MODELLING LARGE DETENTION TANKS

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1. INTRODUCTION

Detention Tanks (frequently referred to as Storage Tanks) are nowadays frequent features of sewerage systems with a high proportion of hydraulic upgrading schemes or environmental improvement schemes completed in the past decade including a detention tank.

The modelling of detention tanks has improved significantly since the early days of modelling with WASSP. In those earlier days it was necessary to use "On-Line Tank Records" and "Off-Line Tank Records" together with several 'fixes' so that tanks could be modelled. Even with these 'fixes' the results needed to be treated with some caution. With Hydroworks it is no longer necessary to use special Tank records and the 'fixes' are no longer required, but it is still necessary for a modeller to understand what is happening within the model and to treat the results accordingly.

This paper discusses the alternative ways in which detention tanks can be modelled and considers the advantages and disadvantages of each. Particular attention is given to the modelling of different control devices. Critical storm durations and sedimentation processes are also discussed.

2. TYPES OF DETENTION TANKS

The frequently used types of detention tanks are:-

- Tank Sewers (with various cross-sections but most commonly circular);
- Insitu Tanks (normally rectangular and constructed of reinforced concrete);
- Shafts;
- Ponds (either wet or dry);

These tanks can either be on-line or off-line but most commonly Tank Sewers and Ponds are on-line and Insitu Tanks and Shafts are off-line.

3. CONTROL DEVICES

The most frequently used types of control device are:-

- Orifice Plates;
- Weirs;
- Vortex Controls (Hydrobrakes);
- Variable Penstocks;
- Pumps;
- Motorised Devices (penstocks, gate valves etc)

Most of these devices control discharges in a direct relationship with the depth of water upstream; it is only with Active Control systems that the discharges become independent of water level in the tank.

4. COMBINATIONS

The combinations of type of detention tank and type of control device is almost endless but the most frequent combinations are:-

Type of Storage	On-Line or Off-Line		Control Device					
	On	Off	Orifice	Weir	Vortex Control (Hydrobarke)	Variable Penstock	Pump	Motorised Device
Tank Sewer	✓	✓	✓		✓	✓		✓
Insitu Tank		✓	✓		✓	✓	✓	✓
Shaft		✓				✓	✓	✓
Open Pond	✓	✓	✓	✓	✓			

5. MODELLING ALTERNATIVES

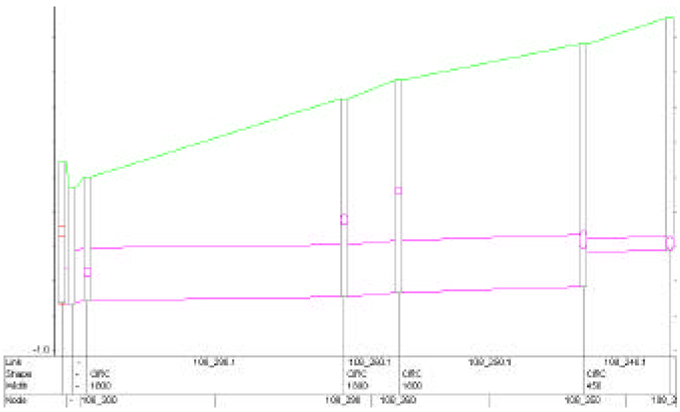
There are 3 principal alternatives for the modelling of detention tanks with Hydroworks:-

- Conduits;
- Nodes;
- Ponds

5.1 CONDUITS

This is the most frequently used method for modelling Tank Sewers and has a significant advantage over other methods as the Modeller simply has to include the sewers and manholes in the model without having to specifically re-arrange any of the physical features of the sewerage network.

In WASSP & WALLRUS the storage in Tank Sewers could only be modelled by means of the "Level Pool Effect"[1] which required the 'Tank Sewer' to be modelled as a single length of pipe with an 'On-Line Tank at the downstream end. This frequently required a number of 'fixes' to bring all of the incoming sewers to the head of the tank sewer with adjustments made to invert levels in order for this to work. Many models built originally as WASSP models still retain these modelling techniques and it maybe worthwhile considering whether these can now be removed and re-modelled in Hydroworks.



