AMP3 cost estimations using sewerage hydraulic models

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Synopsis

It is estimated that over £7 billion will be invested by the water industry during the AMP3 period on environmental improvements. A substantial amount of this expenditure is required to comply with environmental drivers such as intermittent sewage discharge requirements for designated bathing and shellfish waters.

Hyder Consulting recently developed cost models for two water companies to assist in the determination of their AMP3 investment programmes. In both cases, frequency of spillage from Combined Sewer Overflows is to be reduced in specific estuary waters, in order to comply with future environmental standards. The objective for both studies was to derive relationships between key catchment parameters and the sewerage improvements necessary (e.g. additional storage) to achieve compliance with the environmental standard imposed. The experience gained from these two commissions forms the basis of the paper.

The methodology employed assumes that sewerage hydraulic models do not exist for the catchments where improvements are required. A control dataset of models can be used to develop estimation techniques that quickly assess the required levels of expenditure, using characteristics of the study area catchments.

Introduction

It is difficult to estimate the cost of schemes required to achieve compliance with environmental quality standards, without undertaking extensive analysis to produce a solution. Most schemes aimed at improving water quality downstream of intermittent discharge locations inevitably require a reduction in the amount of spillage, with the most cost effective solution usually being the provision of detention tanks. The storage volume required can be accurately assessed by following procedures as outlined in the Urban Pollution Management Manual (FWR, 1998). This may require detailed sewerage, river and/or coastal models. However, cost estimates are often required prior to detailed investigations, in order for levels of capital investment to be determined and schemes to be prioritised.

There will be instances where cost estimates are required for catchments where no computerised sewerage models exist. A predictive methodology is needed to estimate capital expenditure using only global characteristics upstream of each discharge point in question.

Approximately 4,000 unsatisfactory Combined Sewer Overflows (CSOs) and 700 other unsatisfactory intermittent discharges will be improved in the AMP3 period (2000 - 2005). Two cost models recently developed by Hyder Consulting have addressed improvements to discharges required in order to meet standards set by the EC Shellfish Water Quality (79/923/EEC) and Shellfish Hygiene Directives (91/492/EEC). Similarly, improvements will continue to be required to meet the standards set by the Bathing Waters Directive (76/160/EEC).

In the absence of a computerised model, estimations of storage requirements are usually made with reference to the total population upstream of the discharge location. If spillage is to be limited, the impermeable area connected upstream of the discharge point needs to taken into account. The amount of storage required is primarily determined by the contributing area directly connected to the sewerage system upstream of the proposed storage location. Previously, when assessing storage requirements, distinctions have been made between combined and separate systems. However, catchment variations in the relationship between population and contributing area exist, even when the sewerage type present is similar.

Development of a Cost Model

Assumptions

The methodology assumes environmental compliance is initially demonstrated by achieving a spill frequency / volume criteria. For example, when costing improvements for CSO discharges to shellfish waters for South West Water, a design criterion of 10 spills per ‘typical’ year was used. The Environment Agency advised South West Water that this was an appropriate standard to use for costing purposes.

Once a spill frequency criteria has been established, it is then assumed that the standard is achieved by the provision of storage, where required, at discharge locations.

Methodology

The methodology developed is outlined in Figure 1 below.

