Cranfield University

Urmila Brighu

Asset management in urban water utilities: Case study in India

School of Applied Science

PhD

Cranfield University

School of Applied Science

PhD Thesis

2008

Urmila Brighu

Asset management in urban water utilities: Case study in India

Supervisor: Dr Richard Franceys
second supervisor: Prof. Joe Morris

Academic Year 2005 to 2008

ABSTRACT

Access to safe and sufficient drinking water and adequate sanitation are now recognized as basic human rights. One Millennium Development Goal is to reduce by half the proportion of people without access to safe drinking water and basic sanitation by 2015. However, ensuring sustainability of existing and new services is considered to be one of the major challenges for the water sector in the years to come.

In India, in addition to service expansion, existing water service quality has been observed to be deteriorating over recent years. There is therefore an equally urgent need to address sustainability and improvement of service quality to the presently served population. In this low-income country, where water utilities are unable to recover even the service costs of operations and minor maintenance through user charges, there is a need to determine ways and means to be able to maintain a cost-effective service to consumers. For such a capital intensive service these ways have to include not only the introduction of efficiency measures but also the long-term planning of capital maintenance, that is the maintenance of the fixed assets upon which services depend.

Water utilities in high-income countries have been using various fixed asset management techniques to improve asset operational efficiency, to plan capital maintenance and to demonstrate their ability to maintain and improve service to their customers. This study explores the viability of the application of asset management techniques and their potential contribution towards improving water service provision in urban centres in India.

Following a literature review, a generic asset management model for a low-income country water utility was developed and then applied in the water utility serving Jaipur, Rajasthan to assess the viability of this adaptation. Having identified strengths and weaknesses during this fieldwork a revised model was proposed, including distinct phases of asset management/data intensity, which could be used as a generic approach in large urban centres in India.

Following consultations with prospective users in six States, the study showed that it is feasible to take a first step towards asset management at low cost but this will require a change in the management approach. The study identified lack of relevant data as a key factor influencing an effective and comprehensive application of a generic asset management model. The study concludes that the proposed phased asset management models can contribute to improving serviceability for customers; however the concern that remains is the willingness of the organisation to adapt to the necessary changes.

Keywords:

Asset management, India, urban water utility, water service

ACKNOWLEDGEMENTS

I wish to express my heartfelt appreciation to my supervisor Dr Richard Franceys for enthusiastic supervision and reassuring guidance throughout the entire period of this research work. His constructive comments and patience are highly appreciated.

I am also deeply thankful to Prof Joe Morris for his helpful suggestions and Prof. Sue White for her constant encouragement especially when I was experiencing serious health concerns

I am greatly indebted to the staff of the PHED, Jaipur for their assistance during fieldwork in Jaipur despite having other pressing tasks. The information provided by them was extremely useful and without which this study would never be complete. The same appreciation goes to the staff of the PHED Mohali, Chandigarh, Panchkula, Shimla and Patna. I am particularly grateful to my brother Manish Beniwal, Executive Engineer, PHED Jaipur for facilitating the introductions to relevant professionals in PHED Jaipur.

I thank Bob Breach for sharing his expertise and always responding in detail to all my queries.

I would like to gratefully acknowledge the opportunity provided by the Commonwealth Scholarship Commission to enable me to come to UK and undertake this study which in a way is a life time experience, which cannot only be quantified in academic terms. I was able to experience a childhood ambition of living and learning in the UK.

I highly appreciate the moral support from my friends at Cranfield especially Monica, Daniel and Anna, all of them stood by me when it all seemed to go horribly wrong.

I must mention my husband Brighu who stood by me in moments of doubts and despair and his constant encouragement and support saw me through. I am also thankful to my children Vaidehi and Vaibudha who may not have entirely understood why their mother was always hunched over a laptop, but did not complain.

The author gratefully acknowledges the support of Cranfield University in enhancing the written English in this thesis.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

Chapter 1: Introduction

1.1 Context and Background

Lack of access to safe drinking water and use of unsafe water has caused a sizeable population of many developing countries to have health concerns. These concerns have been recognised by the global community and an attempt has been made to address these concerns in the Millennium Development Goals (MDG) adopted by the United Nations (ADB, 2006b). One of the millennium development goals is to "*reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation*" (UN, Undated). The rapid pace of urbanization is cited as one of the major challenges that developing countries are faced with, in the context of the above mentioned MDG, which requires a major effort to keep up the current coverage and service levels regarding water supply and basic sanitation (WHO and Unicef, 2006). These issues of rapid rate of urbanisation and present inadequate water service levels in developing countries are relevant to India.

India is classified as a low-income developing country with a gross domestic product (GDP) at purchasing power parity (PPP), per capita of $2,700 (World Bank, 2008). India is now also seen as an emerging economy with recent annual growth rates of over 9 % (GoI, 2008a). Unlike other low-income countries in South Asia, India has been a functional democracy since its independence with several political groups vying for a share of the economic and political wealth. Hence many economic and social activities in India are significantly influenced by politics or there is a strong linkage between economic activity, its social consequences and the political implications (Chaudhary, 2003). As an example, the pricing of water services is rarely influenced by the costs of production and transmission but is overwhelmingly influenced by social and political considerations (WSP, 1999).

The population of India has been increasing steadily due to increased life expectancy, because of improved health care facilities and a birth rate which is still almost 2 percent per annum according to the 2001 census (GoI, 2003). The annual increase in the urban population however is 3.12% (GoI, Undated c) which suggests that there is a migration to the urban centres by a large number of the rural population. The urban migration is largely due to better employment opportunities offered in the urban centres and the increasing lack of viability of agriculture as a source of livelihood. Rural based activities have been the primary source of livelihood for a large majority of the population since the time of Independence (Srivasatava and Sasikumar, 2003). It is estimated that by 2030, 41 per cent of the country's population will live in cities and towns (ADB, 2006a), up from 27.8% at present (GoI, Undated c). This increase in the urban population is placing a very significant demand on water services and, as a result, the quality of the service is deteriorating. For example in Bangalore water availability has declined from 20 hours/day in the 1980s to 2.5 hours/day today and in Chennai from 10-1**5** hours/day in the 1980's to only 1.5 hours/day as most recently reported (World Bank, 2006b). Of the 393 Class I cities[1] in India, 77 are reported to have one hundred percent water supply coverage (GoI, 2002a). However the 54th round of the national sample survey (NSS) reported that 59 per cent of the urban household population are sharing a public source of water. The irregularity of water supply is reflected in the fact that 18 per cent households reported using some supplementary source of drinking water and 96 per cent reported storing their drinking water (Tewari, 2007).

The water supply is intermittent in almost all cities with a supply duration of, on an average, four hours per day. In some areas water is supplied only for one hour on alternate days (ADB, 2007) with extremes reported of one hour per week in some locations. There is an additional problem of an inequitable distribution of water within the cities with different locations having significantly different water supply durations, usually the lowest income areas receiving the worst services. Intermittent and inequitable water supply is particularly disadvantageous to the poor because for them the coping costs in terms of storage tanks, water purification units, booster pumps, buying water from vendors, are a significant proportion of household earnings (Sharma, 2006). "It is difficult for the government to focus specifically on the needs of the poor when the whole sector is in dire need of reform" (ADB, 2002b). It is especially difficult when the poor are living in rapidly growing, spontaneous, and often illegal settlements, which public providers may be restricted by law from

[1] Cities with population size 100,000 and above are classified as Class I cities. (Source: GoI, Undated)

serving (ADB, 2002a). However, it can be argued that the justification for a public water supply system is to serve all urban consumers (Njiru and Sansom, 2003).

Public private partnerships (PPP) have been proposed as one route to reform and service for all – hoping to introduce private sector efficiencies in development, management, implementation and financing of projects (GoI, 2006a). So far, this concept has not been able to overcome the political obstacles mentioned earlier, hence alternative change drivers have been suggested. “India should aim for the ‘24x7’ principle, that is 24 hour water supply 7 days a week as its ultimate goal” (Franceys 2002). The concept of 24x7 water supplies was disseminated through the Change Management Forum (CMF) for sustainable urban water and sanitation in India with the aim of finding a way of energising moribund public utilities. This goal is yet to be achieved and is cited as a major challenge for the Government of India especially in the context of an increasing population and rapid urban growth (ADB, 2007). It is however succeeding in raising quality of service issues relating to India’s needs for ‘world class cities’ to support the impressive recent economic growth rate.

The underlying infrastructure required to deliver quality water services to all are the pipe networks and the supporting treatment and pumping systems. In practice, the physical infrastructure assets created in urban areas have generally been deteriorating due to inadequate attention and/or improper operation and maintenance. Little effort has been made either to manage these assets efficiently (GoI, 2006b). Maintenance activities are typically reactive wherein maintenance is only resorted to when there is a very obvious breakdown in the service. Such a strategy eventually results in even greater infrastructure deterioration and yet more frequent extended breakdowns in the existing poor levels of service.

The fixed assets form the core of the service offer but similarly, little effort has been made to achieve self-sustainability of those services. Water utilities in the country cannot generate sufficient revenue from consumers when water tariffs are set so far below the operating costs of service provision.

Due to the rapid increase in the urban population the priority of the water utility managers has been to increase the service coverage by installing new infrastructure. The fiscal flows to the sector have also laid emphasis only on the creation of new physical assets (GoI, 2006b). Under the existing system, wherein there is already a financial deficit, this need for a large amount of capital would possibly result in further deferred maintenance towards the existing older assets. With the present shortfalls in revenue and the resultant lack of planned maintenance activities, the challenge of maintaining the functional sustainability of the service becomes increasingly difficult.

Some water utility managers believe that the service can be improved by stepping up investment through an increase in water tariffs (Choe, 2008). However emerging proposals relating to tariff increases have often been opposed by the customers' representatives such as resident welfare associations (RWAs) and social activists, often taking as their justification the poor quality of the services received. Nickson and Franceys (2003) report that consumers are not necessarily opposed to tariff increases but would be prepared to pay after visible and ongoing service improvements.

Water utilities need money to improve services which they perceive they can only achieve through increasing tariffs; however an increase in customer tariffs is not acceptable without improved services. The normal response in such a situation, to access debt financing, is not possible when tariffs are so low as to make it impossible to service any such debts.

There is an understanding amongst the 'intelligentsia' and the economists that to cause a nation's economy to flourish and prosper it is essential to have a basic physical infrastructure to provide effective and efficient services (Yoshino and Nakahigashi, 2000) (GoI, 2008b). Development of a safe drinking water supply and waste collection and treatment system is a significant factor in advancing the overall health of the communities (WHO, 2008). A link between effective infrastructure and living standards has been established (Yoshino and Nakahigashi, 2000) which has led to the concept of 'Sustainable Cities' being developed. Sustainable cities have been defined to be those cities which have functioning infrastructures and are responsive to the needs of the people (DEP, 2007). Sustainability in this context is referring to financial, economic and social aspects as well as environmental.

In developed countries, where the infrastructure assets providing water services are ageing, the challenge to maintain and/or improve service levels has been recognised. The key challenge is to understand the dependence on physical assets to ensure sustainable service, more so in the context of high ‘capital intensity’ (ratio of fixed assets to total revenue) networked water and sanitation systems and the resulting requirement to maximise benefits from these capital assets. ‘Asset management’ therefore is being utilised and promoted as a solution to address this challenge to optimise use of available resources. Infrastructure asset management has been developed as a tool for maintaining serviceability because it promotes the sustainable use of the physical assets and environmental resources by a systematic process (NAMS and IPWEA, 2001). Asset management has the potential to contribute towards the goal of maintaining sustainable water services for all urban water consumers.

1.2 Study aim

The overall aim of the research is to contribute towards providing functionally sustainable water services for all, in urban centres in India, which will not only be able to meet present needs but also the future needs as projected by the rapid growth of urbanisation. A functionally sustainable water service is taken to be one that is able to achieve desired water quality standards, water service level standards and condition of infrastructure assets for the present generation with an aim to enhance these for the future generations.

1.2.1 Research goal

In this context the main goal of the study is to determine the viability and potential contribution of the development and implementation of an appropriate level of asset management towards the functional sustainability of water services in India. This approach necessarily recognises that Indian urban water utilities differ substantially from those for and within which asset management principles and processes have been developed. The goal is to define an asset management model applicable for urban water utilities in India and confirm its potential relevance.

1.3 Research objectives

With respect to the main goal of the study, to determine the viability and potential contribution of an appropriate level of asset management towards the functional sustainability of water services in India, the following objectives were pursued:

Objective 1

To describe ‘sustainability’ in the context of Indian water supply systems and determine the role of asset management with regard to the sustainability of water service.

Objective 2

To determine the key drivers of asset management in water utilities in high-income countries and assess their relevance in Indian context

Objective 3

To determine the principles of asset management, methods and data requirement with reference to water services and to develop a generic asset management model

Objective 4

To assess the viability and adaptability of the developed generic asset management model in an Indian urban water utility and identify any constraints

Objective 5

To propose an asset management model adaptable to Indian urban water utilities

Objective 6

To assess the potential relevance of the proposed asset management model for Indian urban water utilities

1.4 Structure of the thesis

This thesis is divided into eight chapters. This chapter has presented the background and the overall aim of the study and the structure of the thesis. Chapter 2 provides the overview of the factors affecting organisational activities in the context of the Indian urban water sector and sets up the research context. The literature review and the conceptual theoretical framework are presented in Chapter 3. Chapter 4 describes the research methodology. The details of the Case study research in India are provided in Chapter 5 and 6. The focus of Chapter 5 is to investigate the overall financial and environmental sustainability of urban water supply in one city in India. Chapter 6 discusses the application of an analytical asset management framework as a critical aspect of sustainability. Chapter 7 presents an adapted asset management model applicable for an urban water utility in India along with assessment of its applicability through consultation. Chapter 8 offers the conclusions and recommendations emerging from the study.

Chapter 2: An overview of the Indian urban water supply sector

2.1 Introduction

This chapter presents the background of this study, giving an overview of the Indian urban water supply sector with an emphasis on the operating environment, to provide a context to ensure that the major elements that affect the provider organisation's activities are considered. This chapter also presents the justification for this study.

2.2 Urbanisation

Urbanisation is occurring across the developing world at a rapid rate and most of the population growth in cities is concentrated in informal or slum areas (World Bank, 2007).This trend of rapid rate of urbanisation is seen in India also. The total population of India has increased from 238.4 million in 1901 to 1027 million in 2001 whereas the population residing in urban areas has increased from 25.8 million in 1901 to 285.3 million in 2001 which is 27.8% of the total population (Datta, 2006). The level of urbanisation ranges from a maximum of 93% in Delhi to a minimum of 9.8% in Himachal Pradesh. There are 4,378 recognised towns or urban agglomerations in India, 393 with population of 100,000 and above persons and 35 metropolitan cities with population greater than 1,000,000 persons (GoI, Undated c). The projected urban population in India by the year 2017 is approximately 500 million or about 38% of the anticipated total population of India (World Bank, 2006a). According to the 2001 Census, the total population of the slums was estimated at 41 million. Following historical trends, the slum population is expected to increase at an average growth rate of 3.5% during the next fifteen years to reach about 69 million in 2017 (World Bank, 2006a).

