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Sources of flooding on floodplains of the tidal Thames

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SOURCES OF FLOODING ON FLOODPLAINS OF THE TIDAL THAMES

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Abstract

The Thames Estuary 2100 (TE2100) project requires an assessment of flood risk for present day and future scenarios for the tidal Thames floodplains, to provide a basis for planning flood risk management over the next 100 years and beyond.

To do this it is first necessary to understand the causes of flooding. The main potential sources of flooding include the surge tides on the tidal Thames, and fluvial flooding from the Thames, tributaries, land drainage systems and urban drainage systems. Flooding is affected by the operation of moveable gates including the Thames Barrier and barriers on other tributaries.

The paper describes the sources of flooding, the ways in which they interact and the effects that they have on flood levels. The flood management system on the tidal Thames is described, and the impacts of failure of elements of the system are considered.

Extreme sea levels and fluvial flows are expected to increase in the future, and the main implications for flood management on the Thames are summarised.

1. Introduction

The floodplain of the tidal Thames covers an area of about 350 km^2, and extends from Teddington in West London to the sea near Southend. The floodplain covers highly developed areas on both banks of the Thames through London including Kew, Westminster, Canary Wharf, and large areas of residential and commercial development. East of the Thames Barrier at Woolwich the pattern of development is less intense but there are major urban developments including Thamesmead and Canvey Island, and extensive commercial and industrial areas.

There are over 500,000 properties in the floodplain and well over a million residents. In addition, many thousands of commuters work in the floodplain and the transport infrastructure includes over 70 underground stations.

Tidal flooding has always been a threat to London. Walls and other defences have been constructed along the estuary and raised over the years, usually in response to particular flood events. Following the 1953 floods, a comprehensive tidal flood defence system was constructed including the Thames Barrier on the Thames, extensive fixed tidal defences and a range of other barriers and control structures.

The standard of protection provided for tidal flooding is estimated to be 1 in 1000 years in the year 2030, although the standard will gradually reduce as sea levels rise. The defences have a finite life, and therefore a constant programme of maintenance and refurbishment is needed to ensure that the defences fulfil their function.

In addition to flooding from overtopping of the defences, there is a risk of breaching of defences. Hence there is a constant need to inspect the defences, identify weaknesses and carry out necessary repairs.

Whilst tidal flooding is the main potential cause of catastrophic flooding on the Thames, other causes include flooding from tributaries, local drainage and urban drainage. Whilst these are far less serious than potential tidal flooding, the frequency of these local floods can be much higher. The main reason for this is that standards of protection are much lower, typically 30 to 100 years on tributaries where water levels are dominated by fluvial flows. The standard of protection on the Thames in West London for fluvial flooding is also much less than 1000 years.

Flooding from tributaries and drainage systems generally occurs when the systems overflow due to high fluvial flows. However this can be exacerbated by tide locking of watercourses during high tide periods, causing water to back up in the drainage systems.

The paper considers flooding from each of these sources both individually and in combination, based on work carried out in Work Elements EP3, EP4 and EP10 of TE2100 (HR Wallingford 2006a, b and c). Groundwater flooding is not covered as this is not reported to be a serious problem on floodplains of the tidal Thames, although this could change if there are significant rises in future water levels in the Thames.

2. Sources of flooding

2.1 Surge tides

Predicted extreme surge tide water levels at Southend are shown on Table 2.1.

Table 2.1 Extreme tide levels at Southend *(Year 2000, Source JBA 2003)*

Return Period (years):	5	20	50	100	200	500	1000
Tide level (m AOD):	3.94	4.22	4.39	4.57	4.70	4.87	5.03

Typical increases in tide levels along the estuary from Southend are as follows:

- Southend to Thames Barrier at Woolwich: 0.9m
- Woolwich to Westminster: 0.3m (if the Barrier is open)

Thus the 1000-year level at Woolwich is about 6m AOD. The 1000-year level at Westminster would be about 6.3m AOD if the Barrier did not close, over a metre above local defence levels. However the Thames Barrier is operated to prevent overtopping of the upriver defences. These levels contrast with ground levels of close to 0m AOD in the Lower Thames Marshes, and about 4m AOD in central London.

There is uncertainty in the predicted extreme tides at Southend even without consideration of climate change. In addition, considerable variation is possible in the increase in level between Southend and London. An important factor is the steepness of the incoming tide and variations of ± 0.4m are possible (HR Wallingford 2006a). Figure 2.1 shows the variation in level along the estuary for different tide shapes. An event in December 2005 produced levels that were over 0.3m higher than expected for this reason.

