PRACTICAL ASPECTS OF SMALL CATCHMENT SEWAGE TREATMENT WORKS MODELLING AND MANAGEMENT

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1 SYNOPSIS

One of the benefits of Sewage Treatment Works (STWs) modelling is that it allows the influence of catchment changes to be tested and analysed. Any catchment can be subject to future development and so STWs have to deal with an increase in both flows and load, particularly from S104s at new developments. STWs also have to adapt to the ever-increasing regulatory requirements.

In addition at the STW there is an increasing focus on improving the hydraulic and process performance of smaller STWs serving more rural catchments in order to meet tightening consents and reduce upstream (in network) flooding. This paper will outline modelling methodologies utilised at a catchment scale for a case study works serving a modest population (without pre-existing sewerage network or treatment works models) with identified operational drivers.

Differing levels of detail and modelling tools will be discussed together with the practical aspects of their calibration and benefits and limitations of their use.

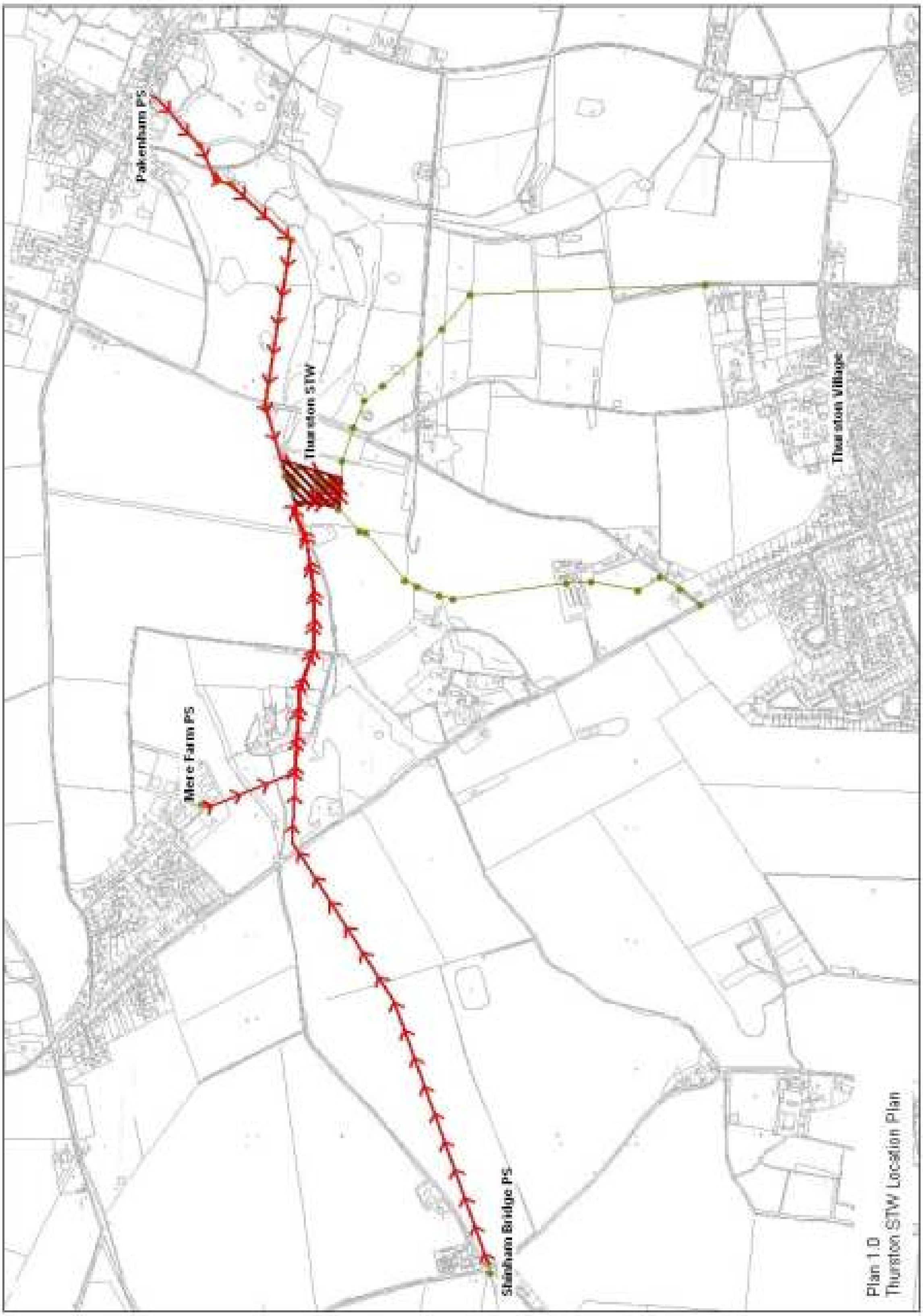
The case study for this paper is the STWs model created for the Thurston catchment. In July 2006, Anglian Water Services (AWS) employed Ewan Group plc (EGP) to investigate the causes of hydraulic deficiencies at Thurston Sewage Treatment Works (STW) which serves the villages of Thurston, Great Barton and Pakenham in Suffolk. Plan 1.0 shows the contributing catchments.

