CHAPTER 145

EFFECTS OF BANK RAISING ALONG THE THAMES

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ABSTRACT

A one-dimensional numerical model was used to estimate the location and volumes of water flooding over the banks of the Thames Estuary under several combinations of bank levels and possible storm surges. An assessment of the probable damage resulting from each of these floods enabled a comparison to be made between the various possible schemes for bank improvement and, indeed, showed that there was a serious need for such improvement even though a start on the construction of the Thames Barrier was imminent. In an estuary such as the Thames the overflow may provide a significant turn in the continuity equation and the effect must therefore be programmed as an integral part of the model; one obvious effect of the overspill is to limit the maximum levels to about 0.2 m above the banks in the upper Thames, almost irrespective of the size of the surge.

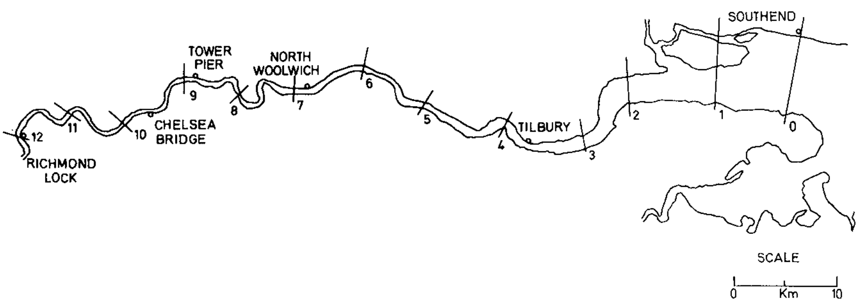

Figure 1. The Thames Estuary, showing the cross-sections at which surface elevation is computed in the numerical model.

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INTRODUCTION

Much of the City of London stands on what was, at one time, the flood plain of the River Thames. The growth of the city has led to increasing reclamation of areas, lying below even the level of high tides, which must be permanently protected by embankments. As the mean sea level at the mouth of the estuary is rising relative to the land at about 30 cm/century and the mean high water level in Central London appears to be increasing at more than twice this rate, the standard of the existing defensive works has in effect been slowly downgraded since their construction.

In January 1953, exceptional meteorological conditions over the North Sea resulted in a storm surge reaching extreme levels which equalled or just exceeded the flood defences in Central London. However, the river banks in the seaward reaches of the estuary were overtopped and, in some cases, breached: an area of some 120 km^2 was seriously flooded. During the rebuilding, the banks of the lower estuary were strengthened and raised to prevent a recurrence of the 1953 disaster. However the flood defences in Central London were not improved at this time, partly because the attempts made to estimate the reduction in the maximum levels reached in Central London due to the extensive overflow from the lower reaches tended to suggest that the maximum levels would not have been much higher (no more than 10 cm higher) had no flooding occurred (Allen, Price and Inglis, 1954).

However during the initial, hydrodynamic investigations for the Thames Barrier it became clear that these older estimates of the effect of overflow were seriously in error. If a surge of the magnitude of the 1953 storm surge was contained by the improved defences in the lower estuary, the results from both the numerical model at Bidston and the large hydraulic model of the estuary at the Hydraulics Research Station, Wallingford, predicted that the statutory defence levels in Central London would be exceeded by 20-25 cms. Although it was obvious that the problem would cease to exist when the Thames Barrier became operational, the question remained as to whether any bank raising was indicated to provide interim protection during the eight years it would take to complete the barrier construction.

THE NUMERICAL STUDIES

To provide a cost-effectiveness study of the benefits of various possible investments in improved defences in the upper estuary, essentially four stages were required in the analysis.

i) the design and costing of a variety of bank levels.

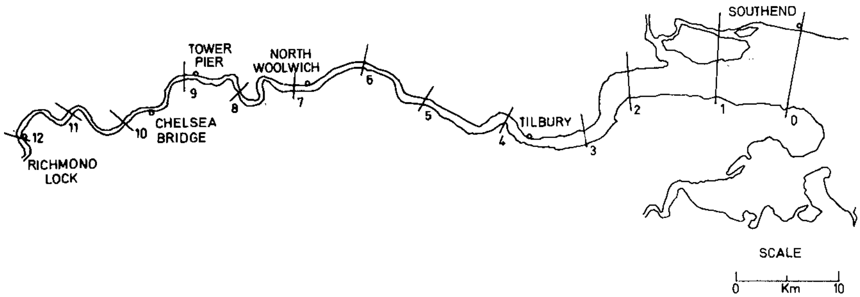
ii) the quantification of the location and volume of water that would flood over into the City during storm surges of various intensities (a variety of extreme levels) for each set of bank levels.