In Hydroworks it is possible to satisfactory model tank sewers with a series of pipes as illustrated to the right with intermediate nodes and with branch sewers. The control devices used in Tank Sewers are located at the downstream end and are usually governed by the water level (or depth) at that location. These can be simply modelled in Hydroworks without any adjustments or fixes being necessary.

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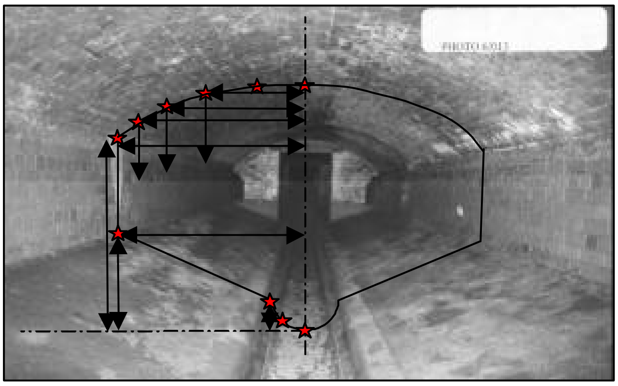
[1] See the withdrawn WaPUG User Note No 7

It is now possible for almost any cross section of a conduit to be modelled with up to 15 points defined for each shape type in a separate 'shape' file. The cross-sections no longer need to be symmetrical. The diagram on the left shows the cross section of a 185m long tank superimposed with the modelled cross section.



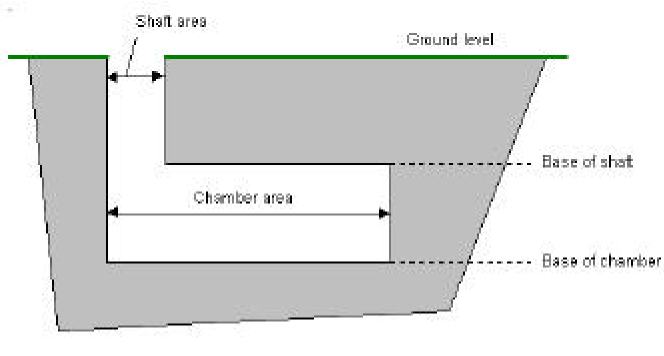
Modelling of Tank Sewers as 'Conduits' also have another significant advantage in that the results replay facilities enable a modeller to easily view the water levels along the length of the tank and appreciate how close to ground level they reach and whether the tank is surcharged or not.

However there are some aspects of modelling tanks as conduits which the modeller should be aware of:-

- In low flow conditions, for any given depth in a conduit there are two different discharges depending upon whether there are 'subcritical' or 'supercritical' flow conditions. These could potentially lead to model instabilities but to overcome this an artificial base flow is introduced artificially in Hydroworks. The base flow is equivalent to 5% of the conduit height. The artificial base flow does not affect volume computations as it is removed within the boundary conditions. However when viewing a results replay on a longitudinal section the depth due to the artificial base flow is shown.
- The modelling of any conduit in Hydroworks includes a "Preismann Slot" extending from the conduit soffit to ground level. This enables a constant series of open channel flow equations to be used and provides a steady transition between un-surcharged and surcharged pipe conditions. The width of the slot is taken as 2% of the conduit width and in the case of tank sewer at significant depths the volume of the slot can become significant. This can be overcome by reducing the modelled diameter or reducing the plan areas of the nodes, but such measures are rarely needed and should only be undertaken after a careful analysis of the local conditions.

5.2 NODE

The on-line documentation in Hydroworks recommends that storage tanks are modelled as 'Nodes' with adjustments made to the plan areas for the manhole and shaft sections of the node. The plan areas used in this context should not be confused with those at normal manholes when the lower portion of the manhole will have a far smaller plan area[2].

