The Highland Council
Project Design Unit
Transport Environmental & Community Services
Council Offices
Dingwall
IV15 9QN

River Ness Flooding - Inverness

Pre-feasibility Study

Flood Protection

June 2005

Mott MacDonald
68 Church Street
Inverness
Scotland
IV1 1EN
UK
Tel : 44 (0)1463 239323
Fax : 44 (0)1463 224951

River Ness Flooding - Inverness

Pre-feasibility Study

Flood Protection

Issue and Revision Record

Rev	Date	Originator	Checker	Approver	Description
A	Dec 04	D R Noble	D Lyons	B Gill	First Issue, for comment
B	Feb 05	D R Noble	S G Robertson	A W Girvan	Second Issue, for comment
C	Mar 05	D R Noble	D Lyons	A W Girvan	Third Issue, for comment
D	Jun 05	D R Noble	S G Robertson	A W Girvan	Final Issue, with minor updates

This document has been prepared for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of Mott MacDonald being obtained. Mott MacDonald accepts no responsibility or liability for the consequence of this document being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on the document for such other purpose agrees, and will by such use or reliance be taken to confirm his agreement to indemnify Mott MacDonald for all loss or damage resulting therefrom. Mott MacDonald accepts no responsibility or liability for this document to any party other than the person by whom it was commissioned.

To the extent that this report is based on information supplied by other parties, Mott MacDonald accepts no liability for any loss or damage suffered by the client, whether contractual or tortious, stemming from any conclusions based on data supplied by parties other than Mott MacDonald and used by Mott MacDonald in preparing this report.

List of Contents

Page

Chapters and Appendices

Figures

Tables

Executive Summary

The existing River Ness flood defences in Inverness provide protection to the order of 1 in 25 year return period (some 600m^3/s of fluvial flow). Although a short river of some 12km, the Ness drains one of the largest catchment areas in the UK.

There are two potential flooding scenarios that occur from the Ness. The fluvial scenario results from rainfall in the catchment; the other scenario is tidal flooding, caused by a combination of high tide plus storm surge. As the scenarios arise from different meteorological events, the 1 in 100 return period events are unlikely to occur simultaneously.

The 1 in 100 years return periods (1% annual probability of flooding) for both tidal and fluvial events have been examined, without the implications of future climate change at this stage. The 1 in 100 years return period for fluvial flow is some 800m^3/s. Two flood maps have been prepared to indicate the areas inundated.

The existing reports and the Hydraulic Model have been reviewed. The design discharges in the River Ness were updated from the original 1991 study in 2004. This takes into account the new data available and any change in climate over that period. At this stage, no allowance has been made for future climate change over the design life of the scheme.

During January 2005, an event with a return period of about 1 in 25 year occurred. The greatest flood impact resulted during the short period around high tide with appreciable storm surge evident. The locations where the defences were breached, and where flooding occurred, provided confirmation that the existing model was predicting reasonably accurately.

In order to progress a flood prevention scheme, a positive cost benefit analysis is required. An examination of damage resulting from the fluvial scenario compared with the cost of basic defences required indicates that a protection scheme is viable. The flood maps predict that the tidal scenario results in more damage that the fluvial scenario which will increase the benefit of an overall scheme.

A flood alleviation scheme for the River Ness is likely to have a positive benefit, and should be progressed to the next stage.

1 Introduction

The River Ness has a history of flooding. The most recent floods of significance occurred in February 1989 and February 1990. Many properties in Inverness city centre were affected and the railway bridge across the river collapsed after the flooding in 1989. Mott MacDonald produced a report on the flooding incidents in 1990 and included in this report was an options study on possible flood protection measures. The recommended flood protection measure was a wall along the banks of the Ness. At this time, no action was taken on the findings of the report.

In 2003 The Highland Council commissioned Mott MacDonald to undertake a review of the hydraulic modelling which had been completed in 1990, in the light of recently published guidance such as Flood Estimation handbook and other guidance on the effects of climate change, and hydrological/hydraulic uncertainty. Statistical analyses were updated with an extra 12 years of data and incorporated recommended distribution fitting from FEH. The updated hydrological assessment resulted in higher 1 in 100 year flow and water levels than predicted in the 1990 study.

In the light of the updated hydrological assessment, recent ground level data and revisions in the method of calculating flood damages and evaluating scheme viability, The Highland Council has decided to reassess the standard of protection and to re-evaluate whether there is a viable scheme to improve the present standard of protection.

In August 2004, Mott MacDonald were commissioned to carry out a Pre-feasibility study for Inverness. The scope of this Pre-feasibility study was to produce a brief overview of the existing reports, review the 1991 preferred scheme, update the preferred scheme focusing on fluvial flooding, and carry out an outline benefit-cost analysis using current DEFRA guidelines. The combined effects of extreme fluvial and tidal flooding was not considered a major issue in the 1991 study, as the metrological conditions for fluvial flooding do not lead to extreme tidal levels.

The scope has since been extended to include investigating the effects of tidal flooding downstream of the railway viaduct. Tidal flooding has been included in the benefit-cost analysis.

The flood damages for each return period event are to be calculated using the “Multi-coloured Manual”, and Flood and Coastal Defence Project Appraisal Guidance (FCDPAG) published by DEFRA. Flood alleviation options are to be identified and appraised to determine their technical, economic and environmental viability.

Phase one of the flood study is to update the work carried out in 1991 by Mott MacDonald, and carry out an outline cost-benefit analysis. The 1991 study looked at the River Ness through Inverness city centre, from the downstream end of Ness Islands to the Railway Viaduct.

Phase two will be to complete a feasibility study for the preferred scheme, leading to implementation.

2 Background

2.1 Catchment Description

The River Ness is the outflow from Loch Ness. The River Ness is approximately 12km long and has one of the highest average flows in the UK at $300m^3/s$. Inverness is situated at the mouth of the River Ness, which flows northwards into the Moray Firth. The river has no significant tributaries.