The drivers for this project were the known flooding issues within the works and the consequential non-consented discharges arising during storm conditions. Investigation found that the STW was affected by two separate hydraulic problems, buffered by the relatively large volume of the activated sludge process.

2 CATCHMENT DESCRIPTION

Thurston STW lies approximately 1km north of the centre of Thurston village. Thurston Village has a population of approximately 3150 and extends to an area of approximately 314Ha; the majority of which drains to a combined system, the more recently developed areas have separate drainage systems.

Great Barton is separated into two populated areas; the larger of the two is served by Shinham Bridge Pumping Station and lies 2km east of the STW. The smaller area comprising of residential and industrial areas is served by Mere Farm Pumping Station, approximately 1km northwest of the works. Pakenham is the other village to drain to the STW, situated 1km northeast of the works. The drainage networks of the Great Barton and Pakenham villages have not been modelled beyond the Pumping Stations, which pump to the STW. The two villages have a combined population of 2940 hd.


Pakenham PS
Thurston STW
Thurston Village
Mere Farm PS
Plan 1.0
Thurston STW Location Plan

3 STW PROCESS SUMMARY

The inlet works directly receives flows from two gravity sewers carrying flows from Thurston Village. The inflows from two areas of Great Barton, Shinham Bridge and Mere Farm, and Pakenham are pumped into the works compound where they have been diverted via a valve arrangement, upstream of the inlet works, into a set of two balancing tanks, from which the flows enter the Inlet Chamber. See Plan 2.0.

Flow then passes through a 6mm, in 2 dimensions, screen positioned in the central of three channels of the Inlet Chamber. The left channel, although shown on the as-built drawings as being at the same level as the central channel, has been altered onsite and now acts as a bypass channel. This is set 150mm below the level of the overflow channel.

Screened flows pass through a flume at the end of the Inlet Chamber before it is discharged directly into the oxidation ditch. Effluent from the Oxidation Ditch is spilt by a side weir into what was originally the screening chamber prior to its relocation upstream. This chamber serves to split the flows to feed the two Secondary Settlement Tanks. Effluent is spilt from the Settlement Tanks via a circular ring of V-notch weirs surrounding the perimeter of the Settlement Tanks.

The Effluent then flows towards the opposite end of the works' compound where it is discharged into a final clarifier. The final effluent is discharged under gravity to the local watercourse.

4 MODEL BUILD DESCRIPTION

A hydraulic model was built of the works using InfoWorks v 6.5. It was agreed with AWS that the model would include the pumped inflows from the three pumping stations and the gravity network directly upstream of the STW. This was because the project was focused on the hydraulics of the works and the immediate system up and downstream, not the wider network. Pumping Station Drop tests have been carried out at all three of the modelled Pumping Stations to obtain the storm pumping rates. It is these storm rates, which have been used in the model.

As the networks above the PSs are not modelled an inflow had to be applied to each of the nodes. Initial runs of the model used the true catchment inflow rates as found on site. However, these initial inflows proved to be insufficient to allow the pumps to run at the storm rates. The inflows were altered to match the storm pump rates so that the pumped flows would always be at a maximum. This allows for the downstream performance to be modelled with the worst possible inflows for both the pumped and gravity connections as described earlier.