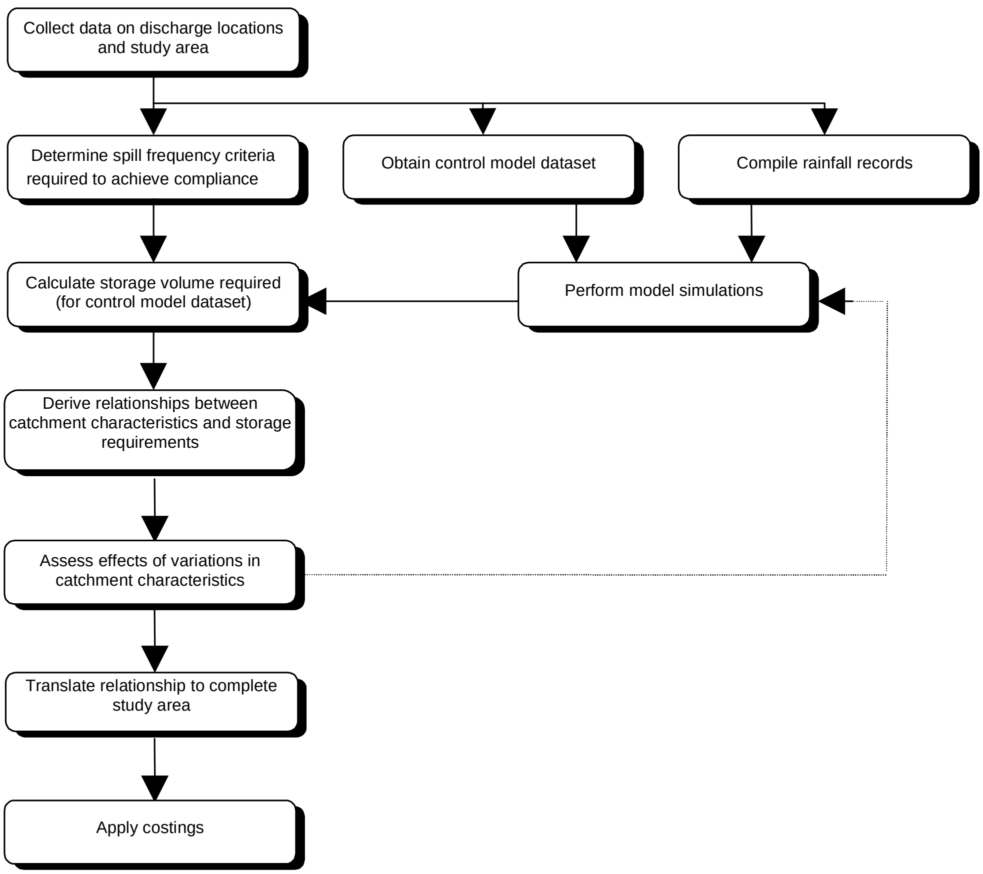

Figure 1: Methodology

The approach basically involves deriving relationships between key catchment characteristics and the storage volume required to meet the imposed spill frequency. Storage volumes are calculated for a control model dataset, using rainfall records representative of the study area. Relationships are then determined between the characteristics of the control model catchments and the storage volume. The relationships can then be applied to the study area catchments, to predict storage volumes and hence, predict costs.

Collect Data and Determine Indicative Spill Frequency Criteria

In order to predict storage requirements for the study area, information detailing the catchment characteristics upstream of each discharge location is required. Typically, the following information may be available:

- Catchment location and area.
- Discharge locations.
- Existing populations (summer and winter).
- Estimated future populations to the required design horizon.
- Infiltration flowrates (with an indication of seasonal variation, if known).
- Trade effluent details.
- Percentage impermeable area, or at least an indication of the split between fully combined, partially separate and totally separate systems.
- Total length of sewerage within the catchment and/or time of concentration.
- Average ground slope.
- Per capita return to sewer flowrate (existing and future design).
- Existing CSO settings, Storm Overflow Committee Formula A values (maximum theoretical Formula A and adjusted Formula A (to allow for upstream restrictions) should be calculated.

As a minimum, the total population, number of CSOs to be improved and indication of sewerage type present (catchment-wide) is required. Any information that gives an indication of the nature of the study area, and which can be quantified in the control model dataset, can be considered.

The indicative spill frequency criteria should be determined and agreed by all interested parties.

Obtain Control Model Dataset

Once details of the study area catchments are known, existing verified models should be carefully selected to ensure that the entire range of catchment characteristics are represented. Particular attention should be made to the overall populations and catchment sizes. The number of control models is dependant on the population range and number of study area catchments. A large number of models will improve accuracy, but at a greater time and expense, as the amount of simulations and analysis will increase proportionately. Catchment characteristics upstream of all discharges should be fully documented. A good model build and verification report should contain the majority of the data required.

