Community-Level Resource Development and Management, Part 1: A Transferable Approach to the Analysis of Community Water Distribution System Expansion

Megan M. Richardson
School of Mechanical, Industrial and Manufacturing Engineering,
Humanitarian Engineering Program,
Oregon State University, Corvallis, OR, USA

Kendra V. Sharp* PhD
School of Mechanical, Industrial and Manufacturing Engineering,
Humanitarian Engineering Program,
Oregon State University, Corvallis, OR, USA
kendra.sharp@oregonstate.edu
* indicates corresponding author

Abstract: *Access to water is extremely important in schools around the world, where students spend most of their day. As schools expand, particularly in areas with limited water resources, it is necessary to develop and manage water resources to ensure their sustainability. In this article, we describe a method of analyzing water piping distribution networks using an open-source software package that allows practitioners to model the increased demands on water distribution systems associated with school growth. The methodology was then applied to the case study of a community-level water distribution system in rural Tanzania. Our intent is to provide a condensed description of a modeling method that can be used by field practitioners who may have limited technical background. Minimal tools are needed for practitioners to create their own system model, namely a global positioning system (GPS) device, tape measure, bucket, stopwatch and access to a computer with the downloaded software. Overall, the method and description herein is intended to be more accessible and straightforward to follow than others currently available to many practitioners, thus improving the ease of modeling for pre-planning and analysis of expansion or other water distribution system modifications.*

Keywords: Catchment system, Pipe network, Water, Water distribution, Tanzania

1 INTRODUCTION

Education is essential to social, economic and political development through access to opportunities and freedoms. Globally, education initiatives have promoted higher enrolment and learning for all, and such initiatives have been integrated into national policies. Across the 54 African countries, 44 have abolished school fees at the primary level (UNESCO, 2016) and six have already implemented free education at the secondary level (Masuda and Yamauchi, 2018). By eliminating part of the financial barrier to education, many countries have seen significant increases in enrolment. However, unless infrastructure and resources are also concurrently developed, schools can become overpopulated and under-resourced. Water security is one of many critical factors for keeping children in school because water is so essential for health, sanitation, food preparation and daily routines. Therefore, it is imperative to evaluate how school water supplies are meeting (or failing to meet) current system demands, how systems will need to be expanded to accommodate continued growth, and how management can ensure that systems are maintained reliably in schools. In this article, we use a freely-available open-source software package (EPANET) to evaluate the ability of an existing water catchment system to meet the water supply needs for a potential school expansion and the associated growth in student population. The program allows the user to consider fluctuating demand at taps in a water system throughout the day, calculate maximum output at each tap based on system architecture and known source, evaluate how demand changes with increased student enrolment, and determine the feasibility of potential design strategies for integrating supplemental water capacity into school infrastructure.

We describe a transferable method that has general application to the analysis of potential expansions of community-scale water systems. As a case study and detailed example, we apply the method to the analysis of the water catchment and potential expansion of the delivery system at Matema Beach High School (MBHS), a government secondary and advanced-level school in southwestern Tanzania. Of the school's 1,000 students, boarding students (males aged 18–25) in the advanced-level program live on campus full-time, while day students (males and females aged 13–18) in the ordinary-level program spend the majority of their weekdays on campus, from 6:30 a.m. to 5:00 p.m. The school is preparing for increased enrolment at the advanced-level with the addition of science programming.

We project estimates of the increase in the school's water demand with increased student enrolment. We then use EPANET to model and analyze the existing water catchment, piping infrastructure, and impact of increased enrolment on resource availability. We create a model of an expanded system based on the additional infrastructure and piping network that would be built to accommodate additional students. Lastly, we include local water storage options in our model to evaluate possible options for integrating additional storage capacity (e.g. tanks) into the infrastructure on campus to serve more students. As in many other rural water systems, there are some uncertainties in the details of the infrastructure (e.g. pipe configuration, underground fittings and pipe bends) and even the overall supply. Thus, we have made the best assumptions we can and have been conservative in our estimates of quantities that would limit flows (for example, we overestimated expected pipe lengths and losses in new latrines).

The authors selected EPANET due to Richardson's experience with the software and the setting of the case study. Working in a rural village, Richardson, like many volunteers, had limited access to educational and methodological resources including system analysis tools related to water development projects (Peace Corps, 2018). The information gap she experienced motivated our work to document a straightforward modeling strategy and applied case study so that others could replicate the approach when working in similar settings to analyze their own water systems, particularly to assess the capacity for expansion. Thus, we have distilled disparate manuals, examples, and other resources down to a concise description of methodology with case study application intended to be easily accessible to development workers or volunteers working in the field, including those both with and without significant technical backgrounds. We further selected an open-access publication outlet with the intent that our work can be beneficial to those outside of academia or those working rurally who have limited or no access to databases, libraries, and library subscriptions to publications. Resource development in schools is particularly relevant as it often aligns with both national and international initiatives. For example, Tanzania's National Strategic Plan in schools relates the development of safe water provisions to better support of student performance, attendance and health (Ministry of Education and Vocational Training, 2012), and the UN's Sustainable Development Goals include ensuring availability and sustainable management of water and sanitation for all (Zhu, 2015).

2 FIELD RESEARCH METHODS

Matema Beach High School receives its water supply from a catchment built in the mid-2000s. While "catchment" is often defined differently in water resources science, our use of the term in this article is in accordance with local Tanzanian terminology. In this terminology, catchment describes the constructed pool of water retained by a hollow trapezoidal wall that creates a version of a settling tank. Water flows into the piping system through the top grate of the trapezoidal wall and through piping down to the community. The water collected in this catchment comes from a river flowing down the Livingstone Mountains. To evaluate the capacity of the catchment and water piping system connected to the school, Richardson used a Garmin GPSMAP 64ST (Garmin Ltd., 2016) to collect location and elevation data between the catchment and school. The GPS unit was also used to measure the distances between each of the taps on campus and the junction where the piping entered the campus from the catchment.

Table 1: Distance and elevation change between the water catchment and the campus.

Elevation Head (m)	Total Pipe Length (m)
82	1025

To determine the catchment's functionality throughout both the rainy and dry seasons, the site was observed monthly. During all visits, the catchment was filled to capacity and overflow was observed across the retaining structure, suggesting that there is consistent excess water supply under the current conditions. (As with other assumptions in our analysis, this assumption should be iteratively re-evaluated as the school's water supply system is incrementally expanded). Three pipes are connected to the base of the hollow trapezoidal wall as intakes that serve solely to supply the school with water. The largest of the three intake pipes is made of steel and was measured to have a 9-cm inner diameter (3.5-in ID).