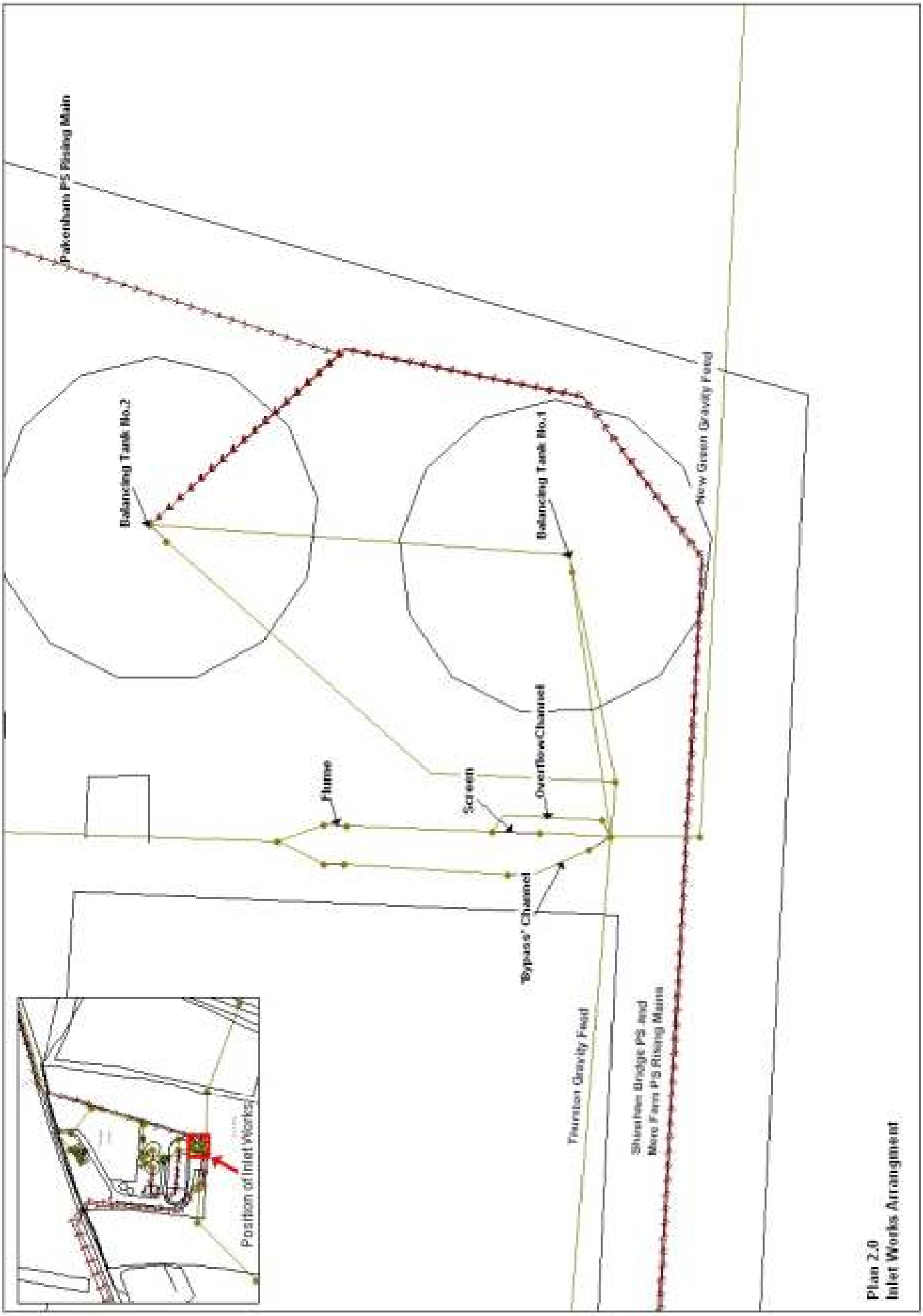
The model includes full representation of:

