University of Southern Queensland

Faculty of Health, Engineering & Sciences

DISSERTATION

COMPARISON OF A TRADITIONAL AND A DISTRIBUTED STORAGE WATER SUPPLY NETWORK FOR AN ISOLATED SYSTEM

Supervisor: Dr. Laszlo Erdei

Submitted by

Darryl Horan

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ABSTRACT

A traditional water supply network has a single water supply reservoir supplying a neighbourhood of households via a reticulation network designed for peak flows. Storage tanks at each household (distributed storage) can be utilised to act as buffers between continuous supply of average flows and intermittent demand of peak flows. This results in the water supply infrastructure needing to cater for average flows only. This research project examines potential savings that can be made to water supply infrastructure when distributed storage (household tanks) is utilised.

An isolated network is modelled for both the traditional design scenario and a design incorporating water tanks at each point of supply. The water supply network is modelled using Pipes++ software package. The reticulation layout is identical for both designs and hydraulic conditions, such as pressure available at the water supply source, are kept the same to isolate differences to those between peak and average flows only. Comparison is made in terms of required pipe sizes and costs.

Pipe diameters and construction costs of the distributed storage network are between 50% and 60% less than that required for the traditional network. The larger percentage of savings were made in the single distribution main linking the subject site to the source of water supply approximately 1.2 kilometres away.

The costs of water tanks and pumps for each household outweigh the savings made by reduction of reticulation pipes. When tanks and pumps are already provided for re-use of rainwater, the distributed storage network provides significant savings.

The prospective merits justify and highlight the need to investigate other characteristics and aspects of distributed storage networks including incorporating water tanks for re-use of rainwater, water quality, minimum pressure requirements, energy use, clustered networks, fire fighting requirements and different sized communities.

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Darryl Horan

Student Number: 0061003055

Signature

22 October 2013

Date

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1. Introduction

This research concentrates on water supply in an Australian setting. This is primarily due to the author residing in Australia and having access to resources that support the requirements for water supply in the Australian environment. Australia is well suited for research into water supply networks because the country has a diverse set of environments within which people choose to live. Conditions range from areas where rainfall can accommodate total demands and reticulated supply is not required, to areas where local sources are practically nonexistent and water needs to be transported long distances to sustain human habitation. There are densely populated regions where expansive reticulated supply costs can be shared, and remote, sparsely populated areas where the cost of a reticulated supply is prohibitive. Whilst this research is focused on the Australian environment, the principles are equally applicable in other parts of the world.

1.1 Current Setting

Water as a resource has come under intense scrutiny in recent years, most likely owing to drought conditions across Australia for almost a decade and water restrictions being imposed in major cities. Whilst drought conditions may be abating, recent experiences have led to the realisation that water as a resource is finite and attitudes have changed with regard to water use and availability.

Historically, large populations find it beneficial to increase the community burden for the benefit of each household. That is, provide communal water supply infrastructure to service each household. The financial imposition on each person shared across the whole community is small compared to the benefit received. This has unfortunately evolved into ever increasing demand being met by upgrades to water supply infrastructure whenever required, regardless of costs and without much thought for alternative techniques. Every development appears to present an opportunity for water authorities to upgrade their supply network to larger pipes. It is remiss of us as a community not to ask if there is an alternative to this approach.

Despite potential conflicts of interest for water authorities that generate increased revenue from increases in metered supply, these authorities have been proactive in recent years in their attempts to reduce household water use. Melbourne water authorities have offered free exchange of shower heads for more efficient fittings and free shower timers to promote shorter showers. These methods may have been introduced because recent experiences of water shortages and imposed restrictions have brought about the realisation that forecast population growth coupled with current water demand rates is unsustainable.

A number of initiatives are being introduced to remedy future water shortage problems. Along with more water efficient fittings and appliances, tanks for storing and re-using roof water are becoming more prevalent. In Melbourne, and numerous other parts of the country, it is now a requirement of many local authorities that rainwater tanks be installed with any new building or substantial extension of an existing building. Roof water must be re-used for irrigation as a minimum, and preferably for washing machines and toilet flushing. The requirement for water tanks and re-use of roof water in new buildings has been introduced as a sustainability measure. The measures appear to be primarily aimed at reducing the total volume of water used so that water supply reservoirs are not depleted during times of low rainfall. In Melbourne, this is being promoted despite the construction of a new desalination plant to service the city, which may have to be run at minimum operational levels until population expansion or drought conditions warrant it.

The current changes in attitude to water use present an opportunity to rethink the way we deliver water supply services to communities. The Water Services Association of Australia (2005) mentions this opportunity when identifying advantages to the use of water tanks for rainwater re-use in the forward of their Integrated Rainwater Tank Systems publication by stating:

> *The collection and storage of roofwater provides the combined benefits of reducing reticulated drinking water demand and decreasing stormwater run-off into local waterways. At the same time integration of rainwater tank supplies with reticulated water supply(s) provides the opportunity for hydraulic redesign of the water supply system and presents a range of challenges that hitherto have not needed to be addressed by water utilities.*

Although this research is not specifically concerned with re-use of roofwater, the "opportunity for hydraulic redesign of the water supply system" mentioned in the quote above serves as an appropriate introductory statement.

1.2 Project Aims and Objectives

Under current Australian water authority design standards, a reduction in total volume consumed, as appears to be the focus of current sustainability measures, does not reduce the requirements of the distribution network. This is because the distribution network is based on theoretical peak demand without consideration that some demand may be met by an alternative source. This research will examine if the introduction of water tanks distributed within the water supply network can be utilised to produce physical savings in the water distribution network itself.

Water supply infrastructure for domestic consumption in Australia is currently designed for peak hourly demand. For the purposes of demand estimation in small communities, Australian design standards (WSA03-2002, p.53) assume peak hourly demand is five times that of average hourly demand. If the requirement to accommodate peak demand can be reduced to that of average demand, the flow rate used for design of infrastructure could be reduced by 80%. There are obvious benefits for existing and proposed supply networks:

- Existing infrastructure should have the ability to service more households than it currently does. Additional development in any area could be accommodated without having to upgrade existing trunk infrastructure.

- Reduced flows during peak times in existing networks could be made to operate at lower pressures. This could potentially reduce maintenance costs associated with pressure related failures.

- New areas of development could be serviced with smaller sized pipes or pipes with less pressure rating than equivalent developments under current guidelines. This would result in lower infrastructure construction costs and/or lower future maintenance costs.

This research examines the third benefit above and aims to determine if water supply infrastructure pipe sizes can be reduced using average demand as compared with that required for peak demand. Each system is costed for construction and maintenance in terms of current day prices to quantify any differences that arise. Lower costs could make a considerable difference for small communities seeking to provide a reliable water supply to their residents.

Water storage tanks are an obvious way in which peak flow demand can be reduced to average flow demand. A constant (average) flow can be used to feed the water tank. During times when household demand is less than the average, the tank will be filled. During times when household demand is greater than the average, the tank will be emptied. Figure 1.2a below illustrates this concept using a typical diurnal water use pattern.

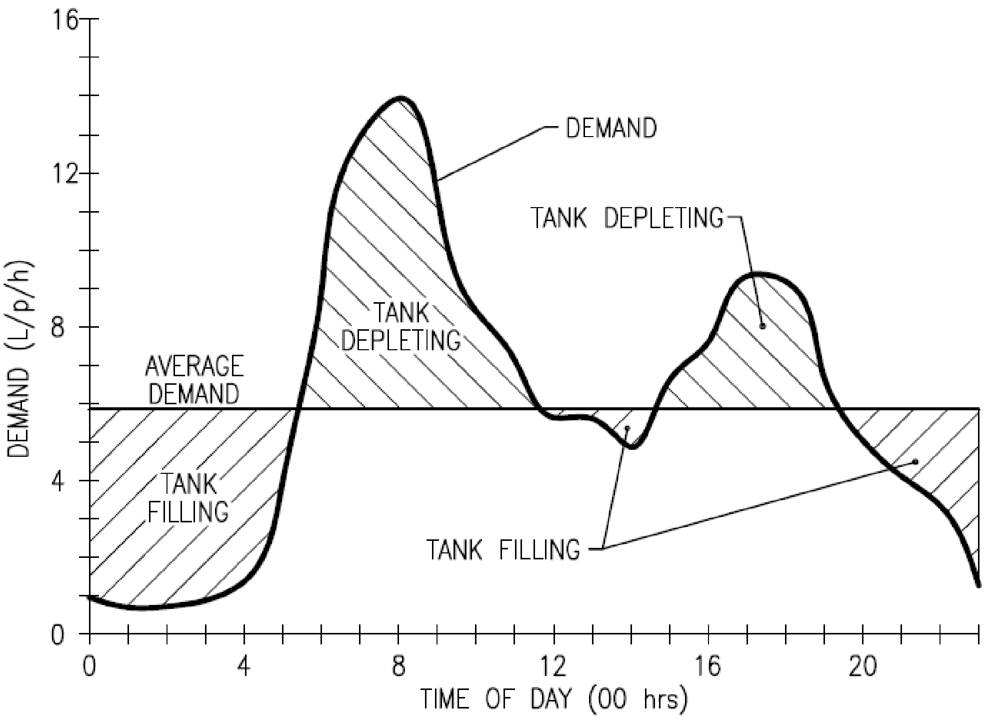

Figure 1.2a Water Storage Tank and Diurnal Water Use Pattern

As an alternative to a potential reduction in pipe sizes, another hypothesised benefit for the distributed tank supply network is a reduction in pressure for the overall network. Reduced pressure through the whole network could potentially result in pipes with a smaller pressure rating to be used and/or less maintenance from pressure related faults.

This scenario is examined by keeping pipe sizes the same for both networks and determining the pressure drop that can be applied at the point of supply.

1.3 What is Traditional Water Supply Network?

The objective of a water supply network is to provide a safe and reliable supply of drinking water. Common sources for water feeding a water supply network are rivers and dams, springs and bores, and the ocean (via desalination plants). A typical water supply network sourced from a dam is illustrated in figure 1.3a below.

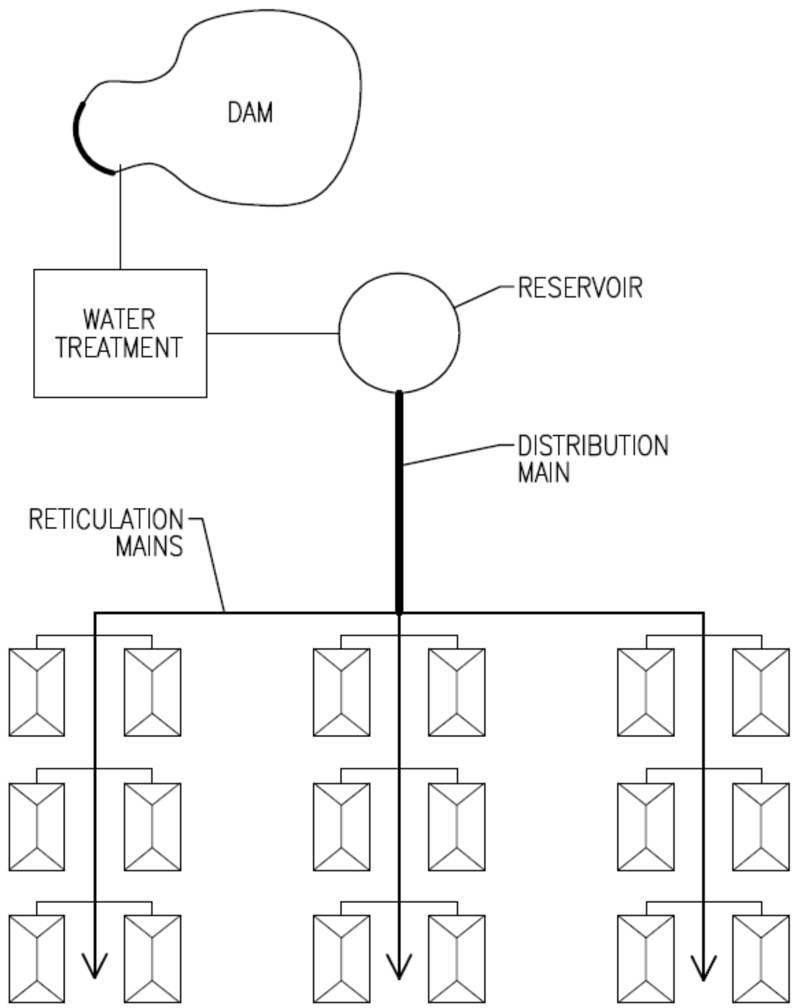

Figure 1.3a Schematic Traditional Water Supply Network

As shown in figure 1.3a above, water is captured from a dam and conveyed through a pipe to a water treatment plant. Treated water is then pumped to a water reservoir which supplies each household via a gravity reticulation network.

Traditionally, this reticulation main is designed to meet the highest peak demands for each and every household. Referring to figure 1.2a, the typical diurnal water use pattern shows peak demand is only required for a brief period of time. Furthermore, different times of the year have higher peaks than others. Therefore a traditionally designed water supply network that is designed for the highest peak demands flows has a capacity that exceeds the required demand for a great majority of the time. The peak flow rate for which it is designed will rarely, if ever, be achieved. I assume this situation has become the accepted industry standard because water supply is considered an essential service and the consequences of inadequate supply are considered unacceptable.

In a traditional design there will be large reservoirs potentially scattered throughout the entire area serviced to ensure pressure and flow is maintained at adequate levels for each point in the system. This is often dictated by topography and a single storage reservoir might service thousands of households.

1.4 What is a Distributed Storage Water Supply Network?

As described in section 1.3 above, a traditional water supply network has a single water supply reservoir supplying each household via a reticulation network designed for peak flows. In fact, a traditional network may have more than one reservoir supplying a town or city depending upon its size, spread and topography.

A distributed storage network is one where numerous smaller reservoirs are distributed throughout the network. For the purposes of this research, the distributed storage reservoirs are deemed to be water tanks provided at each household. This concept is illustrated in figure 1.4a below.

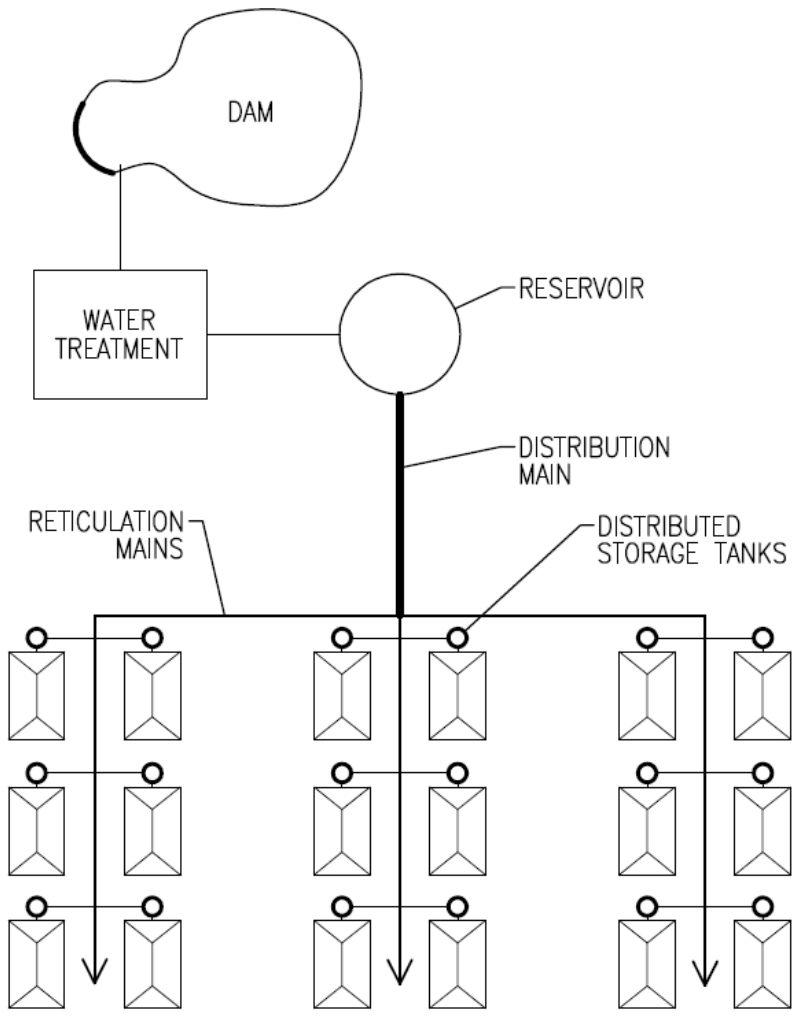

Figure 1.4a Schematic Distributed Storage Water Supply Network

As discussed in section 1.2 above, the volume of water required for intermittent peak demand flows can be provided in the storage tank and flows to the tanks can then be reduced to that of average demand. The reticulation network supplying each household can therefore be designed to convey less flow and should consequently consist of smaller diameter pipes.

Unless elevated, it is unlikely each storage tank can match the pressure currently provided by a traditional network fronting each property. A pump at the point of take off from the storage tank is expected to deliver the required pressure for operation of appliances within each household.

1.5 Examples of Distributed Storage Networks

Literature searches have returned no specific information for distributed storage networks. However, the principles of distributed storage networks can be found in a number of examples currently in operation.

It is not unusual for a private development to have a tank on site that provides storage of water to be used for occasional high flows. It is an acceptable solution within the Building Code of Australia to satisfy fire fighting requirements when pressure in the public water main is insufficient. Pumps are used to deliver water at the required pressure and flow for a specified duration. Less common are similar systems for domestic supply in private developments. These systems are employed only out of necessity because pressure in the public main is inadequate or the fire fighting requirements for large, high risk or tall buildings greatly exceed that for which the public main was designed. A single tank (reservoir) is usually provided with internal reticulation mains sized for peak demand in the traditional way rather than a number of tanks distributed through the site. However, these are examples where tanks are used because the existing public water main cannot accommodate peak demand flows (at the required pressure) and the provision of these tanks negates the need to upgrade the public water main. With the addition of the tank, the public water main can effectively supply the private development at average flow rates rather than peak flow rates.

Scotland Island on the New South Wales coast provides an example where water supply infrastructure is minimised and water tanks are used as the main source of water supply (Scotland Island Community Website, 2013). Piped mains are connected to a communal supply and provided to each property, but use of these mains to top up each residents water tanks is restricted to one resident at a time. The times at which each resident can top up is controlled by a booking system with each resident paying for what is used during their booked timeslot. This example illustrates a system whereby the public reticulation mains are not designed for peak flows as would be the case for a traditional network. The cost of infrastructure is kept to a minimum with each resident being responsible for their own supply through tanks and pumps. It has similarities to the distributed water supply network as defined by this research except the Scotland Island network lacks the continuous reliability of supply being sought. This might not be a problem where regular rainfall results in very little demand being placed on the public reticulation network but would be potentially problematic in arid regions.

It is some mixture of the examples above that is the subject of this research. The intention is to combine a system whereby the householders responsibility of storing water, similar to a situation where water tanks collecting roof water are the sole source, with continuous reliability of supply usually reserved for traditional water supply networks. The storage of water in tanks at each household will be utilised to reduce demand on the water supply network thereby allowing the network to be designed with smaller pipe diameters and at less cost.

It is likely the cost of individual tanks and pumps at each household will outweigh any benefits gained from a reduction in reticulation pipe sizes. However, when these systems are already provided as with Scotland Island, it would appear unnecessary to design for peak flows when the tanks can provide storage for this purpose. If Scotland Island wished to increase reliability of supply, they could implement a system that is being proposed as part of this research. Similarly, if water tanks and pumps are being provided as part of a new development in any case, as with the requirements from Melbourne local authorities, it would also appear unnecessary to design the water reticulation system for peak flows so long as the tanks can be sized appropriately to store sufficient water to supply peak periods.

2. Design Requirements

Internet searches return a vast collection of literature relating to community and household water supply systems. Many publications also focus on water tanks supplying household demands.

Most water supply authorities around the developed world would appear to have guidelines on how to design, construct and maintain their networks. The main design guidance for Australian water authorities comes from the Water Services Association of Australia (WSAA) which publishes the Water Supply Code of Australia (WSA 03-2002).

Design and construction of water supply in private developments in Australia do not fall under the jurisdiction of the Water Supply Code of Australia. Private developments are guided by Standards Australia, most notably AS/NZS 3500.1- 2003 Plumbing and Drainage Part 1: Water services.

Both the Water Services Association of Australia, in their 2005 publication titled Integrated Rainwater Tank Systems (WSA 03-2002 Rainwater Tank Supplement-1.1), and Standards Australia, in a 2008 publication by the Master Plumbers and Mechanical Services Association of Australia (MPMSSA) titled Rainwater Tank Design and Installation Handbook, provide guidance on the use of water tanks for domestic use in Australia. Both publications are primarily concerned with providing tanks for re-use of rainwater rather than a tank to balance intermittent peak demands and continuous average supply.

The WSAA Integrated Rainwater Tank Systems publication mentions an opportunity to resize mains because rainwater tanks with a drip feed top up supplying outdoor and laundry uses will reduce peak demand from the authority supply. However, peak demand is still the design criteria for those fixtures supplied directly from the authority main. It appears the WSAA supports the resizing of infrastructure to suit probable demands and the system proposed in this research would not contradict WSAA requirements.

2.1 Traditional Network Design Requirements

A traditional water supply network is deemed to be one that must meet the requirements set by the Water Services Association of Australia in the Water Supply Code of Australia, WSA 03-2002. Many water authorities in Australia use this publication as the foundation for their own design standards and performance requirements. Generally, the pipes in a traditional network are designed to convey the maximum possible flows that might be generated by the area they supply. If changes in land use or population increase require greater demand, pipe diameters are routinely increased so the increased demand can be met.

In a traditional design there will be a large reservoir supplying peak flows to entire neighbourhoods. Depending upon geography and topography there could potentially be a number of large reservoirs scattered throughout the entire area serviced to ensure pressure and flow is maintained at adequate levels for each point in the system. A single storage reservoir might service peak demand for thousands of households. A schematic of a traditional water supply network is illustrated in figure 1.3a.

2.2 Distributed Storage Design Requirements

There is currently no published guidance for the design requirements of distributed storage networks. The objective of this research is to determine if pipe diameters, and thereby costs, can be reduced for the reticulation network if reduced flows can be justified. Performance requirements for the distributed storage networks are discussed and determined in the following sections based on principles of hydraulics and household water supply requirements.

A distributed storage network is considered to be one where numerous smaller water storage tanks are provided throughout the network. Each tank will service a single household, or potentially a cluster of several households. A schematic of a distributed storage water supply network is illustrated in figure 1.4a.

The volume of water required for intermittent maximum demand flows of each household is provided in the storage tank. Beal, Stewart & Huang (2010) identify peak demand for the Gold Coast as approximately 14 litres per person per hour. For a household of 4 people over a period of 3 hours, water use equals 168 litres. A tank of less than 200 litres would be sufficient to accommodate peak demand. The distributed storage tanks are anticipated to be of the size similar to a tank currently used for collection and re-use of rainwater, say 1000 to 2000 litres.

Similar to the way water reservoirs in a traditional system provide a buffer between steady supply from a water source and varied supply through distribution mains, drip feed to a storage tank at each household can provide a buffer between continual constant flow in the distribution network and intermittent flows required by households. Because maximum demand flows are provided by storage in the tanks, supply to the tank via reticulation mains can be reduced to that of average demand. Pipes will need to convey less flow than a traditional network and should therefore be able to be smaller in diameter.

A pump attached to or submerged within the storage tank delivers the required pressure for operation of appliances within the household.

2.3 Design Flows (Demand)

Design flows (demand) is the key difference between a traditional and distributed storage network that this research will examine. Using tanks to provide multiple small storage reservoirs, average demand is modelled and compared with peak demand required for a traditional network. A cost analysis has been undertaken to determine which of these flows lead to the most economical method for designing and constructing water supply networks, particularly smaller, isolated networks.

The Water Services Association of Australia (WSA03-2002, p.55) specifies that "analysis shall… address peak demand conditions". Furthermore, "demand shall be determined by multiplying the relevant peak hour demand per property or unit and the number of properties serviced" (WSA03-2002, p.50). These requirements form the basis for traditional design of water supply networks in Australia.

Demands, or design flows, are difficult to predict. Individuals are precisely that, individual. The amount of water used by one person is unlikely to be the same as any other person.

A simple example of this variation in water use from one person to another is the amount of water used when showering. Most people will shower, some people shower once a day and some twice a day. Already, there is a large variation in water use between two groups who are prevalent in our society. Flow rates for each persons shower will also vary and will also be influenced by the type of fitting in each shower. Add to this the infinitely variable length of time people spend in the shower, it is easy to see how difficult it is to estimate how much water an average person will use in the shower. The same variability found in showers can be applied to any form of water use. Some people will wash dishes, mop floors, go to the toilet, wash cars, have baths, or water their gardens more regularly than others.

