# THE TOP TEN MOST COMMON MISTAKES IN WASTEWATER MODELLING

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## ABSTRACT

This paper explores some of the most common mistakes made in the development and utilisation of wastewater collection system models. Modelling is not an exact science, and it is critical that those who develop and utilise wastewater models understand the difference between interesting and important so that appropriate focus is given to avoid critical mistakes. This paper provides guidance based on significant experience across multiple projects, local and international, which relied on outputs from wastewater collection system models. Based on these projects a discussion of common mistakes and the potential consequences of these mistakes is provided. Issues pertaining to both model development (e.g. model network builds, field data collection and calibration) and model application will be covered citing specific examples from selected projects. This paper will provide guidance to the readers on how to avoid these mistakes and deliver higher quality results in developing options based on wastewater collection system models.

## KEYWORDS

**MODELLING, HYDRAULICS, WASTEWATER, MONITORING, CALIBRATION, VERIFICATION, BUDGET, SCOPE, FIELD DATA**

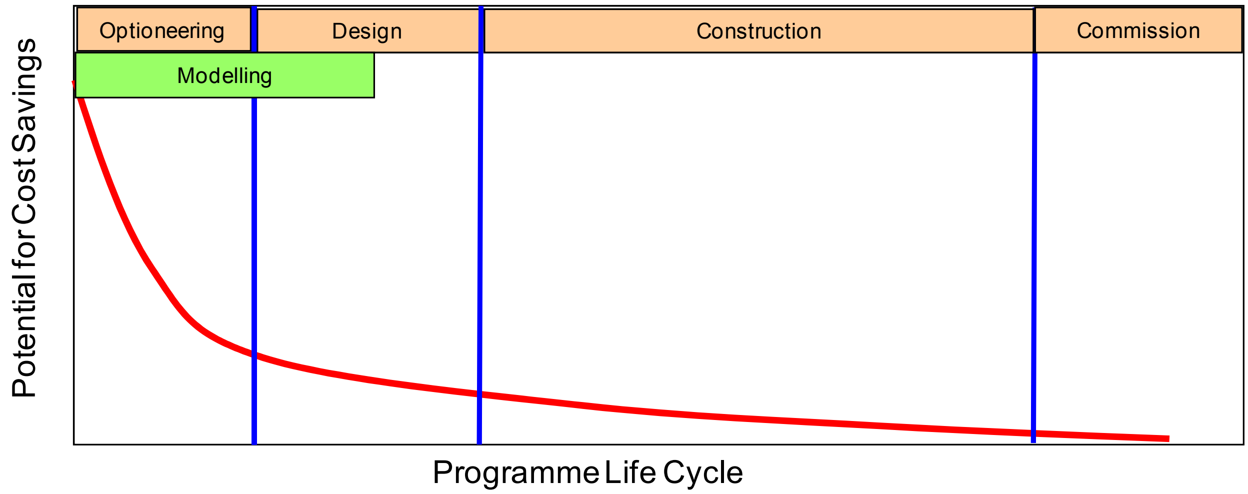
## 1 INTRODUCTION

The use of models to support analysis of wastewater collection systems and development of engineering options to address existing and future needs can provide tremendous benefits. These benefits may include significant capital and operational savings, and more importantly an assurance that any solutions implemented will achieve the targeted objectives. Understanding the performance of a wastewater collection system, including identification of problems and the associated cause of each problem, involves many complex processes which are highly interactive and variable depending on:

- The time of day
- The time of year
- Weather conditions – both antecedent and current
- Development status – from existing to complete build out
- Operational settings (e.g. pump stations)
- Internal pipe conditions – from temporary to permanent hydraulic blockages
- Etc…

Due to the complexities of wastewater collection system hydraulics and the myriad of variables which can impact system performance, appropriate application of models can be essential to the development of cost effective solutions which will achieve targeted goals – in terms of both CAPEX and OPEX. In fact the highest potential of generating capital and operational savings occurs during the initial planning stages of a project when the options analysis is conducted and concepts for feasible solutions are developed. This is typically the point in a project where models are developed and applied, and ultimately serve as a key engineering tool supporting options development and the design of recommended solutions. This is further illustrated in Figure 1 which depicts the relationship between a project life cycle and the potential for generating CAPEX and OPEX savings.

*Figure 1: Potential for CAPEX Savings as a Function of Project Life Cycle*




There are many stories of success in the development and application of wastewater models. In many cases the cost of model development and application has been more than paid for in terms of the savings generated through use of this highly effective tool. Examples include the Massachusetts Water Resources Authority (MWRA) Boston Combined Sewer Overflow (CSO) Programme, where the initial plan was based on a highly course and somewhat inaccurate hydraulic model. MWRA commissioned the development of a more detailed and accurate model which considered both system hydraulics and receiving water quality. In a one year time frame this model was developed and applied to generate revised options for addressing CSOs, and this revised plan reduced the required CAPEX by more than US$800M. Other examples included cases where applications of models resulted in "no-build" solutions, where the need for a capital scheme was reduced and/or eliminated through operational improvements and optimisation of existing infrastructure.

Whilst the application of wastewater models can provide extremely valuable benefits, it is important to consider cases where development and application of models has not resulted in meeting project objectives or identified practical solutions. Understanding the reasons why models have not achieved targeted benefits is key to ensuring that mistakes are not repeated on future projects, and that the value of "modelling" and "modellers" has a strong positive perception in our industry.

The first thing that needs to be understood about modelling is that it is a process that naturally resists standardisation – that being it is more an art than science. The challenge we have in as modellers is educating our 'old school engineers' in the ways of modelling processes, under the umbrella of a competitive, economic model.

The idea that an "engineering process" (i.e. modelling) should be allowed to vary flies in the face of the engineers desire to standardise. Process standardisation was actively encouraged (and awarded) in engineering consultancies during the 1990's. Process standardisation is great for a company that produces repeat products such as staplers or cellphones, but how well does it really apply to engineering services? Isn't every client "special" in their own way? Every modelling project we have ever been involved has surely been different. It's important to understand that modelling is "judgment-based work". It is directly affected by variability in its inputs, the process / resources and its outputs. In short the raw materials aren't uniform and therefore require a craftsperson's touch. This is further complicated by the fact that clients are all "special" and generally don't want your standard, they want "their version" of an output.

