PAPER 15

NO SMART WITHOUT START – INNOVATIONS IN HYDRAULIC MODELLING

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ABSTRACT

In Southern Africa, municipalities often face a very challenging environment comprising constrained operational expenditure (OPEX) and capital expenditure (CAPEX) funding, poor infrastructure information, skills shortages, lack of information and communications technology and software to name a few. Add to these a complex socio-political environment and supply chain blockages, sometimes linked to corruption, the prospect of becoming a SMART municipality fade to an impossible dream or at best, a long-term aspiration. Unfortunately, this kind of thinking effectively eliminates opportunities to develop the digital assets required to better understand physical assets, operations, and even the potential to effectively leverage SMART technologies such as digital twins, internet of things (IoT), artificial intelligence (AI) and cloud processing. Rather than being complacent, these municipalities should try to establish some form of hydraulic model as a first step towards supporting operational understanding towards a preliminary digital twin, and then develop longer-term aspirations such as master planning to ultimately become a SMART municipality.

At many smaller municipalities it is often found that the information required to support the establishment of hydraulic models are wholly inadequate, rendering the effort close to impossible. Critically, many of these challenges require significant and laborious interventions and to compound this, these municipalities more often do not have access to the necessary OPEX budgets to support these inventions. However, through deliberate collaboration, adaptation, and innovation, new and exciting (often disruptive) approaches were developed for municipalities to solve these challenges. These included the development of cost-effective methodologies comprising consumer demand analysis and profiling, data cleansing and network cleaning which are all supported by the development of intelligent software algorithms. The combination of these tools and the necessary engineering skills and creativity enabled municipalities to ingest, analyse, clean, and build hydraulic models at unprecedented rates without compromising quality. This approach has successfully provided many Southern African municipalities, including the Drakenstein Local Municipality, with the capability to build and maintain their hydraulic models. Drakenstein's efforts showcase the value this approach provides and how access to hydraulic modelling capabilities can unlock significant downstream value and set a municipality on course to being truly SMART.

It is proposed that any municipality starting its journey to becoming SMART should consider the establishment of hydraulic models as a top priority.

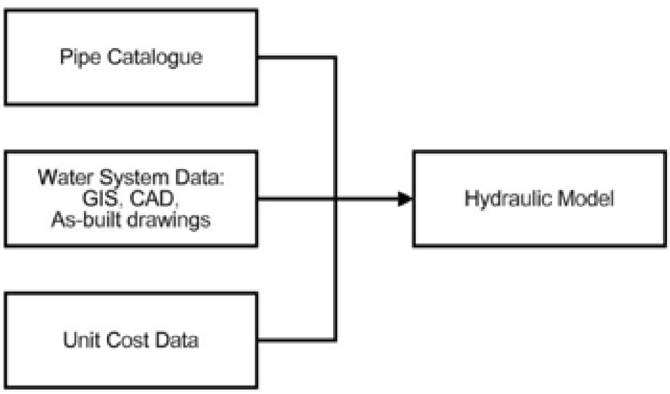

FIGURE 1: *Establishment of a hydraulic model*

INTRODUCTION

South Africa is a rapidly urbanising country facing complex water management challenges, including significant resource shortages, environmental issues, and fragmented institutional structures. Water security is of particular concern (Carden et al 2012). However, with the rise of the Fourth Industrial Revolution, engineers are turning their attention to smart cities: areas that harness the internet of things (IoT), making use of electronic sensors to collect data that can be used to manage assets, resources, and services efficiently (Sinske 2020).

The journey to embrace technology and become a SMART water service provider is less daunting when it is viewed as an incremental process, with each step adding value by offering efficient access to data which leads to more knowledge and better decision making. The foundation that this process is built upon is a well-established, geospatially accurate hydraulic model that reflects the real-world assets and operation as feasible as possible in order to leverage the advantages that advanced technology has to offer to adapt to our changing world. The establishment, and continuous updating, of a hydraulic model is therefore of utmost importance.