Figure 1: Catchment structure with water overflow during the end of the rainy season. (Dog and person included for scale).

Throughout the school day (from 6:30 am to 5:00 pm), Richardson observed water use from the taps across campus, and also asked boarding students when they collected water from the taps. It was noted that the highest number of students were using the taps between 6:30 – 7:30 am, when performing chores prior to their first class. The chores included mopping floors and cleaning bathrooms. Advanced-level students also reported washing each morning. At the time of the field study, up to 48 taps could be operated simultaneously (located in the bathrooms, showers, and at outdoor all-purpose taps).

To determine the current flow rate from each tap, the amount of time required to fill a 20-Liter bucket was measured and recorded at three different taps on campus. When the taps were opened completely, which is how they are used by students, the average time to completely fill the bucket was 155 seconds. The flow rate from each tap $\left(Q_{tap}\right)$ is easily solved using Eq. 1; we take this as an acceptable flow rate for water system users.

$$Q_{tap} = \frac{20[L]}{155\,[s]} = 0.13\,\left[\frac{L}{s}\right] = 0.00013\,\left[\frac{m^3}{s}\right] \qquad (1)$$

3 DEFINING THE SYSTEM

Matema Beach High School is served by a piping network that distributes water to taps across campus for general use, bathrooms, cooking and gardening. In our network model, we divided the 48 taps operating at peak demand into seven clusters across campus, which are all assumed to be connected to the primary junction of the piping from the catchment. The details of the various possible branching topologies are unknown, thus some simplifying assumptions must be made. (We recommend re-running and re-evaluating the model output after, say, addition of an additional tap grouping and before adding other tap groupings to evaluate the accuracy of the model and modify assumptions if needed). All of these clusters are located on a campus map in Figure 2. The incoming flow from the main pipe is split between the clusters, so this incoming flowrate (Q_{in}) is equal to the sum of flowrates outgoing to the seven clusters.

$$Q_{in} = \sum_{n=1}^{7} Q_n \qquad (2)$$

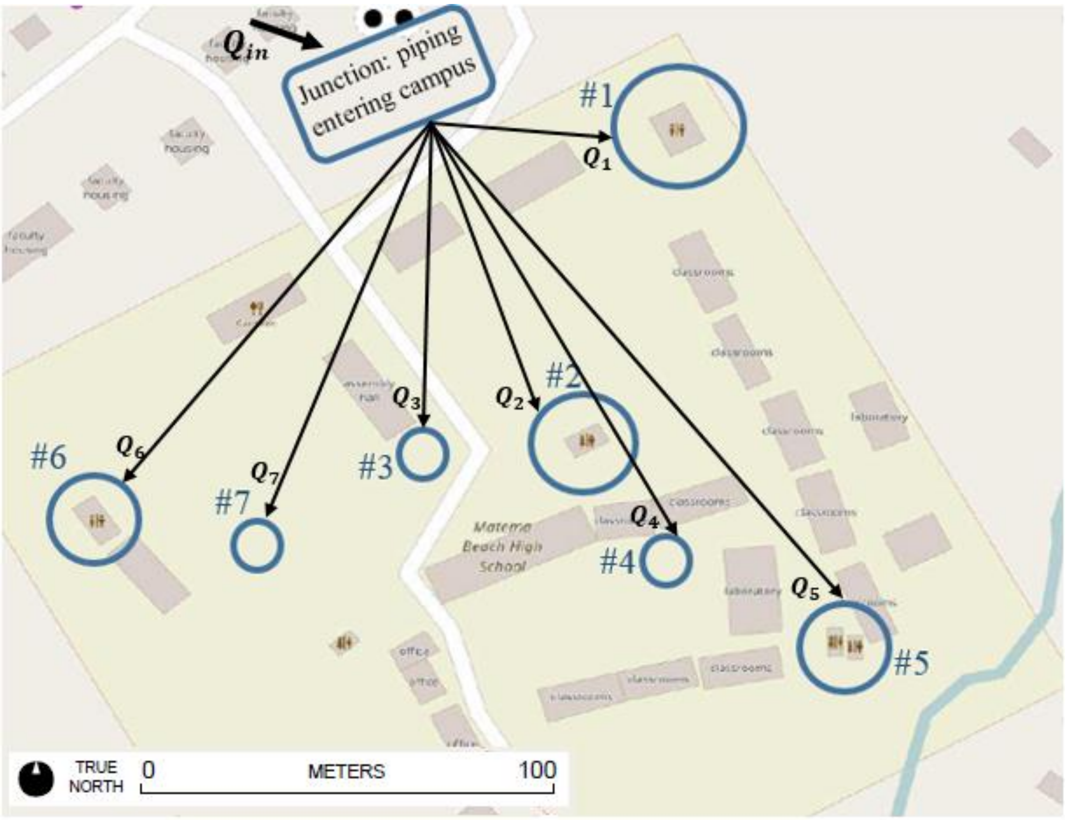


Figure 2: Locations and distanced between the seven clusters of taps (Q_{in}=flowrate into the whole school system. Q_1-Q_7 represent the flowrates at clusters 1-7 respectively).

The measured distances between each of the tap clusters and the primary junction are listed in Table 2, along with the number of taps assigned to each cluster. An additional 10 meters of piping is added in the model for each bathroom building to account for plumbing connections; this is a conservative estimate accounting for additional minor losses caused by additional bends and fittings. (We use the term “minor losses” in the fluid mechanics sense to indicate pressure losses due to components such as bends and tees, in contrast to “major losses” attributed to friction at the pipe walls.) We limited our analysis to water supply; the water is not currently treated and treatment is outside the community-motivated scope of the work.

Table 2: Tap cluster details: locations, number of taps/cluster, and distances to a central junction.

Cluster #	Location	# of Taps	Distance to Primary Junction [m]
1	north bathrooms and communal tap	17	70
2	central bathrooms	6	150
3	communal tap by main hall	1	160
4	communal tap by classrooms	1	200
5	east bathrooms	6	250
6	south bathrooms	16	210
7	communal tap near garden	1	160

4 SYSTEM MODELING WITH EPANET

To evaluate the extent to which network expansion is possible, we modeled both the existing and expanded tap networks using EPANET (https://www.epa.gov/water-research/epanet), an open-source software from the United States Environmental Protection Agency that can be used to model drinking water distribution systems (Murray, 2008). This program and accompanying User's Manual can be downloaded in English via the link above, or in several other languages from other sources, as noted in the references section. In EPANET, users can create a model of a network of pipes, nodes (or pipe junctions), pumps, valves, storage tanks and reservoirs, and run their model to calculate the flow of water in each pipe and the pressure at each junction based on given inputs (Rossman, 2000).