The infrastructure services have not been able to keep pace with the rate of urbanisation over the years (NIUA, 2005) and water delivery to the slums has been particularly problematical. Not only have services failed to expand in pace with growth but, particularly in large cities, services are deteriorating rapidly with cities facing serious shortages of power, water, sewerage and other amenities. As a result, many people are forced to draw water from unsafe sources which leads to widespread incidence of waterborne diseases like diarrhoea, hepatitis, roundworms, etc (MUD 2000b in Chakrabarti, P. G. D., 2001).

Considering all recognised towns or urban agglomerations in India, it is reported that the percentage of urban population in India with access to improved water sources is 96% (ADB, 2006a) – as opposed to the 100% coverage for Class I cities mentioned in the previous chapter. However the commonly used indicator 'percentage of population with access to improved water source' does not take the quality of service into consideration. Therefore although access to water supply infrastructure is increasing according to the official statistics, access to a reliable, sustainable and affordable service is lagging (World Bank, 2006a).

"Public water bureaucracies in developing countries are often regarded as ineffective in meeting rising demand, inefficient in their operations and inequitable in their services which is attributed to three inherent problems associated with the political economy of public provision for water namely populist pressures, conflicts of interest and perverse organizational incentives" (Araral, 2008). In view of these limitations, which are fairly representative of the public water bureaucracies in India, that is rapid urban population growth and the existing service shortfalls, meeting the needs of the people has created a challenge which needs to be addressed.

Overcoming this access and service challenge therefore can only be achieved through very substantial investment in fixed assets, both for expansion and for capital maintenance. The Central Public Health Engineering and Environment Organisation (CPHEEO) has estimated that to provide safe water supply and sanitation services to every person in the urban areas by the year 2021 would require an investment of Indian Rupees (INR) 1,730 billion (US$118 billion at purchasing power parity) (GoI, 2006b).

The effect of this massive investment in fixed assets, at more than $200 per person served, could easily be dissipated unless effective systems are put in place to ensure effective management of these new and renewed assets.

2.3 Water

Assets such as pipe networks, however improved, can only deliver services to people if there is reasonable access to water resources. The natural rainfall in India is dependent to varying degrees on the vagaries of the monsoon. India's climate or *mausim* gave the English lexicon a new word, the monsoon to describe torrential rain. Rainfall in India has significant variations regarding its spatial distribution and there is frequent departure from the 'normal' patterns. Annual rainfall and snowfall are the main sources of water in India though there is a concern that climate change could well affect the Himalayan glacier sources (UNEP, 2007) (Bajaracharya et al., Undated).

India receives almost all of its annual rainfall in less than 100 hours of torrential downpours, usually between June and October. The challenge is then to save enough water from evapo-transpiration to last from October until April–May, the months that mark the period of highest water stress (Shah et al., 2005). The total annual precipitation is estimated to be of the order of 4,000 km^3 or 4,000 cubic metres per person. However, the storage capacity of dams to retain this resource in India is approximately 200 cubic metres per person (Briscoe and Malik, 2006). In addition, the distribution of water resource potential is extremely uneven. Against a national average per capita availability of 1,820 cubic metres (GoI, Undatede), in the North East the average availability is 16,589 cubic metres while in the West it is as low as 360 cubic metres. Any situation of availability of less than 1,000 cubic metre per capita is considered 'scarcity condition' by international agencies (UNEP, Undated). Since the major source of livelihood is agriculture and agriculture related activities which are necessarily water intensive, only 15% of the available water is currently used for other uses including domestic and industrial needs in the urban areas. (GoI, Undated e).

Water resources assets, storage and transfer systems, are therefore critical components of sustainable water supply with important distinctions to be made between surface water and groundwater resources.

Ninety percent of India's territory is drained by inter-state rivers (World Bank, 2005). The Indian polity is a union of States with certain federal characteristics. According to the constitution of India, water is a State subject meaning thereby that legislation with regard to water is the responsibility of the States. There are no clear cut allocation rules at Union level regarding how much water each state has a right to. States which are upstream are naturally better positioned and take more water in times of drought and release more water in times of floods, leading to interstate conflicts and disputes.

This situation can lead to downstream States needing to overinvest in water resources infrastructure.

“India's groundwater resources are almost ten times its annual rainfall. According to the Central Groundwater Board of the Government of India assessment, the country has an annual exploitable groundwater potential” of 396 km^3. It is estimated that nearly 82% of this currently utilisable groundwater is available for irrigation. The remaining 18% is estimated to be utilised for domestic water supply and industrial use (Kumar et al, 2005). *“However, according to the International Irrigation Management Institute (IIMI), the water table almost everywhere in India is falling at between one to three metres every year. Furthermore, IIMI estimates that India is using its underground water resources at least twice as fast as they are being replenished”* (Amarasinghe et al., 2007). Indiscriminate use of groundwater has certain ancillary problems in the sense that there are no quality checks, especially in the rural areas, resulting in water containing traces of arsenic, fluorides, nitrates, iron and heavy metals being consumed (GoI, Undated d).

Water resource reliability for urban water supply in itself is a massive challenge because of the highly seasonal pattern of rainfall and low storage capacity. Given the uncertainty associated with climate change and its impact on water resources, water resource management issues become even more imperative for sustainable water service. Linked to this resource challenge is the need to ensure that water which has been abstracted for urban use is not unduly wasted through leaking pipes, again an asset management challenge.

2.4 Institutional arrangements

Urban development issues including urban water supply and sanitation are supervised by the Ministry of Urban Development in India. The Ministry’s responsibilities include broad policy formulation, institutional and legal frameworks, setting standards and norms, monitoring, promotion of new strategies, coordination and support to State programmes through institutional expertise and finance (GoI, undated b). The national policy issues are decided by the Govt. of India which also allocates resources to the State Governments through various Centrally Sponsored schemes, provides finances through national financial institutions and supports various external assistance programmes for urban development in the country as a whole. “The indirect effect of the fiscal, economic and industrial location decisions of the Government of India exercise a dominant influence on the pattern of urbanisation" and services (GoI, 2005).

The Central Public Health and Environmental Engineering Organisation (CPHEEO) is the technical wing of the Ministry of Urban Development, Government of India. The CPHEEO provides policies, strategies and guidelines to the State Governments and Municipal Corporations / Committees for implementation, operation & maintenance of urban water supply and sanitation although water supply and sanitation is a State subject. CPHEEO also plays a central role in setting design standards and norms for urban water supply and sanitation and promoting latest technologies. It also prepares and publishes technical guidebooks such as Manual on Water supply and Treatment and Manual on Operation and Maintenance of Water Supply Systems (CPHEEO, Undated), which are core issues dealt with in asset management of water supply systems.

The Union Ministry also supports the States by sponsoring research relevant to the sector, largely through the National Environmental Engineering Research Institute (NEERI). Areas of research include urban water treatment plant evaluations, urban water supply tariffs, water distribution system performance evaluation, low cost methods of flocculation, optimisation of water treatment, drinking water in urban slums and leakage management (GoI, 2002a; CPHEEO, Undated).

The Constitution of India vests the States with the responsibility for actual urban water supply and sewerage services. According to the 74th amendment to the Constitution made in 1992 to empower urban local bodies (municipal councils), the state may delegate the responsibility and authority for water supply for domestic, industrial and commercial purposes to urban local bodies for the purpose of decentralisation (GoI, undated a). Within this move toward decentralisation, to engage urban local bodies meaningfully in planning functions of services to citizens, an assortment of agencies, varying from State to State have evolved. There are metropolitan level specialist agencies (in Bangalore, Chennai and Hyderabad), a specialist municipal undertaking (in New Delhi), district engineering agencies (in Uttar Pradesh) and statewide agencies (in Rajasthan, Punjab, Haryana, Bihar etc.).

The overall administrative control at the State level, over the technical and social welfare departments such as water supply, public works, police and health, is exercised by a bureaucracy comprising civil servants. Hence although there is reasonable autonomy exercised by the departmental officials in day to day functioning, matters concerning policy are decided at a higher bureaucratic level. Senior bureaucrats are responsible to the elected representatives who in turn are responsible to the people of India.

Although there has been a system by which key performance indicators of water services are reported through the State level to the nodal Ministry in Delhi little emphasis has been placed upon the serviceability of the infrastructural assets.

2.5 Regulation / Statutory obligation

The National Water Policy of India specifically states that *'**adequate safe** drinking water facilities should be provided to the **entire population** both in urban and in rural areas'* (GoI, 2002b). However the two key words, *adequate* and *safe*, have not been defined and so there appears to be no clear statutory or legal obligation upon the water service providers. The consumer in India is not in a position to seek any legal redress to grievances that he may have with regard to the quantity and/or quality of the water supply, unlike in many developed countries. To offset the lack of legal redress in India today there is a serious public debate which is being driven by the vernacular press to ensure that supply of water issues are brought to the consumer courts (CNN-IBN, 2006). The victims of poor water service, both in terms of quantity and quality, resort to innovative and sometimes violent community agitations to voice their grievances. Access to water is a very emotive issue in India and since India is a democracy and 'the people are supreme' these agitations cause the water service providers to be ready to act in the event of any exigency. However the very nature of these agitations cause them to be location specific and they only achieve very short term or immediate goals when either there is no supply or the aesthetic quality of the water is impacted.

The Government of India has realised the importance of well-functioning infrastructure in facilitating higher economic growth and emphasis has been put on modernisation and augmenting infrastructure capacity along with institutional, regulatory and procedural reforms. A 'Committee on Infrastructure' is constituted to address these issues. However whilst transport, energy and telecommunication services have been included in the list of infrastructure sectors, water services have remained separate (GoI, 2007). This implies that water infrastructure is not given the same consideration as the other infrastructure services and is not considered to be contributing directly to the overall economy. It is considered to be more of a public/social service.

Economic regulation of water services is now proposed as a ‘second generation reform’ under Jawaharlal Nehru National Urban Renewal Mission (JNNURM), having initially been listed as a ‘first tier reform’ by the Ministry of Urban Development (MUD), India (GoI, 2006b). This reflects uncertainty towards the introduction of economic regulation in the context of urban development, perhaps related to the present low tariff levels and the political challenge of raising tariffs.

Water service levels such as quality, quantity and continuity of water supply are paramount issues that require to be dealt with by the government in the interest of public health. The issue of quality and quantity of water supply has been partially addressed by the Central Public Health and Environmental Engineering Organisation (CPHEEO). The CPHEEO has published a ‘Manual on Water Supply & Treatment’ (last revised in 1999) enunciating certain guidelines and principles to ensure pressure of the water supply, quantity and chemical and bacteriological water quality standards (CPHEEO, 1999). This manual is used extensively for designing water supply systems including distribution systems and treatment plants. CPHEEO also attempts to benchmark service provision across the country, but with only limited resources and equally limited powers to require information this approach does not appear to be delivering improved management of services.

The National Water Policy and guidelines regarding water service levels are in place but neither of these are binding on water providers in any legal or statutory manner (GoI, 2002b). In case of non compliance, there is no formal mechanism in place for punitive action. This has led to a lackadaisical approach to the service provided by the water utilities and has contributed to the deterioration of the service over a period of time.

Researcher's personal experience as a consumer: (1976-2008), Jodhpur, Rajasthan

As a child the researcher used to live in a two storey building and there was no need for any booster pump to obtain water at the upper floor. The pressure of the water supply was adequate and the duration of water supply was 5-6 hours a day.

After a few years a ground level storage tank was required and water used to be pumped up with the help of a booster pump. The duration of water supply reduced to 2-3 hours a day. During the summer months the situation was worse with the water supplied once in two days and at times once in three days.

Later with a new water resource developed, the water supply service improved and now it is restored to 3-4 hours of water supply everyday but with inadequate pressure levels. There is not only requirement of a booster pump but an additional water connection is required to meet the demands of the residents of that building.

2.6 Financial resources

Historically urban infrastructure and services in India have been financed by direct budgetary support from the government since only a few of the institutions responsible for infrastructure provision have been able to generate surpluses for their financing from user tariffs (Mathur, 2006). Lately, in certain metropolitan cities in India such as Mumbai, Bangalore, Ahemadabad and Hyderabad, the water service providers have taken initiatives, under the proposed reforms in JNNURM, to tap into the capital markets. This is meant to open up a new channel for infrastructure financing through the issuance of bonds but is only possible in the four metropolitan cities due to earlier, partially successful, attempts to move towards more cost-reflective tariffs.

Overwhelmingly, the supply of water in India is a public sector monopoly service. It is considered to be part of the social services provided by both the Union and State governments to its citizens as reflected in the annual budget statements presented by these governments. Water services, being treated as a social good, would require a new political consensus to even recover operation and maintenance cost in most cities (NIUA, 2005). The supply of water is therefore subsidised by the various State governments by below-cost pricing of water. As a result, the financial resources of the water providers are largely dependent on budgetary allocations from the government both at the State and Union levels. Some finance is obtained as loans from the Multilateral Development Banks (MDBs) - though with limited expectation of service provider debt financing and amortization. User charges are rarely sufficient to cover the operating costs of the water service much less being enough to encompass capital investments that are required to meet the challenge of a constantly growing demand.

Water providers not only need to make capital investments to meet the growing demand, they also need to ensure adequate capital maintenance to ensure the functional sustainability of the infrastructure to maintain the water service. Besides the below-cost pricing, India, being a low-income developing country with equally competitive demands on the available limited finances from other sectors such as education, energy, health, transport etc., finds it difficult to obtain adequate capital flows to ensure the sustainability of water services.

2.7 The role of consumers

Community participation, particularly in rural areas, is believed to have tremendous potential to improve service delivery mechanisms. It is listed as one of the factors affecting organisational activities (NAMS and IPWEA, 2001). Converting that potential into a driver for change in urban areas has led to responses by the urban water utilities ranging from 24-hour customer care grievance phone-lines to citizen charters defining service standards. E-governance mechanisms and consumer courts are also mechanisms which enable water service providers to be (made) more accountable, responsive, and proactive by meeting specific standards of service. The collection of systematic user feedback on services (should) also assist(s) *"service providers to continuously upgrade and better serve customers, by providing services that are closer to customer expectations"* (Agrawal, 2008b).

