oz123

Modelling Engineering Options

Carlos Amaya, Parsons Brinckerhoff Australia Pty Ltd, camaya@pb.com.au
Andrew Hodgkinson, Parsons Brinckerhoff Australia Pty Ltd, ahodgkinson@pb.com.au
Andrew Chapman, Parsons Brinckerhoff Australia Pty Ltd, achapman@pb.com.au

EXECUTIVE SUMMARY

This paper outlines how an innovative Pipe Flow Model (the Model) incorporating hydraulic, water quality and financial analysis can be used as a tool to aid in the assessment of major engineering infrastructure projects. In particular, the Model can be used to test various scenarios for water reuse, waste recycling and sewer mining that might be implemented within a particular region, and assess and compare potential infrastructure configurations that could be more practical, sustainable and cost-effective alternatives in comparison to a base case scenario.

The Model has been tested under a hypothetical wastewater infrastructure scenario. It has been applied to a major sewage conveying system, which receives domestic and industrial wastewater from all major townships and industries located throughout the region where it runs. The wastewater is then carried to a series of large waste treatment lagoons before final disposition into the ocean.

Both the community and regulators are increasingly seeing this type of systems, as an unacceptable environmental management solution to a waste management problem. In particular, with respect to irrigation, the current community sentiment suggests that where possible, it will in the near future be desirable and possibly mandatory to retain for beneficial reuse any waters that may presently be discharged to water bodies in particular (e.g. river streams, lakes, ocean, etc.).

With continually increasing environmental standards, it is unlikely that the current disposal arrangement can continue indefinitely. A major engineering project may therefore be required to upgrade the system, unless alternatives are found.

To test these alternatives, a Strategic Flow Model has been developed to be used as a key tool for the conceptual testing and detailed hydraulic, water quality and financial assessment of a variety of alternative schemes ranging from simple low cost irrigation options up to high cost treatment schemes.

The main outcomes of applying the Model to this situation were a clear understanding of how changes to the inputs to the sewage system would alter the flow and quality of the water carried, what water reuse, waste recycling and sewer mining opportunities would be created when implementing an option or range of options, and what would be the consequences (e.g. technical constraints or environmental impacts), that could result from the implementation of a particular option or range of option set.

KEY WORDS

hydraulic, water quality and financial modelling, wastewater reuse, waste recycling and cost-effective alternatives

INTRODUCTION

Background

A hypothetical sewage conveying system has been established as the basis of a scenario that requires an infrastructure solution to a waste management problem. This system collects and transports domestic and industrial wastewater from all major townships and industries located throughout the region where it runs. The wastewater is then treated before final disposition into an ocean outfall.

Issues pertinent to an examination of the future of the system include:

- Effluent disposal into the ocean;
- Water resource policy; and
- Environmental concerns associated with the current sewage conveying system.

On all counts, both the community and regulators are increasingly seeing this type of sewage system, as an unacceptable environmental management solution to a waste management problem. In particular, with respect to irrigation, the current community sentiment suggests that where possible it will in the near future be desirable and possibly mandatory to retain for beneficial reuse any waters that may presently be discharged to water bodies (i.e. river streams, lakes, ocean, etc.).

To this end, two potential options have been considered as solutions to this infrastructure issue as outlined below.

Base Case Scenario

The comprehensive upgrade of the existing system has been considered as a possible solution to the environmental problems faced by the system. This effectively represents the base scenario because it could be considered as the most technically proven solution.

Future environmental policy directions suggest that in 20 years time when the new iteration of water policy will take place, ocean disposal of wastewater could be prohibited and under that scenario, the upgraded system would become an obsolete infrastructure solution having an extra 30 or so years of asset life to be decommissioned.

As a result, this option would require a high capital expenditure and higher operating costs with minimal community benefit that may become obsolete before expected.