Aside from differences between individuals, there are differences in water use by different cultures. This might be differences between people raised in northern Australia, central Australia and southern Australia or different cultures immigrating to Australia which tend to congregate in similar areas within our major cities. Average water use rates recorded in one location may not be applicable in another.

Recent initiatives to save water, such as free shower timers offered by water authorities in Melbourne, and water efficiency ratings on whitegoods, may inadvertently be reducing the variability in water use between individuals. However, currently it is still a difficult task to estimate water demand.

The Water Services Association of Australia (WSA03-2002, p.51) tabulates estimated peak water use per unit, lot or hectare as appropriate for different types of development in cities around Australia. For high density residential developments, estimates vary from 1.6 L/s/100 units for Newcastle to 9.8 L/s/100 units for Darwin; the upper estimate being over 600% greater than the lowest estimate. WSA03-2002 admits the values in the table should only be used in the absence of other information and states that for large systems "it is particularly important that actual consumption records and a demand forecast method be used to appropriately size system elements" (WSA03-2002, p.50).

Melbourne Water suggests "a single-person home typically uses around 250 litres per person per day" (Melbourne Water 2006, p. 17). WSA03-2002 (p.53) provides factors that can be used to convert this average demand to peak demand:

Peak day demand = Average day demand x Peak Day Factor (PDF), and

Peak hour demand = Average hour demand (on peak day) x Peak Hour Factor (PHF)

For populations less than 2000, as will be the case with this project, WSA03-2002 recommends PDF = 2, and PHF = 5.

Using this method, the Melbourne Water estimate translates as follows:

Average day demand	250 L/person/day
Peak day factor	x 2
Peak day demand	500 L/person/day
Hours per day	÷ 24
Average hour demand (on peak day)	20.8 L/person/hr
Peak hour factor	x 5
Peak hour demand	104.2 L/person/hr
Seconds per hour	÷ 3600
Peak demand per second	0.0289 L/person/s
Persons per 100 units	x 100
Peak demand per 100 units	2.9 L/s/100 units

This has good agreement with the 3 L/s/100 units estimated by the Water Services Association of Australia for Melbourne. However, the sources for these two estimates are unknown and it may be the same source has been used for both estimates.

For the purposes of this research project, a flow of 0.03 L/s/unit will be adopted as the traditional network peak demand for the following reasons:

- The proposed development being modelled as part of this research project consists of single person units.
- The above calculation agrees well with the WSAA estimate (albeit with unverified and potentially identical sources).
- South eastern parts of Australia (Ballarat/Bendigo, Canberra, Melbourne/Geelong, Sydney) are all listed as 0.03 L/s/unit. The proposed development being modelled as part of this research project is situated in south eastern Australia.
- Accurate peak demand is not essential for this research. Although the magnitude of peak demand will affect results, it is the difference between peak and average demand that will be the dominant factor for determining a suitable conclusion.

As mentioned above, peak hour demand is considered to be five times that of average hourly demand. When a reservoir is provided, this serves as a buffer between average hourly demand and peak hour demand. Provided it is adequately sized, the additional flow requirements of peak demand are drawn from storage. A flow one fifth of peak demand (0.006 L/s/unit) will be modelled as the average demand which represents the flow required for a distributed storage network.

2.4 Fire Fighting Supply

Requirements for fire fighting supply vary in different locations around the country and with different land uses, Canberra alone has a flow requirement of 25 L/s to 200 L/s dependent on fire risk category (WSA03-2002, p.52). In general, required flow rates are significantly higher than that required for day to day domestic use and pressure requirements may or may not be higher.

The Australian Standard for fire hydrant installations requires 10 L/s at 200 kPa in most states for feed fire hydrants (AS 2419.1-2005 table 2.2, p.14). For large populations, cumulative demands for each household mean this flow requirement will not be an imposition on the network. For small populations, flow rates of this magnitude might not be reached in any part of the network without up scaling the network to specifically address fire fighting requirements.

The Water Services Association of Australia (WSA03-2002, p.61) specifies that minimum fire fighting demands are addressed. However, the Water Supply Code of Australia also states “the water supply system shall not be specifically designed for fire fighting capability” in recognition of uneconomical designs that might result for smaller networks.

For the purposes of this analysis, flow and pressure requirements for fire fighting demand will not be included in the modelling. The chosen site for modelling is reasonably small and isolated, fire fighting requirements would largely dictate design if it were included and this requirement would not change from one scenario to another. Any change in requirements from one scenario to another would be masked by the requirement for fire fighting.

On the face of it this might appear to be an unjustifiable simplification. However, this research aims to quantify a difference between designing for peak flows and average flows. It will be a simpler task to differentiate between these two if the masking effect of fire fighting flow is omitted. Additionally, it is not unusual for water supply in private commercial developments to have a separate system with pumps and tanks for fire fighting to that for daily consumption. This approach may also be suitable for a small isolated community with public infrastructure.

Inclusion of fire fighting demand within the reticulation or as a separate system will need to be considered in further research.

2.5 Operating Pressure

For the purposes of this project, 1 metre of head will be reported as 10 kPa pressure. Whilst this is technically inaccurate, it is a common approximation and will have no impact on the modelling because modelling is undertaken in terms of metres head only.

In the absence of any other advice, the Water Services Association of Australia (WSA03-2002 p.56) suggests a desirable minimum pressure for domestic areas of 200 kPa (20m). This desirable minimum pressure allows for losses through pipes and fittings installed on the property. I suspect the desirable minimum is a conservative figure that enables a majority of unfavourable scenarios to be catered for.

The desirable minimum pressure is not a mandatory requirement. WSA03-2002 (p.56) states “near reservoirs or in country towns, the minimum SP may be reduced to ensure an economical system design”. In recognition of the problems associated with lower pressures, WSA03-2002 further states, “in some cases the property owner may be required to install a storage tank and an on-property pressurising system”. This is precisely the scenario that is being proposed as a distributed storage network.

Australian Standards (AS3500.1-2003, p.16) specify the “minimum working head at the furthermost or most disadvantaged fixture or outlet shall not be less than 50 kPa (5 m head)”. This requirement is at the flow rates specified for the fixture in table 3.1 of AS3500.1-2003. This is in line with the required pressure for operation of appliances such as washing machines and is more appropriate to use as the basis for pressure requirements in an isolated, small scale network.

If we allow a nominal 10 kPa (1 m head) loss through pipe work from the reticulation branch to the furthermost or most disadvantaged fixture, this results in a minimum pressure at the household connection to the reticulation main of 60 kPa (6 m head). This will be adopted as the minimum pressure required at any point in the traditional network.

In theory, the pressure required for drip fed tanks will be the height to the top of the tank plus an air gap. Assuming tanks are sitting on the ground, this could be in the order of 30 kPa (30 m), half the assigned requirement for a traditional network. However, in order to isolate the effects of reduced flow demand on the network, the same pressure will be used as the minimum pressure required with both the traditional and the distributed storage networks.

The minimum pressures discussed above do not account for a suitable margin to allow for actual flows being greater than designed and to ensure negative pressure does not occur in the system. This is a considerable topic in its own right and should be the subject of further research.

2.6 Pipe & Fittings Pressure Class

The Water Services Association of Australia (WSA03-2002 p.69) requires the minimum pipe and fittings pressure class for reticulation mains to be Class 9. Class 9 pipes and fittings must have a nominal working pressure of 900kPa (90 m head).

AS3500.1 (p.10) specifies a Maximum Allowable Operating Pressure (MAOP) for pipes up to DN 100 to be a minimum of 1200 kPa (120m head) and for pipes larger than DN 100 to be selected to satisfy the design criteria for the system.

Given the minimum pressure is assigned as 60 kPa (6m head) for both the traditional and distributed storage networks as discussed in section 2.5 above, and head loss through the modelled network is likely to be less than 50 kPa (5m head), pipes with pressure ratings significantly less than those required by both WSA03 and AS3500.1 could be used.

Because there is no guidance on distributed storage networks, it is possible that cost savings can be made for this system when compared to the traditional network that requires Class 9 pipes. However, this saving would not be attributed to changes in demand or performance requirements from one system to another. It would be unreasonable to claim such savings as an advantage of a distributed storage network. Comparison of pipe pressure class for the purposes of cost savings will be undertaken on the basis of differences found in modelling between the two systems rather than arbitrary specification of a minimum for the traditional design. In the first instance, it will be assumed that Class 9 pipes are required for both the traditional and distributed storage networks.

The selection of pipe class in itself has no impact on modelling the performance of each system. It could potentially give rise to different pipe materials being chosen that have lower roughness coefficients and thereby increased performance, however this is unlikely as plastic pipes which have low roughness coefficients are available exceeding the likely pressures generated in modelling for this research.

2.7 Minor Losses

This research will not be modelling every valve, bend, junction, contraction or other fitting that causes head loss in the network. There are two simple methods commonly used to make allowance for these minor losses in the early stages of modelling, use of a head loss coefficient (K) or increased pipe lengths.

Head loss for flow in a pipe due to friction (major losses) involves the determination of a friction slope multiplied by the length of the pipe.

Additional to this, a coefficient, K, is multiplied by the velocity head for each fitting, bend, tee etc. to approximate losses through each of these items (minor losses). The loss coefficient, K, depends upon the individual size, configuration and materials of each fitting. At an early stage of design, it is not convenient to design for individual fittings as they will often not be determined.

Instead, a single coefficient can be used to provide a preliminary estimate for the cumulative losses from each fitting. Assuming velocity is constant through each main between modelled nodes, a single coefficient will ideally be the sum of each individual fittings coefficient. Estimates for the single coefficient can be made from historical designs of a similar nature.

Alternatively, the pipe length itself can be increased such that the additional major loss from the increased pipe length is used to approximate minor losses. This method assumes a longer length of main will have more fittings than a shorter length and therefore the minor losses should be greater in a longer pipe. This is often not the case.

Both methods are relatively simple and have advantages and disadvantages. They are equally inaccurate without historical analysis or experience. In this research project, a 15% increased pipe length will be used for all pipes to account for minor losses for both the traditional and distributed storage networks.

2.8 Water Quality

A potable water supply system must, in the first instance, be safe for drinking. A number of issues associated with a tank supplemented system can affect water quality including backflow prevention and stagnancy of water. These issues are also a concern for traditional networks but would become more prevalent in a distributed storage network.

Investigation and analysis for water quality and comparison between each network is not part of this research.

2.9 Summary of Traditional and Distributed Storage Design Requirements

Table 2.9-1 below tabulates requirements adopted for each network for the purposes of this research.

	Traditional Design	Distributed Storage Design
Design Flow (L/s/unit)	0.03	0.006
Minimum Pressure (m head)	6.0	6.0
Minimum Pipe Pressure Class	Class 9	Class 9
Added Pipe Length for Minor Losses	15%	15%

Table 2.9-1 Design Requirements Adopted for Traditional and Distributed Storage Networks

3. Project Methodology

The design requirements and project methodology are designed to isolate analysis to those parts of the network for which a comparison is sought. The objective for this project is to determine if a reduced demand flow arising from the use of water tanks to service each unit is translated into reduced pipe diameters and/or pressures in the system. Therefore we wish to isolate design flow as the variable performance requirement with all other performance requirements being equal.

3.1 Subject Site

An isolated network is used for the project site to limit the impact of external influences on the network. Networks can be considered isolated because of their remote location or distinct separation from other areas. In this case, whilst the subject site is in regional Australia, its isolation is provided by distinct separation rather than remoteness. Isolation by distinct separation can still be applicable to remote sites so long as connection for the site is made in the same manner. The major difference is that the length of this connection is likely to be much greater for remote isolation.

As mentioned above, the site is isolated by distinct separation. A single connection is provided from the existing authority main to the site to replicate that which would be provided for a site with remote isolation.

The site chosen for analysis is a proposed workers camp with accommodation for approximately 400 people in single units. A layout plan for the site is shown in figure 3.1a below.

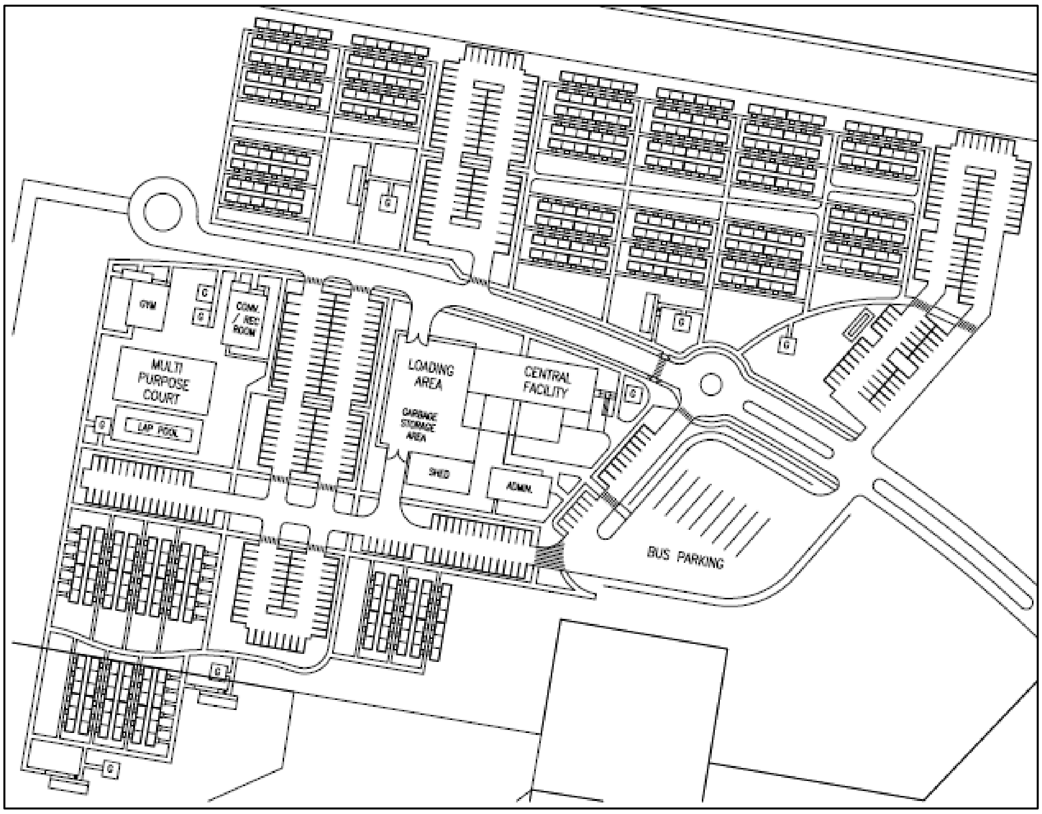

Figure 3.1a Workers Camp Site Plan

The site is small enough so that manipulation of the network requirements and analysis runs are manageable, yet also large enough that differences between network options are readily identifiable.

A real site has been chosen for the analysis to enable the analysis to be directly related to a real world situation and allow quantifiable differences to be determined for a realistic application. Even though we are analysing a single component of the whole water supply system in isolation and ignoring water quality requirements or fire fighting supply, the benefits from using a real site are still worthwhile.

Ground surface levels will be ignored in this analysis. Whilst it would be relevant for designing a reticulation network for the subject site, including changes in level will add unnecessary complication and does not benefit the applicability of this analysis to other sites and general conclusions. Therefore, the site is assumed flat.

3.2 Network Layout

The proposed water reticulation layout is illustrated on plans attached in appendix B and figures 3.2a and 3.2b below. A looped network has been used with "dead ends" only allowed where branches supply a single point of demand. Whilst it is technically feasible to use a "herring bone" supply network in terms of meeting demand requirements, a looped system is widely recommended so that supply to each household can be obtained from two directions. This philosophy allows continued supply when a section of the pipe requires maintenance. It will also aid in circulation of water through the network which reduces the chances of stagnant water and its related water quality issues.

A relatively long connection to the site is required from the current public water authority main. This is an unintended benefit with the chosen site. It is unlikely an isolated development will have existing water supply passing through the site. It is therefore likely that with any isolated development, a considerable length of supply pipe will be required to convey demand for the entire development. This connection further adds a realistic feature to the modelling and can be analysed as a separate item, almost in isolation from the reticulation network for the site itself. This connection to the site is termed a "distribution main" to readily differentiate it from the site reticulation during discussion and analysis. A plan attached in appendix B and figure 3.2 below illustrates the point at which the distribution main ends and the site reticulation network begins. The distribution main extends to the point where a main loop can be formed in the site reticulation. This means a minor reticulation loop and a couple of dead end branches are serviced from the distribution main.

The layout is identical for both the traditional and the distributed tank supply network. This ensures the differences between the traditional network and the distributed storage network are restricted to those resulting from demand requirements only.

A minimum pipe size of 25mm nominal diameter is adopted in the modelling. This minimum has been chosen because PVC-U PN9 pipes, a pressure class adopted as the minimum requirement, are readily available for pipes from 25mm nominal diameter to 375mm nominal diameter.

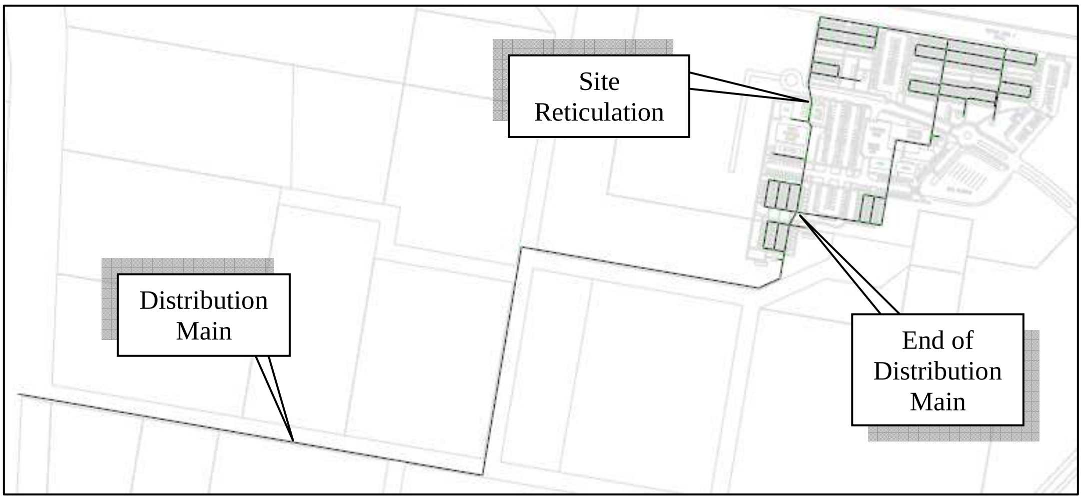

Figure 3.2a Water Supply Network Layout – Entire Layout

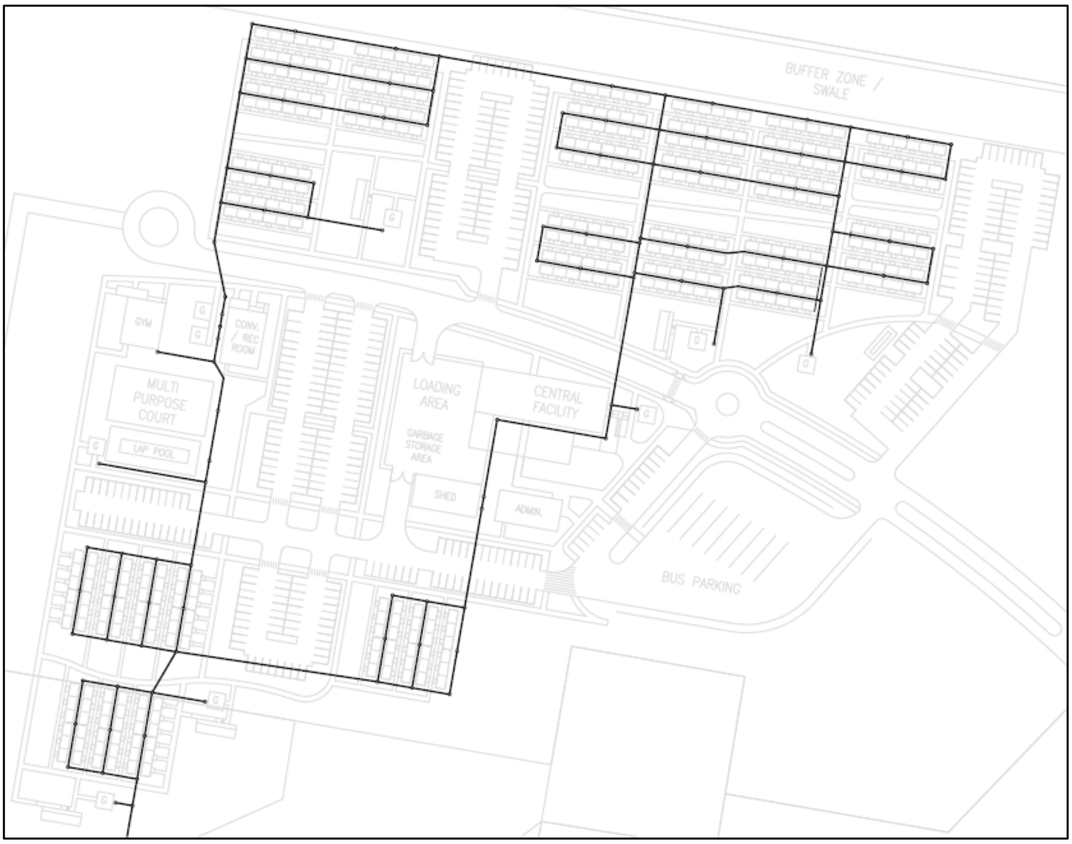

Figure 3.2b Water Supply Network Layout – Site Reticulation

3.3 Modelling

Modelling for the water supply network has been undertaken using Pipes++ software. Watercom Pty Ltd provided a copy of this software free of charge specifically for use in this project.

Pipes++ uses the Colebrooke White formula to determine head loss through each pipe in the network based on the velocity (flow) of water through each pipe. The total flow required at each node is split between each different route to that node. During the modelling process, flows (velocities) are adjusted through each pipe such that head loss through each route deduces the same value for pressure head at the node.

Changes between the traditional network and the distributed storage network are restricted to the demand flows at each node and pipe sizes only. Node locations, pipe lengths, starting pressure at the point of supply from the existing authority main and pressure requirements at each node will remain the same for both networks.

Modelling inputs (pipe sizes and node demands) are illustrated on plans and tables provided in appendix C.

3.3.1 Minor (Fittings) Losses

As discussed in section 2.7, minor losses through fittings (valves, bends, tees, etc.) are represented by increasing the pipe length by 15% for each pipe in the network. This method allows changed velocities between each network to be accounted for in the calculation of losses through fittings.

3.3.2 Network Nodes

For ease of modelling, clusters of interconnected units are represented by a single node with the demand flow rate taken as the demand rate for each unit multiplied by the number of units. Although this research was primarily instigated to investigate separate tanks for each unit, it may also be equally beneficial for each block of interconnected units to be serviced from a single connection to the reticulation main as per the modelling. In any case, whether or not there are separate nodes for each units will have negligible impact on the reticulation system because the take off points for each unit, if serviced from separate connections, will be in close proximity to the single modelled point and minor losses to each node are accounted for by increased pipe lengths rather than the number of fittings along the pipe.

3.3.3 Time Step

Modelling is undertaken for a fixed point in time when demands on the network are at a peak rather than a period of time covering cyclical demands. Given the requirement for Australian water authorities to design for peak demand as mentioned in section 2.3, differences between the two systems at peak demand will provide the potential savings that can be made.

3.3.4 Target Minimum Pressure

The optimum design is produced when all pressures are as close as possible to, and above, the target minimum pressure. Assuming the distributed storage network is delivering water to the top of the tank, and provided potential negative pressures can be avoided, minimum pressure could theoretically be as low as 30 kPa (3 metres head). However, for the purposes of this analysis, target minimum pressure is set at 60 kPa (6 metres head) for both the traditional and the distributed sorage networks in accordance with the discussion in section 2.5.

With both networks obtaining equal minimum pressures, the magnitude of the minimum target pressure is somewhat arbitrary because we are primarily interested in a comparison of pressure loss through the system at different flow rates.

Achieving the optimum design involves an iteration of the following process:

- Hydraulic analysis is performed using Pipes++ software and the resultant pressure at each node in the network noted.
- Pipe sizes are adjusted up or down and analysis repeated until the pressure at each node is as close as possible to, and above, the target minimum pressure.

Plans attached in appendix D annotate each node with resultant hydraulic grade levels for both the traditional and distributed storage networks.