This paper explores the methodologies that can be applied to overcome the first hurdles to becoming SMART by discussing the establishment of a hydraulic model, connecting the model to end-user demands, planning for future requirements and add-on value that can be generated.

ESTABLISHMENT OF HYDRAULIC MODELS

All existing sources of information pertaining to the water distribution system need to be collected and assimilated. These sources can vary from GIS databases, as-built drawings – both physical paper drawings and computer aided design (CAD) files – and operational staff knowledge. Additional asset and costing information is also applied to the model entities as shown in Figure 1.

Building the model

Entities are imported and captured in a geographic information system (GIS) environment and network topology connectivity rules are enforced that connects the entities. Leveraging GIS capabilities, e.g., spatial correlation, allows for data transfer from various sources of information to occur at a rapid rate. If up to date aerial imagery is not available, then

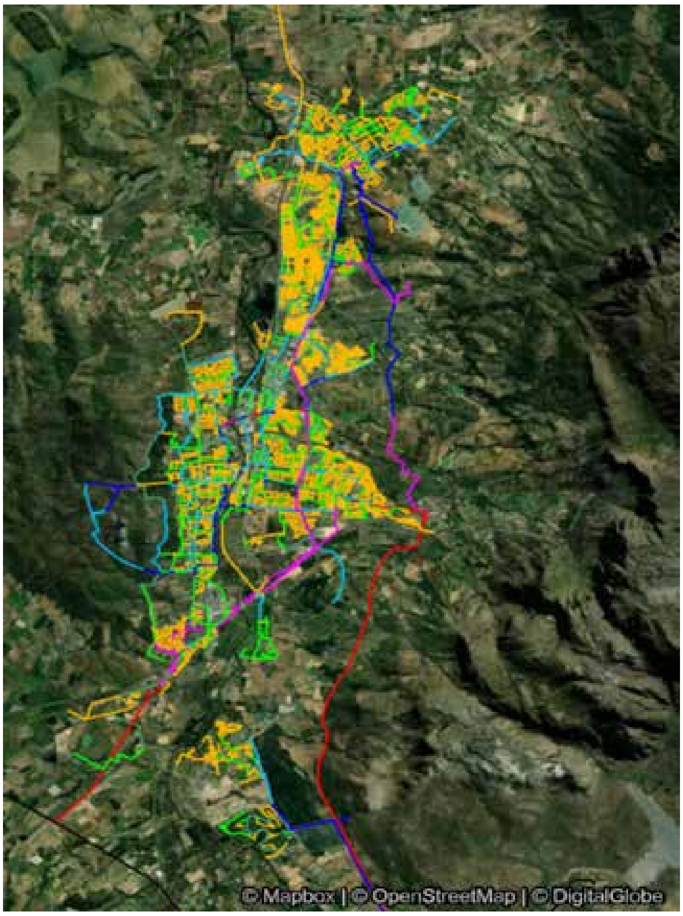

FIGURE 2(A): *Overview GIS representation of different pipe diameters from the Drakenstein hydraulic model*

FIGURE 2(B): *Detailed view GIS representation of different pipe diameters from the Drakenstein hydraulic model*

the use of online maps from either publicly accessible sources or utility licensed sources can be used for verification of asset location or routes.

Physical components which are not required for the operation of a basic hydraulic model, e.g., a hydrant, air valve or shutoff valve, should still be imported or captured if data is available to expand the asset register and may be required if more advanced analyses are considered in future.

Asset Information

A pipe asset catalogue is used to fill relevant characteristics based on the material and pipe size which reduces manual data entry requirements and ensures consistency. The catalogue can be used while capturing individual pipes, or to update a selection of pipes as a post-process.

Age information is captured by providing the construction or refurbishment year and in combination with the material provides knowledge on the expected useful life (EUL) and the remaining useful life (RUL) of the asset.

The construction or replacement value of the assets can also be quantified based on physical attributes and location. The location of buried infrastructure plays a vital role in replacement or refurbishment costs when excavation and backfilling is considered. Intangibles like traffic control are also affected, especially when the asset is buried under a major roadway or residential street, and different costing will apply to assets located in a servitude or open space.