The following presents a series of generalised lessons learnt across a wide span of wastewater modelling projects. These generalised lessons are presented as the top ten most common mistakes made in wastewater modelling, along with guidance on how to avoid them, considering the differences between any two modelling projects.

# 2 COMMON MODELLING MISTAKES AND WAYS TO AVOID THEM

In the great scheme of things, mistakes are a good thing. They are an opportunity to learn something new. Winston Churchill put it aptly when he said "All men make mistakes, but only wise men learn from their mistakes". Every facet of engineering encounters mistakes, and application of wastewater models is no exception. However, mistakes that go unchecked or are repeated can ultimately lead to a loss of credibility. The greater the number of mistakes, or the more basic the mistake, the faster credibility is eroded. Credibility is a key requirement of any profession. Without credibility a profession is not sustainable. Engineering, and modelling in particular, is no exception to this statement.

The following presents a series of common mistakes which occur in the development and application of wastewater models. These are in no particular order, and are intended to provide important lessons learnt which can be leveraged on future projects – both for clients and consultants. Within our industry it is important that we address the stigma sometimes associated with the terms "modeller" and "modelling". We need to work more proactively to promote professional excellence within the engineering discipline of modelling – and by understanding common mistakes and key lessons learnt we can continuously improve the quality of results where models are applied and make the benefits of modelling much more transparent.

## 2.1 PHYSICAL SYSTEM ATTRIBUTE DATA

Probably the most common mistake on any wastewater modelling project is the use of inaccurate system attribute data, or data which incorrectly represents how systems actually operate. Arguably the biggest challenge on any project where wastewater models are applied is understanding the physical system attribute data needs, and then obtaining data which provides a sufficient level of accuracy. Obviously if the models are based on inaccurate attribute data, or data which incorrectly represents the actual physical systems, the model will not accurately predict system behaviour and performance. The consequences of this can be quite serious if the model inaccuracy is not detected and options are developed based on an inaccurate model.

Most client organisations do not have a complete set of accurate physical attribute data for their entire system, and it is not uncommon to find that attribute data may exist in several different repositories including GIS, disparate databases, maintenance management systems, spreadsheets, as-built drawings, or it may not be documented at all. Especially considering that many cities have wastewater systems that were built over a 100 years ago, and accurate drawings and readily available information may be hard to obtain. In fact for many public utilities in can be quite difficult to incorporate attribute data for new sewers due to limited skill sets or other commercial factors. It is also common to find attribute data which has been incorrectly recorded either when transferred into a GIS or database, or even on the official record drawings.

Based on the author's experiences, solicitation from other engineers and review of numerous wastewater modelling projects common mistakes related to physical attribute data can include (this is not an exhaustive list):

- Clients are unaware of or underestimate the accuracy and completeness of existing physical attribute data repositories (e.g. corporate GIS systems) and/or the underestimating of the efforts/budgets to gather required attribute data.

- Incorrect pipe diameters, pipe invert elevations and pipe lengths resulting in inaccurate flow computations.

- Mistakes in the collection system topology – i.e. how the various pipes are connected – resulting in flows being routed incorrectly.

- Incorrect access lid elevations potentially resulting in incorrect hydraulics due to uncontrolled overflows and overall volumetric imbalances.

- Pump station attribute data which does not correctly represent on/off levels, wet well dimensions, rising main dimensions, local head loss conditions, pump curves, constructed pump station bypasses, etc. A common mistake is to apply the original design pump curves only to find out that the original pumps or pump impellors have been changed, or due to wear the pumps operate quite differently than originally designed.

- Complex hydraulic control structures such as combined sewer overflow diversion chambers, bifurcations, weirs, storage chambers, etc. which are not represented correctly.

- The assumption that all pipes are open and clear of any debris or obstructions. Hydraulic obstructions due to siltation, grease, roots, air entrainment in rising mains, other debris and defects are quite common and can have a significant impact on system performance.

Given the above challenges and the importance of avoiding these mistakes, how do we ensure wastewater models are developed based on sufficiently accurate physical attribute data? The following provides some recommended guidelines to follow, and the reader should note that additional detail and guidance can be found in the Water New Zealand Wastewater Network Modelling Guidelines (see Section 3) which can be accessed on line at www.waternz.org.nz .

- Physical system attribute data can be quite laborious to collect, organise and review. It is vital that this effort is focused so that time and resources are not wasted on gathering data which is not important. A critical step prior to conducting any attribute data gathering exercise is to carefully define the required extents of the model to meet the needs of the project, and focus any subsequent data collection efforts on the portions of the collection system to be modelled.

- Some of the most significant mistakes in modelling have occurred when not enough effort has been planned or budgeted to gather sufficiently accurate physical attribute data, including field surveys which are all too often deemed as "too costly". It is highly recommended that clients take sufficient time to develop reasonable estimates of labour and budget to gather required data, and in cases where there are significant gaps or high degrees of uncertainty detailed field surveys should be planned. The most successful modelling projects are ones which included a sufficient component for collecting good quality physical attribute data. Understand that there will likely be data issues and be realistic about the consequences of the data issues on the price and quality of the project.

- Using the defined model extents, collect, organise and carefully review readily available physical attribute data. Use of data contained within a GIS system can be efficient, and most model software allow for direct importing of GIS and other digital data. However, it is recommended that when using GIS or other digital data the modellers also obtain and review record drawings to ensure data within the GIS is correct – especially around complex hydraulic structures such as bifurcations. The modeller can conduct spot checks to compare basic pipe and manhole data between record drawings and digital data.

- Conduct attribute data validation and verification checks – commonly done as part of a gap analysis. Identifying missing data is straight forward. What can be tricky is identifying questionable data. Use built-in model validation tools, but supplement this with visual checks of system connectivity and long-section profiles. Make sure the connectivity is correct, as one of the most common mistakes incorrect pipe connections at complex diversions. It is recommended that long-section profiles are plotted out on hard copy, reviewed and signed off as part of the formal model build documentation. It is also highly advisable that for complex hydraulic structures (e.g. pump stations, weirs, diversion chambers, etc.) hand drawn schematics are prepared and checked by an experienced engineer to ensure a correct representation.