A number of different pipe combinations could be found that result in a similar residual pressure in the most disadvantaged point in the system. This is particularly the case for a looped network. Care must be taken not to attribute a more economical arrangement of pipe sizes as a benefit from the distributed tank network. Having each network design performed by the same person will assist with this potential error because the same logic is applied to each network. However, this approach is not very scientific.

It is difficult to apply a single method to the refinement of pipe sizes and apply it to each network because the refinement process will differ depending upon the residual pressures found in each part of the network. An analysis of the pressure differences at each node and friction slope for each pipe is undertaken to assist with determining inconsistencies between networks.

3.3.5 Pressure Available at the Point of Supply from the Existing Network

A constant head reservoir is used to place the networks under pressure. As the modelling period is instantaneous at peak demand, it is realistic to assume pressure will be constant for the model.

In reality, pressure varies with flow. As flow is increased, potential energy is transformed to kinetic energy and thus the available pressure is reduced. The traditional network will demand greater flows than the tank supplied network. Therefore, reduced pressure at higher flows would disadvantage the traditional network. Technically, a different starting pressure should be used for each network to reflect this. However at this point in time, no information is available for the actual pressures and flows in the public water authority main. Estimating differences in pressure at different flows would introduce more uncertainty into the model and would rightfully be subject to question.

The subject site is small enough that the difference in demand flows from one option to the other will also be relatively small; this will mitigate the inaccuracy of using the same starting pressure for each network. In addition, using the same starting pressure for each option will produce a conservative result with regards potential pipe size reductions and therefore the analysis will not overstate potential benefits from the distributed storage network.

The water level in the reservoir is set at 8 metres (80 kPa pressure at the point of supply). This allows a maximum 2 metres of head (20 kPa) pressure loss through the reticulation network to any node. There are two main reasons for choosing this starting pressure value.

Firstly, limiting the allowable pressure loss in the network will require larger pipe sizes than would be required with a large allowable pressure loss. Given the relatively small size (and therefore relatively small demands) of the development, a large allowable pressure loss might result in the traditional supply network requiring minimum pipe sizes only. There would be no possible reduction in size, and therefore no potential for savings resulting for modelling the distributed tanks network.

Secondly, the starting pressure is aimed at simulating a supply that might be expected in an isolated development. An assumption is made that head loss will need to be kept to a minimum in such a development, either because the existing point of supply is distant from the site or because the development was not accounted for in the design of the existing network. This enables the modelling to be undertaken under conditions that are similar to that which can be expected in a generic isolated site.

3.3.6 Demand Flows

As discussed in section 2.3, current Australian water authority design standards (WSA-03 2002) require a network to be designed for peak hourly demand. The traditional water supply network is modelled with flows required by each unit set at peak hourly demand of 0.03 L/s.

The distributed storage tanks drip feed system will enable supply to be reduced to an average demand because the volume required for peak demand is catered for in tank storage. For the distributed storage supply network, flows required by each unit are set at average hourly demand of 0.006 L/s.

A base demand feature provided in Pipes++ is utilised for assigning demand at each node. The demand flow per unit is entered and each node is assigned with the number of units it feeds. This enabled a single number to be edited when changing from the traditional model to the distributed storage model. The modelling inputs report attached in appendix C lists the number of units fed by each node rather than the design flow at each node. Design flows at each node are annotated on plans attached in appendix C.

3.3.7 Lowest Pressure Network

As an alternative to a potential reduction in pipe sizes, another hypothesised benefit for the distributed tank supply network is a reduction in pressure for the overall network. Reduced pressure through the whole network could potentially result in pipes with a smaller pressure rating to be used and/or less maintenance from pressure related faults.

This scenario keeps the same pipe sizes as the traditional network and runs the hydraulic analysis using the flows from the distributed storage network. A lesser flow in the same diameter pipe will result in lower velocity. As head loss due to pipe friction (major losses) is proportional to velocity, lower velocities will result in lower head loss.

The allowable pressure reduction in the network is the difference between the node with lowest modelled hydraulic grade level and the target minimum pressure.

4. Results and Analysis

4.1 Hydraulic Modelling Results

Pipes++ water supply network modelling software has been used to undertake hydraulic analysis for each network. Modelling inputs are attached in appendix C and modelling outputs are attached in appendix D.

Pipe diameters were limited to standard sizes with a minimum diameter of 25mm. This was chosen because PVC-U PN9 pipes are available in diameters ranging from 25mm to 375mm as standard. This is also a pipe diameter that is between the acceptable minimum for in-ground water supply pipes listed in WSA-03 and AS3500.3-2009.

Although different pipe materials might be more appropriate for different sized pipes, a roughness coefficient of 0.015 was used in the Colebrooke White friction loss calculation for all pipes regardless of size.

4.1.1 Traditional Network Modelling

The traditional network uses peak demand flow, calculated as 0.03 L/s per unit as discussed in section 2.3. A summary of the modelling flows and resultant minimum pressure head is provided in table 4.1.1-1 below.

Demand per Unit (L/s)	0.03
Maximum Flow (L/s)	12.5
Minimum Pressure (m head)	6.01

Table 4.1.1-1 Traditional Network Modelling Flows and Minimum Pressure

Maximum flow to the site from the existing authority water main is the sum of flows for each individual unit. For the traditional network this demand sums to 12.5 L/s. This flow is required to be delivered by the distribution main to the site. The distribution main to the site is 200mm diameter UPVC which results in a head loss of 0.88m between the water authority water main and the main loop within the site. As the nominated pressure at the take off point from the public water authority main is 8m head, the site reticulation has 1.12m allowable head loss to maintain a minimum of 6m head at any point in the system.

The required minimum pressure of 6m head is maintained throughout the network.

4.1.2 Distributed Storage Network Modelling

The distributed storage network uses average demand flow calculated as 0.006 L/s per unit as discussed in section 2.3. A summary of the modelling flows and resultant minimum pressure head is provided in table 4.1.2-1 below.

Demand per Unit (L/s)	0.006
Maximum Flow (L/s)	2.5
Minimum Pressure (m head)	6.00

Table 4.1.2-1 Distributed Storage Network Modelling Flows and Minimum Pressure

Maximum flow to the site from the existing authority water main is the sum of flows for each individual unit. For the distributed storage network this demand sums to 2.5 L/s which, again, is required to be delivered by the distribution main to the site. The distribution main to the site is 100mm diameter UPVC which results in a head loss of 1.36m between the authority water main and the main loop within the site. As the nominated pressure at the take off point from the public water authority main is 8m head, the site reticulation has 0.64m allowable head loss to maintain a minimum of 6m head at any point in the system.

The required minimum pressure of 6m head is maintained throughout the network.

4.1.3 Reduced Pressure Network

The Pipes++ analysis is rerun using the pipe flows from the distributed storage network (average flows) and pipe sizes from the traditional network to see if the system can benefit from reduced pressures. As discussed in section 3.3.7, less flow in the same diameter pipe results in lower velocities and, as head loss is related to velocity, less head loss through the network.

Potential benefits for a network under lower pressure are less pressure related pipe bursts leading to reduced maintenance costs or pipes with lower pressure ratings which results in lower construction costs.

A list of nodes with corresponding hydraulic grade levels for the reduced pressure network is attached in appendix D. Head loss across the entire network is 0.12m for the reduced pressure network as opposed to 1.99m for the traditional network. Head loss for the reduced pressure network is 6% of that for the traditional network.

If a pressure reducing valve were fitted at the start of the distribution main, pressure in the entire network could be reduced by 1.87m (18.7 kPa) to maintain minimum pressure in the system. This reduction in pressure is unlikely to permit use of pipes with lower pressure ratings and it is debatable if such a small pressure reduction would lead to less pipe bursts. However, the modelling was set up with an allowable head loss through the network of 2m head (20 kPa) only, therefore reduction in pressure was never going to exceed 20 kPa under these modelling parameters.

The fact that head loss for the reduced pressure network is 6% of that for the traditional network suggests that, under different modelling parameters simulating a system with greater head loss, the reduced pressure resulting from distributed storage could potentially be beneficial.

4.1.4 Analysis of Modelling Results

To understand the modelling results for each network, comparison is made at certain nodes spaced around the main reticulation loop and zones of nodes in minor loops. Figure 4.1.4a below highlights the chosen nodes numbers around the site reticulation main loop in bold and zones 1 to 10 located in minor loops.

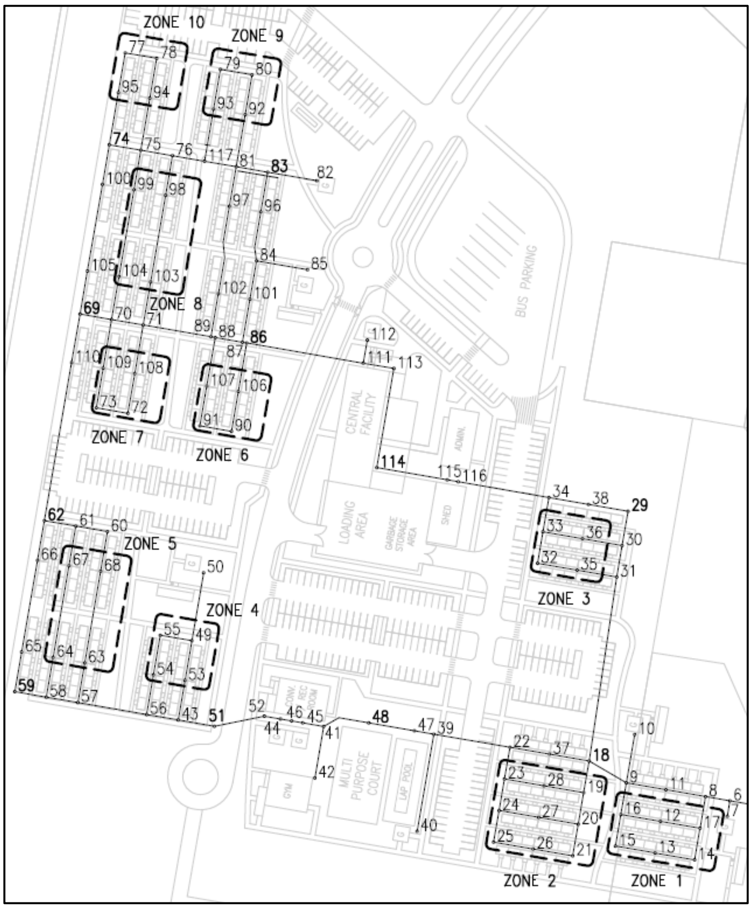

Figure 4.1.4a Site Reticulation Main Loop Nodes & Minor Loop Zones

The primary objective of this analysis is to identify if the comparison being made between the two networks is valid. That is, I want to ensure the comparative advantages and disadvantages of each network are derived from the differences in flow rates rather than other factors such as more efficient design. As many factors as possible, such as physical layout and pipe roughness coefficients, remain identical between the two networks to limit the chances of a more efficient design masking the effects of differing flow rates.

Table 4.1.4-1 below lists the node HGL for certain nodes spaced around the main reticulation loop starting at node 18 and progressing clockwise back to node 18. Node 18 marks the end of the distribution main and the commencement of the site reticulation main loop.

Node	Traditional HGL (m)	Distributed Storage HGL (m)	Difference in HGL (m)	Distance from Node 18 (m)
18	7.12	6.64	0.48	0
48	6.75	6.38	0.37	89
51	6.53	6.21	0.32	152
59	6.32	6.08	0.24	232
62	6.23	6.04	0.19	301
69	6.16	6.02	0.14	384
74	6.14	6.02	0.12	434
83	6.15	6.04	0.11	516
86	6.21	6.14	0.07	584
114	6.47	6.46	0.01	685
29	6.75	6.54	0.21	786
18	7.12	6.64	0.48	886

Table 4.1.4-1 HGL Comparison Around Site Reticulation Main Loop

Head loss at node 18 is greater for the distributed storage network than the traditional network. The friction slope (head loss per metre) for the distribution main is greater for the distributed storage network. This is because the reduction in pipe diameter, even with a fifth of the flow, results in greater friction between the liquid and the pipe wall. There are limited standard pipe diameters available which makes it difficult to exactly match a uniform head loss per metre length along the network from start to end when flow is steadily reducing as it is drawn off for use by households. The distributed storage network allows greater head loss in the distribution main at the expense of less allowable head loss across the site reticulation. This is further discussed in section 4.2.1 below.

Figure 4.1.4b graphs the hydraulic grade levels against distance around the site reticulation main loop for the nodes listed in table 4.1.4-1 starting and ending at node 18. The parabolic shape of the traditional network graph is as expected for a loop with a single pipe diameter where flow gradually reduces towards the extremity of the loop due to demands of nodes along the way. For the site being modelled, the extremity of the main loop is near to node 74, 434m from node 18 in a clockwise direction. As the flow rate closer to the extremity decreases, velocity decreases, and therefore the rate of head loss (slope of the line) also decreases.

To consider the distributed storage network equivalent to the traditional network with regards head loss and allowable head loss in the minor loops, a parabola approximately parallel to the traditional network but with slightly flatter slopes would be expected. The left hand side of the graph does indeed approximately parallel the traditional network, however the right hand side does not. The flatter gradient of the right hand side is associated with a larger (80mm) pipe diameter for that part of the loop than the rest of the loop (50mm). As with the differences in the distribution main, gradations of standard pipe sizes makes it difficult to provide a uniform rate of head loss through to the extremity of the network.

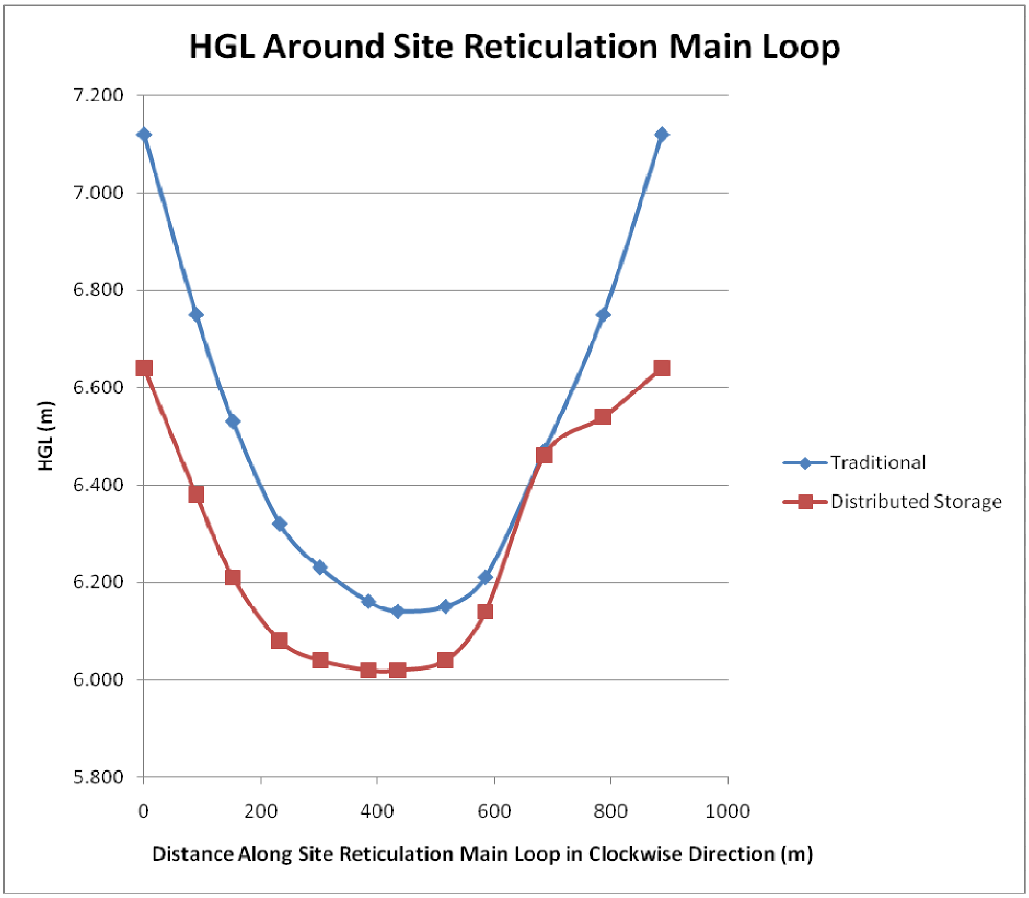

Figure 4.1.4b HGL Around Site Reticulation Main Loop

Non uniform head loss in itself does not make the two networks being compared unequal. However, when one network has reasonably uniform head loss and the other does not, it has the effect of allowing different head losses in different areas. This in turn allows smaller pipe diameters in the area that has a greater allowance of head loss. This disparity should be balanced by larger diameter pipes in the main loop being required to create the inequality. Aside from the disparity associated with the 80mm diameter pipes in the site reticulation main loop for the distributed storage network, the analysis around the main loop demonstrates similarity and is therefore favourable for direct comparison.

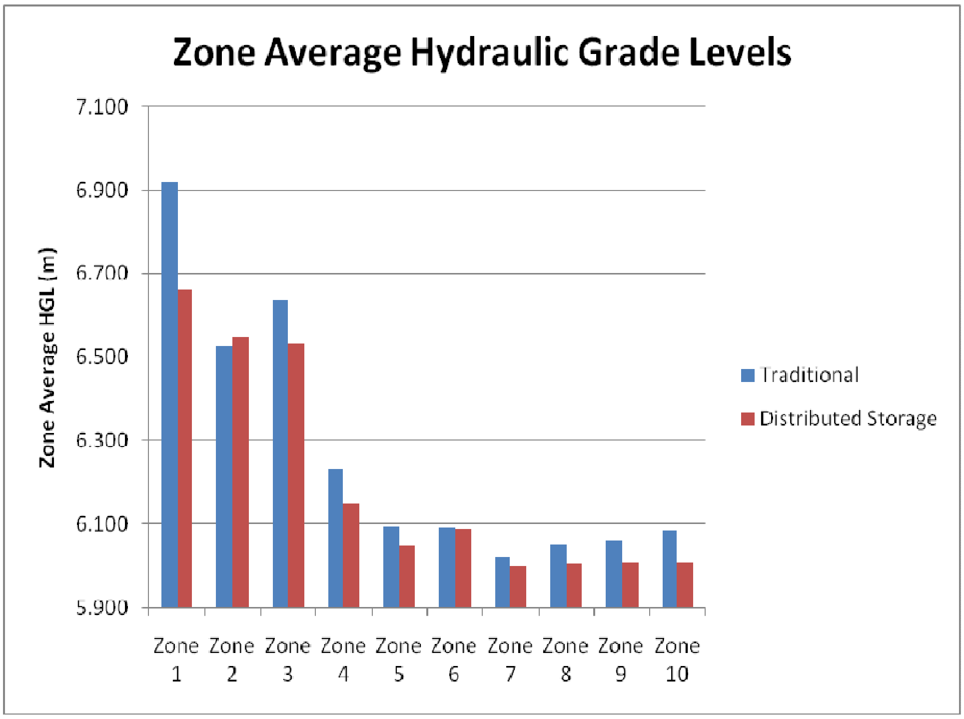

Figure 4.1.4c Zone Average Hydraulic Grade Levels

Figure 4.1.4c charts average hydraulic grade levels for each zone in figure 4.1.4a for both the traditional and distributed storage networks. Zone 1 is serviced directly from the distribution main. The hydraulic grade level at node 18 for the distributed storage network is 0.48m below that for traditional network. As zone 1 is reasonably close to node 18, it is not surprising the average hydraulic grade level for the distributed storage network is significantly lower than that for the traditional network, particularly as both networks have the minimum 25mm diameter pipe diameter for all pipes within the zone. A general pattern is followed by both networks with exceptions further discussed below.

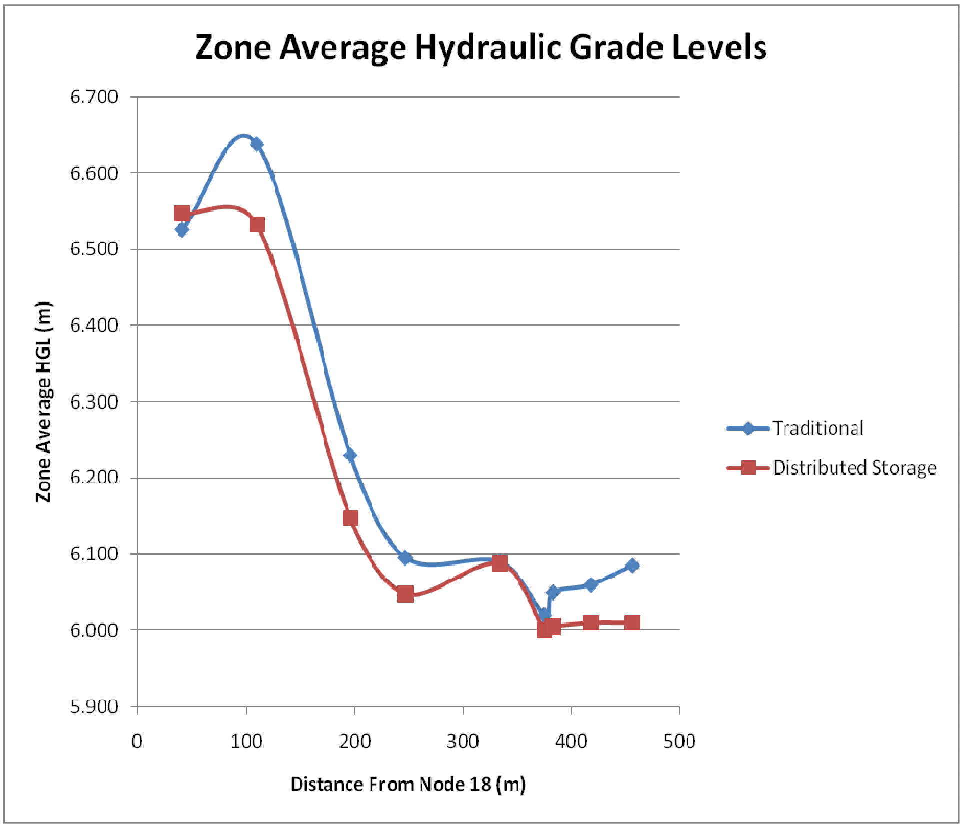

Figure 4.1.4d Zones 2-10 Average Hydraulic Grade Levels v Distance from Node 18

Figure 4.1.4d graphs average hydraulic grade levels for zones 2-10 in figure 4.1.4a for both the traditional and distributed storage networks against distance from node 18. I would have expected a continuous fall in the graph as distance from node 18 increased. This is generally the case except for zones 3 & 6, and zones 8 to 10.

Either zone 2 has a lower than expected average HGL or zone 3 has a higher than expected average HGL. In both the traditional and distributed storage networks the assigned minimum pipe diameters are used for all pipes within these zones. Given the proximity of these zones to the start of the site reticulation main loop, it was always expected these zones would have average HGLs well above the prescribed minimum and therefore minimum pipe diameters were likely. Although zone 3 is more distant from the start of the site reticulation main loop than zone 1, less flow is directed towards zone 3 and therefore velocity and head loss are lower along the main loop towards zone 3. This explains why zone 3 has a higher average HGL than zone 1. As the pipe diameters do not change in these zones between the traditional and distributed storage network, and the pipes are set at the prescribed minimum, potential issues associated with differences between what was expected in these zones are considered negligible.

Zone 6 is fed by the main passing by zone 3 in a counter clockwise direction. Although linked, it is logical that zone 3 does not have the same head loss associated with zones fed by the main loop in the clockwise direction. Average HGL for zone 6 is almost identical for the traditional and distributed storage networks. I would generally expect the average HGLs for the distributed storage network to be lower than the traditional network because flows and velocities are less for the distributed storage network and should therefore generate a flatter slope for the head loss per metre as discussed above. As the distributed storage network uses the prescribed minimum pipe diameters in this zone, it is concluded this prescribed minimum is setting the distributed storage network HGL higher than it could be if no minimum diameters were used.

The zone with the lowest average HGL for both the traditional and distributed storage networks is zone 7. This is slightly surprising given it is not the most remote from the start of the site reticulation. However, when setting up the model, I purposely directed the site reticulation main loop to run past zones 9 and 10 by assigning larger pipe diameters for this route. This is likely the reason zones 9 and 10 have higher average HGLs than zone 7.

Even when the inconsistencies above are included, the general trend for hydraulic grade levels around both the traditional and distributed storage networks is consistent. On this basis a comparison based on the current modelling results is valid.

4.2 Physical Comparison of Networks

There are two distinct components to the water supply network, a distribution main from the existing authority water main to the site, and reticulation through the site itself. Applying this research to an isolated community, the distribution main to the site is analogous to the main pipe from a water source (eg. a bore, reservoir or existing water main) to the community that is to be supplied with reticulated water. This distribution main could be many kilometres in length and may represent the majority of cost associated with providing reticulated water to an isolated community. It is therefore worthwhile separating these two components for comparison.

