Title: A new approach to calculating Formula A
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1. History

Before 1970 the traditional setting (the pass forward at a CSO) was 6dwf, however in the 1950's and 60's the Technical Committee on Storm Overflows and the Disposal of Storm Sewerage carried out a study into the effects of CSOs. The final report was published in 1970 and concluded that it was illogical to base CSO settings solely on a multiple of DWF;

"There was no reason why a community having a high demand for water, which resulted in a high DWF in the sewer, should, for that reason, be compelled to provide accommodation in the sewer and at treatment works for a correspondingly large volume of storm water".

Additionally it was proposed that any new standard should provide a 'modest improvement' in harmful effects of the spills, i.e. spill less frequently.

Before the report was published there was significant discord with regard to how 6dwf should be estimated; whether infiltration should be included and how trade effluents should be considered.

As a result the study recommended a formula in which there was an additional component; runoff, to be included on top of the DWF term;

"It seemed much more logical to have a formula in which the DWF of the sewage was indeed one term, but to have another term, a run-off term, to be added to the DWF and not to provide a multiple for it".

2. Formula 'A'

The 1970 report proposed to overcome the previous uncertainties and concerns by modifying the existing formula to include a constant k as a per capita multiplier to allow for surface water runoff so that the equation became:-

$$Q_c = PG + Pk \quad (1)$$

To achieve the traditional 6dwf setting the constant k should be 5 times the per capita consumption, however the report concluded that the value of k should be higher than this to provide a small improvement resulting in a value for k of 1,360 litres per day (0.0158 l/s).

Further modifications to the formula were proposed in the report to include infiltration (I) and trade effluent (E), the latter of which is increased by a factor of 3 to account for the increased time and concentration of spill that trade effluents can cause. This results in a final formula for fully combined systems of;

$$Q_c = PG + Pk + I + 3E \quad (2)$$

Where the system is fully separate it is acceptable to use 3dwf and k is not required as there would be little or no response to rainfall;

$$Q_s = 3PG + I + 3E \quad (3)$$

For partially combined / partially separate systems, equations 2 and 3 can be combined to produce equation 4, which is considered to be the classic Formula A equation;

$$Q = (P_c + 3 * P_s) * G + I + P_c k + 3E \quad (4)$$

The result of this is that using equation 4 in a catchment where there is no infiltration or trade effluent and where G = 181 litres/head/day (0.0021 l/s) the Formula A setting can range between 3dwf (if the catchment is fully separate) and 8dwf (if the catchment is fully combined).

3. Traditional Approach

Traditionally formula A has been manually calculated for each intermittent discharge location. Upstream of the CSO, the population, per capita consumption, infiltration and trade effluent are estimated. Using a "typical" example which we have named "Catchment 1" (Figure 1) and assuming the information below, we can calculate the Formula A value for the CSO;

$P_c = 0$
$P_s = 5000$
$G = 0.0021\ l/s$
$I = 1\ l/s$
$E = 0\ l/s$
$k = 0.0158\ l/s$

$Q(CSOa) = (0 + 3 * 5000) * 0.0021 + 1 + 0 * 0.0158 + 3 * 0$
$Q(COSa) = 32.5\ l/s$

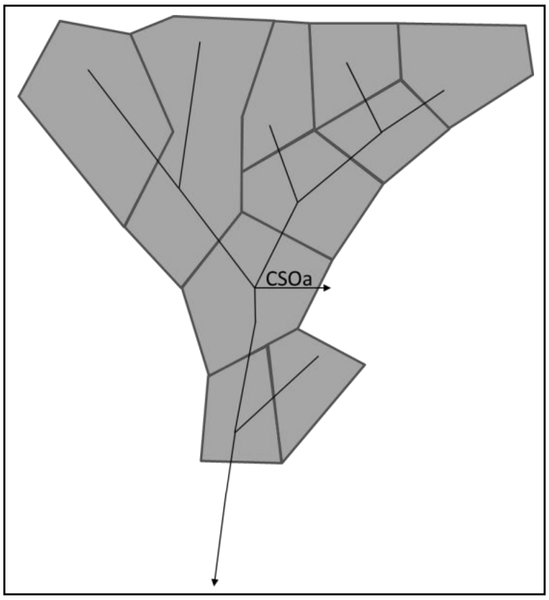

Figure 1 – Catchment 1, a typical simple sewer catchment with a CSO at the downstream end.

While this approach works with simple dendritic catchments, there are significant drawbacks when the process is applied to large complex catchments.

“Catchment 2” (Figure 2) could be considered to be a small part of a complex catchment, this contains multiple CSOs in series down the system, parts of the network are separate and parts combined and there is a bifurcation where flows can go one of the two directions.