It was useful to input the typical local component properties (e.g. material, roughness, and inner diameter for pipes, type of valve, etc.) as the "default" settings for the project at the outset so these properties were automatically populated for each component added when building the system model. If a property, such as length, was different than the default for a specific component, that property was manually changed for the specific component. Because we found some of the entries/entry boxes non-intuitive, screenshots showing the properties we entered into the EPANET model can be found in the appendix (Figs. A1–A5); quantities such as roughness were estimated based on recommended values in the manual (Rossman, 2000) for standard polyvinyl chloride (PVC) pipe since that is the most commonly-used material in the MBHS area. Valve type (pressure-reducing valve, PRV) in the model was also selected based on typical components. The Hazen-William formula was selected as an appropriate head loss formula (Murray, 2008). We found it easiest to work in imperial system units because the software provides a clearer indication of specific units expected for each parameter/variable than when working with the software set to metric system units. We used gallons per minute (GPM) for our flowrate units.

The first step in building a system model in EPANET is to select a water storage element, in our case, a reservoir to represent the water catchment, and connect the storage to a junction with a pipe. The necessary inputs include total head (elevation) for the reservoir, elevation at each junction, and length, diameter, and roughness for each pipe (see appendix, Figs. A1 and A2, for our values). We note that height, elevation and length should be input in feet while diameter is input in terms of inches in this specific software. The reservoir was assigned a total head equal to the elevation difference between the catchment and the school's campus, while the elevation of the primary junction (where the pipe entered school grounds) was set to zero based on the assumption that the main junction is installed at the most easily accessible elevation, namely the campus elevation. Pipe length was estimated from the measured GPS data and inner pipe diameter was measured in the field.

Next, we were able to begin modeling the tap distribution by locating the first cluster with a junction and connecting it to the primary junction with a pipe. The pipe properties were consistent with those of the reservoir pipe, but the length was taken from Table 2. Seventeen taps are located in cluster one, which were drawn into the model as 17 junctions each with a valve connecting the tap-junction to junction-1. Junction and valve properties were set according to base demand, valve diameter, loss coefficients and valve type (ours are found in the appendix Fig. A2). Base demand is the flow rate required out of each tap. For our model the rate was set at 0.13 L/s (2 GPM), the observed flow rate from each tap in the current physical system. Tap diameter was 0.025 m (1 inch) and the loss coefficient, related to pipe and valve components, was a sum of the individual coefficients for changes in pipe diameter, pipe bends associated with the tap, and properties of the specific type of valve (Munson *et al.*, 2013). Our model incorporated two 90°-threaded bends, a sharp-edged change in diameter, and assumed that the globe valve was fully opened. Pressure-reducing valves (PRVs) were modeled as fully open, which is how they are operated at the school. If needed, the model can be modified so that demand can be estimated for non-reducing valves.

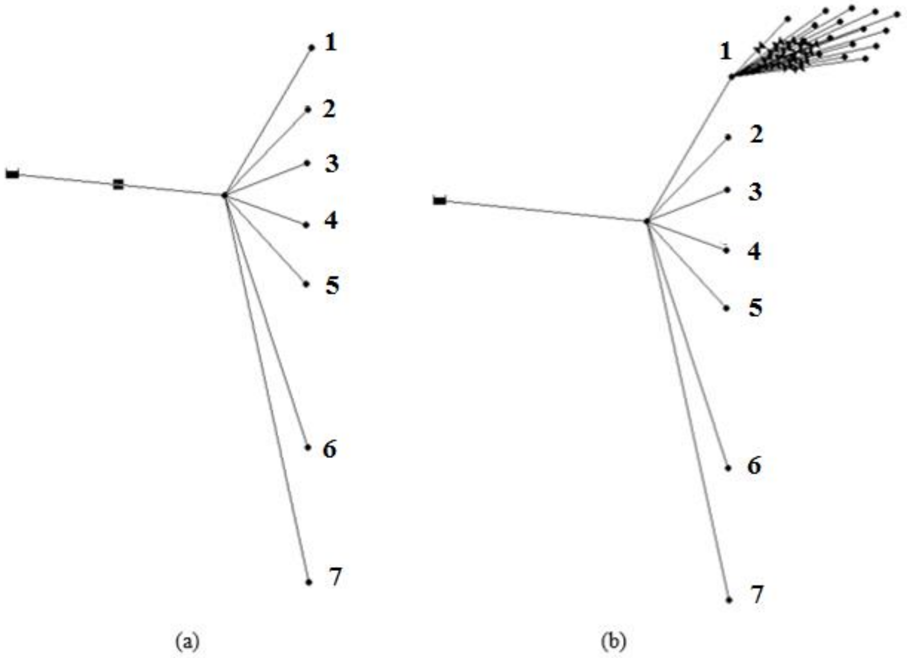


Figure 3: (a) The seven clusters are added to the model, and (b) each of the 17 junctions and valves are connected to junction-1. Note: the distances visualized between the clusters and valves in the figure are not to scale.

The process of adding junctions and valves was continued until the entire current pipe network was represented in the model with each of the seven junctions connected to its own cluster of taps. The valve diameter, loss coefficient, valve type, base demand and status were assumed constant across the network, representing peak demand and simultaneous tap use. The current-system model ran successfully showing that demand at each tap was met. (If the model does not run successfully, it indicates that the currently-configured system model, including desired flowrates, is not theoretically solvable and that there is either insufficient supply or head for the desired flowrate or that there is another problem in the system as configured).

5 RESULTS

5.1 Expanding the pipe network system

Our model showed that with the current base demand (0.13 L/s) from taps across campus, there is still substantial head available from the reservoir to expand the piping network. This capacity for expansion is important because the school is planning to expand its advanced-level program of boarding students to include a science curriculum. The increase in enrolment will require expanding the school's infrastructure, including classrooms, laboratories, dormitories and bathrooms. Each dormitory and accompanying bathroom constructed for students will increase the total number of taps and therefore the school's overall water demand.