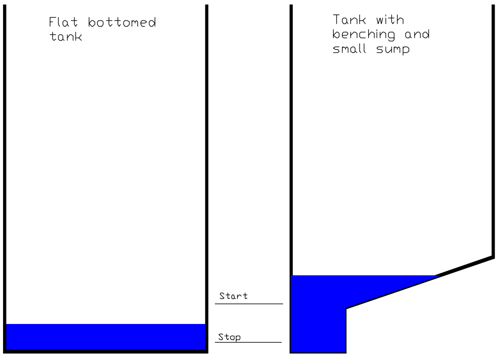


Modelling of tanks as 'Nodes' is very simple but it is important to note that the tanks when modelled this way have a flat bottom and the invert level of the control device must be above the bottom (10mm is frequently used). However it is very unusual for a large detention tank to have a flat bottom as there is either side benching or a sloping floor to try and reduce siltation in the tank. The physical layout of large detention tanks therefore means that the depths of water at the outlet control are far greater than that tank in a modelled tank with a flat bottom. In small tanks this is

[2] See WaPUG Paper "Simulating High Return Period Storms" by Richard Allitt – May 1998

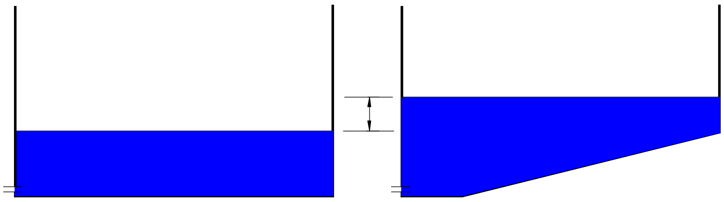
probably not a problem but in large tanks it can produce serious problems with major inaccuracies in tank water levels and tank discharges.

These problems are illustrated in the sketches below. The first sketch shows the arrangement of a tank with a pump as the control. The left hand diagram shows a flat bottomed tank whilst the right hand one shows the arrangement with benching. For the same volume of water in the tank it can be seen that the water level in the flat bottomed tank is far lower and that the pump has not started.



The other sketches show a tank with a flat bottom and with a sloping floor. Again for the same volume of water stored it can be seen that the water levels are far lower in the flat bottomed tank which would result in far lower discharges from the tank and possibly lower water levels throughout the tank operating range leading to overflow weirs being set at the wrong level.

Many people try and overcome these problems by reducing the plan area of the tank, taking an average floor level or making adjustments to the control device. Whilst these maybe considered acceptable with small tanks they should not be attempted with large tanks where the consequences (financial, operational or environmental) could be severe.



Therefore the modelling of large detention tanks as simple 'Nodes' is <u>not recommended</u>

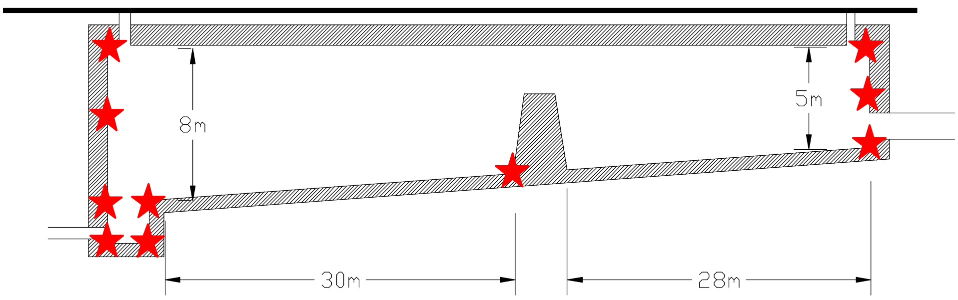
5.3 PONDS

The term 'Ponds' in this context is perhaps mis-leading but is used because in Hydroworks they are referred to as Ponds. In reality they don't need to be ponds as this technique can be used for any tank whether covered or open.

For a covered tank a rainfall profile is not specified and for an open tank (or pond) a rainfall profile is specified. The program treats an open pond as an impervious surface so it is important that rainfall profiles are not inadvertently added for large covered tanks.

The advantage of this technique is that any shape of tank or pond can be modelled whether it has a flat floor, sloping floors, sumps, dividing walls etc. Up to 7 pairs of figures can be given for each pond with the first figure being the level and the second figure being the plan area at that level. In-between the different stages or levels the areas are interpolated. The different stages or levels do not need to be at uniform increments.

The sketch to the left shows the layout of a large detention tank which was recently modelled. The tank has an overall volume of 7,753m^3 in four compartments with a sloping floor and a small sump area at the main outlet. This tank was modelled as a covered pond (ie rainfall profile=0) with the following stages:-



Stage Level	Plan Area	The stars on the above diagram illustrate the locations of the different stages.
2.410mOD	25m^2	
3.175mOD	25m^2	
3.600m OD	1664 m^2	
3.900mOD	2794 m^2	
4.5m OD	2794m^2	
6.5m OD	2794m^2	
8.3mOD	2794m^2	

When this is compared with a flat bottomed tank the difference that this modelling technique makes can easily be appreciated.