Verification

Various technologies exist to verify the integrity of the established model. This includes traversal functions to confirm zone isolation and connection of nodes to sources of water, such as reservoirs. During initial assessments and conceptional planning of future models, the location of reservoirs and their associated viable reservoir zones remain critical to assess initial static pressure requirements at consumers.

Finally, the hydraulic solver will report issues in the actual network connectivity, e.g., zones that are without a source of water, but have demand, or connections of links and nodes in a way that is illegal for the solver, e.g., connecting a pressure reducing valve directly to a reservoir.

The verification of distribution zones should be a high priority if any pressure management activities will be considered because as stated by McKenzie (2014): "the most important issue when trying to introduce any form of pressure management is ensuring that the zone being considered is and remains discrete".

Challenges

The quality of data remains the single biggest challenge. Often as-built plans are simply missing, and parts of the network will have to be estimated initially to ensure the hydraulic results do make sense. The concept of dummy pipes, or provisional pipes can be useful, clearly identified for follow up on-site inspection at a later stage when the budget allows for it.

Calibration of pipe roughness, important for the hydraulic model to accurately calculate flow and velocities in links and pressure head at nodes, remains a challenge when the internal size of pipes and even their existence is uncertain. Again, an iterative approach is recommended, where the data integrity is clearly marked as estimated or provisional, and that later refinement is planned.

A general 80/20 pareto principle should prevail, where 20% of the model establishment effort results in 80% of the model completeness. The challenges are to first focus on the actions that produce the biggest impact.

Figures 2(a) and 2(b) show the GIS representation of different pipe diameters from the Drakenstein hydraulic model at two different zoom levels on satellite imagery.

ESTABLISHMENT OF AN END-USER DEMAND DATABASE

After a representative model has been established it is required to determine the demand or so-called output at system nodes to perform a hydraulic analysis. Cadastral information outlining the stand/property/erf layout is of vital importance and in the absence of reliable (or any) metering

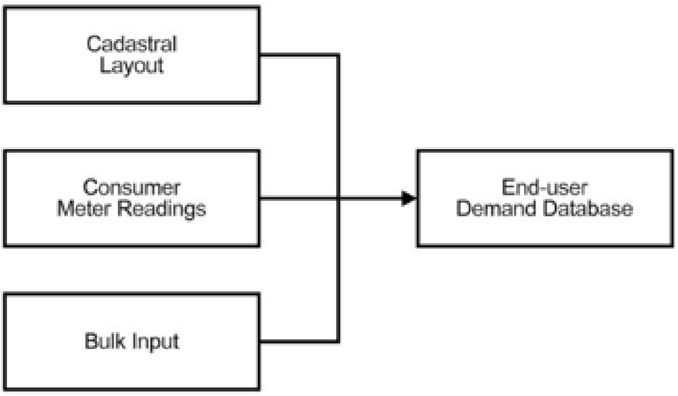

FIGURE 3: *Establishment of an end-user demand database*

data can be used to assign theoretical demands which are then correlated to the model nodes. Further information on land use or zoning is beneficial and allows for a more relevant assignment of theoretical demands based on design guidelines and past experience with hydraulic analyses in areas of similar composition.

If consumer metering data is available, the readings are extracted and the average annual daily demand (AADD) or another seasonal average calculated for the meter in question. Meter readings require inspection to determine if any clock-over events or meter replacements occurred in the extraction period, and if so, the demand calculation needs to be adjusted to reflect actual usage. Similarly, algorithms can be implemented to determine if the reading values are actual readings or more likely to be estimated values. Furthermore, if the consumer meters have associated spatial information they can be assigned to the relevant cadastral entity. In some cases, the consumer address is available and can be used to locate the cadastral entity. Consumer demands are the best reflection of the real-world operational requirements of the system and is the preferred next step in the journey to becoming SMART. In an ideal SMART world, these demands are available for all consumers at a high frequency, e.g., every 15 minutes.

