ports who may wish to assist with costs. It is also understood that some form of Pre-feasibility Study was undertaken for Dalton-in-Furness but the results of this study have not been available to the Project Team at the present time. It is unlikely that Defra will provide Grant-in-Aid for further studies at the other sites, given the small number of properties at risk, but this could be further discussed with Defra.

### 4.3 Application of the Sequential Flood Risk Test (SFRT)

Undertaking the next phase of the Strategic Flood Risk Assessment will require application of the SFRT. JBA has developed guidelines to assist LPAs, and their consultants, in this regard (JBA, 2004). This Section summarises the requirements of each step of the SFRT in individual boxes and highlights where further data or knowledge will be required to inform the process.

### Step 1a: Delineation of High Risk Zone 3

This step effectively has already been undertaken by the Environment Agency in their preparation of Flood Risk Zone Mapping. It has not been possible during the course of the present phase of works to confidently identify the provenance of the information from which the maps have been generated, although it is considered highly likely that:

- the topography is represented by the NEXTMap Britain™ DEM created using IFSAR data;
- the 1% fluvial flood event is defined in accordance with approaches outlined in the FEH; and
- the 0.5% tidal flood event is based on the Coastal Flood Risk Mapping undertaken by Posford Duvivier (now Royal Haskoning) and Mott MacDonald.

NB: These assumptions have now been confirmed as correct by the Environment Agency.

During the consultation process associated with the present study, doubts were expressed in some quarters about the accuracy of the existing flood risk zone mapping. This potentially could be further improved by updating the DEM with LiDAR data, which provides better resolution than IFSAR and covers the majority of the study area, and/or any other detailed surveys that are in existence (e.g. Walney Island photogrammetric analysis of aerial photographs, Roa Island land survey).

**Recommendation:** It is recommended that at the SFRA level, the existing Flood Risk Zone 3 maps initially be used as the best available information and that more detailed assessment of flood risk for specific developments be accompanied by a re-evaluation of the flood risk zone outline based on site-specific surveys and modelling results.

### Step 1b: Identify Areas Subject to Development Pressure

This step effectively has already been undertaken by the project team as part of the present study. This has been achieved through a consultation meeting with the LPA and through superimposing the *Local Plan Review* details on to Figure 2.5.

### Step 1c: Delineation of Zone 3a - Developed Areas

### Step 1d: Delineation of Zone 3b - Undeveloped and Sparsely Developed Areas

### Step 1e: Delineation of Zone 3c - Functional Floodplain

These steps can relatively readily be undertaken by superimposing the Flood Risk Zone 3 mapping and *Local Plan Review* mapping onto existing OS backdrop maps. More detailed consideration would need to be given, however, to the recommendations on pages 8 and 9 of JBA (2004) specifically for Step 1e.

### CHECKPOINT: Can the SFRA process for Zone 3 stop here?

Since the *Local Plan Review* includes the proposed development/re-development of various areas within Flood Risk Zone 3, it is necessary to proceed with the SFRT beyond Step 1e.

#### Step 1f(i): Identify 'Defended Areas'

Whilst much information on the location and type of existing formal and informal defences has been collated as part of the present study and presented in tabulated form, this information needs to be translated to mapped information. In some cases, there may be uncertainty about the location of existing defences and it may be worth undertaking a walk-over survey to review and, if necessary, update the present information on defence location. Further information could also be obtained at this time on crest levels, possibly using a hand-held or kinematic GPS, to assist in improving definition of the standard of service provided by these assets.

**Recommendation:** Undertake a walk-over survey to confirm or update the collated information on defence type and location, especially within the Dock Estate and Barrow Island. This could usefully be combined with additional crest level surveys of key structural assets on the Dock Estate and around Barrow Island. Map the location of existing defences.

#### Step 1f(ii): Assess Hydraulic Risk

##### (a) General

Assessing the hydraulic risks associated with tidal inundation requires consideration of extreme water levels and wave overtopping in conjunction with an evaluation of the physical characteristics and response of the sea defences. Assessing the risks from fluvial flooding requires the development of hydrological and hydraulic models based upon topographic information relating to the watercourse.

##### (b) Tidal Inundation

The present phase of the study has revealed that there undoubtedly is considerable variation in the extreme tidal level values that have previously been calculated in other studies. At the 1 in 100 year return period, for example, there is up to 0.73m difference in water level between the seven methods that have been reported here. This, of course, has huge implications for the assessment of potential flood risk from tidal inundation.