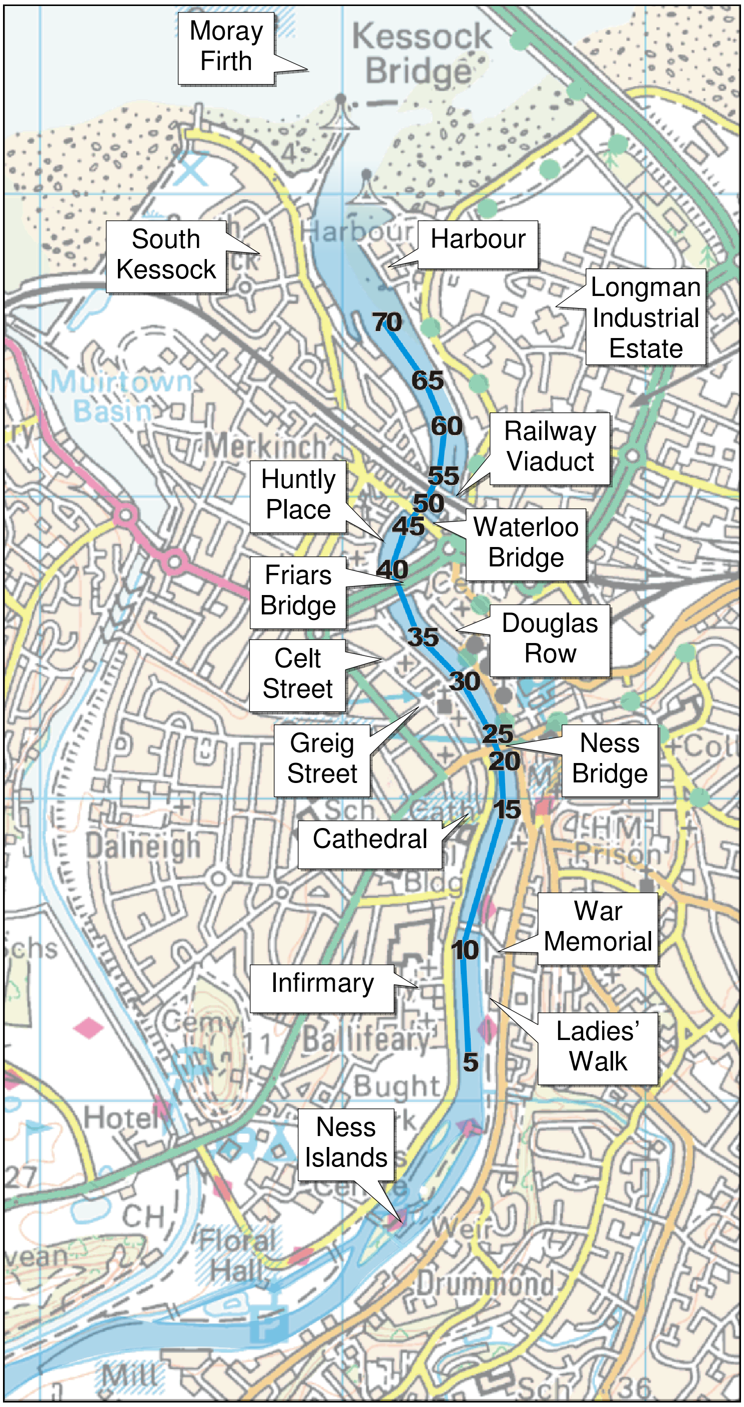
Loch Ness has a total catchment area of over $1850km^2$, the loch has a surface area of over $50km^2$ and a capacity of several billion cubic metres. The surrounding landscape is predominately mountainous. Land use in the area is mainly forestry and pasture farming with some small settlements. Around 35% of the catchment is controlled by hydropower schemes.

Major housing developments have taken place around Inverness over recent years but the majority of these have been outwith the floodplain of the River. The exception to this is the significant development that has taken place around the harbour in the Longman Industrial Estate. This area has been found to be potentially at risk of flooding during extreme tidal events.

2.2 Study Area Description

The study covers a 3km stretch of the River Ness from downstream of the Ness Islands to the Mouth of the river at Inverness Harbour, where the Ness joins the Moray Firth. The land use is primarily residential upstream, with a mixture of commercial properties in the city centre including hotels, restaurants and offices. Downstream there are more residential properties, as well as warehouses, industrial premises and the harbour itself. The study area is shown in Figure 2-1.

Figure 2-1: Map of Study Area



The hydraulic model extent is indicated on Figure 2-1 by the cross-section numbers shown along the river centreline.

2.3 Historical Flooding

There are records of historical floods in the area dating back to 1818. The most severe recorded flood in Inverness was in 1849, when 20 streets around the city centre were submerged. This is thought to be related to the drainage of local moorland for farmland in the early nineteenth century, which significantly increased runoff rates.

There have been two severe floods in the last 15 years on the River Ness, in February 1989 and February 1990. Both of these events occurred because an abnormally high flow in the river coincided with a high tide; and both were preceded by weeks of heavy rainfall in the region, resulting in saturated ground and high storage volumes in the major lochs of the basin. The peak discharge at the Ness-side gauging station during the 1989 flood was about $800m^3/s$ and around $650m^3/s$ during the smaller 1990 event.

In 1989 a stretch of over two kilometres on the right bank[i] was flooded, with extensive damage to property and roads. Two weeks after this flood, the railway bridge across the river collapsed; it is thought to have been damaged by the floods and then undermined by scour due to the continuing high river flows. In 1990 out-of-bank flooding occurred again throughout Inverness, with damage to property.

2.4 Flooding in January 2005

Flooding of the River Ness occurred again in January 2005, when the river overtopped the banks and existing flood defences.

High flows in the river, of approximately $610m^3/s$, occurred on the evening of 7th of January. This high flow equates to around a 1 in 25 year return period (a 4% annual probability of occurrence). The river overtopped the bank level at Ladies' Walk, and inundated the footway. Further upstream, Ness Islands and Whin Island were also partially inundated. The flow in the river was greater than $480m^3/s$ for 5 days, between the 7th and the 13th of January.

A high tide, of 4.9m ACD[ii] combined with a storm surge of approximately 0.8m occurred around midday on the 11th of January. This resulted in the flood defences downstream of Ness Bridge being overtopped. This tide level is approximately a 1 in 15 year return period (or a 7% annual probability of occurrence). Significant sections of the streets adjacent to the river downstream of the Greig Street Suspension Bridge were affected. The high water level was close to that of Inverness Harbour, however the quay was not overtopped. Some flooding occurred in South Kessock, around Anderson Street. East of South Kessock pier, the water level in the Beauly Firth was such that waves were breaking onto Kessock Road around the time of high tide.

[i] Looking downstream
[ii] 4.9m above local Admiralty Chard Datum, 2.65m above Ordnance Survey Datum

3 Overview of Existing Reports

3.1 1991: Highland Regional Flooding Incidents Great Glen/Loch Ness/River Ness

As a result of the severe flooding, Mott MacDonald were commissioned by the Highland Regional Council, at the request of the Minister of State for the Highlands, to undertake a study into flooding incidents and the overall management of the Ness basin. The study focussed on two main issues; firstly a frequency analysis for the tidal and rainfall data for the area, and secondly strategies for flood alleviation at a local and basin scale.