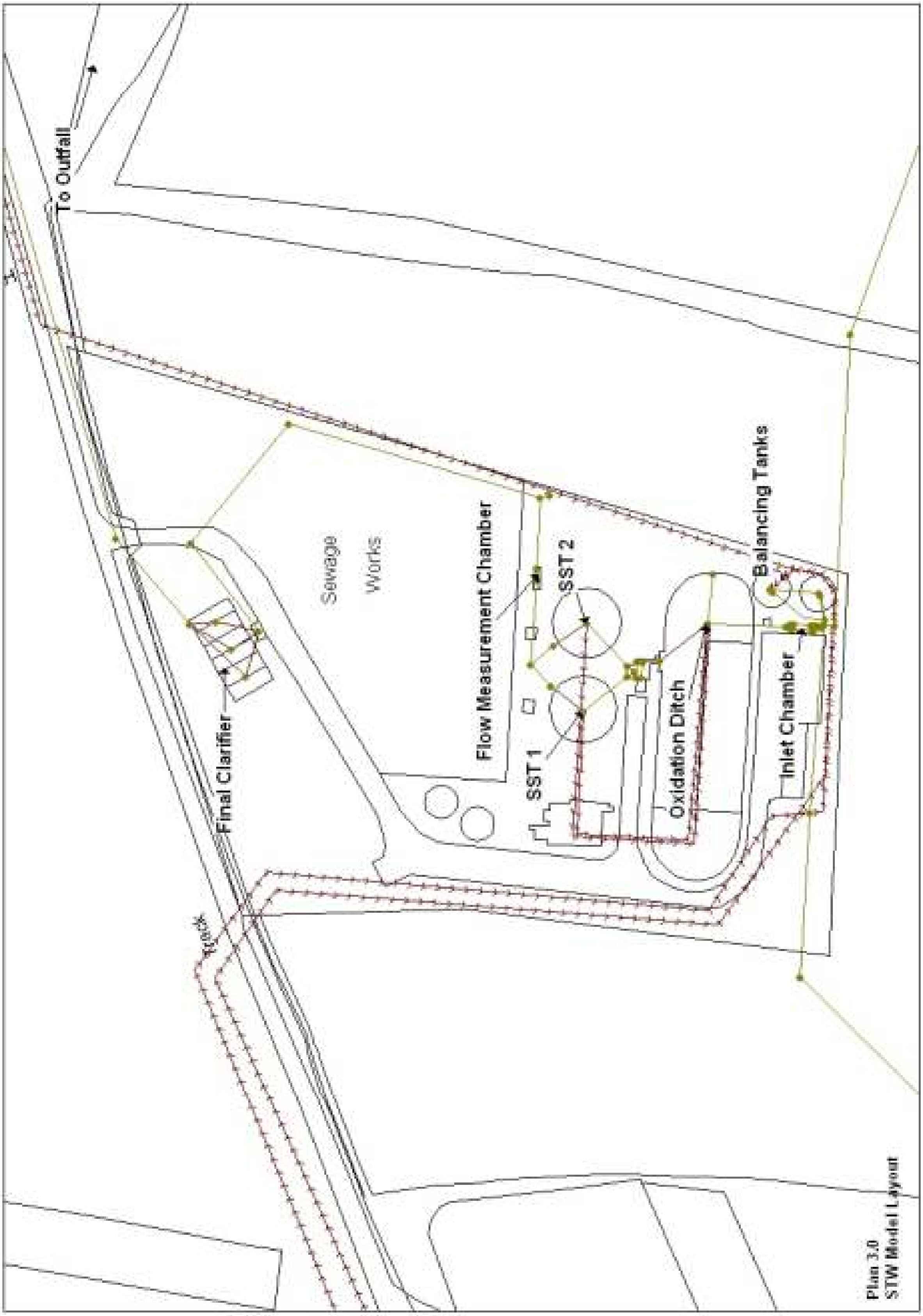
- Pumping Stations (3 no) - Gravity Network directly upstream
- Inlet works – 6mm screen and flume - Balancing Tanks (2 no)
- Oxidation Ditch - Secondary Settlement Tanks (2 no) - Clarifier (1 no)
- Outfall

The basis of the model build was a number of sets of drawings provided by AWS. These drawings date from 1984 to 2004, and were of varying quality. The drawings were supplemented by a site survey, which confirmed key levels extracted from the drawings, and established missing data.

The various structures found within the STW were predominately modelled using the standard features in InfoWorks – e.g. flumes, pumps, weirs, etc. Plan 3.0 shows the STW as modelled.