**Recommendation:** Due to the uncertainty presented in assessments of extreme water levels, it is recommended that one of the two approaches described below is followed in subsequent phases of the present study:

**Option One:** Accept the extreme water level values that have been presented by JBA (1998) based on the GEV assessment method. Data from this study are reported to demonstrate the best fit to the measured data from the Ramsden Dock tide gauge and have previously been recommended or adopted in the following North-West Regional studies:

- *Extreme Sea Levels For Section 105 Surveys* (JBA, 1998);
- *Walney Island Strategy Study* (Atkins, 2000); and
- *Coastal Flood Risk Mapping* (PDMM, 2001).

Furthermore, in a recent inter-comparison of statistical techniques used in different regions of the Environment Agency, ABPmer (2004) identified that the Spatially Revised Joint Probability Method, which was the method used in the two previous studies at Ramsden Dock which yielded the highest water level values, may be best suited to data from east coast tide gauges, with the GEV method being preferred along southern and north-western coasts.

**Option Two:** Undertake a re-examination of the tidal data from Ramsden Dock, using the following approaches:

- (1) Re-assess the JBA (1998) study and examine the regional distribution of extreme water level values at sites where:
  - (i) sufficient data are available to enable an extrapolation to be provided directly;
  - (ii) interpolation has been undertaken owing to a paucity of local site records.
- (2) Acquire tide gauge data from the BODC website for Workington (1992 onwards) and PortPatrick (1968 onwards) to provide two long-term boundary sites to the area of interest and obtain extreme return water levels at these locations.
- (3) Re-assess extreme water levels in the area of interest also on the basis of the two earlier Dixon and Tawn studies (1994, 1995).
- (4) Provide a solution that is consistent with expectations arising from the regional distribution of water levels, based both on levels from tide gauge records and from extrapolated return period values.

It should also be noted that this assessment work would be applicable to a number of the sites at risk of tidal flooding. For example, the extreme water level analysis for assessing tidal inundation in Barrow-in-Furness would also be applicable to flooding issues on the east coast of Walney Island in Vickerstown and at Biggar Village.

**Recommendation:** Since wave overtopping has been noted in several places within the study area, even despite the very limited fetch that most locations are exposed to, it is considered worthy of re-evaluating wind-wave generation and overtopping potential. This will assist in confirming or revising as necessary the recommended freeboard allowance of 0.6m (JBA, 2004) for flood and coastal defences, assessing the standard of service offered by existing defences, and in addressing one of the issues raised by the 'All Reservoirs Panel' Inspecting Engineer in the north-east corner of Cavendish Dock. Areas around the Dock Estate and Barrow Island should also be investigated during this study.

(c) Fluvial Flooding

The mechanisms associated with flooding from the Poaka Beck, the influence of the impounded water within the dock system and extreme sea levels are not well understood. This is almost certainly exacerbated by the fact that there is no reliable modelling and limited physical information associated with the condition of the structures. The development of a comprehensive model for the urban extent of the Poaka Beck and the dock system would benefit Barrow Borough Council, West Lakes and Associated British Ports and give more accurate flood risk mapping for the Environment Agency.

**Recommendation:** Given the number of properties that could be at risk from fluvial flooding in Barrow-in-Furness, it is recommended that an ISIS or TufLOW model is developed to assess flooding from the Poaka Beck to the urban areas of the town. The model should extend from upstream of the urban limit of Barrow-in-Furness incorporating culverts, open channel sections, and the dock and outfall arrangement. A hydrological assessment of the Poaka Beck would also be required to drive the hydraulic model and it is considered that this should be based upon the FEH statistical method. In order to undertake these analyses, the following information and data will be required:

- Topographic cross sections of the Poaka Beck at regular intervals in the open channel sections of the river.
- Details of culverts including horizontal position, condition, dimensions and invert levels.
- Details of bridges, weirs and other structures which impeded the flow within Poaka Beck and influence out of bank flow.
- Maximum water levels from tidal gauges and other statistical data relating to storm surge.

If there is no reliable historical information associated with culverts, it is considered that a man entry diving inspection is undertaken with the objective of assessing the condition and measuring the size of culverts at every change in the section. In addition, the hydrology and modelling for the Poaka Beck in Dalton-in-Furness should be reviewed. NB: This would require its purchase from the Environment Agency at a cost of £150.