The data available at the time were: 61 years of River Ness flow data, 52 years of Loch Ness water levels and transposed tidal records from 1908. Frequency analysis of the flow data indicated that the return periods for the February 1989 flood and February 1990 flood were 1 in 100 years and 1 in 35 years, respectively. Further analysis of the hydrometric records found no trend to indicate that any of these parameters were increasing. No indication was therefore provided as to whether flood frequency was increasing over time.

For the second part of the study, different flood management measures were considered. At a basin level, the impact of changing the management of hydro power schemes around the Great Glen was investigated using a multi reservoir model. The report found that there would be little reduction in peak flow on the Ness from changing the operation of the hydro power schemes. One reason for this was that the reservoirs already provide a large measure of flood control as they have a large storage volume. There is limited scope for changing the operating regime, and the lower power output caused by increasing the available freeboard would not be justified by the possible flood risk reduction.

Potential flood protection schemes for Fort Augustus and Inverness were investigated using localised computational hydraulic models. For Inverness, a one-dimensional hydraulic model of the River Ness was developed. The model extended just over 2km along the major area of development along the river banks. The model was based on 15 cross sectional surveys of the river. It showed that out of bank flooding occurs for river flows of $500m^3/s$ or greater – corresponding to events with a return period of 16 years. The performance of the model in simulating a historical flood event was verified against photos and other evidence recorded during the floods.

Options for lowering or adding a control structure to Dochfour Weir at the head of the River Ness were considered. Both of these options were found to have negligible benefit, with marginal reduction in the level of Loch Ness. An inflatable dam at Dochfour, to increase water levels in Loch Ness during a storm, was also considered. Although this would allow flood waters to be stored until after the storm peak passed, this would require extra flood protection measures around much of the loch side, and is not considered a viable option.

The recommended option for flood protection in Inverness was the construction of a flood wall on both banks of the River Ness through the town centre. None of the proposals for flood protection works have been undertaken.

A key assumption was that tidal extremes (i.e. those involving surge) occur independently of fluvial extremes. Inspection of meteorological conditions around the time of extreme fluvial events displayed good correlation between the events, and that these conditions are unlikely to result in storm surge in the North Sea. As a result the flood study focused on fluvial flooding with a 1 in 2 year high tide. It did not address a tidal flooding scenario.

3.2 2002: River Ness Flood Model Report and Guide for Users

In February 2002, the Emergency Planning Department of the Highland Council asked Mott MacDonald to develop the River Ness model from the 1991 study. The aim was to use the model as a tool for predicting the likelihood of extreme conditions and also the location and magnitude of the maximum water levels. Only two of the six bridges across the Ness are included in the model, as most of the bridges do not significantly affect the river levels.

Mott MacDonald's in-house modelling software, HYDRO-1D, has been revised since the 1991 study was undertaken, and it was therefore necessary to calibrate the 2002 model against the original. Calibration was carried out on the revised model by running the model with data for the 100 year flood and comparing the results at each node with the original data. In the original study, Manning's roughness coefficient 'n' with a value of 0.03 was used. The sensitivity of the updated model was checked by varying the roughness. It was found that using a value of 0.03 for Manning's 'n' gave a good agreement with the original model runs.

To test the model, six different flood events were run through the model, each covering a 48 hour period in 15 minute intervals, and where possible these were compared with photographs of the actual event.

To use the model as a flood forecasting tool, predicted boundary condition data is required. It is therefore necessary for the user to look at the river flow and tidal levels over a period of time and enter the expected values for the following day. If, as suggested in the 1991 report, the model could be linked to an upper catchment model of the storage cells in Loch Ness and the hydro power lochs and the hydraulic model for the River Oich in Fort Augustus, it would be much more accurate and useful as a real time forecasting tool, showing the routing of flood water through the whole catchment.

3.3 2004: River Ness Flooding Review

In December 2003, the flooding assessments which had previously been carried out in Inverness were reviewed. The review considers the extra twelve years of data, which has become available since the original report. It also considered the potential impacts of climate change as well as new methods of analysing flood risks.

For the original 1991 study, there was no local tidal gauge so the nearest available tidal data came from Aberdeen. A tidal gauge was installed at the mouth of the Caledonian Canal in 1991. Although this does not yet provide a long enough record for useful frequency analysis, one of the actions of the 2004 review was to compare the 12 year common record of transposed Aberdeen levels with the levels taken from the local gauge. The difference between the locally recorded and transposed Aberdeen levels varied between -0.34m and +0.23m. The transposition therefore allows a reasonable estimation for the order of tidal peak levels in Inverness.

For the 1991 report, frequency analysis was undertaken using the General Extreme Value (GEV) distribution. The Flood Estimation Handbook (1999) recommends the use of Generalised Logic distribution. For the 2004 review three types of distribution were compared: General Extreme Value Type I or Gumbel, General Extreme Value type II (GEV), and Generalised Logic (GL). These distributions were fitted to the available hydrographic data. The revised analysis indicated an increase in flood potential through higher predicted discharges for given return periods for both of the inflow graphs. It was noted that adding twelve extra years of data also increased the discharge for a given return period.

The impact of climate change is still subject to considerable uncertainty. The Department of the Environment, Transport and the Regions, has assessed the impacts of climate changes in the UK and their report from 2002 (UKCIP02 Scientific Report) presents four possible climate futures for the UK. The major effects that climate change will have on flooding are changes to extreme rainfall conditions and sea level rise.

At present the general recommendation is for consideration of possible increases in peak flow to be included in sensitivity analyses, with an increase in peak discharge of 20% on present day flow rates suggested, though there is still considerable uncertainty in quantifying the increase. For the river Ness, the present day 100 year return period (1% annual probability of occurrence) discharge is $839m^3/s$. When a 10% increase in river flow is considered, the return period of an $839m^3/s$ discharge reduces to 63 years (1.6% annual probability of occurrence). If a 20% increase is considered, the return period of this discharge reduces further to about 41 years (2.4% annual probability of occurrence).

Sea levels will also rise as a result of global temperature increases. This is chiefly attributed to thermal expansion of ocean water and ice melt. The UKCIP02 Scientific Report suggested an approximate rate of 5mm increase sea level per annum should be considered. This equates to an increase of 0.25m over the next 50 years.