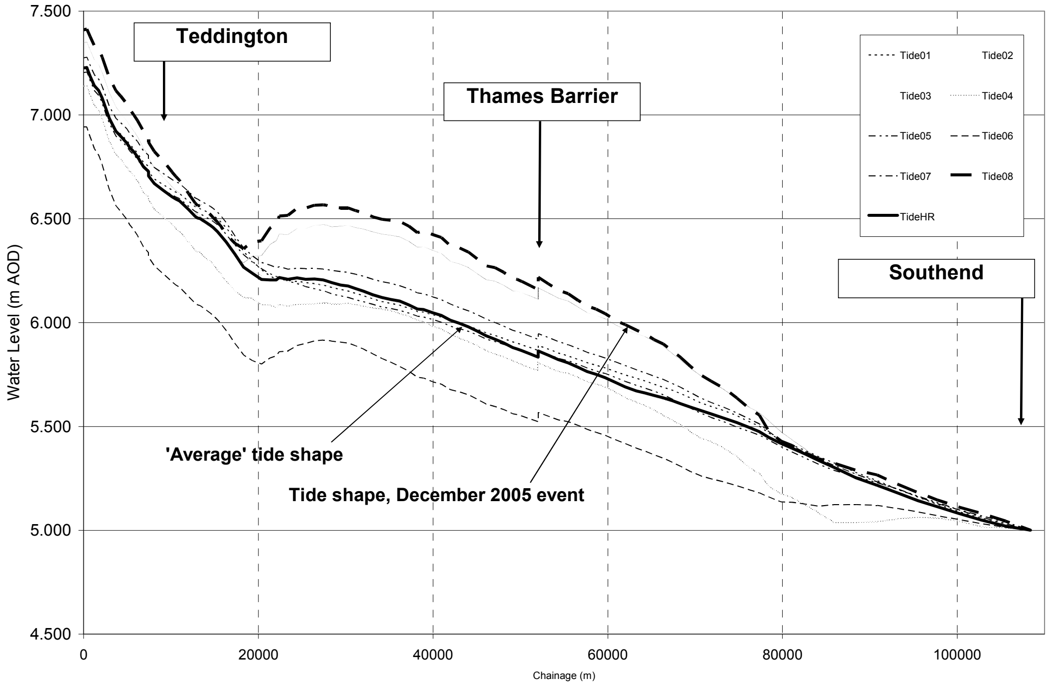

Figure 2.1 Variations in water levels on the tidal Thames for different tide shapes

Not only is the sea level expected to rise as a result of climate change, but the magnitude of extreme surge tides is expected to worsen. Table 2.2 shows a range of predictions of future surge tide levels at Southend. The rate of increase of extreme levels for all scenarios except the Defra scenario is significantly greater than that of Mean Sea Level.

Table 2.2 Predicted future extreme tide levels at Southend *(Source: HR Wallingford 2005)*

Return Period (years)	**2005**	**Name of climate change scenario**							
		Defra (2003)		UKCIP02 Medium High		High Plus		High Plus Plus	
		2050	**2100**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Mean Sea Level rise (m):	0.10	0.40	0.70	0.28	0.55	0.74	1.70	1.38	3.30
100	4.57	4.87	5.17	5.03	5.73	5.48	6.84	6.12	8.44
200	4.70	5.00	5.30	5.21	5.96	5.65	7.07	6.29	8.67
500	4.87	5.17	5.47	5.43	6.27	5.87	7.37	6.51	8.97
1000	5.03	5.33	5.63	5.63	6.54	6.07	7.63	6.71	9.23
10000	5.51	5.81	6.11	6.26	7.37	6.68	8.44	7.32	10.04

2.2 Fluvial flows on the Thames

Predicted extreme fluvial flows on the Thames at Teddington are shown on Table 2.3. The main potential cause of flooding between Teddington and Brentford is from fluvial flows. The effect on water levels is much less noticeable further downstream where levels are dominated by tidal flows.

Table 2.3 Predicted future flood flows at Teddington *(Source: HR Wallingford 2005)*

Return Period (years)	2005	Name of climate change scenario							
		Defra (2003)		UKCIP02 Medium High		High Plus		High Plus Plus	
		2050	**2100**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
100	777	932	932	839	925	901	1088	1088	1554
200	869	1043	1043	939	1034	1008	1217	1217	1738
500	1007	1208	1208	1088	1198	1168	1410	1410	2014
1000	1126	1351	1351	1216	1340	1306	1577	1577	2252
10000	1562	1874	1874	1687	1859	1812	2187	2187	3124

2.3 Tributary fluvial flows

Tributaries of the tidal Thames are shown in Figure 3.1. Catchment areas and peak flood flows are shown in Table 2.4 (HR Wallingford 2006b). Whilst the fluvial flows from tributaries have little impact on flood levels in the tidal Thames, they contribute to flooding on the tidally influenced reaches of the tributaries.

