ASPECTS OF STORM WATER MANAGEMENT

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BACKGROUND

The City of Limerick and its Environs is situated at the upper end of the River Shannon Estuary and has a current population of some 79,000 persons. Most of the development in Limerick is on the south side of the river with approximately one third of the development located on the northern side.

The drainage infrastructure of the city was developed in typical piecemeal fashion over the years, with early development consisting of masonry or brick culverts with more recent development of infill and peripheral areas using piped systems. The older parts of the system were developed on a combined basis with later developments being either fully or partially separate.

The drainage system can be considered in four zones:

- Old city area draining to the river via a multiplicity of outfalls.
- City centre area consisting of a network of large (man-access) culverts discharging to the River Shannon through six major outlets.
- The balance of area within the City Boundary which discharges to the city centre culverts, or directly to the River Shannon.
- Suburbs outside the City Boundary in counties Limerick and Clare, and which discharge to the River Shannon.

Prior to the implementation of the Limerick Main Drainage Project there were no treatment facilities and approximately 22,000m^3 of raw sewage was discharged daily to the Abbey and Shannon Rivers and to the canal, through approximately 50 separate outfalls. This situation was clearly unacceptable from an environmental viewpoint; it failed to meet current standards and was clearly outside the requirements of the EU Urban Waste Water Directive. It also was a significant impediment to the proper development of the city and its environs.

Between 1994 and 1996 an evaluation of the existing drainage system was carried out at the direction of Limerick Corporation (now City Council) and a Preliminary Report was prepared which included the following proposals and recommendations:

1. Provision of a system of Interceptor Sewers to collect all existing foul and combined sewage discharges to the river and to transfer these flows to a new Waste Water Treatment Plant.
2. Construction of a new Main Lift Pumping Station at Corcanree which will pump flows from the city (95% of catchment) to the new treatment plant.
3. Construction of a new 130,000 PE capacity Waste Water Treatment Plant at Bunlicky on the south side of the river.
4. Rehabilitation of existing sewers, which are structurally or hydraulically deficient.
5. Rationalisation of Pumping Stations to eliminate a number of existing pump stations by connecting flows to the new interceptors.
6. Provision of new Foul Collector Sewers to cater for new development areas
7. Provision of new storm sewers to cater for new development areas.

Because of the scale of the overall project it was decided to implement the project on a phased basis. Phase 1 works were determined having regard to the requirements of the EU Urban Waste Water Directive and included items 1 to 3 above. It also includes some elements of sewer rehabilitation and storm water drainage considered urgent. The Phase 1 works are now nearing completion and commissioning of the treatment plant has commenced.

This paper describes the analysis of the existing sewer network and the design of the new upgraded system, specifically in the city centre area. The paper also describes the challenges presented by the integration of the new system with the old culvert system, i.e. the parts which will remain in use in the short term.

STUDY METHODOLOGY

The methodology adopted for the study was essentially along traditional lines for a project of this type, but was designed specifically to make maximum use of the then recent advances in digital mapping and computerised techniques. It included the following:

- Data Collection.
- Construction of Hydraulic Models using the HydroWorks Software Package.
- Flow and Rainfall Survey for Model Calibration.
- Determination of Design Criteria.
- Assessment of Hydraulic and Structural Deficiencies in Existing Sewer Network.
- Design of new sewers and storm structures to cater for long term catchment development.
- Rationalisation of pumping within the catchment.

DATA COLLECTION

Digital Mapping

At the commencement of the study an aerial survey of Limerick City and environs was commissioned through the Ordnance Survey and digital mapping of the entire catchment was produced on a phased basis. This included:

60 No. 1/1000 scale maps, and
43 No. 1/2500 scale maps

Manhole, Sewer and CCTV Survey

Initially all available paper records relating to the existing sewer system were collated and assessed prior to undertaking the following surveys:

- A Manhole survey - approximately 8,300 manholes
- A CCTV survey - approximately 86 km of critical sewers.

In addition to providing details on the physical layout of the sewer network, the results of the surveys were analysed to determine the physical parameters and the structural condition of the existing sewers.

Collection of Catchment Loading Data

The collection of loading data involved compiling a database of information relating to Census Populations, House Counts, Metered Water Consumption, Trade Effluent, Commercial and Institutional Premises and Impervious Areas. A comprehensive house count was carried out and correlated with census data to enable the loading to be distributed throughout the catchment.

