STORMWATER AT A WASTEWATER TREATMENT WORKS

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What Is Storm Water?

To the wastewater works designer and operator storm water might well be defined as the difference between the daily quantity of flow he is required to treat and the maximum daily flow anticipated at the works. Fundamentally the job of a wastewater works is to separate water from the polluting material it carries and recycle the water back to the environment. The current tendency to close off combined sewerage overflows inevitably increases flows to the wastewater plant.

Biochemical Oxygen demand is a simple example of a measurement of this degree of pollution. Inevitably however hard we try there will always be some pollutant left to be discharged with the water back to the environment. As designers we tend to separate the determination of the amount of these materials from the flow itself. So for example failing any real data we could assume BOD arriving at the works will be simply 60 grammes for every person connected to the works. Further we could assume each person consumes say 170 litres per day and this ends up at our works. Adding in Industrial flows and pollutant loads gives us a basic definition of water plus pollutant, one as mass, one as volume. This does not take into account storm flows at all. If we now add in infiltration which comes from ground water, leaking water pipes etc then we have a basic definition of Dry Weather Flow.

The EA will then have produced a discharge consent that effectively defines the maximum pollutant mass that can be discharged and the amount of wastewater arriving at the works that has to be treated. Traditionally in the UK this has been expressed as 3DWF and sometimes 6DWF.

So for this has been fairly rational. But we now need to determine the maximum flow that can arrive at the works and then decide what environmental effect its discharge will have, what consent conditions might apply and consequently how we handle it.

If we now asked a hydrologist what storm water is we would certainly get a different reply. Perhaps ‘storm water’ is merely the flow arising in a sewerage system from the run-off of a rainstorm. But what duration of rainfall and at what intensity constitutes a storm? Sewerage designs have been based on simple concepts like a 1 in 1 year return period. Various statistics have been produced to provide relationships between intensity and duration. Distinct differences in flows produced by similar rainstorms can be observed depending on the nature of the surface rain fall on. In urban areas run off is quick and direct to the sewerage system. On grass run off can be slow and take days to find its way to a system. For this reason open grassed areas are usually neglected for sewerage storm flow analyses. Hydro graphs produced for different rainfall events further complicate the situation. The use of computer simulations can give us a better idea of how sewerage systems deliver the flows to the wastewater works. These definitions of storm flows follow in a list of design methods that include:

- Guesses
- Rational methods (square rainfall events)
- Hydrograph methods (assumed triangular, sine wave run off shapes)
- Regression analyses (old ‘flood studies’ approach)

Whatever the method of finding out what the maximum flow to the works is basically it will be composed of a consumption and rainfall component. What we cater for at the works will be the difference between the total flow and that proscribed for ‘full treatment’ by the EA.

The question as to what treatment to provide depends on the pollutant loads carried by the flows and also the effect of allowing the ‘storm event’ to pass through the works.

Sewer System

If we accept that a storm flow is essentially an event following rainfall then we find that the sewerage system will shape the storm arriving at the works. Traditionally we have :

- separate systems (one system for foul, one for rain discharging to river etc)
- combined systems (a single pipe system accepting all flows)
- partially combined (mixture of both)

You may argue that a separate system would require no storm water facilities at the wastewater works at all. In fact infiltration in old sewerage systems can be very high and flows in these sewers can reflect rainfall and changes in groundwater levels due to rainfall. To provide no facilities for storm conditions at a wastewater works would be very brave. How much of the flow should be allowed to arrive at the works?

An attempt to answer these questions in the seventies resulted in 'Formula A' produced by the Technical Committee on Storm Overflows. They reasoned that if storm water was mainly rain and basically unpolluted then it could be safely discharged to the environment via ditches and watercourses from overflows within the system. Also given that at a any time the mass of pollutant was roughly the same then the diluting effect of the storm would pick up only very little of the pollutant contained in the 'DWF' component. However, such a flow would pick up pollution from paved areas (dog faeces, litter, road grit) and also flush out the pipes them selves resulting in rags and debris arriving in large quantities at the works.

Formula A then was :

Max flow to works = DWF + 1.36 Population + 2 Industrial flow m^3/day

Where:

DWF = Population x Consumption + Infiltration + Industrial flow m^3/day

Another way of looking at this approach is to generalise :

Max flow to works = K(pop. x consumption + Industrial) + Infiltration m^3/day

The value of K is then determined according to practical and economic considerations. This approach is pragmatic and provides simple guidance for the design of overflows in the sewerage systems to limit flows arriving at the works. In the UK K varies around 6 - 10. In the original Formula A an equivalent K looks to be around 9.

ie K = 1+ 1360/consumption

This approach simply provides an estimate of the maximum flow and the inclusion of overflows in the sewerage system is intended to limit the flow.

