FLOOD RISK ASSESSMENT: Emsworth Mill Pond

1.0 Introduction

Havant Borough Council (HBC) commissioned HR Wallingford to investigate the flood risk at the Mill Pond at Emsworth, and in particular the consequences of removing the embankment that creates the Mill Pond. The scope of work undertaken, as described in the HR Wallingford proposal dated 18th September 2000, includes the following tasks:

- Site visit
- Data Review
- Desk based review of flood risk
- Assessment of economic value of assets at risk, with and without embankment
- Preparation of a letter report summarising the study findings

The results from this study are presented in the following sections. Section 2 summarises the information reviewed, and Section 3 details the analysis of existing hydraulic conditions in and around the Mill Pond. In Section 4 consideration is given to flood issues upstream of the Havant Road culvert, whilst in Section 5 the consequences of removing the Mill Pond embankment are reviewed in light of the earlier observations and conclusions. Conclusions from an economic assessment of flood risk with and without the embankment are also presented in Section 5.

During the study it was clear that there are a number of inter- relating issues surrounding flood risk at the Mill Pond. In Section 6 recommendations on a variety of these issues are presented.

2.0 Review of existing Information

2.1 Site Visit

A site visit was undertaken, along with a review of technical information, with Havant Borough Council on 28th November 2000. A summary of the data collected during the study is presented in Section 2.2 below. During the site visit a number of key issues were identified including:

- Nature of the brook entering the Mill Pond via the Havant Road culvert (relatively steep, narrow channel, passing through housing estate)
- Problems with trash racks (frequent blockage) and local flooding upstream of the culvert
- Local topography around the Mill Pond – low lying immediately adjacent to pond
- Operation of the Bath Road outlet structure (twin flap valves, summer stop log operation)
- Poor quality of flood defence wall around low lying properties adjacent to Bath Road outlet structure
- Indications of subsidence of Mill Pond embankment crest, even following relatively new works
- Concrete weir overflow through old lock at site of the mill
- Obvious wave action in Chichester harbour outside of the Mill Pond
- Environmental aspects including wildlife (ducks, swans etc.), views, type of residential area etc.

2.2 Sources of data

During the desk study a range of information from a variety of sources was used, including:

- East Solent Shoreline Management Plan Stage 1 (Volume III) and Stage 2 (Volume IV)
- 1:25000 Ordinance survey map for Chichester, South Harting and Selsey (Explorer series number 120)
- Admiralty Tide Tables for UK and Ireland, Volume 1, 1998
- Yellow Manual (Economics of Coastal Management: *A manual of benefit assessment techniques*)
- MAFF Project Appraisal Guidance – FCDPAG3 – Economic Appraisal
- Discussion with local resident (Mr Reynolds) plus additional information supplied
- Notes and photographs from site visit
- Flood Estimation Handbook (FEH)
- Culvert Design Guide, CIRIA report 168

Havant Borough Council also provided the following:

- Bathymetric survey of Mill Pond
- Aerial views of Mill Pond
- Catchment run-off calculations for West Brook, including a catchment plan
- Drawings and details of operation of the Mill Pond control structures

3.0 Assessment of existing conditions

3.1 Study Approach

In order to determine the economic impact of removing the Mill Pond embankment it is first necessary to quantify existing hydraulic conditions, and then potential conditions likely without the embankment. Conditions in and around the Mill Pond may be affected by a combination of factors including:

- Flow in West Brook (and hence capacity of the Havant Road culvert)
- Stage discharge relationship and operation of the Mill Pond outlet structures
- Stage volume relationship of the Mill Pond
- Geometry of the embankment
- Tidal conditions in Chichester Harbour
- Wave conditions in Chichester Harbour

The approach taken was to collate or determine information on each of these factors and then to simulate behaviour of the Mill Pond and Brook using a numerical model (ISIS). Model simulations would then allow estimation of potential flood levels and consequently potential economic impacts.

