Modelling the impact of storm flows on STW clarifier performance

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Introduction

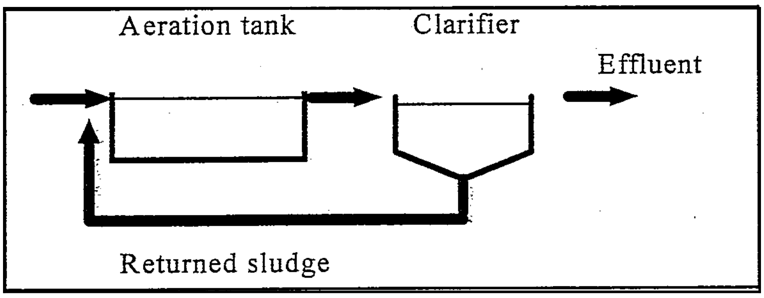
The public perception of sewerage seems to be that once anything is flushed away it is no longer a problem. Sewerage engineers sometimes think that once it reaches the treatment works fence it is no longer a problem.

Treatment works are, however, complex systems and are affected by changes in the pattern of flow and load caused by changes in the sewerage system. The UPM manual has introduced the idea that the wastewater system must be looked at in an integrated manner. This paper describes a new method of looking at an important component of that system - the final clarifier - and presents results from a recent project.

The activated sludge system

The activated sludge system is a popular method of sewage treatment. It needs much less land area than trickle filters and can give more consistent effluent in a range of temperatures and operating conditions. The principle is shown below. The incoming sewage is mixed with a large volume of sludge that contains micro-organisms that feed off the dissolved pollutants in the sewage. The "mixed liquor" in the tank is kept aerated.

The mixed liquor is then passed to a clarifier or settling tank where the sludge of micro-organisms is settled out and thickened for return to the aeration tank. The clean overflow from the clarifier is discharged to the river.



Clarifier operation

The clarifier develops a stratified flow with a distinct flocculating sludge blanket with clean water above this. The sludge blanket can help to "filter" the flow and so give a clean effluent. The position of the sludge blanket varies, depending on the flow rate, the concentration of solids in the inflow and the settleability of the sludge. If the sludge blanket rises too high then the effluent is likely to deteriorate drastically.

The clarifier has three main functions:

- to produce a clean effluent
- to produce a concentrated return sludge
- to provide storage for short-term high loads by allowing the sludge blanket to rise

Use of storage

A clarifier would normally operate close to average dry weather flow with short term peaks of higher flow, up to 3DWF. The clarifier may not be able to cope with a continuous flow of 3DWF, but relies on the storage function to deal with these peaks.

If however the pattern of flow to the treatment works and the clarifier is changed then the clarifier may fail. For example adding a large amount of storm detention storage in the catchment may cause the clarifier to fail. This is because draining down the storage may lead to high flows being maintained in the system for a long time after a storm.

Clarifier modelling

The conditions in a clarifier are complex and are not easy to model. The flow pattern changes from high velocities at the inlet to very low, uniform velocities through the body of the tank. There are likely to be flow vortices. The flows certainly vary in 2d and may even be full 3d flow in some clarifiers. Added to this is the complex behaviour of the flocculating sludge settling against the flow.

Previous modelling studies

An important limitation of previous modelling studies of clarifiers is that they have been carried out in isolation from the rest of the system. The studies have often included the interaction with the aeration tank and sometimes with the storm tanks at the treatment works, but not usually with the sewerage system, which is the source of the flow.

1d clarifier models

Most models that are presently available assume an idealised 1d flow pattern with velocities assumed to be vertically up the clarifier for the effluent and vertically down the clarifier for the returned sludge. The velocity is assumed to be uniform across the width of the clarifier. This is obviously a large simplification. These models do have a very useful purpose for initial studies or for linking into a model of the rest of the sewerage system for long term continuous simulations but they may not represent the real behaviour of the clarifier under high load conditions.

Clarity

Reid Crowther have a new model called CLARITY for use for clarifiers. This offers many advantages over previous models.

2d

Clarity has a 2d flow model to give a truer picture of the flow in the clarifier. For a circular clarifier the model is used for a radial slice of the clarifier with flow assumed to be the same in each radial direction. For a rectangular clarifier the model is used for a longitudinal slice of the clarifier with flows assumed to be symmetrical across the width.

This model is able to deal with the vast majority of clarifiers, but we are also developing a 3d model to cope with unusual designs that are not symmetrical.

Dynamic

Clarity is a dynamic model that shows how conditions in the clarifier change with time. It can therefore look at the effect of diurnal or storm peaks on the performance. To look at design conditions of steady flow it is simply run as a dynamic model with a steady input. It therefore shows the way in which the clarifier reaches steady state conditions. This can give useful information about the stability of the conditions.

Sludge settling

Clarity has a three parameter model to describe how the settling velocity of the sludge particles changes with the concentration of the sludge. This gives low velocities when there are just a few individual particles. High velocities when the particles flocculate together at medium concentrations and low velocities as the sludge thickens and compacts at high concentrations.

