PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Phil. Trans. R. Soc. Lond. A 1972 **272**, 173-178
doi: 10.1098/rsta.1972.0043

Phil. Trans. R. Soc. Lond. A. 272, 173–178 (1972) [173]
Printed in Great Britain

THE THAMES BARRIER

The East Coast and London tidal flood warning systems

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Disastrous tidal flooding on the East Coast of England in 1953 was followed by the setting up of a flood warning system for the East Coast, and led to consideration being given to the feasibility of excluding dangerous surges from London by the construction of a tidal barrier across the Thames. Frequency estimates in connexion with the latter led in turn to the introduction of an improved warning system for London in 1968.

This paper describes the physical setting and the nature of surges on the East Coast and in the Thames estuary, and the means used to forecast them; and refers to supporting investigational work. It discusses the means of disseminating warnings to those at risk and concludes by attempting to foresee how the system might develop.

1. Introduction

The East Coast has suffered from tidal inundations down the centuries. The classic case of the final inundation of Earl Goodwin's 'fair acres' in the 11th century is well known but of doubtful authenticity (Steers 1946). Disastrous flooding occurred in London in 1881 and again in 1928; but the worst disaster in recent times is undoubtedly the flood that occurred on the night of 31 January to 1 February 1953 which caused 300 deaths and 30 million pounds worth of damage. In the Netherlands nearly two thousand lives were lost. Fortunately the London defences, having been improved following the 1928 disaster, for the most part withstood the onslaught, although the river was bank-full. More recently the river reached within about 15 cm of bank-full in London in December 1965, and some places on the East Coast have had levels that were higher than in 1953. Farquharson (1954) has said that one of the peculiarities of the 1953 situation was not so much the levels that were attained but that they were attained over so great a length of the coastline.

Frequencies for a number of places on the East Coast have been computed by Suthons (1963), using the method of Jenkinson. The 1953 flood has a return period for the East Coast generally of about 100 years, but Rossiter (1970) has confirmed that this figure is too great for London. It was first suggested that the higher frequency was due to the hydrodynamic effect of the estuary, superimposed on the relative rise in mean sea level compared with the level of the East Coast generally; but in a contemporary paper (this volume, p. 187) Bowen considers it to be due to the reduction in over-spill caused by the improvement of the defences in the lower part of the estuary. This produces an apparent rise in mean sea level in London of about 0.9 m a century, compared with 0.52 m on the East Coast generally. In London the return period for the 1953 levels is about 10 years. For 0.3 m above bank-full it is about 40 years; 0.6 m about 100 years, and 0.9 m about 400 years.

Following the London floods of 1928 a warning system was set up by the London County Council and the Metropolitan Police. The 1953 floods and the recommendations of the Waverley Committee (1954) led to the setting up of a warning system for the East Coast, with which the existing London system was coordinated. Examination of the feasibility of constructing a tide-excluding barrier, recommended by the Waverley Committee, exposed the risks to which the capital was prone and resulted in the setting up of an improved system in 1968.

2. Physiographical background

The risk to the East Coast arises from the juxtaposition of the restricted waters of the North Sea and areas of coastal and estuarine marsh that are below the level of the highest tides. These marshlands, often occupied by towns and industries, are protected for the most part by earth embankments and have a tidal length of some 1900 km.