3.2 Data Review

3.2.1 Key Structure Levels

A review of structure details and topography shows the following 'facts and figures':

Bath Road weir level	2.27mODN
Lock weir crest level	2.51mODN
Normal Mill Pond water level	2.27mODN
Majority Mill Pond Embankment level	3.00mODN
Lowest Mill Pond Embankment level	2.91mODN
Lowest threshold level for adjacent housing	2.90mODN
Estimated invert of Havant Road culvert	1.62mODN
Estimated soffit of Havant Road culvert	2.62mODN

3.2.2 Fluvial Flow

HBC provided copies of flow calculations undertaken in 1994 to estimate the catchment run-off into West Brook. These calculations suggested that for a 1 in 5 year event, a peak flow of 11.9m^3/s could be expected at the Mill Pond. A comparison was made using the Flood Estimation Handbook (FEH) approach. Based upon catchment information within the numerical model, this gave a peak flow for the same return period event of only 2.2 m^3/s. This difference in estimates is significant, however, a review of data and catchment area used gave no immediate indication as to the cause. On consideration of the channel and culvert dimensions and the anecdotal evidence on the frequency of flooding, it was considered more appropriate to use the flows calculated using the FEH package, although these values should be confirmed before use in any later studies.

Peak flows calculated (using FEH) for 1, 5, 14 and 100-year return period events are shown in Table 1 below.

Flood return period (years)	Peak flood flow (from FEH) (m^3/s)
1	1.3
5	2.2
14	3.0
100	5.5

Table 1 Peak flows for return period events in West Brook

3.2.3 Tidal Water Levels

Tidal water level predictions for Chichester Harbour may be found in Volume III of the East Solent Shoreline Management Plan (SMP), and have been used for this study. The SMP gives marginal and joint probabilities for water levels at a location close to Emsworth. These are shown in Tables 2 and 3 below.

Return Period (years)	Still Water Level (mODN)
MHWS	2.4
1	2.9
5	3.2
10	3.3
50	3.4
200	3.6

Table 2 Marginal extreme water levels – Chichester Harbour (Close to Mill Pond)

Return Period (years)	Significant wave height, Hs (m)	Extreme water level (mODN)
1	-	-
5	0.43	3.01
10	0.43	-
50	0.43	3.35
200	0.43	3.66

Table 3 Joint probability conditions – Chichester Harbour (Close to Mill Pond)

3.2.4 Waves

Wave predictions from Volume III of the SMP have also been used in this study. The SMP gives marginal and joint probabilities for waves at a location close to Emsworth. These are shown in Table 4 and Table 3 respectively.

Return Period (years)	Significant wave height, Hs (m)
1	0.7
5	-
10	0.82
50	0.90
200	-

Table 4 Marginal extreme wave heights

3.2.5 Climate Change - Sea Level Rise

Predictions for the rate of sea level rise are given in the SMP as being between 5mm/year and 13mm/year. Over 50 years this would result in a sea level rise in the Emsworth area of between 0.25m and 0.65m. A sea level rise of 0.3m over 50 years has been used in this study.

3.3 Understanding conditions within the Mill Pond under varying tide and fluvial flow

A numerical model of the Mill Pond was built using the ISIS flow-modelling package. This modelling tool allows simulation of hydraulic conditions including catchment run-off, river flows, hydraulic structures (such as weirs and culverts) and tidal conditions. A model was therefore built to simulate flow conditions in and around the Mill Pond. This model then allowed the prediction of flood water levels under a range of storm or operating conditions.

Initially the model comprised just the Mill Pond, embankment and outlet control structures with a fluvial input directly to the pond and tidal levels imposed on the outlet structures. A range of extreme conditions approximating a 100-year joint probability return event were initially simulated. Results from these simulations showed, not surprisingly, that under extreme conditions the water level in the Mill Pond was dominated by tidal levels.

Table 5 shows the conditions modelled to investigate behaviour of the Mill Pond water levels and discharge over and through the Mill Pond structures.

Fluvial Flood return period (years)	Tidal Water level return period (years)
100	200
100	0.1
14	1
1.4	10
0.28	50
100	100
100	1
1	100

Table 5 Extreme Joint Conditions modelled using ISIS (conditions shown in blue were modelled to emphasise the significance of the tidal influence on Mill Pond Levels)

Figure 1 shows the predicted variation in Mill Pond water levels for three extreme events (as shown in blue in Table 5). It can be seen that the variation in extreme Mill Pond levels is similar for a 100-year fluvial flood /100-year tidal water level event and for a 1-year flood /100-year water level event. This shows that extreme fluvial events have a small effect on Pond water levels when tide levels exceed 3mODN (i.e. overtop the embankment).