It is recommended that large detention tanks are modelled using the 'Pond' record type.

6. MODELLING CONTROL DEVICES

The modelling of the flow control device at a tank is equally as important as the choice of tank modelling technique because both of these must achieve the correct water levels in the tank in all conditions. In almost all cases the discharges are a function of the water depth and therefore if the water depth are wrong because of the tank configuration not being modelled correctly the discharges will be wrong (probably by a greater extent).

If Tank Sewers are modelled as 'Conduits' and other tanks are modelled as 'Ponds' the modelling of the flow control devices becomes very easy as the physical installation is included in the model without any adjustment (eg a 150mm dia orifice will be modelled as a 150mm dia orifice).

7. WATER QUALITY MODELLING

The QM module (Water Quality Modelling module) in Hydroworks will model surface (and pollutant) washoff from the catchment, sediment deposition or erosion in the sewerage network, dissolved pollutant transport through the sewerage network and hence pollutant loads (dissolved and attached to sediment) at the various outfalls or overflows in a network.

At the current time sediment deposition and erosion modelling is only carried out in the conduits. There is no sediment deposition onto the floors of nodes or ponds included in the program because at the moment the nodes are considered as being the locations at which all incoming flows and local inflows are thoroughly mixed before being transported along the outgoing conduits. The only exception to this is that with Version 4.0 of Hydroworks the program allows for a layer of cleaner water at the surface of the tank which could potentially be discharged over an overflow. This effect is confined to the modelling of suspended sediments as dissolved pollutants are assumed to be thoroughly mixed. The dsd file has a fields in each link record for U/S & D/S Settlement Efficiency and in v4.0 the U/S Settlement Efficiency field is active (the D/S field remains inactive at present). However the U/S Settlement Efficiency (as a percentage) must only be added for the overflow link. The settlement efficiency estimates the amount of sediment that settles in the tank and the program reduces the amount of suspended sediment which passes over an overflow weir when the weir discharges. It is, however, very important to note that at the moment the program simply losses this sediment it doesn't actually settle it on the floor of the tank. The overflow factor is directly proportional to the plan area of the tank and for large tanks can become very significant.

A second sediment fraction has been added to Hydroworks with the v4 release and various other improvements are understood to be in the pipeline.

Modelling of the sedimentation processes in large detention tanks is a very complex matter and is beyond the scope of this paper which aims simply to summarise the current state of the art. It is, however, understood that much active research is underway on these aspects with the intention that before too long the sedimentation in tanks will be fully modelled.

8. CRITICAL STORM DURATIONS AND SUCCESSIVE STORMS

When any detention storage is added to a sewerage system the characteristics of the system will alter significantly. The critical storm duration for the portions of the network upstream of the storage may well not alter and therefore flooding assessment can usually be based on the previous storm durations. However, for the tank itself and any downstream portions the critical storm duration (giving the worst flooding or surcharge) will probably be extended from the usual 60 or 90 minute storms to several hours. In these circumstances it is also important to consider the effects of successive storms as the tank may not be fully emptied before the next storm comes along. The Annual Time Series rainfall data is based on 1 hour dry period between storm events and this was adequate before detention tanks became a common feature.

When designing new tanks or analysing the performance of existing tanks it is recommended that a study is undertaken on the effects of repeat storms for tanks with a drain down time in excess of 60 minutes.

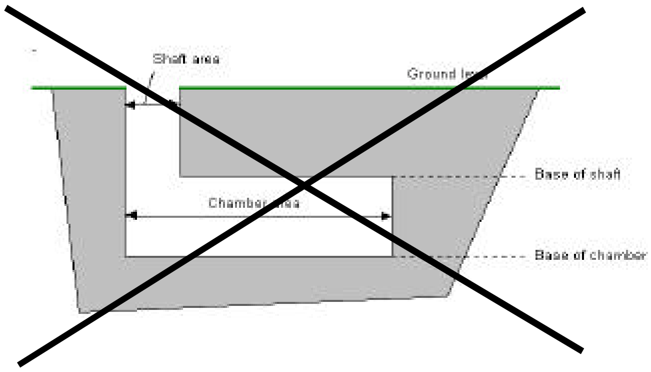
When considering critical storm durations it is important that this is based on sensible criteria such as surcharge levels (ie the number of properties with Restricted Toilet Use (RTU)) rather than the more conventional flooding criteria as the tank is likely to have cured the flooding problems.