iii) a costing of the damage which would result from the predicted flooding.

iv) an analysis of the resulting data, the cost of the defences against the cost of the flood damage, in terms of the estimated chance of occurrence of a storm surge of given magnitude. (Data on the return period of surges was already available from the general oceanographic study for the Thames Barrier, for example for the 1953 surge the estimated return period is 80 years, that is, in any year there is a one in eighty chance of a storm surge of this particular size occurring. The chance of its occurrence over the eight year period required to complete the complete barrier system is therefore one in ten.)

A sophisticated, one-dimensional numerical model of the Thames Estuary was used to study item (ii), the location and volume of flooding which would result from a given combination of surge and defensive scheme.

The basic numerical model was proved on normal tides without any flood effects (Rossiter and Lennon, 1965); the extension to storm surges led to the results, previously mentioned, that without flooding the levels in the upper Thames would have been about 25 cms higher than those actually observed. To reproduce the effects of flooding out of the river the details of the bank levels along the river were programmed into the model. As the overflow into adjacent land seriously alters the actual level in the river, this effect has to be included in the continuity equation of the basic numerical model. An 'overspill-section' was defined as running from each half-section to half-section of the model and was referenced by the number of the midway section where the water elevation is calculated (Fig. 1). The bank levels were split into sets of equal level and the total length of bank at a particular level in each section was input to the



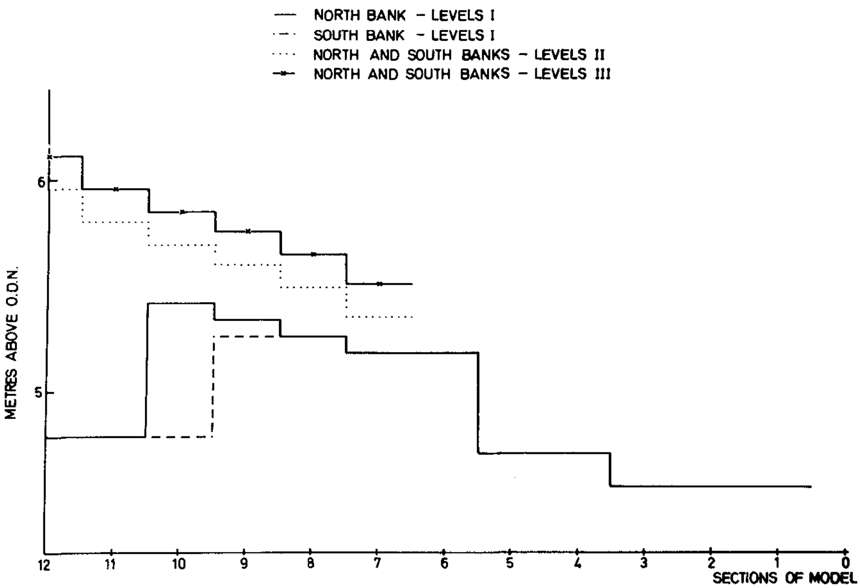
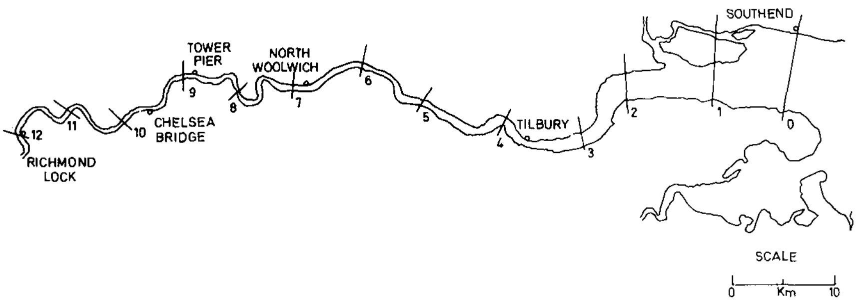


Figure 2. The lowest bank level at each section of the model. The levels in sections 1-6 are approximately those of 1953, by 1970 the bank levels here were sufficiently high that no flooding occurred in the surges used in the study.