Hyder Consulting Limited (HCL) have been able to draw upon a large model database which covers the majority of population agglomerations in Wales. Since 1991, HCL have produced approximately 64 Drainage Area Plans (DAPs) covering a total population of over 3 million in this area.

Rainfall Records

The accuracy of spill predictions depends both on the validity of the hydraulic model and the rainfall used to assess performance. Possible sources for rainfall events include the following:

- Standard Annual Time Series Rainfall (ATSR) events.
- Stochastically generated time series events, utilising data from suitably long historical records;
    a. historical hourly rainfall depth totals, or,
    b. daily rainfall totals.
- Stochastically generated time series events, utilising standard rainfall parameters.

It is unlikely that real rainfall data would be available in the format required for model simulation. ATSR events have not been used for costing exercises as previous studies conducted by HCL have demonstrated that they tend to predict the lowest total annual spill volumes from CSOs, when compared to rainfall generated from both daily and hourly historical data.

Records of hourly or daily rainfall totals may include ‘gaps’ in the data and require lengthy processing prior to usage. Small errors in the record may result in the generation of spurious data. For costing exercises, in the absence of historical data, it is considered that records generated stochastically using parameters such as Standard Average Annual Rainfall (SAAR) are sufficient.

To reduce the number of simulations required to determine spill volumes and frequency at discharge locations, a ‘typical’ year can be selected, from a suitably long stochastically generated dataset (10 years minimum is suggested). When selecting a ‘typical’ year, consideration should be given to the individual event parameters and not just overall yearly parameters (e.g. total depth). Individual events could also be combined to produce a typical set of data (not in chronological order).

Calculate Storage Volumes Required to Achieve Compliance

Simulations are then performed using the control models and the ‘typical’ year rainfall events. A suitable ranking of events should be employed to ensure that all events causing spill are simulated. Spill volumes should be obtained at each discharge point and an assessment can then be made of the storage volumes required to limit spillage to the imposed standard.

It is possible to amend the control models to reflect conditions present in the study area catchments. For example, there may be circumstances when a storage assessment is required for existing (unimproved) systems, and for systems which have been improved to pass forward Formula A (or provide equivalent performance) at each discharge location.

In such cases, for existing systems, all control model CSO continuations can be amended to pass forward a fixed percentage of the Formula A value. HCL have previously used a figure of 70% Formula A to reflect the performance of existing systems. This assumes that, on average, existing system hydraulic performance is 30% less than that required. This average performance figure was determined by drawing on HCLs extensive experience of CSO Improvement Strategies. In some locations within selected control models, even greater restrictions existed. These were not amended as they were deemed representative of restrictions that can be expected on old combined systems that have not been improved to contain more storm flow. Applying restrictions to control model CSOs results in predictions which are truly representative of average conditions.

For improved systems, storage requirements were determined using control models amended to pass forward Formula A at every discharge location. This is representative of catchments where the hydraulic performance of CSOs has been improved to Formula A equivalence.

Derive Relationships Between Catchment Parameters and Storage Requirements

The task of deriving relationships between catchment parameters and storage requirements is made easier by utilising the statistical analysis functions present on most spreadsheet packages. Regression analysis is a powerful tool to quickly identify any significant correlation.

For the cost models developed by HCL, in some instances the available catchment data only amounted to a knowledge of the catchment population and number and location of CSOs present. With such limited data, simple relationships were developed linking the most significant characteristics, population and impermeable area, with the required storage volume.

Population and Impermeable Area

Impermeability per head of population can only be accurately assessed if a verified hydraulic model is available. In view of the importance of this parameter, an assessment of average impermeability per head of population for various models in the HCL model database was undertaken, comparing values to sewerage network type (i.e. covering the range predominantly separate to fully combined). A summary of the results are shown in Table 1.

