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A Feasibility Analysis of the use of the Skipworth model for Bridgetown Water Supply Network and a Whole Life Costing to compare the water distribution systems at Greenvale pumping station.

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ABSTRACT

To promote efficient use of water resources in the developing world, there is a recognized need to make the best use of infrastructure developments and application of Whole Life Costing (WLC) in combination with computational optimization. In this way the efficiency of Water Management in public and private areas can be improved. This case study, a feasibility study and whole life costing analysis, was designed to assess the feasibility of the Skipworth model on the Bridgetown Water Supply Network. The Skipworth model was proved to be more cost effective than the current models used by the Water Corporation at Bridgetown. The whole life costing was conducted with Greenvale Pumping Station in order to compare the water distribution methods, Pump, Gravity and Combined Systems. The feasibility studies provided much information to the Water Corporation and Water Organizations of Australia to enable changes in the existing Water Distribution System of Australia. The whole life costing provided data which proved the Gravity and Combined systems were more cost effective than the current Pumping system. Recommendations were made for the implementation of the Skipworth model at Bridgetown and a Gravity and Combined system at Greenvale.

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List of Abbreviations

ABC	Activity Based Costing
AMP	Asset Management Plan
CI	Cast Iron
CVM	Contingent Value Method
DMA	District Meter Area
EA	Environment Agency
GA	Genetic Algorithm
GIS	Geographic Information System
LCA	Life Cycle Assessment
WLC	Whole Life Costing
NRR	Natural Rate of Rise Leakage
O&M	Operation and Maintenance
RAG	Regulatory Accounting Guidelines
WSZ	Water Supply Zone

Chapter 1 Introduction

There are different Water Distribution Systems used throughout the world. Most cities in India use intermittent Supply (Combined System) (Planning Commission of India, 2009). Most of Pakistan's cities also use Intermittent Supply (Water and Sanitation Program, August 2004). Most of Australia's cities use Continuous Supply (Australian Government National Water Commission – Urban Performance, 2008). The average urban water use is 150 lpcd, 197 lpcd and 191 lpcd for India, Pakistan and Australia respectively.

In Australia, Pumping Systems are mostly used due to fluctuations in geographic conditions and easy availability of electricity. The dominance of the Pumping System in Australia has led to environmental issues and financial issues. Power consumed by Pumping Systems leads to environmental pollution and results in depletion of the ozone layer. Hence Gravity based Systems are likely to be more economical and environmentally friendly compared to Pumping based Systems (Swamee, 2009).

The Advantages of Gravity based Systems over Pumping Systems are:

- Less operation and maintenance cost
- Less impact on the Environment

However, Gravity based Systems have limitations when elevation difference between input and withdraw point is less. In this case pipes with greater diameters have to be selected, resulting in increased costs.

Figure 1.1(Appendix C) and Figure 1.2(Appendix C) show diagrams of Water Supply in Melbourne and Sydney. It can be seen there are several Pumping Stations between one end to the other end of the Water Supply region. In Perth the Water main length is 12,861 kms and contains 1164 Pumping Stations (Water Organization Report, 2010).

1.1 Water Distribution Theory

There are three methods considered in the Water Distribution theory; they are:

1. Gravity System
2. Pumping System
3. Combined System

1.1.1 Gravity System :

Figure 1.3 (Appendix C) shows a Gravity System with a Distribution Reservoir and Distribution Area. Pumping is required from the water treatment plant to the reservoir. The Gravity System is more reliable and economical than the Pumping System and Combined System (Iitbanglore, 1996).

1.1.2 *Pumping System* :

Figure 1.3 shows a Pumping System with Pumping Station and Distribution Area. The Pumping is done directly into the Distribution System.

The Pumping System has some limitations as below:

- Double Pumping may be required.
- Variable speed pumps may be required.
- Distribution is disturbed during power failures.

1.1.3 *Combined System* :

Figure 1.3 shows a Combined System with Pumping System near to an elevated reservoir and Distribution area.

My research compared Whole Life Costing variables of these three Systems and evaluated which among them was the best for one for the Melbourne Pumping Stations.

1.2 Application of Whole Life Costing to Water Distribution Networks

Application of Whole Life Costing to Water Distribution Networks has become complex for the water organisations. There are many reasons for this complexity. Mainly the problem is lack of integration of all the Water Distribution issues related to the application of the Whole Life Costings; this has created the current imprecise life cycle models for Water Distribution Management.

The application of Whole Life Costing (WLC) to pipelines and Water Distribution Networks has been recently discussed in the UK (Herbert, 1994). Herbert commented that preference should be given to solutions which imply higher construction costs but lower operating costs in order to minimize overall costs. Also, costs and benefits of rehabilitation should be considered on all fronts (Mukhopadhyay, 1994). An integrated approach to rehabilitation planning and leakage control can reduce whole life costs (Conroy, 1995).

Burn (2010) of CSIRO has also been involved in life cycle analysis of water networks. He found that polyethylene networks show significantly lower costs throughout their lifetime and the combined benefits of low failure and water loss rates can potentially result in long term cost savings. Young (2010) examined the key elements of customer service standards, replacement analysis and asset life prediction in minimising whole of life costs for water mains. He showed that all three elements should be used in parallel for optimum results.

The Skipworth model allows three elements, details of cost driver, regulation and the boundaries of Water Distribution Network. In other words, it provides an holistic assessment of the Water Distribution Network in the context of whole life costing. The Skipworth model is currently used in the UK and Scotland. The Skipworth model aims to achieve the lowest Network provision and operating cost, by considering costs, to achieve the standard enforced by regulation.

1.3 Skipworth Theory

1.3.1 Skipworth: Whole Life Cost Accounting Framework Implementation

This section describes the Skipworth theory in detail. Consider a Water Supply System as a simple input/output model as provided in Figure 1.4 (Appendix C). A Water Supply System transforms inputs (e.g. raw water, energy, and other resource) into outputs – a Water Supply Service that meets amongst others, the statutory quality requirements. In doing so there is waste in the form of discharges such as bursts and leakage. The resources input are not without costs and therefore the outputs have costs associated with, and apportioned to them.

The physical configuration of the Water Supply System is also an important factor in the costs incurred in supplying the service. An idealised system is where the water is first abstracted from a source. From the treatment works it is transferred to a storage facility that feeds water into a Distribution Network. Each of these stages requires infrastructure, the functioning of which requires activities and inputs (resources).

Regulatory accounting guidelines (Regulatory Accounting Guidelines, 1992) provide a schema for the analysis of operating costs and assets. Details outlining what is included as part of each of the cost items under the various main headings are provided in RAG. Though RAG is used as the example, the approach is sufficiently flexible and could be transposed to other situations, as the treatment of operational and capital maintenance costs would be similar.

In determining the cost of providing a Water Supply service, it is not just the direct costs that are required to be considered, but also the business activity costs that support and underpin these direct activities. The various business activity costs: scientific services; customer services; regulation; and general and support activities are allocated to supply, bursts and leakage depending on how they are incurred in support of them. For example, customer service supports the normal supply of water and thus the cost of this activity should be allocated as part of the overall cost of normal Supply. The allocation for the cost of regulation should reflect this.

The costs for the three categories of supply, bursts and leakage can be built up from the cost categories in Figure 1.5 (Appendix C), which follow the passage of water from source to customer. Figure 1.6 (Appendix C) indicates the way these three categories of cost are built up.

In addition to the operational costs, information on capital maintenance and operational intervention activities is required. The decision tool may also require estimates of the expected efficiency gains over time for various activities and intervention; lastly, the cost model requires information on the scale of penalty costs to reflect the consequences of non–compliance with levels of service set for an operator by regulators.

Costs within the accounting framework can be split into labour related costs, material and equipment costs, service costs and social and environmental costs though it is simpler to work in terms of private costs and social costs. There are a number of issues relating to the environment; for example, water organisations have developed regulations in order to resolve these issues.

1.3.2 Skipworth: Regulation

The regulations, according to Skipworth, should be decided by the Water Authority. These regulations include:

1. Economic Regulations
2. Environmental Regulations
3. Potable Water Quality Regulations

The role of Regulations is to cover a wide array of practical and economic mechanisms; in reality, regulations seek to arrange, direct and govern in such a way as to produce actions that conform to a norm. They are a convenient way to administer public policy as they usually do not involve direct taxation or government spending to achieve goals. Regulations can be divided into economics and social regulations. Economic regulations seek to address issues related to the functioning of a market whilst social regulations deal with the interests of individuals, health and safety and environmentally related goals.

Social regulation is required for similar reasons to economic regulation. In the absence of customer choice, there needs to be safeguards that ensure the quality and safety of the product. Water has to be safe and fit to drink. Additionally, the processes and activities involved in its production and disposal must conform to acceptable standards. For regulations to be successful there have to be accompanying penalties for non-compliance, set in such a way as to provide dynamic incentives that, at a minimum, encourage compliance and, for some aspects, encourage reduction in costs.

In summary, therefore, compliance with regulations should be seen as a process that includes:

- The formation of goals/objectives
- Systems to monitor compliance,
- The provision of incentives for the achievement of goals.

1.3.3 Skipworth- Cost Drivers

There are three cost drivers provided by the Skipworth model:

1. Supply and Demand
2. Structural Performance
3. Water Quality

1. Supply and Demand

The Supply and Demand cost driver is related to the leakage problems in the Water Distribution Network Management and it creates some sub costs drivers.

Leakage can be defined as that water which, having been obtained from a source and treated and put into supply, leaks or escapes other than by a deliberate or controllable action. This water is often referred to as unaccounted-for-water corresponding to the discrepancy between the measured supplies of, and measured and projected demand for, water.

The Supply and Demand cost driver is related to leakage control problems; in order to manage these leakage problems, strategies must be utilised.

The natural rise of leakage is defined as the increase that would take place with time under a passive leakage control policy where only reported bursts or low pressure complaints are acted upon. The natural rate of rise of leakage is a common issue and is worked out through the following equation:

$$\text{NRR} = \text{a}(Lo)^{h1}\left(\frac{L}{N}\right)^{h2}(ANZP)^{h3}(C)^{h4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.1$$

where Lo is current leakage, L/N is metres of main per property, ANZP is average zonal night pressure, C is asset condition, and a,h1,h2,h3,h4 are estimated using pilot data.

The economic level of leakage is defined as the level of leakage where the long run marginal cost of leakage control is equal to the long run marginal benefit of the water saved. The security of supply is a term used in water resource planning with reference to the level of confidence that the volume of the water available for supply can, in any event, meet the demand of the customers. The hydraulic capacity means that, in the Water Distribution Network, there is a certain pressure requirement to flow the water and if a company fails to provide minimum pressure then penalty cost is created as a cost driver, so there is a need for demand projection to give sufficient water to customers with required pressure.

2. *Structure Performance*

The structure performance cost driver is related to the burst rate and its dependencies like Material, Diameter, and Age and the bursting events create some sub cost drivers, e.g. Labour, Material, Transportation Costs.

Within the methodology, there is a need to quantify the likely future number of structural mains failures and their distribution across the pipe asset base.

A main fails when its residual strength becomes inadequate to resist the forces impacting on it. The strength of the main and rate of deterioration in its ability to resist forces depends on the functioning and type of pipe and its environmental attributes. The surge agents (like valve operation, pump operation) may also cause bursting.

Physical deterioration on the mains material type is primarily due to corrosion. The Skipworth theory also considers corrosion in the Water Distribution Network. Chemical interaction occurs both internally with the mains water and externally with the surrounding environment. The corrosion of metallic (ferrous) water mains is largely due to the potential difference between two areas on the surface of the metal which creates the elements of a cell, i.e. an anode and a cathode.

The Skipworth theory also takes account of the loading on water mains.

There are two types of loading: Internal loads and External loads.

Internal Loads

The Water Distribution Network must be able to withstand the pressure exerted by the water that passes through it under normal operational conditions. However, greater pressures are created during surge events caused by, for example, pump switching, valve operation. Surge events have the potential to cause failure by exposing vulnerable parts of the network. The policies include using "soft" or stepped starts for pumps and the use of protocols to ensure gradual opening and closing valves.

External Loads

The external loads that a main experiences are primarily determined by the surrounding environment. The soil, meteorological conditions and the overlying land use all contribute in determining the magnitude and pattern of loading. External loads include those associated with the surrounding media and those superimposed from the overlying land use. The most identifiable of these superimposed loads is traffic loading. The main will also have to resist loads created by any differential movement in the soil.

The Skipworth theory also takes account of different types of pipes and environmental factors affecting mains failure like Pipe Age, Pipe Material, Pipe Diameter, Traffic Loading, Ground Type, and Meteorological Conditions, Pressure, Burst History. The Skipworth theory gives the diagram (Figure 1.7, Appendix C) as "Process regression for temporal failure behaviour of Distribution mains".

There are some formulae given by Skipworth to analyse burst events like Recommended Analysis, how to find Non–dimensional burst rate factor, instantaneous increase in normalised burst rate, average normalised burst rate over the period:

γi(t) =γi (to) ……………………………………equation: 1.2

where, t_0 is the base year of the Analysis,

γ_i (t) is burst rate /unit time per unit length at time t for the ith pipe group,

γ_i (t_0) is burst rate/unit time per unit length at time t_0 for the ith pipe group,

A_i Is the growth coefficient for the ith pipe group.

γ_i(t)= K_i[$\prod_K X_{ik}\, r_{ik}$] ……………………………………………equation: 1.3

B(x) = g'(x)/h'(x) ……………………………………………equation: 1.4

X is an independent variable affecting burst rate, e.g. Pipe Age, Diameter, Service Density,

B(x) is burst rate factor as a function of x,

g(x) is cumulative failures as a percentage of total failures as a function of x,
h(x) is cumulative length as a percentage of total length as a function of x,
g'(x) is the differential of g(x),
h'(x) is the differential of h(x).

$$A_i = \frac{\ln (f(a+t')/f(a))}{t'} \text{ ....equation: 1.5}$$

Where, A_i is the material specific growth coefficient
a is the pipe age at beginning of analysis, time(t_0)
t' is the period of analysis where t=t_0+t', and t is the time horizon

$$F_{aave} = \int_a^{a+t'} f(x).dx / t' \text{ ....equation: 1.6}$$

F_{aave} is the average normalised burst rate over the period t_0 to t

$$B_N = KR_{MD}F_S\text{L} \int_a^{a+t'} f(x)dx \text{ ....equation:1.7}$$

1. *Water Quality*

The Water Quality cost driver takes account of Aesthetic Water Quality, Bacteriological Water Quality, and Sediment Accumulation at dead ends and Chemical Water Quality and its sub cost driver.

Discoloured water can be caused by failure at treatment and sedimentation. Treatment like flushing is required to solve this problem which creates cost or a cost driver.

The Skipworth theory also takes account of disinfection and provides suggestions when complaints of taste and odour are prevalent, e.g. reducing the chlorine demand of pipe walls through replacement, or flushing of rough mains and minimising the age of water.

Sediment accumulates at the very ends of dead end mains where quiescent hydraulic conditions exist. These deposits necessitate periodic flushing at dead ends for their removal. The division of Networks into district meter areas has aggravated this problem by creating extra dead ends mains.

The chemical elements and their concentration also affect Water Distribution Network Management like Iron, PAH, THM and Lead. They create problems like increasing chlorine demand, taste and odour problems, bacteriological failure. To remove this problem some treatment like flushing and replacement of pipe is required which creates cost or sub cost driver.

The following equations are given by Skipworth to work out costs for maintaining the water quality:

$$C_{Tflush} = [\mathrm{F} \sum_{j \epsilon AM} (V_j + W_J) L_j] + E_{flush} \ldots\ldots\ldots\ldots \text{Equation 1.8}$$

Where, C_{Tflush} is the total annual cost of flushing,

j is a main in the Network where AM is the complete set of all mains,

L_j is the length of main j,

F is the number of flushes per year which reflects the source and extent of the introduction of sediment into the Network and the level of failure risk that the operator is willing to tolerate,

V_j is the annual cost associated with the particular main based on whether the main is thought to be sources of sediment build up

W_j is the annual cost associated with the particular main based on whether the main is thought to be a source of discolouration through corrosion

E_{flush} is the sum of annual externalities associated with flushing

$$C_{PAH} = R_{PAH}\, L_{CT} + E_{PAH} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1.9}$$

C_{PAH} is the annual cost associated with the risk of PAH contravention

R_{PAH} is the risk cost associated with a unit length of coal tar lined main

L_{CT} is the length of coal tar lined mains,

E_{PAH} is the sum of annual externalities associated with contravening the PAH standard

$$C_{THM} = [\, R_{THM} \sum_{i \epsilon UF} y_i\, L_i\,] + E_{THM} \ldots\ldots\ldots\ldots \text{Equation 1.10}$$

Where, C_{THM} is the annual cost associated with the risk of THM contravention,

i is an unlined ferrous main in the Network where UF is the complete set all unlined ferrous mains,

R_{THM} is the risk cost associated with a length of unlined ferrous main,

y_i is a weighting factor for each main (dimensionless). and y_i reflects the likelihood that the particular main will contribute to a THM contravention,

E_{THM} is the sum of annual externalities associated with contravening the THM standard.

NPV was also calculated on the feasibility analysis of the Bridgetown Water Supply Project.

1.3.4 Net Present Value

Net Present Value (NPV)

NPV is an indicator of how much value an investment or project adds to the firm. With a particular project, if R_t is a positive value, the project is in the status of discounted cash inflow in the time of t. If R_t is a negative value, the project is in the status of discounted cash outflow in the time of t. Appropriately risked projects with a positive NPV could be accepted. This does not necessarily mean that they should be undertaken since NPV at the cost of capital may not account for opportunity cost, i.e. comparison with other available investments. In financial theory, if there is a choice between two mutually exclusive alternatives, the one yielding the higher value should be selected.

NPV>0 the investment would add value to the firm; the project may be accepted

NPV<0 the investment will subtract value from the firm; project should be rejected

NPV=0 the investment would neither gain or loss value for the firm.

$$NPV = \quad Rt / (1+i)^{t} \quad \text{……………Equation 1.11}$$

t - The time of the cash flow

i - The discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.); the opportunity cost of capital

R_t - the net cash flow (the amount of cash, inflow minus outflow) at time t. For educational purposes, R_0 is commonly placed to the left of the sum to emphasize its role as (minus) the investment (Sev, 2000).

In this study, a 7% discount rate was considered for Bridgetown Water Supply Network.

1.3.5 Skipworth-Discount Rate

The application of the cost accounting framework will lead to the generation of an expenditure profile over the period of analysis adopted. When there is a need to compare alternative uses of available funds, some common method of comparison is required. This is especially important if the streams of expenditures are different over time. Whole Life Costing, in common with a number of other techniques (e.g. cost benefit analysis), uses a discount rate to achieve this. The discount rate chosen can have an enormous impact on the results, especially if the period of analysis is long. High discount rates favour short term improvements over long term investments. Ideally, the discount rate chosen should reflect the operator's time value of money. If An economy is experiencing a growth in income and consumption through time then an additional unit of consumption will be worth less in the future than in the present.

1.3.6 Skipworth - Boundaries:-

Water Distribution Networks exist within a set of boundaries and in applying Whole Life Costing they have a determining influence on the results of any analysis. Therefore a proper appreciation of them is required in order that meaningful and informative results are obtained that will aid decision making. Three sets of boundaries are recognised: geographical, temporal and cost. Geographical boundaries define the extent of the Network considered and this has a bearing on the assets considered and their performance over time. Definition of the spatial boundaries also holds implications for costs; the two are closely linked. Temporal boundaries determine the time horizon for any analysis.

1.3.6.1 Geographic Analysis

Water service providers normally have a functional hierarchy of their Water Supply System that is geographically based. There are integrated systems that treat and transport water from source to consumer and return the waste water from consumer to the environment. A Distribution Network is one part of an integrated System. Water Distribution Networks consist largely of underground assets and can be characterised as being everything down stream of the water service reservoir and upstream of the point of first practical use by the consumer. For the purpose of applying WLC this boundary needs to be further defined and a decision made as to how much of the Distribution Network should be subject to WLC analysis. Such a decision has implications not only with respect to performance but also for the cost accounting framework. The lowest level of aggregation of assets is commonly referred to as a district meter area. There are further levels of aggregation until they are all brought together as the water service provider's assets. The numbers of levels of aggregation reflect the water service provider's management and operation of Network assets and the influence of geographical and physical realities.