As the performance of screens varies greatly dependant on their design and installation it was considered necessary to obtain the manufacturer details and a user defined head discharge relationship determined for the fitted screen. The screen was modelled as a user control using a Head-Discharge Curve and is discussed further in the Hydraulic Analysis Section.


Pakenham PS Rising Main
Balancing Tank No.2
Balancing Tank No.1
New Green Gravity Feed
OverflowChannel
Screen
Flume
'Bypass' Channel
Thurston Gravity Feed
Position of Inlet Works
Plan 2.0
Inlet Works Arrangement


To Outfall
Final Clarifier
Sewage
Works
Flow Measurement Chamber
SST 2
SST 1
Oxidation Ditch
Balancing Tanks
Inlet Chamber
Track
Plan 3.0
STW Model Layout

5 MODEL VERIFICATION / CALIBRATION

'Hand held' velocity/depth monitoring was undertaken at the works, and the results used to calibrate the model for the range of inflows observed. There were two points at which flow measurement were carried out:

- Upstream of the flume at the inlet works in the screen channel
- Upstream of the flume at the inlet works in the 'bypass' channel

In conjunction with the velocity depth measurement further depths were recorded to allow depth/surcharge calibration for the measured flows. It was intended that the depth measurement would extend throughout the works however the large volume of oxidation ditch buffered the variation in downstream flows.

Flow measurements were undertaken only at a single fixed point within the cross section of the channels. This was the centre of the channel, at two-thirds depth, where the average velocity occurs. This was due to the limitations of flow variation from pumping station operation preventing continuous high flows for long periods.

The model was calibrated through a combination of the observed depth/flows and historic verification at the location of know surcharge and flooding within and upstream of the STW. This level of calibration does not provide the same level of confidence as a full flow survey but does allow for sufficient calibration for understanding the hydraulic restrictions and optioneering of solutions.

It was noted during the flow monitoring that a short-term increase in flows at the Inlet Chamber did not have a measurable influence on the levels within the Oxidation Ditch. Higher flows in the Inlet Chamber did not cause the inlet pipe to the Oxidation Ditch to surcharge and did not have any effect on the downstream processes of the STW. This enabled the two issues to be reviewed and resolved separately.

6 HYDRAULIC ANALYSIS

Information from AWS suggests that the problems experienced at the works and in the network immediately upstream are related to a hydraulic incapacity of the works in times of storm. This incapacity may be at the inlet to the works or at the outfall or both and this has been investigated as part of the hydraulic analysis of the works. Since the issues are concerned with how the works performs in storm conditions the maximum inflow has been applied to the model both from the gravity sewer and the three pumping stations.

The as-built plans show the screen situated downstream of the oxidation ditch has since been removed and replaced with a single Rotamat Micro Strainer Ro 9 screen at the inlet.

A maximum constant inflow was applied to the model of 55l/s (approximately the design capacity), split between the gravity and pumped systems. The hydraulic performance of the works was then analysed, and a number of hydraulic restrictions were identified. Site visits by Ewan Group identified another gravity feed entering the works; the source of this feed was confirmed by further site investigation.

Below are descriptions of the hydraulic performance of the key elements moving downstream through the STW.

6.1 Inlet Works to Flume

The inlet works provides the first stage of a continual treatment process that only ends once the effluent leaves the final clarifier. This initial treatment process requires the removal of the larger items suspended within the sewage. This is normally carried out by positioning a screen through which the sewage must pass. In the case of the Thurston STW a single Rotamat Micro Strainer Ro 9 screen has been installed in the inlet.