- Step away from the computer! There is no substitute for going out in the field and inspecting key parts of the system to be modelled. In addition to detailed manhole surveys, clients and modellers should conduct focused field inspections of key structures and spot checks at selected manholes, particularly during wet weather conditions. This is also a great opportunity to interact with experienced operators and obtain their knowledge of current system performance, issues and problems. Plan and budget for this.

- Watch out for pump stations! Pump stations are notorious for being incorrectly represented in models. Unless you have good reason to believe that existing pump station data is correct, it is recommended that you plan and budget for inspections and hydraulic testing of key locations. When inspecting the pump stations meet with the operators to discuss problems, current operational settings, etc. Use hydraulic test results to develop reasonably accurate pump curves and identify potential blockages in the rising mains or pump wearing problems.

- Be careful and organised in planning and conducting manhole surveys. Include sufficient budget to spot check the surveyor's work – which can be done by the modellers or knowledgeable operations staff. Of utmost importance is using a field surveyor who is experienced and understands the basic concepts of sewers and sewer system hydraulics. Be clear about data accuracy needs, such as the importance of getting pipe diameters correct. Photo 1 provides an example of what can go wrong when dealing with inexperience field surveyors. This is a photo taken by the contractor when asked to include a tape measure at all CSO weir chambers for confirming the weir heights. It would have been nice for the contractor to actually extend the tape out of the tape measure when taking the photo!

*Photograph 1: Photo from Field Inspection Contractor when Requested to Include Tape Measure on Weir*

- Consider the relative importance of physical attribute data accuracy and the sensitivity any error may have on results. In some cases putting too much focus on accuracy for a particular element can exhaust resources and budgets and have little impact on the quality of results. Conversely, simple measurement mistakes on basic parameters such as pipe diameters and network connectivity can have significant consequences. Confirming the diameter of a pipe in the field is no simple task, and countless times errors are made in trying to visually estimate the diameter whilst looking down a manhole shaft. Think through the basic concepts of how errors in data and measurements will propagate into model result errors. For example, flow through a rising main is equal to the average water velocity times the cross sectional area ($Q = V_{avg} X A$). The cross section is a function of the diameter squared, so an error in the actual rising main diameter will propagate to the power of two in resulting flow computations. Similarly, forgetting to set the model to use a pressure pipe equation over the St. Venant equations (which are open channel) can result in highly inaccurate results for modelled pump stations, because the computed pipe cross sectional area will be wrong due to the Priessman slot effect.

- Consider possibility of pipe blockages/obstructions which need to be accounted for in the models. Review inspection records and identify locations where siltation and root intrusion is likely (e.g. low velocity areas, trees over pipelines, etc.). There are cases where models have been found to be highly inaccurate after field inspections showed key trunk sewers to be significantly blocked by silt or roots and there was no account for this impact in the modelled pipe.

Failure by either clients or consultants to sufficiently understand attribute data issues in terms of requirements and accuracy and the resulting consequences can have quite severe consequences. Investing in obtaining quality physical attribute data has benefits well beyond supporting the needs of model development, such as improved operational efficiencies, more optimal solutions and a more robust platform for asset management decisions.

## 2.2 PROJECT BUDGETS AND SCOPE

Failure to understand the objectives / outcomes required and matching these with an appropriate budget and then accepting an unsustainably low tender-price can lead to serious problems in the development and application of wastewater models. Competitive pricing is an important issue in our industry, but a price only focused approach for tendering wastewater modelling projects is not a good idea. History has shown that this usually results in greater cost to the client, both in terms of spending more money to get a model of sufficient quality, possibly having to pay for model development more than once (this is not uncommon) or even worse – investing in capital solutions which do not achieve targeted results due to flaws and inaccuracies in the models. This is the equivalent of trying to cut cost on geotechnical investigations for a multi-story building where ground conditions are not understood. Consider that there are many examples where high quality models have resulted in massive capital savings which more than pay for the entire cost of model development, sometimes by orders of magnitude. Also consider that the cost of model development typically is a mere fraction of the cost of capital solutions which will be based on the model.

Many modelling projects are flawed at the start with inappropriate budgets. To follow this up, the client will then accept the lowest tender. When scoping a modelling project it is very important that an appropriate budget is determined and funding gained. It is quite common for the issue of inappropriate budget to manifest itself after tenders are received for a modelling project.

So how can this problem be avoided? Having a good Request for Tender (RFT) with a clear scope focused on deliverables and assurance on the availability and quality of input data is a good start. Publishing the client's project budget in the RFT, even just in the form of estimated labour hours, is also a good idea as it helps further define the scope of the project.

When setting budgets, similar previous projects (say the median tender price plus inflation) can be a good reference point but care is needed to ensure the context of the previous projects being referenced is taken into account. It is also a good idea to allow for a contingency if data availability and/or quality is uncertain.

Clients are not always the best at being clear with the objectives of a modelling project. The objectives of the project are sometimes lost in the client specifying the project methodology, not actually specifying what they need as an outcome. The client brief should be focused on the desired outcomes, and the onus of developing an appropriate approach should be left to the consultant. In fact, this is a good test to ensure the consultant is qualified to meet the needs of the brief in terms of model development and application. Also, consultants who are well qualified and experienced in applying models are constantly looking for innovative ways to improve efficiency and quality, and the risk of a client writing an overly prescriptive methodology is loss of potentially innovative ideas that could result in increased benefits. The other potential risk is that the client may have difficulty in determining the qualifications of a consultant who simply "parrots" the prescribed.

The client should focus on clearly stating what they believe the modelling project objectives to be and, when possible, provide indicatively how much they have budgeted (time and funding) to achieve those objectives.

When scoping projects, clients could also give more consideration to scoping the project (and its deliverables) in manageable sized pieces. Experience has shown that modelling projects than span over a year generally don't stay 'on course' as well as modelling projects which are less than a year in duration. A recent example of this was a modelling project in which the staff changes over the 18 month period of the project resulted in only one member of the original client/consultant team being there to see the project completed – there was a complete change out of all the staff involved with the technical and management aspects of the job.