Table 2.4 Characteristics of Tidal Thames tributaries

River/Tributary	Catchment area (km^2)	URBEXT	Estimated 100-year peak flood flow (m^3/s)	Degree of urbanisation
River Thames to Teddington	9,958.7	0.043	777	Slightly
River Crane	86.5	0.350	35	Very heavily
River Brent	168.4	0.411	61	Very heavily
River Lee	1,412.3	0.120	159	Moderately
River Roding	345.6	0.094	80	Moderately
Beam River	62.9	0.289	21	Very heavily
River Ingrebourne	62.3	0.132	25	Heavily
Mar Dyke	103.6	0.049	47	Slightly
Mucking Creek	15.2	0.125	18	Heavily
Canvey Island Creeks	38.6	Small	-	Small
Beverley Brook	56.4	0.322	22	Very heavily
River Wandle	192.5	0.277	32	Very heavily
River Ravensbourne	177.9	0.312	47	Very heavily
River Darent	253.0	0.053	33	Moderately
River Cray	130.2	0.187	37	Heavily

2.4 Fluvial flows from smaller watercourses and drainage systems

There are about 40 smaller land drainage systems that discharge into the tidal Thames or the tidal reaches of tributaries. Fluvial flood flows are small, typically less than $10m^3/s$. The catchment areas normally include the floodplain itself and adjacent high ground where water drains into the floodplain. Some areas have inflows from small watercourses, for example Thamesmead where the catchment area includes the Wickham Valley Watercourse. In this case the estimated peak 100-year fluvial flood flow is about $17m^3/s$.

Urban areas along the Thames are drained by separate urban drainage systems. Three large systems for the London area discharge via major treatment works at Crossness, Beckton and Mogden. Surplus flows are discharged via over 60 Combined Sewer Overflows (CSOs) into the Thames. The main flooding concern in the urban drainage systems are local floods caused by local problems in the systems. No particular flooding problems related to the outfalls caused by tidelock have been reported by Thames Water.

3. The flood risk management system

In order to appreciate how the sources of flooding can lead to flooding on the tidal Thames floodplains, it is first to understand the flood risk management system. The system is intended to provide a flood defence standard of 1000-years in the year 2030 for most of the tidal Thames floodplain. Exceptions include parts of west London at risk from fluvial flooding, and parts of the relatively undeveloped lower Thames marshes. The area at risk from tidal flooding is shown on Figure 3.1 together with the main elements of the flood risk management system.

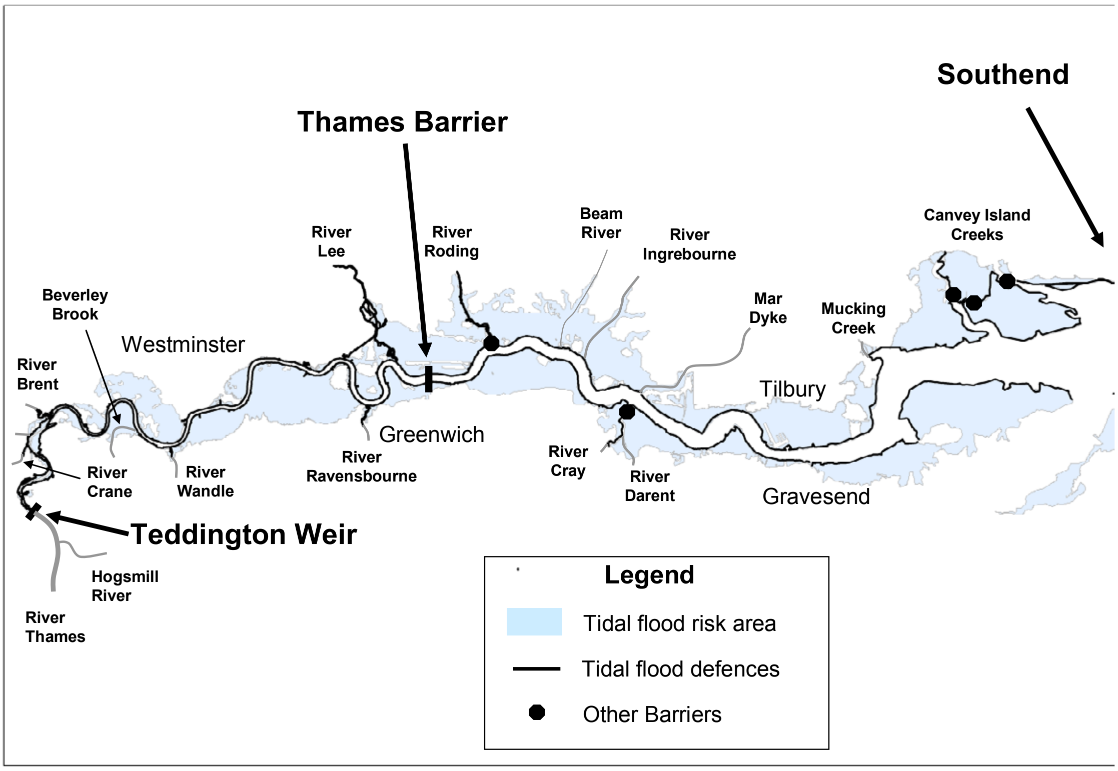

Figure 3.1 The flood risk management system

The system consists of the following elements:

- The Thames Barrier at Woolwich. This barrier is closed for forecast high surge tides to prevent high tidal water levels upriver of the Barrier.
- Other moveable barriers. There are moveable barriers on the River Roding (Barking Barrier), River Darent (Dartford Barrier) and three barriers in the tidal creeks around Canvey Island (Fobbing Horse, East Haven and Benfleet Barriers). These barriers are closed during high surge tides.