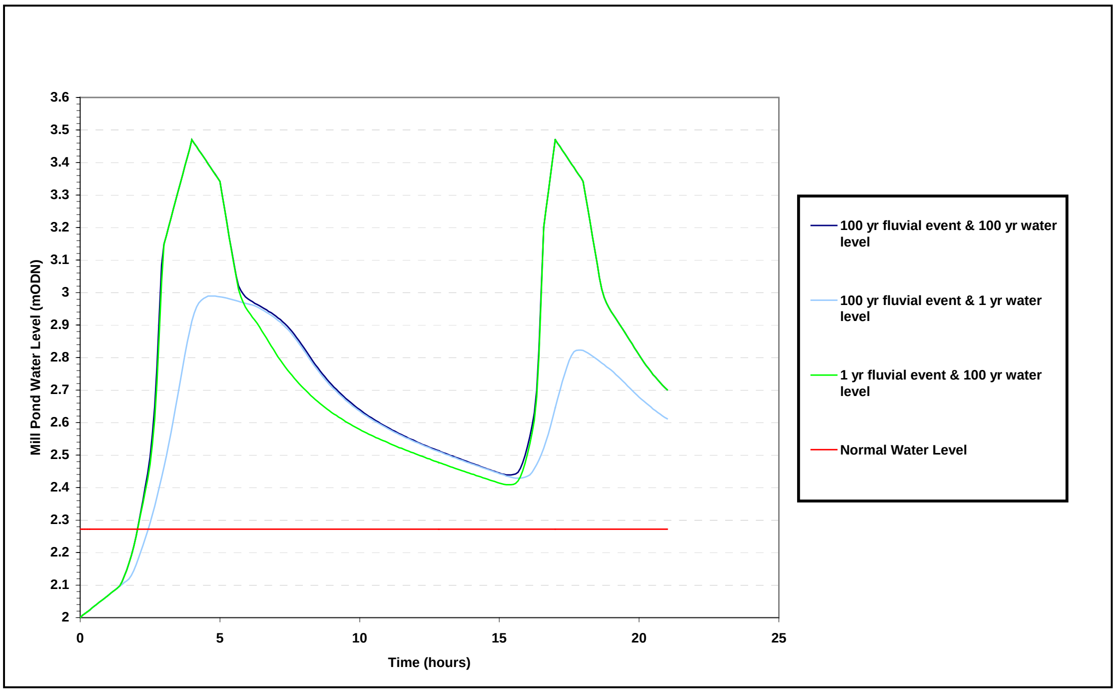

Figure 1 Variation in Mill Pond Water Level With Different Extreme Flood and Water Level Combinations

The third curve in Figure 1 shows predictions for a 100-year fluvial flood combined with a 1-year tidal water level. For this simulation, it can be seen that the water level in the Mill Pond rises to approximately the level of the embankment (2.9m towards the lock gate end) and overtops into the harbour. Normal pond water level has been taken as the level of the Bath Road outlet weir (i.e. 2.27mODN).

It should be noted that these general modelling results were produced without including the influence (restrictions) of the culvert under Havant Road. A review of culvert capacity (outlined in Section 4) determined that the culvert capacity is significantly less than the peak discharge of a 100-year fluvial event. Consequently 'true' pond water levels for the combined event would be lower than shown in Figure 1. The aim of this initial modelling was, however, to demonstrate the relative importance or influence of tidal versus fluvial conditions.

Given the difference in the peak catchment runoff estimates undertaken previously and the estimates provided by the FEH analysis, a check was made to ascertain the sensitivity of the predicted pond water levels to extreme flows from West Brook. It was found that these flows had a negligible effect on the water levels in the Mill Pond when compared to the impact of extreme tide levels.

In order to visualise the interaction between tide, fluvial flow and pond water level, a series of stage-discharge curves were generated for the Mill Pond based upon estimated relationships for the outlet structures. These curves are shown in Figure 2 below. Each curve relates to a fixed fluvial inflow to the pond (ignoring Havant Road culvert capacity) and shows Mill Pond water level varying with tide level. Each point has been determined through steady state conditions. It can be seen that, under steady state conditions, a flow of around 3 m^3/s into the Mill Pond from the West Brook will result in Pond water levels overtopping the embankment. This suggests that the maximum discharge over and through the Mill Pond outlet structures is just less than 3.0 m^3/s

at low tide conditions. At tide levels higher than the level of the lock gates (2.51 mODN) the Mill Pond level will equalise with that of the tide.