4.2.1 Distribution Main Comparison

The distribution main is deemed to extend from the existing water main at node 1 to the main loop around the site at node 18 as shown on plans attached in Appendix C and identified in figure 3.2a.

Table 4.2.1-1 below shows a comparison of the diameter and flows used in modelling of the distribution main for the traditional and distributed storage networks. Pertinent modelling outputs are also listed. Note that velocity is based on internal diameters specified by the software assigned to each nominal diameter.

	Traditional Design	Distributed Storage Design
Pipe Length (m)	1206	1206
Nominal Pipe Diameter (mm)	200	100
Internal Diameter (mm)	208.5	104.7
Max. Flow (L/s)	12.5	2.5
Max. Velocity (m/s)	0.37	0.29
Ave. Friction Slope (m/km)	0.73	1.13
Head Loss (m)	0.88	1.36

Table 4.2.1-1 Physical Comparison of Networks for the Distribution Main

When modelling the entire network inclusive of reticulation mains, the diameter of the distribution main for the distributed storage network is half that required for the traditional design. A component of this reduction is due to the greater allowable head loss over the length of the distribution main. The minimum pipe size chosen for the analysis results in low velocities at extremities of the site reticulation for the distributed storage network where demand is small. As head loss is related to velocity, head loss is also small in these areas thus leading to a smaller overall head loss through the site reticulation. Smaller head loss through the site reticulation component has allowed a greater head loss through the distribution main.

The site used in this research was able to accommodate greater head loss in the distribution main. As a proposed site becomes further away from the point of supply, head loss in the distribution main will contribute a greater proportion to overall network losses inclusive of the reticulation network. When the site is distantly remote from the point of supply, head loss through the site reticulation may become insignificant compared to that lost in the distribution main. Under this situation, head loss in the distribution main will need to be identical for both a traditional and distributed storage network. It is therefore of interest to determine the allowable reduction in pipe diameter for the distributed storage network when head loss is equal.

Head loss through each pipe is calculated using the Colebrooke White equation which can be expressed as,

$$V = -2\sqrt{(2g)\, D\, S_f}\, \log\left(\frac{k_s}{3.7D} + \frac{2.15\, \upsilon}{D\sqrt{(2g)\, D\, S_f}} \right) \qquad (4.1)$$

where:

where:	V	=	velocity, m/s
	D	=	pipe diameter, m
	S_f	=	friction slope i.e. h_f /L, m/m
	k_s	=	pipe roughness, m
	υ	=	kinematic viscosity, m^2/s
	g	=	gravitational acceleration, m/s^2

Kinematic viscosity and gravitational acceleration are identical in both the traditional and distributed storage networks.

It is common for pipe materials to differ when pipe diameters are significantly different. For example, PVC pipes, which largely rely on trench support for load carrying capacity, may have sufficient structural strength at small diameters, but cannot offer the same load carrying ability at large diameters. Changes in pipe materials will affect the pipe roughness coefficient. However, for the purposes of this research, the pipe roughness coefficient is kept the same for every pipe diameter used. The range of pipe diameters used in the modelling for both the traditional and distributed storage networks can all be constructed from PVC-U PN9 pipe. Therefore, the decision to keep the pipe roughness coefficient constant for both networks is considered acceptable.

Head loss from the point of supply at the existing water authority main to the site is a function of the friction slope times the distance. As the length of pipe is identical in both networks, to obtain an identical head loss requires the same friction slope. Using the friction slope obtained in the traditional network modelling in the Colebrooke White equation will enable the equivalent pipe diameter for the distributed storage network to be determined.

As flow rate is a simple function of velocity and pipe diameter, adjusting the pipe diameter by trial and error can be performed to obtain the required distributed storage flow rate. With all other variables fixed, an internal pipe diameter of 114.5mm results, which is 55% of the size required for the traditional design. This still represents a significant reduction in the required pipe size for the distribution main.

Because there is no standard pipe of 114.5mm internal diameter, a less costly design for the distributed storage network results from allowing larger head loss in the distribution main and less head loss in the site reticulation network. Further comment will be made on this in section 4.3.1 below.

4.2.2 Site Reticulation Comparison

Within the site reticulation there are two distinct parts, a looped “trunk” main and smaller loops and branches that infill the area. The looped trunk main is highlighted in figure 4.2.2a below.

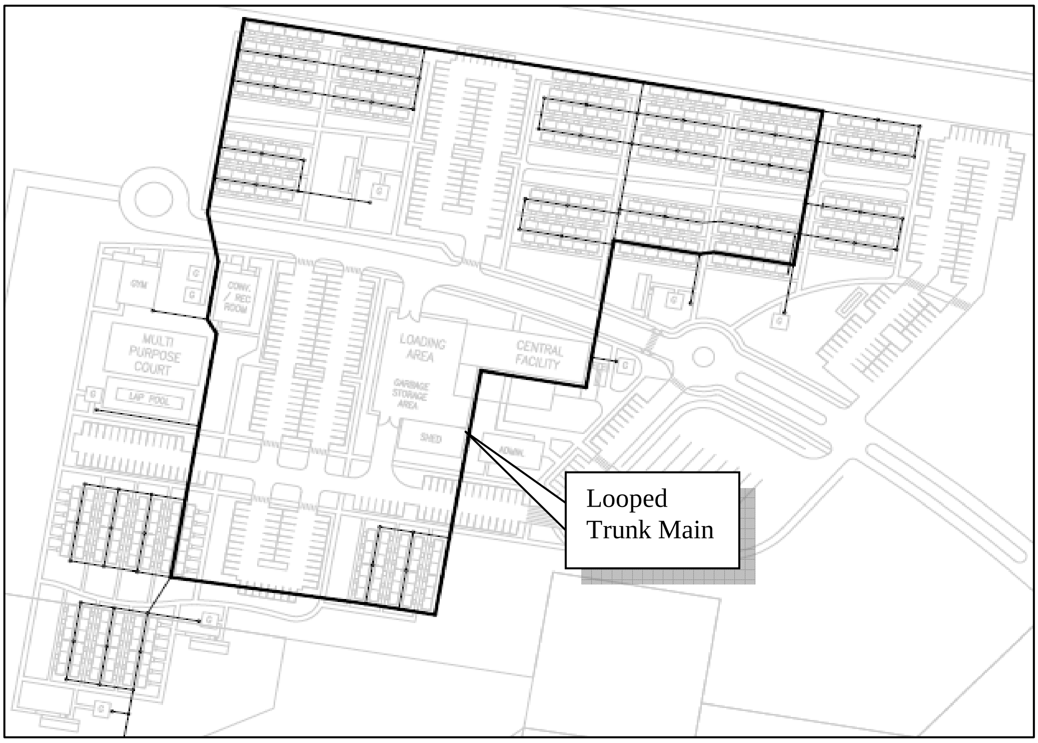

Figure 4.2.2a Site Reticulation Looped Trunk Main

Tables 4.2.2-1 and 4.2.2-2 below list the lengths of each pipe diameter used in modelling the traditional and distributed storage networks for site reticulation.

Pipe Diameter (mm)	Traditional Design Pipe Length (m)	Distributed Storage Design Pipe Length (m)	Difference (m)
100	887	0	-887
80	0	242	+242
50	0	645	+645
Total	887	887	0

Table 4.2.2-1 Pipe Sizes Comparison for Site Reticulation – Main “Trunk” Loop

For the traditional network, all 100mm pipe diameters make up the looped trunk main totalling 887m length. In the distributed storage network, the looped trunk main pipe diameters have been reduced to 242m length of 80mm diameter and 645m length of 50mm diameter. Using a weighted average, the result is a reduction in pipe diameter to 58% of that required for a traditional design.

As discussed in 4.2.1 above, head loss from commencement of the site reticulation network to the most disadvantaged node is less for the distributed storage network than the traditional network. The site reticulation for the distributed storage network is effectively operating under more stringent requirements than the traditional design. As with the distribution main, it is of interest to model the site reticulation network using identical head loss.

Node 18 has been chosen as the point at which the distribution main connecting the site from the point of supply ceases and the site reticulation network commences. In the traditional design model, the hydraulic grade level at node 18 is RL 7.12m. Modelling the distributed storage site reticulation network with a hydraulic grade level at node 18 of RL 7.12m and with all 80mm pipe diameters further reduced to 50mm results in a hydraulic grade level of 5.98m (59.8 kPa) at the most disadvantaged nodes, very nearly the assigned minimum hydraulic grade level of 6.0m (60 kPa). With a slightly greater head loss, the distributed storage network has pipe diameters for the main loop 50% of that required in the traditional design.

Pipe Diameter (mm)	Traditional Design Pipe Length (m)	Distributed Storage Design Pipe Length (m)	Difference (m)
50	66	0	-66
32	644	66	-578
25	673	1317	+644
Total	1383	1383	0

Table 4.2.2-2 Pipe Sizes Comparison for Site Reticulation – Minor Loops and Branches

For the minor loops and branches, all 50mm diameter pipes in the traditional network have been reduced to 32mm diameter, all 32mm diameter pipes have been reduced to 25mm diameter. Pipe diameters have dropped by a standard size. All 25mm diameter pipes remain the same as this is the prescribed minimum diameter for any pipes.

The results above suggest pipe diameters in a distributed storage network, whereby flows are one fifth of that for a traditional design, can be reduced to 50-60% of the size required for a traditional design.

4.3 Cost Analysis

Where appropriate, rates for cost analysis have been obtained from the Rawlinsons Australian Construction Handbook 2005 edition. The objective for this research is to identify the differences in costs between two networks. Extensive costing for the networks is not required for this purpose. Instead, the items that differ from one network to the other are costed. That is, the installation and maintenance of pipes and fittings.

Cost schedules are attached in appendix E.

4.3.1 Construction Costs

Table 4.3.1-1 below summarises construction costs for components of the traditional and distributed storage networks. Costs have been separated into those for the distribution main and those for site reticulation to align with the physical comparison separation.

	Traditional Design Cost	Distributed Storage Cost	Saving	Percent Saving
Distribution Main	$130,000	$60,000	$70,000	54%
Site Reticulation	$90,000	$70,000	$20,000	22%
Tanks & Pumps	-	$320,000	($320,000)	N/A
Total	$220,000	$450,000	($230,000)	(105%)

Table 4.3.1-1 Construction Costs Summary

Construction costs for the distribution main comprise pipe installation costs only. Although fittings for large diameter pipes can be relatively expensive compared to smaller diameters, it is assumed the distribution main will have few fittings along its length. The omission of fittings is justified because there are few branches from the main for which isolation with valves would be required.

Trench excavation, pipe laying and backfill costs have been included in the pipe installation cost and are assumed to be the same for both the 100mm diameter and 200mm diameter pipes. This is because it is assumed the same trench width would be used for both pipe diameters.

The distributed storage construction cost for the distribution main is less than half the construction cost for the traditional design. This represents a significant saving between the two networks and suggests the distributed storage network, at least from the perspective of the connection to the site, is a worthwhile prospect.

As mentioned in section 4.2.1 above, the distribution main for the distributed storage network has a greater allowable head loss at the expense of the site reticulation. This is a more economical solution for the network as a whole. If the 100mm diameter distribution main was increased in size to 150mm diameter to allow a balance in head loss for each component, an additional $30,000.00 would be added to the costs for the distribution main. The benefit of reducing the site reticulation main loop pipes to 50mm diameter throughout would net a saving of $5,000.00. The savings in the site reticulation do not warrant the increased cost for the distribution main.

Cost of fittings has been included in the site reticulation construction costs by using a rate per metre assuming a fitting every 30 metres on average. This is possibly an appropriate spacing for the main loop but may be too sparse for the minor loops. The difference between fitting costs for smaller diameters is less significant therefore it is appropriate to use the larger pipe diameter spacing for preliminary costing.

For the site reticulation, construction costs were found to be less for the distributed storage network compared to the traditional network; however it is a less significant saving than that determined for the distribution main. There are some easily identifiable reasons for the disparity between the distribution main and the site reticulation. Firstly, pipe diameters in the site reticulation reduced by a standard size rather than being halved as they did for the distribution main. Secondly, some pipes in the traditional network were already the prescribed minimum diameter and therefore could not be further reduced. Finally, as pipe diameters are reduced, the trench excavation, laying and backfilling become a larger proportion of the overall pipe installation costs. For small pipe diameters there is not as much saving for reducing pipe sizes as there is with larger diameters.

The traditional network does not require pumps and tanks as part of the water supply system; water under pressure in the reticulation pipes feeds each house directly. Therefore a nil cost for pumps and tanks is assigned for the traditional network.

The distributed storage network requires pumps and tanks, in this case at every household, to enable reticulation mains to be designed for lesser flows. Although the cost of a small tank and domestic pump is quite small, when multiplied by the number of households being serviced the sum total is significantly greater than any other component in the system. This cost outweighs any savings made in the distribution main and site reticulation combined. Initially one might think this makes the distributed storage network unfeasible as an alternative. However, as discussed in chapter 1, many local authorities are making rainwater tanks and re-use mandatory because they reduce demand on limited public water supplies and reduce loads on authority stormwater drainage systems. Under this scenario, where pumps and tanks are required in any case, this cost could be removed from the cost comparison between traditional and distributed storage networks. Other scenarios could also be explored to reduce the cost of tanks and pumps such as a cluster of houses sharing the same tank.

4.3.2 Maintenance Costs

A life cycle study of water networks by Ambrose et. al. (fig.1, p.6) suggests average failure rates for 200mm diameter PVC pipe are less than 1% of the network per year for mains operating at 730 kPa. For the purposes of this research I have assumed a pipe replacement of 0.5% per annum over a period of 50 years. 0.5% of the construction cost multiplied by 50 gives the maintenance costs in present day dollars for the distribution and site reticulation listed in table 4.3.2-1 below. Significant percentage savings can be demonstrated, however the scale of the network being costed results in minimal cost savings for the distributed storage network.

	Traditional Design Cost	Distributed Storage Cost	Saving	Percent Saving
Distribution Main	$30,000	$15,000	$15,000	50%
Site Reticulation	$25,000	$20,000	$5,000	20%
Tanks & Pumps	-	$680,000	($680,000)	N/A
Total	$55,000	$715,000	($660,000)	(1200%)

Table 4.3.2-1 Maintenance Costs Summary

To determine maintenance costs for the tanks and pumps I have assumed a 25 year life for the tanks and 10 year life for pumps. Therefore tanks will need to be replaced once in the 50 year period and pumps will need to be replaced four times. There is significant costs for maintenance of tanks and pumps associated with the distributed storage network that do not occur with the traditional network. As discussed in 4.3.1 above, if tanks and pumps are required for households in any case, as is currently required by many local authorities around Australia, the cost of tanks and pumps could be removed from the calculation.

5. Discussion and Conclusions

5.1 Modelling Results

Modelling produced a reduction of pipe diameters in the order of 50-60% for the distributed storage network over the traditional network.

This reduction required average flows to be one fifth of peak flows as recommended by the Water Standards Association of Australia in the absence of more accurate data. Typical diurnal water patterns suggest average flows are more like 50% of peak flows. However, a considerable margin of safety must be provided for the traditional network to ensure peak demands that might exceed collected data can be accommodated. The distributed storage network will have less need for considerable safety margins. If adequate storage is provided in the distributed storage tanks, a spike in the peak demand can be recovered over the full day or perhaps a number of days. Thus average demand will increase marginally for a spike in peak demand.

The initial specification for this research identified isolated communities as the target. Isolated communities were considered those that might benefit the most from the research, particularly if there is no existing water supply network available. The site used for this project is a proposed workers camp for 400 residents. This proposed development was chosen because it is typical of modern temporary communities set up for significant mining developments and it is of a scale that mimics that of a small community. The modelling results are therefore applicable to similar developments and the targeted isolated communities. Sensitivity of the analysis, although inferred by the results, is not specifically targeted and should be the subject of further research.

5.2 Distribution Main Comparison

The main benefit found by this research is for the distribution main to the site. Pipe diameters and construction costs halved for the distributed storage network. This is because the distribution main carries flow for the entire network. Reducing pipe diameters from 200mm to 100mm results in a greater saving than reducing pipe diameters from 100mm to 50mm diameter. Greater flows, such as that in the distribution main, require larger pipe diameters, and therefore the benefit of reduced pipe diameters for the distributed storage network result in greater savings.

In general, the larger the peak demand (flow), the greater the benefit for the distributed storage network. Therefore, larger communities will likely benefit more than smaller communities. However, as population increases beyond 2000, the Water Services Association of Australia recommendation for peak hour factor, which determines the difference between peak and average flows, starts reducing from 5 to 2. Therefore, for populations above 2000, the difference between peak and average flows will gradually reduce and corresponding benefits will also gradually reduce. Certainly, for populations up to 2000, pipes that convey the full flow demand will benefit greatest from a distributed storage network.

This highlights the benefit of providing a storage reservoir in close proximity to the community being served. For the traditional network, at some point the length of distribution main from the point of supply will warrant inclusion of a storage reservoir closer to the point of demand. The distribution main for the traditional network would be designed as for the distribution main in a distributed storage network. Under this scenario, the advantage of the distributed storage network will be to remove the requirement for a locally sited storage reservoir, the pipe sizes supplying the community will be equivalent with both networks.

5.3 Site Reticulation Comparison

As with the distribution main, the distributed storage network had the effect of reducing pipe diameters by 50-60%. The benefits were not so great for the site reticulation. This is partly because some pipes in the traditional network were already at the prescribed minimum diameter and partly because trench excavation and backfill costs make up a larger proportion of the pipe installation cost with smaller diameter pipes.

5.4 Tanks and Pumps

The cost of supplying tanks and pumps far outweighs the savings made from both the distribution main and site reticulation pipes. If tanks and pumps are needed solely because of implementation of the distributed storage network, there does not appear to be any benefit for the network as a whole unless transfer of costs from the infrastructure network to each household is desired.

Many local authorities in Australia are requiring the installation of tanks and pumps for re-use of rainwater to reduce reliance on the public utility water supply system and to reduce loads on the authority stormwater drainage system. If a development is encumbered with this requirement, the cost of tanks and pumps are not as a result of the distributed storage network and can therefore be excluded from the calculations.

The Master Plumbers and Mechanical Services Association of Australia supports the use of rainwater tanks for all household water consumption subject to the requirements of the local health authority. The Water Services Association of Australia Integrated Rainwater Tank Systems publication recognises authority mains can be resized to better match actual demands required. It appears the only stumbling block to combining the system proposed in this research with rainwater tanks from the perspective of these agencies is the potential health risk. The New South Wales Office of Environment and Heritage (2013) shows concern for the health risk when recommending tank water not be used for potable water supply when a mains water supply is available. To receive the benefit from tanks and pumps being installed for re-use of rainwater, the objections of the New South Wales Office of Environment and Heritage would need to be overcome.

5.5 Reduced Pressure Network

The network modelled with average flows from the distributed storage network and pipe diameters used in the traditional network resulted in head loss across the network being only 6% of that for the traditional network (a 94% reduction in head loss).

Modelling for the subject site assumes 20 kPa loss in pressure from the start of the network to the most distant point. Pipe pressure classes graduate in hundreds of kPa. With the limited allowable drop in pressure over the network, the potential benefits for reduced pressure loss will not result in change of pipe class to a more cost effective pipe. If a distantly remote site were being considered that required large initial pressure to force water long distances, a reduced pressure network may be considered beneficial. Under such a scenario it is likely a long distribution main would be designed for average flows with a large storage reservoir closer to the community being serviced. Whilst there would be no savings in the distribution main because both networks would be designed for average flows, the distributed storage network could remove the requirement for a large storage reservoir, instead replaced with small distributed storage tanks.

The life cycle study of water networks by Ambrose et. al. (fig.1, p.6) suggests a 5% increase in pipe failure for an increase from 730 kPa to 850 kPa, approximately 1% for every 20 kPa increase. For the network being considered as part of this research, the potential benefit for reduced pipe failures is insignificant. However, for larger networks it may become a significant cost saving to be explored, particularly if pressures need to be high at the origin to adequately service the entire area.

Another perhaps more likely advantage of the reduced pressure network may be where limited pressure is available at the point of supply. The reduced pressure network would not necessarily be a way of reducing pipe costs, but could remove the need for large tanks, pumps or elevated reservoirs to raise pressure at the point of supply.

5.6 Summary

This research proves tangible benefits can be obtained when a distributed storage network is adopted even when conservative assumptions regarding minimum pressures are included.

If tanks and pumps need to be included solely due to the implementation of the distributed storage network, the system as a whole is more costly to construct and maintain. Incorporation of rainwater tanks that may be required by local authorities is critical for making the system economical. For this to occur, potential health risks need to be addressed.

6. Further Study

The potential benefits confirmed as part of this research warrant further study to examine topics not covered here, and to better develop the concept for use in real world applications. The following topics have been revealed during investigation for this research and are discussed in brief to identify issues to be the subject for further study.

6.1 Incorporating Rainwater Re-Use

Household water tanks are widely used to collect and re-use roof water. Rainwater re-use can be beneficial in reducing dependence on scarce water supplies and reducing quality and quantity of storm water discharge. Rainwater re-use typically requires tanks and pumps, as does the proposed distributed storage network. It would be economically advantageous to combine rainwater re-use and distributed storage water supply infrastructure.

However, the New South Wales Office of Environment and Heritage (2013) recommends tank water not be used for potable water supply when a mains water supply is available. This is presumably due to potential health risks associated with potable use of rainwater, either directly to the end user or potential contamination of the mains supply. Impacts upon the water supply network will need to be investigated, particularly with regards to water quality and cross contamination.

Aside from the risk posed by contaminants in collected rainwater, reduction in demand from the water supply network will increase the chances of stagnation in the mains which could potentially compromise water quality.

6.2 Water Quality

Investigation into water quality has been omitted for the purposes of this research. Subsequent research will need to address stagnation and cross contamination.

Stagnant water must be avoided in water supply networks because residual chlorine deteriorates and sediments may drop out of the water and accumulate in the pipes. The distributed storage network will produce more regular and smaller flows than the traditional network. More regular flows could be a benefit to the system in reducing the chances of stagnant water. However, the traditional design generates peak flows that can effectively flush the system twice daily. In this regard, smaller flows could be detrimental to water quality.

If water use is suspended, as may be the case for an empty dwelling, water would sit in the household tank for long periods of time. This again could lead to decline in chlorine residue and sediment accumulation.

6.3 Minimum Pressure Requirements

The analysis undertaken as part of this research project assumed minimum pressure of 6m head (60 kPa) at the point of supply to each unit for both the traditional network and the distributed storage network. This assumption was based on an Australian Standard (AS3500.1-2003, p.16) specification that "minimum working head at the furthermost or most disadvantaged fixture or outlet shall not be less than 50 kPa (5 m head)" and an allowance of 10 kPa (1 m head) loss through pipes in the household.

Current Australian design guidance regarding minimum pressure has been discounted for the purposes of this research. The validity of requiring minimum 200kPa (20m) pressure for domestic reticulation should be tested to allow infrastructure to be designed for the requirements of individual sites rather than generic values to cover all situations.

Comparison between the two networks did not require accurate determination of minimum pressure requirements as the method used in this research matched head loss through the network with two different flows by adjusting pipe sizes. Using this method, the starting and ending pressures are largely irrelevant.

For the distributed storage network, assuming a pump is used at each household storage tank to place the internal pipes under pressure, minimum pressure at the point of supply only needs to be the height of the tanks plus an allowance for discharging from above the tank. Common household tanks are 2 to 2.4m high. Therefore, minimum pressure for the distributed storage network could be as low as 3m head (30 kPa), half that of the minimum pressure determined for the traditional network. A lower pressure requirement for the distributed storage network would provide additional benefits above that reported in this research.

No investigation has been carried out to ascertain minimum pressures required to ensure sufficient positive pressure is maintained in the network to prevent ingress of groundwater. Although minimum pressure for the distributed storage network can potentially be lower than that required for the traditional network, a safety margin added to minimum pressure for supply might negate any potential reduction.

Head loss is directly related to flow through the pipe. Assumed hourly flows have been used in the modelling based on basic demand rates published in relevant literature. It is unlikely that demand for any particular development exactly matches published figures produced to encapsulate large geographical regions; at some point demand will no doubt exceed those figures. If safeguards are not adopted to ensure actual flows do not exceed those assumed, head loss could be greater than that produced in the design. Undoubtedly, allowance for this scenario is provided in traditional network design guidance for minimum pressure.

For a remote development, overestimating minimum pressure could have a significant impact on infrastructure costs. Investigation should be carried out to determine what value should be adopted for distributed storage networks including allowance for ensuring negative pressures do not result from flow rates above those adopted in design.

6.4 Energy Use

The effects of increased energy use for pumps required by the distributed storage network in terms of resources and costs have not been included in this research. Increased energy use could be significant when multiplied by the number of households the community.