- Fixed flood defences downriver of the barriers. These provide protection against tidal flooding from the Thames and the associated tidal creeks. These are static defences whose primary purpose is to act as a wall against the tide. They include walls and embankments. There are over 300km of tidal defences along the Thames Estuary.
- Fixed flood defences upriver of the barriers. These also provide protection against flooding, but the defence levels are lower than the downriver defences because maximum water levels are reduced by barrier operation.
- Flood control gates. There are three flood control gates that provide flood protection at dock entrances (Tilbury lock, King George V lock and Gallions lock).
- Drainage outfalls. There are a large number of outfalls for tributaries and other land drainage channels that pass through the fixed flood defences. The majority of these consist of tide flaps with penstocks that allow water to discharge but prevent reverse flow during periods of high tides. There are also some pumping stations.
- Frontager flood gates. These are gates in the fixed defences that provide access to wharves and other riverside facilities.

There are also flood defences on tributaries to protect against fluvial flooding. These include enlarged channels.

4 Flood water levels

4.1 The tidal Thames

Extreme flood levels on most of the tidal Thames are dominated by surge driven tidal conditions. Thus high surge tides are the main cause of flood risk. The Thames Barrier prevents extreme tides propagating upriver of the Barrier. Extreme levels upriver of the Barrier are therefore much lower than downriver of the Barrier. Without the Thames Barrier the standard of protection against tidal flooding upriver of the Barrier is of the order of 10 years. Extreme flood levels in West London on the Thames are dominated by extreme fluvial flows.

The way in which high tides and fluvial flows contribute to flooding can be considered using longitudinal sections of the Thames. Figure 4.1 shows a longitudinal profile of the tidal Thames with the estimated 1,000-year and 10,000-year water levels, with the Barrier open.

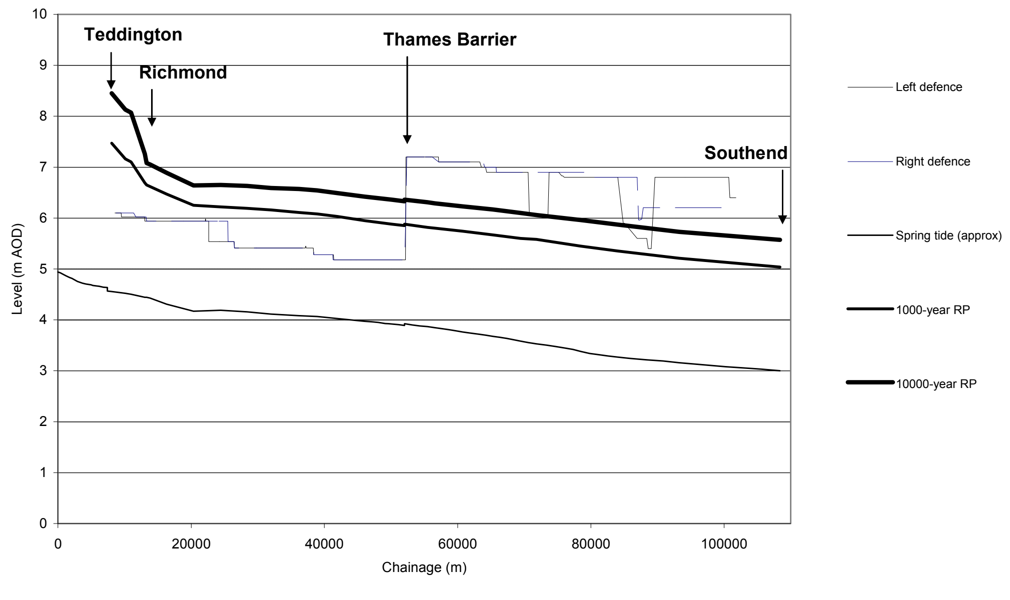

Figure 4.1 Extreme water levels on the tidal Thames, Barrier open

It is apparent that the 1000-year level is generally contained by the defences downriver of the Barrier, but is typically 1m higher than the defences upriver of the Barrier. In West London water levels increase sharply due to fluvial flows, and the 1000-year level at Teddington is about 1.5m higher than the defences.

The Barrier closed case is shown on Figure 4.2.