The 2004 review concluded that the risk of flooding is increasing and improved flood warning and flood prevention measures could bring significant benefits. Several recommendations for further study came out of the report. The existing defences along the River Ness are at a low level, and the increased discharge and tidal levels from the updated frequency analysis suggested that the existing flood defences should be re-examined. The flood model could be updated with the revised boundary conditions, in order to check the level of service in the existing defences. It could also be expanded to include the over bank areas and channel/floodplain interaction. Monte Carlo simulation could be applied to model parameter uncertainties, to provide a better estimation of flood level. This would allow the defences to be analysed and redesigned as necessary.

4 Review of 1991 Preferred Scheme

The preferred flood protection option, as outlined in the 1991 report, comprised of flood walls along the banks of the River Ness. Existing flood walls were to be raised where necessary, and new walls constructed along sections with no protection.

- Design Levels – alternative scheme designs were based on protecting to the estimated 50-year and 100-year return period water levels. These levels were based on hydraulic modelling of the Ness. These design water levels have subsequently been revised resulting in an increase in the respective levels mainly through revised peak flow estimates, but with an allowance for the climate change over this period.

- Alignment and Extents – the preferred scheme outlined in the 1991 report was for flood walls down both banks of the Ness, from upstream of Ballifeary Lane to Thornbrush Quay on the west bank, and from Cavell Gardens to the railway viaduct on the east bank. See Figure 4-1. The existing sections of wall between Ness Bridge and Waterloo Bridge were to be raised in height to accommodate the revised levels. The proposed scheme includes raising of existing walls between Ness Bridge and Waterloo Bridge for increased protection to the Huntley Street/Huntley Place and Douglas Row areas on the left and right bank respectively. New sections of flood defence wall are proposed for the remainder of the reach length between Warrand Rd and Thornbush Quay on the left bank and Ness Bank and the railway viaduct on the right bank. The general alignment of the proposed defences runs along the top of the river banks. Further protection options will be required for the properties on Ladies Walk.

- Freeboard – the previous design includes nominal freeboard allowances of 300mm and 500mm for the tidal and fluvial flood zones respectively. These levels are considered appropriate for use in the scheme update. Higher allowance for the fluvial flood zones was recommended given the high flow velocities and subsequent high velocity head.

- Design Section – preliminary scheme design was based on a combination of new sections of flood defence wall and raising of existing defences using a reinforced concrete section. Although there are potentially various forms of flood defence construction, including temporary or demountable sections, for initial costing of a revised scheme the typical reinforced concrete sections detailed in the 1991 study have been adopted.

- Economic Analysis – Construction costs for the outlined 50-year and 100-year protection schemes were estimated at £370,000 and £527,000 respectively. No formal benefit/cost analysis was undertaken at the time. In updating the scheme, a simple update of the cost schedule can be made by indexing the base costs/unit rate to reflect current prices assuming similar construction methodologies and materials are used.

Figure 4-1: Alignment and Extents of 1991 Preferred Scheme

5 Data Assessment

The predicted flood levels from the 1991 study were updated on the basis of increases in the design flood discharges arising from the hydrological review. Design flood discharges for a range of return periods are available from the revised flood frequency analyses. The design discharges are summarised in Table 5-1.

Table 5-1: Design Peak Discharge for River Ness

Design Return Period (years)	Peak River Ness Discharge (m^3/s)	
	1991 Report	Revised Discharge (2004)
2	-	375
5	400	463
10	-	531
22	600	-
25	-	634
50	-	728
100	800	839
200	-	972
460	1000	-

The existing hydraulic model was applied to estimate the peak flood using the revised design flow inputs. The model extends from downstream of the Ness Islands to the harbour area at Lotland Street. The average spacing between nodal points in the model is approximately 200m. A linear interpolation between the nodal points is used to estimate intermediate water levels.

Some critical property and bank levels along the study reach are available from the 1991 study and The Highland Council provided additional topographical survey. This survey provided detail on property and ground surface levels in potential flood risk locations identified by Mott MacDonald before the updating work was undertaken.

To generate a continuous ground surface for flood outline mapping, the survey data provided by the Council was supplemented with spot height information recorded on the Ordnance Survey mapping of Inverness.

6 Indicative Flood Outlines

Indicative flood outlines were calculated for two scenarios, fluvial flooding and tidal flooding. These were assumed to occur independently of each other, and hence were calculated separately. A combined probability analysis was not undertaken at this stage.

The modelling undertaken concentrated on fluvial flooding of the River Ness, with the current River Ness model extending downstream to the railway viaduct. Tidal flooding was investigated separately, using calculated extreme water levels and modelling the spill volumes.

6.1 Meteorological Conditions

As stated in the 1991 report, it has been assumed that tidal extremes (i.e. those involving surge) occur independently of fluvial extremes. The development of surge conditions in the North Sea are coincident with strong north winds over the North Sea, generally linked to a strong east-west pressure gradient across Great Britain, with a depression centred over the North Sea. Major rainfall across the catchment occurs when the predominant wind direction is from the west, with the centre of the depression located well to the north. Inspection of meteorological conditions around the time of extreme fluvial events has shown that these are unlikely to result in storm surge in the North Sea.

6.2 Climate Change

The design flows and extreme tidal levels were updated during the 2004 River Ness Flooding Review. These revised flows and levels form the basis for the hydraulic modelling carried out in this study.

No allowance has been made, at this stage, for future changes in climate over the design life of the scheme. This will be incorporated into the scheme at the design stage.

6.3 Fluvial Flooding

Design flood water level estimates have been revised from the original 1991 study values on the basis of the hydrological review. Using the updated design flows, the model was used to simulate water levels along the modelled reach of the River Ness. Table 6-1 presents a summary of the simulated water levels for a range of design return periods.

Table 6-1: Design Water Levels for Fluvial Flooding

	Design Water Level (m AOD) for Given Return Period				
Location (Node)	**2 year**	**10 year**	**50 year**	**100 year**	**200 year**
Warrand Rd (5)	4.47	4.94	5.45	5.7	5.97
Infirmary (10)	3.97	4.35	4.78	5.03	5.3
Cathedral (15)	3.64	3.95	4.34	4.56	4.82
U/S Ness Bridge (20)	3.43	3.63	3.91	4.08	4.28
D/S Ness Bridge (25)	3.41	3.6	3.87	4.03	4.22
Greig St (30)	3.32	3.46	3.63	3.76	3.93
Celt St (35)	3.27	3.31	3.41	3.49	3.60
Friar's Bridge (40)	3.27	3.27	3.30	3.33	3.38
U/S Waterloo Bridge (45)	3.27	3.27	3.27	3.27	3.27
D/S Waterloo Bridge (50)	3.27	3.27	3.27	3.27	3.27
D/S Railway Viaduct (55)	3.27	3.27	3.27	3.27	3.27
Harbour Road (60)	3.27	3.27	3.27	3.27	3.27
Cromwell's Tower (65)	3.27	3.27	3.27	3.27	3.27
Lotland Street (70)	3.27	3.27	3.27	3.27	3.27

For all of the model simulations, the 2 year peak tidal level of 3.27m was adopted for the downstream boundary condition.