The current on-campus student dormitories each accommodate approximately 50 male students, so we assumed 50 students per additional dormitory. Each new dormitory will require a common tap to be installed outside of the structure for general use, and eight toilet stalls and eight showers in a bathroom. In total this means that for each addition of 50 advanced-level students, 17 new taps will need to be connected to the piping network that will operate during peak demand. In EPANET, each additional dormitory was modeled with an additional tap-cluster connected to the primary junction. The properties of junctions, pipes and valves that we used can be referenced in the Appendix (Fig. A3), with the exception of pipe length, which was estimated to be the average distance to existing clusters. The school's expansion plan tentatively locates new dormitories closer to the main junction, however, we conservatively assume an average pipe length between the primary junction and new tap-cluster equal to the distance to the current dormitories.

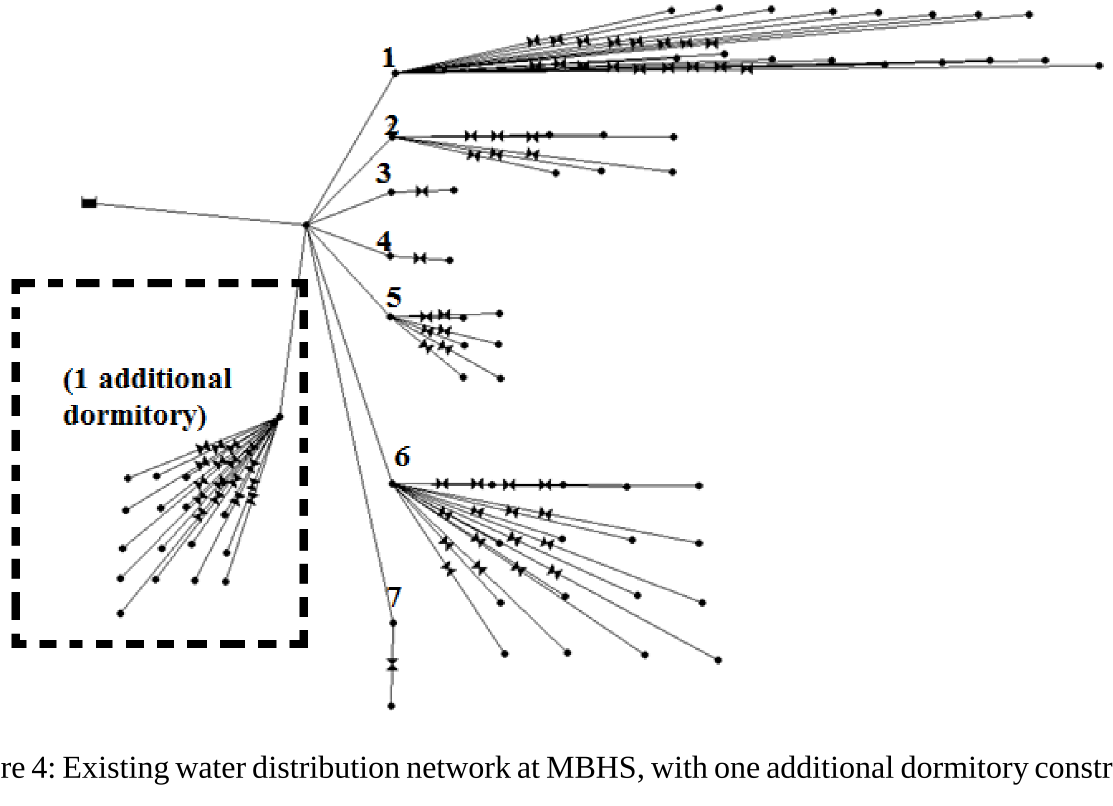


Figure 4: Existing water distribution network at MBHS, with one additional dormitory constructed.

Our model runs successfully with the addition of one dormitory and its associated water demand, suggesting that that the school can increase enrolment by 50 students and demand by 2.6 L/s with the existing supply and connection to the water catchment. To determine the maximum number of additional dormitories and the total demand that the current catchment can supply, we continued to add tap-clusters until the network was no longer able to compute the analysis, at which point it was indicating that the desired demand (input flow-rate) cannot be met. This process of adding tap-clusters showed that the reservoir could accommodate up to five additional dormitories in its piping network. Therefore, we estimate that MBHS could enroll up to 250 new advanced-level boarding students before needing to provide additional water storage infrastructure.

5.2 Expanding with additional water storage capacity

In order to expand beyond 250 students, or to build more than five dormitories connected to the pipe network, it would be necessary to construct additional water storage. One approach to ensuring water availability for the additional dormitories and bathrooms is to integrate water storage capacity (in the form of an elevated tank) into the dormitory design. The tank would need to be filled daily during non-peak demand (for instance, in the evening or at night) and would be used to provide a dormitory's worth of students with their needed volume of water at the same flow rate provided as the rest of the taps on campus.

The daily water needs of an individual boarding student were estimated based on both observations of and conversations with the advanced-level students. In addition to individual needs, water is required for daily dormitory and classroom cleaning. Given a population of 50 students, we assumed that this group would represent two classes of 25 students each and then estimated water demands for the entire group, given in Table 3.

Table 3: Individual, group, and overall daily water needs for 50 boarding students.

Individual Water Demand:		Group Water Demand:		Overall Water Demand:	
Bathing	10 [L]	Mopping the Dormitory	40 [L]	(Total Individual Water Demand) = (Number of students)*(Individual Demand)	1000 [L]
Drinking	3 [L]				
Dishwashing	2 [L]				
Bathroom	3 [L]	Mopping Two Classrooms	40 [L]	(Total Group Water Demand)	80 [L]
Handwashing	2 [L]				
TOTAL	*20 [L]*	*TOTAL*	*80 [L]*	***TOTAL***	***1080 [L]***

Each dormitory of students would require approximately 1.08 m^3 of water to meet their daily needs. Locally, tanks are available in volume increments of 1-m^3. To ensure that adequate supply would be available and to include a factor of safety in the case that the tank was not always filled completely by the start of each day, we selected a 2-m^3 tank per dormitory for our model.

A new cluster of 17 taps was drawn into the EPANET model. However, this cluster was connected to a water tank rather than the reservoir. The same demand and properties at the junctions and valves were inputted but the pipe properties were altered. The most accessible pipes from nearby hardware suppliers are PVC pipes with a 2-inch internal diameter. This scale and type of pipe was modeled and pipe length was estimated to be 30 meters (accounting for the distances from the tank to the bathroom and outdoor tap, and plumbing within the bathroom). The dimensions of a 2-m^3 water tank were also included for the tank properties of diameter and initial level (where the height of the tank equaled its initial level when full) (Izoplas, 2018). Initially we modeled the tank as set on the ground with base elevation of zero to determine if just the initial height of water in the tank would provide adequate pressure to supply the base-demand.