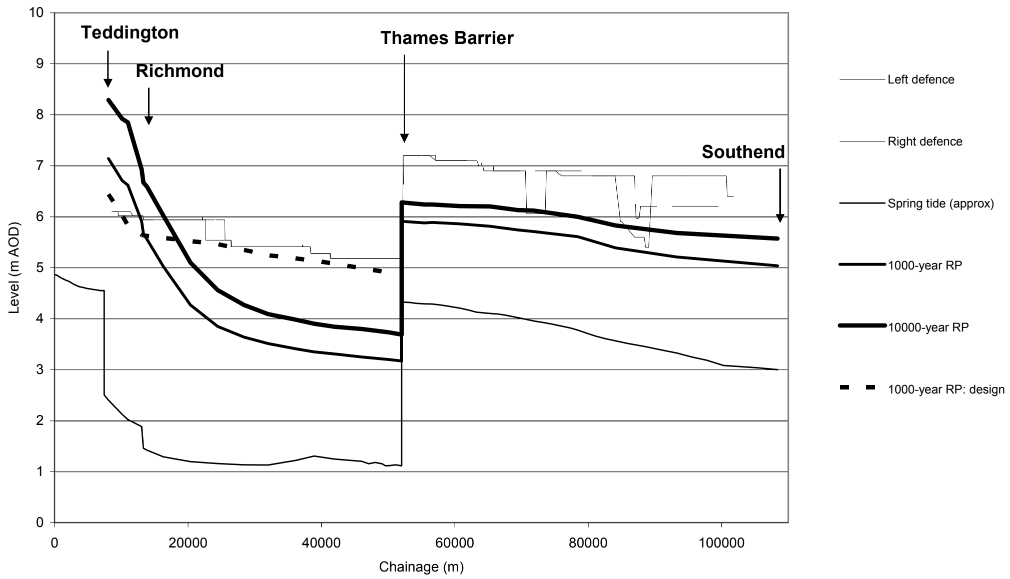

Figure 4.2 Extreme water levels on the tidal Thames, Barrier closed

In this case it is apparent that Barrier operation reduces maximum tidal levels upriver of the Barrier to well below the defence levels. However in West London, where fluvial flows cause the highest water levels, the estimated 1000-year flood level exceeds the defence levels between Richmond and Teddington.

It should also be noted that the 'design' 1000-year water level upriver of the Barrier is higher than the levels shown for extreme events where the Barrier is definitely closed. This is because the design levels take account of cases where the Barrier would not be closed. Essentially the Barrier is operated to keep levels below the upriver defences, and therefore the design levels are just below upriver defence levels.

4.2 Tributaries

Flooding on tributaries can be caused by tidal water levels, fluvial flows and combinations of the two. The way in which these can interact is shown on Figure 4.3. The figure indicates the water surface profiles produced by combinations of a fluvial flood flow and normal tide, and a normal river flow with an extreme high tide. The figure also indicates the impact on water levels of an extreme high tide and river flood flow occurring at the same time.

Tidal fluvial interaction is affected by the presence of structures. Downriver of the Thames Barrier the tributaries either have barriers or flapped outfalls to prevent tidal flooding:

- The tidal barriers on the Roding, Darent and creeks around Canvey Island allow normal tidal propagation but are closed during high surge tides. Whilst the risk of flooding from high tides is prevented, high fluvial flows can cause high upriver water levels during closure periods. This is a particular concern on the Roding.
- Flapped outfall structures prevent tidal inflow into a tributary. However backing up of fluvial flows during closure periods can lead to flooding.

The longitudinal section of the River Darent on Figure 4.4 shows the impact of the Dartford Barrier on extreme water levels. Both the maximum water levels and the flood defence levels are lower than those on the tidal Thames, downriver of the barrier.

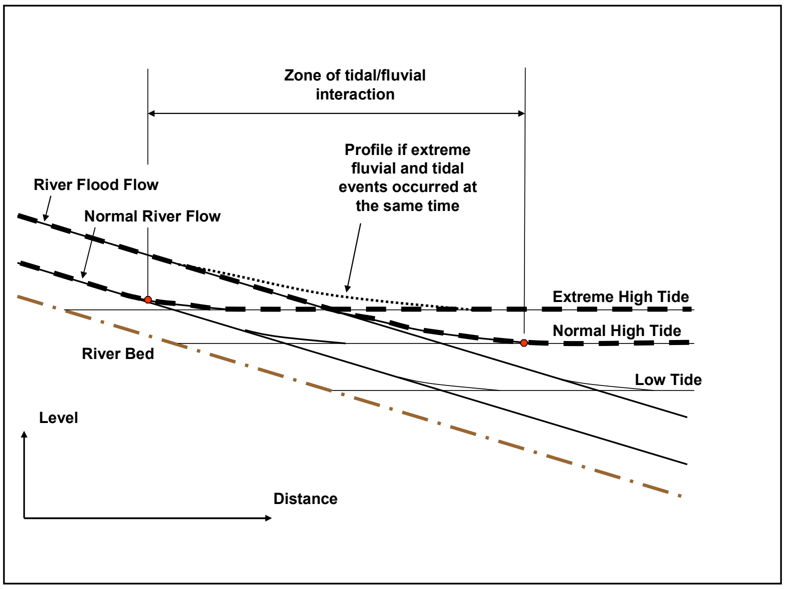

Figure 4.3 Tidal fluvial interaction.