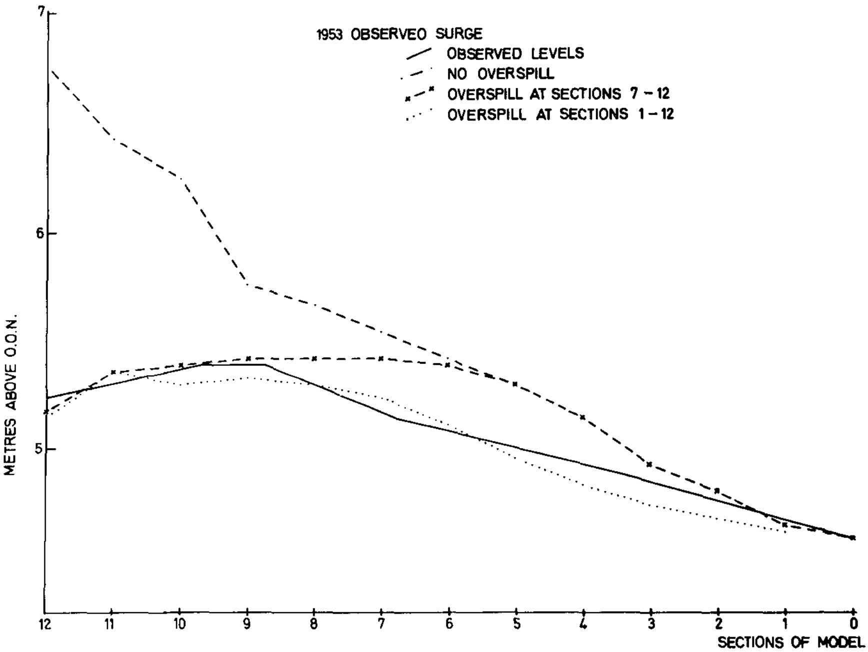


Figure 3. Maximum water levels reached along the river, bank levels I (1953) for overspill at all sections, I (1970) restricting the flooding to the upper river.

model. At every time step of the calculations the rate of discharge over the north and south banks of each 'overspill-section' was separately computed using the formula (Ven Te Chow, 1959),

$$Q = C \sum_{i=1}^{N} L_i \, (z_{n,m} - h_i)^{3/2}$$

where Q = rate of discharge

L_i = length of bank at level h_i

N = number of different bank levels in section

$z_{n,m}$ = elevation at section n and time step m

C = coefficient of discharge, taken at 3.0

The total rate of discharge over the two banks was then computed and used to obtain the new elevation, $z_{n,m+1}$, by the inclusion of this additional term in the equation of continuity. Fortunately the basic method of solution, an explicit, finite difference scheme allows such modifications to be made without difficulty.

Three sets of bank levels were used, levels I were derived from the 1953 statutory defence levels for sections 1-6 and a detailed survey (by the Greater London Council as part of the design process for the improved defences) of the bank levels in the upper river, sections 7-12. This survey provided 1970 levels but these were essentially still the same here as they had been in 1953. Levels II and III represented two alternative improvements for the upper river, approximately an increase of 0.30 m and 0.45 m on the existing levels. Figure 2 shows the lowest level in the set of bank levels associated with each section of the model for the various schemes.

Level I (1953) provided a close approximation of the bank conditions during the 1953 storm surge. Using the water levels observed at Southerd during this surge as input, the model was over with unlimited flooding (no account was taken at this stage of the fact that the capacity of the flood plain might be exceeded). The resulting spill of water over the river banks reduced the maximum water levels reached during the surge to values very similar to those measured in 1953 (Fig. 3).

The distribution and volume of the flooding was also similar to that actually observed in 1953; some difference was expected as several banks were breached during the surge and this type of failure was not represented in the model. The assumption that the capacity of the flood plain at any section was not exceeded was checked after the complete calculation by comparing the total volume of flow over a section with the surveyed volume of the surrounding area. These results seemed to provide an adequate validation of the basic assumptions and method of solution used in the model.

Following the 1953 surge, the banks in the lower estuary (sections 1-6) had to be rebuilt and the opportunity was taken to raise the levels. By 1970, therefore, these banks, designed to withstand a surge 0.6 m higher than that of 1953 were complete. The banks of the upper river remained at essentially their previous level. The model results showed that were a 1953 surge to re-occur, although the maximum water levels reached in the river (Fig. 3) would not be dissimilar from those of 1953, the pattern of flooding undoubtedly would, the overspill of water being concentrated in Central London (Table 1). Although the total flood volume would be less (37.2×10^6 m^3 was the calculated overflow from sections 1-6 for 1953 conditions), it would be concentrated in a much more susceptible area for flood damage. The case for considering some bank improvements was certainly established.