The network (visualized and with parameters listed in the appendices) ran successfully, indicating that the *initial* water level was high enough to provide adequate head to meet the local demand. However, the water level will drop throughout the day as the tank drains. To ensure that there would be sufficient head in the elevated tank system to provide a consistent flow rate throughout the day to the taps supplied by the water in the elevated tank, we continued to iterate in our model runs for this isolated system. We iteratively ran the model, each time decreasing the initial water level in the elevated tank until we reached a minimum head at which the system would compute (meaning that the tap demand could be met). Our calculations suggest that a minimum head of 1.5 meters is required (to top of water surface) to meet the tap-cluster demand from a tank source. We note that the energy losses due to the >1000 m of piping from the catchment source and the many associated piping components (e.g. valves, bends, etc.) are much greater than those in this supplemental elevated tank/nearby tap-cluster system, explaining why a much smaller amount of head is needed to achieve the desired flowrate in the supplemental tank-cluster system. Adding in a factor of safety and recognizing that the base of the elevated tank needs to be at the minimum elevation to meet tap-cluster supply, we suggest elevating the tank to two meters. The prescribed structure height to support this tank was consistent with that of other water tanks in the district, so we concluded that constructing a platform connected to the wall of the dormitory two-meters tall would be feasible.

Finally, to ensure that the tank would be used effectively each day, we proposed and analyzed a filling schedule that could be integrated into the existing student chore routine; a manual filling process is consistent with filling methods used at other similar schools with elevated tanks and piped water although an automated process could be installed if resources are available to do so. Time-to-fill could be calculated assuming that the flow-rate into the tank equaled the flow rate from each of the taps.

$$Volume = Q * time \tag{3}$$

$$2\ [m^3] = 0.000129\ \left[\frac{m^3}{s}\right] * time\ [s]$$

$$time = 15500\ [s] = 4.3\ [hours]$$

The tank would require just under four and a half hours to fill completely. This procedure could be started daily before dinner (at 6:00 pm) and then would be completed before enforced lights-out for the dormitories (at 11:00 pm). With each dormitory's existing chore-management student structure, the procedure could be easily integrated into daily routines.

6 DISCUSSION

The current piping network of MBHS's water distribution system was modeled using EPANET's open-source software to determine the extent of expansion that the built water catchment could support. Given the existing measured flow rate from taps, the catchment can accommodate up to five additional dormitories of demand (or 250 students) by supplying adequate pressure to 85 additional taps. Assuming that the catchment is still providing sufficient water supply on a year-round basis, further expansion would be possible by integrating additional water storage into the dormitory infrastructure. Given that a dormitory sleeps 50 students, the model showed that an additional 2-m^3 water tank could be raised two meters above the ground to provide adequate pressure to all the taps associated with a dormitory.

Although our system was modeled with a reservoir, this does not mean an infinite supply of water is available to the community. The source supplying the catchment is a river running down the Livingstone Mountains. If the village government were to expand the distribution system by attaching more outlet pipes to the catchment, there would come a time when the water being drawn from the system would approach the river's supply into the catchment. At this point the flow rate to each tap would decrease. For future work, we suggest that the catchment supply be quantified over a 1-to-2-year cycle and that any impact on catchment supply be closely monitored with incremental expansions of the school; our system model could be iteratively improved (by improving fidelity of the assumptions) based on field measurements of supply and flowrates at the taps during stages of the expansion.

In addition, a major difference between the model and reality is that when we expand our system to the point at which the reservoir cannot supply the demand we dictated as needed in the model, the model states that the system is not solvable. In reality, at that point, the system would not stop functioning but rather the flow rate from each tap would decrease.

Throughout this article we were able to meet each of the goals of the study related to estimating expansion capabilities and supplementary storage options. We were able to successfully use the open-source software to model the current water distribution system and determine the extent of expansion that this system could accommodate. Beyond network expansion, we were also able to design local water storage that could accommodate additional increases in student enrolment. In future work, this methodology could be compared to other distribution system development and analysis approaches to determine its relevance in the larger scope system modeling and low-resource environments.

7 CONCLUSION

In this article we demonstrated a pipe network analysis method to evaluate the expansion of a community-level water distribution system. This type of methodology is particularly relevant for community development practitioners and volunteers working in highly rural settings. Our application of the method proceeds through the steps of system modeling to analyze expansion capacity and supplementary storage design. The method's major advantage is that it can be employed in a low-resource environment because it only requires basic tools (including a GPS, tape measure, bucket, stopwatch and computer with EPANET downloaded). Our approach and documentation are designed to be simple to follow and accessible to those without a technical background or who have not previously worked on community water system projects, rather than a method developed for professional engineers designing city-water distribution systems. Our goal is to further disseminate this written resource to those working in the field who could utilize a simplified water-system-analysis methodology, and to have practitioners with non-technical backgrounds test the usability of this methodology. One group we are aiming to reach is Peace Corps Volunteers as they are continually working directly with communities. We are especially interested in seeing this written resource used by the volunteers and communities together to develop and manage local water systems.

8 ACKNOWLEDGEMENTS

This research was possible due to the support of Matema Beach High School's students, teachers and staff. The Peace Corps staff and volunteer community in Tanzania provided language, technical and cultural training as well as continual support throughout my service, and special thanks are given to program managers Paul Mairi and Anna Isanzu. Finally, this study was possible because of Oregon State University's School of Mechanical, Industrial and Manufacturing Engineering's collaboration Peace Corps Master's International program, which enabled and supported Richardson's non-traditional degree track.

9 REFERENCES

Garmin Ltd. (2016) *Garmin GPSMAP 64 Owner's Manual*. Olathe. Available at: http://static.garmin.com/pumac/GPSMAP64_OM_EN.pdf.

Izoplas (2018) *2m^3 Plastic Water Tank*, *Izoplas*. Available at: https://en.izoplas.com/2m3-plastic-water-tank/ (Accessed: 16 May 2018).

Masuda, K. and Yamauchi, C. (2018). *The Effects of Universal Secondary Education Program Accompanying Public-Private Partnership on Students' Access, Sorting and Achievement: Evidence from Uganda*, CEI Working Paper Series 2018-4, Center for Economic Institutions, Institute of Economic Research, Hitotsubashi University.

Ministry of Education and Vocational Training (2012) *National Strategic Plan for School Water, Sanitation and Hygiene (SWASH) 2012-2017*. Dar es Salaam. Available at: http://www.who.int/countries/tza/en/.