(d) Summary

It is recommended that an analysis of the risk of fluvial flooding and tidal inundation to Barrow-in-Furness is undertaken. This should include an assessment of extreme water levels and wave overtopping on the long embankment and inner railway embankments at Cavendish Dock. A similar analysis should be undertaken for the Barrow docks area and the inner dock wall. A by-product of the above assessment is that the above study could be used to evaluate the risk of tidal inundation to the east coast of Walney Island at Vickerstown and Biggar Village.

In terms of fluvial flooding, a hydrological and hydraulic model of the urban areas of Barrow-in-Furness should be developed as discussed above. These analyses could be jointly prepared in the form of a flooding Pre-feasibility Study (see Section 4.2). The Pre-feasibility Study would also include the development of preliminary design options to mitigate the risk of flooding to the town.

The fluvial and tidal inundation studies could also be used as the basis for a Flood Risk Assessment for West Lakes' sites in the centre of Barrow-in-Furness and the flood study required for Cavendish Dock by the Inspecting Engineer under the Reservoirs Act. It is further recommended that assessment for other sites be programmed and funded in due course.

In order to assess the hydraulic risk from fluvial flooding, overtopping or breaching of existing defences, it will be important to have information on the topography of the land behind the defences. In areas considered to be at greatest risk, or areas with greatest uncertainty about the risk, this is best provided through either a land-based survey or use of available LiDAR data. In the context of the present study, such key areas are considered to be:

- Land adjacent to the water-retaining (north-eastern) embankment of Cavendish Dock;
- Land within Local Plan Review zones E7 and E8.

In addition, it is considered worthy during this step to re-evaluate the standard of service offered against tidal flooding by existing defence assets, taking into consideration the extreme water levels, crest levels of structures, sea level rise over the lifetime of any proposed developments, and any necessary amendments to the recommended freeboard allowance of 0.6m (JBA, 2004) based on an assessment of the magnitude of possible overtopping due to wind-wave generation across local fetches.

#### **Step 1f(iii): Assess Structural Risk**

The study has identified a number of important structures with respect to tidal inundation and breaching in particular. This includes:

- Cavendish Dock long embankment;
- Embankments on Walney Island, including the Biggar Bank;
- Rock revetment structures on the west coast of Walney Island; and
- A5087 Coast Road.

It should also be noted that there is a 'structural' risk associated with the failure of the natural defences on Walney Island where breaching and tidal inundation as a result of wave damage / overtopping could affect infrastructure and communications on the island.

At present, the only information available on the condition of structural assets has been derived from non-intrusive visual surveys. This means that key structures could have unreported structural weaknesses. This said, there appears to be a relatively frequent programme of visual inspections undertaken, including an annual inspection of Cavendish Dock by a Supervising Engineer in accordance with the Reservoirs Act and, once every 10 years, an inspection by an 'All Reservoirs Panel' Inspecting Engineer.

The tidal flood plain is defined by the water levels reached by a 1 in 200 year return period tidal event and takes into consideration an assessment of the plausible extent and duration of breach failure in existing defences (details of the 'Breach Method' used are presented in Worth and Cox, 2000 and this approach has recently been recommended as industry 'best practice' by CIRIA, 2004). The tidal floodplain is classified as 'defended' if the defences were considered to be secure against still water level overtopping or damage due to wave action during a 1 in 200 year return period event. The structures mentioned above have not been assessed against these criteria.

**Recommendation:** As a pro-active measure it is recommended that structural assessments are made where there are properties at risk of flooding as a result of breaching. Assuming that the Cavendish Dock long embankment satisfies these criteria then this would have a significant impact on assessing the extent of the flood risk in Barrow-in-Furness. There are a number of major benefits, including the removal of potential flood blight to the centre of the town and reduction of the flood risk to sites identified for development within the Local Plan Review. Given that overtopping/breaching of the long embankment is a key potential flooding mechanism within the study area, it is considered that this assessment should be undertaken at the earliest possible convenience or, if possible, as part of a Pre-feasibility Study.

**Recommendation:** In addition to the above, ABP should continue with its ongoing visual inspections of the Cavendish Dock embankments and, if permissible, make the results available to inform updates of the SRFA or individual FRAs.