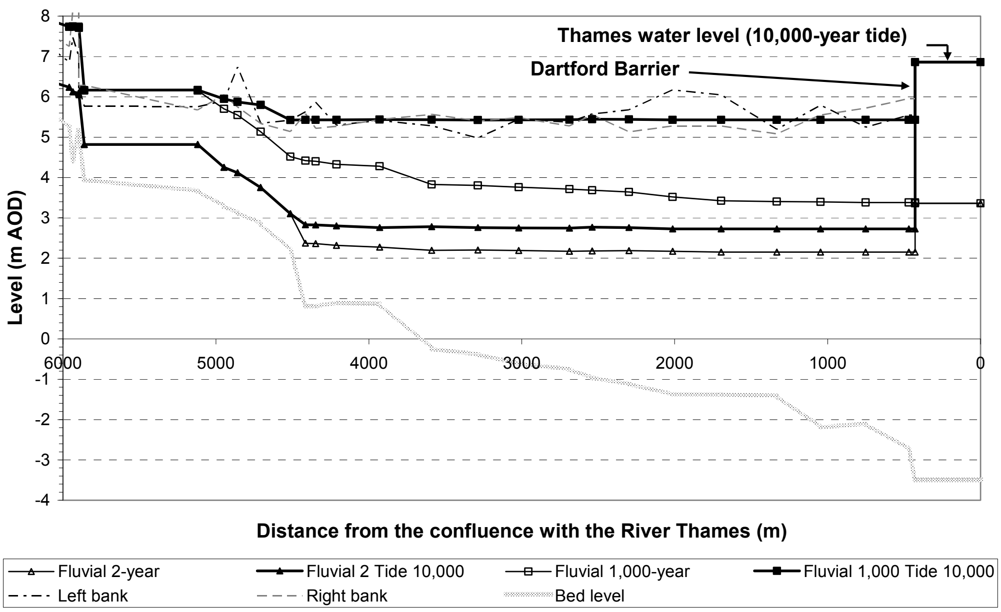

Figure 4.4 Extreme water levels on the River Darent

The longitudinal section on Figure 4.5 shows the Mar Dyke, which has a flapped outfall. Whilst the impact of tidelock on fluvial flood water levels is apparent, the flood levels are far lower than those on the tidal Thames. Thus whilst fluvial flooding on such watercourses may be relatively frequent compared with tidal flooding, it can be readily appreciated that the impact of tidal flooding would be far greater.

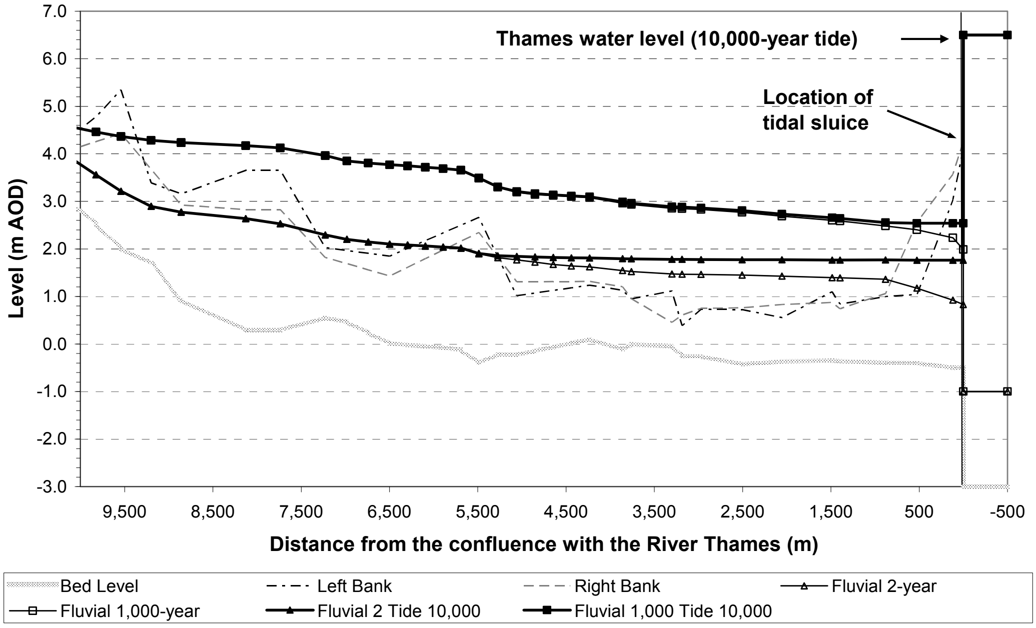

Figure 4.5 Extreme water levels on the Mar Dyke

Upriver of the Thames Barrier, most of the tributaries do not have tide control structures, and the most downriver structure on rivers such as the Ravensbourne and the Wandle are intended to maintain and control upriver levels.