CONSTRUCTION OF HYDRAULIC MODELS

Methodology

On completion of the Manhole, Sewer and CCTV Survey, construction of the hydraulic models, using the HydroWorks modelling package, commenced. The SUSMODEL software package was used to transfer data automatically between SUS25 and HydroWorks. Additional data required for the completion of the models was inputted manually and the models were validated within HydroWorks.

Based on the information obtained on the physical layout of the sewer networks, the city and environs was divided into five sub-catchments.

- North City
- Corbally and Islands
- South City
- Clare Street
- Raheen

These sub-catchments were further divided into sub-areas, which typically ranged in size from 1 to 10 ha, to which DWF's and impervious areas were assigned. The HydroWorks models then required various parameters to be selected including:

- Run-off coefficients that relate to the permeability of the area.
- Flooding Index - which indicates if flood water is recycled or leaves the system.
- Rain profile index - assigns which rain gauge data is applied.
- DWF factor - takes diurnal variation in DWF into account.

In total, 15 models of the foul/combined system with 46 different outfalls were constructed.

MODEL VERIFICATION

Methodology

Once the models of the existing networks were constructed, the next step was model verification. Verification of the hydraulic models establishes confidence in the physical data relating to the sewer network, in the loading data input into the model, and hence, in the results predicted by the model. This is the key to the development of an accurate and representative model that can be used with confidence in evaluating the existing system performance, in the assessment of proposed network design options, and in the consideration of development proposals. Verification was undertaken in accordance with the recommendations of the WaPUG Code of Practice for Hydraulic Modelling of Sewer Systems (1993).

Verification with Flow Data

Model Verification is a two-stage process. Models are initially verified using the results of a flow survey. This is achieved by comparing the flows predicted by the model, when subjected to a known storm event, with the actual flows measured in the sewer network for the same event.

Flow and Rainfall Survey

An extensive flow and rainfall survey was carried out throughout the catchment. Actual flows were measured in the sewers and the catchment response to measured rainfall events was recorded. For the Limerick catchment a total of 108 flow monitor sites and 24 rain gauge sites were selected. To minimise equipment resources required, the survey was carried out in three phases as shown in Table 1 below. The survey period coincided with the very dry summer of 1995, when there was a 6 week period without any significant rainfall events, which significantly lengthened the overall survey duration.

Survey	Area (ha)	Flow Monitors	Rain Gauges
Clare Street / Corbally	834	35	9
South City & Raheen	795	45	6
North City	589	28	6

Verification with Historical Data

Verification by historical data is achieved by comparing known historical operational problems with model simulations for a known range of storm intensities.

Synthetic storm profiles were generated within HydroWorks using existing rainfall intensity-duration-frequency information recorded at rain stations in the vicinity of the city. Synthetic storms were developed in accordance with the Wallingford procedure using the following Limerick city parameters

- Average Annual Rainfall (AAR) - 915 mm
- 5 year return period 1 hour day rainfall (RP5-60) - 14.8 mm
- 5 year return period 2 day rainfall (RP5-2d) - 47 mm
- Urban catchment wetness index - 145 mm Winter
- Urban catchment wetness index - 100 mm Summer
- Antecedent rainfall depth - 99 mm

The most likely sources of error in the model are

- Impervious area data
- Unknown throttles
- Connectivity Unknown overflows
- Pipe roughness (k_s value)
- Allowance for storage in the network

Where model simulation results do not match the results predicted by the flow survey checks are carried out on:

- Flow monitor data and site suitability
    - Scattergraphs
    - Tidal Effects
- Recorded rainfall data
- Accuracy of historic records of operational problems
- Model details – pipe sizes, roughness etc
- Assumptions on hydrological data – catchment wetness, antecedent rainfall
- Catchment data – impervious areas, run-off coefficients

Corrections are made to the Model during verification, only where the flow monitor is known to be recording accurately, and where those corrections are confirmed by independent checking of the physical condition of the sewers and the contributing impervious areas. When agreement is achieved between the Model and the flow survey or where a satisfactory explanation can be given for a small disparity in the results, the Model is accepted.