1.3.6.2 Cost Boundaries

A Water Distribution Network does not exist in isolation; it is an interlinked part of a Water Supply System. How a Water Distribution Network operates and performs can affect systems both upstream (abstraction, treatment and transfer) and downstream (waste Water collection, treatment and disposal). The costs to be accounted for are those that are driven by the activities that occur within chosen Water Distribution Network boundaries. However, given that the cost of treated water is dependent on the upstream system, the interconnected nature of costs should be explicitly included in the accounting framework. This represents an at-boundary on-cost that needs to be reflected and included.

Costs can be broken down into three basic function categories: labour related costs, materials and equipment, and services. This does not indicate where these expenditures originate, how they are represented and how they are tracked. There are two aspects that reflect the nature of the service provided. One relates to other activities required to provide the service and the other is the geographical dimension of those activities. An activity, which involves costs, takes place in asset location and this might fall within or outside the geographical boundaries set.

1.3.6.3 Temporal Boundaries

As WLC considers all costs over useful life for the infrastructure there is a need to understand what is meant by the term “useful life” or “asset life”; this can be problematic. The individual assets that make up the system (e.g. pipes and fittings), may have finite useful lives when their role in a Network is considered. An asset may have a recommended technical service or design life but this may be affected by other factors that can impact on its useful life. However, a Distribution Network is made up of a collection of individual assets, each of differing materials, specification and locations and each with different service histories. The processes of operation, maintenance and repair required to provide a service to consumers continually change the characteristics of individual components and hence the system. The useful life of components changes as does that of the system and this can be very long - hundreds of years perhaps. Useful or asset life becomes something that is indeterminate. The useful life is constantly being altered by the way in which a water service provider operates and maintains a Network and in turn, this will affect performance. It is recognised that assets that are well maintained and looked after last longer than assets that are not well maintained (Skipworth et al. 2002). In other words intervention can extend the life of an item. Thus while the idea of a useful life for an individual component may have some basis in reality when it is factored up to the level of a Water Distribution Network it becomes a great deal more obscure. It is open to question whether the concept of useful life can be applied to a system that providers a service when, even if a particular component fails, it is still able to continue to provide a service.

1.3.7 Skipworth- Environmental Impact

Impacts or externalities can arise in the case of the operation and maintenance of a Water Distribution System, according to Skipworth et al. (2002). These impacts require detailed consideration of the processes that underpin the transport of water to consumers – what might be thought of as the life cycle of water as a product being manufactured from raw materials, commodified and delivered to the consumer as well as the various product support functions. Almost inevitably there will be waste and breakdowns in the production process, which take the form of bursts and leakage. These, too, produce their own social and environmental impacts and have to be added to the costs of product. A starting point for the identification and consideration of the social and environmental impacts is now outlined.

1.3.8 Skipworth- Impact Assessment

The first step is to seek to identify, throughout the life cycle of the Distribution System, what actions taken will cause impacts and on what.

A matrix based approach has been used that considers which environmental characteristics would be affected by, or impacted upon, by an operational situation. Three broad operational situations have been identified by Skipworth: normal Network operation bursts and leakage and rehabilitation. Within each of the operational situations there are a range of activities which are required to make the system function. The activities are water supply, water distribution, sewage treatment, sludge disposal and business activities.

The environmental characteristics have been categorised into physical characteristics, ecological characteristics, land use and character, socio-economics, infrastructure services and environmental pollution. Within each one of these there are a number of sub groupings, each made up of individual characteristics. In this way the range of environmental characteristics specific to the distribution of water and the way in which activities impact are considered and not the secondary impacts arising from an activity. For example, leakage gives rise to high levels of raw water abstraction but it is the abstraction that affects directly the resources not the leakage.

1.3.8.1 Skipworth-Bursts and Leakage

Another impact from Bursts and Leakage in a Distribution System is that it increases the volume of water required to deliver the service to the consumer. Therefore a greater demand is placed on resources. The effects are felt throughout the System in order to determine the full extent of the impact on environmental characteristics.

1.3.8.2 Skipworth- Rehabilitation

Rehabilitation is yet another impact and includes the replacement of parts of the Water Distribution Network, the relining of existing pipes or other physical means of upgrading that extend or enhance the operational usefulness of the infrastructure. This generally has a positive effect on levels of leakage and on the frequency and probability of pipe bursts. Rehabilitation has a positive impact on most environmental characteristics, mirroring the negative aspects of bursts and leakages.

1.3.8.3 Skipworth- Valuation Methodologies

Although it is possible to identify how and where externalities might occur it is less easy to estimate the costs themselves. In some cases the costs of externalities have been internalised through mechanisms, such as taxes, used to simulate market mechanisms and thus create value. The problem remains, however, that in the absence of clear and enforceable property rights and the existence of markets for social and environmental goods and services the task of determining appropriate values remains problematic. The range of methodologies available that has been used as a means to determine value include:

1. Avoidance costs: the cost of avoiding damage by, say, returning the same volume and quality of water to the point of abstraction as was taken out
2. Remediation costs: the cost of restoring the environment to its original state
3. Willingness to pay: the amount the public would be willing to pay to ensure that the environment remains the same as it is
4. Willingness to accept: the amount the public would be willing to accept in compensation for allowing a resource to be used and the consequent loss of environmental stock and services.

It is the value of the relative change of impact with change of scale of operation that is of interest rather than a fixed or single environmental cost. This makes the task of valuation even more difficult. The values that are of interest are either the cost of a service provided by the environment or the cost arising from a change in the quality of an environmental resource. Table 2.1 indicates the various methods available for estimating value.

Table 2.1 Valuation Methodology (Skipworth et al., 2002)

	Observed Behaviour	Hypothetical Behaviour
Direct Estimation	Direct Observed Competitive Market Price Simulated markets	Direct Hypothetical Bidding games Willingness –to-pay questions
Indirect Estimation	Indirect Observed Travel cost Hedonic pricing Avoidance expenditures Referendum voting	Indirect hypothetical Contingent Valuation Methods

Direct use values can be directly observed in the market place and thus are easier to determine. Direct use values are of interest here when there are changes in quality or quality that need to be reflected in prices and costs. Indirect use values (functional values) e.g. a service provided by the environment such as flood control, can be investigated via indirect observed behaviour and equating the service with an equivalent technological solution.

Other external costs are a form of non-use value and as such their value has to be inferred indirectly through simulating pseudo-market conditions.

Methods that use indirect observation, as indicated in Table 2.1, include avoidance, defensive or remediation expenditures. The avoidance approach is based on the idea that additional infrastructure can be provided that will not only allow the use of a resource but will then capture it after use and return it to its original state. By doing so, the consequences of use are avoided, but at a cost. Although most of the capital and operating costs can be calculated from market related prices it is also necessary to take into account other associated costs such as the environmental and social costs of providing the additional infrastructure. The attraction of the approach is that it relies on a technical fix for which the costs can be determined with a good degree of accuracy and certainty. The pitfalls are that the costing may not be comprehensive and may omit important items. This is often a theoretical approach because there would be no intention of actually investing in such a solution. Alternatives to these approaches try to estimate values for environmental characteristics based on simulating a hypothetical market for those environmental goods, a technique known as the Contingent Value Method (CVM). These methods estimate the willingness-to-pay, or the willingness-to-accept, a change in the quality or quantity of an environmental good or service. These bids are used as data from which inference on the shadow price of some environmental gain or loss is drawn.

This research study was designed to evaluate the use of the Skipworth model. Data from Bridgetown Water Supply Network, Western Australia and Greenvale Pumping Station in Melbourne were used to conduct this evaluation.

Specifically this research study had several objectives.

1.4 Research Objectives and Scope

The objectives of the study were to:

- Conduct a Feasibility study of the use of the Skipworth model at Bridgetown Water Supply Network of Western Australia in order to improve the local Water Management System.
- Conduct a Whole Life Costing analysis of the Greenvale Pumping Station in order to compare the Gravity System, the Pumping System and Combined System of the Water Distribution System in Western Australia.
- Assess the Whole Life Costing Accounting for Normal Supply, Bursts and Leakage through Assessment using Matlab programming.

The scope of the study was to work out the Feasibility study of the Skipworth model at Bridgetown Water Supply Network in Western Australia as well as Whole Life Costing analysis of Greenvale Pumping Station.

The case study used both quantitative and qualitative methodologies for gathering data.

1.5 Significance

- There are very few publications dealing with application of the Water Distribution Network Management in Western Australia. In this respect the Feasibility analysis of the Skipworth model provided much information to the Water Corporation or Water Organization about present conditions of the application of the Whole Life Costing for the Water Distribution Network Management.

- The information provided in this research may lead to money and water saving for the Water Corporation. The applications of the Skipworth model in Western Australia may lead to accurate and precise whole life cycle accounting for Water Distribution Network.
- The Whole Life Costing analysis of the Greenvale Pumping Station provided operation and maintenance costs of this Pumping Station which could lead to cost savings and environmentally friendly methods such as Gravity and Combined Systems.

Chapter 2.0 Literature Review

2.1 Introduction

This chapter presents the research studies evaluating Water Distribution Networks around the world and in Australia. Specifically this review analyses the research on optimization of Water Distribution Networks and applications of Whole Life Costing to the Water Distribution Networks. This chapter also presents background studies to this research.

The methodology and application of a genetic algorithm scheme tailor-made to EPANET, for optimizing the Operation of a Water Distribution System under unsteady water quality conditions. The Water Distribution System consists of sources of different qualities, treatment facilities, tanks, pipes, control valves, and Pumping Stations. The objective is to minimize the total cost of pumping and treating the water for a selected operational time horizon, while delivering the required quantities at acceptable qualities and pressures to the consumers (Ostfeld, 2010).

2.2 Optimization of Water Distribution

Bhave (2004) demonstrated future water demands are difficult to predict with any certainty and are considered as fuzzy demand through modelling by possibility Distribution function as was done by Xu and Goulter. The fuzzy linear programming model as formulated by Xu and Goulter for minimum cost design of Water Distribution Networks was modified by including loop-head loss constraints in the form of path-head loss constraints (Bhave, 2004).

Bai (1996) carried out research for the purpose of optimization of Water Distribution Network Management in China. He introduced an LP (linear programming) model for the loop Distribution Network optimal design. He also found that inside the LP model of the looped Distribution Network optimal design, the calculation work may be reduced through the available pipe diameter sizes, and it also guarantees the velocity of flow in the permission scope. Further, the pipe length of standard diameters is used as a decision variable in nonlinear programming. Hence using his model, optimization of Water Distribution Network Management is possible.

Gupta (1992) carried out research for the purpose of optimization of Water Distribution Network Management in India. He also introduced a model for optimization of Water Distribution Network Management. Gupta found that use of the algorithm presented in his research would provide a useful tool to the practising engineers and decision makers in less developed countries enabling them to arrive at least cost solutions to Water Distribution System design problems.

In 1984 a study was conducted on optimization of Water Distribution Networks in London; it found that operation and maintenance costs should be accounted for during optimization of Water Distribution Networks by regulations and boundaries and precise flow of the cost drivers. Compared with India and China, London was using a more adequate system for optimizations of the Water Distribution Networks taking in to account initial cost, operation cost and maintenance cost.

From these three studies it can be seen that optimization of Water Distribution Network models used in these studies had limitations. The models only enabled discovery of initial costs including construction, labour, material costs. The optimizations were done to create minimum cost for initial costs. These models were not adequate enough to determine operation cost and maintenance cost; this means operation cost and maintenance cost contain the cost drivers which should be applied under the regulations and boundaries.

Herbert (1994) also developed models for optimization of Water Distribution Networks and these models considered not only the initial costs but also higher construction costs; he stated that preferences should be given to solutions which imply higher construction costs but lower operating costs in order to minimize overall costs in the models. Mukhopadhyay (1994) stated that the costs and benefits of rehabilitation should be considered on all fronts.

2.3 Whole Life Costing

Skipworth (2002) carried out research for the purpose of deriving a whole life costing model for Water Distribution Network Management in London. He found the type of cost drivers, boundaries and regulations and incorporated them inside the proposed model.

Stewart Burn (CSIRO) (2010) carried out a study on life cycle analysis of Water Networks in Australia. Burn, in his study conducted a simulation; Figure 2.1 (Appendix C) shows the results from a typical simulation. In this case a medium sized Network containing approximately 100,000 customers was selected and the total whole of life costs were modelled over 100 years. As the major focus for water utilities is the ongoing maintenance and replacement costs, all Networks start as new pipe systems already installed, that is, initial installation costs were excluded from this simulation. The simulation shows that the DI Network has the highest cost by a considerable margin, followed by the mixed (DI/PVC/PE) Network and the PVC/DI (DI for large pipes) Network. The polyethylene Network has the lowest cost/mile.

Figure 2.1 (Appendix C) shows that the DI and the mixed (DI/PVC/PE) pipe Networks experience a decrease in costs, before costs begin to increase again. Initial high costs in the first few years are due to high failure rate in the first few years of operation as they are more susceptible to installation related failures of pipes/joints. Once these pipes have been in the ground for several years, age once again begins to cause an increase in the failure rate and thus an increase in costs. Costs for these Networks continue to rise over a 20 year period and then levels out. This represents the growth in the Network, which for this example is set at 10% per year and is essentially complete after 25 years. The PVC (with DI for large pipes) Network also has a more rapid rise in costs during the Network growth period, but rather than flattening, costs continue to increase over the 100 year time period virtually drawing level with the mixed Network cost level at the 100 year mark. The PE Network, once the commissioning tests were completed, had nearly no increase in costs over the simulation period and the costs that did exist were significantly less.

He found also that the lower cost for the polyethylene Network was due to two main reasons. Firstly, because its failure rate was low, the cost per mile for repair/replacement was also low, even though the actual cost of repair and replacement work was similar to other pipe types. Keeping repairs to a minimum has significant benefits; as the model shows, repair costs generally represent 70% to 80% of the total costs experienced by a Network. The second major benefit he found of PE Networks was fusion-welded joints which ensure very low leakage rates and thus low water loss costs.

He found, too, that polyethylene Networks showed significantly lower costs throughout their lifetime and the combined benefits of low failure and water loss rates could potentially result in long term cost savings.

Young (2010) examined the key elements of customer service standards, replacement analysis and asset life prediction in minimising whole of life costs for water mains.

Young (2010) reported three elements as given below:

- *Customer Service Standards:* The loss of water to customers during a water main failure is the major customer impact. Standards are set (and this varies between different authorities) regarding the acceptable level of water outages or discontinuity per year. In the case of HWC, the operating licence requires that no more than 8% of customers are out of water for more than five hours per year. A customer charter also guarantees that no customer will be out of water for more than 24 hours in a given year.

- *Replacement/Rehabilitation Analysis.* This analysis prioritises those water mains which should be replaced or rehabilitated on an economic basis. If the analysis indicates that it is more economical to undertake new works rather than continuing to maintain a water main asset through break repairs then replacement of the asset would be recommended. This strategy should provide the optimum combination of repair costs versus replacement costs.
- *Statistical Life Assessment.* The life of a water main will be reached when it is economic, in business terms, not to continue to repair the main or when the impact on a customer, or customers, exceeds the customer service standards. Water authorities around the world assign different priorities to these two criteria. However, once these priorities have been set, statistical modelling of pipe life can be undertaken, using historical replacement and pipeline repair data. This analysis can provide estimates of short term and long term funding requirements (capital replacement and repair costs). Long term financial modelling, based on this analysis, may form the basis of any future pricing changes (if rapid deterioration of the pipe assets is indicated, prices will need to rise). In the longer term increases in prices may change community opinion on the appropriateness of customer service standards and a trade-off may eventuate between maintaining the price of water and relaxing customer service standards.

It was shown that all three elements should be used in parallel for optimum results. Young found that there is an important link between customer service standards and the economic decisions underlying replacement of mains. The use of a social cost is necessary in setting realistic customer service standards. This also provides a basis for discussions between a regulator and a water authority on the merits, in community terms, of increasing or decreasing a customer service standard for water discontinuity. Further work on social cost is required by ongoing communication with customers. It is proposed that risk theory (involving the determination of probability of failure and the consequence of failure) provides an appropriate framework for water main replacement analysis. In particular, assessment of risk allows a water authority to balance the allocation of capital replacement funds between smaller diameter mains with numerous breaks and the less frequent major breaks/events with high consequence. Young's paper examined the use of statistical modelling to predict the life of pipe assets. It was shown that while broad predictions on future asset performance can be made based on data such as age, pipe type, diameter and laying technique, accurate information on soil type is essential to improve the predictive capabilities of this modelling.

Burn (2010) found that operation and maintenance cost of polyethylene pipe is more economical than other pipes like cast iron pipe, aluminium pipes and steel pipe but Burn's models have limitations because Burn considered only the down side Water Distribution Networks cost drivers which cannot give a clear picture of whole Water Distribution Networks in the context of Whole Life Costing. Furthermore, Young introduced three elements; using these three elements it is possible to work out the whole life costing for Water Distribution Networks but the Young model also has limitations because the Young model lacks the ability to predict operation and maintenance cost for Water Distribution Networks; this produces unbalanced Whole Life Costing. As a result water organizations go over or under budget in addition to wasting water. The Burn and Young models are currently used in Australia. Therefore, the Water Corporation is not able to sort out the issues in the context of Whole Life Costing.

2.4 Water Distribution Methods

Petr et al. (2006) investigated the problems arising from Water Distribution Systems because they are not fully pressurised pipeline networks but networks with very low pressures, with restricted water supply per day and with thousands of ferrule points and roof tank connections. Petr et al. (2006) developed models to manage these problems by using EPANET simulation.

Technically precise and accurate results of the simulation of the software of the Water Distribution Systems lead to solving pressure and water quality issues in the Water Distribution Systems as intermittent Water Supply Systems.

The literature review shows that there is a lack of application of Whole Life Costing in the Water Distribution Networks. A unique model is required in Australia to overcome this problem. This research study presented in this thesis used the Skipworth model and compared it with existing models used in Australia. There has been much research on the optimization of water distribution networks; however these studies only incorporated initial costs and further in Australia as Burn and Young indicated, the models of the operation and maintenance costs contain the downstream of the water distribution networks abut lack accounting of the cost drivers. Still there is lack of Whole Life Costing Accounting in terms of operation and maintenance cost and asset predictions in the above studies.

Chapter 3 Methodology

3.1 Introduction

This chapter presents a discussion of the three main methodological approaches. Then this chapter discusses the methodology used for this particular study, an evaluation of Water Distribution Network Systems Western Australia as well as comparison of Water Distribution methods by Whole Life Costing.

The objectives of the study were to:

- Conduct a Feasibility study using the Skipworth model in order to improve the local Water Management System.
- Compare the Gravity System, the Pumping System and Combined System of the Water Distribution System in Western Australia through Whole Life Costing.
- Assess the Whole Life Costing Accounting for Normal Supply, Bursts and Leakage through Assessment using Matlab programming.

3.2 Qualitative Approach

Qualitative research (Denzin et al., 1996) is a method of inquiry employed in many different academic disciplines, but also in market research and further contexts. Qualitative researchers aim to gather an in-depth understanding of human behaviour and the reasons that govern such behaviour. The qualitative method investigates the why and how, not just what, where, when. Hence, smaller but focused samples are more often needed, rather than large samples.

Qualitative research often categorizes data into patterns as the primary basis for organizing and reporting results. Qualitative researchers typically rely on the following methods for gathering information: Participant Observation, Non-participant Observation, Field Notes, Reflexive Journals, Structured Interview, Semi-structured Interview, Unstructured Interview, and Analysis of documents and materials (Marshall et al., 1998).

Qualitative research methodology has several advantages

Advantages

- Produces more in-depth, comprehensive information
- Uses subjective information and participant observation to describe the context, or natural setting of the variables under consideration, as well as the interactions of the different variables in the context. It seeks a wide understanding of the entire situation (Jacob, 1998).

There are, however, several disadvantages to qualitative methodology:

Disadvantages

- The very subjectivity of the inquiry leads to difficulties in establishing the reliability and validity of the approaches and information.
- It is very difficult to prevent or detect researcher induced bias.
- Its scope is limited due to the in-depth, comprehensive data gathering approaches required (Jacob, 1998).

3.3 Quantitative Approach

Quantitative research refers to the systematic empirical investigation of social phenomena via statistical, mathematical or computational techniques. The objective of quantitative research is to develop and employ mathematical models, theories and/or hypotheses pertaining to phenomena. The process of measurement is central to quantitative research because it provides the fundamental connection between empirical observation and mathematical expression of quantitative relationships (Hunter et al., 2008).

Quantitative research is generally undertaken using scientific methods, which can include:

- The generation of models, theories and hypotheses
- The development of instruments and methods for measurement
- Experimental control and manipulation of variables
- Collection of empirical data
- Modelling and analysis of data
- Evaluation of results

Quantitative research using statistical methods starts with the collection of data, based on the hypothesis or theory. Usually a large sample of data is collected - this would require verification, validation and recording before the analysis can take place. Measurement is often regarded as being only a means by which observations are expressed numerically in order to investigate causal relations or associations (Thomas, 1998).