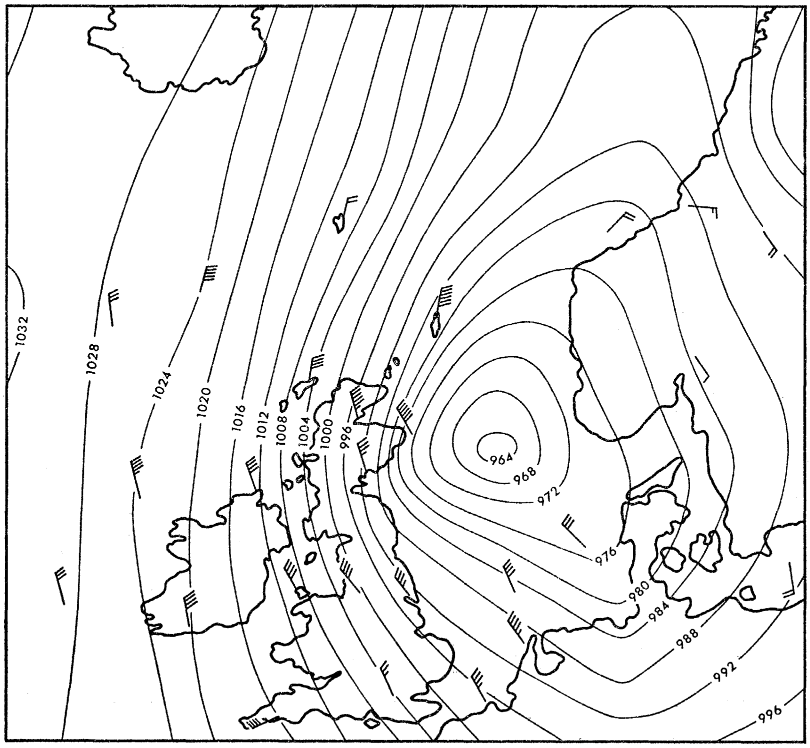

Figure 1

Storm surges are caused by wind stress on the surface of the sea and by barometric differentials. The maximum variation due to the second of these seldom exceeds 0.3 m, and the wind effect is by far the more important. It can be demonstrated in an enclosed flume, in which the still horizontal surface of the water is made to assume a slope under the action of a current of air induced by fans. The North Sea surge has external and internal components: winds from the westerly sector can cause an increase in height to the north of Scotland and at the northern entrance to the North Sea; northerly and northeasterly winds can produce a surge inside the North Sea itself. If the wind veers these two effects can be superimposed. A typical synoptic situation leading to a storm surge is illustrated at figure 1.

The time of travel of the surge down the East Coast is approximately that of the tide, taking about $11\frac{1}{2}$ h to travel from Aberdeen in Scotland to Southend at the mouth of the Thames. It then proceeds round the Belgian and Netherlands coasts. The consequent ability to detect the surge at more northerly posts is of advantage not only to the British forecasters: information of dangerous conditions is passed by them to the Netherlands.

In addition to the North Sea surge, levels in the Thames estuary can be augmented by winds from the easterly sector in the southern North Sea; and the fluvial discharge of the Thames over Teddington Weir, 29 km upstream from Central London, has a variable effect, usually measured in centimetres but in the limit reaching about half a metre.

3. The forecasting process

The central office of the East Coast Storm Tide Warning Service is equipped with repeater tide gauges which continually reproduce the analogue record from gauges at Stornoway, Wick, Aberdeen, Tynemouth, Immingham, Lowestoft, Walton-on-the-Naze and Southend. The information is transmitted by continuously occupied telephone lines, but in the event of a failure readings are transmitted orally.

Warnings are issued at 12 and 4 h before the predicted time of high water or, in the latter case, 4 h before the attainment of danger level if this is expected to occur earlier. Danger levels are locally agreed levels that have been submitted to the S.T.W.S. The 12 h alert is merely a warning that meteorological conditions are such that flooding could occur, and is based on an inspection of the synoptic charts, plus an approximate computation of the likely effects of barometric differentials and wind speeds derived from the barometric gradient. Subsequent warnings (4 h) are based on observed residuals (observed tide–predicted tide) and heights forecast from the regression equations. Formulae have been derived giving heights solely as functions of wind velocities and directions at offshore stations and also incorporating, in addition, residuals at more northerly stations. Accuracy is generally about ± 15 cm, the standard error being 12 cm and the maximum error being an over-estimate of about 0.45 m.

To distinguish between marginal and more dangerous situations the 4 h warning has been subdivided into two classes: a 'danger' and an 'alert confirmed', the 12 h warning being the 'alert'. The phrase 'alert confirmed' is used when it is expected that the tide will be within ± 15 cm of danger level. The 4 h warning is accompanied by a forecast of wind speed and direction.

Under the system installed for London following the tidal flooding of 1928 an alarm sounded automatically in the harbour-master's office at Southend when the tide reached the fairly low danger level of 3.7 m (12.1 ft) O.D. Following the 1953 flood this system was incorporated in the general East Coast system by using the same level as a basis for warnings from S.T.W.S. In 1968 the system was re-examined and the present methods were adopted.