Results of Verification Process

The majority of the main outfall monitors in the Limerick catchment satisfied the acceptance criteria. Low flows and various monitor operational problems (e.g. ragging, unsteady flows) resulted in poorer fits at some less critical monitors further upstream. It was necessary as part of the process, to carry out impermeable area surveys at various locations throughout the catchment where initial assumptions regarding impermeability were resulting in poor fits between observed and predicted flows. This survey resulted in better fits at the relevant monitor locations.

ANALYSIS OF EXISTING SEWER SYSTEM

The steps taken for the hydraulic analysis of the existing sewer system in Limerick were:

1. Models were run for the 1 in 5 year storm at its critical duration and the predicted flood locations were identified.
2. Sewers identified as flooding for the 1 in 5 year storm were upgraded in accordance with the SRM guidelines.
3. The upgraded models were re-run to ensure that all predicted flooding was eliminated.
4. The upgraded models were analysed for the 1 in 20 year storm to check for flooding at the locations identified in 1 above.
5. The upgraded models were further analysed for the 1 in 50 year storm and all sewers in sensitive areas were upgraded to eliminate flooding.

The level of performance of the network at each specific location was further assessed in consideration of the following:

- Location of flooding
- Volume and depth of flooding
- Duration of flooding
- Cost of rehabilitation in relation to the benefit accrued.

Also, the possible separation of storm and foul flows in combined areas was investigated and proposals were developed for evaluation.

CONSTRUCTION OF HYDRAULIC MODELS – PROPOSED NETWORK

Methodology
On completion of the calibration of the models of the existing sewer network, the models were extended to represent the proposed networks. This included the addition of proposed network rehabilitation, both structural and hydraulic, and the proposed interceptor sewers. The collection system design loading was calculated based on the development plans for the catchment.

Catchment Development Plan
The current Limerick Corporation Development Plan (1992), Limerick County Council Development Plan (1991), and Clare County Council Development Plan (1988) set the objectives and policies for the development of Limerick City and Environs. The composite Development Plan for the Limerick City and Environs Catchment was assembled using these individual development plans.

It became obvious at an early stage in the study that the amount of land provided for in the Development Plan, if developed fully, would accommodate a significantly greater population than the realistic population growth which is likely to occur within the proposed design life of the collection system. The population for the full development of the Catchment, in accordance with the development plan, was estimated to be approximately 480,000.

As a result, a plan indicating the areas that are realistically likely to be developed was produced in consultation with the Planning Sections of the respective local authorities. The full Development of all of these zoned areas would have resulted in a population of approximately 379,000. This level of development was also considered to be excessive for the proposed design life of the collection system based on the existing population of approximately 79,411.

A more realistic future population was therefore determined in consultation with the Planning Sections of Limerick Corporation, Limerick County Council and Clare County Council. This was determined to be approximately 220,000 PE. This figure assumes that 100% of the City areas that are zoned for development will develop and that 40% of the County areas that are zoned for development will develop. This still allows for flexibility in the location of future development areas within the Catchment.

Interceptor Sewer Routes
The selection of the preliminary interceptor sewer routes was made based on desk studies and on the ground surveys. The routes were largely dictated by the need to:

- Collect all existing sewer discharges to the Abbey and Shannon rivers.
- Provide a sewer system to cater for the future development of Limerick City and Environs.
- Provide capacity to solve existing problems.
- Ensure that environmentally sensitive areas were protected.

Interceptor Sewer Models
The interceptor sewer models were constructed based on the routes selected and the loadings generated above. The initial diameters and gradients were calculated manually.

Design Criteria
The main interceptor sewers were designed using the following constraints:

- No surcharge for the 5 year return period storm
- No flooding for the 20 year return period storm
- No flooding for 50 year return period storm in sensitive areas

Design Process

The design of the interceptor sewers was carried out as an iterative process as follows:

1. The interceptor sewer models were run for a range of critical storm durations and the critical durations for each interceptor sewer length was identified. The durations chosen for the analysis were 15-minute, 30-minute, 60 minute, 90-minute and 120-minutes.
2. The maximum flow in each of the interceptor sewer pipes was determined for the 5 year return period storm of critical duration.
3. Revised pipe diameter and gradients for the interceptor sewers were calculated based on these maximum flows and these were input to the models.
4. The models were run using the revised diameters to investigate the effect of peak flow attenuation, and sizes were reduced where the model results indicated that the pipes had been oversized.
5. The models were re-run to check for adequacy. The iterative process was continued until the minimum diameters had been selected.