Perhaps that is more of a theory than current practice. In India, the scope of customer involvement appears to have been generally limited to opposition to any kind of privatisation and any rise in tariffs (TNN 2001; TNS 2004). It has not been constructive. Other than registration of customer complaints in the event of service failure (See Chapter 6 for an example), there is, apart from the four Metro cities, no recognised mechanism for any planned consultation with consumers and there are no formal hearing procedures in place. General consumers cannot express their needs and priorities to the decision makers other than through political votes (Gessler et al., 2008). In the absence of direct mechanisms, communities, through NGO 'representatives' have started resorting to the courts by filing Public Interest Litigation (PIL), especially in cases of water quality related issues of water service.

The involvement of communities could be manifested through a '*demand for improved service*' and it could also be through a '*demand for transparency*' in the functioning of the service provider and decision-making. Demand for improved service may well be related to socio-economic development of the region (Franceys and Gerlach, 2008). The present scenario in India in this regard is that there is an absolute lack of demand from the customer's end to improve the service in any form. Those who can afford to do so have already insulated themselves from normal poor service through their various coping strategies. However if and when the present level of service deteriorates suddenly, as compared with the unnoticed constant gradual deterioration, there are protests in many forms such as processions, breaking of earthen pots and riots. This is more common in summer months when service providers are unable to manage the increased demand.

It is not at all clear how this consumer acceptance of steady service deterioration, punctuated by crisis management repairs, can be converted into a demand on service providers to deliver good enough services through appropriate management of their expensive assets. Particularly when that 'expense' has been delivered 'free of charge' from a distant government, not from customers at their doorstep.

2.8 The justification for research

The Indian economy has been growing at a rate of 9% per annum over the last two years and is predicted to grow at 7% in the coming years (GoI, 2008a). Infrastructure plays an important role in maintaining and accelerating economic growth rates, therefore the Government of India has laid special emphasis on the modernisation and augmenting of infrastructure capacity along with institutional, regulatory and procedural reforms (GoI, 2007).

In developing countries 'insufficient investment' and 'inadequate reforms' are considered to be the core issues affecting the performance of the infrastructure sector. In Latin America and Eastern Europe governments have been keen to divest themselves of underperforming state assets (Thomsen, 2007). Similarly, the investment challenge has been identified as the root cause of English water privatisation (OFWAT, 2006). One of the techniques used by governments to offset the problem of investment challenge or insufficient investments has been to embark on a process of building public private partnerships (PPPs). In India, investments through PPPs have been made in the telecommunications, energy and transport sector. However private participation in the water sector is politically sensitive in most countries and India is no exception. PPPs will not bridge any funding gap in the short term. Another source of procuring funds is loans from international donor agencies. However there is a risk associated with the new well-funded projects that is that the governments tend to concentrate on the mega-projects for which the funds are received. Governments then tend to get distracted from the maintenance and repairs of the existing stock or the structural reforms necessary to reduce the losses incurred in transportation and distribution of water (Thomsen, 2007). Technical solutions for reducing these losses are necessary - however their long term sustainability depends on effective institutions and finances. This objective can be achieved by developing appropriate policy solutions which balance the economic, political and social goals of the government (Agrawal, 2008a).

Hall (2003 a) in (Tecco, 2008) reported that in developing countries at present, most investments in the water sector come from central and local governments, national banks and consumers; public budgets represent the biggest source of investments, contributing to 80% of the overall financial and operating costs of more than 90% of water systems. International donor aid provides about 20% of the finance for investment in the water sector in developing countries. In India, only a very minor amount of funding comes from the government. But that public spending on infrastructure is constrained by a large fiscal deficit and other equivalent if not more competitive demands.

It is in this context that infrastructure services reforms are being given attention in India because financial resource gap assessments have made the challenges and constraints of service provision in the urban centres very clear. The Ministry of Urban Development has initiated institutional, financial and fiscal reforms though with limited direct powers. The majority of the suggested reforms have a focus on financial resource mobilisation (GoI, 2006b). The urban reforms suggested are common for all urban infrastructure services including transport, housing, solid waste management and sewerage and are not specific for any service. The Central Government sponsored

JNNURM requires certain reforms to be undertaken by States/ cities in the levy of '*user charges*' for the different municipal services provided. The declared objective is to secure "effective linkages between asset creation and asset maintenance, ultimately leading to self-sustaining delivery of urban services" (GoI, 2006b).

India is a democracy and a large number of the electorate is both poor and illiterate. The nature of the electorate causes political parties to follow populist policies to secure victory in the elections. Populist policies and financially sustainable policies tend to not go hand in hand. Hence pricing of services, especially water services which affect the lives of all, are heavily subsidised by the State governments leading to the formulation and adoption of non cost-reflective pricing policies.

The pace of reforms, as suggested by the Ministry of Urban Development and Poverty Alleviation (MUDPA), has varied from State to State. JNNURM, which required the State Governments to carry out mandatory reforms before they could access funds, also met with a mixed response. However reforms have begun to slowly but surely filter into the water sector. Some water providers have adopted accrual, that is fixed asset, accounting. Some water providers have been corporatized. These few utilities have adopted preliminary cost recovery pricing and are now managing to recover 100% of their operation and minor maintenance costs (ADB, 2007).

Any increase in the water tariff has been known to result in protests by the consumers or customers in India (TNN 2001; TNS 2004). The consumer's resistance to pay is also an indication of the dissatisfaction with the performance and lack of credibility of the water utility (Choe, 2008; Yepes et al., 2001). This makes for a vicious cycle as shown in Figure 2-1.Over a long period, many research studies have emphasised time and again the necessity for cost recovery, recognising that there may be some willingness to pay on the part of the consumer for reasonable services. However there appears to be little willingness to charge on the part of the water service providers (UNDP (1991 b) in McIntosh, 2003). Such studies have also illustrated that poor consumers pay many times more than rich consumers when purchasing water through vendors, often being unable to access the formal supplies. Keeping tariffs low does not necessarily serve the poor. However these studies have had little or no impact on policy, at least in India, where pricing policies are governed by populist politics as indicated earlier. Such politics are necessarily focussed upon minimising headline prices in such a low-income economy where everyday survival takes precedence over quality of services. The coping costs can then be ignored.

The consequent present water pricing policies have ensured that there has only been a marginal or insignificant increase in the water tariff rates over a period of more than a decade. Gessler et al., (2008) demonstrate this for the case of Jaipur. On the other hand operation and maintenance costs have been steadily rising due to ageing infrastructure, scarce water resources and increased energy costs leading to an ever widening gap between the revenue generated from the user charges and the cost of service provision.

Infrastructure renewal requires additional investment of a significant magnitude. With the present below-cost pricing, when operation and minor maintenance expenditure is not being recovered by most utilities, there will be a yet greater challenge to generate revenues for capital maintenance. Disregarding the infrastructural renewal issue will lead to further deterioration in service levels.

The relationship between an increase in tariffs and improvements in water service levels is almost equivalent to the conundrum '*which came first the chicken or the egg?*'. Choe (2008) cites studies reporting that if the service is reliable, consumers are more willing to pay for it. She further advocates that utilities must demonstrate improvements first to gain consumers' confidence rather than charging increased tariffs to break the vicious cycle.

Therefore it is imperative to address service level improvements for building consumer confidence and to narrow the gap between revenue and the cost of service provided by adopting efficiency improvement practices both in operational and financial terms (Kulshrestha and Mittal, 2005). This will facilitate not only a sustainable water supply system but also build the credibility of the service provider so as to make tariff rise acceptable to customers.

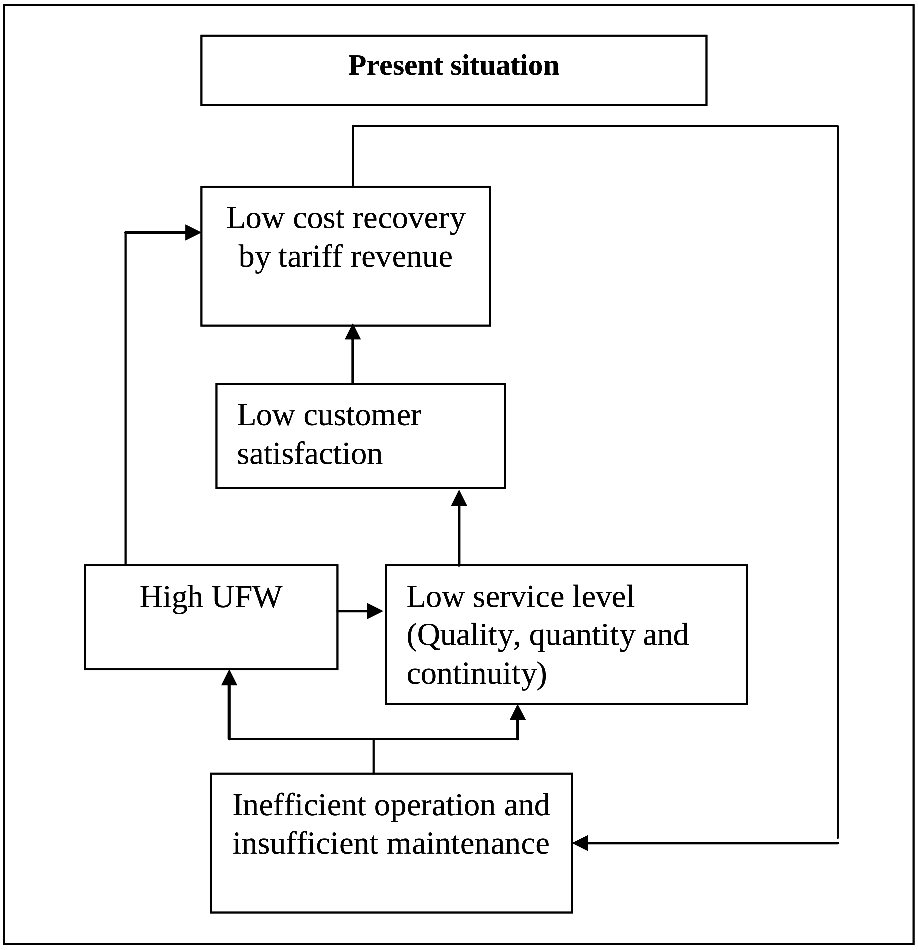


Figure 2-1 A vicious cycle for poor water service

Adapted from: (SAPI, 2004)

Water service levels are dependent on the network design, operating procedures and condition and performance of the assets employed for the delivery of service. *"These assets are subject to deterioration due to ageing, climate, geological conditions, or changes in use. Because of a lack of adequate funding and appropriate decision support mechanisms, these assets tend to be neglected or receive only remedial treatments. Water service providers are faced with many challenges regarding when and how to inspect, maintain, repair, renew, and replace a diverse set of existing facilities in a cost-effective manner. There are few tools in the form of standards, guidelines, technical literature, or best practices to assist them in their decision-making"* (Vanier and Rahman, 2004).

Infrastructure asset management is therefore advocated as one of the critical practices to address the issues concerning performance of assets as related to service levels (NAMS and IPWEA, 2001). It has also been reported to bring about cost reduction and customer service satisfaction. BSI, PAS-55(1) (2004) cites improved performance, control of service delivery and optimised use of limited finances as benefits of adopting asset management. Lewis, (2006) highlights ‘four Cs’ namely Cost reduction, Customer service, Compliance and Change in organisational culture as areas affected most heavily by asset management. Asset management encompasses a series of best practices to ensure optimal utilization of available resources. The optimal use of the assets leads to increased economic efficiency and better water service delivery, thus breaking the ‘vicious cycle’ described earlier in Figure 2-1.

Better water service delivery then becomes a justification for increases in water tariff rates, which can then be expected to be met with reduced resistance by the customers (Choe, 2008). The increase in revenue can be ploughed back into the system to achieve further improvements in service levels and also contribute towards sustainability of the water service. Instead of having a system which is fragile and on the verge of breakdown, a system which is sustainable and cost effective can be developed. Therefore formal asset management may well be a valid starting point for service providers in low-income countries with limited finances to improve water service provision and break the vicious cycle leading to a sustainable water service.

2.9 Summary of the chapter

The chapter has identified the issues associated with the particular operating environment of an urban water utility in a low-income country so as to present the background under which water service providers function.

The Government of India, being keenly aware of its infrastructure services shortcomings and the need for reforms, has taken several steps forward. However, given the importance of the water sector for public health and poverty reduction, it has not been given sufficient consideration relative to other infrastructure services, such as transportation, power and telecommunication, which are assumed to contribute more directly to the economy of the country.

Whereas the urban population is increasing at a high rate, the availability and reliability of water resources, along with limited available storage capacity and other resource assets, is a challenge. The uncertainty of available water is even more of a concern due to climate change. Therefore for optimum use of the available water, effective asset management to deliver leakage minimisation is of paramount importance for the sustainability of the service.

Pricing policies affect the financial sustainability of a water utility in addition to their contribution towards demand management. Since cost recovery pricing is still an anathema in the Indian water sector, recovery of even operation and maintenance costs is not achieved through user charges. This results in neglect for planned maintenance of the existing assets. Continuing deferment of maintenance of assets affects the sustainability of water services.

The review has highlighted the factors concerning the sustainability of the water service in urban centres in India. It has also called attention to the necessity of improvement in service levels through a focus on asset management It is apparent that with the current scenario it is very difficult for urban water utilities to maintain serviceability. There is a need therefore to explore ways to improve service levels and to consider to what extent these can contribute towards achieving the goal of sustainable water service.

Chapter 3: Sustainability of water service and asset management – a literature review

3.1 Introduction

This chapter provides the background to the role of asset management, particularly as it relates to the sustainability of water services as evidenced by the available literature, both academic and professional. In order to address the first three research objectives, it investigates the sustainability of water supply systems, key drivers of the asset management in water utilities in high-income countries and deals with the principles and methods of application of asset management for the sustainability of the water service within the context of urban water supply.

Asset management is defined as a business process and decision support framework that covers the extended service life of an asset and draws from engineering as well as economics for an inclusive understanding of the topic (Vanier and Rehman, 2004). With regard to water supply and wastewater asset management, the approach to date has been from the practice (utility associations and utilities) to the theory (academics and research) (Alegre, 2007a). Very limited research has been undertaken in developing systematic asset management methods for water utilities (Wu, 2006). Chapter 3 relies heavily on the utility oriented, grey literature because there is an extremely limited academic literature available on the subject area of asset management in water utilities. An academic literature search proved to be a challenge. The reference lists in the available literature consisted mainly of national research reports. Therefore the standard ‘back-referencing’ method to search for additional academic literature was not very productive.

The initial literature survey revealed that the concept of asset management in the water supply sector was developed primarily for compliance with regulatory or financial reporting requirements. Since these are not applicable in India, as presently there is no regulatory mechanism or financial reporting requirements for water supply, the focus of the literature review has been on the application of asset management as a process to maintain or improve water service levels rather than reporting compliance.