#### Step 1f(iv): Assess Consequences of Failure

Assessing failure of the existing sea defences and breaching of natural defences on the Furness Peninsula and Walney Island is complex. A simplistic model for all failures/breaches to determine consequences could be to assume that the extent of the flood risk area is commensurate with the maximum tidal and surge level. This model is considered appropriate where property or infrastructure is located close to the coast, such as the Biggar embankment, but does neglect the condition of the defence or the integrity of the natural shoreline protecting the property.

Where there would be significant overland flow and dispersion, then this model may not be sufficiently representative to reflect the consequence of failure. This is particularly true for a breach to the long embankment at Cavendish Dock as a result of a structural failure of the armouring and core under extreme wave conditions. If the results of the hydraulic and structural assessments (Steps 1f(ii) and 1f(iii)) indicate that a more sophisticated assessment is required to evaluate the consequence of failure then the simplistic model may not be appropriate. Under these circumstances, it would be necessary to model the physical development of the breach and overland flow. This could be in the form of a dynamic 2-D model such as Tuflow driven by water level and using LiDAR data to represent the topography.

**Recommendation:** It is considered that for flood risk mapping and pre-feasibility purposes the consequence of failure for all sites is based upon the simple model of maximum water level. However, if there are particular problems associated with the existing condition of the Cavendish Dock long embankment or a specific requirement to assess the consequence of failure for return periods greater than 1 in 200 then breach development and overland flow modelling could be perceived as necessary. This form of modelling would, however, be more appropriate to the Project Appraisal Report.

**Recommendation:** Undertake topographic surveys/obtain LiDAR data from the Environment Agency covering these key 'at risk' areas. Then combine outputs from Steps 1f(i) to 1f(iii) to assess the consequences of overtopping or breaching, taking into consideration the fact that should the 'long embankment' of Cavendish Dock fail, then the inner dock walls and embankments become the primary flood defence against tidal inundation to large parts of Barrow. In this scenario, the north-eastern embankment has a crest level only just in excess of HAT.

**NB:** It is considered that some other areas which potentially are at risk from flooding, such as Walney Island and Roa Island, have already been subjected to adequate assessments of the consequence of asset failure within previous strategic studies.

**Step 1f(v): Detailed Assessment of Actual Risk**

In this context the actual risk is assumed to mean risk of loss of life, economic damage, disruption and social vulnerability. Disruption includes the impact on hospitals, infrastructure and other public institutions. The evaluation of Actual Risk requires the assessment of hydraulic and structural risk and an evaluation of the consequence of failure (Steps 1f(ii), 1f(iii) and 1f(iv)). The level of detail should be suitable for the purpose for which the analysis is used.

**Recommendation:** It is considered that all new development within the existing flood risk zones be subject to a Flood Risk Assessment (sometimes known as a Flood Consequence Assessment) in accordance with PPG25.

**Recommendation:** Local Planning Authorities have specific responsibilities under PPG25 for assessing the flood risk for areas identified for development in the Local Plan. Figures 2.1, 2.2 and 2.5 show zones which have been identified for potential housing or industrial development within the existing flood risk area (zones 2 and 3). It is considered that there is a requirement to produce a flood risk assessment for development proposals within these sites.

**Recommendation:** It is recommended that Grant-in-Aid be sought from Defra for the preparation of a Flooding Pre-feasibility Study with a view to extending this to a Project Appraisal Report and the possible procurement of designs and construction works to mitigate the risk of flooding to Barrow-in-Furness

**Recommendation:** It is considered that Barrow Borough Council review the risks to schools, hospitals, fire stations, local authority premises, key industrial locations and other places where vulnerable groups such as the elderly are concentrated.

#### Step 1g: Review Non-Flood Risk Related Planning Constraints in Zone 3

**Recommendation:** This task should be undertaken in conjunction with Barrow Borough Council following Step 1f(v).

#### Step 2a: Delineation of Medium Flood Risk Zone 2

**Recommendation:** It is recommended that at the SFRA level, the existing Flood Risk Zone 2 maps initially be used as the best available information and that more detailed assessment of flood risk for specific developments be accompanied by a re-evaluation of the flood risk zone outline based on site-specific surveys and modelling results.