The HydroWorks model enabled detailed analysis of storm overflow devices and pumping stations to be carried out, such that design spill frequencies and overflow volume limits would not be exceeded.

Combined Sewer Overflows

The inclusion of Combined Sewer Overflows (CSO's) in the interceptor sewer design was considered as an alternative to providing large downstream sewer capacity, without compromising the achievement of the water quality objectives and standards for the receiving water. The design of the CSO's was carried out in accordance with the recommendations of the Department of the Environment Procedures and Criteria in relation to Combined Sewer Overflows, the Urban Waste Water Treatment Directive and the Urban Pollution Management (UPM) produced by the Foundation for Water Research.

The following were the design criteria for the discharge from the proposed CSO's:

- Designation of CSO's as High Significance – due to the scale of the overflows and the requirements of the Shannon Estuary Water Quality Management Plan.
- Formula A adopted as minimum overflow setting.
- Allowable number of spills 7 No. per bathing season.
- Aesthetic control requirement 6mm solid separation.
- Design of CSO structures in accordance with A Guide to the Design of Combined Sewer Overflow Structures by WRc.
- Discharge below low water level.
- Water quality standards for the receiving water - as per the Shannon Estuary Water Quality Management Plan.

The CSO discharges were input into the River Water Quality Model to check for compliance with the quality standards. The HydroWorks model was used to generate peak discharge rate and volume of overflow and the design quality module was used to generate the concentration of the pollutants discharged. These parameters were input to the River model and checked for compliance with the water quality standards.

Rationalisation of Pumping within the Catchment

It was apparent during the study that a significant reduction of the sewage pumping within the catchment could be achieved. Following the construction of the low level interceptor sewers, described above, a total of 16 existing pumping stations could be decommissioned with 5 new pumping stations to be constructed. Many of the existing pumping stations would have, in any event, had to be significantly upgraded to comply with current operational requirements and health and safety standards.

Summary Flows

DWF (130,000 PE)	29,250 m^3/d
Max Flow to Treatment	0.865 m^3/s
Formula A Flow	1.850 m^3/s
Storm Flow	11.85 m^3/s

CULVERT SYSTEM, CITY CENTRE

Development of Culvert System

The system of man-entry culverts, which serves as the drainage network for the city centre area, has developed over a period of about 200 years. There is historical evidence to show that the culverts were constructed in the Newtown Pery area of the city in the period 1765 to 1820.

Typically culvert construction comprises cut stone, rough masonry and brick walls and arch roofs with masonry slabs in the invert. In some place the culverts have been constructed directly on the bedrock, which also forms the invert.

Plate 1 Culvert, O'Connell St

Culvert sizes are variable but typically are in the range of 1200 mm to 2000 mm high by 800 to 1300 mm wide. In general the size of the culverts was not determined by capacity requirements.

The culvert network is constructed in a grid system with 4-way connections at some street junctions allowing the possibility of 2-way flow. Outlets to the river are at varying levels but are usually well below high tide level and as a result become fully surcharged during every tidal cycle.

In order to prevent surcharging of the culverts and flooding of basement premises, check valves have been widely installed usually in the first or second manhole away from the river. These check valves require frequent maintenance to ensure their continuing effectiveness. However, because of the location of many of these valves with very restricted access, there are regular problems with valves being held in the semi-open position due to the build up of solids and debris.

Although not sized for flow capacity, the culverts do provide storage capacity for sewage flows during periods of high tide. This storage is generally adequate to prevent surcharging of property drainage but not during periods of very high river levels combined with high rainfall, thus giving rise to flooding of some basement properties. Clearly the system of culverts is not watertight and acts as a groundwater drainage system with inflow occurring through the floor, the wall/floor joint and through the wall where joints have become eroded with time. Also, in one case at least, the culvert (Mount Kennet) appears to have been built in the bed of an existing watercourse. In effect therefore the culverts serve as conduits for river and groundwater flow as well as foul and stormwater discharges. Ex-filtration can of course also take place and this will occur when the culverts are surcharged by high tide and/or high flow conditions. Over the years there have been many alterations to the Over the years there have been many alterations to the culvert system.