If bulk input information is available, then the system-wide non-revenue water (NRW) can be calculated. Various resources are available from the International Water Association (Allegre et al. 2000) to assist with the calculation of NRW, such as the Infrastructure Leakage Index (ILA).

Figure 3 shows that the cadastral layout, consumer meter readings and bulk input data are integrated into an end-user demand database. This data can then be used to confidently allocate spatially accurate demand data to the water model.

Usage summary reports per suburb can then be generated indicating the demand per land use per suburb. Theoretical demands per land use can then be determined per suburb, or a global average can be used in cases where the number of active users for the land use in question is deemed too low in an area to be representative. Vacant stands, or stands without water demand, can be identified and a theoretical demand based on the land use can be assigned to these stands to determine future demand requirements. Figure 4 shows a GIS representation of the AADD per stand from a subset of the Drakenstein end-user demand database.

Challenges

When extracting consumer meter reading from utility billing data from the municipality, care must be taken to conform to the new South African Protection of Personal Information Act (POPIA). Most often billing data does contain some personal identifiable information. Typically, the municipality would be the Data Controller and the consultant the Data Processor. A Data Privacy Agreement must be concluded between the parties and is often included in the Service Level Agreement. The municipality typically facilitates the provision of a data extract from the treasury system and the consultant would add value by processing the data and later returning the data to the municipality in some processed form. The municipality ultimately remains responsible for obtaining necessary consent and or ensure that they have the lawful basis for processing any personal data from the Data Subjects, their own end customers. However, all Data Processors have an equal important role to comply with POPIA.