To examine the impact of these complexities on calculating Formula A we can separate them off before looking at the catchment as a whole;

3.1. System Type

As shown previously the proportion of the catchment which is considered to be combined or separate has a significant impact on the final Formula A value. A simple approach may be to assume this based on the system type in the model. For example this network could have a population of 1000 in the combined subcatchments and 4000 in the foul (separate) subcatchments, giving;

$Q\ (CSOa) = (4000 + 3 * 1000) * 0.0021 + 1 + 4000 * 0.0158$
$Q\ (CSOa) = 78.9\ l/s$

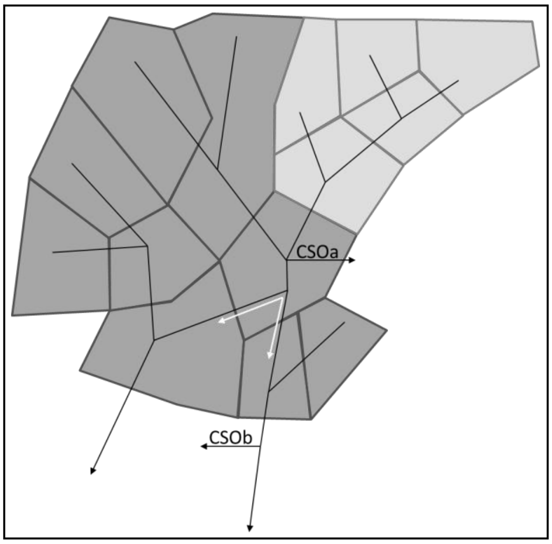

Figure 2 – Catchment 2, part of a complex sewer catchment with multiple CSOs, a bifurcation and combined and separate systems.

3.2. Multiple CSOs

This becomes an issue when a CSO spills before Formula A is reached. When this is the case then the calculated Formula A for the CSO downstream will be higher than the actual flows which will reach it. In these circumstances a Restricted Formula A needs to be calculated; this is the sum of the standard Formula A value for the CSO being examined minus the standard Formula A values for all upstream CSOs, plus the sum of the settings (pass forward flow) for all the upstream CSOs.

Assuming a setting at CSOa of 50 l/s and a total population upstream of CSOb of 1000 (separate) and 8000 (combined) then we can calculate the Restricted Formula A at CSOb to be;

$Q\ (CSOb) = (8000 + 3 * 1000) * 0.0021 + 1 + 8000 * 0.0158 + 3 * 0$
$Q\ (CSOb) = 150.5\ l/s$

$$Restricted\ Q\ (CSOb) = Q\ (CSOb) - Q\ (CSOa) + Setting\ (CSOa) \quad (5)$$
$Restricted\ Q\ (CSOb) = 150.5 - 78.9 + 50.0$
$Restricted\ Q\ (CSOb) = 121.6\ l/s$

To get this information a simulation needs to be run to identify the pass forward flow at first spill; however this value is affected by the return period and duration of the simulation used and can vary by at least 25% above and below the average, so the restricted formula A value could be;

$$Restricted\ Q\ Min\ (CSOb) = 150.5 - 78.9 + 37.5$$
$$Restricted\ Q\ Min\ (CSOb) = 109.1\ l/s$$

$$Restricted\ Q\ Max\ (CSOb) = 150.5 - 78.9 + 62.5$$
$$Restricted\ Q\ Max\ (CSOb) = 134.1\ l/s$$

3.3. Bifurcations

Bifurcations add a further level of complexity to the estimation of Formula A as there is no simple way to calculate to proportion of flow which passes down each of the branches. Traditionally these have either been ignored resulting in over estimation and possible double counting of flows through downstream CSOs or an attempt has been made to calculate the flows based on a ratio of either the pipe sizes or based on relative invert levels.

If the two branches of the bifurcation were exactly the same diameter and had the same invert levels, headloss coefficients, roughnesses and gradients then it would be reasonable to assume that the flow down each of the branches would be 50% of the total flow, however when these values start to differ it becomes almost impossible to manually calculate the impact (Figure 3). This is made even more complicated where one of the branches is controlled by a weir, penstock or orifice.