It is interesting to note that even a surge 30 cm lower than the 1953 (53- in Table 1) would, in 1970, produce almost exactly the same flooding in the upper river as the larger surge did in 1953. However the damage in the upper river in 1953 was quite minor.

Larger surges, 30 cms (53+) and 60 cm (53++), give for the 1970 bank levels very similar maximum water levels in London to the 53. In fact, the highest surge loses so much water by overspill in sections 7 and 8 (Table I) that the maximum level reached at the head of the river is actually less than that of the smaller surges (Fig. 4).

Although the chance of the co-occurrence of a major surge and a major fresh water flood is small, it was of interest to compute the relative importance of the two effects. A value of 283 m^3/sec corresponds roughly to the maximum recorded fresh water flow in the Thames, 566 m^3/s to the estimated maximum

TABLE I

Overspill volumes at each section. ($\times 10^6$ m^3)

Surge	River Flow	Bank Level	7	8	9	10	11
53	-	I (1970)	2.33	2.62	0.52	1.15	2.27
53	-	I (1953)	0.10	0.23	0.05	0.78	1.72
53	283 m^3/s	I (1970)	2.66	3.45	0.91	1.51	3.94
53	566 m^3/s	I (1970)	3.05	4.06	1.00	1.65	4.74
53-	-	I (1970)	0.14	0.25	0.08	0.67	1.48
53+	-	I (1970)	7.00	6.25	1.14	1.87	3.14
53++	-	I (1970)	15.5	10.2	1.72	2.56	3.14
53	-	II	1.03	0.50	0.09	0.54	1.92
53	-	III	-	-	-	0.56	1.42

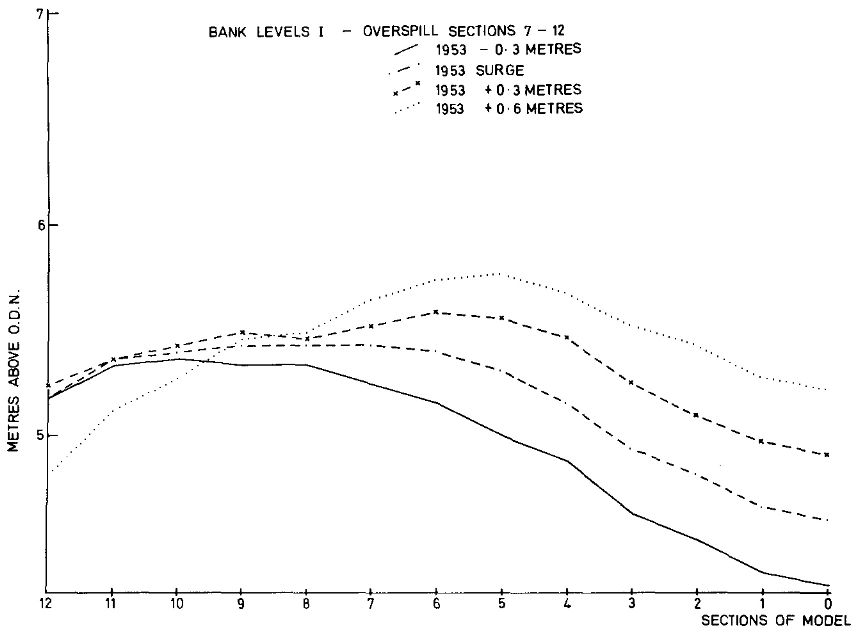


Figure 4. Maximum water levels reached along the river, bank conditions I (1970), surges 53-, 53, 53+, 53++.