Plate2 Culvert outfall to river at Shannon St (low tide)

These alterations have been generally carried out on an ad hoc basis and include:

- Construction of new connections.
- Alterations to existing connections.
- Repairs to collapsed sections of culvert. In some cases collapses have been repaired by insertion of a small diameter pipe.
- Construction of cut-offs in one culvert to divert flows to other culverts.
- Removal of access chambers.

The nature and aging of the culvert system, and the alterations that have been made, has resulted in a system which is inadequate as an urban sewerage system. Whilst much of the system remains in relatively good condition there are significant lengths of culvert that allow high levels of infiltration, and there are many cases where the culverts are structurally unsound with frequent collapses in city centre streets.

Plate 3 Sewer Collapse O'Connell Street

Because of the very limited access to many of these culverts and because of the build-up of debris and solids in the inverts it is difficult – in many cases impossible – to safely survey the system in order to fully ascertain the full extent of the problems.

Where the CCTV and manhole surveys found existing sewers or culverts to be in serious structural condition (Grade 4 or 5 -SRM) the Phase 1 contracts provided for appropriate rehabilitation. Given the limited access to some culverts and their consequently unknown condition, provisional monies were also included in respect of other culverts that were found to require urgent repair.

However given that much of the culvert system will remain in use in the short term, and given the manner in which the culvert system operates, i.e.

- providing for groundwater drainage;
- as a conduit for river flow;
- the open joints which allow both infiltration and ex-filtration;

both its continued use following connection to the new interceptor sewers, and ultimately the replacement of the culverts, present a number of issues which must be addressed.

The main issues are:

1. Infiltration

The permeable nature of the ground, the open jointed condition of the culverts and the quay walls means that much of the existing culverts will remain subject to significant levels of infiltration. The potential scale of infiltration is illustrated by monitoring of flows on a completed section of interceptor sewer – the Abbey River Interceptor.

This interceptor sewer runs from Clare Street to Honans Quay, a total length of approximately 1 km and picks up 10 outfalls. It was constructed as an advance sewer and, pending completion of the downstream section of this interceptor, flows are pumped to the Shannon River via a temporary pumping station (TPS) located downstream of Sarsfield Bridge.

A monitoring system installed at the TPS allows both the pumped volumes and the river level to be continuously monitored. (The data produced by the monitoring system is downloaded automatically to a web site where authorised personnel can access it). The data which has been collected clearly shows that there is very significant infiltration occurring whenever the river level is above 1 metre OD and that the rate of infiltration increases with the height of the tide.

The recorded flow at low tide – when the river is below the culvert level – is of the order of 75 l/s. However, with tidal variations and depending on whether there are neap or spring tides, the actual

average flow - during dry weather - varies from 125 l/s to 190 l/s. At high tide flows increase to circa 350 l/s.
This variation in flows is illustrated in the chart below.
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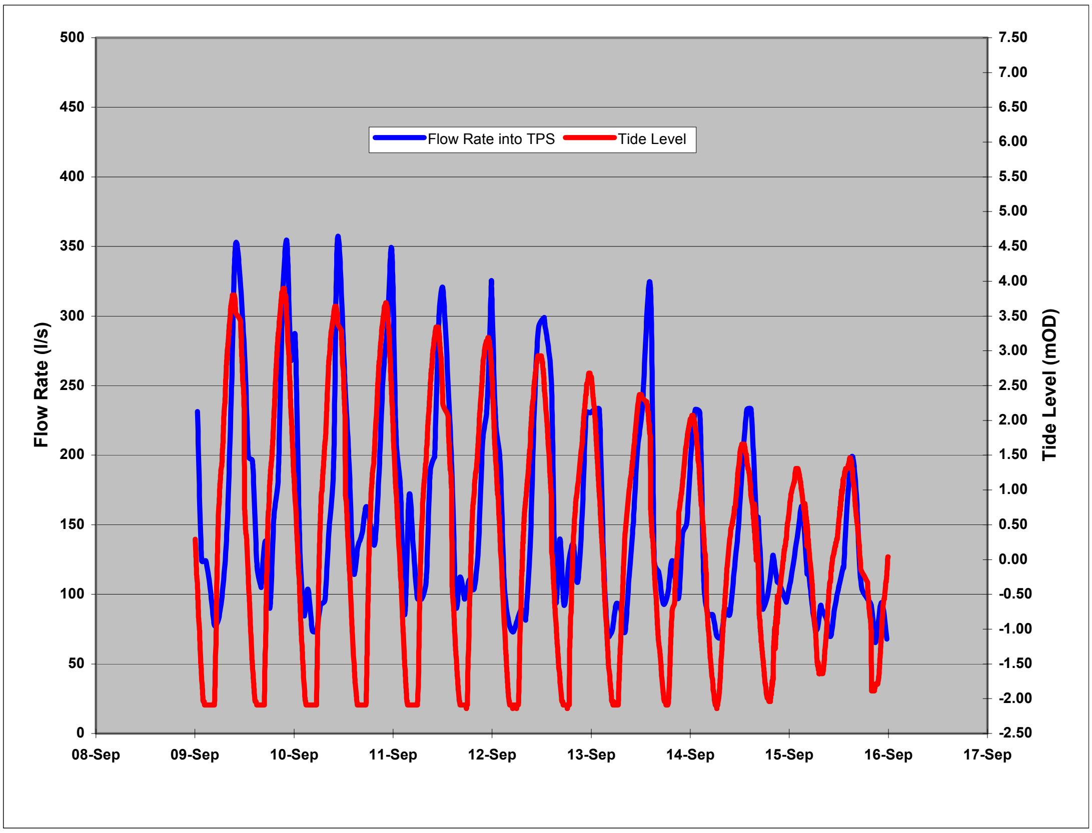
Temporary Pumping Station Flow Data 9 to 16 September 2002