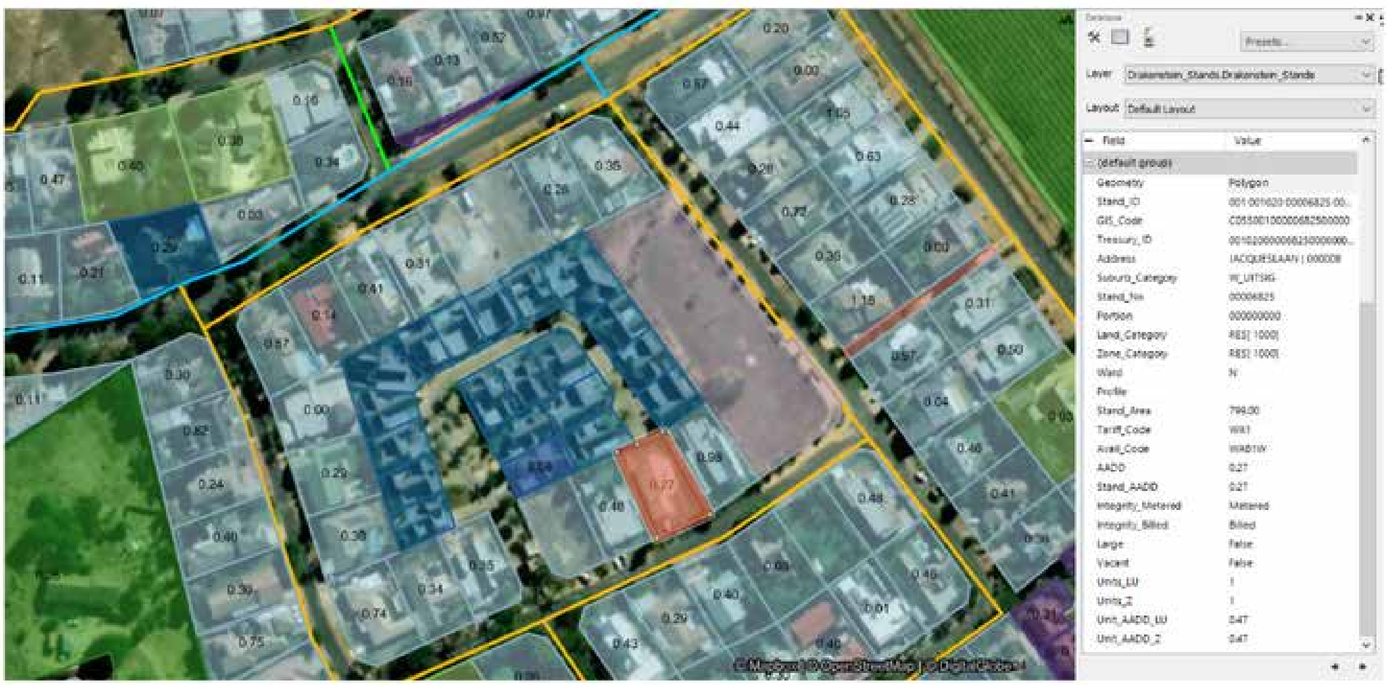

FIGURE 4: *GIS representation of the AADD per stand from the Drakenstein end-user demand database.*

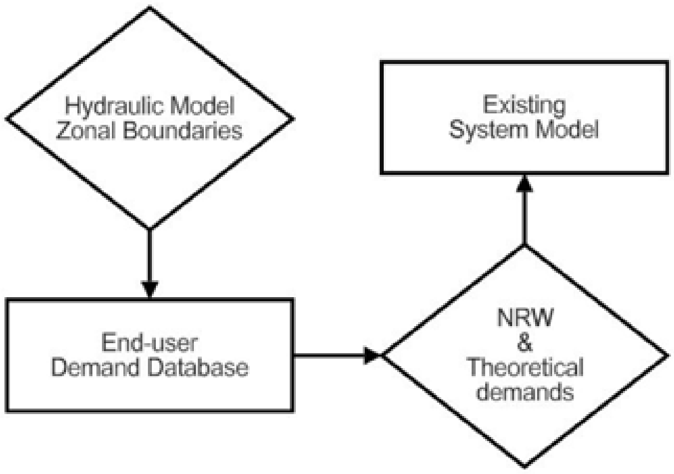

FIGURE 5: *Extension of end-user demand database and allocation of demands*

ALLOCATING SPATIAL DEMANDS

To aid in creating more accurate digital representations of the physical system, water demands, either theoretical (based on design guidelines or expected use) or from consumer meter readings, can be incorporated into a model. This is achieved by extracting demands per stand and combining them with the spatial data from a cadastral. The spatial demand data, in conjunction with the spatially accurate model, allows for the allocation of consumer demands to appropriate nodes. This spatial linking of water usage allows demands to be more precisely applied over a model and results in a more accurate model.

With a detailed system, zonal boundaries can be defined and demands established per zone. These digital zones can be compared to physical zones where water usage can be tracked using bulk water meters. The combination of physical and digital demands can be compared to allow for detailed breakdowns of NRW and aid in the identification of areas with high loss. This also helps in finding cross boundary connections and highlight where valves may need to be closed or opened to ensure the physical system operates as required. If all avenues of high NRW are accounted for and water usage remains high in comparison to water sold, then it could aid in identification of areas of high leakage or zones of large "free water" supply to indigents. Furthermore, it can inform of requirements for pressure reduction efforts. This process is illustrated in Figure 5.

The greater the correlation between physical assets and the digital model the easier and more efficiently areas of concern can be found and prioritised for action.

MASTER PLANNING

With a well-established existing system representation, the hydraulic model can be expanded and modified to perform planning for future requirements. This expansion could be as simple as capacity investigations and upgrade requirements for individual development applications. More importantly it can be used to create long term master plans, often looking twenty to thirty years into the future. These plans can leverage inputs such as the spatial development framework (SDF) and integrated development plan (IDP) to determine short-, medium- and long-term developments. Hence, upgrades and extensions can be designed to ensure that a level of service is maintained which always adhere to proper design guidelines.

The information obtained from the SDF and IDP are used to compile GIS shape files of the future development areas, linked to a database of expected land use, development density and expected unit water demands. From this information the number of units which will be developed, and their combined water demand can be determined. Schematic future distribution network sections can then be added to the model and the future demand allocated. Apart from water demand from future developments, the existing vacant stands throughout the area that already have access to the water distribution network may also be developed and the expected demands from these stands need to be incorporated into the future model.