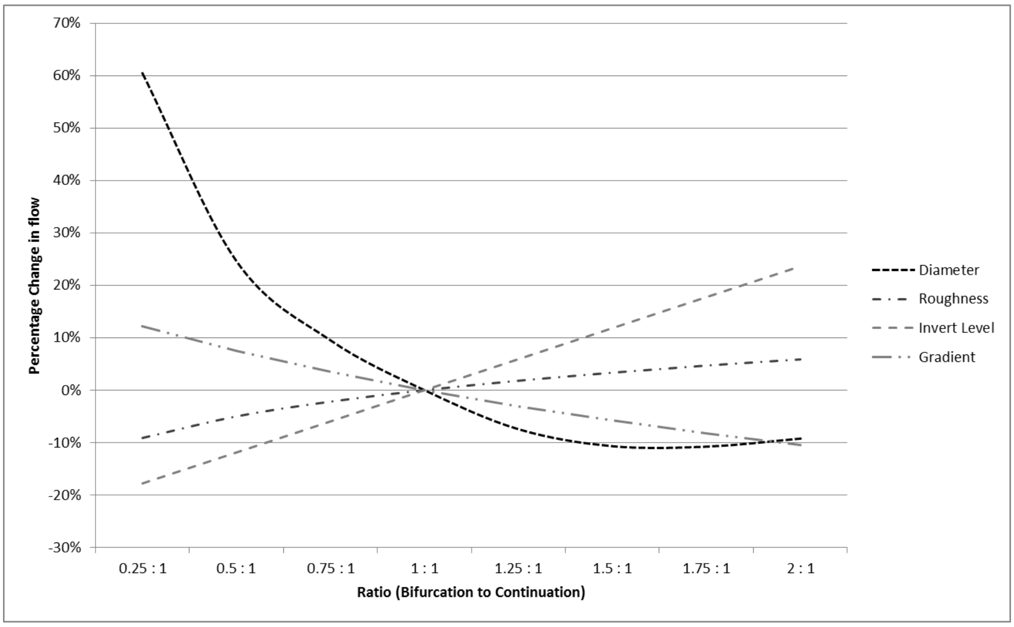

Figure 3 – Percentage change in continuation flow at a bifurcation based on changes in pipe diameter, roughness, invert level and gradient.

Figure 3 shows the potential impact of altering the pipe diameter, roughness, invert level (assuming an initial level of 0.1m) or gradient (assuming an initial gradient of 0.001m/m) at a bifurcation. As can be seen in this example it resulted in changes in flow of between +60% and -18%, with a 50% increase in the ratio between bifurcation and continuation resulting in a 10% decrease in the flow through the continuation. These differences could easily be the difference between a CSO being considered satisfactory or not.

4. Modelling Approach

In order to overcome the issues described above a new approach to calculating Formula A has been devised using InfoWorks. Through manipulation of the waste water and trade profiles an estimation of Formula A for each CSO in a catchment can be simulated. Essentially this approach seeks to achieve the following;

1. Apply 3 times multiplier to trade flows
2. Apply 3 times multiplier to fully separate system subcatchments
3. Apply the k multiplier to foul flows from combined system subcatchments

This can be achieved in 4 steps;

1. Modify the trade profile file so that a 3 times multiplier is applied to all the design trade profiles.

2. Modify the waste water profile to include a duplicate set of profiles, the original set should have a 1 times multiplier applied to the design profile while the new set should have a 3 times multiplier applied to the design profile.
3. Update the waste water profile for fully separate subcatchments so that the 3 times multiplier is applied to the foul flows from these subcatchments.
4. Update the additional foul flow column for all combined subcatchments to equal k (in m^3/s) multiplied by the population.

Steps 3 and 4 can be automated using an SQL and the separate and combined subcatchments can be identified either by system type or by percentage impermeable area. A dry weather flow simulation can then be run using the updated waste water and trade profile files. This simulation can be considered to be equivalent to the Restricted Formula A as continuation flows from any CSOs which operate below Formula A will be restricted and no longer representative of the upstream catchment parameters.

Through the use of SQLs this approach has the significant advantage that the proportion of separate system to combined system can be quickly and accurately calculated, and the flow routing will ensure that the proportion of flows through bifurcations is appropriate. Finally the pass forward flows at first spill (where CSO settings are less than Formula A) can be ascertained based on the restricted Formula A flow, rather than an arbitrary design storm flow.

5. Lessons Learnt

While the modelling method allows for flow routing there are some drawbacks to the approach. The most significant of these is the effect of pumps on the steady state flows; however by running the simulation for a full 24 hours the impact of these fluctuations which occur with the pumps switching on and off can be to be overcome. Testing of this found that over a 24 hour period pumped flows were within ±1% of the manually calculated Formula A.

As previously noted the simulation represents the restricted Formula A for each CSO, if there are overflows in the catchment which operate and the standard (unrestricted) Formula A is required then some further work needs to be undertaken to the model to prevent the CSOs from operating and ensure that the network is not restricting the flows. This needs to be undertaken using a methodical approach from upstream to downstream as modifications to the upstream network could result in more flows being restricted downstream. Modifications may include, but not be limited to, reducing the restriction on continuation pipes at CSOs, increasing pump rates and raising weir levels (where the flows are not restricted by the sewer network). The model can then be re-run and checks carried out to ensure no CSO spills remain.

6. Conclusions

The method of calculating Formula A proposed in this paper is aimed at reducing and avoiding some of the errors which can occur when undertaking a manual calculation. During AMP6 there is an effort by a number of water companies to achieve complete or close to complete coverage of their sewerage networks and as such models are now available for a significant proportion of the UKs CSOs. These models represent endless opportunities to assist water companies and the wider water industry with a huge array of challenges and solutions; however as was the case in 1970 when the original Formula A equation was proposed this should not be considered a precise value. It is important to remember that even the slightest error in the way a bifurcation is modelled could result in a different value and so it is recommended that this approach is used in conjunction with a model confidence assessment. In short this should be considered to improve confidence rather than precision.

There is a need to consider whether we, as an industry, think Formula A is still good enough. The 1970 technical note went on to propose a possible Formula B (which took account of impermeable area and rainfall intensity) and Formula C (which took account of the BOD in the receiving watercourse and sewer). At the time these were dismissed due to *"too many unknown factors to make it workable"*, however with modern modelling capability many of their concerns could now be overcome.

References:

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