Alternative Option – Enablement of Irrigation

As an alternative option to the base case scenario, the enablement of wastewater reuse for irrigation has been considered. The selection of this scenario has been motivated by a desire to avoid or substantially delay “upgrading the system” and to use the associated capital expense more productively. The financial analogue to this approach is to achieve the least community cost solution and to make an investment that would last for at least the lifetime of the asset. In that respect, the construction of an industrial wastewater treatment plant to deal with all industrial wastewater in the region and prevent industrial flows with high content of salts (i.e. high TDS load) from entering the system has been considered as an alternative in the Model. This would allow irrigation suitable domestic wastewater to remain in the system. It has been proposed that although this would require greater up-front capital expenditure than the base case, this option could bring greater benefits to the community through the enablement of wastewater reuse for irrigation.

To test these options and others that may be considered as infrastructure alternatives, a Strategic Flow Model has been developed to be used as a key tool for the conceptual testing and detailed hydraulic, water quality and financial assessment of a variety of alternative schemes ranging from simple low cost irrigation options up to high cost treatment schemes.

In developing this Model, the aim was to create a tool for understanding how changes to the inputs to the sewage system would alter the flow and quality of the water carried. In particular, it was a primary objective of the Model to test various scenarios for water reuse, waste recycling and sewer mining that might be implemented within a particular region, and to predict the consequences for the sewage system of such proposals.

THE MODEL

Basic Principle

The Model was developed in a series of Excel spreadsheets and in principle, it balances the inputs and outputs of flow including the mass and concentration of selected water quality parameters at any particular point (chainage) along the sewage system[1]. The inputs and outputs of both discharge and water quality parameters are variable and can be easily changed by the user. The model allows the user to insert or delete flow points and to analyse different options with the summaries in tabular and graphical forms provided in it.

Key Assumptions

In developing the Model, the sewage system has been viewed as a small river, in which the final flow is comprised of a series of smaller tributary streams entering the main flow sequentially. Each of these tributary streams corresponds with particular sub-catchments that collect both domestic and industrial wastewater. A series of simplifying assumptions were made regarding these sub-catchments and the main flow itself. These include:

- All sub-catchment flows mix completely and instantly with the main flow;
- There is no evaporation loss from the open channel section;
- There are no exfiltration or infiltration impacts on the flow or quality;
- Seasonal variations are ignored;
- All flows entering the system are constant (peak flows and hydraulic capacity are considered in a separate portion of the model but do not affect the quality or flow output calculations); and
- System inertia, hysteresis, concentration diffusion rates, channel wall interactions and other dynamic effects can be neglected.

How the Model Works

As in every model simulation tool, its performance depends in the accuracy and availability of the data used. In this particular case, several data inputs are required to achieve the expected outcomes of the model. These include:

[1] Chainage refers to the distance from the beginning of the sewage system where different flows are received or extracted along its length, and is a key variable throughout the model used to link the relevant data between the sheets.

- Sub-catchments;
- Oxygen dosing points; and
- Reuse options.

Detailed explanation and examples of these inputs can be found below.

Sub-catchments

As outlined above, each sub-catchment is treated as a small tributary entering the main flow of water. The user must enter the flow and water quality of each individual township or industry that contributes to the overall sub-catchment as can be seen in Figure 1 below. The number of equivalent residential lots is an important parameter and is used in the water industry for comparison purposes between different discharge points.