Density state effects

An important part of the behaviour of clarifiers is the effect of sludge concentration on the hydraulics of the flow. Most models do not include this, but it is included in Clarity.
Where there are areas of high concentration of sludge in the clarifier this increases the effective density of the water. This then affects the flow pattern, with the flow avoiding the high density areas and giving increased flow in low density areas. This can have a dramatic effect on the flow pattern and the clarifier performance.

Sludge blanket effects

The position of the sludge blanket can have a large effect on the operation of the clarifier. There is often a level for the sludge blanket below which the clarifier will operate satisfactorily, and above which it will move towards failure. The clarifier therefore has a "memory" of previous conditions. If it has been subjected to high load and still has a high sludge blanket level then another period of high flow will rapidly lead to failure. However if it has been subject to a period of low load so that the sludge blanket is low then it may cope satisfactorily with the new high flow conditions.

Case study

The example described here is based on a recent study and shows the effect of changes in the sewerage system on clarifiers that are already working close to their design capacity. The treatment works is an oxidation ditch system with a bank of three clarifiers. The clarifiers are circular, 22 m in diameter with sloping bottoms with central sludge draw-off. There is a rotating scraper to move the sludge to the centre, but the bottom slope is sufficient that most sludge will move under gravity.

Dry weather flow

In dry weather flow conditions the clarifers are operating under fairly low hydraulic loading and are giving good results. The sludge has good settling properties and so the sludge blanket is at a low level. The final effluent is reasonable although there are some small sludge particles that fail to settle and are carried into the effluent.

Storm flow

In a one year storm the peak flow through the clarifier rises to about 3 times the average dry weather flow. This peak flow lasts for about three hours. During these conditions the sludge blanket rises, but does not reach a level where it severely affects the effluent quality. The effluent quality is still good with only a small increase in the amount of fine sludge carried over the weir. After the storm the flows and effluent quality return to normal, and the sludge blanket is gradually drawn back down to the normal level.

Addition of detention storage

The catchment that is served by the works has problems of unacceptable overflow spill into a river which offers only small dilution. The proposed solution to this is to construct storage at the overflows in line with the recommendations of the Scottish Development Department method. This will provide approximately 30 000 m^3 of storage.

This storage is drained back to the sewer after the storm flows subside. A model of the sewerage system shows that the effect of this is to increase the duration of high flow through the clarifier to 6 hours compared to the previous 3 hours. The effect of this on clarifier performance is dramatic.

During the period of high flow the sludge blanket rises almost to the weir level of the clarifier. The effluent quality deteriorates drastically to over 100 mg/l compared to a consent of 20 mg/l. If the high flow continued for longer the high concentration sludge blanket would probably reach the weir giving effluent concentrations of over 1 000 mg/l.

It also takes many hours for the sludge blanket to be drawn back down to normal levels, and the clarifier is susceptible to failure if another large storm occurs during this period.

Possible solutions

The existing method of operation of the treatment works is unlikely to be satisfactory if the detention storage is constructed. However there are some changes that can be made that may improve the operation.

One possible change is to reduce the rate at which the storage is drained down after the storm. However this increases the risk of overflow of the storage in a succeeding storm.

Another operational change is to increase the rate of return of sludge from the base of the clarifier. This may allow the sludge blanket to be held at a lower level so the clarifier operation remains satisfactory. However this will increase the flow through the aeration tanks and may overload these.

The operation of the aeration tanks can be modified so that more of the return sludge is retained at the upstream end of the tank so that a lower concentration of flow is fed to the clarifiers. However this may have an impact on the biochemical processes in the aeration tank.

All of these options can be tested using integrated modelling of the system.

Conclusions

The components of wastewater systems do not operate in isolation. Making changes to any one component: the sewerage system, the storm tanks, the treatment stream, can affect all other components.

Integrated modelling can identify these interactions before they lead to problems.

The final clarifiers are an important part of this system in activated sludge plants. They are also a part that is likely to fail in storm conditions.

Detailed modelling of the clarifiers is one component of integrated modelling to identify optimum system performance.

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Question David Searby Wessex Water
In the example you discussed what amount of storage was incorporated in the upstream system ?
Answer
The population was about 40,000 and storage was added in accordance with the Scottish Development Department Method ?
Question John Stubbs Southern Water Services Ltd
Does the model need to be verified and if so how ?
Answer
Yes the model does need to be verified. We propose a three stage approach to data collection.

1. The first stage is to collect the minimum which is all input data. This is the inflow rate, inflow concentration, sludge settling characteristics and return flow rate. This is enough to give a first definition of the clarifier performance, and to plan the verification data collection.
2. The second stage is to is to collect verification data over a two week period. This consists of effluent suspended solids concentration, sludge blanket position and possibly returned sludge concentration and the use of dye tracing to define the hydraulic characteristics.
3. If the verification does not give good agreement then the third stage is to collect more detailed calibration data. This involves a lot of dye tracing and measurement of sludge concentrations at various points across the clarifier.

   To date, we have not had to go to stage 3.