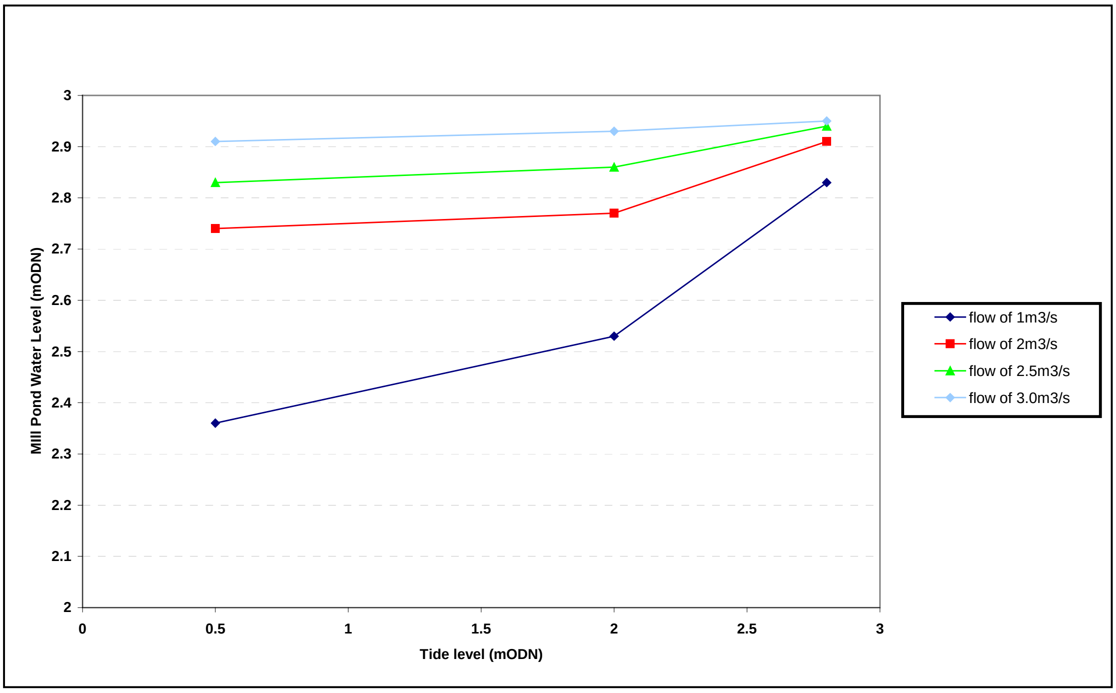

Figure 2 **Stage discharge relationship for total discharge from the combined structures under different fluvial and tide conditions**

4.0 Flood risk upstream of the culvert under Havant Road

There are records showing that flooding occurs relatively frequently upstream of the inlet to the Havant Road culvert. A local resident (Mr Reynolds) provided considerable information detailing dates and extents of flooding. To investigate the cause of flooding, the capacity of the culvert under Havant Road was first estimated using the Manning's equation. The capacity was estimated to be approximately 1.6 m^3/s. This equates approximately to the peak discharge of a 1 in 2-year flood (according to the FEH estimates). Any flood larger than a 2 year event could therefore be expected to cause flooding upstream of the culvert.

It should be noted that this estimation of capacity is only an approximation based upon limited topographic and structure data. The culvert is over 100m long and quite likely to contain bends and changes in section along its length. A more detailed assessment should be undertaken if any works are planned based on estimated culvert capacity.

4.1 Interaction with Mill Pond

In order to determine the influence that Pond water levels may have on West Brook water levels upstream of the culvert, the ISIS model of the Mill Pond was extended to include the culvert. A series of model runs were then undertaken simulating flow along the Brook of a 5 year and a 100 year flood in conjunction with varying water levels in the Pond. The results from this analysis may be seen in Figure 3 below.