Having determined the volume of wastewater to arrive at the works the composition of the water under these conditions needs consideration. If the basic organic pollutants are constant in mass per day but the flow increases then the diluting effect reduces the concentration of BOD,COD, NH3 and SS. However the flushing effect will increase rags and grit suspended in the flow. In the case of overflows provided in the sewerage system it is not only a case of spilling flow exceeding Formula A etc. The discharge will require at least screening and arguably further treatment before an environmentally acceptable discharge is created.

The nature of the sewerage system will effect the rate at which the flows arrive at the wastewater treatment works and it is crucial in the operation and design of the plant to understand the interaction. In simple terms the average works is designed as quasi-steady state and operated as near steady state as possible. In practice this means that the biochemical process designs are based on averages but sedimentation processes are based on anticipated hydraulic maxima.

The sewerage system can be either large or small with varying amounts of pumping. Any sewerage system will create a time lag between surface water entering and arriving at the works. A large system will be beneficial in flattening out flows and reducing peaks but the smaller the system the more likely it is to be highly destructive to the operation of the works. Even a large system with significant and badly designed pumping stations will present the works with a challenge. A small system is infinitely worse however. Such a system may be composed of a series of manhole shaped duty/standby submersible pumps each rated at 6 -10 DWF. On normal days flow is delivered to the works in 2 short slugs. In storm conditions rags and grit are delivered at an unrelenting 6 - 10 DWF. A small system is less likely to be supplied with in system overflows, and if they are supplied they are likely to be crude. To try and combat these problems various devices have been installed to artificially reduce the flow rate and force the system to attenuate the flow. However under storm conditions ragging can render this strategy a liability.

In large systems these problems can be addressed by computer analysis of various storm scenarios. In this way new sections of sewerage can include ‘Tank Sewers’ that are deliberately oversized to increase attenuation. Pumps can be variable speed with sophisticated control and computer simulation can facilitate the design of storm overflows. Storm balancing tanks can also be included within the system. In urban areas this is an operational liability.

Wastewater Treatment Works

Once the storm flow arrives at the works it has to be managed. Accepting the previous definitions of storm flow then :

Flow to full treatment = K1 (pop. x consumption) + Infiltration

Storm flow = (K - K1) (pop. x consumption) + Infiltration

Typically (K - K1) = 9 - 3 = 6

This varies in practice between 3 and 7.

The choice when the storm flow arrives is whether to treat the full flow or to divert all or a proportion. The consent conditions issued by the EA will define what flow is to be fully treated and the main body of the works will be designed for this flow. A works can be designed to accept the full flow but this requires some special consideration. It is unlikely such an option would be economic but may be required on environmental grounds. The effects this has will require design changes:

- hydraulic design
- settlement design
- biochemical design

The design changes required in the pipework and channels of a works required to pass storm flows are obvious. The head loss through the works increases, the pipes and channels are bigger, the dangers of grit and solids deposition increases as the range of flows is increased. Operational problems will result due to pipes being oversized at low flows. Pipes can be duplicated to provide a separate storm route between structures operating when a simple weir is over topped. This inevitably leads to increasing cost. Additional head requirements also increase the provision of pumping and the cost of operation.

Settlement tanks are designed on maximum flows. Hence an increase in flow will result in a proportional increase in size (and cost). This is manageable in primary settlement where the performance of the tank is not so sensitive to flow but in clarification of activated sludge this may well lead to problems. Here, the tank performance is sensitive to flow and will re-act badly to under loading as well as overloading. At normal flows the tank designed for storm events will have an increased retention leading to ‘rising sludge’ due to de-nitrification. In the past oxidation ditches designed for full treatment of all flows have excluded primary settlement and included clarifiers downstream of the oxidation ditch arranged via weirs to sequentially bring into play clarifiers as flows increase. The returned sludge pumping systems associated with activated sludge systems are also increased to prevent washout of solids from the aeration tank, which in turn increases both capital and operating costs.

The design of biological treatment presents difficulty. All design information is semi empirical based on average conditions. It would be uneconomic in the extreme to simply factor these parameters up. So a 6DWF works will be twice as big as a 3DWF works. In fact common practice was to adopt extended aeration as a solution on the basis that with long retention times even at high flows sufficient treatment was provided.

In a process such as activated sludge slightly more rationale can be brought to this problem. Essentially the process can be limited either by:

- sludge age
- utilisation rate

The sludge age of a system can be regulated and maintained by good design of the sludge recycle system and by providing a clarifier that won't spill the sludge blanket over the weirs. As storm conditions build up the mixed liquor starts to fill the clarifier raising the sludge blanket. The recycle rate increases to return the sludge back into the aeration tank .A large recycle will for a time control the sludge blanket. The increased sludge storage required in the clarifier will result in a deeper unit as well as a larger surface area.(required for flow rate)Keeping the sludge in the system will result in maintenance of sludge age and washout of micro organisms is avoided.