Munson, B. R. . *et al.* (2013) *Fundamentals of Fluid Mechanics*. Seventh Ed. Edited by J. Welter. John Wiley & Sons, Inc., Hoboken, NJ, USA.

Murray, R. (2008) 'EPANET'. Cincinnati: United States Environmental Protection Agency. Available at: https://www.epa.gov/water-research/epanet. At the time of publication (2019), EPANET appears to be available in French, Portugese, Spanish and Russian at http://epanet.de/index.html.de.

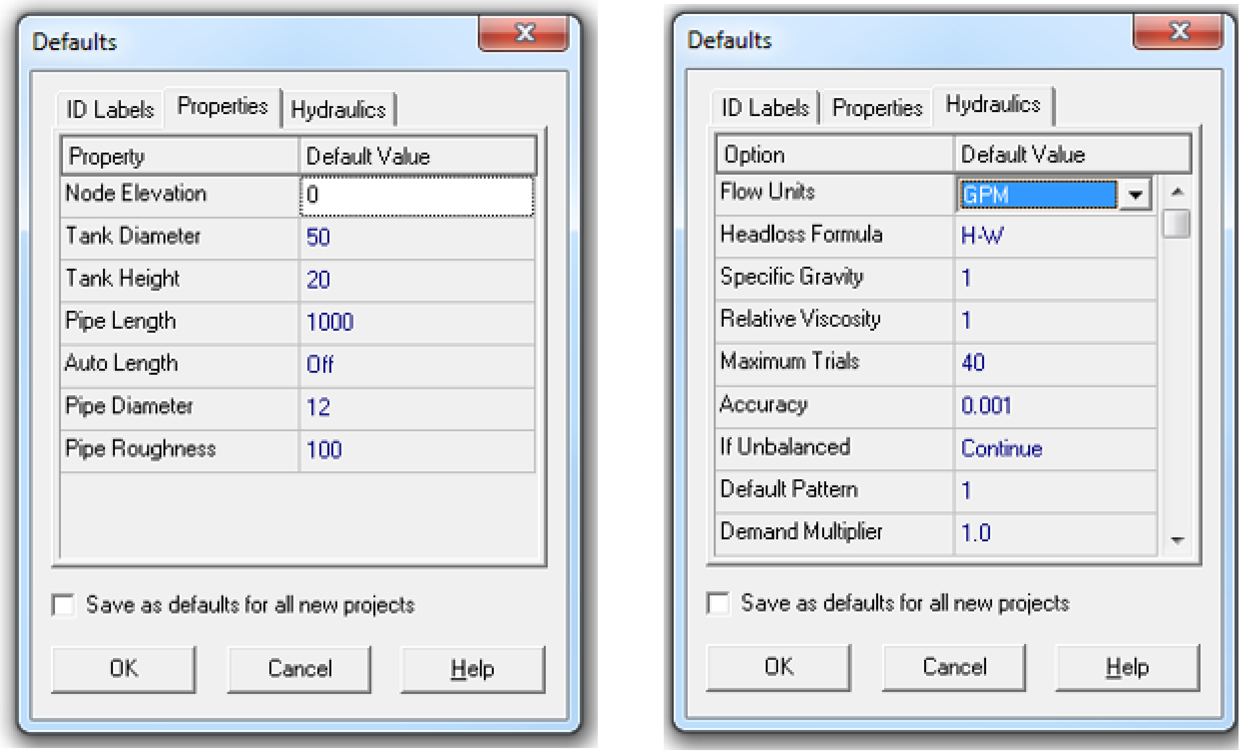
Peace Corps (2018) *Resource Library*, *PCLive*. Available at: https://pclive.peacecorps.gov/pclive/index.php/library (Accessed: 21 May 2018).

Rossman, L. A. (2000) *EPANET 2: Users manual, National Risk Management Research Laboratory*. Cincinnati. doi: 10.1177/0306312708089715. At the time of publication (2019), links to translated versions of the manual can be found at: (1) French, https://www.arnalich.com/epanetes/descargas/Epanet_fr.pdf; (2) Spanish, https://epanet.info/manuales/epanet-2-manual-de-usuario-espanol/; (3) Portugese http://www.lenhs.ct.ufpb.br/html/downloads/epanet/manual_do_epanet_brasil.pdf.

UNESCO, Global Education Monitoring Report (2016) *Can Africa afford free education?*, *World Education Blog*. Available at: https://gemreportunesco.wordpress.com/2016/01/27/can-africa-afford-free-education/ (Accessed: 10 May 2018).

Zhu, J. (2015) *Sustainable Development Knowledge Platform*, *United Nations Department of Public Information*. Available at: https://sustainabledevelopment.un.org/?menu=1300 (Accessed: 30 April 2018).

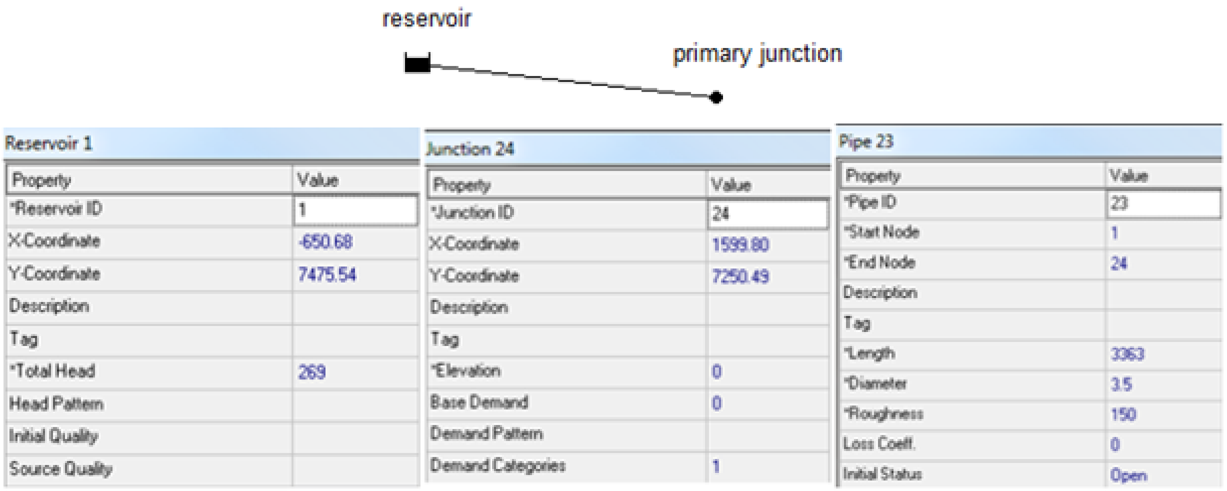
10 APPENDIX



Property	Default Value
Node Elevation	0
Tank Diameter	50
Tank Height	20
Pipe Length	1000
Auto Length	Off
Pipe Diameter	12
Pipe Roughness	100

Option	Default Value
Flow Units	GPM
Headloss Formula	H-W
Specific Gravity	1
Relative Viscosity	1
Maximum Trials	40
Accuracy	0.001
If Unbalanced	Continue
Default Pattern	1
Demand Multiplier	1.0

Figure A1: Default properties and hydraulics when setting up an EPANET model.