Model	Population (hd)	Impermeable contibuting area per head (m^2/hd)	Catchment sewerage type description (from Model Build Reports)
1	12,400	11.6	Totally separate for large areas with some small combined sub-catchments.
2	11,500	11.7	Predominantly separate.
3	6,398	16.0	Totally separate for large areas with some small combined sub-catchments. Outlying rural areas exhibit a storm response.
4	68,383	20.2	Combined older settlements, newer developments cover approximately 2/3 of the catchment - predominantly partially separate.
5a + 5b	3,450	28.1	5a - fully combined (population 1,800). 5b - separate.
6	1,500	36.3	Predominantly combined with new separate developments.
7	76,236	37.3	Predominantly combined.
8	8,952	41.9	Fully combined urban area with new separate developments in suburbs. Separate outlying rural areas.

Table 1: Assessment of average values of impermeability

Note

Model impermeable areas determined in accordance with WaPUG User note 21

The following results were obtained when considering catchments with a SAAR of approximately 1050mm, where an aggregate 10 spill per year criterion is to be achieved (i.e. 10 spills per 'typical' year permitted from the catchment as a whole).

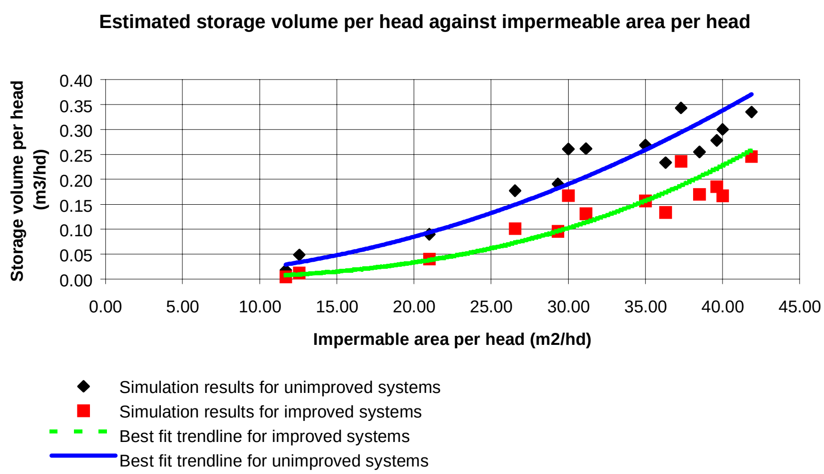

Figure 2: Average storage volumes obtained

Notes

1 SAAR =1050mm.

2 Lower storage values for similar impermeability averages imply that additional system storage is present, and/or the rate of run-off from the catchment is less. Greater attenuation of run-off and sewer flow may also occur.

3 Improved system - achieves Formula A (or equivalent) performance.

4 Existing system - assumed to achieve approximately 70% Formula A performance.

Sewerage network type	Impermeable	Storage volume required

	contributing area per head (m^2/hd)	Existing systems (Restrictions below SOC A present) (m^3/hd)	Improved systems (SOC A performance) (m^3/hd)
Predominantly separate	10	0.022	0.005
	15	0.04	0.015
	20	0.086	0.033
	25	0.134	0.061
	30	0.192	0.102
	35	0.261	0.157
Predominantly combined	40	0.341	0.228
	45	0.431	0.316
	50	0.532	0.425

Table 2: Estimated storage volumes

Notes

1 SAAR =1050mm.

2 Aggregate 10 spill per year criterion.

3 Areas built initially as totally separate systems exhibit a measurable storm response. Typically, 'separate' catchment areas exhibited a runoff response equivalent to an impermeable connected surface covering 3 - 10 % of each of the sub-catchment areas within the separate system. Therefore, in areas where separate systems exist, Formula A should be calculated assuming a proportion of the population is connected to a combined system.

4 Impermeability greater than 50m2/hd has been observed in areas that include commercial and industrial development, served by a combined system.

5 If CSOs are present to limit flow in networks which serve areas of significant industrial/commercial developments, an equivalent population should be determined.