The underground pipe network constitutes about 70-80 % of the infrastructure assets of an average water utility - requiring high initial investment with subsequent network maintenance being utterly necessary for sustainability of the service (Cromwell et al., 2001). It is relatively easy to monitor the condition of the 20- 30 % above ground assets; therefore asset management in the water industry is primarily focussed on the underground infrastructure assets (Schulting and Alegre, 2007). This review has also concentrated on pipe networks because most of the available literature is directed at the underground infrastructure. There is only limited literature available regarding asset management of mechanical and electrical (M & E) assets in water industry. To overcome this limitation other sources were employed to enhance details on information regarding asset management of M & E assets in water industry.

Overall, the literature emphasises that asset management is a data intensive process (Walker, 2004). However all water utilities started asset management with whatever data was available and gradually developed it over the years, usually as their understanding and needs developed. Recognising the limited data availability within water utilities in developing countries, this literature review has focussed especially on the practices of the initial stages of the asset management process in high-income countries.

Varied terminology was found to be in use regarding the classification of assets across the literature surveyed. For pipe network assets the terms used were underground assets, infrastructure assets, linear assets, network assets, reticulation assets. Assets other than pipes have been termed as non-infrastructure assets, surface assets, and non-linear assets. The researcher has adhered to the terminology, *underground assets* for the pipe network assets and for the rest of the assets, *above ground assets*.

Throughout the literature reviewed, the terms renewal, rehabilitation and renovation have been used interchangeably for *asset maintenance* options. Gangl et al. (2007) referred to the German guidelines and stated that “rehabilitation includes all activities for preservation and improvement of the operability of existing supply networks, such as cleaning, restoration or replacement. Repair of failures is not considered a part of rehabilitation because with a repair an extension of lifetime is not possible”. Grigg (2004) has defined ‘renewal’ as a common term for repair, replacement and rehabilitation. He has further defined ‘repair’ as restoring functionality of existing components after damage, ‘replacement’ as providing a substitute for a component and ‘rehabilitation’ as restoring or upgrading existing components through extensive work. From this point onwards the researcher has adhered to the latter definition for the term *renewal.*

3.2 The concept of ‘sustainability of service’

Before reporting further on the literature regarding asset management, it is necessary to consider again what it is that such assets are presumed to deliver. Sustainability and sustainable development has been written about in many different contexts. Sustainable development is defined by Bruntland as ‘meeting the needs of the present without compromising the ability of future generations to meet their own needs’ (WCED, 1987 in Ashley et al., 2004). The UK government defines sustainable development as “ensuring a better quality of life for everyone, now and for generations to come” (DETR, 1999a in Ashley et al., 2004)). Sustainability is about taking the long term perspective and being aware of what will, what might and what should change from one generation to the next (Beck et al., 2006).

Abrams (1998) in Carter and Rwamwanja (2006) defined the concept of sustainability of water and sanitation services in a very simplistic manner as ‘one which continues to work over time’. ASCE/UNESCO (1998) in Marlow (2005) defined “sustainable water systems” as those systems that are designed and managed to contribute fully to objectives of society now and in the future while maintaining ecological, environmental and hydrological integrity. *To be sustainable, the water service provision and cost distribution must be equitable for both current and future generation*.

In the water sector, sustainability has mostly been defined in the context of *water resources* or *sustainable water management* (Alegre, 2007b; Baptista and Alegre, 2007; Heinicke and Stenstrom, 2006; Marlow et al., 2006). Treatment and transmission of water requires large amounts of energy. This demand on electric energy has an impact on the environment, implying that the environmental sustainability issue is critical from an energy perspective also (Olsson, 2007). Kayaga et al. (2007) highlighted the role of water demand management, besides supply side options, to ensure sustainable provision of water services in the context of an increasing urban population and rising living standards. More recently, climate change is considered to be one of the biggest threats to the sustainability of water service in the medium term (Water UK, 2007). Efficient use of water resources and energy resources as supply side initiatives along with water demand management can therefore pave the way for environmentally sustainable water service provision.

In addition to water as an environmental resource, financial resources are essential for the utilities to continue to provide services. Appropriate water pricing policies are regarded to be imperative for financial sustainability of the water service, with the added benefit of promoting sustainable use of water resources (Rogers et al., 2002; World Bank, 2005). Franceys (2006) states that charging appropriate water prices, aiming for complete financial cost recovery including operation and minor maintenance costs, capital maintenance costs, and (on occasion) the cost of capital, is a long term process but is a worthy goal to be aimed at to ensure financial sustainability of water services.

Carter and Rwamwanja (2006) emphasise that systems are required to be built, to be rehabilitated and renewed for the sustainability or improvement of the service and referred to this concept as *functional sustainability*. Marlow (2006) highlighted the direct influence of the asset stock used to treat and transport water as an environmental resource. Parsons (1999) reported that the water lost through leakage due to deteriorating infrastructure has a value. There needs to be a balance between the value of reducing leakage against the cost of a new source or supply which can be achieved through identifying an economic level of leakage. Sohail et al. (2005) recognise the role of operation and maintenance to enhance the sustainability of existing infrastructure. ISO (2007) also stresses the importance of maintenance of assets along with water resource management for achieving the objective of the sustainability of a water utility. Heare (2007) recognizes the need to define the concept of infrastructure sustainability relative to service provision. Operational efficiency, asset management, source water protection and full cost pricing were identified as actions to achieve infrastructure sustainability.

Ofwat (2000) stresses the concept of 'serviceability' to describe the ongoing functional sustainability of service provision, with a particular focus upon how customers experience that service as opposed to how utilities might measure it. Throughout the literature therefore the term sustainability is used in many different contexts: sustainable development, sustainable water management, sustainable utility, sustainable water system, sustainable infrastructure and sustainable water service provision. In the researcher's view, the three essential elements required for a sustainable water system to be able to provide a sustainable water service to consumers are:

***Water* -** Does the utility have access to a reliable quantity of water to meet the present as well as future demand? Does the utility have the requisite storage and/or transmission capacity?

***Assets* -** Are the utility's physical assets, i.e. distribution network, electrical and mechanical machinery, storage reservoirs and treatment plants, capable of an acceptable level of performance now and to what extent are these assets capable of meeting any future increase in demand?

***Finance* -** Does the utility have access to sufficient financial resources to operate and maintain these assets in order to provide an acceptable service to consumers?

Based on these three essential elements, in the context of water service provision, sustainability can be classified into three categories as, 'environmental sustainability', 'functional sustainability' and 'financial sustainability'.

To ensure the sustainability of service levels and to limit inter-generational transfer of the costs (whereby present consumers pay less than they should such that subsequent consumers have to pay more), high-income countries use asset management plans as a strategy for capital maintenance investment planning. Asset management is acknowledged to be the most cost effective way, through creation, acquisition, maintenance, operation, rehabilitation and disposal of assets, to provide the required level of service for present and future consumers (NAMS and IPWEA, 2001). In England and Wales, the policy climate for asset management in the water industry has shifted significantly towards sustainability issues and the regulatory policy stance has seen an emphasis placed on securing value 'not just in the narrow sense of customer bills, but also in the wider sense of value to society, encompassing the environment and economy' (Day, 2007).

On the basis of the above discussion Figure 3-1 illustrates the factors affecting the three different aspects of sustainability of water service provision and the role of asset management towards overall sustainability of the service. This understanding of various factors associated with sustainability of a water supply system guided the formulation of the conceptual framework for research shown in Chapter 4.

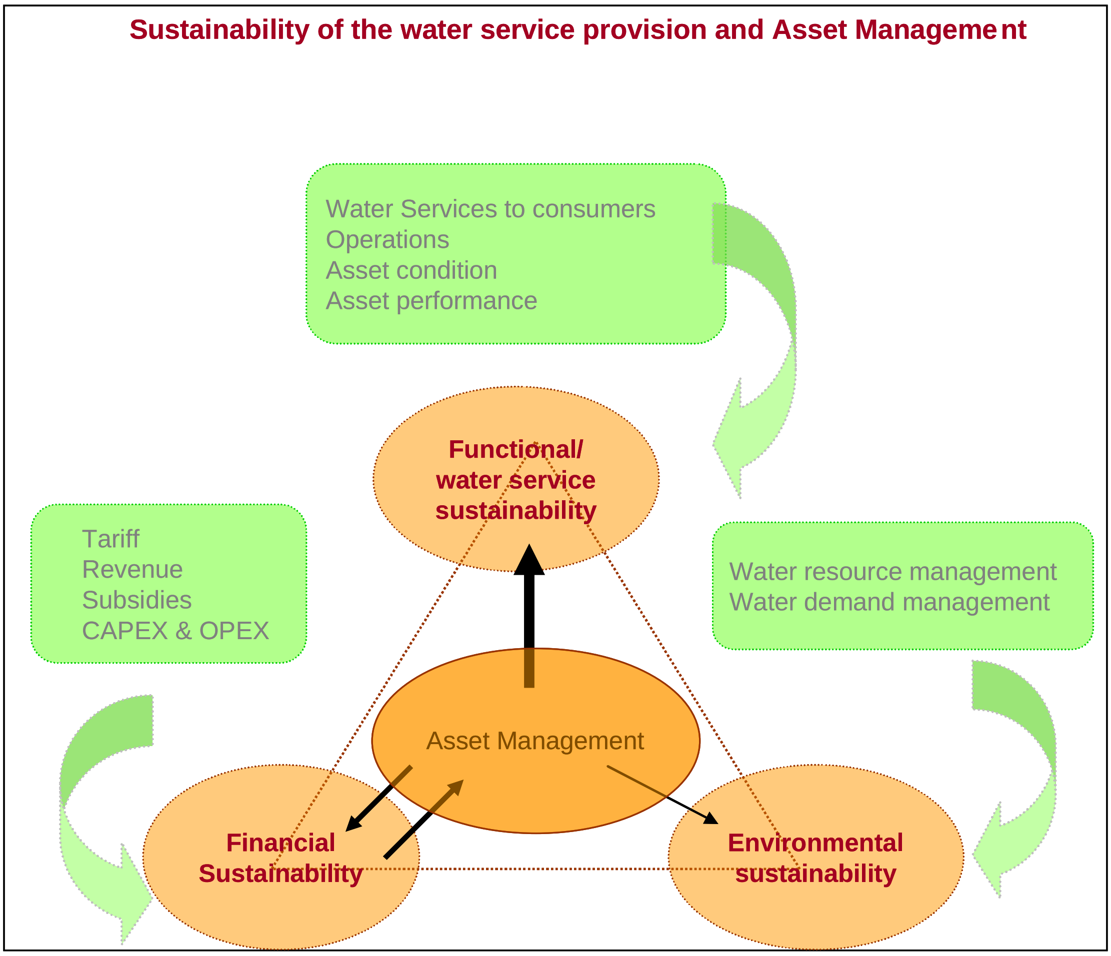


Figure 3-1 Sustainability and asset management

Source: Brighu, U.

3.3 The concept of Asset management

3.3.1 Introduction

A water utility has certain unique characteristics when compared to other utilities in terms of the size of its asset base and the 'capital intensity' of its operations (Foley, 2005) (Cromwell et al., 2001). Because of past failures in asset management, water utilities are often faced with the problem of ageing pipe networks and the associated increasing costs (Moglia et al., 2006). Recent studies undertaken in the UK, Australia and USA have shown that water utilities need to make substantial investments in capital maintenance projects, involving renewal of existing assets, to enhance the capabilities of the assets to maintain existing service levels and to meet any new or improved service requirements (Heare, 2007; Urquhart, 2006).

The lifecycle or ageing process of a buried pipe, as for most physical systems, is often described as a '*bathtub curve'*. The 'bathtub curve' (See Figure 3-2) often distinguishes between three phases in the life of an asset. The first phase describes the period right after installation, in which failures occur mainly as a result of faulty installation or, as an example, faulty pipe connections. In phase two, the pipe operates with some low failure frequency resulting from random phenomena such as heavy loads, third party interference, etc. The third phase, also called "wear-out phase", depicts a period of increasing failure frequency due to pipe deterioration and ageing (Gangl et al., 2007) (Kleiner and Rajani, 2001) (Todinov, 2006) .

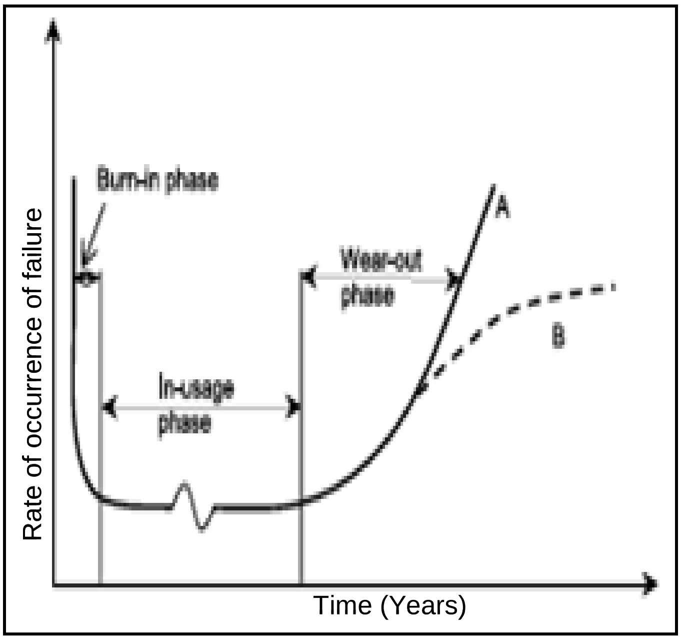


Figure 3-2 The bathtub curve of the lifecycle of a buried pipe

Source: Kleiner and Rajani, 2001

"Not every pipe experiences every phase of the bathtub curve and the length of the phases may vary dramatically for various pipes and under various conditions" (Kleiner and Rajani, 2001). Therefore "water utilities must understand asset condition, performance, remaining life and risks to facilitate improved asset maintenance investment decision-making" (Urquhart, 2006). Banyard and Bostock (1998) emphasised the importance of optimisation and prioritisation in large capital maintenance programmes as a rational approach to the assessment of the asset capability, which is preferable to subjective judgments. This is particularly relevant where utilities do not simply have a single pipe system all of one age, but rather a multiplicity of pipe sizes, soil conditions, loading characteristics, materials, manufacturing techniques as well as installation times. It is the challenge of asset management to understand these variations and optimise the use of scarce resources to maintain serviceability, that is functional sustainability.

Burn et al. (2007) demonstrated that for the majority of assets the cost of repair is small relative to the cost of replacement if only the direct costs borne by the utility are considered (including customer compensation). As service levels deteriorate there is no marked increase in the total cost borne by the water utility, because the cost of additional repairs is relatively low. Burn et al (2007) further affirmed that by not taking the indirect and social cost associated with service deterioration into account, in conjunction with limited available budgets, water utilities may be tempted to defer investment for asset replacement.