Master planning of an area needs to be updated on a regular basis to ensure that future developments will not exceed the current capacity of the systems that are in place or the planned future capacity that needs to be designed for (Fair et al. 2008). As such the ultimate future model represents the system required for the ultimate future flow scenario, with all future areas fully developed and with every existing stand occupied and sub-divided or re-zoned where applicable. This model consists of the existing system model that is merged with the pipes required for the future development areas, and then reinforced/augmented where required so that the design criteria are met. Individual upgrades are identified, and an associated cost is calculated for each item. The expected or proposed implementation year can also be assigned to the item. Projects are created which may contain several items and can span over several years, e.g., a re-zoning project after a new reservoir has been completed. Cost summaries for capital expenditure are produced per item and per project and together with the proposed phasing can be used to compile budgetary requirements. Inversely, in cases where access to funding is constrained, the available funds for each financial year can be used to identify and impose phasing on the most critical items.

ADDED VALUE

With established existing models and future models considering master plans that fulfil future requirements, further value can be extracted. We are now getting much closer to the digital twin.

Detailed model summary reports can be generated, not just for the system as it is currently but also for various dates in the future.

Plan books can be generated that not only shows the detail of the existing system for operational and field staff, but also outlines the location and projected phasing for when upgrades and extensions will be required.

What-if scenarios can be run using methods such as sensitivity analyses. This allows various combinations of growth or demands patterns to be investigated to ensure the system will be able to cater for changes. This might include consequences of potential rezoning or the densification of an existing zone.

The digital water model network topology that emulates the physical system and known valve locations allows for the determination of valve closure programmes in the event of a pipe bursts or other maintenance activities to isolate sections of the system. Furthermore, if the model has been linked to an end-user consumer database, the affected stands may be reported and by embracing innovative technology, an automated notification system can send mobile notifications to the affected users when unplanned maintenance activities will occur.

A Pipe Replacement Prioritisation (PRP) study can be performed to identify the pipes with the highest comparative risk or greatest criticality grade, clearing the way to transition to the implementation of a proactive intervention approach and address possible problematic issues in the system before failure occurs. This aids CAPEX budgeting requirements and planning of large sections for the financial year and beyond.

Combining the results of the PRP study with master plan upgrades allow upgrades and replacements to be planned and implemented at the same time, reducing overhead costs and other operational expenses that come with fixing small sections at a time due to failures, and allowing for greater levels of service to the consumers.

Fire risk compliance analyses can also be performed to ensure that the entire system is compliant with regulations, or to which extent there is a shortfall. A level of compliance in terms of firefighting "readiness" can be attributed to every stand in terms of network capability to deliver the required flow and additional requirements like adequate hydrant availability.

Redundancy studies can be performed. This allows any single points of failure to be identified that can be rectified to ensure no single failure results in a failure to supply water to a zone.

All data can be exported and spatially viewed on online platforms that allow a quick and easy overview of the system whenever and wherever needed. Of particular interest is also viewing the integrity information of collected data to plan data collection improvements projects.

CONCLUSIONS

This paper explored the methodologies that can be applied to overcome the first hurdles to becoming SMART. This included the establishment of a hydraulic model, connecting the model to end-user demands, planning for future requirements and exploring add-on value that can be generated.

Various challenges were overcome, especially the poor quality of data, the legal extraction of end-user demand data and the best spatial allocation of demands to the hydraulic model. Additional steps included the master planning and further unlocking of added value of the preliminary digital twin in the form of advanced analyses.

Visibility of all collected data with their integrity information at any point in a centralised online spatial platform was key to present the large volumes of data effectively to the municipality. This technology exists today and has been implemented at Drakenstein Municipality and many other clients.

RECOMMENDATIONS

Current and future developments include the completion of the digital twin, to link IoT meter sensors managed by our technology partners. Near-live data will then flow into the extended period time simulation of Wadiso (GLS 2022) to augment simulated data. Soon powerful what-if questions can be answered, for example, will any reservoirs run dry during the peak summer period, given the current initial conditions, and typical historic consumption data?

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