Quantitative research has several advantages.

Quantitative Advantages

- Allows for a broader study, involving a greater number of subjects, and enhancing the generalisation of the results.

- Can allow for greater objectivity and accuracy of results. Generally, quantitative methods are designed to provide summaries of data that support generalisations about the phenomenon under study. In order to accomplish this, quantitative research usually involves few variables and many cases, and employs prescribed procedures to ensure validity and reliability.
- Using standards means that the research can be replicated, and then analysed and compared with similar studies. Kruger (2003) confirms that 'quantitative methods allow us to summarize vast sources of information and facilitate comparisons across categories and over time'
- Personal bias can be avoided by researchers keeping a 'distance' from participating subjects and employing subjects unknown to them, (Bryman, 2006).

There are, however, several disadvantages to qualitative methodology:

Quantitative Disadvantages

- Collects less in-depth and sometimes superficial dataset
- Results are limited as they provide numerical descriptions rather than detailed narrative and generally provide less elaborate accounts of human perception
- The research is often carried out in an unnatural, artificial Environment so that a level of control can be applied to the exercise. This level of control might not normally be in place in the real world yielding laboratory results as opposed to real world results
- In addition preset answers will not necessarily reflect how people really feel about a subject and in some cases might just be the closest match.
- The development of standard questions by researchers can lead to 'structural' bias and false representation, where the data actually reflect the view of the researcher instead of the participating subject (Bryman, 2006).

This study utilised both quantitative and qualitative methodologies. The qualitative methodology was used in this study because it enabled collection of in-depth, personal perspectives on the Water Distribution Network model utilized by Bridgetown Water Supply Water Networks and the Distribution Systems used at Greenvale Pumping Stations from the chosen staff who participated in the interviews. The quantitative methodology, using the Skipworth model for Bridgetown Water Supply Networks and Whole Life Costing analysis for Greenvale

Pumping Stations provided accurate data required for this study.. In particular this study used the case study approach and within that approach a Feasibility study of the use of the Skipworth model was conducted using samples from Bridgetown Water Supply Network and a Whole Life Costing analysis was also conducted using data from Melbourne. These approaches allowed the researcher to determine which method was more suited to the Western Australian Water Supply Network System.

Qualitative data were gathered for his study through individual interviews. This method provided 'rich' data which complemented the quantitative data.

3.4 Case Study Research

The research study used a case study approach (Stake, 1995) to conduct a Feasibility study and an LCCA. The two orientations to doing case study research, quantitative and qualitative are not necessarily conflicting; they may be seen as differences in emphasis (e.g. Stenhouse, 1998). However, in designing a new case study, the research should be sensitive to these different orientations. This case study used as mentioned both quantitative and qualitative methodologies for gathering data (Figure 3.1 and 3.2).

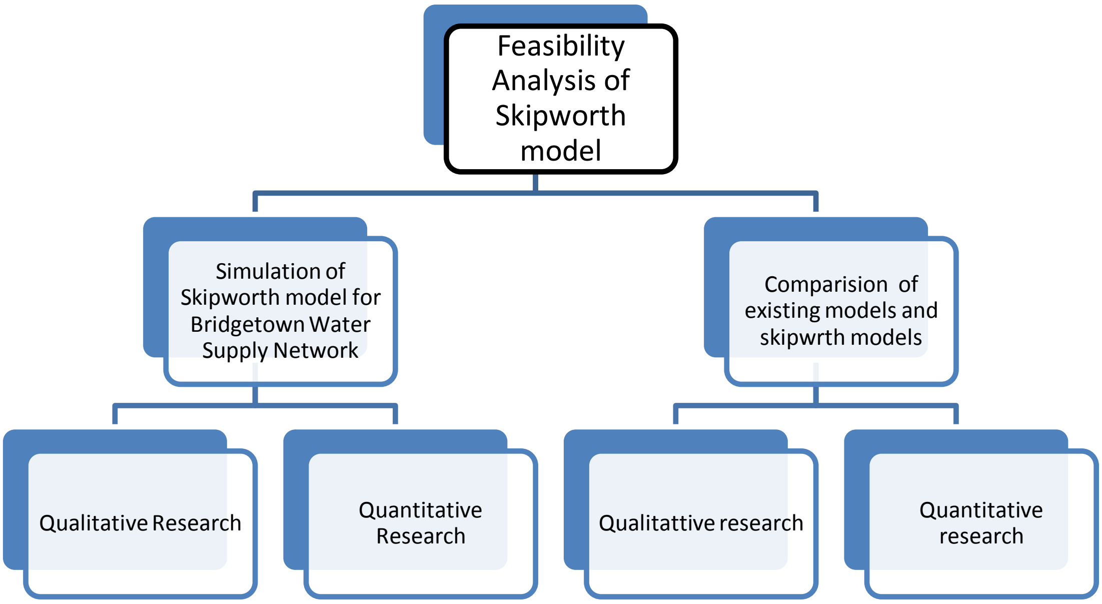

Figure 3.1 Flow Chart for Feasibility Analysis of Skipworth model

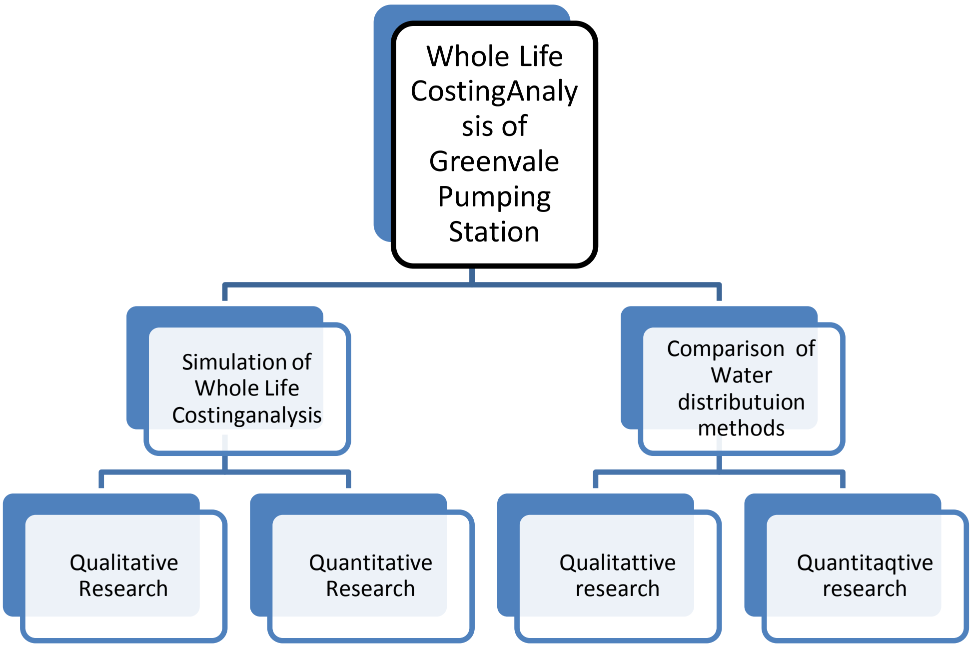

Figure 3.2 Flow Chart for Whole Life Costing Analysis of Greenvale Pumping Station

Case Studies have both advantages and disadvantages

Case study Advantages

- Allows for exploration of solutions for complex issues
- More in-depth information can be collected (Merriam 1990).

Case study Disadvantages

- May need to make sure responses are relevant to the objectives of the study
- Insufficient information can lead to inappropriate results
- With a researcher observing the participant closely, the participant may change his/her behaviour (Yin, 1984).

This case study comprised a Feasibility study conducted with Bridgetown Water Supply Network to evaluate the efficacy of the Skipworth model; currently Bridgetown uses the Young Model and straight wise Whole Life Costing Accounting (interviews/plus statistical data from website from the Western Australian Water Corporation).

A Whole Life Costing was conducted for Melbourne, Greenvale Pumping Station to compare the current Pumping System with the Gravity and Combined Systems using data from interviews with personnel from the Melbourne Water Organization and from personnel in the Western Australian Water Corporation - plus statistical data from Melbourne Water Organization website.

For the Feasibility study, a segment of the Water Supply Zone (WSZ) from Bridgetown was used. Details are as follows:

Sample: - The Whole Life Costing accounting or a small WSZ serving around 2825 customers. The WSZ comprises 40 kilometres of Water mains, predominantly steel pipe; a small WSZ is located at Bridgetown (Western Australia). Drawing details are given in Figure 3.3 (Appendix C).

The drawing of this sample or drawing of hydraulic model for this sample was transferred into the Epanet and Water gems software using the Water Corporation's existing data from the Water Corporation Website.

Skipworth (2002) considered three cost drivers – Supply and Demand, Structural Performance and Water Quality.

Skipworth demonstrated also from his study that Water Distribution contains three divisions including Normal Supply, Burst and Leakage and his equations to work out cost drivers for three divisions are given here:

- Normal Supply

The cost of normal supply is taken to be all the costs incurred in operating a Water Distribution Network to supply water to consumers excluding those costs associated with burst and leakage. The cost of supply is made up of fixed and variable costs. The total cost of normal supply in a Distribution Network can be represented by equation

CSUPPLY=(CINPUTW+COP&M+CVOP&M+CR&M+CRRM+CCM+C BINSPEC+CDISTR+CE&C+CASM+CWQ+CCAPM)+ (CREG+CSS+CG&S+CCS)………………………………..Equation 3.1

CSUPPLY is the annual cost of normal Supply for a given WSZ, which is made up of:

CINPUTW is the annual cost of the input Water into the WSZ,

COP&M is the normal operation and maintenance cost,

CVOP&M is the valve operation and maintenance cost,

CR&M is the cost of repair and maintenance of service pipes,

CRRM is the cost of replacement and repair of meters

CCM is the cost of installation and replacement of consumers meters,

C BINSPEC is the cost of bye-law inspection,

CDISTR is the cost of operation and control of the Distribution Network, CE&C is the cost of inquiries and complaints not associated with bursts or leakage,

CASM is the portion of administration, supervision and Management costs associated with the Distribution System,

CWQ is the cost associated with maintaining Water quality,

CCAPM is the cost of capital maintenance works carried out on the System and the costs associated with business activities,

CREG is the cost of regulation associated with the WSZ,

CSS is the cost of scientific services associated with the WSZ,

CG&S is the cost of general and support services associated with the WSZ,

CCS is the cost of customer services associated with the WSZ.

- Input Water

The cost of the input Water is given by;

$$CINPUTW = CF + CV.V + EINPUTW \text{ ……….. Equation 3.2}$$

Where, CF is the fixed cost of the input Water (£/a), CV is the variable cost of the input Water (£/MI), V is the volume of input Water (MI) and EINPUTW Is the external cost associated with the input Water (£/a).

- Mains Operation and Maintenance

The annual cost of normal or planned operation and maintenance of mains in a WSZ is;

$$Cop\&m = f op\&m + \sum_i Cop\&m(i).L\ OP\&M + EOP\&M) \text{ …….. Equation 3.3}$$

Where, $f$op&m is the fixed cost of normal operation and maintenance cost of mains (£/a), i is a set of all combinations of pipe material and diameter in the WSZ, $Cop\&m(i)$ is the annual cost per unit length of main (£/m), $L\ OP\&M$ is the length of each main group and $EOP\&M$ is the external cost associated with the operation and repairs of mains (£/a).

- Valves Operation and Maintenance

The annual cost of operating and maintaining valves and other fixtures and appliances in the Network zone is:

$$CVOP\&M = f Vop\&m + \left(\sum_j \eta vop\&m\ (j)\ N\ vop\&m\ (j)\ cvop\&m(j)\right) + E\ vop\&m \text{ …………………….. Equation 3.4}$$

where, fVop&m is the fixed cost associated with the operating and maintaining of valves etc., j is set of all combinations of valve type and diameter in the WSZ,

$\boldsymbol{\eta}$vop&m is the percentage of each diameter valve group on which work is to be carried out , N vop&m (j) is the number of valves of a given group j, cvop&m(j) is the annual operation and maintenance cost of valves of a given valve group and E vop&m is the societal costs associated with the operational and maintenance of valves.

- Service pipes maintenance and repair

The annual cost of repair and maintenance of service pipes is given by:

C r&m = fr&m + $\sum \eta\ r\&m\ \ N\ r\&m\ Cr\&m + E\ r\&m \ldots\ldots\ldots\ldots\ldots\ldots$Equation 3.5

Where, fr&m is the fixed cost associated with the repair and maintenance of service pipes (£/a), $\eta\ r\&m$ is the percentage of service pipes for repair and maintenance, $N\ r\&m$ is the number of service pipes, $Cr\&m$ is the annual repair and maintenance cost (£/unit) and $E\ r\&m$ is the associated social cost (£/a).

- District and zonal meters

The annual cost of the repair and replacement of district and zonal meters is given by:

CRRM = fr&m + $\sum_K \eta REPLACE(K) N\ REPLACE\ (K) CREPLACE(k)$+
$\sum_k \eta\ repair\ (k) Nrepair(k) Crepair(k) + Errm \ldots\ldots\ldots\ldots\ldots$..Equation 3.6

where, fr&m is the fixed cost associated with the repair and replacement of the meters (£/a). K is set of all district and zonal meters in a WSZ, $\eta REPLACE$ and $Nrepair$ are the percentage of meters of description k to be replaced and repaired, $N\ REPLACE$ and $Nrepair$ are the numbers of meters in the WSZ of description k to be replaced and repaired, $CREPLACE$ and $Crepair$ are the respective costs for the replacement and repair of meters of description k (£/unit) and Errm is the societal cost associated with the repair and replacement of meters (£/a).

- Consumer Meter Repairs

The annual cost of the repair and replacement of consumer meters is given by:

Ccm = $f$cm + $\sum \eta cmreplace\ (l)\ N\ cmreplace(l) Ccmreplace(l) +$
$\sum \eta cmrepair(l) Ncmrepair(l) Ccmrepair(l) + Ecm \ldots\ldots\ldots\ldots$Equation 3.7

Where $f$cm is the fixed cost associated with the repair and replacement of consumer meters (£/a), l is a set of all consumer meter diameters in the WSZ , $\eta cmreplace$ and $Ncmrepair$ are the percentage of consumer meters to be repaired or replaced respectively, $Ncmreplace$ and $Ncmrepair$ are the numbers of consumer meters of description l to be replaced or repaired, $Ccmrepair\ and\ Ccmreplace$ are the respective costs for the replacement or repair of consumer meters of description l ((£/unit) and Ecm is the societal cost associated with the repair and replacement of consumer meters (£/a).

- Bylaw Inspections

The annual cost of byelaw inspections is given by:

C binspec = N binspec C binspace + E binspec…………Equation 3.8

Where, N binspec is the number of inspections, C binspace is the unit cost of inspection (£/inspection), E binspec is the associated social cost (£/a).

- Distribution operation and control

The annual cost of operation and control of Distribution is given by:

Cdistr = α. ($f$distr + Edistr)…………..Equation 3.9

Where, α is a factor determined by the operator representing the proportion of the costs of operation and control of Distribution to be allocated to a WSZ, $f$distr is the fixed cost of the operation and control of Distribution at company level (£/a) and Edistr is the social cost associated with the operation and control of Distribution (£/a).

- Enquiries and Complaints

With respect to enquiries and complaints it is noted that an operator provides a service and therefore interacts with the public and customers will give rise to enquiries and complaints. These may be related to requests for information, queries about bills, and complaints about service, passing on information or to work related matters. The occurrence of an accident, such as a pipe burst, may generate enquiries and or complaints. Such incidents might be planned, as in the case of relaying water mains, or unplanned as in the case of a pressure burst. Incidents may be internal to the Distribution System or external, such as an interruption to a trunk main, though both will affect the public and customers.

The numbers of complaints arising from an incident will be determined by, among other factors, number of customers affected, location, time, type of incident, type of customer. The numbers of complaints can be represented by:

Ncomp = $\boldsymbol{\eta}$b + $\sum \eta ti.Nti$………… Equation 3.10

Where, Ncomp is the total number of complaints etc. received , $\boldsymbol{\eta}$b is the base load complaints etc., ti is a set of incident types, ηti is the number of incidents of a particular type, Nti is the number of complaints generated by a particular type of incident.

Total cost of inquiries and complaints attributable to normal supply of a Water Distribution Network is given by;

$$C\ e\&c = C\ \text{norm comp} + \text{Cicom} \ldots\ldots\ldots\ldots\ldots \text{Equation 3.11}$$

- Administration, Supervision and Management Costs

The administration, supervision and management activities ensure the proper, efficient and effective running of a Distribution Network. As an overall function they support a number of other activities including operation, maintenance, monitoring investigations and dealing with bursts and leakages amongst others. Cost of Capital Maintenance should be proportioned across these different activities, rather than being directly allocated to supply alone.

- Cost of Capital Maintenance

The cost of capital works maintenance is determined by how much of the Distribution Network within a water supply zone is to be either replaced or rehabilitated.

The cost of capital maintenance is:

$$\text{Cop\$m} = f\text{capm} + \sum_x lx \sum_y \Gamma y \sum_z Cz + \text{E capm} \ldots\ldots\ldots\ldots \text{Equation 3.12}$$

Where, $f$capm is a fixed cost item (£/a), lx is the length of each pipe group x in a WSZ to be rehabilitated, x is a se t of pipe groups by material and diameter, Γy is set of location based (y) cost modifiers, Cz is the unit cost for rehabilitation methods z and E capm is the societal cost associated with the rehabilitation or replacement work (£/a).

- Business Activities

To these direct costs now have to be added the indirect costs associated with business activities that are applicable to Water Supply services.

1.2.1 Cost of Regulation

The cost of regulation (Creg) attributed to the Distribution of Supply could be spread equally between all the DMAs.

$$\text{Creg} = (C \sum reg/\text{Ndma}) + \text{Ereg} \ldots\ldots\ldots\ldots\ldots \text{Equation 3.13}$$

Where, Ndma is the number of DMAs being considered, C $\sum reg$ is the total cost of regulation for Water Supply as a whole

(£/a) and Ereg is the societal cost associated with regulation (£/a).

1.2.2 Customer Service Costs

Customer services can be mostly attributed to Supply and could be allocated on the basis of number of customers.

$Ccs = (C\sum cus.\ C\sum cusenq)\ /Ncus + Ecs$…………..Equation 3.14

Where Ncus is the number of customers in the area under consideration, $C\sum cus$ is the total cost of customer services per customer (£/customer), $C\sum cusenq)$ is the proportion of the total cost attributable to handling customer enquiries etc. and Ecs is the societal cost associated with customer service (£/a).

1.2.3 Scientific Services Costs

Scientific services are mostly applicable to Supply Distribution. The costs are associated with the investigation and analysis of particular and potential problems, for example of a Water quality nature.

$Css = \omega ss\ C \sum SS - C \sum CSSENQ\ ) + Ecs$…………Equation 3.15

Where ωss is a scaling factor, $C \sum SS$ is the total cost of scientific services attributed to Water Supply (£/a), $C \sum sseng$ is the total cost associated with handling of enquiries (£/a) and Ess is the social cost associated with scientific services (£/a)

General and support costs

General and support activities apply to all aspects of Water Supply including activities associated with bursts and leakage.

$Cg\&s = \delta\ (C\sum g\&s - C \sum info) + E\ g\&s$…………………Equation 3.16

Where δ is a non –dimensional scaling factor, $C\sum g\&s$ is the total cost of general and support activities attributable to Water Supply (£/a).

$C\sum info$ is the total cost of information services associated with call centres for customers (£/a) and Eg&s is the social and Environment cost associated with general and support activities (£/a).

1.2.4 Water Quality:

The costs associated with the handling and investigation of complaints related to water quality follows the same form as that for normal operation. The cost of handling water quality related complaints is given by:

$\beta\ wq.\ C\ comp$

where β wq is the proportion of the total number of complaints and enquiries related to water quality issues. The cost of investigating a water quality related complaint is:

$\beta\ wq.\sum_{ti}^{N} Cti.\eta ti + Eicom$……………..Equation 3.17

- Bursts

Mains bursts are structural failures of a pipe or main such that it can no longer perform its proper function or represent a visible failure of the system to the customers. Action is required to restore the functioning of the system, usually through repair of the burst section of main.

The cost of a burst can be characterised as:

C burst = C repair + C indb + Cextb (+CWB)…………..Equation 3.18

Where, C burst is a full burst, C repair is the cost of repairing a burst, C indb is the indirect cost associated with a burst, Cextb is the external cost associated with a burst and Cwb is the cost of water lost through a burst.