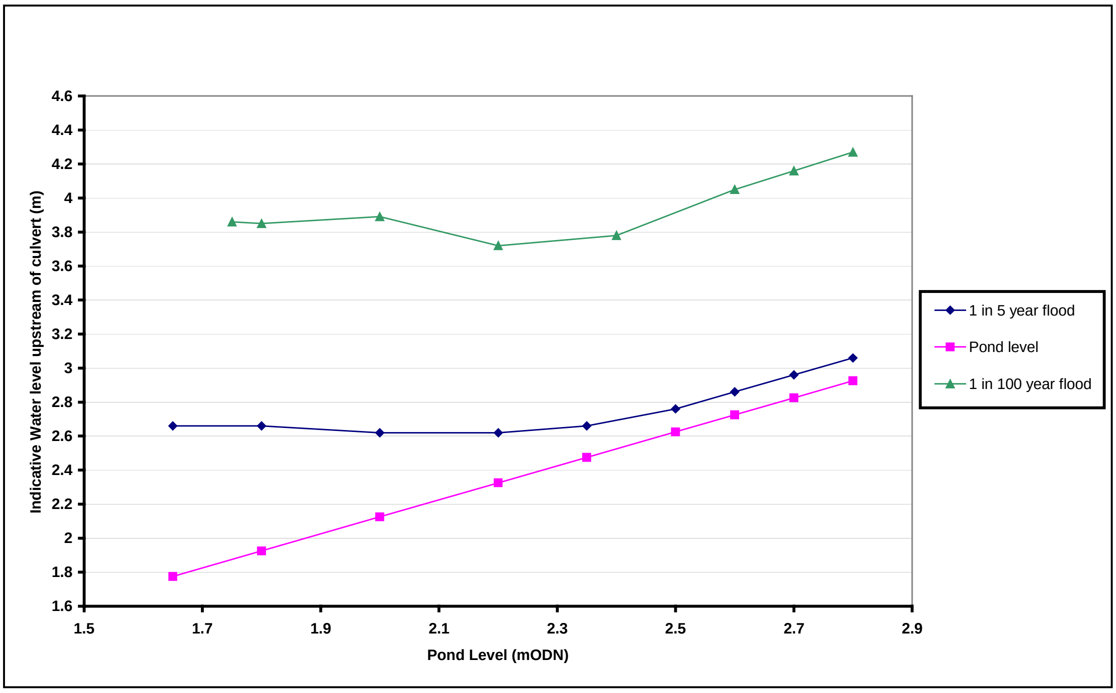

Figure 3 Indicative upstream level versus Pond Level

When looking at Figure 3, note the following points:

- Culvert invert level at Pond: 1.62mODN
- Culvert soffit level at Pond: 2.62mODN
- Culvert invert level upstream: 1.75mODN
- Culvert soffit level upstream: 2.75mODN
- The effect of trash screens has not been included within the model
- It has been assumed that flooding occurs upstream when water levels exceed 2.80mODN
- Upstream water levels are quoted as indicative only since overbank details within the model are based on judgement rather than survey data – upstream water levels should be only taken as an indication of potential flooding rather than absolute levels

Consideration of the 1 in 5 year flood curve on Figure 3 shows that the water level upstream of the culvert is not unduly affected by Pond water level until the pond levels exceed approximately 2.35mODN. For the 100 year fluvial flood this level may be taken as approximately 2.4mODN.

Assuming that the Mill Pond water level is initially at 2.2mODN it may be estimated that during a summer event (where the Bath Road outlet is closed and requires manual operation) pond water levels will rise and begin to affect flood levels upstream of the culvert after approximately 1 hour of ‘culvert capacity’ flow.

4.2 Causes of flooding

Flooding upstream of the culvert at Havant road may therefore be caused by three factors – or a combination of these factors:

1. Culvert capacity is relatively low and can only cope with an estimated 2 year fluvial event
2. Culvert capacity is further restricted when pond water levels exceed 2.35mODN
3. Many flood events relate to blockage of the two trash racks upstream of the culvert entrance

Note that water levels within the mill pond may only be lowered when tide levels outside of the mill pond permit. If tide levels exceed 2.35m then the mill pond level may not be lowered below this level until such time as the tide level also drops below this level. If the tide level exceeds the lock weir crest (2.51mODN) or the embankment crest (>2.91mODN) then water levels within the pond will rise relatively quickly to match the external tide levels.