Downstream of Celt Street (node 35) the tidal design water level is generally higher than the fluvial design water level for equivalent return periods, see Table 6-2.

The design water level for the 1 in 100 year return period (1% probability of flooding event) is approximately 0.15m higher than that predicted in the 1991 simulation. This is due to the revised peak flow estimates. Figure 4-1 showed the levels of the flood defences in brackets for the 1991 scheme. Figure 8-1 shows the indicative level of the flood defences of the reviewed scheme.

Based on the simulated water levels and available topographical data, an indicative flood outline has been produced for the 100 year return period (1% annual probability of occurrence) design event as shown in drawing 215825/INV/010. The outline shows out-of-bank flooding concentrated along narrow corridors adjacent to the river as controlled by the natural topography. Upstream of the Celt Street vicinity, the critical flooding condition is fluvial dominated, with the area downstream predominantly tidal affected. Given the estimated peak tide levels and the level of existing defences in the downstream areas, significant flooding in extreme tide events may be expected.

During the study, low ground levels at the mouth of the river and outwith the model scope were highlighted by an application for a proposed development at Anderson Street, and the introduction of the Water Framework Directive. As a result, the implications of tidal effects were examined and are discussed in Section 6.4. There is overlap in the regions affected by fluvial and tidal flooding, between Ness Bridge and Friars Bridge.

6.4 Tidal Flooding

The additional extent of tidal flooding has been scoped using the existing model and topographical information from OS mapping.

The 1 in 100 year high tide level (1% annual probability of occurrence) has been estimated as 3.68m above Ordnance Datum[iii]. Initial investigations have shown that the ground levels in the South Kessock area are generally below this level, with most of the area north of the railway line potentially at risk of flooding. On the east bank of the river, significant portions of the Longman industrial estate are also below this level.

To accurately model the effects of tidal flooding in this region would require the existing model to be extended to the mouth of the River Ness, and further topographical and property survey work to be carried out on both banks of the river around the harbour area.

Peak tide levels for extreme events have been estimated from frequency analysis of available tide records as summarised in the 2004 River Ness flood Review. These levels have been updated to include data obtained since the original 1991 study, and are given in Table 6-2.

Table 6-2: Design Water Levels for Tidal Flooding

	Design Water Level (m AOD) for Given Return Period					
Location	**2 year**	**10 year**	**50 year**	**100 year**	**200 year**	**1000 year**
All locations downstream of Celt Street (node 35)	3.27	3.46	3.61	3.68	3.75	3.90

Note that upstream of Celt Street (node 35) the fluvial design water level for the return period is higher than the tidal design water level, see Table 6-1.

An indicative tide profile was generated and scaled to match the extreme event peaks. Using this tidal profile with approximate lengths and crest level for the river embankments, spill volumes were estimated for the left and right overbank regions. The spill volumes were overlaid on the ground surface generated from the available spot height survey data to generate tidal flooding inundation areas.

The indicative tidal flood outline is shown in drawing 215825/INV/011.

The estimate of spill volumes and subsequent inundation areas is a very coarse assessment at this stage. The estimated peak water levels at the Clachnaharry gauge have been directly applied along the river reach. As the tidal wave propagates up the river, changes to the tidal profile will occur due to spilling over river banks, the effect of storage in the river channel and the combined fluvial/tidal interaction. The propagation of the tide wave, overbank spilling from the channel and inundation patterns requires a more detailed modelling investigation of the tidal excursion, downstream defence levels and overbank topography.

[iii] note that local chart datum is 2.25m lower than Ordnance Survey datum

7 Standard of Protection

7.1 Present Flood Defence Standard

The simulated flood levels indicate that the existing capacity of the River Ness through Inverness is of a similar order to the peak discharge of the 25-year return period event. For events at and below this magnitude, flood flows largely remain in-bank through the city with no property inundation. This is supported by observed conditions for the 1990 flood event, where only one property was believed to have been flooded, Braeness Hotel (17 Ness Bank) as stated in the 1991 report. The estimated return period for the 1990 event from the flood frequency analysis is approximately 30 years for a peak discharge of 653m^3/s.

The only existing flood defence is a low wall running from downstream of Ness Bridge to Waterloo Bridge. This provides an existing standard of protection that has been estimated to be about 1 in 25 years for Douglas Row on the right bank of the river and the Celt Street area on the left bank.

There are approximately 160 properties within the 100 year fluvial flood region, see drawing 215825/INV/010. There are also about 500 properties within the 100 year return period tidal flood region that are potentially at risk, drawing 215825/INV/011. As discussed earlier, there is some overlap between the calculated fluvial and tidal flood extents in the areas between Ness Bridge and Friars Bridge, with about 100 properties affected by both.

7.2 Indicative Standard

The Indicative Standard of Protection is determined in accordance with Tables 6.1 and 6.2 of FCDPAG3. The study area is classified as Land Use A, intensively developed urban areas. Hence an Indicative Standard of 1 in 50 to 1 in 200 years applies. The existing standard of protection is therefore less than the Indicative Standard.

8 Flood Defence Options

At this stage, one option was considered to protect properties in Inverness from fluvial flooding of the River Ness and tidal Flooding of the Moray Firth. This would require the existing flood defences through the city centre to be raised, and new defences to be constructed along the banks of other areas potentially at risk.

It is envisaged that further options will be considered in Phase 2 of the Ness Flooding Study.

8.1 Damage to Properties

Flood damage to residential and commercial properties has been assessed using the "Multi-coloured Manual"[iv], using February 2004 property values.

Property survey data are currently only available for 86 properties along the banks of the River Ness, those that were judged to be at risk of flooding in the 1991 report. The estimated damage of not protecting these properties has been calculated, and is detailed in Table 8-1. The estimated present value damage for these properties during the 1 in 100 year design flood is over £800,000. The existing flood defences provide a level of protection, up to approximately a 1 in 25 year flood.