1.2.5 Cost of Burst Repair

The cost of burst repair will be a function of the number of burst, pipe diameter, material and depth of cover as well as location of the burst. It should be possible to assign a series of probable costs of repair determined by these characteristics.

Crepair = $\sum_i ni \sum_j Cj$…………Equation 3.19

Where, ni is the number of burst event s for pipe group i, j is the set of location based costs and cj is the cost of repair (£).

Indirect burst costs

The indirect costs associated with structural failure, as described above are:

CindB = CregB + Ccompen+ C compl + CimageB + C penb………Equation 3.20

Where CregB is the annual regulatory cost associated with structural failures, Ccompen is the cost of compensation paid to customers and third parties, Ccompl is the annual operational cost of dealing with complaints and Cimageb is the annual image cost associated with structural failures

1.2.6 Regulatory Bursts Costs

The annual regulatory costs associated with structural failure may be taken as:

C regB = Nbursts. CregB + E reg ………….Equation 3.21

Where, Nbursts is the total number of structural failures taking place in a Water Supply zone , CregB is the unit marginal regulatory cost to the operator of a structural failure (£/burst) and Ereg is the external cost associated with meeting regulation requirements (£/a).

Bursts compensation Costs

The annual cost of compensation is derived from that due to customers affected by a structural failure plus compensation paid to third parties. There are guidelines that determine whether customers are entitled to compensation and how much that would be. In the case of compensation to third parties the amount that would be determined by the loss suffered will vary on a case by case basis and be location dependant.

C comp= $\sum \epsilon$N bursts c bcomp + $\sum N$ 3pc3pcomp……….Equation 3.22

Where , $\boldsymbol{\epsilon}$ is the proportion of customers affected by a structural failure entitled to compensation, Nburst is the number of customers affected by a burst, cbcomp is the customer compensation entitlement (£/Customer), N3p is the number of third parties entitled to compensation and c3pcomp is the compensation entitlement (£/Party).

1.2.7 Burst Complaints Costs

The cost of burst complaints, like that for those associated with normal operation of the Water Distribution Network is made up of the cost of handling the complaints and the cost of investigation of the complaints and enquiries received.

Ccomplaints = Ccompl + Cinvburst…………Equation 3.23

Handling burst complaints

Ccompl = $\boldsymbol{\eta}$. Nburst. C compl + Ecompl……….Equation 3.24

Where , $\boldsymbol{\eta}$ is a scaling factor relating number of customers complaining to a structural failure , Nburst is the number of structural failures experienced (Nti = Nurst) Ccompl is the unit marginal cost of handling complaints and enquiries arising from a structural failure (£/item) and Ecompl is the social cost associated with handling of complaints (£/a).

1.2.8 Investigation of Burst Complaints

The cost of investigation of bursts is

Cinvburst = βburst $\sum_{ti=1}^{N} Cti.Nti\ +\ E\ icom$…………….Equation 3.25

Where, βburst is the proportion of the total number of complaints and enquiries related to bursts. Fixed costs are not included in the above equations as it is the marginal costs associated with these incidents that are of interest.

1.2.9 Image Burst Costs

C imageB = Nburst. C imageB + Eimage……………Equation 3.26

Where, Nburst is the number of structural failures, C image is the unit marginal image cost and E image is the external costs associated with maintaining a positive public image.

1.2.10 Burst Penalty Costs

The occurrence of a burst event can lead to a reduced service to customers. If there is a regulatory regime in place that sets and monitors standards of service, repeated service failure due to bursts may not be acceptable and the regulator may impose financial penalties. The scale of penalties could be a function of the numbers, frequency and severity of bursts, depending on the regulatory System and the attitude of the regulator.

$$\text{Cpenb} = f\ (\text{Nburst}) \text{ ……………..Equation 3.27}$$

1.2.11 External Burst Costs

The external costs have been identified as being related to disruption caused and unrealised willingness to pay.

$$\text{CextB} = \text{Cdisrup} + \text{CWTP}\text{…………….Equation 3.28}$$

Cdisrup the total cost of disruption as calculated from the UKWIR manual and CWTP is the total willingness –to-pay for a lower level of bursts.

$$\text{CWTP} = \text{Ncust } \int_{L1}^{L2} \Delta(WTP) \text{ ……………..Equation 3.29}$$

1.2.15 Leakage

The cost of leakage is determined by the leakage strategy adopted, the value of loss, the indirect and external costs associated with leakage and its control.

$$\text{C leak} = \text{C lds} + \text{Cindl} + \text{Cextl} + \text{Cw}\text{……………..Equation 3.30}$$

Where , C leak is the total cost of leakage, Clds is the annual cost for a given leakage detection strategy , Cindl is the annual indirect cost of leakage , Cextl is the annual external cost of leakage and Cw is the annual cost of Water lost.

1.2.12 Leakage detection strategy costs

The annual cost in undertaking leakage detection can be given as:

$$\text{Clds} = f\text{lds (a)} + \text{Clds (a).L} + \text{Elds (a)}\text{……………Equation 3.31}$$

Where, $f$lds (a) is the fixed cost associated with a leakage detection strategy a (£/a), Clds (a) is the variable cost associated with that leakage detection strategy (£/unit) and Elds (a) is the social costs associated with the leakage detection strategy (£/a).

1.2.13 Indirect Leakage Costs

The indirect costs associated with leakage are:

$$\text{Cindl} = \text{Cregl} + \text{Ccomplaint} + \text{CimageL}\text{……………Equation 3.32}$$

Cregl is the annual regulatory cost associated with leakage, Ccomplaint is the annual operation cost of dealing with complaints and CimageL is the annual image cost associated with leakage.

1.2.14 Leakage Regulatory Costs

The annual regulatory costs associated with leakage may be taken as:

$$\text{Cregl} = \text{Ncust P reg Creg} + \text{Ereg} \quad \text{……………….. Equation 3.33}$$

Where, Ncust is the number of customers, Preg is the probability that the customer will complain about leakage or a leak, Creg is the marginal unit cost of regulation requirement (£/Complaints). Ereg is the social cost associated with regulation (£/a).

1.2.15 Leakage Complaints Costs

As with normal supply and burst, the cost of leakage complaints is the sum of the handling and investigation of the enquiries and complaints.

Handling Leakage Complaints

The cost of handling complaints associated with leakage is:

$$\text{C compl} = \rho.\ \text{Ncurst. Ccuscompl} + \text{Ecuscompl} \quad \text{……………. Equation 3.34}$$

Where, ρ is a scaling factor relating number of customers with the number likely to lodge an enquiry about a leakage related matter, Ncurst is the number of customers in a Water Supply zone , Ccuscompl is the unit marginal cost of handling complaints and enquiries from customers (£/item) and Ecuscompl is the social cost associated with handling of complaints (£/a).

1.2.16 Investigating leakage complaints

The cost of investigation of leakage is

$$\text{Cinvl} = \beta\text{teak} \sum_{ti=l}^{N} Cti.\eta ti + \text{Eicom} \quad \text{…………… Equation 3.35}$$

βteak is the proportion of the total number of complaints and enquiries related to leakage.

1.2.17 Leakage Image Costs

The image cost associated with leakage can be taken as:

$$\text{Cimagel} = \text{Ncust. Cimagel} + \text{Eimage} \quad \text{…………….. Equation 3.36}$$

Wher, Ncust is the number of customers failures, Cimagel is the unit marginal image cost (£/item) and Eimage is the social costs associated with maintaining a positive public image (£/a)

1.2.18 Leakage Penalty Costs

Records of required levels of service, operator performance and financial penalties imposed would have to be examined in order to decide whether to include an allowance and, if so, what an appropriate formulation might be.

$$\text{Cpenl} = f\ (\text{Leakage Level}) \quad \text{………….. Equation 3.37}$$

1.2.19 External Costs

The external cost, taken as willingness-to-pay and confidence may be represented in simple terms:

Cextl = CWTP

$$\text{CWTP} = \text{Ncust} \int_{L1}^{L2} \Delta(WTP) \text{ ……………..Equation 3.38}$$

Where Ncust is the number of customers in a Water Supply zone, $\Delta(WTP)$ is the change in willingness-to-pay, L1& L2 are different levels of leakage.

In deriving an accounting framework an activity based costing approach is proposed to determine the costs of operational activity. Costs are associated with an action or driver making it possible to link unit costs to performance of the Network, the cost drivers, over the service life and to determine the whole life cost operation. Network performance is also a consequence of rehabilitation actions (capital maintenance) and these must be included.

In addition to conducting a feasibility study, this case study also conducted interviews.

3.5 Interview

An interview is a conversation between two people (the interviewer and the interviewee) where questions are asked by the interviewer to obtain information from the interviewee (Dick, 2002).

3.6 Structured Interview

Structured interviews can also be used as a qualitative research methodology (Kvale, 2008). These types of interviews are best suited for engaging in respondent or focus group studies in which it would be beneficial to compare/contrast participant responses in order to answer a research question (Lindolf, 2002). For structured qualitative interviews, it is usually necessary for researchers to develop an interview schedule which lists the wording and sequencing of questions (Patton, 1991). Interview schedules are sometimes considered a means by which researchers can increase the reliability and credibility of research data (Lindolf, 2002).

3.7 Semi Structured Interview

A semi-structured interview is a method of research used in the social sciences. While a structured interview has formalized, limited set questions, a semi-structured interview is flexible, allowing new questions to be brought up during the interview as a result of what the interviewee says. The interviewer in a semi-structured interview generally has a framework of themes to be explored.

However, the specific topic or topics that the interviewer wants to explore during the interview should usually be thought about well in advance (especially during interviews for research projects). It is generally beneficial for interviewers to have an interview guide prepared, which is an informal grouping of topics and questions that the interviewer can ask in different ways for different participants. Interview guides help researchers to focus an interview on the topics at hand without constraining them to a particular format. This freedom can help interviewers to tailor their questions to the interview context/situation, and to the people they are interviewing (Lindolf, 2002).

Advantages of interviews

The main advantages of an interview are:

- It is useful to obtain detailed information about personal feelings, perceptions and opinions
- It allows more detailed questions to be asked
- It usually achieves a high response rate
- Respondents' own words are recorded
- Ambiguities can be clarified and incomplete answers followed up
- Precise wording can be tailored to respondent and precise meaning of questions clarified (e.g. for students with English as a Second Language)
- Interviewees are not influenced by others in the group
- Some interviewees may be less self-conscious in a one-to-one situation (Cathie, 2011).

Disadvantages of interviews

The main disadvantages of interviews are:

- They can be very time-consuming: setting up, interviewing, transcribing, analysing, feedback, Reporting
- They can be costly
- Different interviewers may understand and transcribe interviews in different ways (Cathie, 2011).

Questions

A set of Questions (Structured and Unstructured) was prepared for the Water Corporation for deep investigation of existing models used for Water Distribution Network System employing Whole Life Costing in Bridgetown, Western Australia. These questions also helped to overcome the confusion among the Cost Drivers and Boundaries for the Water Distribution Network System. The answers to these questions were used to conduct a Feasibility study of the efficacy of the Skipworth Model for Bridgetown's Water Supply Network.

The interview questions were designed to elicit responses about any deficiencies in the current System and the level of need for using another model.

- This study used both face to face and telephone interviews. Interviews were used because they enabled collection of data which could be used to compare Water Distribution Systems at Greenvale Pumping Stations and to manage the issues relative to the Feasibility study for Bridgetown Water Supply Network.

Sample

4 personnel from the Western Australian Water Organizations, one manager from Bridgetown and two staff members from Perth and one staff member from Melbourne, Grampians, Wimmera, Mallee (GWM Water) participated in the study. These staff members were chosen because they all had considerable experience and qualifications in water engineering in Australia as well as specific knowledge of Bridgetown Water Supply Networks, Greenvale Pumping Stations and of Whole Life Costing modelling used in Australia.

Statistical data

Matlab programming was done for the Skipworth model and input data, the Microsoft Excel file, were provided from the Western Australian Water Corporation's website.

A Whole Life Costing was conducted with Greenvale Pumping Station, Melbourne, in order to compare the Pumping System with the Gravity and the Combined Systems.

3.8 The Case – Whole Life Costing

The Greenvale Pumping Station is located on Melbourne Water owned land on Somerton Road, Greenvale (opposite Greenvale Reservoir) (see Figure 3.4, Appendix C). The operation and maintenance costs were worked out for the Greenvale Pumping Station to compare with the Gravity and Combined Systems.

Whole Life Costing is a six-staged process. The first four stages comprise the Life Cost Planning phase with the last two stages incorporating the Life Cost Analysis Phase (NSWT, 2004). Life Cost Planning concerns the assessment and comparison of options/alternatives during the design/ acquisition phase. It utilises similar techniques as those for economic appraisal in the future; nominal costs are discounted to today's monetary discounted cost.

Life Cost Analysis, according to NSWT (2004) enables the creation, operation and disposal costs of a selected alternative to be monitored throughout its life to enable accurate and timely decision-making as to how these costs can be minimised. Where ownership of the asset changes over time, each owner takes responsibility for decisions required during the period of ownership only. Life Cost Analysis is used as the basis for monitoring and management of costs over an asset's life. It is essentially a financial management tool; costs are generally not expressed as real or discounted costs, but as nominal costs (i.e. estimated costs that are to be paid when due) to enable a comparison of the predicted cost and the actual cost. This enables better prediction and adjustment of the Whole Life Costing model (LCC). Whilst the research proposed here sought to examine all cost drivers related to the performance of Water Distribution Networks, additional external cost drivers were required in model of the Water Corporation within cost driver estimates, both direct and/or indirect.

In this study, operation cost and maintenance cost and the NPV were worked out.

3.9 Recording of data

The data were recorded by note making at the time of the interviews.

3.10 Data Analysis

Coding

Coding is an interpretive technique that both organizes the data and provides a means to introduce the interpretations of it into certain quantitative methods. Most coding requires the analyst to read the data and demarcate segments within it. Each segment is labelled with a "code" – usually a word or short phrase that suggests how the associated data segments inform the research objectives. When coding is complete, the analyst prepares reports via a mix of: summarizing the prevalence of codes, discussing similarities and differences in related codes across distinct original sources/contexts, or comparing the relationship between one or more codes.

Some qualitative data that are highly structured (e.g., open-end responses from surveys or tightly defined interview questions) is typically coded without additional segmenting of the content. In these cases, codes are often applied as a layer on top of the data. Quantitative analysis of these codes is typically the capstone analytical step for this type of qualitative data.

Contemporary qualitative data analyses are sometimes supported by computer programs, termed Computer Assisted Qualitative Data Analysis Software. These programs do not supplant the interpretive nature of coding but rather are aimed at enhancing the analyst's efficiency at data storage/retrieval and at applying the codes to the data. Many programs offer efficiencies in editing and revising coding, which allow for work sharing, peer review, and recursive examination of data.

A frequent criticism of the coding method is that it seeks to transform qualitative data into quantitative data, thereby draining the data of its variety, richness, and individual character. Analysts respond to this criticism by thoroughly expositing their definitions of codes and linking those codes soundly to the underlying data, therein bringing back some of the richness that might be absent from a mere list of codes.

In this study, the data from the interviews were categorised, coded and written up descriptively (Taylor, 1998).

3.11 Validity

Data from the Feasibility study and the Whole Life Costing were cross checked with data from the individual interviews in order to establish validity.

3.12 Ethics

The researcher was mindful of ethical issues. Approval was received from the university ethics committee to proceed with this study. The participants in this study were informed that their responses would be kept confidential and they themselves would remain anonymous. In addition, they were informed that their participation was voluntary and that could leave the study at any time.

3.13 Methodology Conclusion

This research incorporated both quantitative and qualitative methodologies.

1. **Feasibility Study of the Skipworth Model**

The qualitative research was useful to investigate requirements in existing models of the Water Corporation and to be able to test the knowledge of the water professionals in application of Whole Life Costing in the Water Distribution Network Management.

The quantitative research was useful to get input data to simulate the Skipworth model.

The case study research incorporated Qualitative and Quantitative methodologies were useful for collecting data with particular characteristics and simulation with particular obligations. The case study provided data for the Feasibility analysis of Skipworth model for Bridgetown.

2. **Comparison of Water Distribution methods**

The qualitative research was useful to test the knowledge of the water professionals in Water Distribution methods through the use of interviews.

The quantitative research was useful to get input data for Whole Life Costing analysis.

The case study research incorporated Qualitative and Quantitative methodologies were provided information for the Whole Life Costing analysis.

Chapter 4 Results and Discussion

4.1 Introduction

This chapter presents the Results and Analysis of the data collected from a Feasibility study and a Whole Life Costings. The data pertained to a Feasibility study of the use of the Skipworth model for Water Distribution Network Systems, Bridgetown and Whole Life Cycle costing analysis for Greenvale pumping system ,are presented in Table 4.1 and Table 4.7(Appendix c). The staff members are designated: 1, Manager of Water Organization; 2, Project Engineer, Water Organization: 3, Project Engineer, Water Organization; 4, Senior Project Engineer, Water Organization.

4.2 Analysis of Interview Data for Skipworth Feasibility Analysis

The analysis of the interview data for the Skipworth Feasibility analysis is based on the raw data provided in Table 4.1 (Appendix C). The raw data were categorised in terms of the coding as follows:

Water Distribution Network System (Question 1)

When the four interviewees were asked for their definition of Water Distribution Network System, interviewees 1, 2, 3 and 4 were able to give definitions of Water Distribution Network in technical terms. However, no definition in terms of Whole Life Costing and optimization was given by any of the interviewees. The lack of understanding of the definition of the Water Distribution Network System could lead to many issues such as lack of Whole Life Costings, lack of technical operation and improper understanding of the planning of the water supply projects.

Currently Used Model (question 2).

When asked about their currently used model, Interviewees 2, 3 and 4, although using a model, had no idea about the specific name of the model used in the Water Organization, but interviewee 3 said he could work out the operation and maintenance cost and interviewee 4 said he currently used NPV for particular Projects. Interview 1 stated that there were no currently used specific models which accommodate customer standards. Although the interviewees were not aware of the specific models available it should be noted there are opportunities to use different models throughout Australia; these provide different outputs of the simulations of the Water Supply Projects in the context of Whole Life Costing; from rural towns to State and from State to national there is a hierarchy of Water Management Organizations which study the outputs of the simulations of the water supply projects and, because of the different models, miscommunication can occur, there can be lack of Whole Life Costing and difficulty integrating particular water supply projects in terms of costing, planning and execution of water supply projects. This creates fluctuations in the water supply projects' budgets.

Whole Life Costing (question 3)

Interviewee 1 did not give a technical definition; he simply said Whole Life Costing was used for working out maintenance and NPV.

Interviewees 2, 3 and 4 were not able to satisfactorily give a definition of Whole Life Costing. According to Skipworth (2002) this confusion about definitions of 'Whole Life Costing' instead of just 'Whole Life Costing' arises because there is confusion about Whole Life Costing and about life cycle analysis (indeed this was mentioned by interviewee 2).

Benefit of Existing Model (questions 4)

Interviewees 1 and 2 mentioned that the existing model takes little time and it is very easy to calculate Whole Life Costing for particular water supply projects. (According to the Annual Progress Reports of 2010 for the Water Corporation, the Young model is currently being used). Interviewee 3 stated it was a convenient model for calculating Whole Life Costing accounting; however he said it was very difficult to work out social and environmental cost because of the unavailability of some of the cost drivers and the methodologies of the social and environmental costs. Interviewee 4 stated that, by using the current model customer standards can be achieved by supplying water 24 hours. Therefore, the main problem seems to be inadequate methodologies for social and environmental costs.

Cost Drivers (question 5)

Interviewees 1 and 2 seemed to have good knowledge about the cost drivers. They also believed that there is a systematic approach for counting cost drivers. Interviewees 3 and 4 had experience in working out the Whole Life Costing but lacked knowledge of different cost drivers. Consideration of cost drivers did not seem to have been undertaken. Therefore, specific cost drivers are required for Water Distribution Network Management by applying specific boundaries and regulations which will give precise and accurate results using Whole Life Costing.

Which Cost Drivers were Introduced (question 6)

None of the interviewees knew about types of cost drivers. However, interviewee 4 stated that cost drivers for maintenance and operations were used. It seems that, because of the different methodologies used to work out Whole Life Costing for water supply projects, water professionals are not able to specify cost drivers by regulations and boundaries.