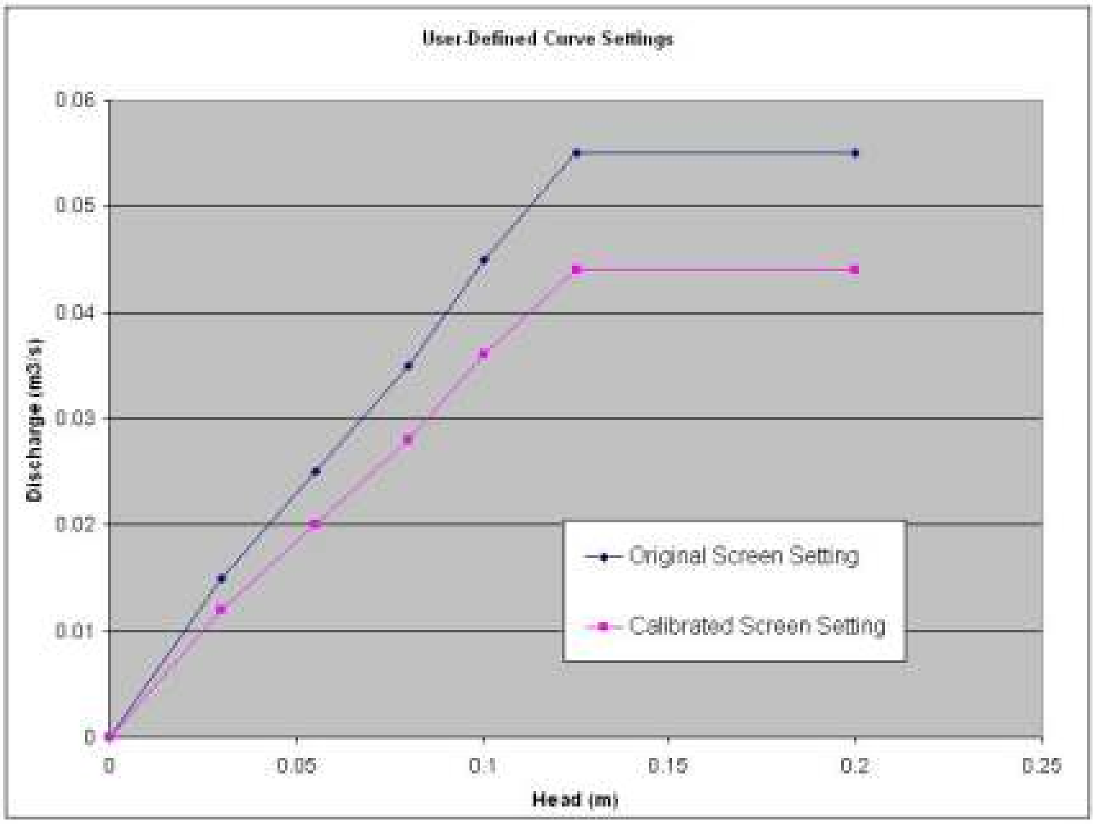
Inlet Chamber – 2 main flow channels (Only one used during DWF)

Inlet Chamber – Screen in open channel.

The Thurston Inlet works lies in the southeast corner, the highest part of the works' compound. There are hydraulic capacity issues with this part of the works. At normal Dry Weather Flow (DWF) the inlet had an average water depth of 300mm. This only leaves 270mm freeboard before the bypass is activated during storm/high flow events. It has been observed on site that the 6mm screen has screenings washed off and collected, so it has been assumed in the model that it never becomes blinded: however any blinding would serve to worsen the head required. The second flow channel has been arranged as a bypass. The bypass does operate in times of storm as can be seen from the ragging on the bypass board. This will always operate before the overflow level is reached, positioned on the opposite side of the open channel.

The Inlet works has been modelled as a series of nodes and open rectangular pipes. The screen itself has been modelled as a head discharge curve rather than using the standard InfoWorks screen utility. The flumes have also been modelled in both of the Inlet channels.

The model has been tested with both the InfoWorks screen utility along with the user-defined curve settings calculated from the manufacturer's details. Upon calibration of the model it was found that the user-defined curve performed more accurately than the screen utility. Various settings of the curve have been tested to provide a better calibration of the model. The original and calibrated screen curves are shown below.



6.2 Balancing Tanks

The balancing tanks are constructed to provide a form of storage at the Inlet works. The limiting discharge on the outfall pipes from the tanks allows a buffer to be formed against the flows entering the works from a Rising Main. The collecting end of the outfall pipe is normally supported on the surface of the water by a number of floats. The positioning of these floats acts as a restriction limiting the flows leaving the tanks. The tanks operate in series with one filling and spilling to the second when high flows persist.

Balancing Tanks 2No

The two Balancing Tanks (BTs) are situated alongside the Inlet Chamber. The full flows from all three of the PSs are currently diverted into balancing tank No.2, with the option of being redirected straight into the other tank or the Inlet Chamber, as was originally designed.