Table 8-1: Estimated Damages to 86 Surveyed Properties

Flood Severity (Return Period 1:n years)	Total PV damage (£)
2	-
5	-
10	-
25	-
50	614,071
75	714,424
100	829,261
150	1,501,240
200	1,901,059

The revision to water levels and flood return period in this report results in a significantly greater number of properties predicted to be at risk of flooding. Preliminary investigations, using the 100 year return period (1% annual probability) data, show that there are approximately 100 additional residential properties potentially at risk of fluvial flooding, as well as further non-residential properties. There are also about 500 residential properties potentially at risk of tidal flooding. The overlap between these 2 groups is approximately 100 properties.

[iv] Flood Hazard Research Centre & Middlesex University (2003) "*The Benefits of Flood & Coastal Defence: Techniques & Data for 2003*"

This gives a total number of properties potentially at risk of flooding to be in the region of 500 to 600, around 8 or 9 times more than were identified as being at risk in 1991, and hence surveyed. An estimate of the total damage has been calculated by scaling the costs pro-rata the number of properties. The number of affected properties was determined using OS Landline mapping. The damages are presented in Table 8-2.

The total damage estimate in Table 8-2 takes into account the fact that a number of properties are at risk of both fluvial and tidal flooding. These properties have not been double counted, as this would skew the results of the cost-benefit analysis.

Table 8-2: Indicative Revised Estimated Damages for All Affected Properties

	PV damage (£)	
	1 in 100 year	**1 in 200 year**
Fluvial Flooding	1,500,000 to 2,500,000	3,000,000 to 4,000,000
Tidal Flooding	5,500,000 to 7,500,000	6,000,000 to 8,000,000
Total (Fluvial & Tidal Flooding)	6,000,000 to 8,000,000	7,000,000 to 9,000,000

Note that these costs do not include the damage to commercial properties on the Longman Industrial Estate and the Harbour.

A further property survey will be required to calculate a more accurate analysis of the potential benefit obtained from protecting these properties from flooding. This will cover properties at risk of fluvial flooding in King Street, Alexander Place and Friars Street. Significant areas of South Kessock and the Longman will also need to be surveyed, to allow a more accurate analysis of the tidal flooding.

8.2 Improvement Options

The 1991 report considered a number of flood defence options but the recommended solution was to extend and raise the existing flood wall. This study focuses on this option, considering the 1 in 100 year return period event. Other options, e.g. demountable flood defences, will be considered in more detail in Phase 2.

The existing flood wall runs from slightly downstream of the Ness Bridge to Waterloo Bridge, on both sides of the river. To increase this to give 1 in 100 year protection, the wall would be extended from the south end of Ness Walk to Kessock Road on the right bank, and from Ladies Walk to the Inverness Harbour on the left bank. The wall would be a maximum height of 1.2m above the existing pavement and would be an average of approximately 0.6m high.

The walls required to protect South Kessock and the Longman areas would be significantly lower. An average wall height of 0.5m would be required in these areas. The existing sea defences would need to be incorporated into the new scheme.

Figure 8-1: Indicative Revised Flood Wall Heights

8.3 Cost Estimates

The cost of the above scheme has been developed based on a plain concrete wall, of similar section to that discussed in the 1991 report. This follows the same route as outlined in 1991, along the top of the river bank, see Figure 8-1. This will give a preliminary estimate of the costs of such a scheme. However it should be noted that this analysis does not include costs such as those associated with planning mitigation and disruption.

This initial costing has been developed using a wall height to give protection to a 1 in 100 year return period event (1% annual probability of flooding). At this stage future climate change has not been included, although this will be considered in the design stage.

A ground level survey has only currently been undertaken for the banks between Ness Islands and Waterloo Bridge. Downstream of this location, an estimate of required wall levels has been made based on the available data. The location of the proposed defences follows that of the existing defences upstream of Waterloo Bridge, as shown in the 1991 report.

Downstream of Waterloo Bridge, the cost estimate has been based on a route along the edge of the river. This is only to give a preliminary estimate of the cost of constructing defences to protect this area.

On the left bank, the wall is assumed to follow the top of the river bank, under the railway viaduct and round to Thornbush Quay. It then follows the existing wall along Kessock Road to near the pumping station. On the right bank, the provisional wall alignment follows Shore Street and Cromwell Road round to Stadium Drive. For this exercise, the wall does not protect the Harbour buildings or quays.

The location of a flood wall in this region will be investigated further in the next phase of this project, once additional survey data have been collected.

Table 8-3 Approximate Scheme Costs for Plain Concrete Wall

	Present Value Cost (£)	
	1 in 100 year	**1 in 200 year**
Left Bank	530,000	590,000
Right Bank	540,000	610,000
Total	1,070,000	1,200,000

8.4 Economic Evaluation

A full economic evaluation of the options will be calculated in accordance with the guidelines set out in FCDPAG3 once the additional data are colleted. Revisions to economic appraisal procedures arising from the new HM Treasury “Green Book” (March 2003) will also be considered.

Other costs of flooding, including damage to roads and indirect costs will be included in this analysis.

The simple cost benefit ratios derived from the indicative damages and plain concrete wall costing are given in Table 8-4. It is important to note that these ratios are not derived from a full economic evaluation of all the costs associated with a flood alleviation scheme.

Table 8-4 Costs Benefit Ratios

	1 in 100 year	**1 in 200 year**
Cost Benefit Ratio	5.6 to 7.5	5.8 to 7.5

8.5 Environmental Assessment

Preliminary calculations indicate that an average flood wall height of 0.6 to 1.2m would be required above existing levels to achieve the required flood protection. The area is already heavily developed and part of the flood wall is already in place so it is unlikely that any natural habitats will be disturbed.

Archaeological interest is likely to be minimal as the location on the wall along the pavement boundaries would be on previously disturbed ground. This would need to be checked and confirmed with The Highland Council.

Mature trees grow in the footways in places along both banks of the River through Inverness. The flood alleviation scheme will need to incorporate these into the design. This issue will be considered in more detail in the next phase of the study.

The critical environmental issues are likely to centre on the potential loss of visual amenity and in increase in visual intrusion, both during construction and when the scheme is completed. The banks of the river are heavily used for recreational walking and a raised flood wall is likely to be met with objections from local residents. A detailed survey of property boundaries would be needed to assess the potential loss of river views, combined with discussion with the property owners to explain the implications of the scheme.

Potential mitigation would include raising the footway levels to reduce the visual impact for pedestrians, facing the wall with an attractive stone cladding, and increasing the number of benches and trees along the footway. Non-permanent options, such as demountable barriers would limit the loss of visual amenity to the periods of flooding. These options will be considered further in phase 2 of the study.