There has also been evidence that as capital maintenance investment rates fall, operational expenditure rises to maintain the service levels. (See Figure 3-3) "Ideally the rate of capital investment should be such that the total cost of capital and operational expenditure is minimised" (Parker, 2008).

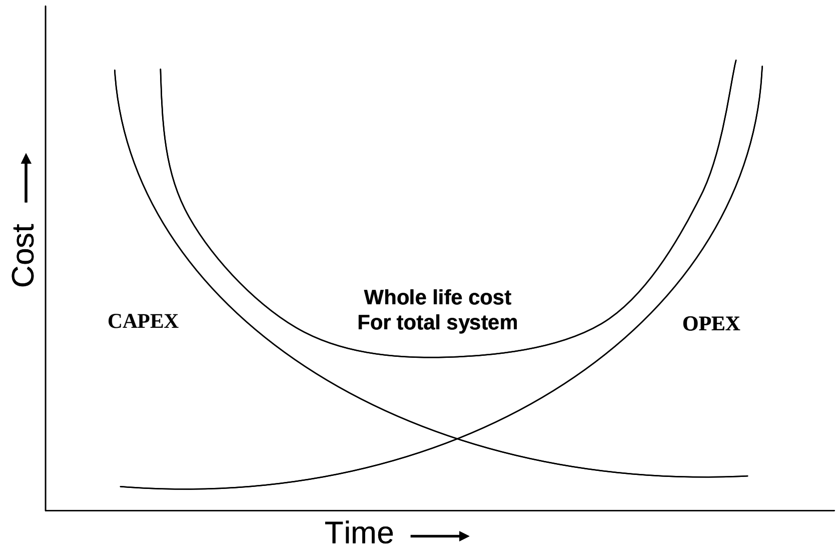


Figure 3-3: Capex vs. opex

Source: Parker, 2008

However (Parsons, 2006) recognised that the deferment of capital maintenance by increased operational maintenance will not be effective over many years. The problem of deferring maintenance and asset replacement leads to potentially higher capital expenditure in future years (Byrne et al., 2003).

This is where asset management comes to the fore: when making decisions related to asset operations and maintenance in order to provide quality services at low cost to consumers whilst maintaining and protecting the environment. Asset management of water networks is an approach which allows the asset base to be managed in a way which ensures that future investments deliver maximum benefit for customers and service providers (Banyard and Bostock, 1998). Though asset management of water networks is largely concerned with determining capital maintenance investment strategies (McAll and Brooks, Undated) and achieving the lowest lifecycle cost is one of its key objectives (Cashin, 2006), it is not restricted to just capital maintenance investment planning. Ideally, it also covers the whole of the asset life cycle including design, procurement, operation and reinforcement of assets (Conroy and Williams, 2007). "Asset management is a way of thinking that considers capital, operations, maintenance, repair, renewal and replacement as investment decisions" (Albee and Byrne, 2007). Cox (2005) affirmed that asset management has the ability to optimally allocate capital and operational expenditure to achieve short-term value and long-term sustainability.

3.3.2 Definitions

Asset management as applicable to infrastructure services has been defined in many ways.

"*Systematic and coordinated activities and practices through which an organisation optimally manages its assets, and their associated performance, risk and expenditure over their lifecycle for the purpose of achieving its 'organisational strategic plan'*" (BSI, 2004).

"This is a systematic approach to managing service assets in order to minimize costs over the useful life of the assets while maintaining adequate service to customers" (GAO, 2004).

"The combination of management, financial, economic, engineering and other practices applied to physical assets with the objective of providing the required level of service in the most cost effective manner" (NAMS and IPWEA, 2001).

Marlow and Burn (2008) has modified the above into a more comprehensive definition:

"Asset management is a combination of management, financial, economic, engineering and other practices applied to (physical) assets with the objective of maximising the value derived from an asset stock over the whole lifecycle, within the context of delivering appropriate levels of service to customers, communities and the environment and at an acceptable level of risk"

The three key elements in these definitions are *'adequate/appropriate service levels', 'cost effective' and 'risk'*, as also summarised by Brown and Humphrey (2005), in (Schulting and Alegre, 2007), who proposed the following definition: "Asset management is the art of balancing performance, cost and risk. Achieving this balance requires support from three pillars of competence: management, engineering and information."

3.3.3 Drivers of asset management

"Asset management", by these definitions, was not commonly practiced in the water industry of high-income countries until the late 20th century. Because of the apparently long life of underground networks, not to mention their invisibility, capital maintenance tended to be ignored in many public sector operations (Stephenson, 2005). All over the world asset management planning in the service sector has been an offshoot of structural reforms aimed at improving the efficiency of the internal economy or the price regulation of the services provided (Urquhart, 2006). By one view of this process, it might be seen that the generality of assets in a country had to have aged sufficiently such that the resulting challenge to services demanded not only enhanced asset management but also structural reforms to deliver that management. Underground and above ground water fixed assets are that important.

Enhanced accounting standards and/or public sector financial reporting requirements have been a key driver of asset management in New Zealand and Australia. Financial reporting and tariff justification requirements by the economic regulator OFWAT, as part of the quinquennial business planning process have been the key drivers of asset management practices being adopted by the water industry in England and Wales (NAMS and IPWEA, 2001; Worley International, 2000).

In New Zealand the laws require that strategic asset management principles are applied to a diverse range of municipal asset portfolios owned and managed by municipalities. In Australia a report card on the nation's infrastructure prepared by the

Institution of Engineers using a grading range of A (excellent) to F (inadequate) where the water supply infrastructure was evaluated at a grading of C-, revealed that the current state of assets required for public sector service was not up to the required standards and there was a large scope for improvement. It also highlighted that the current expenditure rates were much less than the required investment rates to extend and maintain the service. If this gap continued to exist or widen the report stated that the infrastructure's present grading could be lowered further. This realisation led to the adoption of asset management practices. In Australia, laws relating to asset management requirements are generally limited to water, electricity and gas companies which are subject to price regulation. However some organisations are choosing to implement asset management practices to maximise efficiency and effectiveness associated with service provision even where there are no regulatory laws or other statutory requirements (NAMS and IPWEA, 2001).

The water industry in England and Wales was privatized in response to the need for increased investment in the industry, investment required not only to meet improved standards from the European Union but also to overcome the backlog of capital maintenance (OFWAT, 2006). Thames Water was reporting one third of its London pipe network being older than 150 years, half older than 100 years with separate reports that at the time of privatisation new plastic pipe house connections were being fitted into original wooden water mains in South East London (Franceys, personal communication).

To prevent water companies from maximising their profits by reducing service levels and/or allowing assets to deteriorate further in the long term, government, through economic regulation, required utilities to meet statutorily defined service levels. Utilities were required to prepare detailed asset management plans for managing underground infrastructure assets (Thackray, 1990). Afterwards a 'Common Framework for Capital Maintenance Planning'(UKWIR, 2002a) was developed to provide an agreed structure for estimating the future capital maintenance requirement of the companies to manage the assets so as to provide and sustain defined levels of service to customers, in the most economic manner over the long term, by incorporating risk based analysis (Smith, 2007). Risk based asset management has evolved due to regulatory requirements and the rising stakeholder and customer expectations regarding risk management for the types of risks popularised by media and environmental activists (Pollard et al., 2007).

”The water companies need to demonstrate how the flow of services to customers can be maintained at least cost in terms of both capital maintenance and operating expenditure, recognising the trade off between cost and risk, whilst ensuring compliance with statutory duties” (OFWAT, 2000). Asset management provides a basis for demonstrations that utilities have a sound long term plan to maintain their assets and a justification for their tariff submission (NAMS and IPWEA, 2001).

In the pre-privatisation era service levels were planned internally but after privatisation attention was directed mainly to the statutory minima, which were set at levels below design standards. Thackray (1990) had questioned the validity of asset management plans for internal management against its use as merely a regulatory tool. The issue regarding whether the Common Framework for Capital Maintenance’ should focus solely on investment planning or more generally on overall asset management was discussed recently at a UK Water Industry Research (UKWIR) workshop (UKWIR, 2007). This indicates that to date asset management planning in England and Wales is being driven by investment needs for capital maintenance and the requirement for regulatory compliance.

In Europe an acknowledged need for hundreds of billions of Euros in terms of capital investment in water supply networks throughout Europe led to the Hydro-plan EU demonstration project being developed and tested in five cities. This was designed to promote and disseminate particular engineering procedures for urban water asset management with an aim to make significant economic savings and improve the quality of the service (Van den Broeck et al., 2005). Within the 5th Framework research programme of the European Commission, the twin systems CARE-W (Computer Aided Rehabilitation of Water networks) and CARE-S (Computer Aided Rehabilitation of Sewer and storm water networks) were developed with a focus on underground assets. The emphasis is on engineering aspects in both CARE-W and CARE-S. There appears to be no formal structured asset management being practiced in Europe, however the importance of the principles of the Common Framework is being recognised and in some way implemented (Alegre, 2007a).

As in Australia, New Zealand, and Europe, following the clear identification of the need for higher expenditure in maintenance and rehabilitation of infrastructure, Canada has also taken some initiatives directed towards creating awareness and establishing guidelines for the implementation of asset management (Vanier and Rahman, 2004).

In the USA the current average rate of renewal of pipes implies an asset life of 200 years. There is no direct regulatory control over the integrity of pipes and renewal projects have to compete with other projects for expansion, reliability, service and capacity (Grigg, 2004). There is little evidence of an overall asset management framework, as in Australia and New Zealand, or an investment planning regime as in England and Wales (Urquhart, 2006). Rast (2003) in (Marlow et al., 2006) has identified four key drivers for adoption of formal asset management approaches in the USA:

- Increased demand on the infrastructure system combined with a significant budget shortfall
- A growing awareness of the impact of ageing infrastructure and environmental factors on water quality and quantity
- Changes in regulatory requirements including GASB34 (Governmental Accounting Standards Board) and CMOM (Capacity assurance, Management, Operation and Maintenance) requirement of US Environmental Protection Agency USEPA
- Availability of new technology

Urquhart (2006) remarked that most of the information technology used by leading utilities worldwide is developed in the USA (though SAP from Germany might dispute that point) and emphasised that advances in technology have enabled modern asset management practices by enabling analysis of vast amounts of asset data.

In summary, the literature suggests that the drivers of asset management in the water industry across the globe are: financial reporting requirements, economic regulation and the increasing awareness regarding the ageing infrastructure by the water utilities, the enormous investment requirement for rehabilitation and environmental factors such as water quality and quantity. Advances in information technology, climate change and community expectation regarding environment have encouraged and assisted in adopting more sophisticated tools for asset management.

Low-income countries have a strong focus on asset creation but lack an overall planning structure that enables optimization of investments. Management practices that are followed in developing countries are steeped in historical procedures. These practices are quite unsophisticated to have an impact on the overwhelming water supply problems such as chronic leakage and unauthorized supply. Unless existing water schemes have been evaluated for development purposes there is usually no reliable record of the assets (Worley International, 2000). Due to the non-existence of regulation and mandatory financial reporting requirements, formal asset management practices are practically absent in water utilities in developing countries.

3.3.4 Asset maintenance strategies

Broadly the asset maintenance strategies can be classified into reactive and predictive maintenance strategies. Reactive strategies are based on stimuli in the form of events that trigger replacement actions. In contrast, a proactive strategy is future oriented in that replacement and operational decisions are based on the anticipated evolution of failure rates in order to minimise cost and avoid other undesirable outcomes (Moglia et al., 2006) (Cromwell et al., 2001) (Deb et al., 2000).

The capital maintenance planning ‘Common Framework’ describes “doing nothing” i.e. waiting until assets fail, as a reactive maintenance approach. It suggests considering some kind of proactive intervention where it is forecast that a reactive approach will result in deteriorating service. The Common Framework also requires a consideration of costs (capital, resulting changes in operational costs, net of cost savings gained by avoiding asset failure) and quantified service benefits for the evaluation of a maintenance strategy (UKWIR, 2002a).

Ackerman (1999) has illustrated that in cost terms over the life time of an asset the most expensive type of maintenance is reactive maintenance and the least expensive is predictive maintenance. However the selection of reactive vs. proactive maintenance strategies is not very simple. The proactive maintenance strategies require estimating the probability of failure of assets, which is a very complex area requiring good quality data. Much progress has been made in the understanding of asset deterioration processes and failure modes; however the knowledge gap challenge still remains

(Rajani and Kleiner, 2004). Most utilities have an inadequate understanding of their assets and have data constraints. The data that is available with the water utilities is often incomplete. There are often poor records about the condition or even location of the underground assets (Hobson, 2005) (Walton[2], 2006). Wood (2007) reported that the data collection challenges mainly consist of missing and conflicting historical data, poor reliability of existing data and non computerised information.

The tacit knowledge and experience regarding assets and asset failure held by utility staff is considered to be important and recommended to be utilised for asset maintenance decision making. The experience of Oakes and Phillips (2006) was that "better and perfect data will take many years to collect and assimilate, however if the available data is used correctly, it is of a standard to improve asset maintenance decisions". Mather (2006) reported that in his experience, "many predictive asset maintenance programmes are based on approximately 30% empirical data and 70% expert knowledge". Albee (2005) stated that the quality of the decisions taken by the water utility managers or the water policy planners reflects their professional judgment on the basis of experience that they have gained because of working in this sector, however guesswork and chance too often influence key choice.

Figure 3.4 illustrates the challenge faced by one English water utility in managing one class of pipe. In the past, front-line utility expertise might have noticed abnormal failure rates and suggested that certain lengths of pipe needed replacing sooner than their installation time would otherwise indicate. Now that efficiency improvements demand far fewer front-line staff, with many activities contracted-out to external providers, expert knowledge is no longer available and is definitely not available over the necessary time horizon. In its place, sophisticated record-keeping is required to be able to highlight, in this example, where one period of manufacturing has delivered pipes with a significantly higher early failure rate and therefore likelihood of service failure.