The estimated volume of infiltration during each cycle of high spring tide is approximately 5,000 m3, i.e. 10,000 m3 per day, which represents 30% of the design dry weather flow capacity of the waste water treatment plant. When culverts are connected to other sections of interceptor sewer the overall extent of infiltration is expected to be significantly greater than this volume. In addition to utilising available hydraulic capacity at the treatment plant, significant pumping costs will also be incurred.

Surveys are continuing to identify the culverts and sewers which are the source of this infiltration and appropriate remedial works will then be implemented.

2. Effect of Culverts on Groundwater Regime

As already described the existing culverts discharge via open outfalls to the river and water levels in the culverts would have been in balance with surrounding groundwater levels. These culverts will have a free discharge to the interceptor sewer when connected. In the short term and where the culverts will remain in use the following effects could arise:

- Additional hydrostatic loading on the external culvert walls due to groundwater pressure on the outside no longer being balanced by the direct connection of the culvert to the river.
- Possibility of high infiltration flows leaching out fines from the ground around the culvert leading to the creation of voids in the ground.
- High infiltration could also result in erosion of mortar in the masonry blockwork leading to structural weakening of the culverts.

- Exfiltration from the culverts can occur when groundwater levels are low resulting in pollution of the groundwater and the river.

When the necessary rehabilitation and replacement of the old culverts does proceed it will result in a closed pipe system, which will eliminate both infiltration and ex-filtration. As outlets for groundwater flow will then be closed off this could result in a rise in groundwater levels potentially flooding untanked basements and creating new subterranean flow channels to the river. It is considered necessary therefore to provide for groundwater drainage at the present level.

THE FUTURE

Further phases of the Limerick Main Drainage project will see progressive rehabilitation of the existing culvert and piped systems together with some separation of stormwater run-off where development opportunities occur.

Whilst the new upgraded system will ultimately deal with sewer related flooding events, a significant increase in the potential for river related flooding is anticipated due to global warming and associated rise in sea levels.

The tidal range is approximately 5.5 metres with maximum high water spring tide level at 2.32 mOD (Malin). The highest astronomic tide is 2.59 m OD.

Tidal levels are however significantly impacted by weather and atmospheric conditions as well as river flows with a combination of strong westerly winds and low atmospheric pressure resulting in water levels significantly in excess of predicted tide levels.

As a result, tide levels in the range 3.6 mOD to 4.0 mOD occur at least once per year. The highest recorded tide level is 4.2 mOD, a level that has been recorded at least four times in the last 40 years and twice in the last 4 years. As much of the existing quay walls in locations such as Honans Quay, Harveys Quay, O'Callaghan's Strand, Clancy Strand and Sir Harry's Mall are at levels very close to (in some cases below) the maximum recorded river level, the potential for flooding to occur and the need for substantial works to protect the city is clear.

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