5.0 Consequences of removing the Mill Pond Promenade

5.1 Summary of issues

There are numerous potential impacts associated with removal of the Mill Pond Promenade, including:

- Waves would propagate into the Mill Pond from Chichester Harbour increasing the risk of flooding and undermining existing bank protection
- Low tide levels would result in exposed mud banks across a majority of the pond area
- Fluvial flow would be limited to a small channel cut through the mud
- Flows from the culvert may cause scour problems at the culvert at low tide conditions
- The change in water conditions would significantly affect flora and fauna in the Mill Pond area, especially the bird life
- Implicitly, there would be a visual impact for the surrounding residential properties

The impact on flood risk around the Mill Pond may be estimated in economic terms and is detailed in Section 5.2 below. The impact on flood risk upstream of the Havant Road culvert is not immediately obvious. An advantage of removing the embankment would be the elimination of any high water level effects caused by delayed operation of the Bath Road outlet. A disadvantage would be exposure to increased wave action and any impact that this may have on culvert capacity.

5.2 Economic assessment of assets at risk

An economic assessment of the assets at risk from flooding adjacent to the Mill Pond has been carried out, according to the latest guidance provided by the Ministry of Agriculture, Fisheries and Food (FCDPAG3). Appendix 5 of the ‘Yellow Manual’ was used to relate economic damage to the depth of flood water above property threshold levels. The published values in this manual are for January 1990. These have been updated to January 2001 values using the Retail Price Index (RPI) which stood at 119.5 in January 1990 and 171.1 in January 2001. Therefore, damage values have been increased by 43.2%.

The tables in the ‘Yellow Manual’ provide average damage values for all properties and a breakdown of damage values for different types of property such as detached, semi-detached, terraced etc. It should be recognised that the damage estimates used within this analysis are only an approximation of reality, but represent the best information currently available (without undertaking property by property valuations).

5.2.1 Current conditions

Having established a relationship between flood depth and damage, water level predictions have been used in conjunction with topographic data to predict likely flood depths at individual properties. The extreme water level predictions outlined in Section 3.2.3 were used. Fluvial flows were ignored in this analysis since they were found to have little effect on water levels in the Mill Pond under extreme conditions (i.e. at levels of 2.9mODN and above). For the existing conditions assessment, waves were not considered and potential damage was estimated for a range of return period events. The calculations were also repeated assuming a 50-year sea level rise of 0.3m. The results can be seen in Table 6 below:

	Year 0 and 50 Assuming No Change in Tide Levels Return Period (years)				Year 50 Assuming 0.3m Change in Tide Level Return Period (years)			
	1	**5**	**100**	**>200**	**1**	**5**	**100**	**>200**
Water Level (mODN)	2.9	3.2	3.5	3.7	3.2	3.5	3.8	4.0
Damage £k	3	30	90	200	30	90	260	370

Table 6 Estimated value of flood damage to properties under current conditions

5.2.2 Walk Away Scenario: Without Promenade

From a flood risk perspective, the main impact of removing the Mill Pond Promenade would be to allow waves to enter the Mill Pond from Chichester Harbour. The lowest threshold level of surrounding property is 2.9mODN for the property adjacent to the Bath Road outlet. This is also the level of the Promenade near to the Mill lock.

The effect of extreme wave conditions was accounted for in the calculations by assuming an average increase in the water level by 0.2m, this is a crude but sensible first estimate. This increase was derived from the Joint Probability wave conditions given in Table 3.

Potential damages were also calculated including this 0.2m allowance for waves and the results are given in Table 7 below.

	Year 0 and 50 (No Climate Change) Allowing +0.2m for Wave Effects Return Period (years)				Year 50 (+0.3m for Climate Change) Allowing +0.2m for Wave Effects Return Period (years)			
	1	**5**	**100**	**>200**	**1**	**5**	**100**	**>200**
Water Level (mODN)	3.1	3.4	3.7	3.9	3.4	3.7	4.0	4.2
Damage £k	10	75	200	330	75	200	365	490

Table 7 Estimated value of flood damage to properties assuming Mill Pond promenade is removed

5.3 Conclusions
The damage values for different return period events may be converted into an average annual damage estimate as shown in Table 9 below:

Scenario	Average Annual Damage (£K)
With Promenade (Year 0)	20
With Promenade in year 50 (assuming climate change)	80
Without Promenade (Year 0)	60
Without Promenade in year 50 (assuming climate change)	165

Table 9 Average Annual Damage estimates

If the damages are considered to vary linearly with sea level rise it is possible to determine the Present Value of the likely damage over the next 50 years. This has been done using a discount rate of 6% in line with current MAFF guidance and can be seen in Table 10 below:

Scenario	Present Value Estimates(£K)
With Promenade (no climate change)	380
With Promenade (with climate change)	640
Without Promenade (no climate change)	1,000
Without Promenade (with climate change)	1,500

Table 10 Present Value Flood Damage

It can be seen from Table 10 that the Present Value of potential damage costs increased by removing the promenade without consideration of climate change is approximately £620K and with consideration of climate change is £860K.