The London Flood Room is equipped with a continuous tide gauge repeater for Southend backed-up by repeaters for Tilbury (as an emergency supplement to Southend), North Woolwich and Tower Pier (as an indicator of the actual levels in Central London). As a first line of defence against the failure of the Southend repeater there is a direct telephone line to the Port of London Authority at Gravesend, on the south bank of the estuary, where there is another repeater of the Southend levels. Readings can also be obtained by telephone from Southend, and the Flood Room has a direct line to the S.T.W.S. at Bracknell which is itself connected to the Southend gauge.

The risk of crying 'wolf' is inherent in all warning systems, but its avoidance has been a primary object in the case of London. The most potent means of achieving this has been to delay the issue of warnings as long as is compatible with the time required to take action, and clearly no improvement in this respect can be obtained over a system which does not warn the public until the dangerous tide has actually arrived. Accordingly, sirens are sounded on the attainment of danger level at Southend. Under these conditions, if the danger level at Southend were just attained and no more, it is expected that the defences would be just overtopped in Central London, although a considerable amount of flooding would occur upstream. It is possible that there might be isolated breaches, and some flooding would be caused by the backing-up of sewers and by leakage.

Before the order is given to sound the sirens the height of the tide as recorded on the repeater is compared with that obtained by telephone direct from Gravesend. In the event of failure of the Flood Room a 'fail safe' system is provided by the 3.7 m alarm at Southend, and a further alarm at a level of 4.15 m (13.6 ft), which warn Scotland Yard of the attainment of dangerous levels.

The magnitude of the discharge over Teddington Weir is received from the upstream river authority (the Thames Conservancy) daily when the flow exceeds 4500 m^3/day (10^9 gallons/day). The basis of the system is essentially the further monitoring of the approaching tide following initial warnings received from the S.T.W.S., using empirically established stage relations to allow for the varying flow over Teddington Weir. A further empirical allowance can be made for any increase in water levels caused by easterly winds in the estuary.

Considerable research in support of the Storm Tide Warning Service and the London System has been done by the Institute of Coastal Oceanography and Tides (I.C.O.T.) – formerly the Liverpool Tidal Institute – and the National Institute of Oceanography, working under the aëgis of the Advisory Committee on Oceanographic and Meteorological Research. Their work has taken two main forms: the derivation of empirical formulae by statistical analysis and the investigation of the dynamics of storm surges. I.C.O.T. has also done work to improve the quality of the tidal predictions.

Great improvement in accuracy has been elusive, but the work done on surge dynamics with mathematical models is promising. Notable pioneer work was done by Otter & Day (1960), and I.C.O.T. has produced two digital models: one of the North Sea and another of the Thames Estuary, which have now been linked (Banks 1970). N.I.O. has devised an analogue model (Ishiguro 1969). The ambition is to use the models in real time, and hindcasting tests are in progress. The broad basis of both is to enter the model with wind velocities and directions at points on a grid over the North Sea, and to obtain residuals at reference ports on the coast as output.

Work by I.C.O.T. and the U.K. Ordnance Survey also continues on mean sea-level, and a Working Party of the Oceanographic and Meteorological Committee has steadily improved the quality of tidal recording. The Hydraulics Research Station has provided information on flood risks and stage relations.

4. Dissemination of warnings

Central Government responsibility for the protection of the low-lying areas of the East Coast, including the Thames Estuary, lies with the Ministry of Agriculture, who are advised by the Hydrographic Department of the Ministry of Defence and the Meteorological Office. Immediately following the 1953 floods the system was operated from the Headquarters of the Ministry but was before long re-established (and remains at) the Headquarters of the Meteorological Office, now at Bracknell in Berkshire. This location satisfies the need for the officers of the

Hydrographer's Department to work on meteorological as well as tidal information, and takes advantage of the Meteorological Office's communications network.