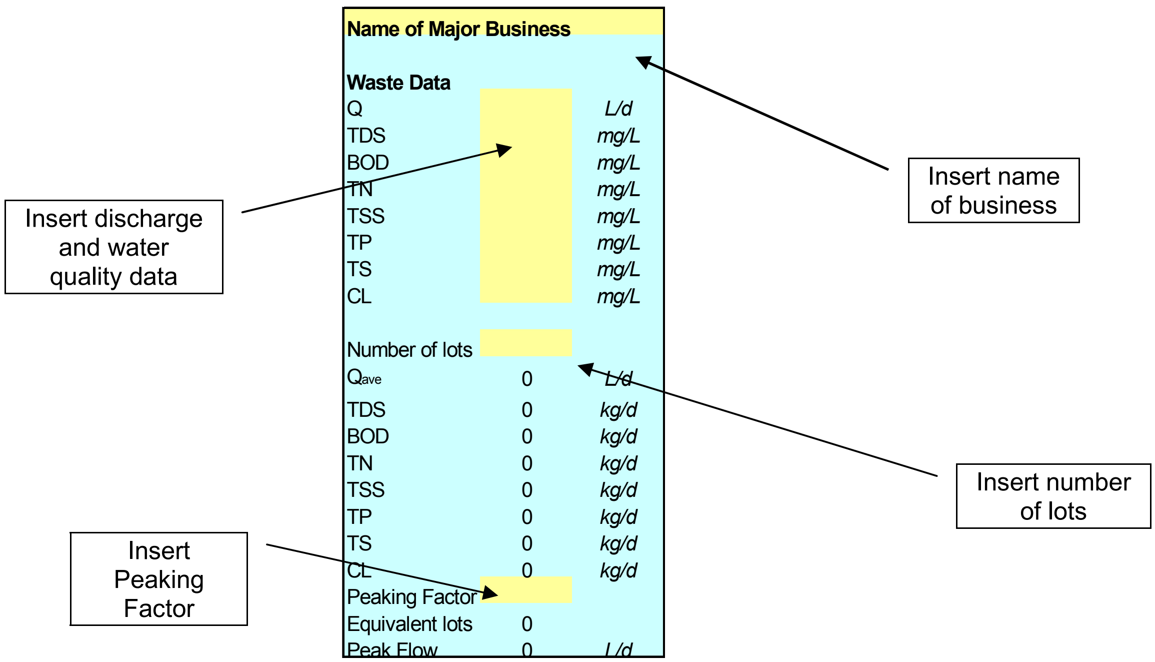

Figure 1: Sub-catchment example

Oxygen Dosing Points

The system has the facility to receive oxygen dosing at several points and this represents a potential treatment effect. Each injection point has been specified in the Model, and their treatment capabilities have been estimated (see Figure 2 below). This information is then used to calculate the amount of load (e.g. BOD) treated along the system due to each oxygen dosing point.

It is noted that oxygen dosing is assumed to have a significant effect upon BOD, but negligible effect upon some other parameters, e.g. TP, TDS, etc.

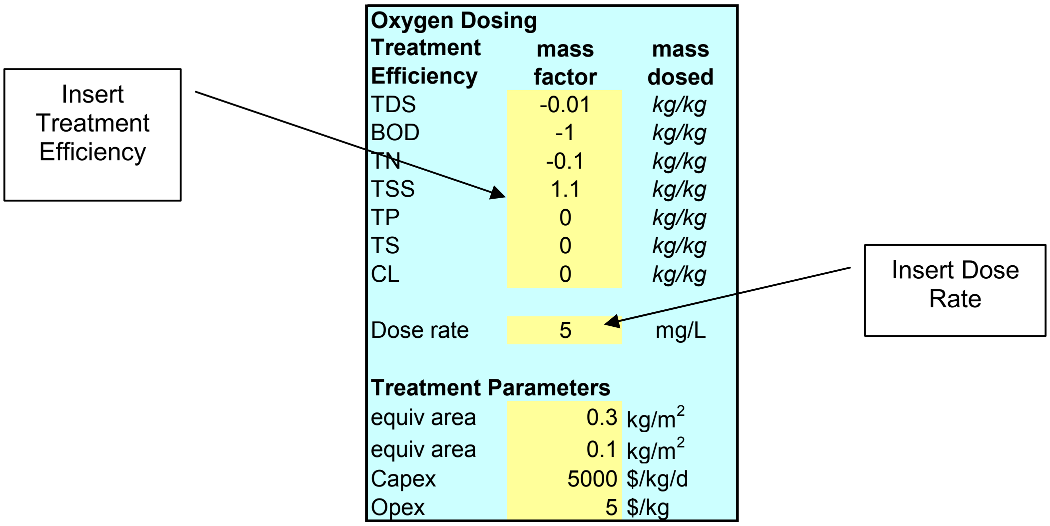

Figure 2: Oxygen Dosing Point Example

Reuse Options

In order to predict different what-if scenarios, a reuse options sheet has been incorporated into the Model as shown in Figure 3 (next page). This sheet allows the user to set the amounts of flow to be extracted from the sewage system for reuse and the treatment process that will be used with an estimation of the quality of water resultant from the treatment that will be either reused in a different process or disposed of as wastewater. The disposition options of treatment process wastewater include return to the sewage system, or transfer into another system to be defined by the user. In the latter option, the reuse represents a total loss of salt from the system, whereas in the first option (return of waste from treatment process to the sewage system), the resultant salinity concentration of the system would increase as there will have been a disproportionate water loss. Figure 4 gives an overview of how the model works when a reuse option is incorporated.