This environmental assessment will continue to be updated and developed as more information becomes available during the course of the study.

9 Conclusions and Recommendations

9.1 Conclusions

- A flood alleviation scheme is required for the River Ness. The issue of extreme tidal flooding around the mouth of the river is also a significant risk and will need to be incorporated into any scheme.

- As a result of the nature of this scheme, it falls under the remit of the Flood Prevention (Scotland) Act of 1961, and thus a Flood Prevention Order will be required for the works.

- The present Standard of Protection for city centre properties on the banks on the Ness in Inverness is about 1 in 25 years. The indicative Standard of Protection for this location is 1 in 50 to 1 in 200 years therefore the existing Standard of Protection is less than the indicative standard.

- The current preferred flood alleviation scheme involves raising and extending the existing flood wall along both sides of the river. This will protect the properties in the centre of Inverness against a 1 in 100 year fluvial flood event. It will also protect properties in South Kessock and the Longman from a 1 in 100 year extreme tidal level.

- There are no significant environmental risks associated with the schemes however it is recommended that an Environmental Assessment should be undertaken at project appraisal stage to identify any ecological, archaeological and social impacts and to put in place suitable mitigation measures.

- Planning considerations are a significant issue, and will be investigated further in due course. This is likely to significantly increase the costs of any flood alleviation scheme.

- The outline economic assessment has shown the potential damage to property would be at least £6 to 8 million for the 1 in 100 year flood event. Constructing a plain concrete flood wall to provide a 1 in 100 year level of protection would cost about £1 million.

9.2 Recommendations

This study has identified that improvements to the flood defences on the River Ness are required, and that it is likely this would have a favourable cost-benefit ratio. Therefore the flood alleviation study should be progressed to the next stage, and a full feasibility study should be undertaken. This would require:

1. Ground and property surveys covering the enlarged areas identified to be potentially at risk of either fluvial or tidal flooding.

2. A more detailed assessment of the tidal flooding behaviour leading to an improved estimate of properties at risk from extreme tides.

3. Undertake a full economic analysis. This will include additional items such as: indirect benefits, damage to roads and services, disruption to services. It will also take into account a more accurate cost of the proposed scheme options.

4. Consideration of alternative protection options should be made, as well as investigating the cost implications of different standards of protection.

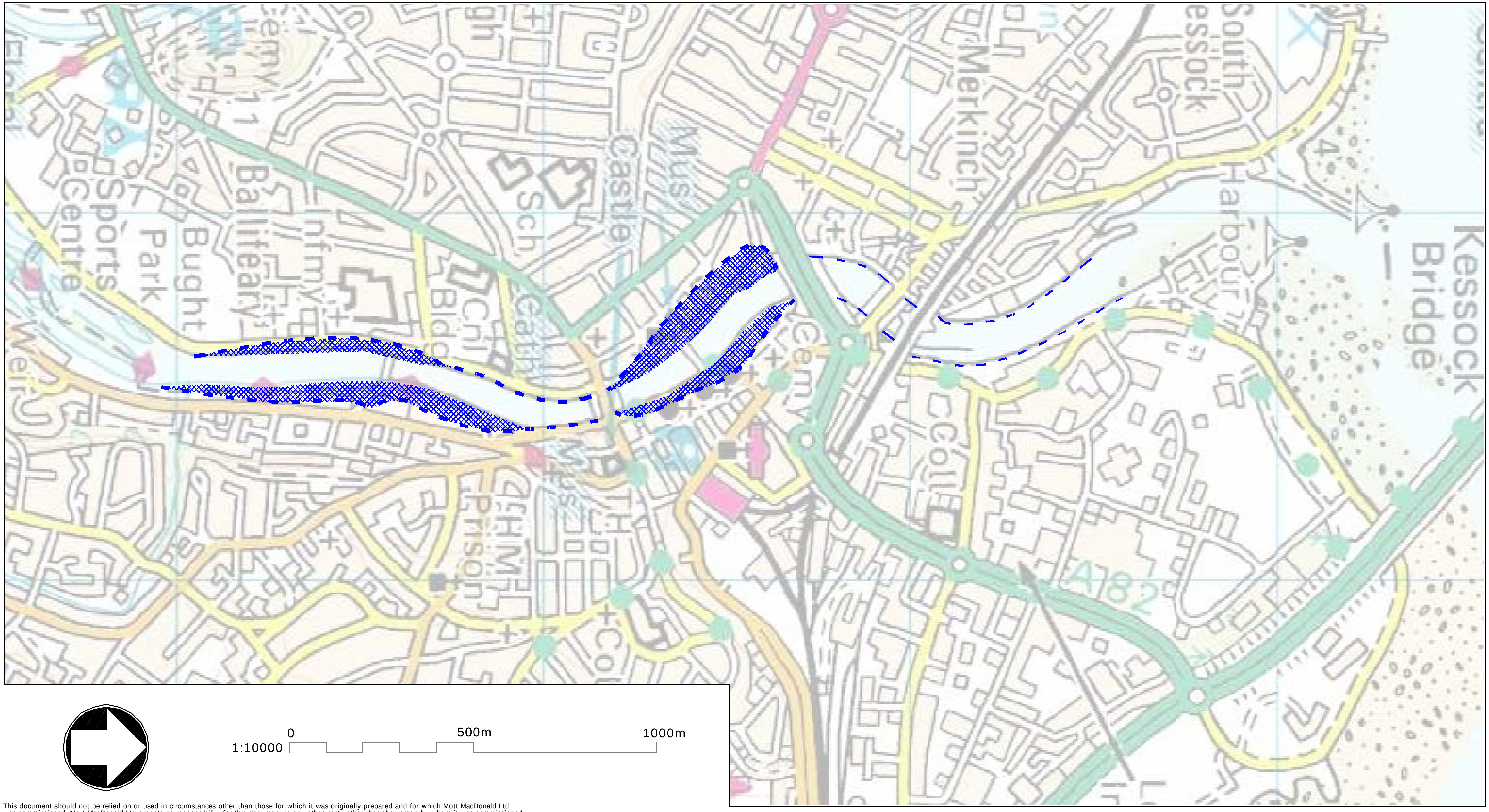
5. An allowance for future climate change over the design life of the scheme will also have to be incorporated. Options to allow for future increase in the level of protection should also be assessed.