Reservoir 1

Property	Value
*Reservoir ID	1
X-Coordinate	-650.68
Y-Coordinate	7475.54
Description	
Tag	
*Total Head	269
Head Pattern	
Initial Quality	
Source Quality	

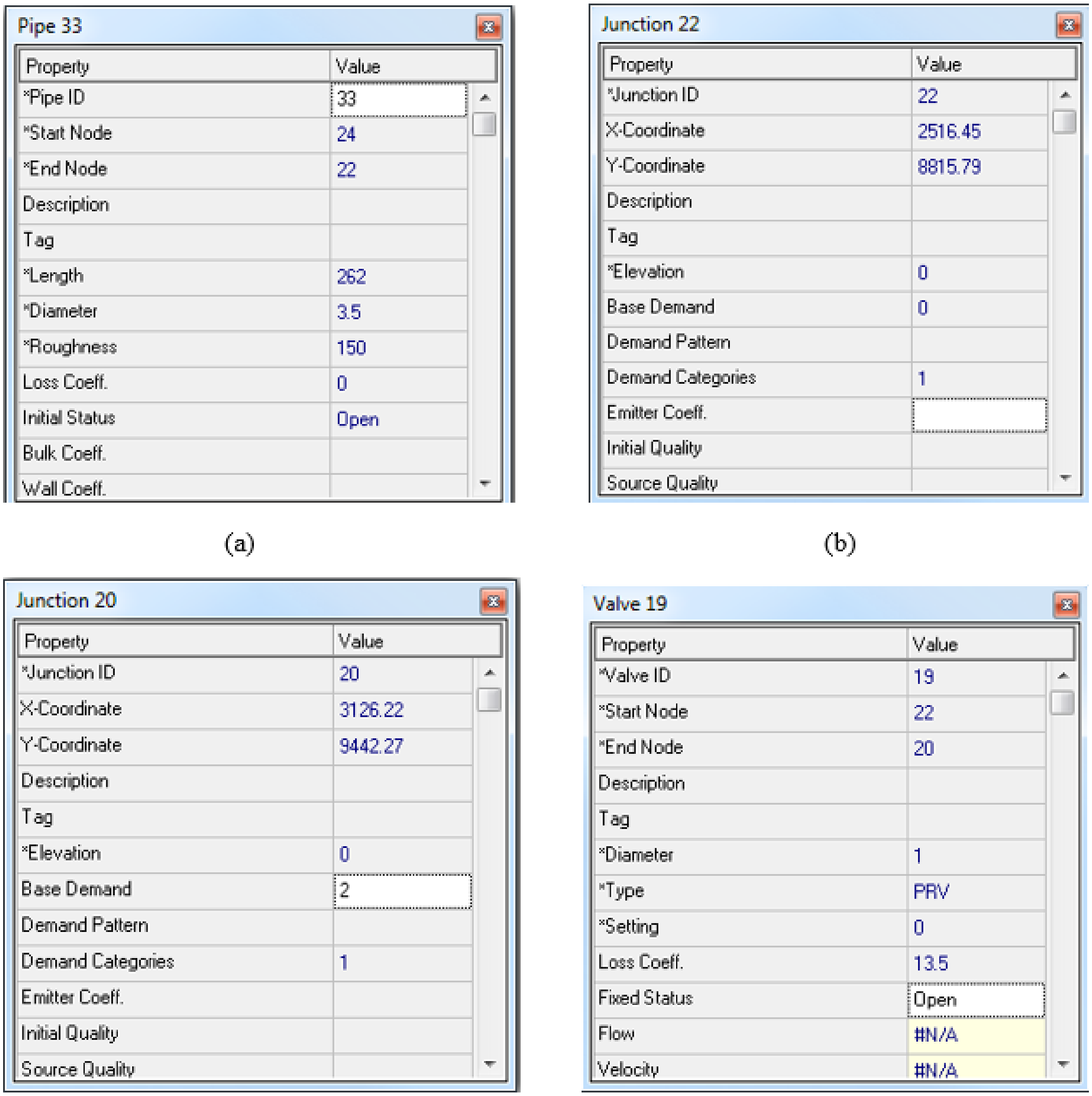
Junction 24

Property	Value
*Junction ID	24
X-Coordinate	1599.80
Y-Coordinate	7250.49
Description	
Tag	
*Elevation	0
Base Demand	0
Demand Pattern	
Demand Categories	1

Pipe 23

Property	Value
*Pipe ID	23
*Start Node	1
*End Node	24
Description	
Tag	
*Length	3363
*Diameter	3.5
*Roughness	150
Loss Coeff.	0
Initial Status	Open

Figure A2: Reservoir-to-junction model and component properties.



Pipe 33

Property	Value
*Pipe ID	33
*Start Node	24
*End Node	22
Description	
Tag	
*Length	262
*Diameter	3.5
*Roughness	150
Loss Coeff.	0
Initial Status	Open
Bulk Coeff.	
Wall Coeff.	