The balancing tanks have been modelled as two nodes with volume to match that of the as-built tanks. The balancing pipe arrangements have also been modelled to allow flow between the two nodes and then into the inlet at appropriate levels. A number of 'Sim' State files have been used to allow the tanks initial condition to range from empty to full during the modelled storm events.

6.3 Oxidation Ditch

Oxidation Ditch

The flows enter the Oxidation Ditch and are circulated around the tank. On the opposite side of the tank to the incoming effluent, are the RAS returns. The outlet for the Oxidation Ditch is via an adjustable side weir leading to a split chamber dividing the flows before they reach the settlement tanks. Immediately after the Oxidation Ditch there is very little restriction placed on the hydraulic behaviour of this part of the works.

From an early stage of the project it was identified that the oxidation ditch was not a significant factor in the hydraulic behaviour of the works. As such it's modelling is not as detailed as other more influential elements without detracting from the overall performance of the model.

6.4 Secondary Settlement Tanks and Flow Measurement Chamber

The Secondary Settlement Tanks (SSTs) are positioned downstream of the secondary treatment, oxidation ditch.

Secondary Settlement Tank No 1

Secondary Settlement Tank No 2 – Partly empty for cleaning

The screening chamber (Overflow Chamber from the Oxidation Ditch) splits the flow two ways – one leg to SST 1, the other to SST 2. Flows enter from the bottom of the tank and allowed to settle. Scum is removed from the surface via the rotating arm and scum board. Each SST is surrounded by a 360° V-notch weir. These weirs discharge freely into a 300 mm diameter pipe when the overflow level is reached.

Effluent discharging from the two tanks is then collected in one manhole and flows through an open Flow Measurement chamber. After passing through the flume as part of the flow measurement, the flows skirt around the perimeter of the works compound before turning to reach the clarifier distribution chamber.

For simplicity, the settlement tanks have been modelled as two nodes, each with an incoming pipe, v-notch weirs, to a continuation pipe. Since it was deemed that the RAS was not affecting the general hydraulic behaviour of the works, the sludge return, RAS, has not been modelled.

Again to accurately represent the normal behaviour of the tanks, the sim state has been used on all of the optioneering and testing runs, so that when the events are run, the settlement tanks initialise in a full state.

To enable stable simulation a fixed nominal inflow has been attached to the Oxidation Ditch together with a corresponding fixed pump rate from the SSTs back into the Oxidation Ditch. The creation of the constant loop is to allow InfoWorks to correctly predict the behaviour of the processes that would initialise full at the start of any runs/ storm events.

6.5 Clarifier Chamber and Outfall

Distribution Chamber – Penstock Control

Final Clarifier – Central beds in use

The final clarifier is served by a single open distribution chamber. The effluent is collected in this chamber and then distributed via a number of penstocks into the clarifier beds. There are 6 No. clarifier beds at the works and these are filled in groups of two, before reaching the end weir level and spilling to the outfall.

The clarifier itself suffers from hydraulic incapacity during times of storm due to the capacity of the outfall pipe. In times of high flow the clarifier provides a storage amount of approximately $340m^3$ before it drowns itself and final effluent breaches the walls of the open chamber.

The necessity of the final clarifier has been investigated and it has been found that the clarifier can be removed in terms of the treatment requirements since the Secondary Settlement Tanks do provide sufficient treatment.

The final clarifier has been simplified in the model as a set of three weirs spilling flows from a single distribution chamber back into a collection chamber. The final effluent is then spilt via the collection chamber into the outfall pipe and then into the receiving watercourse.

7 OPTIONEERING

As discussed above, there are a number of key areas of incapacity within the STW contributing to the current hydraulic capacity issues.

A number of options have been investigated in order to determine the possible solutions of reducing the flow through the works or increasing the works capacity. These are discussed below, both individually and in combination.

The options reviewed to solve the u/s flooding have included altering the current set up of the inlet works and providing an amount of storage u/s of the STW to allow for the increased storm flows. Since the Oxidation Ditch is acting as a buffer for the STW the d/s flooding will not be affected by solving the u/s flooding. With respect to the d/s flooding consideration has been given to the suitability of the final clarifier and whether the network would be better prepared if it was replaced with an equivalent storage volume. An increase of the outfall size has also been considered but this has environmental impact considerations.