#### Step 2b: Review of Planning Constraints within Flood Risk Zone 2

**Recommendation:** This task should be undertaken in conjunction with Barrow Borough Council at the same time as Step 1g.

#### Step 3: Delineation of Low Flood Risk Zone 1

By default, this covers all areas within the borough that fall outside of Flood Risk Zones 2 and 3.

#### Step 4: Identification of Local Drainage Issues

The present study has collated known information on local drainage problems.

**Recommendation:** The findings of the present report should be reviewed by appropriate organisations and, if necessary, expanded on in order that all known information on local drainage issues may be presented and available to inform future development.

Following completion of SFRT steps 1-4, the Local Plan should be reviewed by BBC as the LPA and, if necessary, revised in the light of the findings of the SFRA. Any development proposals forthcoming in Flood Risk Zones 2 and 3 should be subject to development-specific FRAs. This will include the Barrow Port Master Plan. In such a FRA, consideration should be given to mitigating flood risk through the design process by, for example, raising or improving flood defence structures, designing suitable floor levels and drainage systems, and considering flood warning and evacuation plans. This should be undertaken in compliance in accordance with the recommendations of CIRIA (2004).

#### 4.4 Responsibilities for Implementing the Recommendations

The responsibilities associated with the development of flood risk assessments is administratively complex with a number of authorities and other bodies responsible for the development of models, production of mapping and assessment of risk. Table 4.2 is extracted from "Development and Flood Risk - Guidance for the Construction Industry". (CIRIA Publication No. C624).

Table 4.2 Hierarchy of flood risk assessment studies (from CIRIA, 2004)

Type of Study	Scale	Objective of Study	Responsible parties
Flood plain mapping	National or regional	To identify the extent of areas at risk of flooding	Flood defence agency
Catchment Flood Management Plan (CFMP)	Catchment	To identify flood risk issues and flood alleviation policies	Flood defence agency
Strategic Flood Risk Assessment (SFRA)	Catchment or district	To identify flood risk issues on a sub-regional scale for development plans	Local planning authority
Flood Risk Assessment (FRA)	Individual site or development	To identify and address flood risk issues associated with an individual development	Developer

It should be noted that several of the recommendations described for various steps of the SFRT (Section 4.3) have benefits beyond the development of a SFRA alone. Most immediately, many clearly overlap with the requirements of a development-specific FRA associated with the Barrow Port Master Plan. Also, some are of benefit to ABP in their undertaking of recommendations made under the Reservoirs Act, 1975, whilst others are of wider benefit to the Environment Agency or Barrow Borough Council in their flood and coastal management capacities. Table 4.3 attempts to summarise where various recommendations can be of mutual benefit to different studies and/or organisations.

Table 4.3 Summary of mutual benefits in executing the key study recommendations

Key Recommendations for Additional Studies		BBC	West Lakes	EA	ABP
1	Map the location and type of all existing defence assets in the borough.	SFRA FCM		FCM	
2	Undertake a crest level survey of assets in the Dock Estate and around Barrow Island.	SFRA	FRA	FCM	FCM
3	Confirm extreme water level values at Ramsden Dock tide gauge (two options available).	SFRA FCM	FRA	FCM	FCM
4	Assess the standard of service of assets in the Dock Estate, including assessments of overtopping potential due to wind-wave generation across local fetches, sea level rise and freeboard allowance. Assess the consequences of overtopping/breaching of defence assets (this would involve the creation of a DEM covering land adjacent to the water-retaining embankment in the north-east of Cavendish Dock and covering land within Local Plan zones E7 and E8).	SFRA	FRA	FCM	Res FCM
5	River model of lower reaches of Poaka Beck (to assess flooding through urban area of Barrow), together with collection of necessary supporting data and information. This may necessitate a man-entry diving inspection of culverts.	SFRA		FCM	
6	Assessment of the consequences of high flows from Poaka Beck at time of high impoundment in Cavendish Dock.	SFRA	FRA	FCM	FCM Res
7	Structural assessment of Cavendish Dock 'long embankment'.	SFRA	FRA	FCM	FCM Res
8	Flood Risk Assessment of developments arising from Barrow Port Master Plan.		FRA		
SFRA = assists with Strategic Flood Risk Assessment for Barrow borough FRA = assists with Flood Risk Assessment for Barrow Port Master Plan FCM = assists with Flood or Coastal Management responsibilities Res = assist in implementing a recommendation under the Reservoirs Act, 1975					

**Note:** Many of the items recommended in Table 4.3 could potentially be part of a *Flooding Pre-feasibility Study* for Barrow-in-Furness.