Whole Life Costing Problems (question 7)

All the Interviewees apart from Interviewee 4 stated that there were problems. Interviewee 1 stated that, because of the current model used, there was poor asset prediction. Interviewee 2 reported that he was not happy about the cost of water and Interviewee 3 stated that it was difficult to differentiate cost from upstream to downstream. The poor asset predictions were a consequence of the predictions of the operation and maintenance cost for particular cost drivers. Different regions of Australia have different water costs which mostly depend on the calculations of the Whole life costing and because of the inadequate calculation of Whole Life Costing, there are fluctuations in the cost of the water. The boundaries of the Water Distribution Networks make two divisions – upstream to downstream and both are dependent on each other in the context of Whole Life Costing.

Whole Life Costing Improvements (question 8)

All of the Interviewees believed the model needed to have the capability to predict better life of pipe asset. Interviewee 1 also stated that the missing cost drivers e.g. service cost for inlet pipe and more regulations should be added into the boundaries of the Water Distribution Networks and social and environmental methodologies. Interviewee 2 suggested that more predictions are required in asset predictions. Interviewees 3 and 4 suggested that the required suitable models were required appropriate to the situations of the Water Supply Projects. The better asset predictions including all types of the social and environmental methods as well as specific cost drivers and boundaries are characteristics of the Skipworth model.

Boundaries (question 9)

Interviewees 1, 2, 3 and 4 were not able to give specific answers regarding boundaries. Skipworth gives three boundaries cost, temporal and geographic boundaries as explained in the literature review of this research.

Definition of Social and Environmental Costs (question 10)

Interviewees 1, 2, 3 and 4 were able to give good definitions for social and environmental cost. All Interviewees stated in their definitions that there is an adverse effect to social and environmental life because of human activities and to minimise this effect Water Organizations have schemes which create cost. There are different methods to work out social and environmental costs and there are particular social and environmental issues to be accounted for in whole life costing.

Methods Used to Work out Social and Environmental Costs (question 11)

The Interviewees used their own models to work out the social and environmental costs and the different water organizations have different models. Interviewee 1 reported that there are different types of methodologies but they are difficult to understand in the context of the customer standards. Interviewee 2 stated that the Water Corporations had created their own models which do not contain human rights for land management. Interviewee 3 stated, too, that the Water Corporations had created their own models because of regulations relating to permits for water supply projects which could have adverse effects on the environment. Interviewee 4 pointed out that different water supply options are able to maintain the water cost. The integration of the social and environmental costs for Water Distribution Networks passing through different divisions of the Water Distribution Network like upstream and downstream contains different cost drivers which maintain the financial flow of the Water Distribution Networks. So when we incorporate the social and environmental costs the Water Organizations need to consider all the aspects of the Water Distribution Networks e.g. boundaries, cost drivers and regulations. Therefore the social and environmental cost methods are very critical parts of the Whole Life Costing; because of the fulfilment of all the variables (boundaries, cost drivers and regulations) of the cost for Water Distribution Networks.

Regulations Followed by the Water Corporation (question 12)

All the interviewees provided a different response to the question about regulations they follow.

Interviewees1 and 2 stated that they have their own regulatory bodies whose regulations they follow. Interviewee 2 stated, however, that if there were changes, suggested by the customers or employees the Water Corporation’s decision would be final. Interviewee 3 stated they need specific regulations to solve the different issues, e.g. environmental issues, water quality issues and economic issues. Interviewee 4 reported that the different water supply options that they use, are able to maintain water cost. The water organizations and the Water Corporations which are run partially by the government or privately have their own regulations which may not sit well with customers or employees ethics.

Risks When Implementing a Water Distribution Network (question 13)

Interviewees 1, 2, 3 and 4 mentioned some risks when applying their models to calculate the Whole Life Costing; these were over budget, water quality, burst and leakage. Therefore, it is clear, the risks when implementing a Water Distribution Network are varied.

4.3 Feasibility Study for Bridgetown Water Supply Network

A Feasibility study was executed for Bridgetown Water Supply Network. This case study was carried out with Bridgetown Water Supply Network and included Whole Life Costing using the Skipworth model. Distribution covers the supply of treated water from the service reservoir into a Distribution Network that supplies consumers - industrial, commercial, business, public or domestic. In order to maintain and perform the supply function, a number of activities have to be undertaken, which incur costs. The costs include the day-to-day costs associated with operation and management, routine repair and maintenance, and associated business activity support costs. The planned maintenance covers all the maintenance activities including operation and capital expenditure in terms of budget. The Skipworth model divides the Distribution System among three elements: Normal Supply, Leakage, and Bursts. Skipworth et al. (2002) identified three main performance based cost drivers: Supply and Demand, Structural Failure and Water Quality.

Leakage increases the overall volume of water required to feed a Network. To prevent leakage there are many strategies like leakage control.

This research incorporated the three cost drivers for Bridgetown Water Supply project: Supply and Demand, Structural Failure and Water Quality. In addition 18 sub cost drivers were incorporated to fulfil the Feasibility study of the Skipworth model.

Results of the Feasibility study

Results encompassed cost drivers, comparison of the models and the benefits of the models.

A Mat lab programme based on the Skipworth model was developed. Tables 4.2 and 4.3(Appendix C) show three cost driver values related to Water Supply and Demand, Burst and Leakage, Water Quality. For example, Water Input, Burst Repair and Complaints were the cost drivers for the Bridgetown Water Supply Network and Skipworth provided the following equations for the calculations:

1. $CINPUTW = CF + CV.V + EINPUTW$

Where, CF is the fixed cost of the input Water ($AUD), CV is the variable cost of the input Water ($AUD/MI), V is the volume of input Water (MI) and EINPUTW is the external cost associated with the input Water ($AUD/a).

2. Crepair = $\sum_i ni \sum_j Cj$

Where, *ni* is the number of burst event s for pipe group i, j is set of location based costs and *cj* is the cost of repair (£).

Table 4.2 (Appendix C) shows input data for 0 to 5 year time step and the next series of cost driver values can be generated as per the predictive theory of the Skipworth Model.

The Asset prediction theory presented by Skipworth is very important for planned maintenance of a particular Water Supply project. The application of asset prediction theory results in lower maintenance and operation costs for the selected model.

Table 4.3 (Appendix C) shows that the cost driver values for three divisions of normal supply, leakage, burst were done for up to 50 years by using the Asset Predictive Theory of Skipworth. The total cost of normal supply, burst and leakage was discounted at the rate of 7%. The graphical representation shows normal Supply, leakage and burst cost increasing with the aging of the Water Supply Network but can be minimized by rehabilitation (Figure 4.1, Appendix C).

The Feasibility study of the use of the Skipworth model, based on the interaction and interviews with the project engineer of the Water Organization and samples taken, proved that the Skipworth model can be easily used as a tool to calculate the Whole Life Costing Accounting of the Water Supply Projects.

The Feasibility study showed that the Skipworth model of Whole Life Costing is less time consuming than existing models – for example the calculations for Whole Life Costing for Bridgetown can be done within 15 minutes as opposed to one hour with the current method; the current method, it should be noted, incorporated less than 5 cost drivers. The Skipworth model incorporates 40 cost drivers.

The Skipworth model was shown to be able to track small variations in the particular cost drivers e.g. Water Supply and Demand and Water Quality; small variations in costs could also be tracked of the sub cost drivers e.g. chlorine, lead as a part of the simulations of the Skipworth model or with the help of the Matlab programming (see Figure 4.1 Appendix C).

Also the Skipworth model was shown to be able to track small variations in the particular boundaries related to cost e.g. temporal boundaries, cost boundaries; the

Skipworth model was able to track small variations in the intake cost to delivery cost of water.

These variations can be calculated for the various regions of Australia.

Knowing the wide variation between, or in, the boundaries, i.e. when there is a high cost, it can be minimized by adopting the different management options or water delivery options or water extracting options.

Using the Skipworth model the results appear sequentially and holistically i.e. incorporate information from all the 40 cost drivers.

Comparison of the Skipworth Model with the Young Model Used by the Water Corporation

Through this Feasibility study it was found that there were several missing cost drivers after comparing the Water Annual Progress Report of the Water Corporation with the Skipworth model:

- Service pipes (leakage or burst) were not included in the current calculations
- Water quality was not assessed by the Water Corporation (the Environment Department checked water quality); this system leads to greater management costs.

The comparison of the Skipworth model with the Young model proved that the Young model is lacking in terms of the asset predictions because of the lack of Whole Life Costings associated with NPV and future predictions of water supply projects.

4.4 Benefits of the Skipworth Model:

1) The Feasibility study of Skipworth model proved that it could be used successfully for Western Australia to improve local application.

2) The Skipworth model is both specific and holistic.

3) It is possible to precisely calculate water tariff based on the Skipworth model.

To do this, proper understanding between organizations to understand cost drivers, boundaries and regulation for Water Distribution is required while using the Skipworth model.

4) Cost and water savings can be realized when the Skipworth model is applied to a particular Water Supply project.

5) Asset prediction for a particular Water Supply project can be done precisely and accurately by using the Skipworth model.

4.5 Conclusions for Feasibility Analysis of the Skipworth Model

Based on this case study results and analysis, the Skipworth model was successfully implemented for the Bridgetown Water Supply Network. The Skipworth model, it seems, can be applied to small or large scale Water Supply Projects. Through the use of Skipworth theory, a clear picture was shown of cost drivers, regulations and boundaries in a Water Supply organisation. Further, it enabled better communication between the employees and the organization to sort out the management and technical issues without any confusion at Bridgetown Water Supply Network. It was also easy to work out annual progress reports precisely and in detail at Bridgetown Water Supply Network. Several cost drivers were required to be incorporated into the Water Corporation which resulted in cost savings and they also provided clear vision of Whole Life Costing at Bridgetown Water Supply Network. Several research studies in the past have dealt with the Water Distribution Network Management problems (e.g. Burn and Young, 1994). Burn gives detailed knowledge about the Water Distribution Network Management. The model presented by Young concluded that, while broad predictions on future asset performance can be made based on data such as age, pipe type, diameter, and laying technique, accurate information on soil type, it is also essential to improve the predictive capabilities of this modelling. The Skipworth model is a holistic approach (including information on soil type, age of pipe, diameter of the pipe, type of cost driver and boundaries of cost drivers) and enabled working out Whole Life Costing for Bridgetown water supply projects with detailed and precise results.

4.6 Analysis of Interview Data for Comparison of Water Distribution Methods.

The second set of interviews enabled comparison of Water Distribution methods to acquire knowledge about Whole Life Costing Analysis of Greenvale Pumping Station. The analysis of the data for the comparison of the Water Distribution methods was based on the raw data provided in Table 4.4(Appendix C).

1.0 Water Distribution methods.

All the Interviewees showed that they had good knowledge about the Water Distribution methods. They stated that continuous supply plays a dominant role throughout Australia. They stated, though, that the increasing population has resulted in more operation and maintenance costs. In addition, interviewee 4 stated that inferior material quality had become a major problem. As he explained, inferior quality materials lead to short life of the asset for water supply projects; therefore there is less efficiency as the materials have to be replaced more often. Interviewee 4 stated that sustainable options are required – possibly the Gravity and Combined Systems should be used.

2.0 Benefits of Continuous Supply.

Interviewees 2 and 4 stated that the water quality and amount of supply were currently adequate. Interviewees 1 and 3 only stated that the water quality was adequate. To change from the current continuous supply system to either the Gravity or the Combined System, most of the Interviewees said, would require more research. Some of the rural areas, e.g. Mandurah, are already, according to two of the Interviewees, using the Gravity or the Combined System.

4.7 Whole Life Costing Analysis for Greenvale Pumping Station

A Whole Life Costing analysis was conducted at Greenvale Pumping Station in order to compare the Water Distribution methods, Gravity, Combined, with the existing method, pumping, at Greenvale Pumping Station

The Whole Life Costing Analysis showed that the Gravity and Combined Systems are superior compared to the Pumping System used in Melbourne. The investigation of this site showed that there have been effects from construction and Environmental impacts. The increasing number of Pumping Stations is increasing the construction and Environmental impact as per the statistics of the Annual Water Progress Reports of the Water Corporation (1994-2012). Due to increasing operation and maintenance costs, it was shown that there is a need to switch to other Water Distribution methods.

Table 4.5 (Appendix C) shows that the operation and maintenance cost goes on increasing with the increasing life of the Pumping Station. The operation and maintenance costs of the Pumping System are very high compared to the Gravity and Combined System. The Combined System helps to reduce operation and maintenance costs. Further, the Gravity System helps to minimize the construction and environmental impact.

4.8 Further Benefits of the Gravity and Combined Systems

1) The Gravity and Combined System are more environmentally friendly than the Pumping System

2) The Combined System can be applied to certain water restriction areas of Australia. This can lead to savings of water and limited hours of pumping. Hence an

environmentally friendly and more sustainable connection can be provided to customers with less water tariff.

The Pumping System is dominant in Australia and this results in more fuel gas emissions.

4.9 Conclusion for Whole Life Costing analysis for Greenvale Pumping Station.

Environmentally friendly Water Distribution solutions are currently being sought. Distribution Systems based on Pumping Systems have several environmental impacts on society. As per the Water Organization Report 1717 tonnes of CO_2 emissions are produced in Perth (Annual Progress Report 2010). According to this study, the Gravity System is the best option to minimize the environmental impact and the construction impact at Greenvale Pumping System. The results showed that the operation and maintenance cost of the Pumping System increased the budget of the Water Corporation and had a social and environmental impact in millions of dollars.

4.10 Discussion of Feasibility Analysis and Interviews

This study has shown that the Skipworth model has the ability to give precise and perfect results for whole life cycle accounting of a particular water supply project, Bridgetown. The study highlighted certain aspects including cost drivers, regulation, boundaries, asset predictions and social and environmental impact.

Cost Drivers

The cost drivers were important elements in the Whole Life Costing of this particular water supply project. Skipworth mainly described three cost drivers such as Supply and Demand, Structural Performance and Water Quality. Analysis of Interviewee data and literature review indicates that there is no proper understanding of the cost drivers and a few of the cost drivers are missing in existing models of the Water Corporation. The study showed that, if the Water Corporation were to follow the Skipworth model, then it would be possible to minimize the communication error from rural to State operation and back to national operation. Various water supply projects in Western Australia contain a number of cost drivers and discussion about a particular cost driver can allow for changing the resources to control the Whole Life Cost Accounting. Following the Skipworth cost driver model would be useful for preparing the water project progress or Annual Reports of the Water Corporation. Accounting for missing cost drivers through the use of the Skipworth model could lead to money and water savings and effective time utilization.

Regulation

A regulation system is proposed by the Skipworth model. This is stated as economic, environmental, and potable water quality regulation. Regulation is a process that includes:

1) The formation of goal /objectives
2) Systems to monitor compliance
3) The provision of incentives for the achievement of goals.

The above goals play an important role in water supply projects for regulation purposes. The goals should be such that maximum efficiency of performance of the Water Distribution Network should be obtained with minimum cost to the customer. The regulation of the cost drivers and boundaries would give guidance to achieve the required goals. Regulation would also consider the deterioration of mains. Penalties could be imposed on the Water Corporation in the event of deterioration of serviceability. Therefore this means that division of regulation would address the related issues more conveniently.

Boundaries

Providing boundaries to any model of Water Distribution Network Management is very important. The study showed that the Skipworth model provided the necessary boundaries for Water Distribution Networks. The Skipworth model suggests providing a system of boundaries. The three boundaries mentioned are 1) geographical 2) temporal 3) cost.

If the Water Corporation provided boundaries then they would be able to count the effect of fluctuation of cost related to water and resources used for the Water Supply Projects from downstream to up stream. However, they would not be able to work out the unit cost related to Water and resources used for the Water Supply Projects because of interaction between upstream and downstream in terms of costing.

Asset Management prediction

Young (2010) proposed statistical modelling for predicting the life of pipe assets. He concluded that prediction of life of pipe assets also depends upon the age, pipe, diameter, soil type and laying technique. The Skipworth study also considered these factors for predicting the life of pipe assets. This means that if the Water Corporation used the Skipworth model, it would be possible to predict the life of pipe assets more accurately. As a result, the overall operation and maintenance cost of Water Supply Projects would not be over budget.

Social and Environmental impact

Calculating the social and environmental cost is an important aspect in Australia. According to the responses from the interviewees and the Feasibility analysis of the use of the Skipworth model, Skipworth provided a methodology to convert the different aspects of Water Supply Projects to calculate social and environmental costs like avoidance cost, remediation cost, willingness to pay. Skipworth also mentioned the contingent value method. This method enabled consideration of the differing situations of Bridgetown Water Supply Network. All types of Water Supply Projects with regard to their different situations and details and precise results are considered in the Skipworth model and they enable the social and environmental costs to be worked out more effectively.

The next section presents the discussion of the Whole Life Costing analysis of Greenvale Pumping Station.

4.11 Discussion of Interview Data for Whole Life Costing Analysis for Greenvale Pumping Station.

Water Distribution Methods

The Water Distribution method based on the Pumping System is the current method, according to our literature review and interview data, in Australia. The increase in Pumping Systems means an increase in emissions and increasing operation and maintenance costs. One of the arguments, according to the interviewees, against Combined Systems and the Gravity Systems would be poor water quality but this could easily be solved with advanced research. Increasing Combined and Gravity Systems could, in fact, lead to less operation and maintenance costs and less environmental impacts.

In case of intermittent Supply or Combined System, a few hours of water supply is provided. In the commercial type of available tanks like galvanized steel, polyethylene, fibre glass, pvc and cement, there could be water quality problems due to:

- Microbial re-growth
- Chemical and Physical changes
- Loss of chlorine residual
- Accumulation of sediments

To overcome these problems, in case of Intermittent Supply (Combined Systems), a few hours of water supply is provided during water supply hours. Water for drinking purposes can be stored in the filter vessels and the rest of the water can be stored in the storage tank for indoor and outdoor purposes. From the literature review of this study it was found that PVC and cement storage tanks are better than polyethylene, galvanized steel and fiber glass. Regular cleaning of the storage tank for monitoring the bacterial growth is therefore required.

There are restricted areas in Australia where insufficient water is available for distribution into the towns. Intermittent Water Supply is the best option for this type of situation.

The topography is another very important factor in Water Distribution Systems. Gravity based Systems have limitations when the elevation difference between input and withdraw point is small. In this case one has to use pipes with increased diameter resulting in increased costs. There are up and down slopes into the town’s areas;

hence wise pressure management plays a dominant role in reducing burst and leakage in the Water Supply Network.

Based on the application of Whole Life Costing to the Pumping Station, it was proved that the Gravity and the Combined System are more environmentally friendly and have less operation and maintenance costs.

The Gravity System has been used in a few of the States in Australia. Because there are certain limitations of the Gravity System inside particular areas, more research is required to make it feasible. In the same way, an Intermittent Supply based System can play an important role in certain rural towns due to restrictions on water usage in certain areas. A sustainable method is required since the population and numbers of industries are increasing in Australia. The Gravity System and Combined System have been proven from his study to be the best option based on Whole Life Costing for sustainability aspects of the accounting.

4.12 Limitations and strengths of study

There were certain limitations to this study. Only four personnel were interviewed; more data could have been collected with a greater number of interviewees. There was a time constraint which meant that further data collection could not be carried out.

Strengths of study

Despite the limitations, it is believed this study, using the case study method, found valuable data which highlighted the fact that the Skipworth model could be effectively used for water projects in Western Australia; in addition the study showed that the Gravity and Combined Systems could be effectively implemented.

4.13 Conclusion for Discussion on Feasibility Study of Skipworth Model

The Skipworth model has been shown from the Feasibility study and from the interview data to have the ability to give holistic results covering most of the elements like types of cost drivers, boundaries, regulation, asset management prediction and social impact methods. Using this model the Water Corporation of Australia and Water Organizations of Australia can achieve systematic Whole Life Costing of Water Supply Projects. The comparison of this model with existing models showed that a change from existing models to the Skipworth model would be advantageous in Australia. These changes could lead to water and money saving for the Water Corporation of Australia.

5.0 Conclusions and Recommendations

This research evaluated the use of the Skipworth model at Bridgetown Water Supply Network and a Whole Life Costing analysis at Greenvale Pumping Station. The study comprised two different parts: a Feasibility study using Skipworth model in Western Australia for Bridgetown Water Supply Network and a Whole Life Costing Analysis of Greenvale Pumping Station (Melbourne town). The application of Whole Life Costing was common for both the subjects. The subject of water engineering is important for Australians because of the existence of large dry areas and hence, scarcity of Water. Moreover, due to increasing population and industrialisation, it is very difficult to manage the water engineering application. The analysis of the interview data and literature review suggests that more improvements are required in existing Water Distribution Network Management and Distribution methods.