## 2.3 MONITORING

Monitoring generally follows a simple rule – you get what you pay for. The lower the price you pay, the lower quality data set you will get, the less reliable your model will be. As a minimum you should expect to pay upward of $900 per site per month for a flow gauge and $200 per site per month for a rain gauge. Typically flow surveys will cost in the order of $1,500 - $2,200 per site per month depending on traffic management requirements to access the site.

Follow guidelines such as the Wastewater Planners User Group (WAPUG) guidelines for planning your survey, if you cut corners then expect to have a lower confidence in the models predictions and any decisions you base on those predictions. Don't underestimate the amount of time you need to keep monitors in place to ensure a robust data set covering sufficient dry weather periods, seasonal variations and wet weather conditions. This is a function of the issues which need to be addressed by the model, but it is not a bad idea to include a contingency in case the required range of conditions are not observed by the monitors such as a sufficient number and range of wet weather events. Typically a significant portion of the monitoring cost is associated with installation and initial setup, and the cost of leaving monitors in for a longer period is relatively insignificant to the cost of solutions which will be based on the models.

It is also recommended that clients work closely with the flow survey contractors, or engage the modelling consultants to do so, to ensure that quality data is collected and provided. Guidance can be found in Section 4 of the Water New Zealand Wastewater Network Modelling Guidelines on flow and rainfall monitoring.

Common mistakes related to monitoring for wastewater modelling purposes include:

- Selection of flow monitoring locations which do not provide sufficient information for calibrating the models to suit the needs of a project. For example, if a significant objective of the project is to address wastewater overflows, it would make sense to include monitors at key overflow locations as part of the planned monitoring network. Believe it or not there have been a number of wastewater projects focused on developing controls to address overflows, and not a single overflow was monitored to ensure model accuracy. This issue can also apply to the number of in-pipe flow meter and the spatial distribution of these meters. This paper cannot address in detail the subject of how to locate flow monitors properly to provide sufficient coverage, but suffice it to say this is a very important issue and should be dealt with by someone who has significant experience in the development and application of wastewater models.

- Selection of flow monitoring sites and/or equipment which will not produce accurate measurements of flow. Current technology for monitoring flow mostly relies on the use of a velocity sensor and sensors for measuring the depth of water. Based on these two parameters, flow is then calculated. Therefore any error in the measurement of these parameters equates to an error in flow. The velocity sensor technology is commonly based on the measurement of a point velocity (i.e. one point in the flow column) and then is converted to an average. Either this is done automatically, or through a process of developing a conversion factor through site calibrations using a hand held velocity probe. Incorrect conversion of a point to average velocity can produce significant errors in flow. It is also important to note that velocity sensors will be challenged to produce reasonable measurements in significant hydraulic turbulence conditions. This also applies to depth measurements. Again, the process of choosing flow monitoring sites and appropriate equipment is a paper by itself. The key point is that this is a critical issue, and should not be left solely to the discretion of a flow survey contractor. The client needs to be involved in this process either directly or through a well qualified consultant who has experience in dealing with flow monitoring data.

- Insufficient rain gauge networks and rain gauges which are not installed properly and/or are not calibrated. Even with a perfect flow monitoring network and a well developed model, problems with inaccurate or insufficient rain gauge data will be directly manifested into inaccurate wet weather model results. Quite often the accurate measurement of rain is taken for granted. There are many projects where rain gauges have been found to be faulty, and these are quite sensitive instruments which need to be well maintained and calibrated regularly. Clients should seek proof of this for all projects. It is also quite common that the number of gauges and/or spatial distribution of gauges is not sufficient to provide reasonable coverage for the modelled system. Again, there are published guidelines on this, but clients should seek to have a well qualified person involved to ensure rain gauging is done properly, including a review of how the gauges are installed so that precipitation is monitored correctly. One of the best guidelines published on how to install rain gauges is provided by the US National Weather Service.

- Not accounting for typical errors in gauging when utilising data to analyse the system and calibrate models. A very good flow monitoring site will produce data which is within plus or minus 10% of reality. Obviously a perfectly calibrated model is only as accurate as the monitoring data it is calibrated to. Another significant issue is the process of flow meter data subtraction to determine flows from an unmonitored subcatchment. The errors between two meters could produce resulting data which is significantly off from reality, as the errors at both meter sites can propagate when the data is subtracted. It is much better to place monitors on all key tributary branches to avoid the need for meter data subtraction.

- No provision for detailed quality assurance reviews of monitoring data. Undertake an independent review of monitoring data to ensure sufficient quality. The client should do this internally if there are qualified staff available, or should require this of the consultant responsible for developing the hydraulic model. History has shown that on almost every monitoring project there are problems and issue in data quality ranging from malfunctioning sensors to sites which simply cannot be monitored due to local hydraulic complexities. The key is to identify the problems as quickly as possible so that corrective action can be taken and data loss is minimised.

- Lack of consideration for other simplistic monitoring methods. Beyond the use of sophisticated technical equipment for monitoring, there are a number of means to enhance or supplement the understanding of current system performance to ensure models are predicting reality. Examples include having modellers go out into the field to lift manhole lids where the model predict surcharge and check for evidence of actual surcharge. If manhole surveys are being conducted the surveyor can also check for evidence of surcharge and/or overflows, and can chalk the inside of the manhole chamber so that it can be checked after a large wet weather event for surcharge activity. Also, it is important to consider that well experience operations and maintenance staff are essentially human system monitors and it is a very good idea to review model system performance predications with them to check for accuracy. Other good sources of surrogate monitoring data include customer complaints, condition inspection records and preventative maintenance records. Last but not least use of system telemetry data can be invaluable, and there are many low-cost measures for installing additional logging sensors such as pump station run time meters which will greatly enhance the ability to check for model accuracy.