[2] Personal communication

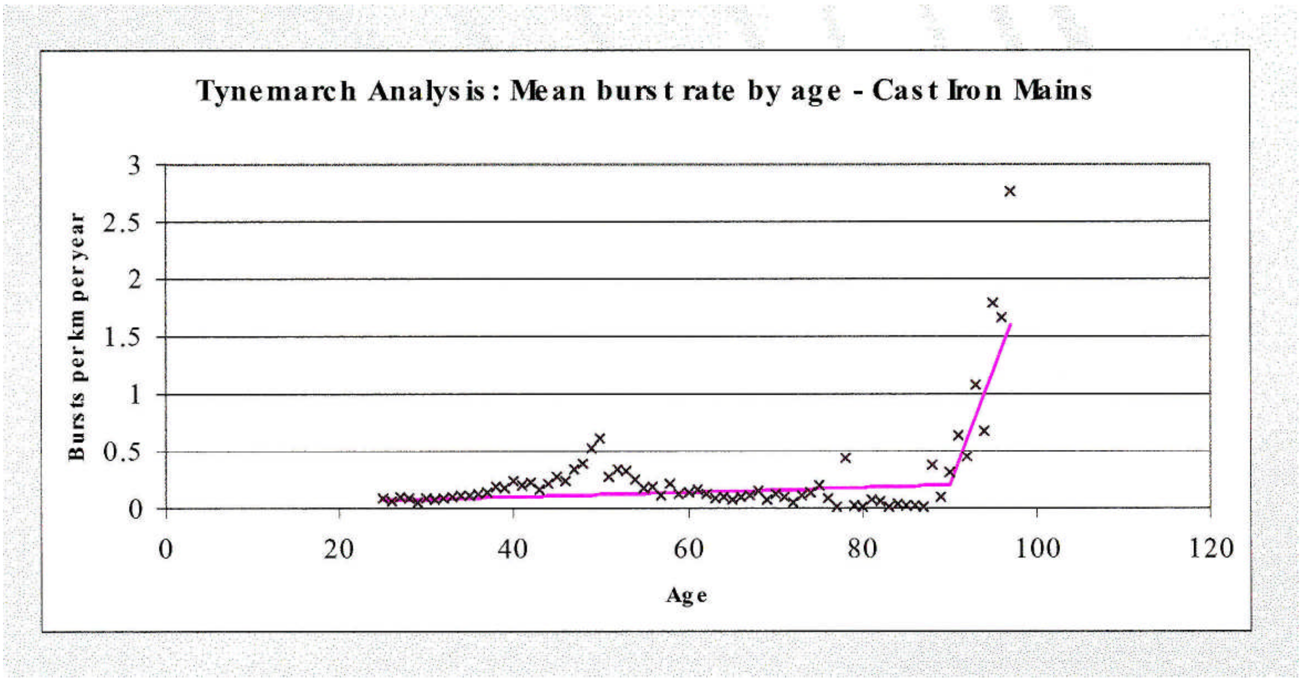


Figure 3-4 Results from Tynemarch analysis of SST Data (During pilot of Common Framework)

Source: South Staffordshire Water PR04 presentation to WaterVoice, 2004

Generally the pipe mains are of the most interest in maintenance strategies and are considered to be *critical assets* as the consequence of their failure is high, whereas the other assets are allowed to fail and the frequency of failure is used as a parameter to make a decision regarding asset replacement (D'Agata, 2003). Rajani and Kleiner (2004) illustrated that *failure management* is a typical strategy for relatively small diameter distribution mains with low failure cost, while *failure prevention* is appropriate for large water transmission mains, with relatively high cost of failure. High failure cost may also justify costly condition assessment measures to anticipate future failures and prevent them in a proactive approach (D'Agata, 2003; Marlow and Burn, 2008).

Quick (2007)[3] pointed out that the approach adopted in CARE-W applies to the whole distribution network altogether, which is in contrast to the approach applied by the Australian utilities wherein the identification of critical assets was the initial stage of the asset management. It is not considered to be appropriate and practical to adopt the

---

[3] Personal communication at LESAM 2007 conference in Lisbon, Portugal. (17-19 October, 2007)

same methodology for all the categories of distribution network assets on account of the costs and effort involved in obtaining information regarding their condition and performance (D'Agata, 2003).

Urquhart (2006) recommends choosing the maintenance strategies for different categories of assets based on the assessed level of risk. Risk is determined by taking into account both the probability and consequences of asset failure (Harlow, 2005). (Burn et al., 2007) stated that in Australia, the probability and consequences of failures are considered for the selection of asset maintenance strategies (reactive/proactive). Assets are divided into proactive and reactive assets on the basis of assessed risk and different practices are applied to these asset classes (See Figure 3-5)

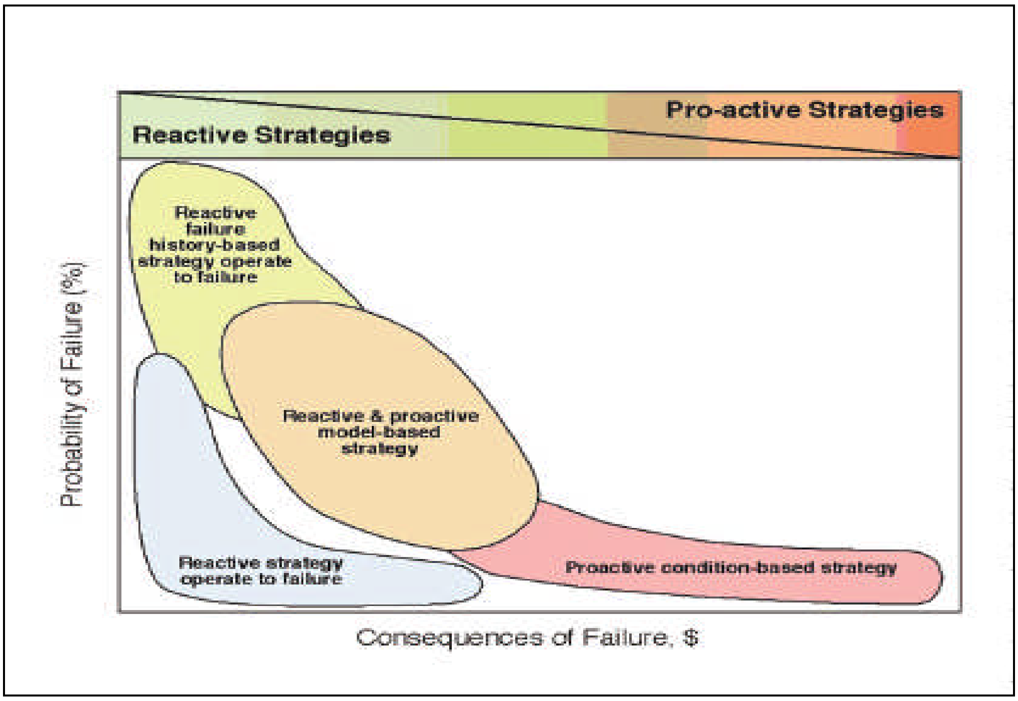


Figure 3-5 Asset management strategies for assets with different failure probabilities

Source: Burn et al., 2007

The individual importance of proactive assets is more on account of the scale of potential consequences associated with their failure, however in any water supply system reactive assets (mainly distribution network) comprise the majority of assets and overall cost the most to maintain and replace. “Proactive strategies are stated to be generally more justifiable for assets with high consequence of failure” (Rajani and Kleiner, 2004). However for reactive assets, the need for strategic asset management planning is emphasised to minimise the overall cost of service provision and to attain an appropriate balance between operational and future capital expenditure (Burn et al., 2007).

3.4 Evolution of asset management approaches

Asset maintenance management, defined as a continuous process improvement strategy for improving the availability, safety, reliability and longevity of physical assets, has been in practice for a long time. However, *asset management* covers other elements too such as serviceability, sustainability, resilience in addition to asset maintenance (Rojas and Davis 2008). In a web-based survey of managers of water utilities in America and Australia one third of the respondents indicated that in their respective utilities there was no defined formal asset management practice being adopted or implemented. Marlow et al. (2006) called this practice as 'informal asset management' because although there are no formal asset management aims and methodologies adopted by the managers of these water utilities the managers are in a way managing the assets in their control or possession.

Asset management in conceptual terms or as a system of thought is undergoing an ongoing evolutionary process. It has been greatly assisted by technological advances. Over the last twenty years different drivers have created different approaches (Urquhart, 2006). Over time, these approaches have evolved from a purely asset-centric view (asset maintenance) to the provision of service at an acceptable level of risk (asset management) (Marlow et al., 2006).

3.4.1 Age based asset management

Stephenson (2005) demonstrated that age based asset management was the very first methodology in the evolution of asset management planning. In England and Wales at the time of privatisation of water services, many companies made assumptions about asset renewal rates on the basis of nominal book lives such as 80 years for water mains and 20 years for pumps. This approach relied on simple assumptions. This age-based approach was simple to apply to a majority of groups of assets, however in reality assets were replaced as they deteriorated and targeted investments were made to only those assets which directly affected services. These investments were generally delayed beyond the assumed nominal life (Heather and Bridgeman, 2006).

In other countries, with different approaches to capital maintenance, asset renewal lives of 30 years (Denmark) and 40 years (Berlin) are reported which, although more costly, remove any concern over delaying renewal and at some level diminish the need for asset management (personal communication).

A research study undertaken by American Water Works Association (AWWA) to provide comparative case studies in asset management to help water utilities to identify asset management options, defined three approaches to asset management planning. One of the approaches, called the *basic option*, used the concept of service life (age), based on realistic estimates of the useful lives of assets, to approximate the condition of assets. The report also emphasised the challenge of taking specific contextual factors (environmental, operational, maintenance practices) into account while estimating the useful service life (Matichich et al., 2006a). Byrne et al (2003) also recognized that age of the asset is not necessarily the best indicator of its capability to provide satisfactory service. Therefore age based asset maintenance is not necessarily the least cost approach to maintain service to consumers but may well be the simplest.

3.4.2 Condition, performance & water–service based asset management

In England and Wales a further development to the nominal life /age based approach was to review the current condition and performance of the individual assets to enable water utilities to understand the way in which individual assets had deteriorated, such that the investment could then be targeted to those assets needing renewal the most (Heather and Bridgeman, 2006). As mentioned earlier, asset management in England and Wales is oriented towards the capital maintenance investment planning reporting requirement; the initial approach was to develop asset registers which identified individual assets on works, and then to grade those assets in respect of both *condition and performance* (OFWAT, 1998). This approach was focussed on the assets rather than customer service and was based on the assumption that the service is maintained as long as the assets are kept in operable condition. This approach relied on the continuation of current investment levels (Heather and Bridgeman, 2006).

OFWAT, however, did not accept this concept, believing that expenditure on asset maintenance should be accepted only when the *serviceability to customers* had reached an unacceptable level (Banyard, 2004). This resulted in the requirement for capital maintenance investments to be justified by the water utilities in the context of serviceability to customers. However, significant improvements in operational efficiency led to service improvements that seemed to be independent of the condition of the assets. The capital maintenance investment requirement could not be justified because of the stable trend of the serviceability indicators. Since this approach did not attempt to forecast future service, the water companies were unable to demonstrate higher capital maintenance investment requirement (Heather and Bridgeman, 2006). The water companies then felt that they had not been allowed sufficient funding by the regulator to meet their capital maintenance requirements. This backward-looking approach to assess capital maintenance needs, based on historical capital maintenance investments and the historical serviceability trend, was criticised and led to the development of a new forward-looking risk based approach, known as the Common Framework, which allows a more proactive approach to assessing capital maintenance needs ((Banyard, 2004; Water UK, 2002). The concepts of probability and consequences of asset failures are at the core of the Common Framework. The Common Framework advocates three stages of analysis namely historical analysis, forward looking analysis, (See 3.4.3) and a comparison of these two for capital maintenance planning (Day, 2007) - see Appendix 2 for details.

3.4.3 Risk based asset management

Risk based asset management is one such forward-looking approach. This approach aims to achieve management of assets by factoring in considerations of risk to the service provision over the life-cycle of the asset. In this approach the probability of service failures and asset failures in the future and their potential consequences are estimated to calculate the risk cost (Risk cost = probability of failure (no./year) * cost consequences of failure (£/year)) (Harlow, 2005; NAMS and IPWEA, 2001). This risk cost is then taken into consideration for optimisation of the maintenance activities. The risk based asset management approach employs predictive modelling of asset failures which requires a superior quality of detailed historical data on assets in addition to superior computing facilities (Marlow et al., 2006). OFWAT has also recognised that data limitations may be a constraint in a full application of the Common Framework for capital maintenance planning incorporating risk analysis (UKWIR, 2004b). Therefore the Common Framework recommends forward-looking analysis to be applied to only those asset groups and service areas where there is likely to be significant capital maintenance issue.

A comparative study of these three approaches of asset management conducted by AWWA stated that all three options provide substantial value addition for the water supply system. Age based, condition, performance and water-service based and risk based approaches received an overall average rating score of 3.4, 3.9 and 4 respectively on a 5.0 point scale from the participating utilities. Data management challenges were considered a lot tougher for the condition, performance & water-service based and risk based options (Matichich et al., 2006b).

Depending on the degree of sophistication of the available data and its analysis the condition, performance and water-service based asset management approach is identified as 'core/basic asset management' and an asset management philosophy based on the incorporation of an element of risk is called 'advanced asset management'. In core/basic asset management, the priorities are usually established on the basis of financial returns. In the case of advanced asset management, priorities are based on risk analysis (Marlow, 2005). The evolution sequence of various asset management approaches has been illustrated diagrammatically in Figure 3-6. The understanding of the evolution of different approaches to asset management and the inputs required to undertake these approaches have supported addressing the research objective 3 that is, the formulation of generic asset management model.

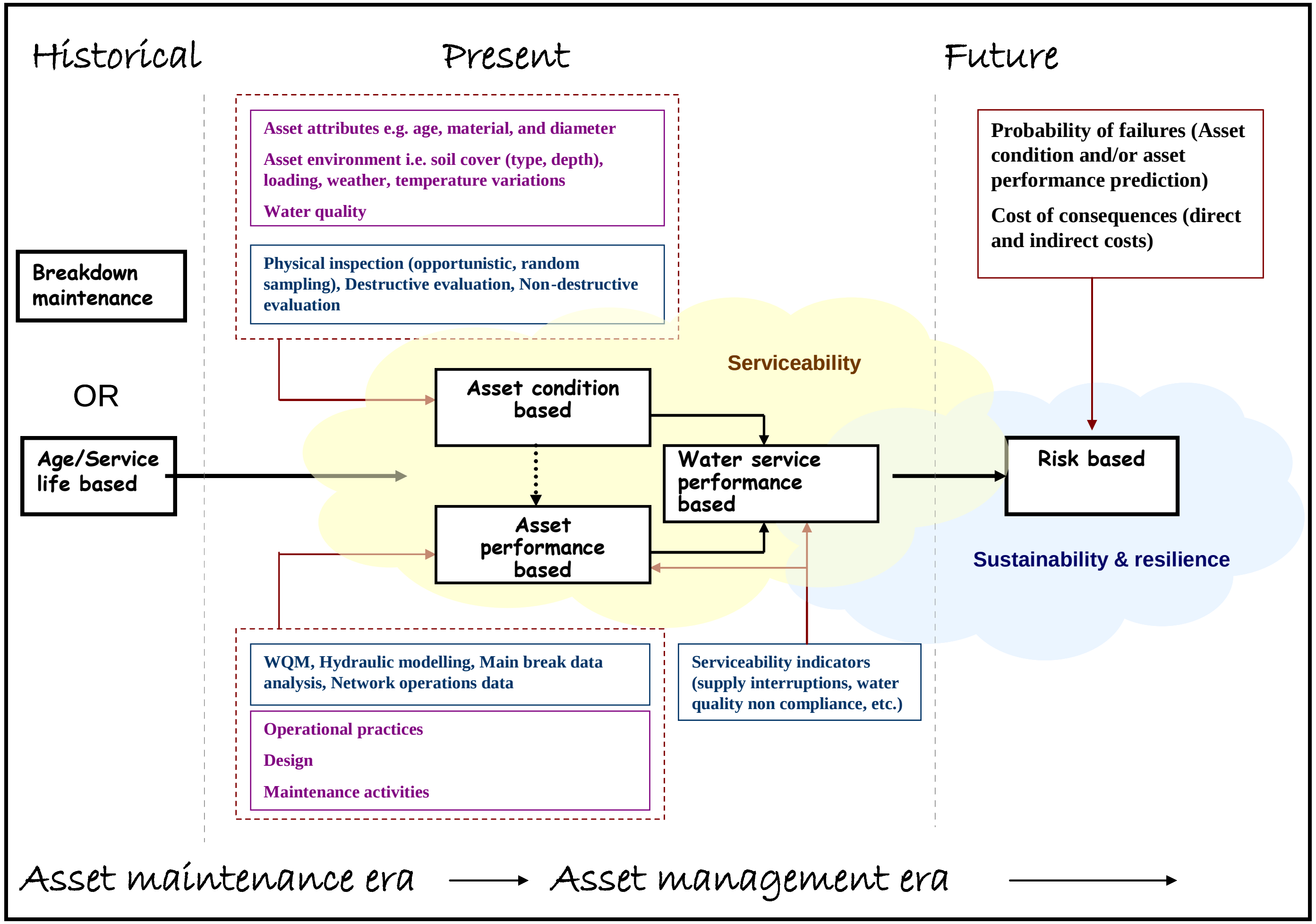


Figure 3-6 Asset management evolution

Source: Brighu, U.