The Feasibility of using the Skipworth model in Australia as part of improvement of existing models was discussed. The analysis of data and interviews suggested that existing models of the Water Distribution Network Management were not capable of managing the problems in terms of cost drivers, regulation, boundaries and asset prediction of pipe assets. The Skipworth model has been shown to have the ability to give precise and detailed results for the accounting of a small scale water supply.

Developed countries have adopted the Pumping System because of the main advantage of 24 hours supply and water quality. Even the Gravity and Combined System have been proved to provide less operation and maintenance cost compared to the Pumping System. Underdeveloped countries still have the Gravity and Combined System. The Pumping System has more water tariff than the Gravity System and Combined System. The Gravity System and Combined System have been shown to be more environmentally friendly.

Overall, this research has focused on improving the existing model used by Bridgetown Water Supply Network. The Skipworth model was shown to lead to water savings and cost savings. It may be possible to use the Skipworth model for other Water Supply Networks. The Gravity System and Combined System were demonstrated to be more sustainable options than the Pumping System for Greenvale and possibly for other similar situations where Pumping Systems have been dominant.

The recommendations based on the research conducted are as follows:

It is recommended that:

- Bridgetown Water Supply Network should implement the Skipworth Model for precise and accurate results of Whole Life Costings.

Whole Life Costings of the Bridgetown Water Supply Network contained all the cost drivers including Water Normal Supply, Burst and Leakage as well as the Social and Environment Cost by considering regulations and boundaries. The operation and maintenance cost with externalities is necessary by considering the regulations and boundaries. Otherwise, this will give a worst case scenario in terms of land management, resource management, industry management and financial management.

- Greenvale Pumping Station should adopt the Gravity or the Combined System by creating the feasibilities for the Gravity or Combined System

The Whole Life Costing study suggested that the Gravity and Combined Systems are superior to the currently used Pumping System. In the future there will be problems regarding the social and environmental costs even nowadays the world is facing the sustainability issues and because of that the Gravity and Combined Systems, rather than the Pumping System, are proven to be better options for developed countries.

- The Water Corporation and private Water Organizations need to update their existing models and Water Distribution methods to upgrade the level of water management. To update this level of management requires more highly skilled water professionals who are able to work with highly qualified models like the Skipworth model; they should also have good knowledge of the Water Distribution methods.

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Appendices

The Appendix A contains Matlab programme to calculate Skipworth cost drivers and secondary data (Appendix B) from the Skipworth for further study on the Skipworth model. The appendix also contains Tables (Appendix C).

Appendix A

Mat lab programming

```
clc
% input parameter (Normal Supply Cost)
Cinputw= xlsread('raghu.xls','Sheet2','C6');
Copm= xlsread('raghu.xls','Sheet2','C6');
Cvopm = xlsread('raghu.xls','Sheet2','C8');
Crm = xlsread ('raghu.xls','Sheet2','C9');
Crrm = xlsread ('raghu.xls','Sheet2','C10');
Ccm= xlsread ('raghu.xls','Sheet2','C11');
Cbinspec= xlsread ('raghu.xls','Sheet2','C12');
Cdistr=xlsread ('raghu.xls','Sheet2','C13');
Cec= xlsread ('raghu.xls','Sheet2','C14');
Casm = xlsread ('raghu.xls','Sheet2','C15');
Cwq = xlsread ('raghu.xls','Sheet2','C17');
Ccapm= xlsread ('raghu.xls','Sheet2','C18');
Creg= xlsread ('raghu.xls','Sheet2','C20');
Css= xlsread ('raghu.xls','Sheet2','C21');
Cgs=xlsread ('raghu.xls','Sheet2','C22');
Ccs = xlsread ('raghu.xls','Sheet2','C23');
% detrmine outputs
CSupply= Cinputw+ Copm+ Cvopm+Crm+Crrm+ Ccm+
Cbinspec+Cdistr+Cec+Casm+Cwq+Ccapm+Creg + Css+ Cgs+ Ccs;
%Display outputs
display (CSupply);
% Input parameter  (Input Water cost)
Cf= xlsread('raghu.xls','Sheet2','C25');
Cv= xlsread('raghu.xls','Sheet2','C26');
v= xlsread('raghu.xls','Sheet2','C27');
Einputw=xlsread('raghu.xls','Sheet2','C28');
% determine outputs
Cinputw=Cf + Cv*v+Einputw;
% Display outputs
display ( Cinputw);
```

```
% input parameter (Mains Operation and Maintenance)
fopm = xlsread('raghu.xls','Sheet2','C30');
Cl = xlsread('raghu.xls','Sheet2','C31');
Eopm = xlsread('raghu.xls','Sheet2','C32');
% Determine outputs
Copm= fopm + Cl + Eopm;
% Display outputs
display (Copm);
% Input parameter (Valves operation and Maintenance cost )
fvopm= xlsread('raghu.xls','Sheet2','C34');
nNC =  xlsread('raghu.xls','Sheet2','C35');
Evopm =  xlsread('raghu.xls','Sheet2','C36');
% Determine outputs
Cvopm = fvopm + nNC+ Evopm;
% Display outputs
display ( Cvopm);
% Input parameter ( Service Pipe Maintenance and repair)
frm = xlsread ('raghu.xls','Sheet2','C38');
nCN = xlsread ('raghu.xls','Sheet2','C39');
Erm= xlsread ('raghu.xls','Sheet2','C40');
% Determine outputs
Crm= frm +  nCN + Erm;
% Display outputs
display ( Crm);
% Input parameter ( District and Zonal meters)
frrm=xlsread ('raghu.xls','Sheet2','C42');
nNC=xlsread ('raghu.xls','Sheet2','C43');
nCN=xlsread ('raghu.xls','Sheet2','C44');
Errm=xlsread ('raghu.xls','Sheet2','C45');
% Determine Outputs
Crrm= frrm+ nNC+ nCN + Errm;
% Display Outputs
display ( Crrm);
% Input parameter (Consume Meter Repair)
```

```
fcm=xlsread ('raghu.xls','Sheet2','C42');
nNCcm=xlsread ('raghu.xls','Sheet2','C43');
nCNcm=xlsread ('raghu.xls','Sheet2','C44');
Ecm=xlsread ('raghu.xls','Sheet2','C45');
% Determine Outputs
Ccm= fcm+ nNCcm+ nCNcm + Ecm;
% Display Outputs
display ( Ccm);
% Input parameter (Bylaw Inspection)
Nbinspec=xlsread ('raghu.xls','Sheet2','C52');
Cbinspec=xlsread ('raghu.xls','Sheet2','C53');
Ebinspec=xlsread ('raghu.xls','Sheet2','C54');
% determine outputs
Cbinspec=Nbinspec * Cbinspec+ Ebinspec;
% Display output
display ( Cbinspec);
% Input parameter ( Distribution operation and control)
Alpha=xlsread ('raghu.xls','Sheet2','C56');
fdistr=xlsread ('raghu.xls','Sheet2','C58');
Edistr=xlsread ('raghu.xls','Sheet2','C59');
% determine outputs
Cdistr = Alpha*fdistr+ Alpha* Edistr;
% display output
display( Cdistr);
% Input parameter ( Enquiries and Complaints)
nb=xlsread ('raghu.xls','Sheet2','C62');
ntiNti=xlsread ('raghu.xls','Sheet2','C63');
% dETERMINE OUTPUTS
Ncomp= nb+ ntiNti;
% Display output
display ( Ncomp);
% Input parameter ( Cost of handling enquiries and Complaints )
ccomp=xlsread ('raghu.xls','Sheet2','C66');
fcomp=xlsread ('raghu.xls','Sheet2','C67');
```

```
Ncomp=xlsread ('raghu.xls','Sheet2','C68');
Ecomp=xlsread ('raghu.xls','Sheet2','C69');
% DETERMINE OUTPUTS
Ccomp= fcomp+ ccomp*Ncomp + Ecomp;
%  display output
display ( Ccomp);
% Input parameter ( Cost of investigating enquiries and complaints)
Bn =xlsread ('raghu.xls','Sheet2','C71');
ficom=xlsread ('raghu.xls','Sheet2','C72');
cbi=xlsread ('raghu.xls','Sheet2','C73');
nb=xlsread ('raghu.xls','Sheet2','C74');
ctinti=xlsread ('raghu.xls','Sheet2','C75');
Eicom=xlsread ('raghu.xls','Sheet2','C76');
% determine outputs
Cicom = ficom+ cbi*nb+Bn * ctinti+ Eicom;
%  display output
display ( Cicom);
% Input parameter ( Customer service cost)
 Ncus =xlsread ('raghu.xls','Sheet2','C86');
Ccus=xlsread ('raghu.xls','Sheet2','C87');
Ccusenq =xlsread ('raghu.xls','Sheet2','C88');
Ecs=xlsread ('raghu.xls','Sheet2','C89');
% Determine outputs
Ccs= (Ccus*Ccusenq)/Ncus+ Ecs;
% display outputs
display ( Ccs);
% Input parameter ( Scintific service cost)
wss =xlsread ('raghu.xls','Sheet2','C91');
Css=xlsread ('raghu.xls','Sheet2','C92');
Cssenq =xlsread ('raghu.xls','Sheet2','C93');
Ess=xlsread ('raghu.xls','Sheet2','C94');
% Determine outputs
Css= wss(Css-Cssenq)+ Ecs;
% display outputs
```

```
display ( Css);
% Input parameter ( Water quality cost)
Ctflush =xlsread ('raghu.xls','Sheet2','C101');
Cpah=xlsread ('raghu.xls','Sheet2','C102');
Cthm =xlsread ('raghu.xls','Sheet2','C103');
Cbac=xlsread ('raghu.xls','Sheet2','C104');
% determine outputs
Cwq= Ctflush + Cpah + Cthm + Cbac;
% display outputs
display(Cwq);
% Input parameter ( cost of burst repair)
 ni =xlsread ('raghu.xls','Sheet2','C107');
CJ =xlsread ('raghu.xls','Sheet2','C109');
% determine outputs
Crepair= ni*CJ;
% display outputs
display(Crepair);
% Input parameter ( indirect burst costs)
CregB =xlsread ('raghu.xls','Sheet2','C111');
Ccompen=xlsread ('raghu.xls','Sheet2','C112');
Ccompl =xlsread ('raghu.xls','Sheet2','C113');
CimageB=xlsread ('raghu.xls','Sheet2','C115');
Cpenb =xlsread ('raghu.xls','Sheet2','C114');
% determine outputs
CindB= CregB+Ccompen+Ccompl+ CimageB+Cpenb;
% display outputs
display(CindB);
% Input parameter (regulatory burst cost)
Nbursts =xlsread ('raghu.xls','Sheet2','C117');
cregB=xlsread ('raghu.xls','Sheet2','C118');
Ereg=xlsread ('raghu.xls','Sheet2','C119');
% determine outputs
CregB = Nbursts*cregB+ Ereg;
% display outputs
```

```
display(CregB);
% Input parameter ( Bursts compensation costs)
sigmaNc =xlsread ('raghu.xls','Sheet2','C121');
N3C3=xlsread ('raghu.xls','Sheet2','C122');
% determine outputs
Ccomp = sigmaNc+N3C3;
% display outputs
display(Ccomp);
% Input parameter ( handling burst complaints)
n =xlsread ('raghu.xls','Sheet2','C124');
Nburst=xlsread ('raghu.xls','Sheet2','C125');
Ccompl=xlsread ('raghu.xls','Sheet2','C126');
Ecompl=xlsread ('raghu.xls','Sheet2','C127');
% determine outputs
Ccompl = n*Nburst*Ccompl+Ecompl;
% display outputs
display(Ccompl);
% Input parameter ( image burst costs)
cimageB =xlsread ('raghu.xls','Sheet2','C132');
Nburst=xlsread ('raghu.xls','Sheet2','C131');
Eimage=xlsread ('raghu.xls','Sheet2','C133');
% determine outputs
CimageB= Nburst*cimageB+Eimage;
% display outputs
display(CimageB);
% Input parameter ( external burst cost)
Cdisrup =xlsread ('raghu.xls','Sheet2','C135');
Cwtp=xlsread ('raghu.xls','Sheet2','C136');
% determine outputs
CexB= Cdisrup+Cwtp;
% display outputs
display(CexB);
% Input parameter  ( leakage detection strategy costs )
fld =xlsread ('raghu.xls','Sheet2','C140');
```

```
Clds=xlsread ('raghu.xls','Sheet2','C141');
L=xlsread ('raghu.xls','Sheet2','C142');
Elds=xlsread ('raghu.xls','Sheet2','C143');
% determine outputs
Clds= fld+ Clds*L+Elds;
 % display outputs
display(Clds);
% Input parameter  ( indirect leakage costs)
CregL =xlsread ('raghu.xls','Sheet2','C145');
Ccomplaint=xlsread ('raghu.xls','Sheet2','C146');
CimageL=xlsread ('raghu.xls','Sheet2','C147');
% determine outputs
CindL= CregL+Ccomplaint+CimageL;
% display outputs
display(CindL);
% Input parameter ( leakage regulatory costs)
Ncust =xlsread ('raghu.xls','Sheet2','C149');
Preg=xlsread ('raghu.xls','Sheet2','C150');
Creg=xlsread ('raghu.xls','Sheet2','C151');
Ereg=xlsread ('raghu.xls','Sheet2','C152');
% determine outputs
CregL= Ncust*Preg*Creg+Ereg;
% display outputs
display(CregL);
% Input parameter ( handling leakage complaints)
factorp =xlsread ('raghu.xls','Sheet2','C154');
Ncust=xlsread ('raghu.xls','Sheet2','C155');
Ccuscompl=xlsread ('raghu.xls','Sheet2','C156');
Ecuscompl=xlsread ('raghu.xls','Sheet2','C157');
% determine outputs
Ccompl= factorp*Ncust*Ccuscompl+Ecuscompl;
% display outputs
display(Ccompl);
% Input parameter ( leakage image costs)
```

```
Ncust =xlsread ('raghu.xls','Sheet2','C159');
CimageL=xlsread ('raghu.xls','Sheet2','C160');
Eimage=xlsread ('raghu.xls','Sheet2','C161');
% determine outputs
CimageL= Ncust*CimageL+Eimage;
% display outputs
display(CimageL);
```

Appendix B Secondary Data

These secondary data are part of the Skipworth model's simulation which were carried out in London Water Supply Networks and these secondary data also provided information on the Skipworth studies.

The case study application is for a small WSZ CONSISTING OF TWO DMAS serving around 2000 customers in total (population =5000). The WSZ comprises 24 kilometres of Water mains, predominantly cast iron, dating as far back as 1920, with the majority laid in the 1930s and 1940s.

The first set of accounts for the first time step for the case study System are provided in Table B.2 (once again assuming no pipe intervention).These accounts are the breakdown of the left most point on the cost stream of Figures B.1 through Figure B.3.All entries of the WLC Accounts, in line with Table B.1 are detailed and separated into three primary cost types (Normal Supply, Leakage, Bursts) the costs provided in these Tables are based on the initial values of the cost drivers, and the current performance of the System. Similarly, these accounts could be generated over the period of analysis, tracking where the increase in costs accrue.

The second set of accounts can be generated by WLC Model provide a summary over the period of analysis through Reporting just the cost types. These accounts are in Table B.3 with the values provided graphically in Figure B.1 through Figure B.3.

A breakdown of the regulatory penalty costs can be seen in Figure B.4 and Figure B.5.

In Figure B.6 illustrates, all CI 100 MM mains in the Water Supply zone are replaced at time step o. On top of this, all CI 75 mm mains are scheduled for replacement in the time step starting 2021.

Cost Table Input for a WSZ (All costs are £ p.a) (Table B.1)

(Case Study)							
Name	Private Fixed	Social Fixed	Private Variable	Social Variable	Variable Driver	Table Name	Time Target Table
Bacteriological Risk			0.0003	0.00003	Metre Ferrous Mains		
Burst Complaints	780.98		17.96	0	Burst Complaints		
Burst Congestion				5.38	Burst Number		
Burst Cost of	10919.64		1	0.1	Burst Cost		

Repairs							
Burst Image Costs		0	100	0	Burst Number	Burst Image	
Burst Net Losses				0	Customers		
Burst WTP				0.01	Customers		
Bursts Regulatory					Burst Number	Burst Penalty	
Byelaw Inspection	3000		20	0	Inspections		
Complaints	7607.12		17.96	0	Normal Complaints		
Consumer Meters	3000		50	0	Increase Consumer Meters		
DG2 Regulatory					DG2 Failures	DG2 Penalty	
DG3 Regulatory			10		DG3 Failures	DG3 Penalty	
Interruption Cost				7.34	Customer Interruption Hours		
Iron Removal			0.0015	0.00015	Consumers		
Iron Risk			0.002	0.0002	Meter Ferrous Mains		
Leakage Complaints	346.72		17.96	0	Leakage Complaints		
Leakage Confidence				0.01	Customers		
Leakage Cost of Water			97.5	0	Leakage Volume		
Leakage Detection	4709.82	0	0	0			
Leakage Image Costs		0	100	0	Leakage Volume	Leakage Image	
Leakage Regulatory					Leakage Volume	Leakage	Leakage Target
Leakage WTP				0.01	Customers		
Operation & Control	14000		0	0			
PAH Risk			0.00166	0.00017	Metre Coal Tar Lining		
Phosphate	0	0	0.2	0	Volume Water		
Raw Water & Treatment	4593.2	0	95	0	Accounted Volume		
Replace & Repair meters	3000		60	0	Meter Repair		
Sediment Cleaning			0.0015	0.00015	Consumers		
Supply	39830.53	0					
THM risk			0.0003	0.00003	Metre Ferrous		

					Mains		
Treated Water	2504	0	2.5	0	Accounted Volume		

The WLC Accounts by Cost Types over the Period of Analysis for the WSZ (All costs are in £1000 p.a)

Table B.3

	Years										
	0 to 5	5 to 10	10 to 15	15 to 20	20-25	25-30	30-35	35-40	40-45	45-50	50-55
Cost	Private Cost by Type										
Supply(M)	104.18	106.39	116.68	123.03	184.45	210.95	262.53	264.2	265.2	267.81	269.76
Burst	26.25	27.49	27.88	37.44	43.7	54.69	139.94	141.48	143.32	145.51	148.05
Leakage	26.96	24.99	24.78	24.88	25.08	25.31	25.56	25.82	26.09	26.4	27.12
Regulatory	0.06	2.06	11.06	25.07	90.07	125.08	250.08	250.09	250.1	250.11	250.12
	Social Cost by Type										
Supply(M)	9.08	9.29	9.61	10.06	10.65	11.41	12.35	13.5	14.86	16.45	18.3
Burst	1.49	1.51	1.55	1.61	1.69	1.79	1.92	2.08	2.27	2.5	2.77
Leakage	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98
Regulatory	0	0	0	0	0	0	0	0	0	0	0
	Total cost by Type										
Supply(M)	113.26	115.68	126.28	133.08	195.1	222.36	274.88	277.69	280.81	284.26	288.06
Burst	27.74	29	29.43	39.05	45.39	56.48	141.86	143.56	145.59	148.01	150.82
Leakage	29.94	27.97	27.76	27.86	28.06	28.29	28.54	28.8	29.07	29.38	30.1
Regulatory	0.06	2.06	11.06	25.07	90.07	125.08	250.08	250.09	250.1	250.11	250.12

The WLC Accounts for the Period 0-5 years for the WSZ(Table B.2)

	Private	Social	Total
Routine	104.18	9.08	113.26
Bac Risk	0.01	0	0.01
Byelaw Inspection	3.24	0	3.24
Complaints	8.17	0	8.17
Consumer Meters	3	0	0
DG2 Regulatory	0	0	0
DG3 Regulatory	0.06	0	0.06
Interruption Cost	0	9.02	9.02
Iron Removal	0.31	0.03	0.34
Iron Risk	0.04	0	0.04
Operation & Control	14	0	14
PAH Risk	0	0	0
Phosphate	0.06	0	0.06
Raw,Water, & Treatment	28.03	0	28.03
Replace & Repair Meters	4.01	0	4.01
Sediment Cleaning	0.31	0.03	0.34
Supply	39.83	0	39.83
THM Risk	0.01	0	0.01
Treated Water Cost	3.12	0	3.12
Water Supply Zone	0	0	0

The WLC Accounts for the Period 0-5 years for the WSZ (Table B.2)

	Private	Social	Total
Burst	26.25	1.49	27.74
Burst Complaints	0.81	0	0.81
Burst Congestion cost	0	0.08	0.08
Burst Cost of Repairs	24.81	1.39	26.19
Burst Image Costs	0.64	0	0.64
Burst Net Losses	0	0	0
Burst WTP	0	0.02	0.02
Bursts Regulatory	0	0	0
Leakage	26.96	2.98	29.94
Lekage (Passive)	4.71	0	4.71
Leakage Complaints	0.39	0	0.39