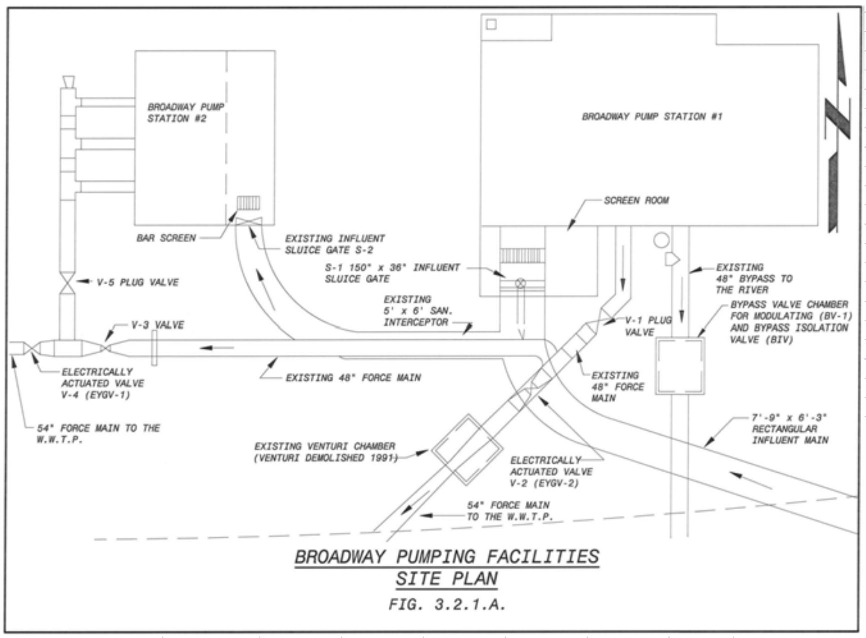
- Ensure data units are correct. It is important to check what units of measurement were used in collecting the survey data, and that these units are correctly loaded into the model software at the time of uploading the survey data. There can be a big difference between rainfall in loaded as mm/hr when it was recorded in the field as rainfall per time step.

## 2.4 REPRESENTATION OF COMPLEX HYDRAULIC STRUCTURES

This issue was discussed in the previous section on Physical System Attribute Data. It is covered again in this section due to the critical importance, and the common mistake of not representing these structures appropriately in the model. Examples of complex hydraulic structures include such things as pump stations, bifurcations, combined sewer overflow regulators, complex connections and throttles, and storage tanks. In order to represent these properly in a wastewater model, it is imperative that the modeller understand the fundamental concepts of how these structures work – outside of the model world. It is highly recommended that on any wastewater modelling project there is a provision for conducting field inspections of all identified complex structures, particularly ones which can have a significant impact on the system performance. Based on past experience a good way to facilitate this is to request that the modellers visit these sites with experienced operators and other client staff who understand how these structures operate and can point out any pertinent details, such as changes to pump impellors or operational control settings. These visits should include detailed photos and sketches which will subsequently be used to develop the model representations and be included in the model development documentation. Figure 2 provides an example of a typical schematic diagram developed for a complex control structure which was modelled.

*Figure 2: Typical Schematic of Complex Hydraulic Control to be Modelled*

| Wet Well Information | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Type: **Wet Well / Dry Well** / Other: | | | | | | | | |
| Dimensions (feet): | 7' x 7' x length of buildings | | | Shape: | rectangular | | | |
| Material: | concrete | | | Condition: **Good** / Fair / Poor | | | | |
| Evidence of Surcharging? Y / **N** | | | | Depth of Hist. Surcharge: | | | N/A | |
| Exposed Reinforcement? Y / **N** | | | | Liner/Coating: Y / N | | | | |
| Wet Well Coordinates: | Broadway 1 | | | Northing | | | Easting | |
| Wet Well Coordinates: | Broadway 2 | | | Northing | | | Easting | |
| Other Comments: | | | | | | | | |
| Depths: | Top of Slab | | | | | | | |
| | High High Alarm | | | 716 | | Low Low Alarm | | 707 |
| (distances measured from bottom of wet well) | High Alarm | | | 715 | | Low Alarm | | 707.25 |
| | 6th Lag | | on | | | off | 713.5 | four from #1, three from #2 |
| | 5th Lag | | on | 714.5 | | off | 713 | four from #1, two from #2 |
| | 4th Lag | | on | 713.5 | | off | 712.5 | three from #1, two from #2 |
| | 3rd Lag | | on | 713 | | off | 711.5 | two from each |
| Under Auto Control, which is typical how the pump station is run | 2nd Lag | | on | 712 | | off | 709.5 | two from #1, one from #2 |
| | Lag | | on | 710.5 | | off | 708.5 | one from each |
| | Lead | | on | 709.75 | | off | 707.5 | one from #1 |
| | Bottom | | | 703 | used #1 bottom elev. | | | |
| | Bypass | | | | | | | |
| | Other | | | | | | | |
| Sketch of Wet Well | | | | | | | | |




It is also recommended that all complex hydraulic structures represented in the model are reviewed in detail by an experienced engineer who has a thorough understanding of the hydraulic and operational characteristics, and the limitations of a model's ability to represent these elements. To facilitate this, the modeller should provide documentation including sketches, photos and field notes inclusive of information obtained from experienced operators. Some of the more complicated structures may include real time control systems that regulate the operations, such as offline storage tanks that are utilised under certain conditions with filling and draining that are controlled by various monitored parameters. Examples of common mistakes include improper pump station on/off settings, mistakes in representation of head losses and flow control systems, invalid connectivity within complex diversion structures and oversimplification of dynamically controlled elements. Quite often the mistakes are simple in nature, including an example where a modeller input pump flow capacities in litres per second in a model data field which was defined in cubic meters per second.

## 2.5 APPROPRIATE LEVELS OF ACCURACY "FIT FOR PURPOSE APPROACH"

How accurate does a model need to be? This is a challenging question which has received quite a bit of debate throughout the international arena of wastewater network modelling. Probably the best fundamental guide to go by is to make sure that the model is "fit for purpose". Essentially this requires that clients and consultants carefully think through the objective of the project for which the models are being developed and applied. Even if the scope of the project is solely to develop and calibrate a model, those involved need to define what questions/issues the model will ultimately need to address. Understanding this will help to define the required levels of detail and accuracy, including the extents of the model and how many monitoring sites are required for calibration. It is importance to understand that model development is typically a staged process similar to the various stages of design to support construction of an asset. Therefore depending on the nature of the project, a skeletal model with limited extents and detail may be quite appropriate to support the required outputs. Conversely a highly detailed model with robust asset and monitoring data may be appropriate in supporting a project which is nearing the detail design stage of solutions development.