3.5 Asset Management principles and methods

Best practice in asset management comes from across the world and, as outlined previously, different drivers have created different approaches. Levels of asset management may vary from 'basic' to 'advanced' asset management. However the key principles remain broadly the same in all the water utilities.

3.5.1 Knowledge of assets and their environment

For a water utility to incorporate or adopt asset management principles as a philosophy or ethos there are certain data which are *de rigueur,* namely what assets are owned by the water utility, their value, their location and their condition (Vanier, 2001) . The primary information required for adopting asset management practises for an underground network are the physical attributes of the network i.e. the diameter of the pipe, the material from which the pipe is made, the age of the pipe and the spatial location of the pipe. Other information required relates to the environmental factors which affect the underground asset condition such as type of soil, ambient soil temperature, groundwater properties and information related to the climatic conditions. The tertiary information regarding type of traffic flow and the depth of soil cover above the underground asset, are also relevant (Hu and Hubble, 2005).

England was a frontrunner in recognising the importance of data. The Manual of British Engineering Practices, 1969, recommends recording data on leakage relative to various types mains bursts (Brandon, 1984). It further recommends recording of data regarding the details of mains, joints, fittings where appropriate, the causes of fracture, and the impact of pressure. It also mentions that the most valuable records are the drawings of the network of the distribution system. However there are still many water utilities in England which do not have this level of data about all of their underground assets.[4] Similarly, the availability of the range of general information on assets within the American and Canadian water utilities varies greatly (Wood et al. 2007). Most of the Australian water utilities have improved their data capture

[4] Walton, B., 2006, Personal communication

practices substantially over the years after realising their significance in asset management and they believe they now have a reliable database (Moglia et al., 2006).

3.5.2 Condition and performance assessment

The renewal decisions regarding the underground assets of a water utility are dependent on the information about the condition and performance of the assets. Condition of an asset is an indicator of the probability of failure. Condition and performance assessment, in combination with assessment of failure consequences, provides an understanding of risk. Given an understanding of risk, utilities are able to determine appropriate operational and capital maintenance and other asset management strategies (Urquhart, 2006).

The term ‘condition’ is used to refer to some measure of asset state when used in the context of asset management (Marlow and Burn, 2008). Grigg (2006a) has defined ‘condition of an asset’ as ‘readiness of a component to serve its function’ which includes physical integrity and the operational readiness of the asset. In the researcher’s opinion, Grigg’s definition of ‘condition’ is confusing in that it refers to a combination of two terms defining ‘condition’ (structural integrity) and ‘performance’ (functional capability) of an asset. Marlow and Burn (2008) interpreted condition and performance of an asset as complementary but separate views of an asset’s state. From this point onwards the researcher has adhered to use the word ‘condition’ to imply *structural integrity* and ‘performance’ to imply *functional capability*.

Assessing the condition of a complex water supply system is not easy and is therefore expensive. Most systems are composed of many different types of material, ages and are subjected to different loading conditions, differing soil conditions and even different qualities of water (Ellison, 2001). Many assets can continue to perform their function satisfactorily even when their condition has significantly deteriorated. Hence expenditure priorities are often more effectively determined by assessment of asset performance rather than merely structural condition (Urquhart, 2006).

Condition

It is difficult to make any physical observation on the condition of each of the components of the assets which are part of an underground network because of the sheer volume of the underground assets, on account of their inaccessibility and the costs involved (Knudson et al., 2006). The observation process is a disruptive and costly process which adds to the degree of difficulty in executing such a procedure (Ellison, 2001). Harlow and Stewart (2006) recommended that condition assessments are costly and should only be undertaken if the benefits outweigh the costs.

Marlow and Burn (2008) reported that for many types of water utility assets there is a general relationship between age, condition and the asset's propensity to fail when failure mechanisms such as corrosion, fatigue and mechanical wear dominate (See Figure 3-7). However, the rate of deterioration (worsening of condition) is highly asset and context (environmental, operational, installation) specific. Given the inherent spatial and temporal variability of these factors, to establish any time dependent relationship between asset condition and failure probability in even a moderate size water supply system, is very complex (Rajani and Kleiner, 2004).

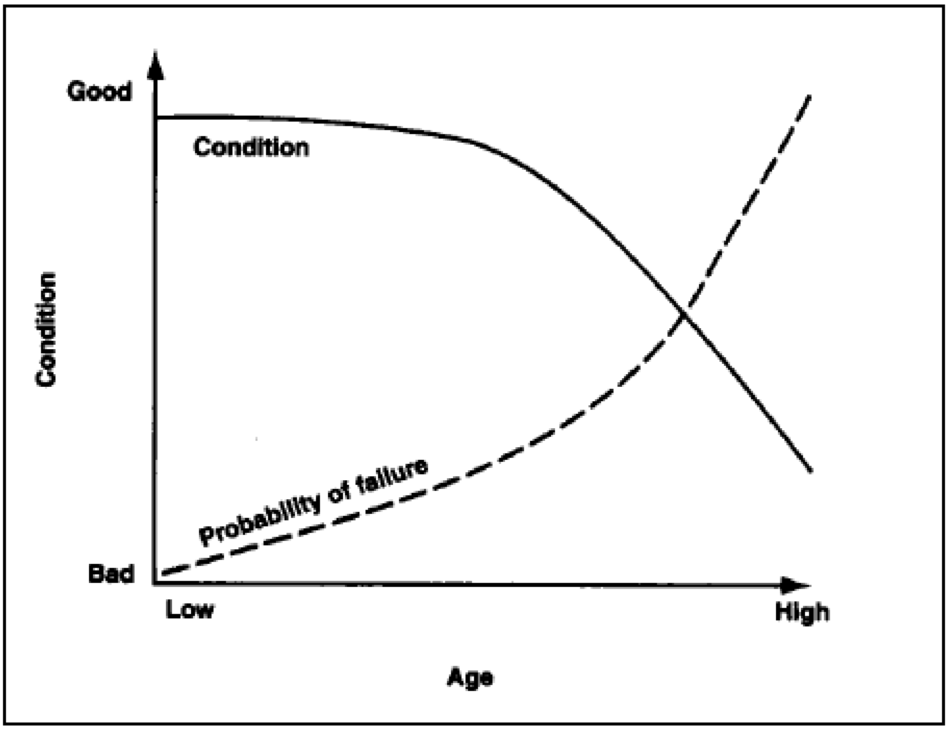


Figure 3-7 Conceptual relationship between condition, age and failure probability

Source: Marlow and Burn,2008

Kleiner and Rajani (1999) report that, there have been many studies and reports that have considered the impact of factors such as environment (type of soil, temperatures), operational (pressures, water quality), pipe material on the condition of pipes. However they have emphasised that no two systems are similar in terms of a combination of these factors. Hence no single model can be suitable for all the systems.

The methods that are commonly used for a structural integrity assessment of the pipes are direct inspection, coupon sampling, controlled destructive evaluation, remote field eddy current (RFEC) and acoustics (Ellison, 2001; Grigg, 2006b). Coupon sampling is one of the destructive methods used for old cast iron pipes that measures remaining wall thickness, encrustation, corrosion or other physical indicators of the pipe. Grigg (2006b) advocates the coupon sampling method only for those pipe materials where loss of wall thickness or corrosion might be related to conditions that can be generalised. Severn Trent Water, UK, made use of coupon and opportunistic sampling to develop a model for the assessment of the remaining useful life of the pipes by estimating corrosion rates taking into consideration all the factors affecting the process of corrosion (Kane, 1997). Opportunistic sampling refers to collecting samples of the underground assets when these assets are exposed because of reasons such as repair work, new connections being made. Severn Trent's model specifies the need for coupon sampling over and above opportunistic sampling, stating that the latter has no additional cost but has a bias in that samples are collected only from failure sites. The process of coupon sampling is more expensive, however this method is necessary to neutralise the bias in the opportunistic sampling. Alternatively, if opportunistic sampling is adopted then it is recommended to collect significant proportions of random samples also (Kane, 1997).

A majority of the underground infrastructure in the developed world is metallic (UK-80%, Australia-70%, Sweden-58%, Germany-75%, Russia-71%) (Savic and Walters, 1999). Non destructive evaluation (NDE) techniques have been developed for the evaluation of the condition of metallic and pre-stressed pipes. Remote Field Eddy Current (RFEC) method is the most common and effective NDE method for the condition evaluation available for iron pipes (Jackson et al. (1992) in Grigg, 2006b) (Ellison, 2001). Practical NDE techniques have not been used for non metallic/polymer pipes so far.

In this context, Grigg drew attention to the importance of the 'hidden' potential for evaluation of the condition of the underground assets, suggesting the value of making use of existing records and the knowledge and experience of employees. In the researcher's opinion this potential could be particularly of use in developing countries where advanced technologies are not available.

Canning (2002) and others (Ellison, 2001) and (Grigg, 2004) advocate analytical methods which do not directly measure pipe condition but only infer it from other measurements and data such as hydraulic evaluation involving pressure measurements of the water supply and water quality evaluation of the underground pipe network for condition assessment of water distribution networks. They also suggested the C-factor (Hazen Williams factor) test, which determines the roughness coefficient (indicating the smoothness of the inside of a pipe), as relevant to assess the physical integrity/structural condition of a pipe. Other methods such as water audit, flow gauging, pressure measurement and fire flow tests have also been recommended to assess the condition of the water system (Canning, 2002). Wood (2007) states the number of annual water main breaks is typically used as a surrogate for the condition of the network, though it does not necessarily reflect the pipe condition because breaks can result from causes other than lack of strength.

Ellison (2001) reports that the simplest method to assess the condition of an underground pipe network, is to use statistical analysis with age as a dependent variable and material and diameter of the pipe as independent variables. But DeSilva et al. (2005) contradicts this approach by reporting that condition assessment through statistical modelling may be a very complicated process, which may require extrapolation from the condition of inspected samples to a relevant asset population or pipe length. However, statistical sampling is widely used for the condition assessment undertaken for financial or regulatory reporting (Urquhart, 2006).

The condition of the underground assets is affected by many other factors such as water quality, assets' operational practices, and local environmental factors apart from age hence to make an accurate assessment of the useful life of the underground asset a holistic approach needs to be adopted (Hu and Hubble, 2005). Rajani and Kleiner (2004) provided an approach to estimate the probability of failure due to structural deterioration or poor condition of the asset by taking into consideration other factors affecting the condition of an asset by using physical or statistical models. It was further emphasized that these empirical models typically oversimplify a complex reality. For a reliable predictive model, substantial historic data relating condition of the pipe to factors affecting the condition of pipes is critical. A lack of appropriate data leads to reliance on overly simplistic models, which are really not useful for predicting the condition of the underground assets Cox (2003) in (Moglia et al., 2006).

In the researcher's view no single method can be suggested for assessment of the condition of the network. On the basis of the knowledge of factors affecting the condition of the pipe, including the experience of water utility staff who have a working knowledge about the condition and functioning of the pipe as well as the available technological and financial resources with the utility, a judicious decision needs to be made regarding selection of appropriate methods for condition assessment of the underground pipe network. In the researcher's view, special care needs to be taken into account for the possible influence of factors other than the condition of the network on water quality modelling in the particular case of intermittent supply.

Performance

Performance, that is the functional capability of assets, can also be viewed in terms of either the failures of assets or failure of the asset base to deliver the required levels of service. Marlow and Burn (2008) emphasised that service provision is a more appropriate focus for asset management and recommended a comprehensive service level performance monitoring system as the more relevant guide to decision making because service levels are a measure of both the effectiveness of asset management and a water utility's performance.

Future performance of assets, or future failure rates, need to be projected through predictive modelling of failures for any decision-making regarding renewal of these assets. One of the most vital pieces of information regarding the performance of an asset or class of assets is the *cause of failure* of the assets. Failure of an asset or poor performance could be a result of poor operational practice or 'condition' of the assets. To construct a model to predict the future performance of the assets to estimate capital maintenance investment, failure records need to be sorted out. Only those records need to be considered where the failure had been because of poor condition of the assets. For other types of failures where the cause has been incompetent operational practices or external loads or third party interference, performance predictions cannot be made (Ellison, 2001).

Predictive models based on pipe material performance do not take the variation in construction methods, ground conditions, consumption pattern, climate etc. into consideration adequately. However, these variations are implicit in historical performance data of the assets (D'Agata, 2003). Ellison (2001) stated that ‘the knowledge of the historical performance of a pipe is the best guide for prediction of future performance’.

Wu (2006) highlighted the role of hydraulic and water quality modelling to evaluate the system performance and service levels. It was further emphasised that although the computer models provide a good tool for systematically analysing the hydraulic and water quality behaviour, this approach requires a thorough understanding of the system in the real world and network hydraulics.