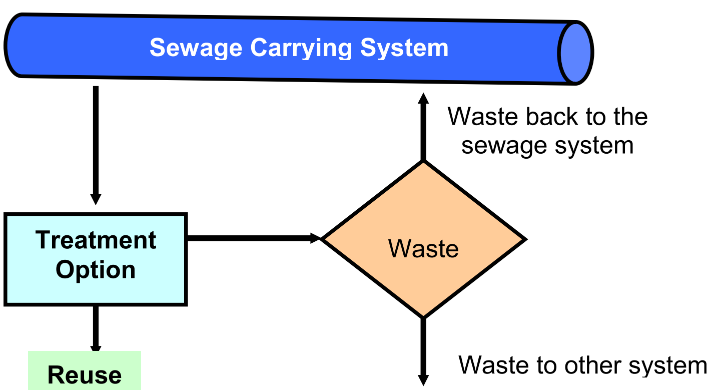

Figure 4: Reuse Option

	Chainage	57	km
	Jack's RO Pilot Plant Scheme		
Extract water	**Extracted water details**		
	Q_{extr}	0	L/d
	TDS	1874	mg/L
	BOD	401	mg/L
	TN	59	mg/L
	TSS	126	mg/L
	TP	5	mg/L
	TS	520	mg/L
	Cl	125	mg/L
	$TDS_{mass\ extr}$	0	kg/d
	$BOD_{mass\ extr}$	0	kg/d
	$TN_{mass\ extr}$	0	kg/d
	$TSS_{mass\ extr}$	0	kg/d
	$TP_{mass\ extr}$	0	kg/d
	$TS_{mass\ extr}$	0	kg/d
	$Cl_{mass\ extr}$	0	kg/d
Treatment Process	Process:	Reverse Osmosis	
	Flow yield	60	%
	Q_{prod}	0	L/d
	$TDS_{Reject\ Ratio}$	95	%
	$BOD_{Reject\ Ratio}$	85	%
	$TN_{Reject\ Ratio}$	90	%
	$TSS_{Reject\ Ratio}$	99.99	%
	$TP_{Reject\ Ratio}$	90	%
	$TS_{Reject\ Ratio}$	90	%
	$Cl_{Reject\ Ratio}$	80	%
Product Stream Data	$TDS_{prod\ flow}$	94	mg/L
	$BOD_{prod\ flow}$	60	mg/L
	$TN_{prod\ flow}$	6	mg/L
	$TSS_{prod\ flow}$	0.01	mg/L
	$TP_{prod\ flow}$	1	mg/L
	$TS_{prod\ flow}$	52	mg/L
	$Cl_{prod\ flow}$	25	mg/L
	$TDS_{mass\ reuse}$	0	kg/d
	$BOD_{mass\ reuse}$	0	kg/d
	$TN_{mass\ reuse}$	0	kg/d
	$TSS_{mass\ reuse}$	0.000	kg/d
	$TP_{mass\ reuse}$	0	kg/d
	$TS_{mass\ reuse}$	0	kg/d
	$Cl_{mass\ reuse}$	0	kg/d
Waste Data	$Q_{waste\ flow}$	0	L/d
	$TDS_{waste\ flow}$	0	kg/d
	$BOD_{waste\ flow}$	0	kg/d
	$TN_{waste\ flow}$	0	kg/d
	$TSS_{waste\ flow}$	0	kg/d
	$TP_{waste\ flow}$	0	kg/d
	$TS_{waste\ flow}$	0	kg/d
	$Cl_{waste\ flow}$	0	kg/d
	Waste to Sewage System	*80%*	
	Waste to Other System	*20%*	
		100%	

Insert Chainage

Insert Extracted Flow

Insert Treatment Type

Insert Flow Yield

Insert Reject Ratio

Insert % of waste sent back to the sewage or other system

Figure 3: Reuse Option Example

Analysis of Results
In order to gain an overall appreciation of the simulations performed in the Model, the concentration chart (using synthetic data) allows the user to see the water flow and water quality at any particular point along the sewage system in terms of water quality and flow. On this chart, a line is plotted showing the accepted TDS limits for effluent irrigation in Victoria[2]. This visual output enables easy indication of the relative performance of various changes that can be made to the system or its inputs. The following section shows concentration charts that result from the testing of the Model.