Leakage Confidence	0	0.02	0.02
Leakage Cost of Water	6.01	0	6.01
Leakage Image Costs	0.81	0	0.81
Leakage Regulatory	0	0	0
Leakage WTP	0	0.02	0.02
Additional Inspection	4	2.14	6.14
Pressure Reduction	1	0.1	1.1
Detection and Repair Service	3	0	3
Normal Leakage detection	7.04	0.7	7.74

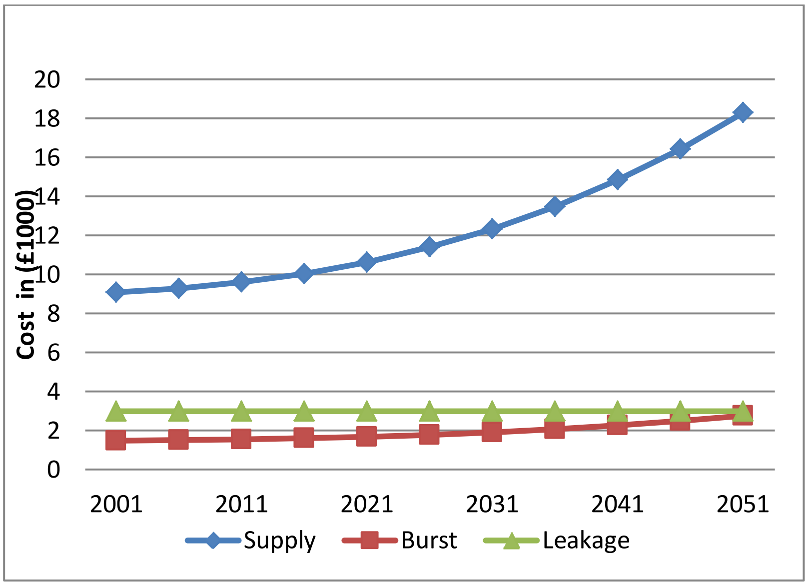

Figure B.1 Social Cost

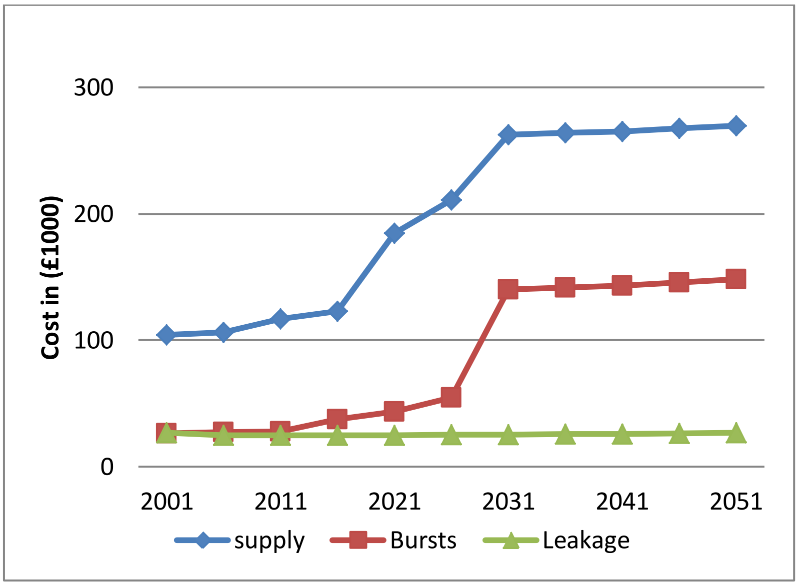

Figure B.2 Private Cost

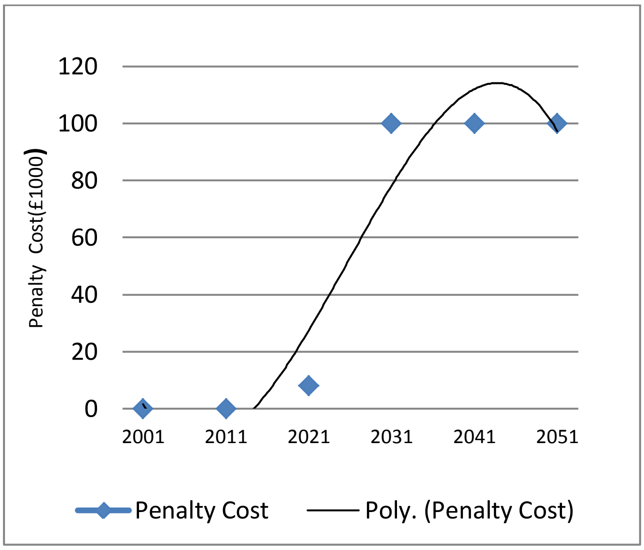

Figure B.4 Penalty Cost

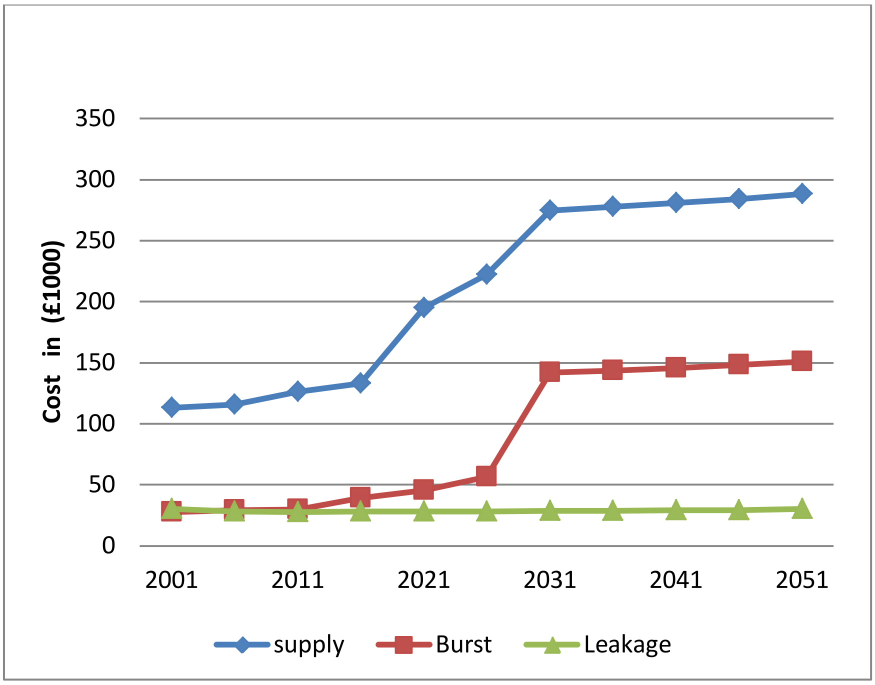

Figure B.3 Total Cost

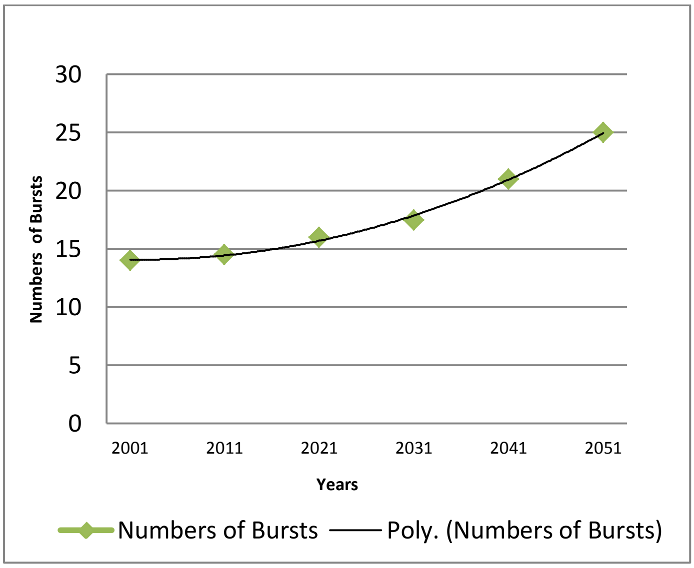

Figure B.5 Numbers of Bursts

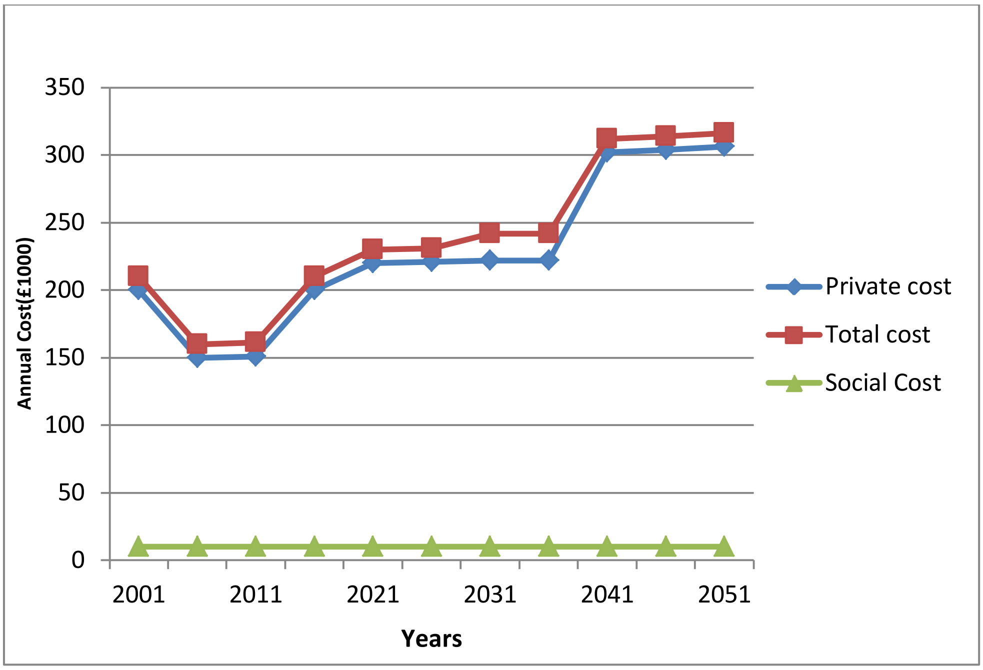

Figure B.6 After the Intervention

Appendix C

Table 4.1 Raw Data for Skipworth Feasibility Analysis at Bridgetown

Q.1 How would you define a Water Distribution Network System?			
Water is distributed from the Pumping Station to the customers with required quality and pressure	The Water Distribution Network System that Water is distributed from the Pumping Station to the customers with required quality and pressure including the intake structure and Water treatment plant	I know about the optimization of the Water Distribution Network System.	Technical clear but not clear in terms of whole Whole Life Costing.

Q.2 What are the models in use currently by the Water Corporation to manage their Water Distribution Network System.			
There is no specific model. To manage the Water Distribution Network System customer standard should have to be	No specific model; I used to work with rehabilitation of Water Distribution Network as a part of managing the Water Distribution Network System.	No idea about model but work out the op & m cost	I currently use e NPV but have no idea about models currently used.

balanced with respect to Water Supply , sort out the complaints			

Q.3 What is your definition of Whole Life Costing?			
Working out maintenance cost, operation cost and NPV	I am confused regarding the difference between Whole Life Costing and life cycle analysis	I am confused about Whole Life Costing analysis	I used to work out the social and Environment cost as part of Whole Life Costing analysis.

Q.4 What benefits have been obtained by using this model? What disadvantages, in your opinion, have arisen through using this model?			
Less time consuming, Disad:Very difficult to organize rehabilitation	Well-developed statistical model for work out the pipe asset value, disad: Asset prediction is poor	Easy whole life cycle accounting, Disad: very difficult to account social and Environment cost	Customer standards can be achieved by Supplying Water 24 hours. I don't know about any disadvantages.

Q.5 What cost drivers did you consider before selecting some when calculating the Water Distribution Network System by Whole Life Costing?			
I used to work out	No idea of cost	I used to calculate	I used to work out

the cost drivers as ‘straightway’ as an event occurs in Water Distribution Network Management	drivers	cost drivers for level of expectation of the customers standards, asset prediction and rehabilitation.	the whole life cycle accounting as ‘straight way’.

Q.6 Which cost drivers were introduced by the Water Corporation into the Water Distribution Network Management System? Does the model currently in use incorporate all cost drivers? If not, what effect do you think this has on the calculation of the Water Distribution Network System by whole Whole Life Costing?			
Essential to accounting all the cost drivers: yes : not accurate whole life cycle accounting	All the activities should be accounted for in whole the Water Supply Projects but not clear about the cost drivers yes: poor life cycle accounting	Not specific model: yes: over budget	The operation and maintenance cost should be calculated on precise and accurate way.: yes: lower budget

Q.7 Have there been any problems when applying whole Whole Life Costing into the Water Distribution Network Management Systems? If so, what have they have been?			
Poor asset prediction	Not happy with cost of Water	Confused when working out cost from upstream to	No particular problems

		downstream	

Q.8 How could the application of Whole Life Costing be improved?			
Incorporate cost drivers, explanations about the boundaries and Environmental and social methods in existing models	More perfection in prediction	Change the model as per the situation	Incorporate new models

Q.9 Which boundaries e.g. temporal, cost boundaries have the Water Corporation decided upon for Water Distribution Network Management System? Why?			
No idea about the boundaries	No idea about the boundaries	No idea about the boundaries	No idea about the boundaries

Q.10 How would you define social and Environmental costs?			
The adverse effect to Environment and social life because of any activities; cost created to minimise the impact	The adverse effect to Environment and social life because of any activities; cost created to minimise the impact. I used to work out the social and Environment cost to maintain customer standard	The adverse effect to Environment and social life because of any activities; cost created to minimise the impact. I found it difficult to work out the social and Environment cost.	The adverse effect to Environment and social life because of any activities; cost created to minimise the impact. I used to work out the social and Environment cost by using the willingness to pay

			method.
Q.11 Please describe methods used to work out social and Environmental costs into the Water Distribution Network System for the Water Corporation of Australia?			
There are different types of models for working out the social and Environment cost but difficult to work out the social and Environment cost for customer standard.	The Water Corporation has its own models to work out the social and Environment cost. Different approaches are required for typical situations to maintain the human rights for land Management.	There are different types of models for working out the social and Environment cost.	The Water Organization has its own models to work out the social and Environment cost

Q.12 What regulations are followed by the Water Corporation with respect to the Water Distribution Network Management System?			
Water Organization has its own regulatory body	Water Organization has its own regulatory body; if changes have to be made then Water Organization decision will be final.	Water Organization has its own regulatory body the Water Organization follows its own Environment regulation to protect the Environment because of adverse effects from	Water Organization has its own regulatory body. The Water authority tries to maintain Water cost by adopting different Water Supply options.

		activities of Water Organization.	

Q.13 What are the types of risks considered while implementing your Water Distribution Network Management System? How, in your opinion, could these risks be minimized?			
Over budget	Water quality, burst and leakage	Lower budget	Water quality

Table 4.2 Whole Life Cycle Accounting for Bridgetown Water Supply Network (all cost in $ per year)

	Private	Social	Total
Routine(Normal Supply)			
base risk	0.00	0	0.
Byelaw Inspection	8.64	0	8.64
Complaints	21.92	0	21.92
Interruption cost	0	24.20	24.20
Iron removal	0.83	0.4	1.23
Iron Risk	0.06	0.5	0.56
Operation & Control	0	0	0
PAH Risk	0	0	0
Phophate	0	0	0
Raw Water & Treatment	31.2	0	31.2
Replace & Repair Meter	10.84	0	10.84
Sediment Cleaning	0	0	0.0
Supply	408.5	0	408.5
THM Risk		0	0
Treated Water Cost		0	0
Water Supply Zone	0	0	0
	482	25.1	507.1

	Private	Social	Total
Burst			
Burst Complaints	1.3	0	1.3
Burst Congestion Cost	0	1.1	1.1
Burst Cost of Repair	20	1.4	21.4

Burst Image Costs	0	0	0
Burst Net Losses	0	0	0
Bursts WTP	0	0	0
Burst Regulatory	0	0	0
	21.30	2.50	23.80
Leakage			
leakage	12.63	0	12.63
Leakage Complaints	1.04	0	1.04
Leakage Confidence	0	0	0
Leakage cost of Water	0	0	0
Leakage image cost	0	0	0
leakage Regulatory	0	0	0
Leakage WTP	0	0	0
Additional Inspection	10.73	3.14	13.87
Pressure Reduction	2.68	0.2	2.88
Detection and Repair Service	20	0	20
Normal Leakage detection	0	0	0
	47.08	3.16	50.24

Table 4.3 The WLC Accounts by Cost Types over the Period of Analysis for the Bridgetown WSZ up to 55 Years (All costs are in AUD $1000 p.a.)

	Years										
	0 to 5	5 to 10	10 to 15	15 to 20	20-25	25-30	30-35	35-40	40-45	45-50	50-55
Cost	Private Cost by Type										
Supply(M)	482	482	482	482	482	482	482	482	482	482	482
Burst	21.3	22.54	22.93	32.49	38.77	49.76	135.01	136.55	138.39	140.58	142.53
Leakage	47.08	47.08	47.08	47.08	47.08	47.08	47.08	47.08	47.08	47.08	47.08
	Social Cost by Type										
Supply(M)	25.1	25.1	25.1	25.1	25.1	25.1	25.1	25.1	25.1	25.1	25.1
Burst	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Leakage	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16
	Total cost by Type										
Supply(M)	507.1	507.1	507.1	507.1	507.1	507.1	507.1	507.1	507.1	507.1	507.1
Burst	21.3	22.54	22.93	32.49	38.77	49.76	135.01	136.55	138.39	140.58	142.53
Leakage	50.24	50.24	50.24	50.24	50.24	50.24	50.24	50.24	50.24	50.24	50.24
Total cost area	578.64	579.88	580.27	589.83	596.11	607.1	692.46	693.89	695.73	697.92	699.87
NPV	421.56	294.782	210.316	152.43	109.532	79.753	64.858	46.338	33.126	23.693	16.94

- **Note:** There were Restrictions in collective data from the Water Corporation.

Table 4.4 Raw Data for Whole Life Costing Analysis

Q.23 What Water Distribution System does the Water Corporation use?			
Pumping System is dominant; More research is needed to justify changing to Gravity or Combined System	Pumping System is dominant; Need more research to change Systems	Pumping System is dominant but few of the Rural towns have been used Gravity and Combined System but more research is needed	Pumping System is dominant but few of the Rural towns have been used Gravity and Combined System Inferior material quality has become a problem Sustainable options are required e.g. Gravity and Combined Systems; more research is required to change to Gravity and Combined.