Increased energy use from pumps may be partially offset by reduced energy and resources required for manufacture of smaller pipes.

6.5 Clustered Distributed Storage Networks

If included in the analysis, the cost of tanks and pumps required for the distributed storage network greatly outweighs savings for reduced pipe sizes in both the distribution main and the site reticulation combined. The site layout for the proposed development being modelled is characterised by clusters of units. If houses are in close proximity, there may be opportunity to share tanks and pumps between households and thereby reduce the costs associated with these items.

Cursory investigation suggests the distributed storage network construction costs would be less than the traditional network inclusive of tanks and pumps if every four households shares tanks and pumps. Minimal tank volumes and domestic pump rates would make this feasible.

However, households sharing tanks and pumps would need to be in close proximity otherwise the cost of interconnecting pipes might outweigh the benefits.

6.6 Fire Fighting

Fire fighting requirements were not included in this research. The Water Services Association of Australia suggests domestic supply networks should not be upgraded solely for satisfying fire fighting requirements although they further state that fire fighting requirements must be addressed. Generally, a separate system for fire fighting is provided with larger pipes that service hydrants only.

Investigation should be carried out to find out if fire fighting requirements can be integrated in the traditional or distributed storage network and thereby determine if there is an advantage for one network over the other.

6.7 Different Size Communities

As mentioned in section 5.2 above, whilst conclusions can be drawn from the results with regards different flows, sensitivity analysis including changes in peak hour factor (PHF) with increasing population was not undertaken as part of this research.

It is likely that benefits for communities may need to be determined on a case by case basis. However, the effects of different sized communities should be investigated to see if trends might reveal those situations where benefits are most likely.

7. References

Ambrose, M., S. Burn, D. DeSilva and M. Rahilly. *Life Cycle Analysis of Water Networks*, Retrieved from: www.pepipe.org/uploads/pdfs/Life_Cycle_Cost_Study .pdf, (Accessed on: 10 October, 2013)

Beal, C.D., Stewart, R.A., Huang, T. (2010), *South East Queensland Residential End Use Study: Baseline Results – Winter 2010*, Urban Water Security Research Alliance Technical Report No. 31, Griffith University, Queensland

Ergonomics in Australia 2013, Mark Dohrmann and Partners Pty Ltd, 200 Mt Alexander Rd ,Flemington, Victoria 3031, Australia , viewed 25 May 2013, <http://www.ergonomics.com.au/pages/400_useful_info/420_how_to_sit.htm>

Master Plumbers and Mechanical Services Association of Australia (MPMSSA) 2008, *Rainwater Tank Design and Installation Handbook*, MPMSSA, Melbourne

Melbourne Water 2006, *Water Supply –Demand Strategy for Melbourne 2006 – 2055*, Melbourne Water, Melbourne

Scotland Island Community Website 2013, Scotland Island Residents Association, viewed 18 May 2013, <http://scotlandisland.org.au/living/community-services/emergency-water/>

South Australian Water Corporation 2011, *Allowable Pipe Size, Class and Materials for Water Mains*, TG 105, South Australian Water Corporation, Adelaide

Standards Australia 2003, *Plumbing and drainage Part 1: Water services*, AS/NZS 3500.1- 2003, Standards Australia, Sydney

Standards Australia 2005, *Fire hydrant installations Part 1: System design, installation and commissioning*, AS 2419.1-2005, Standards Australia, Sydney

Water Services Association of Australia 2002, *Water Supply Code of Australia*, WSA 03-2002, Water Services Association of Australia, Melbourne

Water Services Association of Australia 2004, *Dual Water Supply Systems*, WSA 03-2002 Supplement 1.1, Water Services Association of Australia, Melbourne

Water Services Association of Australia 2005, *Integrated Rainwater Tank Systems*, WSA 03-2002 Rainwater Tank Supplement-1.1, Water Services Association of Australia, Melbourne

New South Wales Office of Environment and Heritage (OEH) 2013, New South Wales Government , viewed 10 May 2013, http://www.environment.nsw.gov.au/watersaving/raintanks.htm

APPENDIX A

PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
Project Specification

FOR: Darryl Horan (0061003055)

TOPIC: COMPARISON OF A TRADITIONAL AND A DISTRIBUTED STORAGE WATER SUPPLY NETWORK FOR AN ISOLATED SYSTEM

SUPERVISOR: Dr. Laszlo Erdei

PROJECT AIM: Design both a traditional water supply network and a distributed storage water supply network for an isolated community, and compare them in terms of performance and costs.

PROGRAMME (Issue B, 14 March 2013):

1. Conduct a literature review, covering both traditional water supply networks and distributed storage networks, with particular focus on isolated locations.
2. Research and determine appropriate performance requirements for use in hydraulic system modelling.
3. Design both a single storage and distributed storage network for a real site.
4. Compare physical and performance differences between the two systems using typical modelling scenarios.
5. Quantify cost differences for each system in terms of both construction and operation/maintenance.
6. Summarise the advantages and disadvantages of the two systems, and determine under what conditions they may be preferable for isolated locations.
7. Write up the work undertaken to produce a dissertation and a short presentation.

As time permits

8. Prepare an extract of the project report for a conference presentation or journal publication.

AGREED ________________ (student) ________________ (supervisor)

Date: 14 / 03 / 2013 Date: 14 / 03 / 2013

APPENDIX B

WATER SUPPLY NETWORK LAYOUT PLANS

NETWORK LAYOUT PLAN

SCALE 1:5000

NETWORK LAYOUT PLAN

SCALE 1:2000

DISTRIBUTION MAIN

SITE RETICULATION

NETWORK LAYOUT PLAN

SCALE 1:5000

APPENDIX C

HYDRAULIC MODELLING INPUTS

MODELLING INPUTS - TRADITIONAL NETWORK NODES

NODES

Node	X	Y	RL (m)	Base Demand	Demand (L/s)
N1	738,475	6,418,055	0	0	0
N2	739,147	6,417,938	0	0	0
N3	739,204	6,418,268	0	0	0
N4	739,547	6,418,209	0	0	0
N5	739,578	6,418,223	0	0	0
N6	739,583	6,418,249	0	0	0
N7	739,575	6,418,251	0	1	0.03
N8	739,585	6,418,261	0	0	0
N9	739,592	6,418,300	0	0	0
N10	739,615	6,418,296	0	1	0.03
N11	739,588	6,418,281	0	12	0.36
N12	739,573	6,418,283	0	12	0.36
N13	739,557	6,418,286	0	12	0.36
N14	739,554	6,418,267	0	0	0
N15	739,561	6,418,306	0	0	0
N16	739,576	6,418,303	0	0	0
N17	739,569	6,418,264	0	0	0
N18	739,602	6,418,319	0	0	0
N19	739,587	6,418,321	0	0	0
N20	739,571	6,418,324	0	0	0
N21	739,556	6,418,327	0	0	0
N22	739,609	6,418,358	0	0	0
N23	739,594	6,418,360	0	0	0
N24	739,578	6,418,363	0	0	0
N25	739,562	6,418,366	0	0	0
N26	739,559	6,418,346	0	12	0.36
N27	739,575	6,418,343	0	12	0.36
N28	739,590	6,418,341	0	12	0.36
N29	739,725	6,418,299	0	0	0
N30	739,708	6,418,302	0	0	0
N31	739,693	6,418,305	0	0	0
N32	739,699	6,418,344	0	0	0
N33	739,715	6,418,341	0	0	0
N34	739,732	6,418,338	0	0	0
N35	739,696	6,418,324	0	12	0.36
N36	739,712	6,418,322	0	12	0.36
N37	739,606	6,418,338	0	12	0.36
N38	739,728	6,418,319	0	6	0.18
N39	739,616	6,418,395	0	0	0
N40	739,568	6,418,403	0	1	0.03
N41	739,619	6,418,449	0	0	0
N42	739,594	6,418,454	0	1	0.03
N43	739,623	6,418,521	0	0	0
N44	739,623	6,418,471	0	1	0.03

MODELLING INPUTS - TRADITIONAL NETWORK NODES

NODES					
Node	X	Y	RL (m)	Base Demand	Demand (L/s)
N45	739,621	6,418,459	0	1	0.03
N46	739,622	6,418,465	0	1	0.03
N47	739,617	6,418,405	0	1	0.03
N48	739,621	6,418,427	0	1	0.03
N49	739,661	6,418,514	0	0	0
N50	739,695	6,418,508	0	1	0.03
N51	739,619	6,418,503	0	0	0
N52	739,624	6,418,478	0	0	0
N53	739,642	6,418,517	0	12	0.36
N54	739,645	6,418,533	0	12	0.36
N55	739,664	6,418,530	0	0	0
N56	739,625	6,418,536	0	0	0
N57	739,631	6,418,570	0	0	0
N58	739,634	6,418,586	0	0	0
N59	739,636	6,418,601	0	0	0
N60	739,715	6,418,556	0	0	0
N61	739,718	6,418,571	0	0	0
N62	739,720	6,418,587	0	0	0
N63	739,651	6,418,567	0	12	0.36
N64	739,653	6,418,582	0	12	0.36
N65	739,656	6,418,598	0	6	0.18
N66	739,701	6,418,590	0	6	0.18
N67	739,698	6,418,575	0	12	0.36
N68	739,696	6,418,559	0	12	0.36
N69	739,822	6,418,569	0	0	0
N70	739,819	6,418,554	0	0	0
N71	739,817	6,418,538	0	0	0
N72	739,773	6,418,546	0	0	0
N73	739,776	6,418,561	0	0	0
N74	739,905	6,418,555	0	0	0
N75	739,903	6,418,539	0	0	0
N76	739,900	6,418,524	0	0	0
N77	739,950	6,418,547	0	0	0
N78	739,948	6,418,531	0	0	0
N79	739,942	6,418,500	0	0	0
N80	739,940	6,418,484	0	0	0
N81	739,894	6,418,492	0	0	0
N82	739,888	6,418,453	0	1	0.03
N83	739,892	6,418,477	0	0	0
N84	739,848	6,418,482	0	0	0
N85	739,844	6,418,457	0	1	0.03
N86	739,808	6,418,487	0	0	0
N87	739,808	6,418,489	0	0	0
N88	739,810	6,418,503	0	0	0

MODELLING INPUTS - TRADITIONAL NETWORK NODES

NODES

Node	X	Y	RL (m)	Base Demand	Demand (L/s)
N89	739,811	6,418,505	0	0	0
N90	739,764	6,418,495	0	0	0
N91	739,767	6,418,510	0	0	0
N92	739,920	6,418,488	0	10	0.3
N93	739,923	6,418,503	0	12	0.36
N94	739,928	6,418,535	0	12	0.36
N95	739,931	6,418,550	0	6	0.18
N96	739,872	6,418,480	0	12	0.36
N97	739,875	6,418,496	0	12	0.36
N98	739,880	6,418,527	0	12	0.36
N99	739,883	6,418,543	0	12	0.36
N100	739,886	6,418,558	0	6	0.18
N101	739,829	6,418,486	0	12	0.36
N102	739,832	6,418,501	0	12	0.36
N103	739,838	6,418,534	0	12	0.36
N104	739,840	6,418,550	0	12	0.36
N105	739,843	6,418,565	0	6	0.18
N106	739,784	6,418,491	0	12	0.36
N107	739,787	6,418,507	0	12	0.36
N108	739,793	6,418,542	0	12	0.36
N109	739,795	6,418,558	0	12	0.36
N110	739,798	6,418,573	0	6	0.18
N111	739,798	6,418,430	0	0	0
N112	739,809	6,418,428	0	1	0.03
N113	739,795	6,418,415	0	0	0
N114	739,747	6,418,423	0	1	0.03
N115	739,741	6,418,388	0	1	0.03
N116	739,740	6,418,383	0	1	0.03
N117	739,897	6,418,508	0	1	0.03

MODELLING INPUTS - TRADITIONAL NETWORK PIPES

Pipe Data:

id	From	To	Length (m)	Nom. Dia. (mm)	Roughness (mm)	K	Type
180	N11	N8	18	200	0.015	0	uPVC to AS1477 Class 9
175	N8	N6	11	200	0.015	0	uPVC to AS1477 Class 9
174	N6	N5	25	200	0.015	0	uPVC to AS1477 Class 9
136	N3	N4	322	200	0.015	0	uPVC to AS1477 Class 9
135	N2	N3	310	200	0.015	0	uPVC to AS1477 Class 9
134	N1	N2	631	200	0.015	0	uPVC to AS1477 Class 9
133	N9	N18	20	200	0.015	0	uPVC to AS1477 Class 9
118	N4	N5	32	200	0.015	0	uPVC to AS1477 Class 9
117	N9	N11	18	200	0.015	0	uPVC to AS1477 Class 9
266	N117	N81	15	100	0.015	0	uPVC to AS1477 Class 9
249	N115	N116	5	100	0.015	0	uPVC to AS1477 Class 9
248	N116	N34	42	100	0.015	0	uPVC to AS1477 Class 9
247	N111	N86	54	100	0.015	0	uPVC to AS1477 Class 9
246	N101	N84	18	100	0.015	0	uPVC to AS1477 Class 9
242	N86	N87	2	100	0.015	0	uPVC to AS1477 Class 9
239	N96	N83	18	100	0.015	0	uPVC to AS1477 Class 9
236	N81	N83	15	100	0.015	0	uPVC to AS1477 Class 9
231	N110	N69	22	100	0.015	0	uPVC to AS1477 Class 9
230	N69	N105	20	100	0.015	0	uPVC to AS1477 Class 9
223	N105	N100	40	100	0.015	0	uPVC to AS1477 Class 9
222	N100	N74	18	100	0.015	0	uPVC to AS1477 Class 9
219	N76	N117	15	100	0.015	0	uPVC to AS1477 Class 9
217	N75	N76	15	100	0.015	0	uPVC to AS1477 Class 9
213	N57	N56	32	100	0.015	0	uPVC to AS1477 Class 9
210	N58	N57	15	100	0.015	0	uPVC to AS1477 Class 9
209	N65	N66	42	100	0.015	0	uPVC to AS1477 Class 9
208	N62	N110	73	100	0.015	0	uPVC to AS1477 Class 9
207	N66	N62	18	100	0.015	0	uPVC to AS1477 Class 9
203	N43	N51	17	100	0.015	0	uPVC to AS1477 Class 9
202	N56	N43	15	100	0.015	0	uPVC to AS1477 Class 9
200	N44	N46	5	100	0.015	0	uPVC to AS1477 Class 9
199	N46	N45	5	100	0.015	0	uPVC to AS1477 Class 9
198	N45	N41	10	100	0.015	0	uPVC to AS1477 Class 9
197	N47	N48	21	100	0.015	0	uPVC to AS1477 Class 9
196	N39	N47	9	100	0.015	0	uPVC to AS1477 Class 9
195	N34	N38	18	100	0.015	0	uPVC to AS1477 Class 9
191	N38	N29	18	100	0.015	0	uPVC to AS1477 Class 9
190	N30	N29	16	100	0.015	0	uPVC to AS1477 Class 9
187	N22	N39	35	100	0.015	0	uPVC to AS1477 Class 9
186	N37	N22	18	100	0.015	0	uPVC to AS1477 Class 9
165	N52	N44	7	100	0.015	0	uPVC to AS1477 Class 9
163	N52	N51	23	100	0.015	0	uPVC to AS1477 Class 9
162	N41	N48	22	100	0.015	0	uPVC to AS1477 Class 9
156	N59	N58	15	100	0.015	0	uPVC to AS1477 Class 9
151	N59	N65	18	100	0.015	0	uPVC to AS1477 Class 9
148	N74	N75	15	100	0.015	0	uPVC to AS1477 Class 9
146	N96	N84	23	100	0.015	0	uPVC to AS1477 Class 9
145	N87	N101	20	100	0.015	0	uPVC to AS1477 Class 9
140	N113	N111	14	100	0.015	0	uPVC to AS1477 Class 9
139	N113	N114	46	100	0.015	0	uPVC to AS1477 Class 9
137	N18	N37	18	100	0.015	0	uPVC to AS1477 Class 9

MODELLING INPUTS - TRADITIONAL NETWORK PIPES

Pipe Data:

id	From	To	Length (m)	Nom. Dia. (mm)	Roughness (mm)	K	Type
132	N31	N18	85	100	0.015	0	uPVC to AS1477 Class 9
120	N114	N115	33	100	0.015	0	uPVC to AS1477 Class 9
119	N31	N30	15	100	0.015	0	uPVC to AS1477 Class 9
245	N89	N71	31	50	0.015	0	uPVC to AS1477 Class 9
244	N88	N89	2	50	0.015	0	uPVC to AS1477 Class 9
243	N87	N88	13	50	0.015	0	uPVC to AS1477 Class 9
229	N70	N69	15	50	0.015	0	uPVC to AS1477 Class 9
227	N71	N70	15	50	0.015	0	uPVC to AS1477 Class 9
241	N106	N86	22	32	0.015	0	uPVC to AS1477 Class 9
240	N107	N88	22	32	0.015	0	uPVC to AS1477 Class 9
238	N97	N102	40	32	0.015	0	uPVC to AS1477 Class 9
237	N81	N97	18	32	0.015	0	uPVC to AS1477 Class 9
235	N92	N81	24	32	0.015	0	uPVC to AS1477 Class 9
234	N93	N117	24	32	0.015	0	uPVC to AS1477 Class 9
233	N108	N72	18	32	0.015	0	uPVC to AS1477 Class 9
232	N109	N73	18	32	0.015	0	uPVC to AS1477 Class 9
228	N70	N109	22	32	0.015	0	uPVC to AS1477 Class 9
226	N71	N108	22	32	0.015	0	uPVC to AS1477 Class 9
225	N103	N71	20	32	0.015	0	uPVC to AS1477 Class 9
224	N104	N70	20	32	0.015	0	uPVC to AS1477 Class 9
221	N99	N104	40	32	0.015	0	uPVC to AS1477 Class 9
220	N98	N103	40	32	0.015	0	uPVC to AS1477 Class 9
218	N74	N95	24	32	0.015	0	uPVC to AS1477 Class 9
216	N75	N99	18	32	0.015	0	uPVC to AS1477 Class 9
215	N94	N75	24	32	0.015	0	uPVC to AS1477 Class 9
214	N95	N77	18	32	0.015	0	uPVC to AS1477 Class 9
212	N63	N57	18	32	0.015	0	uPVC to AS1477 Class 9
205	N61	N60	15	32	0.015	0	uPVC to AS1477 Class 9
204	N68	N63	42	32	0.015	0	uPVC to AS1477 Class 9
173	N111	N112	11	32	0.015	0	uPVC to AS1477 Class 9
159	N62	N61	15	32	0.015	0	uPVC to AS1477 Class 9
157	N60	N68	18	32	0.015	0	uPVC to AS1477 Class 9
155	N76	N98	18	32	0.015	0	uPVC to AS1477 Class 9
154	N72	N73	15	32	0.015	0	uPVC to AS1477 Class 9
153	N78	N77	15	32	0.015	0	uPVC to AS1477 Class 9
152	N78	N94	18	32	0.015	0	uPVC to AS1477 Class 9
150	N80	N79	15	32	0.015	0	uPVC to AS1477 Class 9
149	N79	N93	18	32	0.015	0	uPVC to AS1477 Class 9
147	N89	N102	20	32	0.015	0	uPVC to AS1477 Class 9
144	N80	N92	18	32	0.015	0	uPVC to AS1477 Class 9
143	N91	N90	15	32	0.015	0	uPVC to AS1477 Class 9
142	N91	N107	18	32	0.015	0	uPVC to AS1477 Class 9
141	N90	N106	18	32	0.015	0	uPVC to AS1477 Class 9
274	N53	N43	18	25	0.015	0	uPVC to AS1477 Class 9
211	N64	N58	18	25	0.015	0	uPVC to AS1477 Class 9
206	N67	N64	42	25	0.015	0	uPVC to AS1477 Class 9
201	N54	N56	18	25	0.015	0	uPVC to AS1477 Class 9
194	N33	N34	16	25	0.015	0	uPVC to AS1477 Class 9
193	N35	N31	18	25	0.015	0	uPVC to AS1477 Class 9
192	N36	N30	18	25	0.015	0	uPVC to AS1477 Class 9
189	N24	N23	15	25	0.015	0	uPVC to AS1477 Class 9

MODELLING INPUTS - TRADITIONAL NETWORK PIPES

Pipe Data:

id	From	To	Length (m)	Nom. Dia. (mm)	Roughness (mm)	K	Type
188	N23	N22	15	25	0.015	0	uPVC to AS1477 Class 9
185	N28	N19	18	25	0.015	0	uPVC to AS1477 Class 9
184	N27	N20	18	25	0.015	0	uPVC to AS1477 Class 9
183	N26	N21	18	25	0.015	0	uPVC to AS1477 Class 9
182	N20	N19	15	25	0.015	0	uPVC to AS1477 Class 9
181	N19	N18	15	25	0.015	0	uPVC to AS1477 Class 9
179	N12	N17	18	25	0.015	0	uPVC to AS1477 Class 9
178	N16	N9	15	25	0.015	0	uPVC to AS1477 Class 9
177	N13	N15	18	25	0.015	0	uPVC to AS1477 Class 9
176	N17	N14	15	25	0.015	0	uPVC to AS1477 Class 9
172	N84	N85	24	25	0.015	0	uPVC to AS1477 Class 9
171	N83	N82	23	25	0.015	0	uPVC to AS1477 Class 9
170	N49	N50	31	25	0.015	0	uPVC to AS1477 Class 9
169	N40	N39	45	25	0.015	0	uPVC to AS1477 Class 9
168	N9	N10	22	25	0.015	0	uPVC to AS1477 Class 9
167	N7	N6	7	25	0.015	0	uPVC to AS1477 Class 9
166	N41	N42	24	25	0.015	0	uPVC to AS1477 Class 9
164	N49	N55	15	25	0.015	0	uPVC to AS1477 Class 9
161	N49	N53	18	25	0.015	0	uPVC to AS1477 Class 9
160	N55	N54	18	25	0.015	0	uPVC to AS1477 Class 9
158	N61	N67	18	25	0.015	0	uPVC to AS1477 Class 9
138	N32	N33	15	25	0.015	0	uPVC to AS1477 Class 9
131	N23	N28	18	25	0.015	0	uPVC to AS1477 Class 9
130	N24	N27	18	25	0.015	0	uPVC to AS1477 Class 9
129	N25	N24	15	25	0.015	0	uPVC to AS1477 Class 9
128	N33	N36	18	25	0.015	0	uPVC to AS1477 Class 9
127	N32	N35	18	25	0.015	0	uPVC to AS1477 Class 9
126	N15	N16	15	25	0.015	0	uPVC to AS1477 Class 9
125	N21	N20	15	25	0.015	0	uPVC to AS1477 Class 9
124	N25	N26	18	25	0.015	0	uPVC to AS1477 Class 9
123	N16	N12	18	25	0.015	0	uPVC to AS1477 Class 9
122	N14	N13	18	25	0.015	0	uPVC to AS1477 Class 9
121	N8	N17	15	25	0.015	0	uPVC to AS1477 Class 9

MODELLING INPUTS - DISTRIBUTED STORAGE NETWORK NODES

NODES

Node	X	Y	RL (m)	Base Demand	Demand (L/s)
N1	738,476	6,418,435	0	0	0
N2	738,681	6,418,399	0	0	0
N3	738,698	6,418,500	0	0	0
N4	738,803	6,418,481	0	0	0
N5	738,812	6,418,486	0	0	0
N6	738,814	6,418,494	0	0	0
N7	738,811	6,418,494	0	1	0.006
N8	738,814	6,418,497	0	0	0
N9	738,816	6,418,509	0	0	0
N10	738,824	6,418,508	0	1	0.006
N11	738,815	6,418,503	0	12	0.072
N12	738,811	6,418,504	0	12	0.072
N13	738,806	6,418,505	0	12	0.072
N14	738,805	6,418,499	0	0	0
N15	738,807	6,418,511	0	0	0
N16	738,812	6,418,510	0	0	0
N17	738,810	6,418,498	0	0	0
N18	738,820	6,418,515	0	0	0
N19	738,815	6,418,516	0	0	0
N20	738,810	6,418,517	0	0	0
N21	738,805	6,418,517	0	0	0
N22	738,822	6,418,527	0	0	0
N23	738,817	6,418,528	0	0	0
N24	738,812	6,418,528	0	0	0
N25	738,808	6,418,529	0	0	0
N26	738,807	6,418,523	0	12	0.072
N27	738,811	6,418,523	0	12	0.072
N28	738,816	6,418,522	0	12	0.072
N29	738,857	6,418,509	0	0	0
N30	738,852	6,418,510	0	0	0
N31	738,847	6,418,511	0	0	0
N32	738,849	6,418,523	0	0	0
N33	738,854	6,418,522	0	0	0
N34	738,859	6,418,521	0	0	0
N35	738,848	6,418,517	0	12	0.072
N36	738,853	6,418,516	0	12	0.072
N37	738,821	6,418,521	0	12	0.072
N38	738,858	6,418,515	0	6	0.036
N39	738,824	6,418,538	0	0	0
N40	738,809	6,418,541	0	1	0.006
N41	738,825	6,418,555	0	0	0
N42	738,817	6,418,556	0	1	0.006
N43	738,826	6,418,577	0	0	0
N44	738,826	6,418,561	0	1	0.006