4.3 Drainage systems

Figure 4.6 shows a longitudinal section through the Crayford Marshes drainage system. This system has a flapped outfall. As the fluvial inflows are relatively small compared with the size of the marsh area, the depths of floodwater even during very large rainfall events are small. Once again, the impact is very small compared with that of tidal flooding. Flood water levels lie between 1.0 and 1.5m AOD compared with tidal levels in the Thames in excess of 5m AOD. The flood extent for the estimated 100-year flood from the local drainage system is shown on Figure 4.7 with and without climate change (HR Wallingford 2006c).

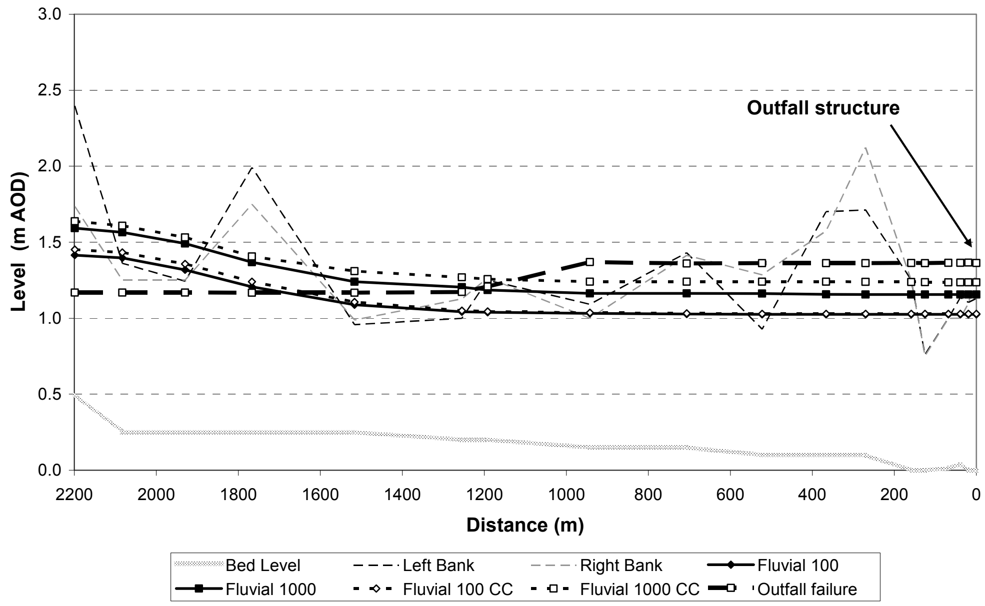

Figure 4.6 Extreme water levels on Crayford Marshes

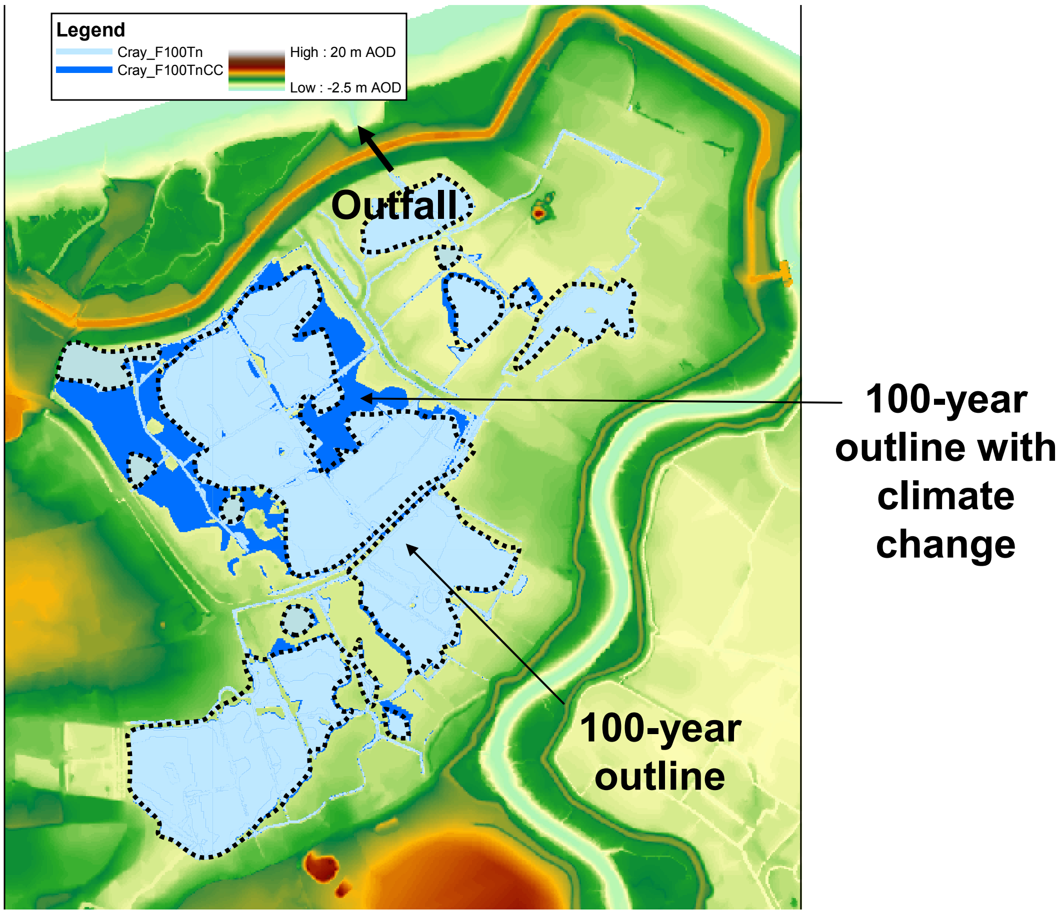

Figure 4.7 Crayford Marshes: Estimated 100-year flood extent with and without climate change

5. Impacts of structure failure

The impact of failure of the Thames Barrier can be assessed by comparison of Figures 4.1 and 4.2. If failure occurred during a high surge tide, the impacts could be catastrophic. In practice the amount of upriver flooding would depend on the nature of the failure. If one gate failed to close, the barrier would still present a large constriction to the flow of an incoming tide and the upriver levels would be less than those shown on Figure 4.1.

In the case of the barriers downriver of the Thames Barrier, failure to close during a large event would result in high upriver tidal water levels. The effect on flooding can be appreciated from Figure 4.4, by extending the Thames water level upriver. For the example shown, the defence levels would be exceeded by about 2 metres if the Dartford Barrier failed. Failure of these barriers to open following an event would lead to increases in upriver levels due to high fluvial flows.

Flapped outfall structures that fail to close would allow tidal water to enter the drainage systems. The magnitude of the inflow would depend on the size of the culvert. In the example of the Crayford Marshes on Figure 4.6, failure of the flap would cause higher flood levels than the 1000-year fluvial event in the area of marsh closest to the outfall.

There is a risk that flapped outfalls will fail to discharge fluvial flows, for example because of blocked trash screens or silted flaps. In such cases fluvial flooding could occur, although the rate of build up would be slow and it should be possible to implement mitigation measures.

There are a number of drainage pumping stations, particularly in Thamesmead and Canvey Island. Failure would obviously lead to a fluvial flood risk, but the rate of build up and extent would be limited by the relatively small inflow volumes.

The risk of breaching of the fixed flood defences is clearly another potential source of flooding. This is covered elsewhere in the TE2100 studies.

6. Future changes in flood levels