The level of detail in the quantification of the storage required is dependant on the study area data provided. Simply, the total catchment storage volume could be determined and distributed between the discharge locations requiring improvement. If catchment details upstream of each discharge location to be considered are known, then individual storage requirements can be determined.

Distribution of Total Storage Volume Across the Catchment

During the studies performed, cost estimates have been prepared when only the total catchment population and number of CSOs to be improved are known. Therefore, using a relationship as shown in Table 3, and assuming a catchment-wide sewerage type, a total storage volume can be predicted.

The proportioning of the total storage volume across individual CSO discharge locations is an important consideration if an accurate assessment of expenditure is to be achieved. Economies of scale result in unit storage cost decreasing with increased total storage provision. Therefore, simplified cost models must have a mechanism to distribute the total 'catchment wide' volume between the identified discharge locations. The method employed is dependant on the information available. A control model dataset can be interrogated to determine typical distributions.

Additional Parameters

If the information is available for the study area, additional parameters besides population and impermeable area can be used to derive relationships. This will improve the accuracy of the predictions. The value of Formula A (allowing for upstream restrictions) is highly significant when determining the storage volume, which is to be expected as the greater the overall restriction on the system, the more spillage occurs. Also, the major component of Formula A is usually derived from population.

Assess Effects of Variation in Catchment Characteristics

Once significant parameters have been determined, the accuracy of the methodology can be improved by further investigating the sensitivity of the results to variations in significant parameters. The control models could be altered to reflect changes in a specific parameter. For example, a global increase could be made to the contributing area contained within a model, synthetically producing a model with greater runoff.

Other potential considerations:

- Seasonal variations.
    a. Population variation - tourists will only proportionately increase the foul component of sewer flow. Small local increases in storage are to be expected. This effect could be magnified if the study focuses on compliance with bathing season standards.
    b. Other seasonal variations affecting Dry Weather Flow (e.g. infiltration).
    c. Variations in the level of storm response from areas other than impermeable surfaces (e.g. land drainage inputs).
- Small catchment cost models.

    Storage requirements in small catchments (e.g. populations less than 2,000) area more susceptible to variations in land usage. Proportional land usage displays less variation as the catchment size increases. Separate relationships should be determined for small catchments.

Apply Costings to Results Obtained

Once the required storage volumes have been obtained, it is a relatively simple task to apply costs. Most companies have extensive cost databases that are able to produce good quality estimates. Associated ancillaries can then be added to the final cost estimate.

When determining final costs for compliance with the required standard, the following should be considered:

- Potential outfall extensions (e.g. to mean low water spring tides).
- Aesthetic requirements. The extent of civils modification required to accommodate screens at existing overflow structures will vary from site to site.

Conclusions

A methodology has been outlined to provide storage (and hence cost) estimations for schemes to improve intermittent discharges in the absence of verified hydraulic models of the sewerage system.

Throughout the process, a balance has to be achieved between the time and costs involved in improving accuracy, and the need to produce a robust estimate. By carefully selecting a control model dataset, and limiting simulations using techniques such as the ‘typical’ year approach, accuracy of the determined volumes can be maintained. Thus, confidence bands can be attributed to the predictive results, dependant on the sensitivity analysis performed.

Ideally, a complete matrix of catchment characteristics for the study area will be available. In reality, the cost estimate methodology is needed because of limited catchment knowledge, in areas where future improvements are required. The cost models developed have demonstrated that estimates can be obtained by focusing on the most significant parameters (e.g. population and impermeable area).

References

(1) Urban Pollution Management Manual, 2nd Edition, Foundation for Water Research,1998.

Discussion

Question   Adrian Saul   Sheffield University

Clearly the simplified model is key to the methodology.

1. Is there much variation between catchments?

2. Cost model dos not include an estimation of quality?

Answer

Answer in reverse order.

2.We use 10 spills per year criteria to meet Category B compliance but may not meet Category A

1. Yes there was a great variation, less than 1,000 pop to 120,000. This is why we used various levels of information.