Warning information from the Storm Tide Warning Service at Bracknell is addressed jointly to river authorities, who are the local authorities directly responsible for the sea defences, and the police in their areas; but because some river authorities are not on the Telex network, messages go direct from Bracknell to county police headquarters, and the police pass them to the river authorities by the quickest means, usually telephone. From this stage the river authorities monitor the situation locally by means of their own gauges, and the police, whose responsibility is the protection of life and property, act on their advice. Contingency plans have been produced by the police and river authorities in consultation with local government.

In London the Greater London Council and the Metropolitan Police would normally play the same part as the river authorities and police in the provinces, but this is modified to the extent that the Ministry of Agriculture is operating the London Flood Warning System with the collaboration of the G.L.C. As in the provinces, 12 and 4 h warnings are received by the police from Bracknell and passed to the G.L.C.

The London Flood Room maintains a teleprinter link with Headquarters of the Metropolitan Police at Scotland Yard, which is normally used only for the transmission of pre-punched tape messages, and is supplemented by a direct telephone line. Because of the vital importance of the Underground railway network a direct line is maintained to the Headquarters of London Transport Executive. (The Executive consider that if the Underground were seriously flooded it would be out of action for something in the order of 9 months, apart from a skeleton service.)

As in the case of the river authorities the Ministry, acting for London, advises the police on the issue of warnings, which it does by means of the standard messages which have been agreed with them. Although the defences of Central London are more vital to the life of the Capital, the defences upstream from West London to Teddington Weir are lower. This has the effect of dividing the system into two parts, and makes it necessary to issue warnings earlier and more often for the less vital part upstream.

The system has been arranged so as to give the necessary flexibility for a tide running early, but it is convenient to describe the situation that occurs with the smaller surges, which usually run to time. (The principal difference is that timings with the larger surges are all related to the time of achievement of danger level at Southend: with the smaller surges this usually coincides with the time of predicted high water.)

The Flood Room is manned if an 'alert' from Bracknell is still in operation at such time as will permit officers to start operating $4\frac{1}{2}$ h before high water at Southend. From that time onwards the actual tide is plotted and regular contact is maintained with Bracknell.

If a dangerous situation is still indicated 3 h before high water at Southend (which is 4 h before high water in Central London) a general warning is sent to the police who, through their divisions, warn a short list of about a dozen authorities who need to take advance action. These include, for example, the Post Office and the power authorities. An hour later the same thing is, if necessary, done for the upstream sector.

If the situation persists, a second warning is sent in the case of Central London by the same route, and local authorities are warned to have their emergency services standing by. One of the main aims of this is to prepare for the evacuation of the aged and infirm, but no public warning is issued at this stage. The time of issue of this warning coincides approximately with that of the first upstream warning.

Finally, if the situation has not abated, the seal is broken on its container and a tape is sent through the teleprinter reading 'Flooding expected in approximately one hour. Sound flood warning sirens now.' On receipt of this sirens are sounded throughout the Central London floodable area by the operation of a keyed switch in Metropolitan Police Headquarters. The equivalent executive action upstream is taken, not by sirens, but by police on patrol.

One hour before it is expected that the sirens will have to be sounded the British Broadcasting Corporation is telephoned to send a reporter to the Flood Room, from which there is direct connexion to the radio transmitter. On deciding to sound the sirens the television authorities are requested to display an instruction to viewers to listen-in to the radio for advice. This includes the names of areas expected to flood and advice on where to go. It supports written instructions given in advance by the local authorities.

Contingency plans from this stage onwards are in the hands of the London Boroughs, which are autonomous within the G.L.C. area. The G.L.C., through the Borough Welfare Officers, has achieved a measure of coordination, and Central Government is now taking action to consolidate the position. As with the East Coast system, the Ministry of Agriculture does not have a formal role beyond the flood warning stage.

5. Conclusions

Warning systems are needed either because physical flood protection is not practical or because its extent is limited. Physical protection must always be incomplete in so far as the upper limit of floods is not known. Thus it seems that warnings systems will continue to be needed both for the East Coast and for London, both before the tidal barrier is built and then in connexion with its operation.

Warning systems (as the name implies) seem to be ideal subjects for systems analysis and synthesis, and it seems likely that a real-time system will be established for the operation of the barrier. Moreover, there is no obvious reason why the East Coast system should not be treated in the same way. For the immediate future, however, manned supervision may continue to be necessary to deal with the unexpected.

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