The Code of Practice for the Hydraulic Modelling of Sewer Systems, developed by WAPUG provides excellent guidance on determining the level of accuracy and detail required to support various types of projects. Section 2 of this document, Project Definition, provides very good guidance on how to categorise the required level of modelling detail to support a project as follows:

- Type I – Skeletal Planning Model
- Type II – Drainage Area Planning Model
- Type III – Detailed Design Model

This document provides very useful information in how to determine an appropriate model "type", and what the required levels of detail are to create either a Type I, II or III model. Understanding an appropriate level of detail for a project model is critical. There are many examples where solutions have been developed and designed using too course of a model, resulting in potentially disastrous consequences. Conversely it is also a common mistake to try and develop a model which is too detailed to support a high level of planning analysis which can be appropriately addressed with more basic analysis methods, some of which may not require a model at all.

Beyond the selection of an appropriate model detail, the issue of accuracy on data used to develop and calibrate the model is critical. How accurate do we need to measure manhole rim elevations, pipe invert elevations, flow, pump station curves, tributary drainage areas, residential dry weather flows, industrial flows, pipe roughness coefficients, etc.? This is a complex question and there is no simple answer. What is important is to ensure these issues are assessed by individuals who have substantial experience in applying models and can understand the sensitivity of any key parameter and the consequential effect on model results accuracy. Being focused on getting accuracy levels where they need to be will ultimately save time and money and will results in much better model results. Too much focus on accuracy for parameters which do not significantly affect key results for solutions development may well detract from focusing on parameters that are critical. Also important is the understanding of reasonable accuracy levels to expect to ensure this accounted for in the solutions development stage. For example, a very good in-pipe flow monitor will produce flow data within a plus or minus 10% level of accuracy – and models calibrated to this data would be subject to the same amount of error.

Making sure a model is fit for purpose and provides sufficiently levels of accuracy is a function of the stage of options/solutions development and also the type of solutions being considered. If the project is at a stage where recommended solutions have been developed and detailed designs are required, and WAPUG Type III model is recommended. If the project is at an initial planning stage a Type I Skeletal Planning Model may be appropriate. Accuracy requirements must be focused with consideration of the type of solutions and problems being targeted. For example, if property flooding and backups are a risk due to pipeline surcharge, than accuracy of peak water levels can be critical to ensure solutions prevent future flooding up to the targeted levels of service. If the models are being used to design relief sewers, then peak flow accuracy need to be assessed very carefully. Finally, if storage is a targeted solution then the model's ability to predict overflow volumes is vital. There are examples of very large storage facilities (including storage/conveyance tunnels) which were constructed but did not achieve targeted levels of service. In one case a large diameter tunnel was constructed which was designed to reduce overflows to no more than 4 spills per recreational bathing season. When the tunnel was put on line the system experienced 16 spills in the first bathing season and 14 during the next. The monitoring data and models were reviewed in detail and it was discovered that the collection system experienced very long periods of significant infiltration after rainfall events had ended – for as long as 10 days. The models used to design the tunnel did not accurately account for the "lagging infiltration" which accounted for a significant amount of the total volume from targeted overflows. It was subsequently determined that the tunnel needed to be roughly doubled in volume to achieve the 4 spills per bathing season target.

## 2.6 APPROPRIATE MODELLER EXPERIENCE

The biggest mistakes on wastewater modelling projects are typically related to a lack of appropriate experience by clients, consultants or both.

For projects which involve the use of wastewater models it is vital to include engineers who are well experienced in the areas of fundamental hydraulics and hydrology, wastewater collection systems, complex wastewater control structures, typical wastewater system problems and associated causes, and development of practical and feasible options to address problems. In addition, the experience should include significant time in the field and a strong understanding of wastewater collection system operations. All of this experience is in addition to experience in the use of any particular model. In fact quite often the most senior engineer providing quality assurance and technical oversight may not be that well versed in the use of a particular model software application, but has the ability to meet with a modeller and assess the quality of their work. Understanding where to put specific numbers and parameters in a modelling programme requires a limited amount of training, but understanding the meaning behind these numbers and how to tell if they are right are wrong takes many years of experience. This experience only comes through the process of working on many challenging projects, including ones where mistakes have been made, and important lessons have been learnt. This experience is not obtained by attending a model software training workshop.

For large projects it is recommended that formal peer reviews are conducted and are focused on ensuring that the model is fit for purpose, provides a sufficient level of accuracy and adequately represents options being considered and/or designed. Use of an appropriately qualified and independent peer reviewer quite often results in further enhancement of models being applied and the robustness of developed solutions. The peer review process should be quite focused and efficient, and not dwell on details which do not have a significant impact on the project outcomes. Having engineers with an appropriate level of experience will facilitate this.

Through experience you learn how to manage expectations as a modeller. Projects of any sort will deliver better outcomes for all concerned when the parties involved are realistic with their expectations. In the case of modelling projects, this starts upfront when the business need is identified but it needs to be continued through for the duration of the project. Whatever the expectations, it is important that they are kept realistic through the project – as it is while working on the project that you will gain a better understanding of data issues, resourcing etc that could affect the overall outcomes of the modelling project. Managing expectations come with experience and is key to avoiding disappointment, tension and financial losses as the project progresses.

An experienced modeller will never be over-optimistic about the availability and quality of input data (nor will they hide away from data issues in order to keep the client on side). Through experience a modeller can articulate, in terms that the client understands, the consequences of low quality data based on previous project experience.

Through experience you can address unrealistic expectations about the time required to complete the project including, not just the modelling component, but also the time required to gain approvals with respect to awarding contracts, gathering additional data, etc. Anyone who has significant experience in the development and application of wastewater models knows that the model build and calibration process can be quite time consuming, and should anticipate this when setting realistic programme targets for key project stages. Projects involving use of wastewater models quite often have a reputation for taking longer than expected, but typically this can be traced back to unrealistic expectations of the client, consultant or both. More often than not the delays are related to a lack of experience or a focus on things that are interesting but not important.

## 2.7 CALIBRATION AND VERIFICATION REALITY CHECKS

The overall accuracy of a model in terms of its ability to represent system performance is a function of the overall model extents, number of monitoring points and the quality of data used to develop the model.