The second limitation is utilisation rate. To work the system requires that micro -organisms can grow in sufficient quantities, controlled by sludge age but in addition there has to be sufficient time for the mass of pollutant to be oxidised. This is an expression of the monod form :

$$q = k \cdot s / (ks + s)$$

where:

q = utilisation rate kg/kg mlss per day

K= max utilisation rate

s = effluent required   mg/l

ks = utilisation rate at half life

Typical values in the above equation lead to a value of about 1 kg BOD removed/kg mlss per day. Using this parameter a design can be checked at maximum flow to ensure that a minimum period of retention can be maintained.

ie $q_{actual} = BOD/(mlss \cdot T)$

or T required (hours) = BOD x 24 / mlss

expressed in mg/l

Similarly for nitrification q based on ammonia would be 0.035 kg NH_3/ kg mlss per day.

In other words increase the size of the tank! Computer simulations are valuable for testing the likely effects of a storm. The above approach may be taken to obtain a basic size then tweaked using a computer simulation to provide the final design.

Flow Balancing

The design of a biological plant to treat large incoming flows is likely to be costly and result in a plant that is difficult to operate. Past practice has been to separate out storm flows during preliminary treatment. Here the screening plant and grit removal is provided to cater for maximum flows but then all flow exceeding the consented flow to full treatment are diverted to storm tanks. The diversion usually consists of a simple combination of flume, penstock and side overflow weir. The penstock closing as flow increases and spilling the excess over the upstream side weir. Many works end up with the hunting penstock switched off and set at what looks like an average position.

Once the flow has been diverted then it enters storm tanks. When the EA issue a consent to discharge from a works it will include the quantity and quality of the storm water. At this point the designer has the choice of how to treat the storm flow. The traditional approach has been to provide a tank based on 2 hours retention at maximum storm flow and a maximum upward flow velocity of around 1.5 m/hour. If there is inadequate information, this has often been reduced to a simple 6 hours at DWF. This often resulted in a bank of rectangular tanks fed so that they filled sequentially, the last tank then discharging to the watercourse. This discharge ideally needs to be screened. As flow to the works subside to a normal level the storm tanks are emptied back into the flow to treatment and the sludge scraped out.

Alternatively, the storm tanks can be of a circular construction, each individually scraped by a half bridge unit and filled either simultaneously or sequentially. These units can be used where land area is not a problem. A small works however is inevitably not equipped with a storm tank. This makes it vulnerable to washout, particularly processes such as Rotating Biological Contactors(RBC). Here different approaches can be taken. A small (2 Hours at DWF) balancing tank can be provided with a constant flow floating arm draw-off. These may not be popular as they need more maintenance than they often get. Placing septic tanks as combined buffer tanks/sludge storage tanks helps.

Grass plots can also be used. Here the diverted storm flow passes over a grass plot or a reed bed (or maybe an earth lagoon) prior to discharge. This will reduce the suspended solids concentration. A limit of 200 mg/l is often given as the storm water discharge consent. Given that the flow is dilute anyway this concentration is generally achieved in practice. The use of storm tanks combined with grass plots sees some occasional use in medium sized works.

A consent to discharge storm water may not confine itself to the parameters discussed above but may also include a minimum retention time. This would then preclude devices that are aimed at solids separation like hydro-dynamic separators that reduce solids economically but provide little storage.

Future of Storm Treatment

As wastewater treatment works are required to meet more stringent consents the effects of large flow variations will become more and more significant. Biological phosphorous removal for example works best at constant flow being vulnerable to washout. The management of storm flows practised at most works was devised years ago when the basic criteria was ‘the Royal Commission’ and most works were based on trickling filters. The relationship of the sewerage system to the works was in reality ignored. If the future retains the concept of a large infra structure leading to large centralised treatment works then the sewerage system operation should be integrated with the operation of the works. The existence of semi-dynamic pipe system models coupled to detailed works models should lead to the economic design and operation of new works and the optimisation of existing plant. The widespread use of telemetry will facilitate the integration of pumping plant operation allowing smoothing of flows and the use of real time control. Data mining and neural networks allow the continual review of data and highly sophisticated control algorithms to be developed. This approach is feasible in the large urban systems but is unlikely to be implemented in small rural areas. Here perhaps the only real solution is to provide more robust treatment units. Sequenced Batch Reactors which feature balancing as an integral operational requirement can provide high quality effluents but at a cost that exceeds the normal accepted small works economics. Small scale continuous flow activated sludge can be a solution when coupled with large balancing tanks. However all these solutions will require more maintenance than is at present provided. It seems inevitable that the cost of small works cost and operation will increase if they are to deliver the higher effluent qualities that are required.