The development of flood defence options in stage 2 of the feasibility study, including full economic analysis, will identify the flood defence improvements recommended to be progressed through detailed design in order to provide the desired standard of protection. This scheme will have two major drivers, fluvial and tidal flooding, with an area of overlap between Ness Bridge and Friars Bridge

Appendix A Flood Outlines

The following two drawings show the calculated extent of fluvial and tidal flooding of the River Ness for three separate return periods:

1.	Fluvial Flooding	1 in 100 year (1% annual probability)	215825/INV/010
2.	Tidal Flooding	1 in 100 year (1% annual probability)	215825/INV/011



0 500m 1000m
1:10000

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Mott MacDonald Ltd was commissioned. Mott MacDonald Ltd accepts no responsibility for this document to any other party other than the person by whom it was commissioned.

Mott MacDonald
68 Church Street
Inverness
Scotland IV1 1EN
United Kingdom

Tel +44 (0)1463 239323
Fax +44 (0)1463 224951
Web www.mottmac.com

Client

The Highland Council

Reproduced from the Ordnance Survey mapping with the permission of the Controller of Her Majesty's Stationery Office (c) Crown Copyright.
Unauthorised reproduction infringes Crown Copyright and may lead to prosecution or civil proceedings.
The Highland Council Licence No. LA09036L.

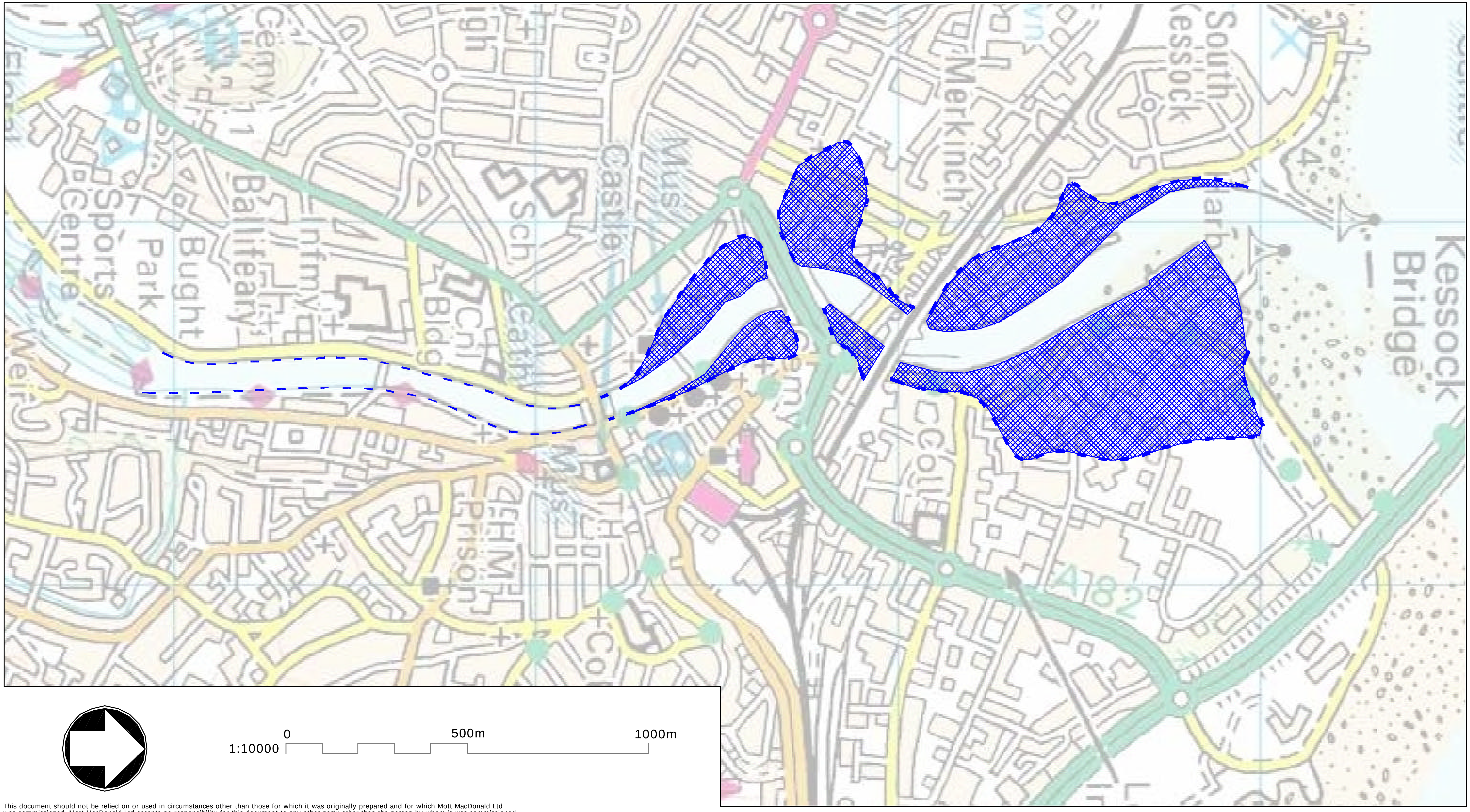
Rev	Date	Drawn	Description	Ch'k'd	App'd
P1	20 Jan 05	LFE	Issue for information		
P2	11 Feb 05	DRN	Issue for information		
P3	21 Apr 05	SS	Issue for information		
A	25 Apr 05	DRN	Issue for information		

Title
1:100 Year (1%) Indicative Fluvial Flood Outline

Drawn	SS
Checked	
Approved	
Scale	1:10000

Drawing No. 215825/INV/010

Rev	Status
A	INF



0 500m 1000m
1:10000

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Mott MacDonald Ltd was commissioned. Mott MacDonald Ltd accepts no responsibility for this document to any other party other than the person by whom it was commissioned.

Mott MacDonald
68 Church Street
Inverness
Scotland IV1 1EN
United Kingdom

Tel +44 (0)1463 239323
Fax +44 (0)1463 224951
Web www.mottmac.com

Client

The Highland Council

Reproduced from the Ordnance Survey mapping with the permission of the Controller of Her Majesty's Stationery Office (c) Crown Copyright.
Unauthorised reproduction infringes Crown Copyright and may lead to prosecution or civil proceedings.
The Highland Council Licence No. LA09036L.

Rev	Date	Drawn	Description	Ch'k'd	App'd
P1	20 Jan 05	LFE	Issue for information		
P2	11 Feb 05	DRN	Issue for information		
P3	21 Apr 05	SS	Issue for information		
A	25 Apr 05	DRN	Issue for information		

Title
1:100 Year (1%) Indicative Tidal Flood Outline

Drawn	SS
Checked	
Approved	
Scale	1:10000

Drawing No. 215825/INV/011

Rev	Status
A	INF