9. RECOMMENDATIONS

The increasing power and sophistication of modelling software over the years has meant that the models nowadays are becoming a exact copy of the physical sewerage networks. It is no longer necessary to make 'fudges' and 'fixes' and carry out endless stability checks in order to get satisfactory (and sensible) results. The modelling of detention tanks is no exception to this and we should now include in the model what is actually (or will be) in the ground.

It is therefore recommended that:-

- ***For "Tank Sewers" the manholes and pipelines forming the tank are modelled exactly as manholes and conduits;***
- ***For all other "Tanks" they are modelled as 'Ponds';***
- ***Modelling of large tanks as 'Nodes' should be dis-continued and it is hoped that the Hydroworks documentation is brought up to date to reflect this.***



DISCUSSION

Question Martin Osborne Reid Crowther

Disappointed to hear about the problems with simple nodes. I feel I have to make a couple of corrections on quality. The sediment is not lost it is held in suspension in the tank. The model was designed so that efficiency becomes available on both continuation and on overflow.

Answer

Difficult for me to answer that, Wallingford Software have provided theinformation for me on this one and I am aware that some changes were madebetween the way sediment was modelled in MOSQITO and is now modelled in

QSIM.

Comment Andrew Walker Wallingford Software

Here is the relevant extract from the QM documentation on what theefficiency factors do.

* The concentration in the link exiting the node will be lower than inthe node if the efficiency is greater than zero.

* This applies regardless of whether the link is a continuation oroverflow, although using it on overflows would seem to make more sense.

* Conservation of mass means that no sediment is 'lost'. If anefficiency is set on both the overflow pipe and the continuation pipe from a node, then the concentration will continually increase in the upstream node.

* QM does not deposit sediment in nodes.

From the last two points, you can see that Martin's statement is technically correct, but as a general point, the suggestion is to model tanks with links instead of nodes in QM, so that you can model the sediment deposition correctly.

With respect to MOSQITO computability, the HydroWorks QM model can be made to behave like MOSQITO by setting a non-zero settlement efficiency on the overflow link only (as I think Richard Allitt said in his paper).

I think it's also worth mentioning that there is a problem in earlier versions of HydroWorks (pre version 4.0) where QM only applied the settlement efficiency to non-surcharged conduits. Not very useful if your overflow was a weir!

It may be information overload, but I've also enclosed a document containing the full equation set used by HW v4.0 to model sediment.

Hope this clears things up.

HydroWorks QM governing equations for sediments

Applying conservation of mass to the sediment entering, leaving, and in the man-hole, the mass of sediment or pollutant, M_J, in node J is given by

$$\frac{dM_J}{dt} = \sum_i Q_i C_i - \sum_o Q_o C_o + \frac{dM_{sJ}}{dt}$$

where Q_i is the discharge out of link i into node J

C_i is the conc. of sediment or dissolved pollutant entering node J from link i

Q_o is the discharge out of node J into link o

M_{sJ} is the additional mass coming into node J

The concentration C_o out of node J into link o is assumed to be the same as the concentration in the node, unless modified by a tank overflow factor, f_o

$$C_o = f_o C_J = f_o \frac{M_J}{V_J}$$

where V_J is the volume of water in node J (=0 for out-falls) and

$$f_o = \max\left(0, 1 - e_o \frac{w_s A_J}{Q_o}\right)$$

with f_o=1 for non-overflow links and also in the undefined case where Q_o=0. Here

e_o	is efficiency of the overflow
w_s	is the settling velocity of the sediment
A_J	is the area of the tank J at the overflow
Q_o	is the discharge over the overflow.

At out-fall nodes, there are no out-going links and there is no storage so the constraint $\Sigma Q_i = \Sigma Q_o$ is imposed.

Question David Fortune Wallingford Software

Should we be changing the way help recommends using nodes and ponds?

Answer

Yes