Finally, it is recommended that the findings from Phase 1 of the SFRA be presented to BBC, West Lakes, the Environment Agency and other interested parties (i.e. ABP, United Utilities, etc.) and discussed before progressing with subsequent phases of the SFRA. It is anticipated that such a meeting may be possible in April 2005.

## 5. References

ABP Research & Consultancy, 1994. *A numerical model of wave climate in Morecambe Bay*. Report commissioned by Shoreline Management Partnership on behalf of South Cumbria Consortium.

ABPmer and Coastal Engineering UK, 2003. Roa Island Shorelink Sustainability Study. Report to Barrow Borough Council.

Airey M, 2003. Report on the result of an inspection and inspecting engineer's certificate under Section 10(5) of the Reservoirs Act 1975. Report to ABP, 07/08/2003.

Atkins, 2000. Walney Island Coastal Management Strategy Study: Volume 1 - Strategy Development Report. Report to Barrow Borough Council.

Atkins, 2004. Walney Island Coastal Management Strategy Study: Volume 2 - Strategy Recommendations. Report to Barrow Borough Council.

Badley J H, 2004. Statement of an inspection by Supervising Engineer under Section 12 of the Reservoirs Act 1975. Report to ABP, 21/07/2004.

Bullen Consultants, 2005. South West Lakes Catchment Flood Management Plan: Inception Report. Report to Environment Agency, January 2005.

CIRIA, 2004. Development and flood risk - guidance for the construction industry. CIRIA Publication No. C624.

Defra, 2002. Futurecoast. Published on CD-Rom.

DETR, 2001. Planning Policy Guidance 25 (PPG25): Development and Flood Risk.

Hames D, Reeve D, Marriott M and Chadwick A, 2004. *Effect of data quality on the analysis of water levels along the Cumbrian coastline*. International Conference on Flood Risk Assessment. University of Bath, April 2004.

Hames D, 2005. Estimate of Extreme Tides at Ramsden Dock. Report to ABP Barrow.

Institute of Hydrology, 1999. *Flood Estimation Handbook*.

Jeremy Benn Associates, July 1998. *Extreme Sea Levels For Section 105 Surveys: Final Report*. Report for Environment Agency (North West Region).

Jeremy Benn Associates, 1999. *Roa Island Causeway, Cumbria: Condition Assessment*. Report to Rail Property Limited, May 1999.

Lennon, G.W., 1963. The identification of weather conditions associated with the generation of major storm surges along the west coast of the British Isles. *Quarterly Journal of Royal Meteorological Society*, 89, 381-394.

MAFF, 1999. Flood and Coastal Defence Project Appraisal Guidance #3: Economic appraisal. MAFF Publications, PB4650.

MAFF, 2001. Flood and Coastal Defence Project Appraisal Guidance #2: Strategic planning and appraisal. MAFF Publications, PB5476.

MAFF, 1999. High Level Targets for Flood and Coastal Defence. MAFF Publications.

McConnell K, 1998. Revetment systems against wave attack: A design manual. Thomas Telford.

Owen Williams Consultants, 2001. Devonshire Dock Facility Design Substantiation for the Astute Safety Case: Condition survey of the outer Dock system. Report to BAE Systems Marine Limited, December 2001.

Phillips, A.W. and Rollinson, W., 1971. *Coastal Changes on Walney Island, North Lancashire*. Research Paper No 8, Department of Geography, University of Liverpool, 36pp.

PDMM (Posford Duvivier and Mott MacDonald), 2001. *Coastal Flood Risk Mapping*. Report to Environment Agency North-West Region, North Area Office. September 2001.

Worth D and Cox R, 2000. Tidal flood risk areas: simply credible. *Proceedings 35<sup>th</sup> MAFF Conference of River and Coastal Engineers*, Keele University.