MODELLING INPUTS - DISTRIBUTED STORAGE NETWORK NODES

			NODES		
Node	X	Y	RL (m)	Base Demand	Demand (L/s)
N45	738,825	6,418,558	0	1	0.006
N46	738,826	6,418,560	0	1	0.006
N47	738,824	6,418,541	0	1	0.006
N48	738,825	6,418,548	0	1	0.006
N49	738,838	6,418,575	0	0	0
N50	738,848	6,418,573	0	1	0.006
N51	738,825	6,418,571	0	0	0
N52	738,826	6,418,564	0	0	0
N53	738,832	6,418,576	0	12	0.072
N54	738,833	6,418,580	0	12	0.072
N55	738,839	6,418,579	0	0	0
N56	738,827	6,418,581	0	0	0
N57	738,828	6,418,592	0	0	0
N58	738,829	6,418,596	0	0	0
N59	738,830	6,418,601	0	0	0
N60	738,854	6,418,587	0	0	0
N61	738,855	6,418,592	0	0	0
N62	738,856	6,418,597	0	0	0
N63	738,834	6,418,591	0	12	0.072
N64	738,835	6,418,595	0	12	0.072
N65	738,836	6,418,600	0	6	0.036
N66	738,850	6,418,598	0	6	0.036
N67	738,849	6,418,593	0	12	0.072
N68	738,848	6,418,588	0	12	0.072
N69	738,887	6,418,591	0	0	0
N70	738,886	6,418,587	0	0	0
N71	738,885	6,418,582	0	0	0
N72	738,872	6,418,584	0	0	0
N73	738,873	6,418,589	0	0	0
N74	738,912	6,418,587	0	0	0
N75	738,911	6,418,582	0	0	0
N76	738,911	6,418,578	0	0	0
N77	738,926	6,418,585	0	0	0
N78	738,925	6,418,580	0	0	0
N79	738,923	6,418,570	0	0	0
N80	738,923	6,418,566	0	0	0
N81	738,909	6,418,568	0	0	0
N82	738,907	6,418,556	0	1	0.006
N83	738,908	6,418,563	0	0	0
N84	738,895	6,418,565	0	0	0
N85	738,893	6,418,557	0	1	0.006
N86	738,882	6,418,566	0	0	0
N87	738,883	6,418,567	0	0	0
N88	738,883	6,418,571	0	0	0

MODELLING INPUTS - DISTRIBUTED STORAGE NETWORK NODES

NODES

Node	X	Y	RL (m)	Base Demand	Demand (L/s)
N89	738,883	6,418,572	0	0	0
N90	738,869	6,418,569	0	0	0
N91	738,870	6,418,573	0	0	0
N92	738,917	6,418,567	0	10	0.06
N93	738,918	6,418,571	0	12	0.072
N94	738,919	6,418,581	0	12	0.072
N95	738,920	6,418,586	0	6	0.036
N96	738,902	6,418,564	0	12	0.072
N97	738,903	6,418,569	0	12	0.072
N98	738,905	6,418,579	0	12	0.072
N99	738,905	6,418,583	0	12	0.072
N100	738,906	6,418,588	0	6	0.036
N101	738,889	6,418,566	0	12	0.072
N102	738,890	6,418,571	0	12	0.072
N103	738,892	6,418,581	0	12	0.072
N104	738,892	6,418,586	0	12	0.072
N105	738,893	6,418,590	0	6	0.036
N106	738,875	6,418,568	0	12	0.072
N107	738,876	6,418,572	0	12	0.072
N108	738,878	6,418,583	0	12	0.072
N109	738,879	6,418,588	0	12	0.072
N110	738,879	6,418,593	0	6	0.036
N111	738,879	6,418,549	0	0	0
N112	738,883	6,418,548	0	1	0.006
N113	738,879	6,418,544	0	0	0
N114	738,864	6,418,547	0	1	0.006
N115	738,862	6,418,536	0	1	0.006
N116	738,862	6,418,535	0	1	0.006
N117	738,910	6,418,573	0	1	0.006

MODELLING INPUTS - DISTRIBUTED STORAGE NETWORK PIPES

Pipe Data:

id	From	To	Length (m)	Nom. Dia. (mm)	Roughness (mm)	K	Type
117	N9	N11	18	100	0.015	0	uPVC to AS1477 Class 9
118	N4	N5	32	100	0.015	0	uPVC to AS1477 Class 9
133	N9	N18	20	100	0.015	0	uPVC to AS1477 Class 9
134	N1	N2	631	100	0.015	0	uPVC to AS1477 Class 9
135	N2	N3	310	100	0.015	0	uPVC to AS1477 Class 9
136	N3	N4	322	100	0.015	0	uPVC to AS1477 Class 9
174	N6	N5	25	100	0.015	0	uPVC to AS1477 Class 9
175	N8	N6	11	100	0.015	0	uPVC to AS1477 Class 9
180	N11	N8	18	100	0.015	0	uPVC to AS1477 Class 9
119	N31	N30	15	80	0.015	0	uPVC to AS1477 Class 9
120	N114	N115	33	80	0.015	0	uPVC to AS1477 Class 9
132	N31	N18	85	80	0.015	0	uPVC to AS1477 Class 9
139	N113	N114	46	80	0.015	0	uPVC to AS1477 Class 9
190	N30	N29	16	80	0.015	0	uPVC to AS1477 Class 9
191	N38	N29	18	80	0.015	0	uPVC to AS1477 Class 9
195	N34	N38	18	80	0.015	0	uPVC to AS1477 Class 9
248	N116	N34	42	80	0.015	0	uPVC to AS1477 Class 9
249	N115	N116	5	80	0.015	0	uPVC to AS1477 Class 9
137	N18	N37	18	50	0.015	0	uPVC to AS1477 Class 9
140	N113	N111	14	50	0.015	0	uPVC to AS1477 Class 9
145	N87	N101	20	50	0.015	0	uPVC to AS1477 Class 9
146	N96	N84	23	50	0.015	0	uPVC to AS1477 Class 9
148	N74	N75	15	50	0.015	0	uPVC to AS1477 Class 9
151	N59	N65	18	50	0.015	0	uPVC to AS1477 Class 9
156	N59	N58	15	50	0.015	0	uPVC to AS1477 Class 9
162	N41	N48	22	50	0.015	0	uPVC to AS1477 Class 9
163	N52	N51	23	50	0.015	0	uPVC to AS1477 Class 9
165	N52	N44	7	50	0.015	0	uPVC to AS1477 Class 9
186	N37	N22	18	50	0.015	0	uPVC to AS1477 Class 9
187	N22	N39	35	50	0.015	0	uPVC to AS1477 Class 9
196	N39	N47	9	50	0.015	0	uPVC to AS1477 Class 9
197	N47	N48	21	50	0.015	0	uPVC to AS1477 Class 9
198	N45	N41	10	50	0.015	0	uPVC to AS1477 Class 9
199	N46	N45	5	50	0.015	0	uPVC to AS1477 Class 9
200	N44	N46	5	50	0.015	0	uPVC to AS1477 Class 9
202	N56	N43	15	50	0.015	0	uPVC to AS1477 Class 9
203	N43	N51	17	50	0.015	0	uPVC to AS1477 Class 9
207	N66	N62	18	50	0.015	0	uPVC to AS1477 Class 9
208	N62	N110	73	50	0.015	0	uPVC to AS1477 Class 9
209	N65	N66	42	50	0.015	0	uPVC to AS1477 Class 9
210	N58	N57	15	50	0.015	0	uPVC to AS1477 Class 9
213	N57	N56	32	50	0.015	0	uPVC to AS1477 Class 9
217	N75	N76	15	50	0.015	0	uPVC to AS1477 Class 9
219	N76	N117	15	50	0.015	0	uPVC to AS1477 Class 9
222	N100	N74	18	50	0.015	0	uPVC to AS1477 Class 9
223	N105	N100	40	50	0.015	0	uPVC to AS1477 Class 9
230	N69	N105	20	50	0.015	0	uPVC to AS1477 Class 9
231	N110	N69	22	50	0.015	0	uPVC to AS1477 Class 9
236	N81	N83	15	50	0.015	0	uPVC to AS1477 Class 9

MODELLING INPUTS - DISTRIBUTED STORAGE NETWORK PIPES

Pipe Data:

id	From	To	Length (m)	Nom. Dia. (mm)	Roughness (mm)	K	Type
239	N96	N83	18	50	0.015	0	uPVC to AS1477 Class 9
242	N86	N87	2	50	0.015	0	uPVC to AS1477 Class 9
246	N101	N84	18	50	0.015	0	uPVC to AS1477 Class 9
247	N111	N86	54	50	0.015	0	uPVC to AS1477 Class 9
266	N117	N81	15	50	0.015	0	uPVC to AS1477 Class 9
227	N71	N70	15	32	0.015	0	uPVC to AS1477 Class 9
229	N70	N69	15	32	0.015	0	uPVC to AS1477 Class 9
243	N87	N88	13	32	0.015	0	uPVC to AS1477 Class 9
244	N88	N89	2	32	0.015	0	uPVC to AS1477 Class 9
245	N89	N71	31	32	0.015	0	uPVC to AS1477 Class 9
121	N8	N17	15	25	0.015	0	uPVC to AS1477 Class 9
122	N14	N13	18	25	0.015	0	uPVC to AS1477 Class 9
123	N16	N12	18	25	0.015	0	uPVC to AS1477 Class 9
124	N25	N26	18	25	0.015	0	uPVC to AS1477 Class 9
125	N21	N20	15	25	0.015	0	uPVC to AS1477 Class 9
126	N15	N16	15	25	0.015	0	uPVC to AS1477 Class 9
127	N32	N35	18	25	0.015	0	uPVC to AS1477 Class 9
128	N33	N36	18	25	0.015	0	uPVC to AS1477 Class 9
129	N25	N24	15	25	0.015	0	uPVC to AS1477 Class 9
130	N24	N27	18	25	0.015	0	uPVC to AS1477 Class 9
131	N23	N28	18	25	0.015	0	uPVC to AS1477 Class 9
138	N32	N33	15	25	0.015	0	uPVC to AS1477 Class 9
141	N90	N106	18	25	0.015	0	uPVC to AS1477 Class 9
142	N91	N107	18	25	0.015	0	uPVC to AS1477 Class 9
143	N91	N90	15	25	0.015	0	uPVC to AS1477 Class 9
144	N80	N92	18	25	0.015	0	uPVC to AS1477 Class 9
147	N89	N102	20	25	0.015	0	uPVC to AS1477 Class 9
149	N79	N93	18	25	0.015	0	uPVC to AS1477 Class 9
150	N80	N79	15	25	0.015	0	uPVC to AS1477 Class 9
152	N78	N94	18	25	0.015	0	uPVC to AS1477 Class 9
153	N78	N77	15	25	0.015	0	uPVC to AS1477 Class 9
154	N72	N73	15	25	0.015	0	uPVC to AS1477 Class 9
155	N76	N98	18	25	0.015	0	uPVC to AS1477 Class 9
157	N60	N68	18	25	0.015	0	uPVC to AS1477 Class 9
158	N61	N67	18	25	0.015	0	uPVC to AS1477 Class 9
159	N62	N61	15	25	0.015	0	uPVC to AS1477 Class 9
160	N55	N54	18	25	0.015	0	uPVC to AS1477 Class 9
161	N49	N53	18	25	0.015	0	uPVC to AS1477 Class 9
164	N49	N55	15	25	0.015	0	uPVC to AS1477 Class 9
166	N41	N42	24	25	0.015	0	uPVC to AS1477 Class 9
167	N7	N6	7	25	0.015	0	uPVC to AS1477 Class 9
168	N9	N10	22	25	0.015	0	uPVC to AS1477 Class 9
169	N40	N39	45	25	0.015	0	uPVC to AS1477 Class 9
170	N49	N50	31	25	0.015	0	uPVC to AS1477 Class 9
171	N83	N82	23	25	0.015	0	uPVC to AS1477 Class 9
172	N84	N85	24	25	0.015	0	uPVC to AS1477 Class 9
173	N111	N112	11	25	0.015	0	uPVC to AS1477 Class 9
176	N17	N14	15	25	0.015	0	uPVC to AS1477 Class 9
177	N13	N15	18	25	0.015	0	uPVC to AS1477 Class 9

MODELLING INPUTS - DISTRIBUTED STORAGE NETWORK PIPES

Pipe Data:

id	From	To	Length (m)	Nom. Dia. (mm)	Roughness (mm)	K	Type
178	N16	N9	15	25	0.015	0	uPVC to AS1477 Class 9
179	N12	N17	18	25	0.015	0	uPVC to AS1477 Class 9
181	N19	N18	15	25	0.015	0	uPVC to AS1477 Class 9
182	N20	N19	15	25	0.015	0	uPVC to AS1477 Class 9
183	N26	N21	18	25	0.015	0	uPVC to AS1477 Class 9
184	N27	N20	18	25	0.015	0	uPVC to AS1477 Class 9
185	N28	N19	18	25	0.015	0	uPVC to AS1477 Class 9
188	N23	N22	15	25	0.015	0	uPVC to AS1477 Class 9
189	N24	N23	15	25	0.015	0	uPVC to AS1477 Class 9
192	N36	N30	18	25	0.015	0	uPVC to AS1477 Class 9
193	N35	N31	18	25	0.015	0	uPVC to AS1477 Class 9
194	N33	N34	16	25	0.015	0	uPVC to AS1477 Class 9
201	N54	N56	18	25	0.015	0	uPVC to AS1477 Class 9
204	N68	N63	42	25	0.015	0	uPVC to AS1477 Class 9
205	N61	N60	15	25	0.015	0	uPVC to AS1477 Class 9
206	N67	N64	42	25	0.015	0	uPVC to AS1477 Class 9
211	N64	N58	18	25	0.015	0	uPVC to AS1477 Class 9
212	N63	N57	18	25	0.015	0	uPVC to AS1477 Class 9
214	N95	N77	18	25	0.015	0	uPVC to AS1477 Class 9
215	N94	N75	24	25	0.015	0	uPVC to AS1477 Class 9
216	N75	N99	18	25	0.015	0	uPVC to AS1477 Class 9
218	N74	N95	24	25	0.015	0	uPVC to AS1477 Class 9
220	N98	N103	40	25	0.015	0	uPVC to AS1477 Class 9
221	N99	N104	40	25	0.015	0	uPVC to AS1477 Class 9
224	N104	N70	20	25	0.015	0	uPVC to AS1477 Class 9
225	N103	N71	20	25	0.015	0	uPVC to AS1477 Class 9
226	N71	N108	22	25	0.015	0	uPVC to AS1477 Class 9
228	N70	N109	22	25	0.015	0	uPVC to AS1477 Class 9
232	N109	N73	18	25	0.015	0	uPVC to AS1477 Class 9
233	N108	N72	18	25	0.015	0	uPVC to AS1477 Class 9
234	N93	N117	24	25	0.015	0	uPVC to AS1477 Class 9
235	N92	N81	24	25	0.015	0	uPVC to AS1477 Class 9
237	N81	N97	18	25	0.015	0	uPVC to AS1477 Class 9
238	N97	N102	40	25	0.015	0	uPVC to AS1477 Class 9
240	N107	N88	22	25	0.015	0	uPVC to AS1477 Class 9
241	N106	N86	22	25	0.015	0	uPVC to AS1477 Class 9
274	N53	N43	18	25	0.015	0	uPVC to AS1477 Class 9

NETWORK NODE NUMBERS

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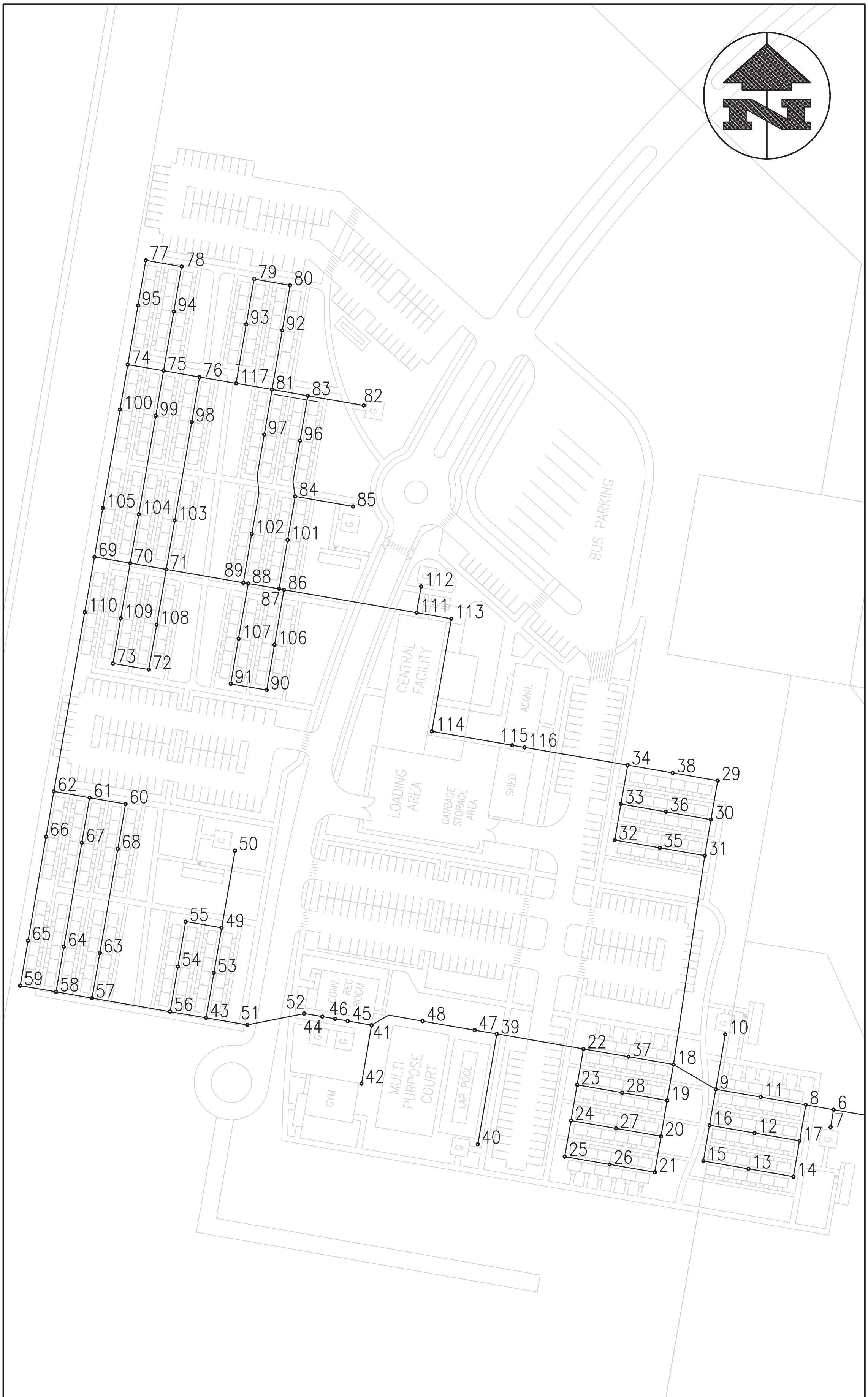
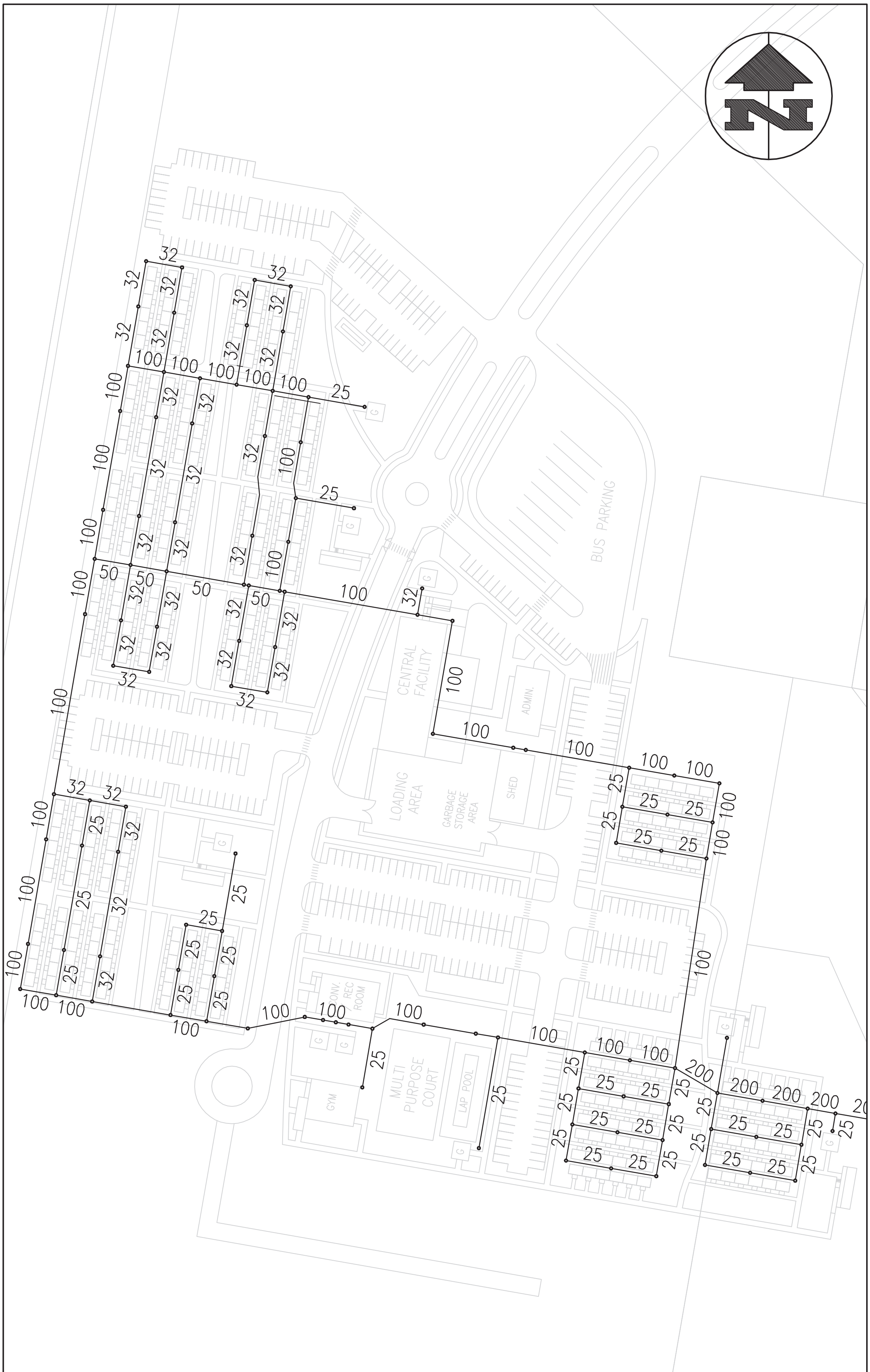