APPLICATION OF THE MODEL TO TEST ALTERNATIVE SCENARIOS AGAINST THE BASE CASE

As stated above, the aim of the Model is to serve as a tool to test various scenarios for water reuse, waste recycling and sewer mining that might be implemented within a particular region, and assess and compare various infrastructure configurations that could be considered as more practical, sustainable and cost-effective alternatives in comparison to the base case scenario. In order to understand the applicability of the model, an example is shown below where a comparison is being made between the base case scenario and a more sustainable option.

Base Case – Upgrade Existing System
In the Model, the Base Case is essentially a representation of the current average steady state flow condition. However, the upgrade would require extra oxygenation of the flow along its entire length. In the Model, this has been specified as an increment of the dosing rate of the oxygenation points to levels that would reduce anaerobic activity and hence odour generation to acceptable levels.

Final cumulative flow is thus calculated to be 31.1 ML/D and final TDS is calculated to be 1,770 mg/L. The summary chart is shown in Figure 5 below.

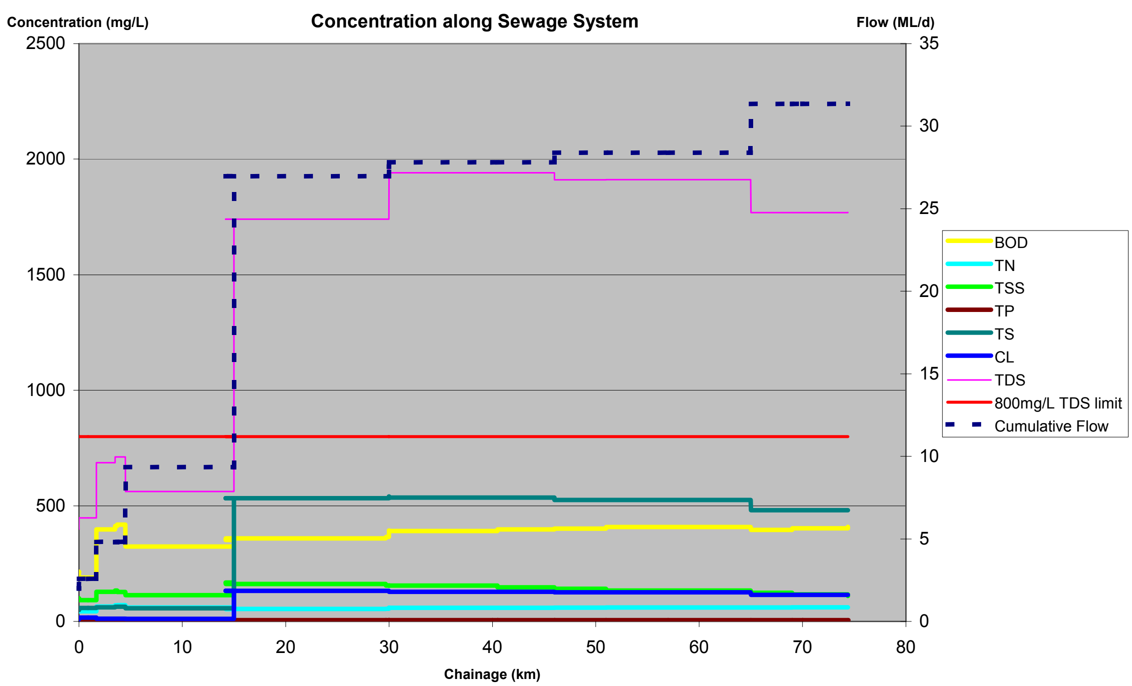

Figure 5: Base Case

[2] Currently set at 800mg/L, can be altered as required.