Q.24 What are the benefits of using the continuous Supply System?			
Better Water quality	Adequate Water Supply	Better Water quality	Adequate Water Supply

Table 4.5 The Operation and Maintenance Costs for Greenvale Pumping Station

Net Present Value - 30 year Operation and Maintenance Costs																																
Costs in AUD $' 000																																
onfigurat n	**Present Value**	**Pump Stations**	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Pump Operating costs			47.8	49.8	51.9	54.0	56.2	58.2	61	63.5	66.2	70.7	71.7	75.5	77.5	78	76.8	78	78.6	80.3	80.5	81.3	81.3	82.6	83.3	86.7	86.4	86.8	86.4	89.5	86.0	88.3
Pump Station generic maintenance			5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Total Cost			53.3	55.3	57.4	59.5	61.7	63.7	66.5	69	71.7	76.2	77.2	81	83	83.5	82.3	83.5	84.1	85.8	86	86.8	86.8	88.1	88.8	92.2	91.9	92.3	91.9	95	91.5	93.8
	NPV		49.50	48.30	46.855	45.39	44	32.92	15.57	40.15	39	38.73	36.67	35.96	34.42	32.38	29.82	28.28	26.62	25.38	23.77	13.96	21	19.88	18.73	18.17	16.932	15.894	14.78	14.28	12.861	12.32

Table 4.6 Power Consumption

Power	Maintenance cost	
Consumption	fixed speed	variable speed
kwh/year	$/mwh/year	$/mwh/year
1000	1000	1380
2000	720	1100
3000	550	910
4000	440	800
5000	380	660
10000	200	500
15000	120	380
20000	100	280
>25000	85	170

Table 4.7 Electricity Tariff

Year	Finical Year	HWC Electricity Prices (c/KWhr) (2010/11 dollars)	Year	Finical Year	HWC Electricity Prices (c/KWhr) (2010/11 dollars)
2010	2009/10	15.96	2031	2030/31	27.55
2011	2010/11	16.62	2032	2031/32	27.77
2012	2011/12	17.30	2033	2032/33	28.92
2013	2012/13	18.02	2034	2033/34	28.82
2014	2013/14	18.76	2035	2034/35	28.94
2015	2014/15	19.54	2036	2035/36	28.81
2016	2015/16	20.35	2037	2036/37	29.86
2017	2016/17	21.19	2038	2037/38	28.69
2018	2017/18	22.07	2039	2038/39	29.46
2019	2018/19	23.57	2040	2039/40	29.41
2020	2019/20	23.91	2041	2040/41	30.83
2021	2020/21	25.19	2042	2041/42	30.52
2022	2021/22	25.84	2043	2042/43	31.03
2023	2022/23	26.02	20	2043/44	31.30

			44		
2024	2023/24	25.62	2045	2044/45	31.78
2025	2024/25	26.01	2046	2010/46	31.81
2026	2025/26	26.23	2047	2046/47	32.58

Figure1.1 Water Supply Network (Water Corporation of Australia, 2011)

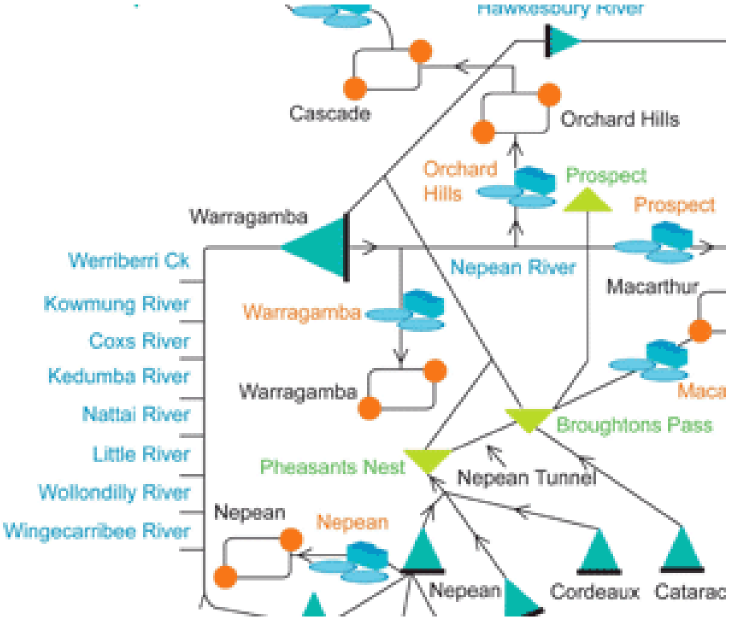

Figure 1.2 Water Supply Network, (Water Corporation of Australia, 2011)

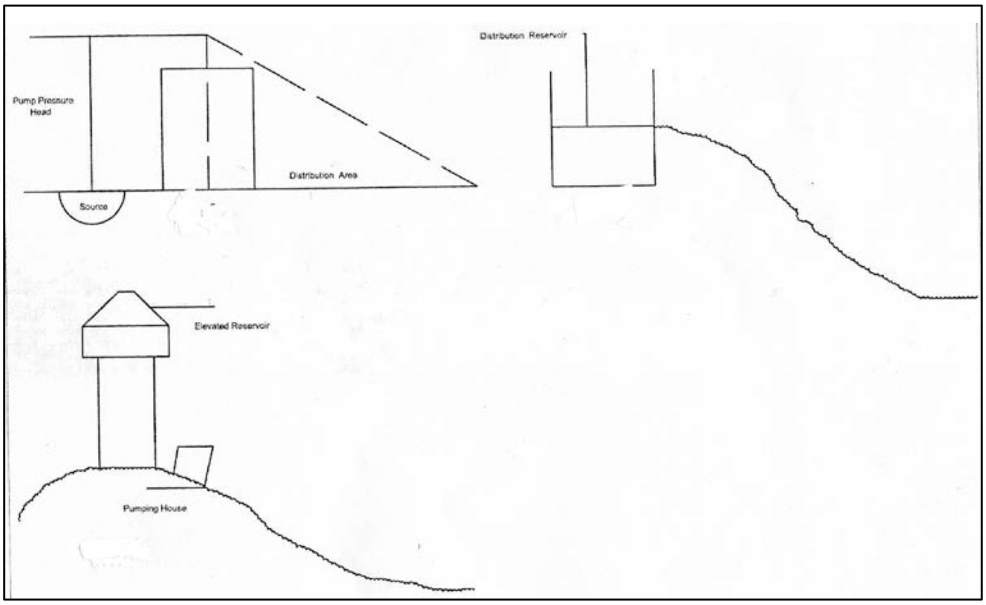

Figure 1.3 Water Distribution Methods

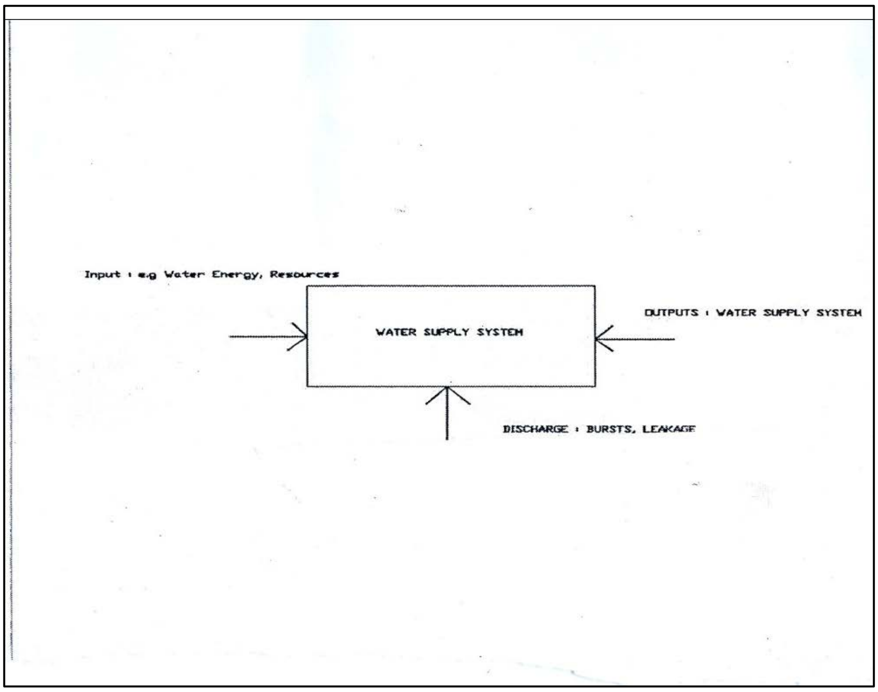

Figure 1.4 Water Supply System Transform Input

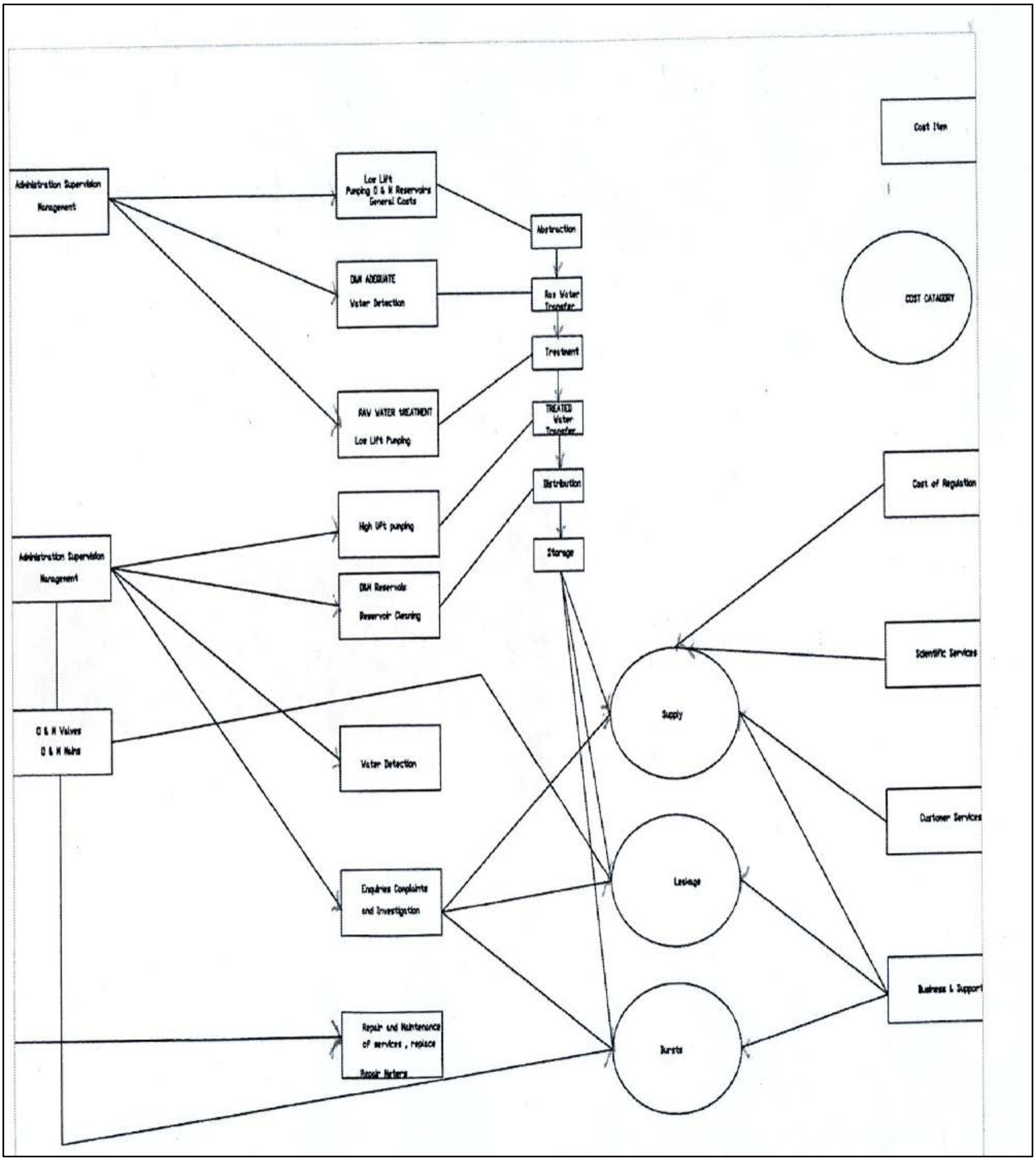

Figure 1.5 Cost Categories

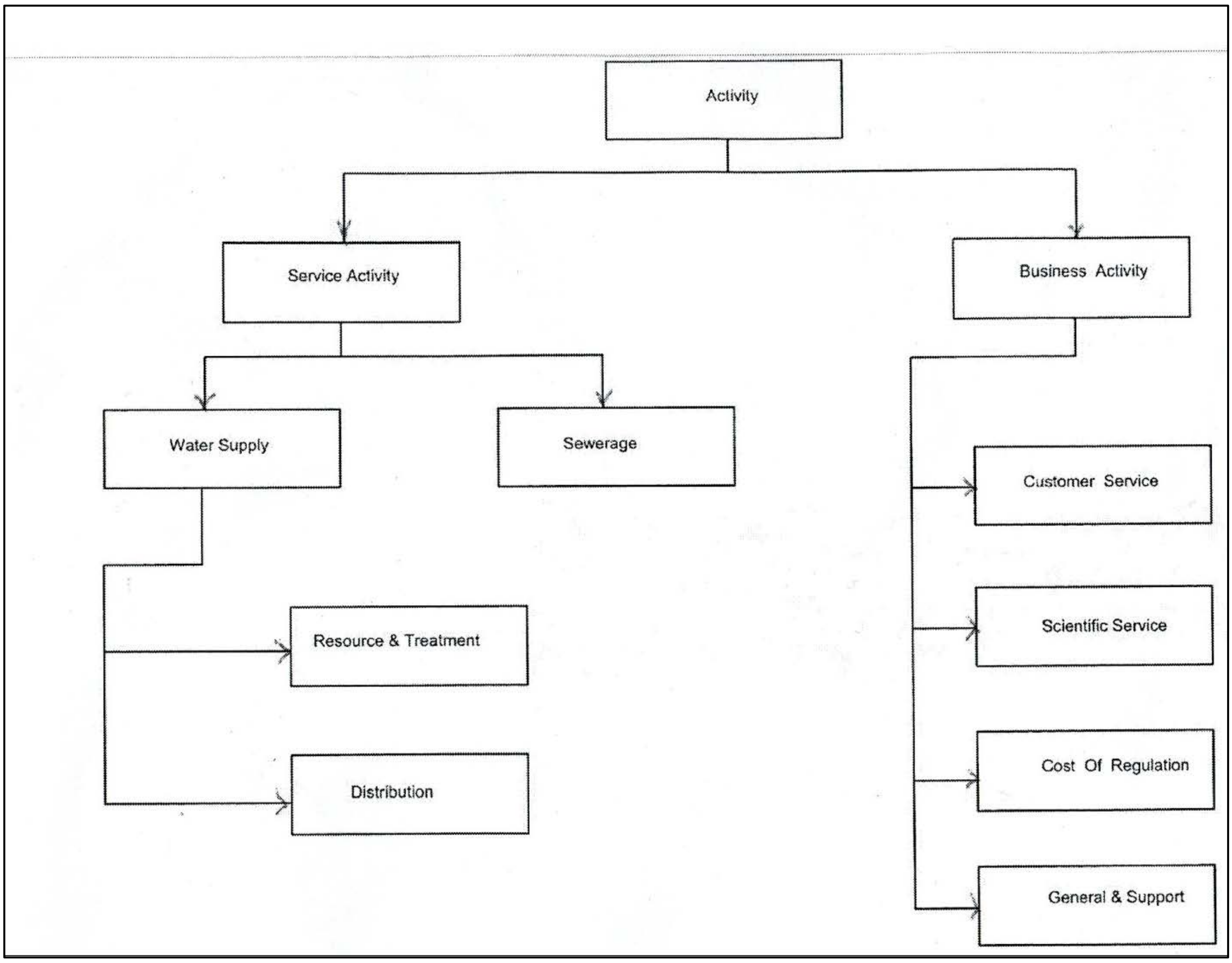

Figure 1.6 Breakdown of Activities and Cost Items

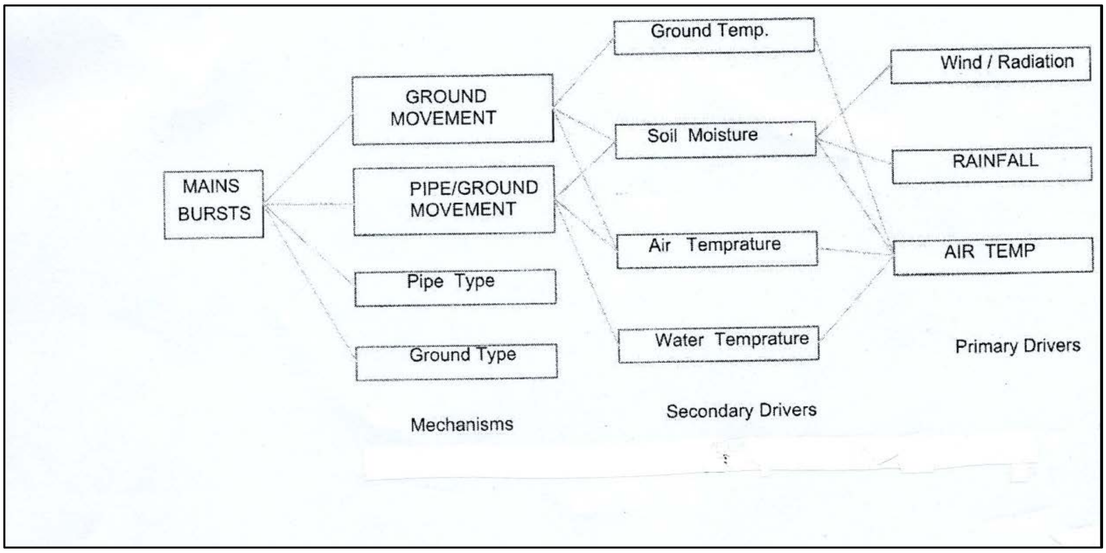

Figure 1.7 Process Regressions for Temporal Failure Behaviour of Distribution Mains

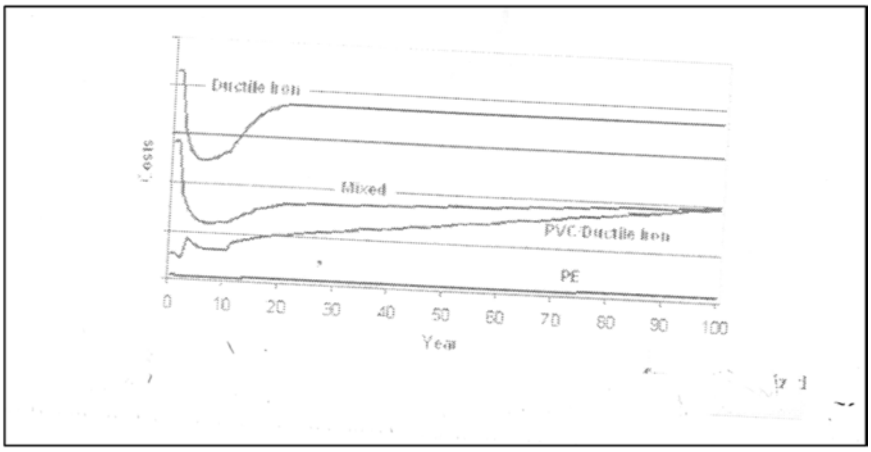

Figure 2.1 Whole Life Costing Simulation

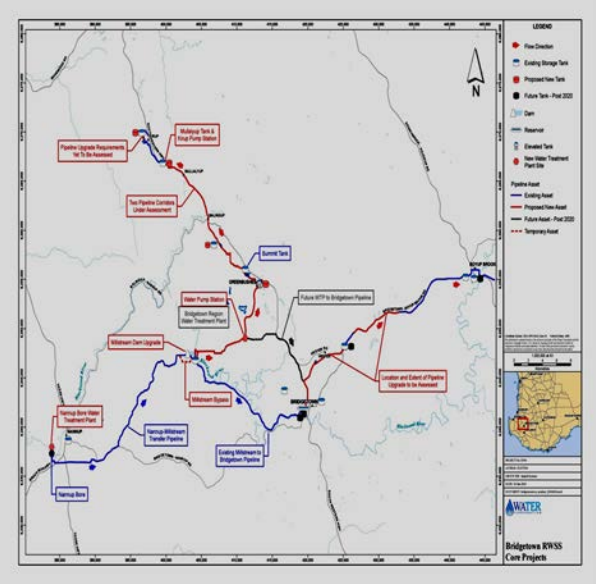

Figure 3.3 Bridgetown Water Supply Network (Water Corporation, 2011)

Figure 3.4 Greenvale Pumping Station (Water Corporation, 2011)

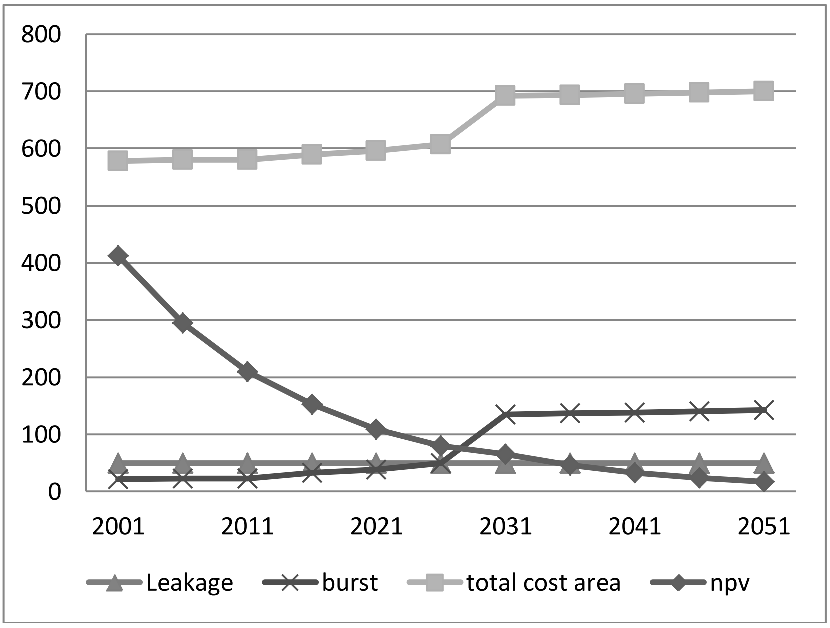

Figure 4.1 Whole life Cycle Accounting for Bridgetown