Increases in sea levels and fluvial flows due to climate change are discussed in Section 2. As the sea level rises the standard of protection provided by the defences reduces, and part of the challenge of the TE2100 project is to develop the flood management system to cope with higher sea levels. The effects of sea level rise on flood risk include the following:

- Increase in design water levels in the Thames and tributaries downriver of barriers
- Need to increase the frequency of closure of barriers if upriver defence levels are not to be increased
- Increase in the length of closure periods for barriers and flapped outfalls, leading to higher upriver levels. In some cases, new pumping stations are already being considered for outfalls with drainage constraints.

As fluvial flood flows increase, the standard of protection provide by the fluvial flood defences will also reduce. The particular impacts of increases in fluvial flows on the tidal Thames are as follows:

- Extreme flood levels in West London will increase and the frequency of flooding will increase unless mitigation measures are provided.
- Flood levels in tributaries which freely discharge into the Thames will increase.
- On tributaries with tidal barriers, the risk of fluvial flooding during closure periods with increase.
- On tributaries and drainage systems with flapped outfalls, the fluvial inflow during tidelock periods will increase, thus increasing flood risk.

7. Conclusions

7.1 The main potential source of flooding on the tidal Thames is from surge tides. Most of the floodplain is defended to a high standard against tidal flooding.

7.2 The Thames in West London is prone to fluvial flooding. The standard of protection is lower than for tidal flooding, but the affected area is relatively small.

7.3 Tributaries of the tidal Thames and other drainage systems have a high standard of protection against tidal flooding but are prone to more frequent (but less severe) fluvial floods.

7.4 There is a risk of local flooding in parts of the extensive urban drainage systems, although flooding at outfalls due to tidelock is not reported to be a significant problem. Groundwater is also not reported to be a serious problem in the tidal Thames floodplains.

7.5 Much of the tidal defence system on the Thames depends on the successful operation of barriers and other moveable structures. Structure failure is therefore an important factor when considering flood risk.

7.6 Surge tide levels are likely to increase as a result of climate change. This not only affects water levels in the tidal Thames but also the frequency of operation of moveable structures and maximum water levels on tidelocked tributaries and drainage channels.

7.7 Fluvial flood flows are likely to increase as a result of climate change. This will not only increase flood levels on the Thames and other freely discharging tributaries, but also increase levels on tidelocked tributaries and drainage channels.

8. References

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