Alternative Option – Enablement of Irrigation Reuse

As stated above, the implementation of this option would result in both zero discharge of industrial wastewater, and the return of high quality water to industry resulting from the industrial treatment plant. At the same time, the domestic wastewater carried by the system could be used for irrigation in agriculture or other suitable uses.

The simulation of this option into the Model results in the reduction of system flow to about 13 ML/D whilst also delivering water that would be suitable for agricultural reuse (TDS < 800 mg/L). The summary chart is shown in Figure 6 below.

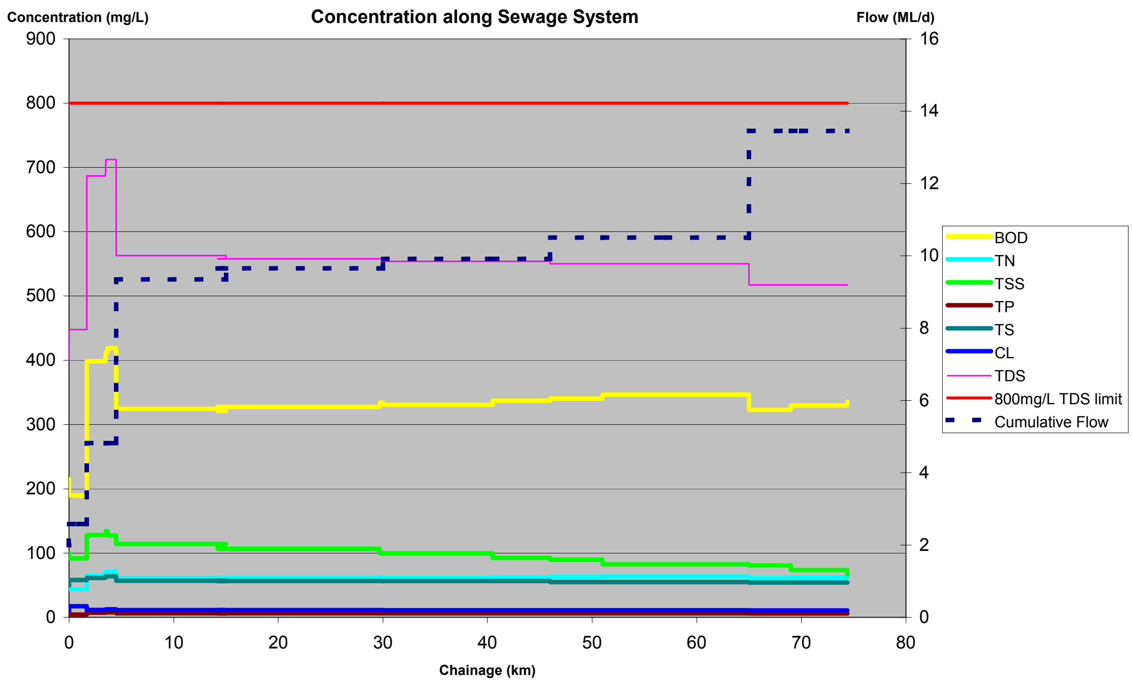

Figure 6: Enablement of Irrigation Reuse

Clearly this option requires greater capital expenditure than the base case due to the construction of the wastewater treatment plant and irrigation networks for water reuse. However, it also brings greater benefits to the system operator, the community, and the local environment. It is therefore likely to be a more sustainable and cost effective approach. This possibility is to be the subject of a separate study.

CONCLUSIONS

Increased environmental standards and community demands for a better environment and quality of life requires practical, sustainable and cost effective solutions to address current environmental problems. Often, a “simple and quick” infrastructure solution, such as upgrading an existing system is considered the best solution to address a particular infrastructure problem, without taking into account the regional context and/or future policy directions and other environmental, social or economical impacts that can arise from this solution.

The development of simulation models that take into account not only the present circumstances of a particular issue but that enable the analysis of different potential scenarios, aids immensely in the assessment of major engineering infrastructure projects. In this particular case, it is possible that a similar outcome could be achieved without aid of a model, but there are many systems where the cumulative effect of dozen of smaller “source” changes could be modelled with potentially similar outcomes. This would then enable a system planner to ensure that the most sustainable and cost-effective solution could be chosen, instead of just choosing an “end of pipe” solution, which is simpler to conceptualise.