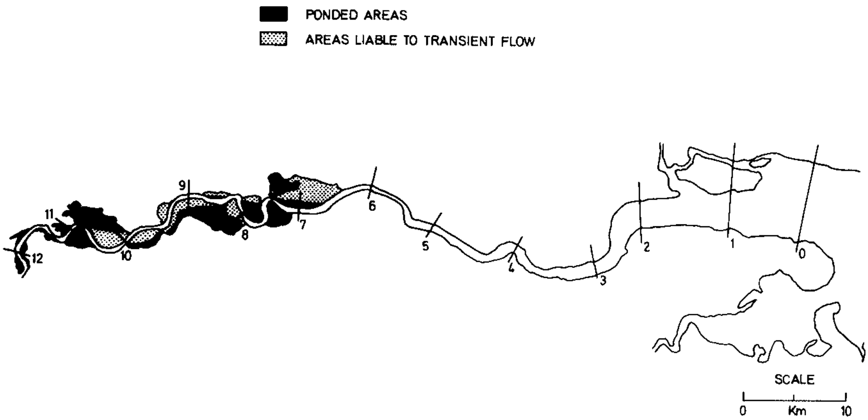


Figure 5. Areas likely to be flooded by a repetition of the 1953 surge after the bank improvements in the lower estuary, bank conditions I (1970).

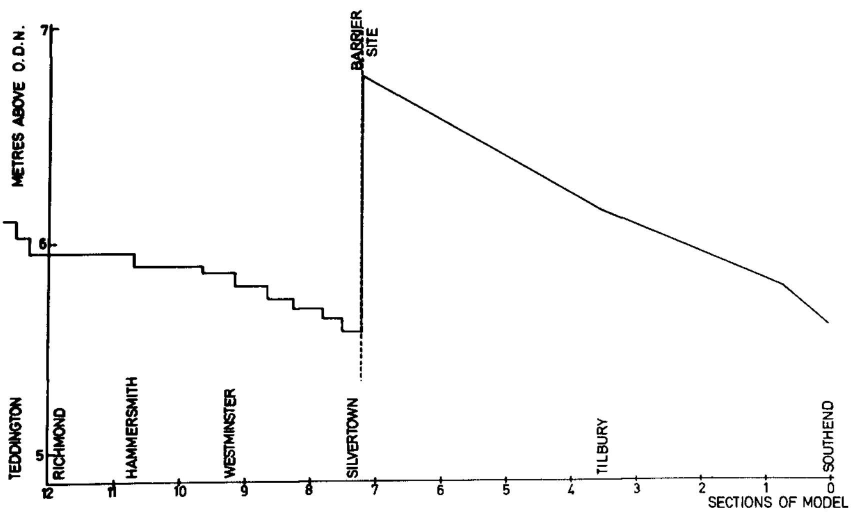


Figure 6. Design bank levels for the Thames. Construction to the standard designated landward of the barrier site was largely completed in 1973

conceivable flow. In either case the flooding is substantially increased along the whole upper river, however it can be seen in Table I that this effect is relatively small compared to the increase in flooding that occurs with the higher surges.

ESTIMATION OF FLOOD DAMAGE

The basic physical processes of the model having been established, a series of experiments were run for combinations of various surges, bank levels and fresh water flows. Some typical results are included in Table I. In all these cases the banks in the lower estuary were not overtopped; the flooding was confined to the upper river. The flood volumes at each section were normally determined in terms of the flow over the north and south banks (in general different due to differing bank levels). This data, the location and volume of water flooding over either bank, enabled the engineers of the Thames Barrier Project team of the Greater London Council to estimate the route of the flood water and consequent depth of flooding in the areas of ponding. Figure 5 shows these areas for a surge of the 1953 level at Southerd with the 1970 bank levels, it also shows areas where transient flow would pass through the streets on the way to drains and lower areas. It was thus possible to assess and cost the probably extent of flood damage in Greater London for a variety of surge conditions and bank levels along the Thames Estuary. The results clearly showed that an increase in the defense levels in the upper river by some 0.45 m could be justified, in terms of a cost-effectiveness analysis, to provide an interim protection while the Thames Barrier is under construction. The bank raising meet the new standards, illustrated in Figure 6, was largely completed in 1973.

CONCLUSIONS

The inclusion of bank levels into the numerical model not only provided detailed, predictive information on flood volumes and locations for input to the cost-effectiveness study for improved defences, it also illustrated some fundamental problems in the relation between the extreme levels of the surge and the flood volumes. In Figure 4 it is clear that the flow of water over the banks restricts the maximum level reached to some 0.2 m above the banks. This presumably represents a balance between the flow up the estuary and the overflow. It is obvious that any prediction of extreme levels at Richmond, at the head of the estuary,would be pointless unless it included details of the existing bank levels. An interesting question emerges as to how far seawards one must go before estimates, for example in terms of return periods, of the levels associated with major surges can be reasonably made without including the effects of coastal flooding.

ACKNOWLEDGEMENTS.

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