(a)

Junction 22

Property	Value
*Junction ID	22
X-Coordinate	2516.45
Y-Coordinate	8815.79
Description	
Tag	
*Elevation	0
Base Demand	0
Demand Pattern	
Demand Categories	1
Emitter Coeff.	
Initial Quality	
Source Quality	

(b)

Junction 20

Property	Value
*Junction ID	20
X-Coordinate	3126.22
Y-Coordinate	9442.27
Description	
Tag	
*Elevation	0
Base Demand	2
Demand Pattern	
Demand Categories	1
Emitter Coeff.	
Initial Quality	
Source Quality	

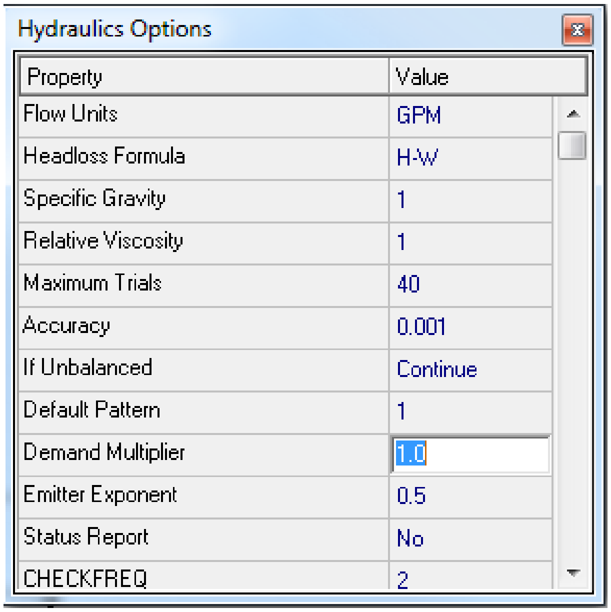
(c)

Valve 19

Property	Value
*Valve ID	19
*Start Node	22
*End Node	20
Description	
Tag	
*Diameter	1
*Type	PRV
*Setting	0
Loss Coeff.	13.5
Fixed Status	Open
Flow	#N/A
Velocity	#N/A

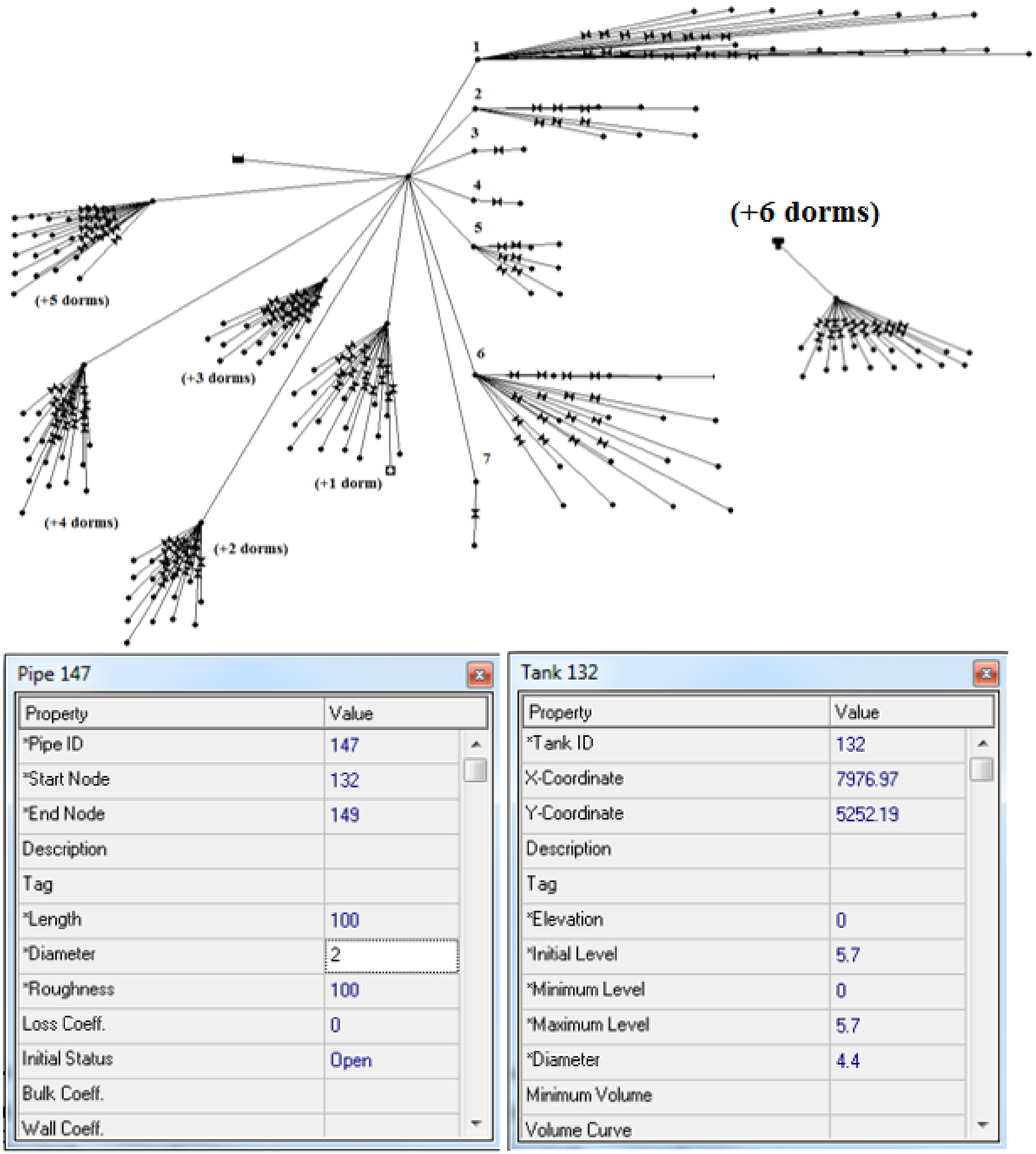
(d)

Figure A3: Properties set for (a) the pipe connecting the primary junction with junction-1, (b) junction-1, (c) each of the 17 junctions in the tap cluster, (d) each of the 17 valves.



Property	Value
Flow Units	GPM
Headloss Formula	H-W
Specific Gravity	1
Relative Viscosity	1
Maximum Trials	40
Accuracy	0.001
If Unbalanced	Continue
Default Pattern	1
Demand Multiplier	1.0
Emitter Exponent	0.5
Status Report	No
CHECKFREQ	2

Figure A4: The location of the demand multiplier within analysis options.



Property	Value
*Pipe ID	147
*Start Node	132
*End Node	149
Description	
Tag	
*Length	100
*Diameter	2
*Roughness	100
Loss Coeff.	0
Initial Status	Open
Bulk Coeff.	
Wall Coeff.	

Property	Value
*Tank ID	132
X-Coordinate	7976.97
Y-Coordinate	5252.19
Description	
Tag	
*Elevation	0
*Initial Level	5.7
*Minimum Level	0
*Maximum Level	5.7
*Diameter	4.4
Minimum Volume	
Volume Curve	

Figure A5: The expanded system with an additional 6th dormitory, and the pipe and tank properties for the local water capacity.