**Figures** (see separate pdf)

# Appendices

# Appendix A

Review of National and Regional  
Guidance Documents

## Appendix A. Review Of National And Regional Guidance Documents

### A1. Planning Policy Guidance Note 25 (PPG25)

PPG25 was introduced in July 2001 and it reinforces the responsibility that Local Planning Authorities have to ensure that flood risk is understood and managed effectively, using a risk-based approach, as an integral part of the planning process. It encourages the application of a Sequential Flood Risk Test (SFRT) that zones a local planning district into areas of 'high', 'medium' or 'low' flood risk (Table A1). SFRT involves assessment and categorisation of flood risk on a catchment-wide basis.

Table A1. PPG25 flood risk zones and sub-zones

Zone	Flood Risk	Sub-zone	Description of Sub-zone
3*	High	3a	Developed Areas
		3b	Undeveloped and sparsely developed areas
		3c	Functional floodplain
2	Medium	N/A	N/A
1	Low	N/A	N/A

\* PPG25 does not immediately preclude future development in areas situated within high risk zones. Some areas may be provided with a level of protection from flooding by a form of flood defence.

### A2. Development and Flood Risk: Guidance for the Construction Industry

This document was published by CIRIA in 2004 and contains a flood risk assessment toolkit, developed using a series of checklists and flow charts, which guides a user through the flood risk assessment process. It proposes a three-tiered approach to flood risk assessment. The toolkit is available from the following web page: [www.ciria.org/news\\_240205.htm](http://www.ciria.org/news_240205.htm).

### A3. Meeting the Sequential Flood Risk Test: Guidelines for the North West Region

This report was produced in July 2004 by JBA Consulting on behalf of the Environment Agency (North West Region), the Government Office for the North West, and the North West Regional Assembly. It presents pragmatic 'best practice' guidance and is intended for use by Local Planning Authorities to assist them in undertaking a Sequential Flood Risk Test (SFRT), as outlined in PPG25, and to assist in the implementation of Regional Planning Guidance Policies ER8 and CZ2B.

The guidelines present a step-by-step approach to the SFRT process, highlighting potential data sources, technical issues and recommendations regarding outputs from individual stages and the overall process.

#### A4. Regional Planning Guidance for the North West (RPG13)

RPG13 contains two policies of relevance to flood risk, namely: ER8; and CZ2B.

- Policy ER8: *“In preparing development plans and other relevant strategies and considering individual planning proposals, local authorities should apply the precautionary principle. In accordance with this precautionary principle they will make use of Indicative Floodplain Maps, Shoreline Management Plans, Estuary Management Plans and Local Environment Agency Plans to develop the information necessary to apply the sequential approach to flood risk set out in PPG25.”*
- Policy CZ2B: *“In the preparation of plans, policies and proposals for the integrated planning and management of the North West coast, local authorities and relevant partners should ensure that development proposals are compatible with the sustainable planning and management of coastal defences.”*

# Appendix B

Catchment Descriptors

## Appendix B. Catchment Descriptors

AREA	Catchment drainage area (km <sup>2</sup> )
ALTBAR	Mean catchment altitude (m above sea level)
ASPBAR	Index representing the dominant aspect of catchment slopes
ASPYAR	Index describing the invariability in aspect of catchment slopes
BM	Baseflow index
BF1HOST	Base flow index derived using the HOST classification
DPLBAR	index describing catchment size and drainage path configuration (km)
DPSBAR	Index of catchment steepness (m/km)
FA RL	Index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FEH CD-ROM	A software package of particular relevance to the use of Vols 2 and 5
FSR	Flood Studies Report
HOST	Hydrology of soil types classification
LAKE	FSR index of flood attenuation
LDII	Longest drainage path (km)
MS1	FSR catchment characteristic describing main stream length
POT	Peaks-over-threshold
PROPWET	Index of proportion of time that soils are wet
RN1ED	Median annual maximum rainfall (mm)
RMED-ID	Median annual maximum 1-day rainfall (mm)
RMED-2D	Median annual maximum 2-day rainfall (mm)
RMED-11-1	Median annual maximum 1-hour rainfall (mm)
SAAR	1961-90 standard-period average annual rainfall (mm)
SAAR 4170	1941-70 standard-period average annual rainfall (mm)
SOIL	Index of winter rainfall acceptance potential
SPR	Standard percentage runoff (%)
SPRHOST	SPR derived using the HOST classification
UR13CONC	Index of concentration of urban and suburban land cover
URBEXT	FEI-I index of fractional urban extent
URBEXT 1990	FEH index of fractional urban extent for 1990
URBLOC	Index of location of urban and suburban land cover



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