6.0 Conclusions
The following points may be concluded :

- A large difference between FEH values and previous hand calculations for estimates of catchment runoff was found. The FEH predicts a 1 in 100 year flood with a peak of approximately $5m^3/s$. Previous hand calculations suggested $20m^3/s$.

- The Havant Road culvert is estimated to have a capacity of approximately $2m^3/s$. However, there is considerable uncertainty surrounding the internal geometry. This estimate also ignores the impact of the trash racks located just upstream.

- Maximum culvert capacity is reached at about a 1 in 2 year event (and confirms HBC comments).

- Flooding upstream of the culvert is frequently worsened by trash on the racks.

- The Mill Pond water level will start to affect culvert discharge capacity and hence flooding upstream of the culvert when levels exceed approximately 2.35 mODN in the Pond.

- Assuming the Bath Road outlet is closed (i.e. summer operation) pond levels will exceed 2.35mODN (starting from 2.2mODN) after approximately 1 hour, assuming maximum culvert capacity (this confirms Mr Reynolds observations of the initiation of flooding upstream of the culvert)

- Removal of the Mill Pond promenade will have significant environmental impacts as well as increasing the risk of flood damage to properties around the pond. Estimates of the Present Value of property at risk suggests that removal of the promenade will result in an increase of £620K in damages without considering climate change, or £860K including an assessment of climate change over 50 years.

7.0 Recommendations

In light of these conclusions the following points are emphasised:

1 HBC could reduce flood risk upstream of the culvert at minimal cost by dealing with the trash rack problem. A possible solution would be to locate a new trash rack upstream from the culvert entrance, perhaps adjacent to the car park. Land in this area could be modified such that any flood flow resulting from a blocked rack would be directed across the grass and back into the channel some way upstream of the culvert entrance. Careful landscaping, soil protection and review of adjacent housing land level / walls could allow such a scheme to be implemented with minimal visual impact on the existing area.

2 Given plans for housing development within the catchment and the uncertainty around catchment runoff, culvert capacity (at both the railway and West Brook) and local flooding it is recommended that a detailed study of hydrology, culvert capacity and Mill Pond interaction is undertaken. Perhaps HBC could set this as a condition of the development, or even require the developer to contribute towards the costs of increasing the Havant Road culvert capacity. Note that the current HR ISIS model is based on very limited topographic data and that flood levels shown for upstream of the culvert are indicative of flooding only and should not be used as predicted levels for any subsequent calculations. These values are based on assumed ground levels that need to be confirmed.

3 Mr Reynolds allegations that high levels in the Mill Pond worsen flooding adjacent to his property may be founded. Levels above 2.35mODN in the pond will affect flood levels upstream of the culvert. HBC will need to respond to flood events within 1 hr of full culvert capacity flow in order to keep pond levels below 2.35mODN. This assumes that tidal levels in the harbour remain sufficiently low to allow discharge of water from the Mill Pond. Release of water from the Mill Pond will not be possible unless the pond water level is higher than the harbour water level. When tide levels exceed the lock gate weir crest (2.51mODN)

or embankment level (>2.9mODN), water levels within the Mill Pond will rise quickly to match harbour levels.

If capital works are planned for the embankment it may be appropriate to consider automatic discharge structures - perhaps a siphon – to avoid the need for manual operation.

4 The economic assessment suggests that there is a reasonably high risk to residential housing in this area from flooding. These figures should be considered in light of the cost of remedial works to maintain the promenade. It should be noted that these figures do not make any allowance for environmental impacts (visual, smell, flora / fauna etc.) which could be considerable. No allowance for direct wave action of existing bank protection, or for possible scour around the culvert outfall has also been made.