Calibrations and verifications to monitored sites are the ultimate "test of truth" in determining the accuracy of a wastewater collection system model. So how accurate does a model need to be? That potentially is the million dollar question. As stated above, appropriate levels of accuracy are a function of how the model needs to be used to support the requirements of a project, and are also commensurate with the project stage. For example if the model is being used to support detailed design of a large diameter conveyance/storage tunnel to address wet weather overflows, it would be vital to ensure that the model can accurately predict overflow volumes under a range of conditions.

When calibrating and verifying a model to a particular flow monitoring site it is reasonable to apply the same levels of accuracy standards in spite of the type of solution or project stage. Section 6 of the WAPUG Code of Practice for Hydraulic Modelling of Sewer Systems, as referenced above, provides very good guidance on calibration and verification standards to follow. As stated above the overall accuracy of the model will be primarily a function of the system extents, the quality of data used to develop the model and the number of monitoring locations used to calibrate and verify the model. Oddly enough many mistakes related to model calibration and verification are related to not understanding the difference between calibration and verification processes. These processes can simply be defined as follows:

- *Calibration* is a process of adjusting appropriate (emphasis on the word "appropriate") model parameters to achieve a reasonable match between model predictions and monitoring data. For wastewater collection system modelling, the calibration checks usually include depth, velocity, flow and volume. At a minimum the model needs to be calibrated to typical dry weather conditions for weekday and weekend patterns, and holiday patterns (e.g. Christmas holidays) that significantly change flows. The model will also need to be calibrated to a range (emphasis on the word "range") of wet weather conditions when project requirements dictate this.

- *Verification* is a process of comparing model results to monitoring data not used for calibration (i.e. different periods of dry weather flow and different wet weather events) with no adjustments being made to the model. The model should be able to meet the prescribed verification accuracy levels with no adjustments. If the model fails this test, the modeller needs to understand the cause of this failure and repeat calibration steps as required to address the problems.

So what are the typical mistakes in calibrating and verifying wastewater collection system models? The following provides some of the more common examples based on a range of project experience:

- One of the most common mistakes is skipping the verification process altogether. Quite often the calibrated models are not tested against independent monitoring data sets to ensure that the model will hold accuracy to a range of conditions without any adjustments to input parameters. It is recommended that the calibrated models are tested against at least one or two independent data sets, with no adjustments to input parameters, and that the independent data sets are representative of conditions other than those used for calibration – such as a different wet weather event.

- Not accounting for seasonal variations in the calibration process as required to support the project needs. Seasonal variations can have a dramatic effect on system performance and associated problems, such as the difference between groundwater infiltration in summer and winter conditions. This must be accounted for relative to the needs of the project. For example, if the project goal is to design a storage control system for reducing overflow during bathing recreation conditions, it could be a serious mistake to use a model only calibrated to winter conditions.

- Using discrete storm events for model calibration when a continuous time series calibration approach (i.e. calibrating the model to a continuous time period of monitoring data – such as three straight months with typical dry weather and multiple rainfall events) is more appropriate. In the early days of wastewater collection system modelling computer processing time was quite demanding and quite precious, so the tendency was to calibrate models using only well defined discrete wet weather events. This is no longer the case. The decision of the need to apply a continuous time series calibration approach is a function of system response characteristics and project needs. For example if groundwater infiltration is a significant issue it is likely that a continuous time series approach to calibration will be needed given the relative timeframes of groundwater table responses to rainfall events. Continuous time series calibration also provides a more robust approach to ensure that slow response infiltration (which can potentially go on for several days) is accurately represented. This can be particularly important when assessing/designing storage facilities.

- Adjusting the wrong parameters to achieve a calibration fit. This is where calibration can get very tricky and requires someone with significant experience and a thorough understanding of hydraulic and hydrologic processes and concepts. Examples of mistakes include inappropriate adjustments to increase pipe roughness factors to achieve a fit for depth. This is quite often done when flow monitor data exhibits unusually high depths for corresponding velocities (i.e. not typical of uniform flow and normal depth conditions). Initial calibrations may show the model to be reasonably accurate for flow, but too high for velocity and too low for depth. The modeller may simply try to correct this by adjusting the pipe roughness factor up until the depths and velocities match better. In reality, this may be the correct calibration adjustment to make – however it could also be a case where there is an obstruction in the pipe downstream of the flow meter creating a backwater effect. Whilst the modeller may achieve a reasonable calibration by adjusting the roughness factor, they may completely miss the fact that there is a blockage in the sewer which could be responsible for upstream problems and easily be removed. There are other cases where models were thought to be well calibrated, only to find in later inspections that key modelled trunk sewers had significant sediment build up which was not accounted for in the model at all.

- Not being focused in terms of achieving calibration and verification accuracy which reflects the needs of the project. For example, if you are supporting the design of a storage tank which needs to reduce overflows to a targeted spill frequency it is vital to ensure the model does a good job of predicting overflow volumes. Probably the first question to ask is "have the overflows been monitored and has the model been calibrated to those overflow monitors"? Alternatively if you are supporting the design of a relief sewer there should be a particular focus on getting peak flows correct, with a realisation that with the relief sewer in place the resulting peak flows may be quite a bit higher – which could result in problems further downstream.

- Not using readily available field observation data/information to provide further model confidence and to enhance model verifications. Typically there are several sources of readily available information and data which can be used to enhance the confidence of model predictions. These sources include customer complaints, field inspections, maintenance reports and operator knowledge. Observation records may show clusters or problems and/or repeated problems in certain areas of the sewer system, and model predictions should be checked to see if they confirm a problem with the sewer system in that area. If model predictions and field observations do not agree, this should be resolved though subsequent investigation and analysis.

## 2.8 OPTIONS FEASIBILITY ASSESSMENTS

Options assessments really gets to the heart of the value of modelling to support wastewater collection system projects. A reasonably accurate and fit for purpose model provides a powerful platform to assess multiple options efficiently, and to determine the model cost effective way to address the targeted problems. Models can also provide a much higher degree of confidence that solutions will work under the full range of potential conditions, including future growth and development.

A common mistake in options assessment using wastewater models is a disconnection between what can be simulated in a model and real world feasibility. All too often a considerable amount of time is spent simulating options which are not practically feasible due to issues such as consenting or constructability. This is quite often the case with high level optimisation analysis using highly advanced models where the simulations are allowed to permutate into solutions which cannot practically be implemented.