NETWORK NODE NUMBERS

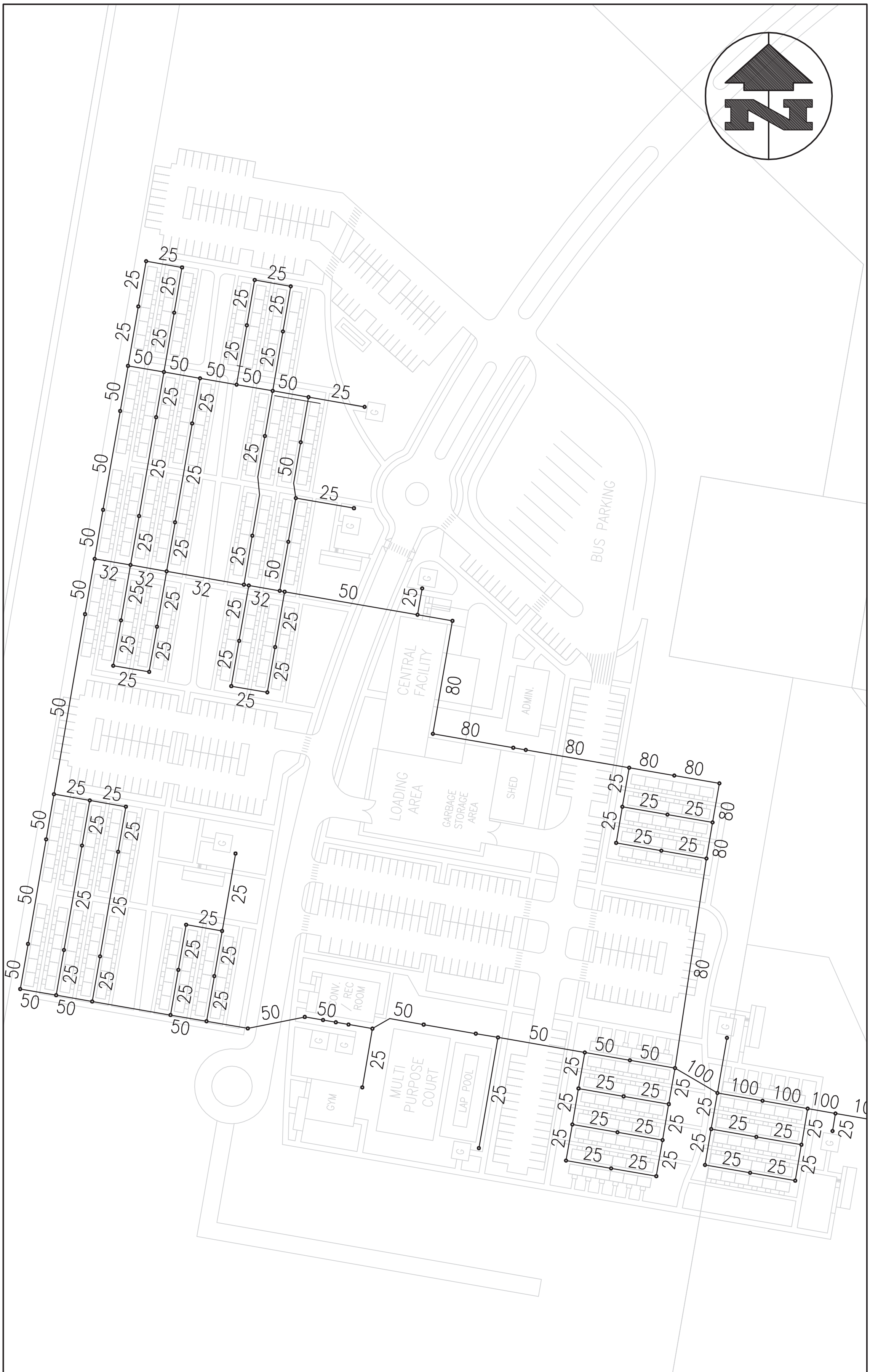
SCALE 1:2000

TRADITIONAL NETWORK
PIPE DIAMETERS (MM)
SCALE 1:5000



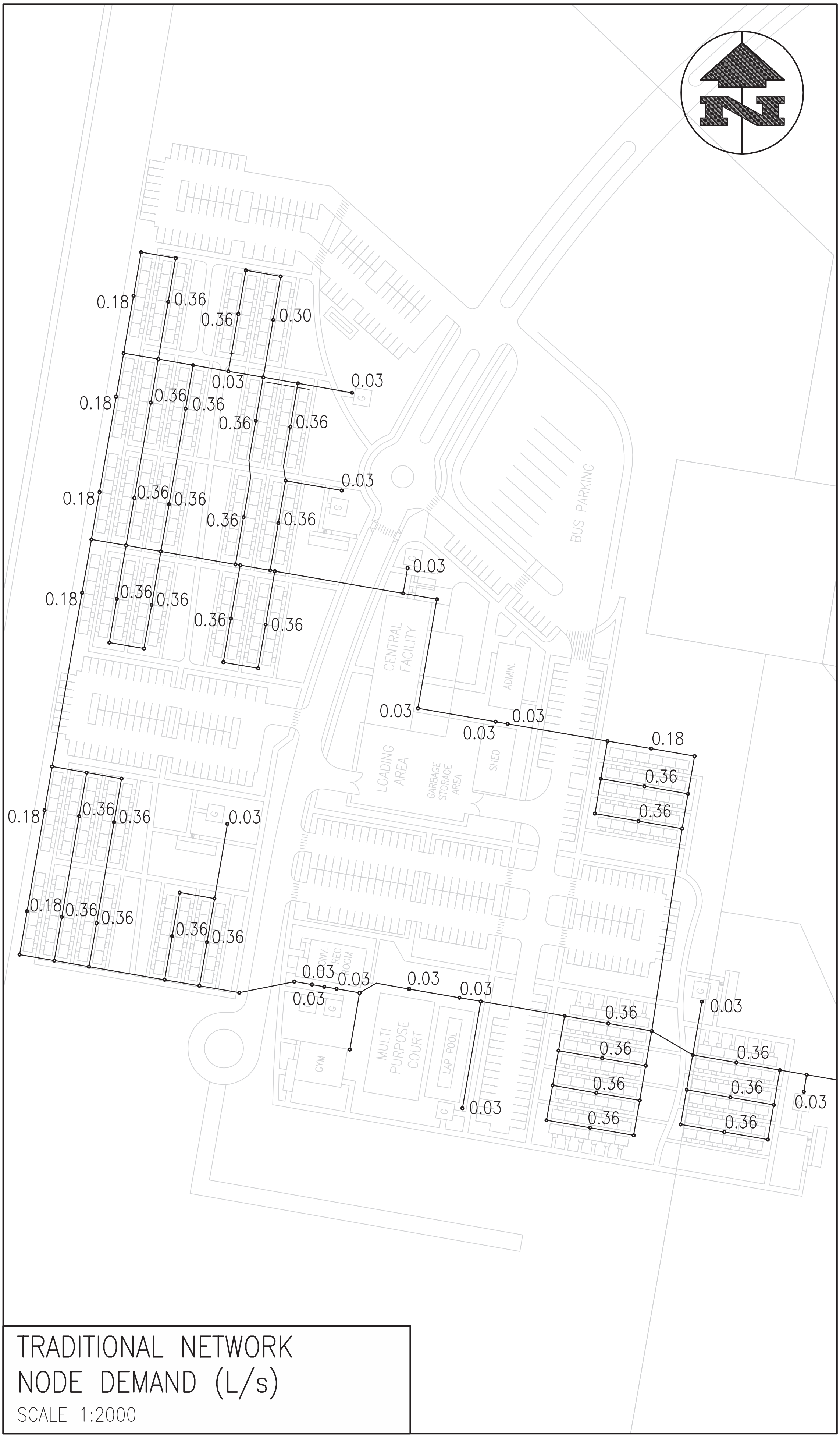
TRADITIONAL NETWORK
PIPE DIAMETERS (MM)
SCALE 1:2000

DISTRIBUTED STORAGE NETWORK
PIPE DIAMETERS (MM)
SCALE 1:5000

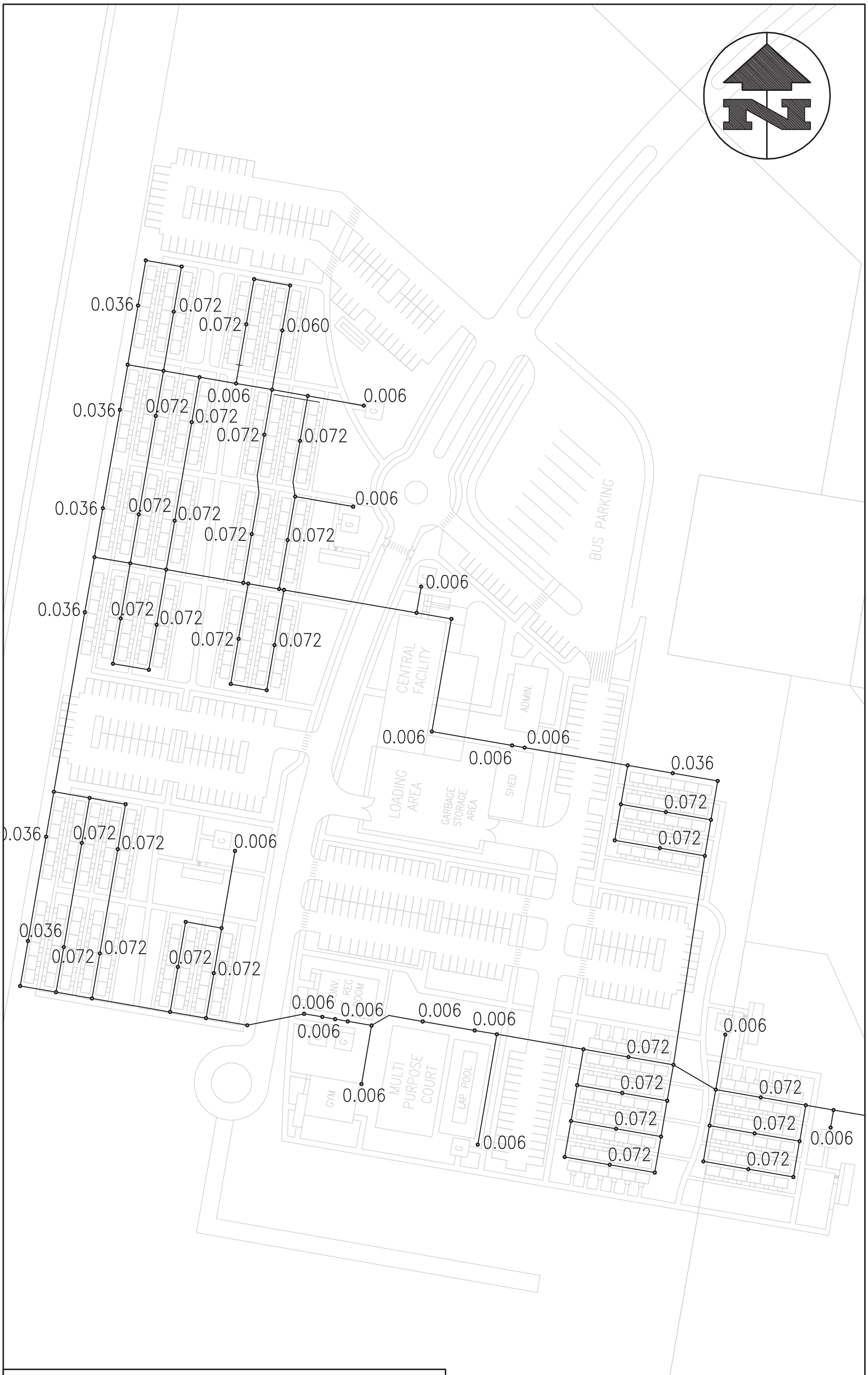


DISTRIBUTED STORAGE NETWORK PIPE DIAMETERS (MM)

SCALE 1:2000



TRADITIONAL NETWORK
NODE DEMAND (L/s)
SCALE 1:2000



DISTRIBUTED STORAGE NETWORK
NODE DEMAND (L/s)
SCALE 1:2000

APPENDIX D

HYDRAULIC MODELLING OUTPUTS

MODELLING OUTPUTS - TRADITIONAL NETWORK NODES

NODE HGL

Node	Min.HGL	Node	Min.HGL	Node	Min.HGL
N1	8.000	N45	6.650	N89	6.140
N2	7.600	N46	6.640	N90	6.090
N3	7.400	N47	6.820	N91	6.090
N4	7.190	N48	6.750	N92	6.060
N5	7.170	N49	6.230	N93	6.060
N6	7.160	N50	6.220	N94	6.080
N7	7.160	N51	6.530	N95	6.090
N8	7.150	N52	6.600	N96	6.160
N9	7.130	N53	6.230	N97	6.070
N10	7.130	N54	6.230	N98	6.050
N11	7.140	N55	6.230	N99	6.050
N12	6.900	N56	6.440	N100	6.140
N13	6.850	N57	6.360	N101	6.190
N14	6.910	N58	6.340	N102	6.070
N15	6.910	N59	6.320	N103	6.050
N16	6.960	N60	6.140	N104	6.050
N17	6.970	N61	6.150	N105	6.150
N18	7.120	N62	6.230	N106	6.100
N19	6.700	N63	6.200	N107	6.080
N20	6.510	N64	6.040	N108	6.020
N21	6.460	N65	6.290	N109	6.020
N22	6.970	N66	6.240	N110	6.170
N23	6.660	N67	6.010	N111	6.330
N24	6.500	N68	6.130	N112	6.330
N25	6.450	N69	6.160	N113	6.360
N26	6.390	N70	6.110	N114	6.470
N27	6.440	N71	6.100	N115	6.540
N28	6.620	N72	6.020	N116	6.550
N29	6.750	N73	6.020	N117	6.140
N30	6.790	N74	6.140		
N31	6.830	N75	6.140		
N32	6.640	N76	6.140		
N33	6.640	N77	6.090		
N34	6.650	N78	6.080		
N35	6.640	N79	6.060		
N36	6.630	N80	6.060		
N37	7.040	N81	6.140		
N38	6.700	N82	6.150		
N39	6.850	N83	6.150		
N40	6.840	N84	6.180		
N41	6.680	N85	6.170		
N42	6.680	N86	6.210		
N43	6.480	N87	6.210		
N44	6.620	N88	6.140		

MODELLING OUTPUTS - TRADITIONAL NETWORK PIPES

PIPE Results:

From	To	Flow	Friction Slope	Darcy f
N9	N11	11.8	0.56	0.0191597
N4	N5	12.5	0.63	0.0192082
N31	N30	4.64	2.67	0.0188644
N114	N115	4.03	2.12	0.0198561
N8	N17	0.37	12	0.0279713
N14	N13	0.18	3.33	0.032797
N16	N12	0.17	3.33	0.0367689
N25	N26	0.17	3.33	0.0367689
N21	N20	0.19	3.33	0.0294355
N15	N16	0.18	3.33	0.032797
N32	N35	0.02	0	0
N33	N36	0.06	0.56	0.0496386
N25	N24	0.17	3.33	0.0367689
N24	N27	0.17	3.33	0.0367689
N23	N28	0.15	2.22	0.0314851
N31	N18	4.99	3.41	0.0208316
N9	N18	11.4	0.5	0.0183284
N1	N2	12.5	0.63	0.0192082
N2	N3	12.5	0.65	0.0198179
N3	N4	12.5	0.65	0.0198179
N18	N37	5.8	4.44	0.0200768
N32	N33	0.02	0	0
N113	N114	4	2.39	0.022722
N113	N111	4	2.14	0.0203452
N90	N106	0.07	0.56	0.116877
N91	N107	0.07	0.56	0.116877
N91	N90	0.07	0	0
N80	N92	0.03	0	0
N87	N101	2.44	1	0.0255499
N96	N84	2.05	0.87	0.0314905
N89	N102	0.34	3.5	0.0309634
N74	N75	0.53	0	0
N79	N93	0.03	0	0
N80	N79	0.03	0	0
N59	N65	2.96	1.67	0.0289936
N78	N94	0.07	0	0
N78	N77	0.07	0.67	0.139836
N72	N73	0	0	-1.#IND
N76	N98	0.42	5	0.0289875
N59	N58	2.96	1.33	0.0230907
N60	N68	0.13	0.56	0.0338875
N61	N67	0.28	7.78	0.0316663
N62	N61	0.42	5.33	0.0309006

MODELLING OUTPUTS - TRADITIONAL NETWORK PIPES

PIPE Results:

From	To	Flow	Friction Slope	Darcy f
N55	N54	0	0	-1.#IND
N49	N53	0.03	0	0
N41	N48	4.85	3.18	0.0205642
N52	N51	4.73	3.04	0.020669
N49	N55	0	0	-1.#IND
N52	N44	4.73	2.86	0.0194452
N41	N42	0.03	0	0
N7	N6	0.03	0	0
N9	N10	0.03	0	0
N40	N39	0.03	0.22	0.0780036
N49	N50	0.03	0.32	0.11346
N83	N82	0.03	0	0
N84	N85	0.03	0.42	0.148916
N111	N112	0.03	0	0
N6	N5	12.5	0.4	0.0121957
N8	N6	12.5	0.91	0.0277451
N17	N14	0.18	4	0.0393957
N13	N15	0.18	3.33	0.032797
N16	N9	0.35	11.3	0.0294359
N12	N17	0.19	3.89	0.0343856
N11	N8	12.1	0.56	0.0182214
N19	N18	0.59	28	0.0256678
N20	N19	0.38	12.7	0.0280654
N26	N21	0.19	3.89	0.0343856
N27	N20	0.19	3.89	0.0343856
N28	N19	0.21	4.44	0.0321276
N37	N22	5.44	3.89	0.0199949
N22	N39	4.94	3.43	0.02138
N23	N22	0.49	20.7	0.0275114
N24	N23	0.34	10.7	0.0295366
N30	N29	4.34	2.5	0.0201897
N38	N29	4.34	2.78	0.0224509
N36	N30	0.3	8.89	0.0315205
N35	N31	0.34	10.6	0.0292605
N33	N34	0.08	0.63	0.0314119
N34	N38	4.16	2.78	0.0244358
N39	N47	4.91	3.33	0.0210111
N47	N48	4.88	3.33	0.0212703
N45	N41	4.82	3	0.0196424
N46	N45	4.79	2	0.0132595
N44	N46	4.76	4	0.0268543
N54	N56	0.36	11.7	0.0288081
N56	N43	4.34	2.67	0.0215626

MODELLING OUTPUTS - TRADITIONAL NETWORK PIPES

PIPE Results:

From	To	Flow	Friction Slope	Darcy f
N43	N51	4.73	2.94	0.0199891
N68	N63	0.23	1.67	0.0322849
N61	N60	0.13	0.67	0.040544
N67	N64	0.08	0.71	0.0354008
N66	N62	2.6	0.56	0.0126011
N62	N110	2.18	0.82	0.0262464
N65	N66	2.78	1.19	0.0234221
N58	N57	3.4	1.33	0.017501
N64	N58	0.44	16.7	0.0275261
N63	N57	0.59	8.89	0.0261178
N57	N56	3.98	2.5	0.0240072
N95	N77	0.07	0	0
N94	N75	0.29	2.5	0.0304006
N75	N99	0.41	5	0.0304187
N75	N76	0.17	0	0
N74	N95	0.25	2.08	0.0340347
N76	N117	0.59	0	0
N98	N103	0.06	0	0
N99	N104	0.05	0	0
N100	N74	0.78	0	0
N105	N100	0.96	0.25	0.0412635
N104	N70	0.31	3	0.0319254
N103	N71	0.3	2.5	0.0284077
N71	N108	0.36	3.64	0.0287234
N71	N70	0.19	0.67	0.115
N70	N109	0.36	4.09	0.0322743
N70	N69	0.86	3.33	0.0278983
N69	N105	1.14	0.5	0.0585233
N110	N69	2	0.45	0.0171128
N109	N73	0	0	-1.#IND
N108	N72	0	0	-1.#IND
N93	N117	0.33	3.33	0.031272
N92	N81	0.33	3.33	0.031272
N81	N83	1.66	0.67	0.0369851
N81	N97	0.38	3.89	0.02755
N97	N102	0.02	0	0
N96	N83	1.69	0.56	0.0298252
N107	N88	0.29	2.73	0.0331975
N106	N86	0.43	5	0.0276549
N86	N87	3.54	0	0
N87	N88	1.1	5.38	0.0275504
N88	N89	0.81	0	0
N89	N71	0.47	1.29	0.0361847

MODELLING OUTPUTS - TRADITIONAL NETWORK PIPES

PIPE Results:

From	To	Flow	Friction Slope	Darcy f
N101	N84	2.08	0.56	0.0196893
N111	N86	3.97	2.22	0.021426
N116	N34	4.09	2.38	0.0216421
N115	N116	4.06	2	0.0184564
N117	N81	0.95	0	0
N53	N43	0.39	13.9	0.0291622

MODELLING OUTPUTS - DISTRIBUTED STORAGE NETWORK NODES

NODE HGL

Node	Min.HGL	Node	Min.HGL	Node	Min.HGL
N1	8.000	N45	6.300	N89	6.070
N2	7.380	N46	6.290	N90	6.090
N3	7.080	N47	6.430	N91	6.080
N4	6.760	N48	6.380	N92	6.010
N5	6.730	N49	6.150	N93	6.010
N6	6.700	N50	6.150	N94	6.010
N7	6.700	N51	6.210	N95	6.010
N8	6.690	N52	6.270	N96	6.060
N9	6.660	N53	6.150	N97	6.030
N10	6.660	N54	6.140	N98	6.010
N11	6.680	N55	6.150	N99	6.000
N12	6.660	N56	6.150	N100	6.020
N13	6.660	N57	6.100	N101	6.100
N14	6.660	N58	6.080	N102	6.040
N15	6.660	N59	6.080	N103	6.010
N16	6.660	N60	6.040	N104	6.000
N17	6.670	N61	6.040	N105	6.020
N18	6.640	N62	6.040	N106	6.100
N19	6.570	N63	6.060	N107	6.080
N20	6.550	N64	6.050	N108	6.000
N21	6.550	N65	6.070	N109	6.000
N22	6.540	N66	6.050	N110	6.020
N23	6.540	N67	6.040	N111	6.370
N24	6.540	N68	6.040	N112	6.370
N25	6.540	N69	6.020	N113	6.430
N26	6.540	N70	6.020	N114	6.460
N27	6.540	N71	6.020	N115	6.490
N28	6.550	N72	6.000	N116	6.490
N29	6.540	N73	6.000	N117	6.020
N30	6.550	N74	6.020		
N31	6.560	N75	6.020		
N32	6.530	N76	6.020		
N33	6.530	N77	6.010		
N34	6.520	N78	6.010		
N35	6.540	N79	6.010		
N36	6.530	N80	6.010		
N37	6.590	N81	6.030		
N38	6.530	N82	6.040		
N39	6.460	N83	6.040		
N40	6.450	N84	6.080		
N41	6.330	N85	6.080		
N42	6.330	N86	6.140		
N43	6.170	N87	6.130		
N44	6.280	N88	6.080		

MODELLING OUTPUTS - DISTRIBUTED STORAGE NETWORK PIPES

PIPE Results:

From	To	Flow	Friction Slope	Darcy f
N9	N11	2.31	1.11	0.0316423
N4	N5	2.5	0.94	0.0228779
N31	N30	1.11	0.67	0.0233516
N114	N115	1.04	0.91	0.0361296
N8	N17	0.11	1.33	0.0350752
N14	N13	0.05	0	0
N16	N12	0.01	0	0
N25	N26	0.02	0	0
N21	N20	0.05	0	0
N15	N16	0.02	0	0
N32	N35	0.040	0.56	0.111687
N33	N36	0.030	0	0
N25	N24	0.020	0	0
N24	N27	0.010	0	0
N23	N28	0.030	0.56	0.198555
N31	N18	1.23	0.94	0.0266812
N9	N18	2.27	1	0.02952
N1	N2	2.5	0.98	0.0238514
N2	N3	2.5	0.97	0.0236081
N3	N4	2.5	0.99	0.0240948
N18	N37	0.83	2.78	0.0250046
N32	N33	0.04	0	0
N113	N114	1.03	0.65	0.0263104
N113	N111	1.03	4.29	0.0250561
N90	N106	0.05	0.56	0.0714796
N91	N107	0.05	0	0
N91	N90	0.05	0.67	0.0855203
N80	N92	0.01	0	0
N87	N101	0.54	1.5	0.0318738
N96	N84	0.46	0.87	0.0254762
N89	N102	0.12	1.5	0.0332402
N74	N75	0.02	0	0
N79	N93	0.01	0	0
N80	N79	0.01	0	0
N59	N65	0.31	0.56	0.0361073
N78	N94	0.02	0	0
N78	N77	0.02	0	0
N72	N73	0	0	-1.#IND
N76	N98	0.07	0.56	0.0364692
N59	N58	0.31	0	0
N60	N68	0.01	0	0
N61	N67	0.02	0	0
N62	N61	0.03	0	0

PIPE Results:

From	To	Flow	Friction Slope	Darcy f
N55	N54	0.02	0.56	0.446748
N49	N53	0.03	0	0
N41	N48	0.74	2.27	0.0256858
N52	N51	0.72	2.61	0.0311965
N49	N55	0.02	0	0
N52	N44	0.72	1.43	0.0170923
N41	N42	0.01	0	0
N7	N6	0.01	0	0
N9	N10	0.01	0	0
N40	N39	0.01	0.22	0.702032
N49	N50	0.01	0	0
N83	N82	0.01	0	0
N84	N85	0.01	0	0
N111	N112	0.01	0	0
N6	N5	2.5	1.2	0.0292058
N8	N6	2.5	0.91	0.0221478
N17	N14	0.05	0.67	0.0855203
N13	N15	0.02	0	0
N16	N9	0.03	0	0
N12	N17	0.06	0.56	0.0496386
N11	N8	2.38	0.56	0.0150384
N19	N18	0.22	4.67	0.0307897
N20	N19	0.11	1.33	0.0350752
N26	N21	0.05	0.56	0.0714796
N27	N20	0.06	0.56	0.0496386
N28	N19	0.11	1.11	0.0292733
N37	N22	0.76	2.78	0.0298228
N22	N39	0.76	2.29	0.0245662
N23	N22	0	0	-1.#IND
N24	N23	0.03	0	0
N30	N29	1.02	0.62	0.0255905
N38	N29	1.02	0.56	0.023114
N36	N30	0.1	1.11	0.0354207
N35	N31	0.11	1.11	0.0292733
N33	N34	0.07	0.63	0.0410279
N34	N38	0.98	0.56	0.0250394
N39	N47	0.75	3.33	0.0366819
N47	N48	0.75	2.38	0.0262171
N45	N41	0.73	3	0.0348824
N46	N45	0.73	2	0.0232549
N44	N46	0.72	2	0.0239054
N54	N56	0.05	0.56	0.0714796
N56	N43	0.61	1.33	0.0221474

MODELLING OUTPUTS - DISTRIBUTED STORAGE NETWORK PIPES

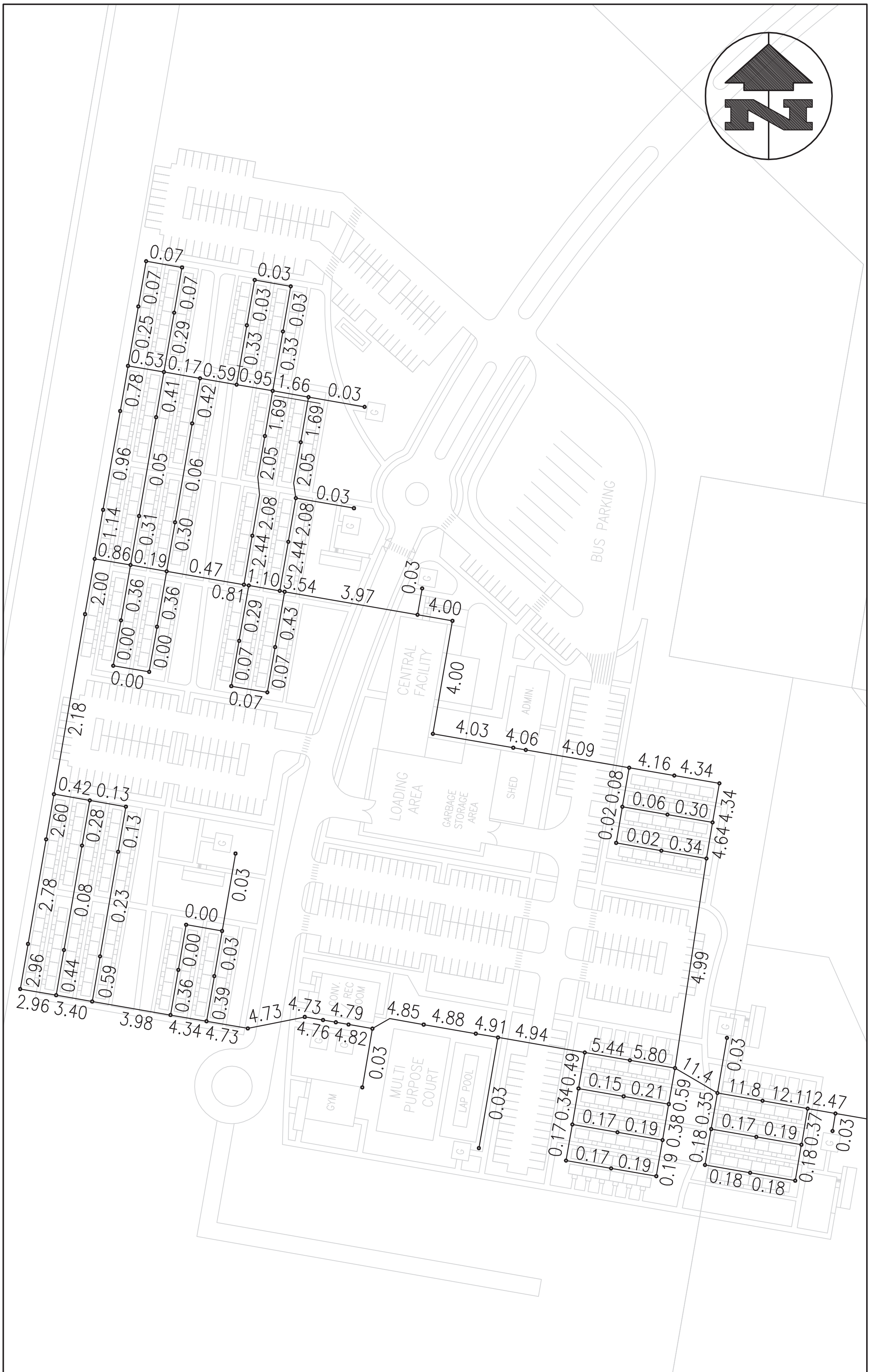
PIPE Results:

From	To	Flow	Friction Slope	Darcy f
N43	N51	0.72	2.35	0.0280888
N68	N63	0.06	0.48	0.0425474
N61	N60	0.01	0	0
N67	N64	0.05	0.24	0.0306341
N66	N62	0.24	0.56	0.0602415
N62	N110	0.21	0.27	0.0379364
N65	N66	0.27	0.48	0.0407985
N58	N57	0.43	1.33	0.0445703
N64	N58	0.12	1.67	0.0370074
N63	N57	0.13	2.22	0.041918
N57	N56	0.57	1.56	0.0297513
N95	N77	0.02	0	0
N94	N75	0.06	0.42	0.037229
N75	N99	0.07	1.11	0.0722872
N75	N76	0.15	0	0
N74	N95	0.05	0.42	0.0536097
N76	N117	0.22	0	0
N98	N103	0	0	-1.#IND
N99	N104	0	0	-1.#IND
N100	N74	0.03	0	0
N105	N100	0.07	0	0
N104	N70	0.07	1	0.0651236
N103	N71	0.07	0.5	0.0325618
N71	N108	0.08	0.91	0.0453728
N71	N70	0.07	0	0
N70	N109	0.07	0.91	0.0592625
N70	N69	0.06	0	0
N69	N105	0.1	0	0
N110	N69	0.17	0	0
N109	N73	0	0	-1.#IND
N108	N72	0	0	-1.#IND
N93	N117	0.06	0.42	0.037229
N92	N81	0.07	0.83	0.0540526
N81	N83	0.38	0.67	0.02875
N81	N97	0.02	0	0
N97	N102	0.05	0.25	0.0319106
N96	N83	0.39	1.11	0.0452193
N107	N88	0.02	0	0
N106	N86	0.12	1.82	0.0403314
N86	N87	0.9	5	0.0382486
N87	N88	0.36	3.85	0.0303805
N88	N89	0.34	5	0.0442335
N89	N71	0.22	1.61	0.0340188

PIPE Results:

From	To	Flow	Friction Slope	Darcy f
N101	N84	0.47	1.11	0.0311356
N111	N86	1.02	4.26	0.0253711
N116	N34	1.05	0.71	0.0276546
N115	N116	1.04	0	0
N117	N81	0.29	0.67	0.0493639
N53	N43	0.1	1.11	0.0354207

TRADITIONAL NETWORK
PIPE FLOWS (L/s)
SCALE 1:5000



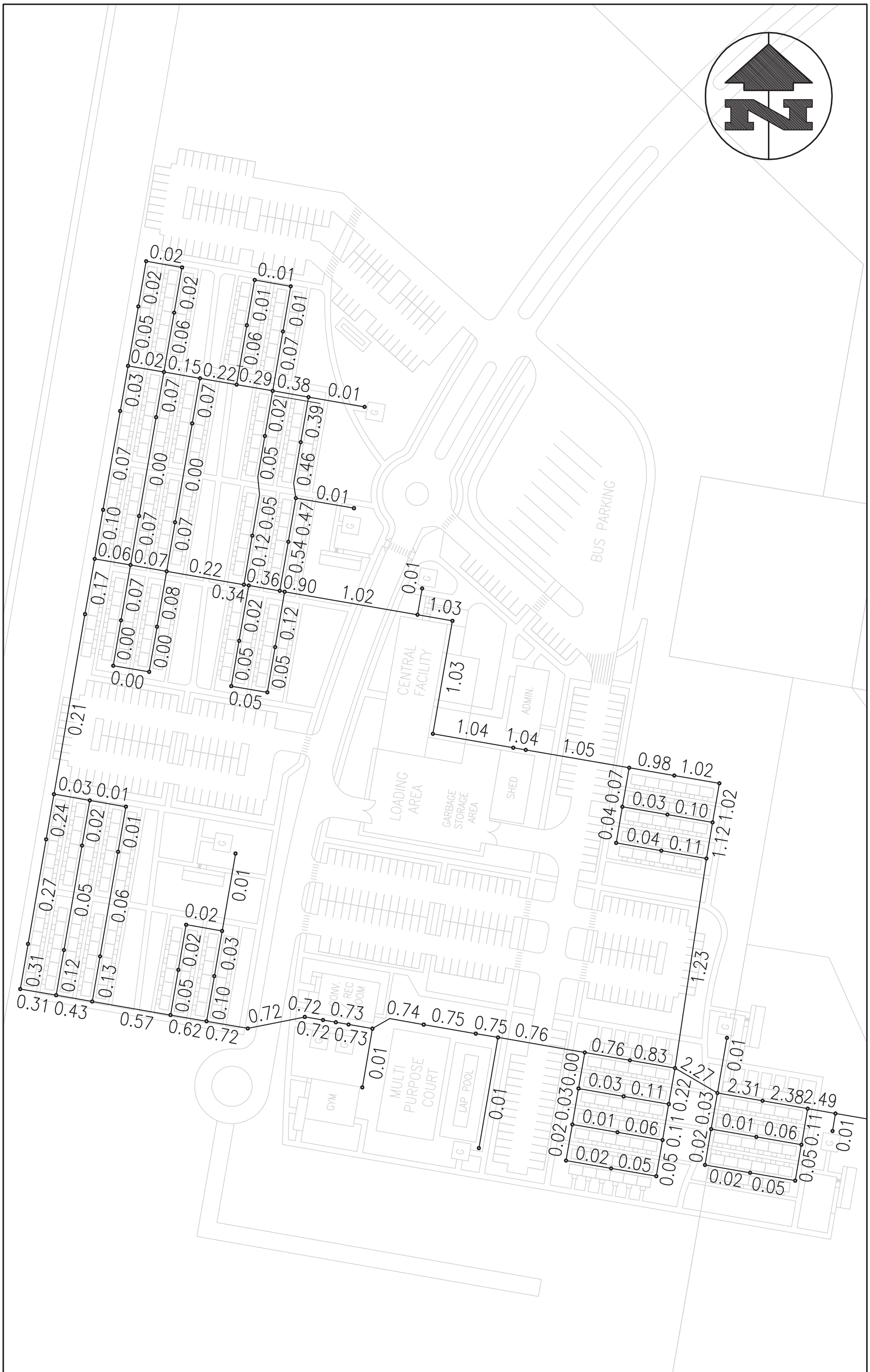
TRADITIONAL NETWORK

PIPE FLOWS (L/s)

SCALE 1:2000

DISTRIBUTED STORAGE NETWORK
PIPE FLOWS (L/s)

SCALE 1:5000



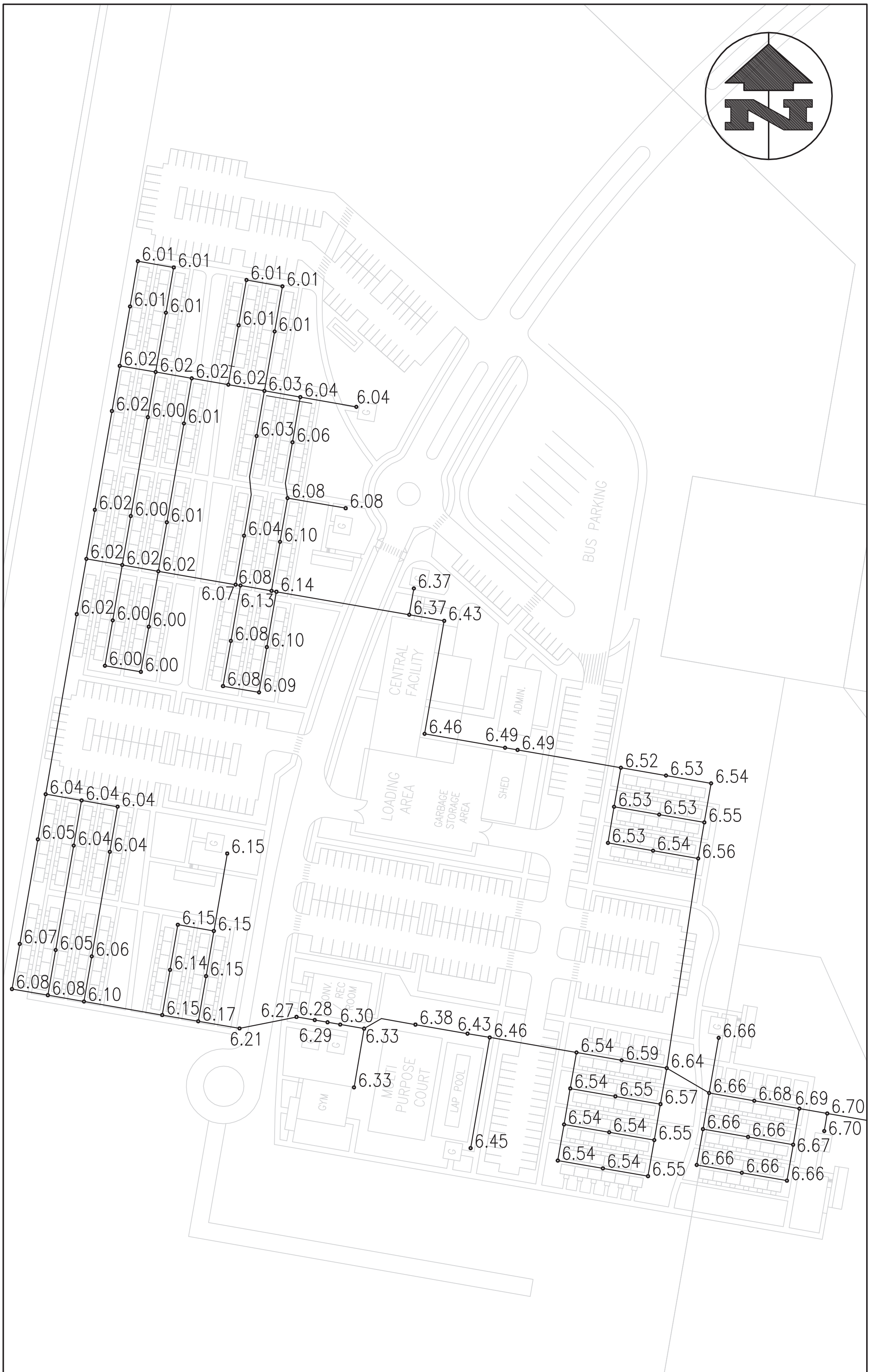
DISTRIBUTED STORAGE NETWORK
PIPE FLOWS (L/s)

SCALE 1:2000

TRADITIONAL NETWORK

HYDRAULIC GRADE LEVEL (M)

SCALE 1:2000



DISTRIBUTED STORAGE NETWORK
HYDRAULIC GRADE LEVEL (M)
SCALE 1:2000

MODELLING OUTPUTS - REDUCED PRESSURE NETWORK NODES

NODE HGL

Node	Min.HGL	Node	Min.HGL	Node	Min.HGL
N1	8.000	N45	7.920	N89	7.890
N2	7.980	N46	7.920	N90	7.890
N3	7.970	N47	7.930	N91	7.890
N4	7.950	N48	7.930	N92	7.890
N5	7.950	N49	7.900	N93	7.890
N6	7.950	N50	7.900	N94	7.890
N7	7.950	N51	7.920	N95	7.890
N8	7.950	N52	7.920	N96	7.890
N9	7.950	N53	7.900	N97	7.890
N10	7.950	N54	7.900	N98	7.890
N11	7.950	N55	7.900	N99	7.890
N12	7.940	N56	7.910	N100	7.890
N13	7.930	N57	7.910	N101	7.900
N14	7.940	N58	7.900	N102	7.890
N15	7.940	N59	7.900	N103	7.890
N16	7.940	N60	7.890	N104	7.890
N17	7.940	N61	7.890	N105	7.890
N18	7.950	N62	7.900	N106	7.890
N19	7.920	N63	7.900	N107	7.890
N20	7.910	N64	7.890	N108	7.880
N21	7.910	N65	7.900	N109	7.890
N22	7.940	N66	7.900	N110	7.890
N23	7.920	N67	7.880	N111	7.900
N24	7.910	N68	7.890	N112	7.900
N25	7.910	N69	7.890	N113	7.910
N26	7.910	N70	7.890	N114	7.910
N27	7.910	N71	7.890	N115	7.920
N28	7.920	N72	7.880	N116	7.920
N29	7.930	N73	7.890	N117	7.890
N30	7.930	N74	7.890		
N31	7.930	N75	7.890		
N32	7.920	N76	7.890		
N33	7.920	N77	7.890		
N34	7.920	N78	7.890		
N35	7.920	N79	7.890		
N36	7.920	N80	7.890		
N37	7.940	N81	7.890		
N38	7.930	N82	7.890		
N39	7.930	N83	7.890		
N40	7.930	N84	7.890		
N41	7.920	N85	7.890		
N42	7.920	N86	7.900		
N43	7.910	N87	7.900		
N44	7.920	N88	7.890		

Min. 7.880

APPENDIX E

COST ANALYSIS SCHEDULE OF RATES

TRADITIONAL AND DISTRIBUTED STORAGE WATER SUPPLY
COMPARISON OF OPTIONS
SUMMARY

		TRADITIONAL SUPPLY (PEAK HOUR FLOW)	DISTRIBUTED STORAGE (AVERAGE HOURLY FLOW)
INSTALLATION			
DISTRIBUTION MAIN		$127,233	$57,587
SITE RETICULATION		$91,984	$69,061
PUMPS & TANKS		$0	$320,000
SUB TOTAL		**$219,217**	**$446,648**
MAINTENANCE			
DISTRIBUTION MAIN		$31,808	$14,397
SITE RETICULATION		$22,996	$17,265
PUMPS & TANKS		$0	$680,000
SUB TOTAL		**$54,804**	**$711,662**
TOTAL		**$274,022**	**$1,158,310**

TRADITIONAL AND DISTRIBUTED STORAGE WATER SUPPLY
SCHEDULE OF QUANTITIES/RATES FOR COMPARISON OF OPTIONS
DISTRIBUTION MAIN

				TRADITIONAL NETWORK		DISTRIBUTED STORAGE	
ITEM	**DESCRIPTION**	**UNIT**	**RATE**	**QTY**	**COST**	**QTY**	**COST**
1.00	**PIPES**						
	Trenching costs included, assumed to be the same for 25-65mm diameter and 80-200mm diameter						
1.01	200 mm DIA.	L.m	$ 105.50	1,206	$ 127,233.00		$ -
1.02	150 mm DIA.	L.m	$ 73.50		$ -		$ -
1.03	100 mm DIA.	L.m	$ 47.75		$ -	1,206	$ 57,586.50
1.04	80 mm DIA.	L.m	$ 40.75		$ -		$ -
1.05	65 mm DIA.	L.m	$ 35.00		$ -		$ -
1.06	50 mm DIA.	L.m	$ 28.30		$ -		$ -
1.07	40 mm DIA.	L.m	$ 24.90		$ -		$ -
1.08	32 mm DIA.	L.m	$ 24.10		$ -		$ -
1.09	25 mm DIA.	L.m	$ 22.00		$ -		$ -
	SUBTOTAL			**1,206**	**$ 127,233.00**	**1,206**	**$ 57,586.50**
	TOTAL				**$ 127,233.00**		**$ 57,586.50**

TRADITIONAL AND DISTRIBUTED STORAGE WATER SUPPLY
SCHEDULE OF QUANTITIES FOR COMPARISON OF OPTIONS
SITE RETICULATION

				TRADITIONAL NETWORK		DISTRIBUTED STORAGE	
ITEM	**DESCRIPTION**	**UNIT**	**RATE**	**QTY**	**COST**	**QTY**	**COST**
1.00	**PIPES**						
	Trenching costs included, assumed to be the same for 25-65mm diameter and 80-200mm diameter						
1.01	200 mm DIA.	L.m	$ 105.50		$ -		$ -
1.02	150 mm DIA.	L.m	$ 73.50		$ -		$ -
1.03	100 mm DIA.	L.m	$ 47.75	887	$ 42,354.25		$ -
1.04	80 mm DIA.	L.m	$ 40.75		$ -	242	$ 9,861.50
1.05	65 mm DIA.	L.m	$ 35.00		$ -		$ -
1.06	50 mm DIA.	L.m	$ 28.30	66	$ 1,867.80	645	$ 18,253.50
1.07	40 mm DIA.	L.m	$ 24.90		$ -		$ -
1.08	32 mm DIA.	L.m	$ 24.10	644	$ 15,520.40	66	$ 1,590.60
1.09	25 mm DIA.	L.m	$ 22.00	673	$ 14,806.00	1,317	$ 28,974.00
	SUBTOTAL			**2,270**	**$ 74,548.45**	**2,270**	**$ 58,679.60**
2.00	**FITTINGS**						
	Assumes a fitting on average every 30m for the site reticulation mains.						
2.01	100 mm DIA.	L.m	$ 15.00	887	$ 13,305.00		$ -
2.02	80 mm DIA.	L.m	$ 14.33		$ -	242	$ 3,468.67
2.03	65 mm DIA.	L.m	$ 10.87		$ -		$ -
2.04	50 mm DIA.	L.m	$ 5.83	66	$ 385.00	645	$ 3,762.50
2.05	40 mm DIA.	L.m	$ 4.23		$ -		$ -
2.06	32 mm DIA.	L.m	$ 3.50	644	$ 2,254.00	66	$ 231.00
2.07	25 mm DIA.	L.m	$ 2.22	673	$ 1,491.82	1,317	$ 2,919.35
	SUBTOTAL			**2,270**	**$ 17,435.82**	**2,270**	**$ 10,381.52**
	TOTAL				**$ 91,984.27**		**$ 69,061.12**

TRADITIONAL AND DISTRIBUTED STORAGE WATER SUPPLY
SCHEDULE OF QUANTITIES FOR COMPARISON OF OPTIONS
TANKS AND PUMPS

				TRADITIONAL NETWORK		DISTRIBUTED STORAGE	
ITEM	**DESCRIPTION**	**UNIT**	**RATE**	**QTY**	**COST**	**QTY**	**COST**
3.00	**TANKS & PUMPS**						
3.01	1000 L Tank	No.	$ 500.00		$ -	400	$ 200,000.00
3.02	0.6 L/s Pump at 30m Head	No.	$ 300.00		$ -	400	$ 120,000.00
	SUBTOTAL				**$ -**		**$ 320,000.00**
	TOTAL				**$ -**		**$ 320,000.00**

TRADITIONAL AND DISTRIBUTED STORAGE WATER SUPPLY
SCHEDULE OF QUANTITIES/RATES FOR COMPARISON OF OPTIONS
MAINTENANCE COSTS

				TRADITIONAL NETWORK		DISTRIBUTED STORAGE	
ITEM	**DESCRIPTION**	**UNIT**	**RATE**	**QTY**	**COST**	**QTY**	**COST**
1.00	**Distribution Main**						
	0.5% of Construction Value per year						
1.01	Annual Maintenance Cost (Present Day Dollars)			1	$ 636.17	1	$ 287.93
1.02	Maintenance Cost over 50 Years			50	$ 31,808.25	50	$ 14,396.63
	SUBTOTAL				**$ 31,808.25**		**$ 14,396.63**
2.00	**Site Reticulation**						
	0.5% of Construction Value per year						
2.01	Annual Maintenance Cost (Present Day Dollars)			1	$ 459.92	1	$ 345.31
2.02	Maintenance Cost over 50 Years			50	$ 22,996.07	50	$ 17,265.28
	SUBTOTAL				**$ 22,996.07**		**$ 17,265.28**
3.00	**TANKS & PUMPS**						
3.01	Replace Tank once in 50yr Period	No.	$ 500.00		$ -	400	$ 200,000.00
3.02	Replace pumps 4 times in 50 years	No.	$ 1,200.00		$ -	400	$ 480,000.00
	SUBTOTAL				**$ -**		**$ 680,000.00**
	TOTAL				**$ 54,804.32**		**$ 711,661.90**