Since there are no known issues with incapacity at the three pumping stations no consideration has been given to altering the pumping rates at the works.

7.1 Inlet Works Capacity and restrictions

Since the screen has been moved into the central inlet channel all of the flow is forced through half the original inlet capacity. Once a storm event begins to increase the flows they will be held at the start of the inlet, until flows reach a level to activate the bypass channel. However the current setting of the bypass is too high and causes backing up and flooding in the gravity sewer immediately upstream of the works.

Removal of the single screen has also been considered in favour of positioning the screen downstream of the inlet in a single channel. However, this was deemed less favourable than providing a screen identical to the current one which could be positioned in the other DWF channel.

Provision of this other screen would allow flows to be split equally between the two DWF channels and would increase the efficiency of the inlet whilst at the same time reducing the amount of surcharge upstream in the gravity sewer.

7.2 Capacity in Works between the SSTs and Clarifier

Investigation identified that the capacity of the connecting pipe work was insufficient to pass high storm flows, and this would become of greater importance if upstream issues were resolved. Various options have been modelled to determine the minimum pipe sizes required to prevent surcharging of the pipes.

As has been noted previously, one of the key factors in the choice of proposed options is the necessity of the final clarifier as the tertiary settlement treatment. Since a large amount of storage is currently provided by the clarifier, when it is flooded, any removal of this treatment process would necessitate the requirement of some in-line storage at this location or sufficient increases in capacity to remove the need for any storage.

7.3 STW Outfall

The outfall pipe work is currently under capacity and is surcharged in times of storm. There is some flooding around the clarifier, which is providing additional storage for the works and outfall pipe work. Any increase in the size of the outfall must be considered with the consented discharge in mind due to the nature of the environmental impact discharging to the watercourse would cause.

7.4 Storage Provision in U/S network

A further option is to provide storage within the network upstream of the works to deal with extra storm flows and then release them in a controlled manner once flows have returned to a normal DWF level. The storage would have to be capable of restricting flows entering the works without causing the gravity system to back up and flood Thurston village. This option was considered but deemed to be too costly in comparison to other possible solutions.

8 MODELLING AND PRACTICAL ISSUES

The key to modelling a STW is to review all of the available as built drawings to pick out key levels. Areas of conflict between the drawings will sometimes be found and it is crucial to highlight these so that, during site visits, measurements can be taken and then inputted into the model.

During model build for a STW it is important to focus on the elements of interest and not provide an onerous level of detail to processes that do not influence the situation the model is to be utilised for. This is important for both time and model stability issues and allows focus on the key ancillaries and processes.

The as-built drawings are very important but should never replace the benefit of a site visit by the modeller. During the course of the Thurston project it was found that the site visits were invaluable in aiding the understanding of how the STW should be modelled, there also important items and insights that may be missed.

An example can be found at Thurston, on the original set of drawings there was only one gravity feed to the STW. However, a second feed was found whilst on site. Further drawings were found as a result of this discovery allowing us to more accurately represent the flows entering the inlet works.

Due to the small size of the catchment and the STW it was only practical to carry out a small flow measurement survey, no impermeable area checks were undertaken to clarify the separation of the catchment. As a result the calibration of the model is as close to the measured value as possible, further calibration would be used before this model could be used for design purposes.

9 CONCLUSIONS

- Key to modelling a STW is to break down each process as simply as possible without initially trying to include too much detail but still allowing for the hydraulic to be accurately represented
- Site visits are key to helping you understand how each process works and how they interact with each other.
- Velocity/ depth gauging calibration of the model without the need for full flow survey.
- STW staff have invaluable insight into how the site works/ does not work on a daily basis and its history and evolution
- Modelling the STW gives you a much more useful tool for monitoring the behaviour of the STW and predicting how it will be affected by future changes both to the contributing networks and to the works itself. It is more useable than the steady state hand calculations traditionally used.
- The STW model allows various options to be quickly tested and compared to find the most appropriate and cost effective solution to a known and replicated hydraulic deficiency.

Acknowledgements
Thanks and recognition is given to reviews and contributions by: -

Jonathan Cutting, Ewan Group Plc
Adam Dean, Ewan Group Plc
John Rose, Anglian Water Services, for allowing me the opportunity to present a paper using Thurston STW as a case study.