It is highly recommended that engineers with significant experience in the implementation of typical options to address wastewater collection system issues work closely with modellers during the options assessment stage. This will help to ensure that options which are analysed are considered to be practically feasible and implementable, and that modelling efforts are focused and efficient. As the options analysis progresses it is also important to involve experienced operators so that their knowledge can be leveraged into the more detailed model analysis of preferred options.

## 2.9 QUALITY OF EXISTING DATA SETS

It is not uncommon, as a cost saving measure, for clients to rely heavily on the quality of existing data when starting a wastewater modelling project. This typically includes historic physical attribute and monitoring data, and in some cases includes previously developed models. Quite often the onus of assuming that existing data is of sufficient quality is placed on the consultant. More often than not the quality of existing information is overrated and can significantly impact the effort required to develop a model of sufficient accuracy. History shows that it is not too far off to assume at least a 50% error rate with existing attribute data based on extensive reviews of GIS systems and other typical sources of model input data. These are errors in actual data which has been input, and does not include missing data. Similarly historic models and flow monitoring data can be found to be quite error ridden and of poor quality. Unfortunately the burden of this is commonly placed on the selected consultant and not necessarily reflected in adjusted scope or budgets.

An example of this was in the North Island a few years back, where the client (through a consultant) had collected the data sets for the job ahead of the modelling aspects of the project. There was no level attribute data for over 40% of the pipe network – and this wasn't helped (this was before LIDAR) by a lack of ground level data. As for the flow survey, there were monitors in a 12 month survey that only recorded 'poor' quality data for the entire 12 months, and many of the other monitoring sites were poorly located and influenced by the hydraulic characteristics of the network. This was primarily due to cost cutting – no regular inspections (by any one) of the survey sites once the survey was started.

The end result of not recognising the true state of data quality up front typically leads to either a poor quality model or a good quality model from a consultant who is willing to incur a significant project loss. Unfortunately this mistake is far too common as evidenced by the general industry perception that "modelling projects are loss making jobs". Whilst clients may think this is a great way to obtain services as a discounted rate, what ultimately happens is that:

- Poor quality models will be developed – potentially leading to solutions which don't work, solutions which are not cost effective, or models which have to be completely redone

- Loss of good quality engineers who are talented at modelling and capable of delivering the full benefits of leveraging models as an effective options development tool. It is a foregone conclusion that loss making projects are not commercially sustainable, so either consultant have to cut corners or will ultimately choose to not pursue those types of projects.

It is vital that every effort is made up front to identify the true state of existing data quality, and that the results of this are reflected in the scope and budget. If clients are not prepared to make this evaluation, they should consider engaging a qualified consultant to conduct an upfront data gap analysis and use the results of this to develop the modelling brief and budget. Consultants who pursue modelling project where the existing data quality is not defined or understood would be wise to include strong clarifications and assumptions in their proposals to protect against budget overruns, or being put at risk to deliver a low quality model that does not meet the needs of the project.

## 2.10 EFFECTIVE WORKING RELATIONSHIPS

Underestimating the power of an effective working relationship is definitely one of the top ten mistakes. Effective relationships are probably the single greatest thing that people have for the successful delivery of any project. Good business relationships are built on trust, and that trust goes both ways.

Disclosure is a key aspect of building a trusting relationship. Owning up to and fixing mistakes is key to this. Whether it is the client recognising their datasets are of poor quality or the consultant knowing key staff are away on leave during a critical time, by discussing it openly, their affect on project outcomes can generally be mitigated, and at the very least managed. The more time you have to consider your options when these 'surprises' turn up, the better.

Basic human nature dictates that it is not easy to work with people that you don't respect or trust. The best projects are when like minds connect and challenge each other. The people have got to connect; it is through this connection that trust can be built. With trust comes the confidence to challenge, and challenge leads to innovative thinking. Wastewater collection system models are a powerful tool to support assessments of innovative thinking, as we can test these ideas without actually pouring any concrete. Some of the most successful modelling projects are ones which resulted in a no-build or reduced-build solution, and this almost always comes as a result of strong culture of challenge and innovation. To achieve this the client must be engaged with the consultant. Whilst the client does not need to be an expert in modelling, the client does need a strong degree of basic technical understanding providing a basis for challenging the consultant throughout the project stages. Equally the client must encourage the consultant to challenge as well, as a very common mistake is to only hire consultants who tell you only what they think you want to hear, not what you need to hear. This requires effective working relationships!

When you have a good relationship communications become less formal and consequently easier to maintain. This facilitates more and open communication, resulting in project issues being resolved faster and with less disruption to the project overall. The teams are pulling in the same direction as they are more likely to be on the same wave length. Through this improved communication, the classic 'them and us' mentality will be less likely to occur. Improved relationships also provide the opportunity for overall better outcomes as the consultant is more open to disclose their value add ideas, as opposed to just grinding out the project.

# 3 CONCLUSIONS

This paper has set about documenting some real world experiences on the mistakes made in modelling projects. It has been developed from the experience of both the clients and the consultants' points of view. It is from this joint experience that the above top ten mistakes were selected in an attempt to provide lessons learnt – hopefully improving the quality and results of future wastewater collection system modelling projects. As stated in the introduction, whilst the focus on this paper is a discussion of common mistakes, effective application of wastewater models can provide tremendous benefits including:

- Surety that solutions will achieve targeted objectives
- A holistic understanding of complex system performance, operations and the link between targeted problems and causes (which is not always obvious)
- Significant capital and operational savings
- A highly effective tool for planning for the future – ensuring sufficient capacity for future generations

For your next modelling project, having the following summary points in the forefront of you mind should help you avoid the key modelling mistakes.

- Planning is where the most savings can be made in terms of delivering an engineering solution, so ensure the planning budget is appropriate.
- Put time aside at the start of the project to set, scope and confirm project objectives, to ensure the budget (and expectations of all parties) are realistic
- Work to ensure the quality of model inputs (data quality and coverage, field visits, modeller experience, reviewer availability etc).
- Remember – with flow surveys, you get what you pay for.
- Understand that the modelling process is more like art than science, but resist doing what's interesting over what's important and focus on what's "fit for purpose"
- Work to ensure the quality of model outputs (reality checks, operational experience), and
- Work on relationships as trust and open communications are critical to the success of any project.

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