Performance indicators of the assets are considered to be management tools fundamental to monitoring the actions of the assets (Alegre et al., 2006). Selection of performance indicators/measures is very crucial to asset management. Performance indicators can be influenced by a range of factors such as capital maintenance or operational practices. ‘An ideal performance indicator would allow assessing the scope for improvement in system efficiencies and tie in with the organisation’s strategic policy and plan’ (UKWIR, 2002b). There are costs and efforts involved to gather inputs and maintain each performance measure. Therefore the selection of performance measures regarding asset management should be carefully evaluated in terms of their strategic value to either management decision making or stakeholders’ expectations and also should be strongly justified on a cost benefit basis. Performance measures should provide objective quality evidence to assist in decision making or the preparation of action plans (Matichich et al., 2006a).

Each year water and sewerage companies in England and Wales are required to report information on their performance against various aspects of service as shown in Table 3-1.

Table 3-1 Serviceability indicators used by OFWAT

Source: OFWAT, 2008

DG2	Inadequate pressure
DG3	Supply interruptions (unplanned)
DG4	Restriction on water use (Hosepipe restrictions or drought orders)
DG5	Flooding from sewers
DG6	Billing contacts
DG7	Written complaints
DG8	Bills for metered customers
DG9	Ease of telephone contacts

These are known as serviceability indicators, which are focussed on the service to the customers. These serviceability indicators measure the performance of the system instead of performance of a particular asset or asset category. It is 'serviceability to customer' and not 'serviceability of the assets' (Parsons, 2006). DG2 to DG5 can be directly related to capital maintenance however DG6 to DG9 clearly have little direct connection with pipe network operation or capital maintenance issues.

Serviceability as defined by OFWAT is "A long-run approach, which considers the ability of the appointed water companies to maintain the existing standard of service to customers" and *Serviceability indicators* are defined as "A defined set of (high level) outputs or outcomes that are considered, when taken together, to indicate the capability of the fixed assets to provide service to customers now and in the future" (OFWAT, 2007). Parsons (2006) reported that serviceability is considered at company level and the aim is to ensure that the trend in serviceability remains stable or improves and that absolute values of indicators are not considered important for asset management planning. However the trend of serviceability indicators with respect to capital maintenance can be affected by the impact of the deterioration of a number of different types of assets and it may not be possible to isolate the impact of a particular asset or class of assets (UKWIR, 2002b).

It has been observed that the terms 'service', 'service to customer' 'serviceability', 'asset performance' and associated indicators, that is service indicators, asset performance indicators and serviceability indicators, are often used without correctly defining these terms. Service is used in context of 'use/performance of the asset' and 'service to customer'. 'Service to customer' includes both customer service and water service.

Parsons (2006) has illustrated with reference to the UKWIR report (UKWIR, 2002b) that the indicators can be pictured in the form of a Venn diagram where one set is service indicators and the other set is the asset performance indicators and the intersection of the two sets is the serviceability indicators.

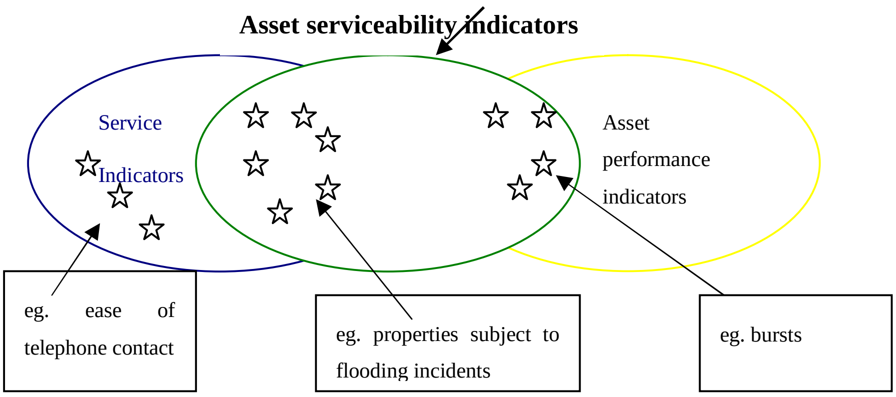


Figure 3-8 Asset serviceability indicators

Source: Parsons, 2006

In the researcher's opinion it would be better if a distinction is drawn between 'customer service' and 'water supply service'. Since performance of assets and water service delivery are interrelated, for example a mains burst will result in service interruptions, a combination of asset performance indicators and water service indicators could be called serviceability indicators. Indicators like ease of telephone contact could be customer service indicators, independent of the physical asset performance.

An AWWA study utilised seven performance measures to gain insight into asset condition and renewal requirements from the data gathered from eleven water utilities in the USA. These were number of unplanned service interruptions, number of main breaks/mile, number of water quality violations, renewal and replacement status, maintenance activity, preventive maintenance and age vs. service life (Matichich et al., 2006a). In Australia, water supply interruptions are regulated and used as key performance indicators (Moglia et al., 2006).

Alegre et al. (2006) reported that in the European CARE-W programme, performance indicators were classified into five categories for the rehabilitation manager tool, specifically directed at pipe network renewal. Table 3-2 provides details of indicators used by CARE-W. Alegre et al. (2006) has also reported that in the pilot study of application of these performance indicators, economic and financial indicators had the lowest rate of success because of unavailability of this data at subsystem level.

Table 3-2 The CARE-W performance indicators for network rehabilitation (relevant to performance),

Source: (Alegre et al., 2006)

Operational indicators	
Rehabilitation	Mains rehabilitation (%/year): Mains renovation (%/year), Mains replacement (%/year), Valve replacement (%/year) Service connection rehabilitation (%/year)
Failures and repairs	Mains failures (No./100km/year): Pipe failures (No./100km/year), Joint failures (No./100km/year), Valve failures (No./100km/year), Service connection insertion point failures (No./100km/year) Critical mains failure (No./100km/year) Service connection failure (No./1000conn./year) Hydrant failures (No./1000hydrants/year) Power failures (hours/pumping station/year) Active leakage control repairs (No./100km/year)
Water losses	Water losses (m^3/connection/year), Real losses (l/connection/day)
Financial indicators	
Annual costs	Unit total costs /m^3, Unit running costs /m^3
Annual investment for network mains	Unit investment for network mains /m^3, Annual investment for new assets and reinforcement of existing assets (%), Investment for asset replacement and renovation (%)

Quality of service indicators	
Service	Pressure of supply adequacy (%) Water interruptions (%): Interruptions per connection (No./1000connections), Critical interruptions per connection (No./1000connections) Population experiencing restrictions to water service (%): Days with restrictions to water service, Quality of water supplied (%): Aesthetic test compliance (%), Water taste test compliance (%), Water colour test compliance (%), Microbiological test compliance (%), Physical-chemical test compliance (%)
Customer complaints	Service complaints per connection (No. /1000conn./year): Pressure complaints (%), Continuity complaints (%), Water quality complaints (%), Water taste complaints (%), Water colour complaints (%), Interruption complaints (%), Critical interruptions complaints (%)

Marlow and Burn (2008) suggest performance indicators relevant to the strategic objective of water utilities as shown in Table 3-3 below.

Table 3-3 Performance indicators relevant to strategic objectives of water utilities

Source ((Marlow and Burn, 2008)

Strategic objective	Performance indicator
Improve water quality	Water quality compliance at treatment facility, turbidity at treatment facility, water quality compliance at tap, coliform compliance (treatment facility, service reservoir), iron pick up in system
Invest in measures to reduce discoloured water complaints	Number of customer complaints
Reduce interruption to supply	Unplanned interruptions, interruption duration, interruption frequency, water pumping station failures, bursts per unit length

The indicators recommended by OFWAT to be reported for assessment of capital maintenance requirement through asset management planning by water utilities in England and Wales have a specific focus on service to customer. By contrast, the pool of performance indicators recommended in CARE-W is for internal asset management planning of water utilities, encompassing financial and operational aspects, and resource availability besides customer service.

3.5.3 Optimisation and prioritisation of renewal options

Optimisation is defined as ”to find the best possible solution to a technical problem in which there are a number of competing or conflicting considerations’[5] i.e. ‘solve in the best way possible”. In this case competing considerations are sustainable service and limited finance.

Prioritisation is ranking something according to importance or urgency. In the case of asset management practices it is the ranking of infrastructure renewal actions involving spatial and temporal dimensions.

In the case of asset management practices, decisions are required regarding

- Which assets (i.e. geographical locations or asset ID) need to be renewed?
- How should these be renewed? (Selection of an intervention option)
- Which will be renewed first?

The decision regarding the selection of an intervention option for renewal is an exercise in financial/economic optimisation; the other two decisions involve spatial and temporal prioritisation (Raven, 2006a).

Raven (2006b) described prioritisation as meaning ‘replacing the *right* pipe’ and full economic optimisation as ‘replacing that pipe at the *right* time’. Cox (2005) reported that the basic process of optimisation is to maximise value for minimum cost.

Based on a thorough literature search, Deb et al. (2002) grouped basic approaches for prioritisation of the pipes for renewal into four categories: break-even analysis method, deterioration point assessment method, failure probability and regression analysis and mechanistic models.

- ***Break-even analysis***

---

[5] At http://www.casegroup.org/, accessed on 2/5/08

This method is cost based and considers costs of all the possible options of renewal simultaneously. This method needs to be supported by predictive modelling of pipe failures. It compares the cost of ongoing repair or rehabilitation with the cost of replacement to find a break-even point at which the present value (PV) cost of replacing pipes equals the cost of continuing to repair it. In this method historic pipe failure data is needed for predictive modelling of pipe failures and detailed cost information is also required. It is essential to apply rational and consistent discount and inflation rates while considering PV. Secondary and indirect costs such as administrative costs or pavement repair cost also have to be taken into consideration along with intangibles, for example traffic disruption and reputation loss, by assigning economic values to them. The prioritisation is based on financial returns (Deb et al., 2002).

PARMS-Priority is the model presently being tested by Australian water utilities based on the above mentioned approach (Moglia et al., 2006).

The same concept is taken further from financial returns to risk analysis. Here, risk costs are added to the financial costs for prioritisation by incorporating the cost of adverse consequences of a failure along with its probability.

- ***Deterioration point assignment method (DPA method)***

This method uses a scoring methodology to rank pipes for renewal. All the factors affecting the pipe failures are identified. These may include age, diameter, material and location of pipe, water pressure, type of soil and number of previous breaks. Each factor is grouped into several class intervals and a numerical value or failure score is assigned to each class interval. For any pipe a total failure score is obtained by summing up all the failure scores for each factor. This composite failure score of a pipe is compared against a threshold failure score value to make a decision regarding renewal of the pipe. The shortcoming of this approach is that pipes receiving the same score cannot be prioritised further. This becomes particularly relevant in case of limited funding.

- ***Failure probability and regression methods***

These methods are similar to the DPA method. They consider possible factors responsible for pipe deterioration but also involve predictive capability by assessing the probability of the survival of the pipe. The methods require very detailed water main break data to effectively analyse and predict the future failure rates.

- ***Mechanistic models***

Mechanistic models employ strength estimates as a function of failure causing factors. The mechanistic methods/models are incorporated within a probabilistic model to assess the residual strength of a given pipe at a given time. Residual strength is the information used for making decisions regarding renewal of pipes. The background deterioration of the pipe or loss of strength is attributed to corrosion. Other factors contributing to an accelerated rate of failure after corrosion has set in, such as frost load, temperature effects and traffic load are also factored into this approach.

In the researcher's view the break-even analysis method is the most comprehensive optimisation and prioritisation method. This method optimises renewal intervention options and the timing of the renewal. It provides a decision-support system for financial/economic optimisation as well as prioritisation. The other three methods only rank the assets in the order of the probability of future failure rates. Cox (2005) recommended optimisation rather than simply ranking assets or prioritisation as best practice in investment planning. Therefore break-even analysis is the best approach for the optimisation and prioritisation step of the asset management process. However Marlow and Burn (2008) have highlighted the difficulties involved with the quantitative cost and benefits of maintenance strategies for formalised asset management and have emphasised these as the key areas to address for the water utilities and research communities.

3.6 Asset management framework for underground assets

Since the available literature regarding asset management in water utilities is predominantly focussed on the underground assets; a generic model for the asset management process specific to underground assets of water supply network system has been developed by the researcher on the basis of the principles and methods discussed in Section 3.5 and 3.6. This framework is presented in Table 3-4 below.

Table 3-4 Generic asset management model for underground assets of a water supply system

A. Define asset management objective
B. Document asset and its environment information
a. Asset information
a. Attributes i.e. diameter, manufacturing material, age
b. Geographic location
b. Asset environment information
a. Type of surrounding soil
b. Historic information regarding variation of temperature & weather
c. Depth of soil cover
d. Volume and type of traffic details
C. Serviceability (asset performance, service performance) assessment and forecasting
a. Selection of indicator(s)
b. Service performance / asset performance / asset condition observation &/or assessment incl water quality delivered by asset
c. Identification of gaps in objectives and existing serviceability
D. Identification of possible intervention options
E. Optimisation (Based on financial rate of return or risk cost)
F. Prioritisation (Spatial and/or temporal)

3.7 Asset management framework for above-ground assets

A water supply infrastructure system has a large number of assets such as water treatment plants, electrical and mechanical machinery, dams, reservoirs and pump houses which are called above-ground assets because of their location relative to the ground surface. The asset management practices which are brought to bear on above-ground assets are distinct from the asset management practices utilized for underground asset management, mainly because physical inspection of these assets and therefore assessment of their condition and performance is possible.

Although the focus of this literature review has been on underground assets it is necessary to also consider an appropriate generic model for above ground assets. Not only are above ground assets more visible, by the very nature of predominantly mechanical and electrical equipment they are likely to have much shorter asset lives. In the context of India, and taking a forward-looking risk based approach, it is likely that serviceability issues related to cost will manifest themselves primarily in above-ground assets for at least the present period.

Asset management practices of the above ground infrastructure, specifically electrical and mechanical machinery involves a *life cycle costing* (LCC) approach. A LCC analysis attempts to develop a cost profile over the life of the assets (Engelhardt, M., et al, 2003). The advantage of adopting this approach is stated to be optimal value for money in the ownership of physical assets by taking into consideration all the cost factors related to an asset during its operational life (Woodward, D., 1997). It has also been postulated that the concept of LCC modelling is a very strong and useful tool that offers considerable opportunities to reduce the cost associated with operating pumping equipment. However LCC is a strategic model that can also be used to assist in developing equipment purchasing strategies linked together with clear maintenance and operational procedures (Redit, M. 2007).

In England and Wales because of an increasing pressure from the economic regulator on the water companies to ensure that their capital maintenance decisions reflect an understanding of the long term impact on their operational costs and risks, water utility managers approach the management of their M & E assets by adopting a life cycle costing process. A further reason for the adoption of LCC approach in England is that it has been found that there is a 2-3% reduction in the energy efficiencies of pumps annually which is leading to a major refurbishment of the pumps every two to three years.[6]

It is an accepted management premise that for any decision support system, availability of superior quality and quantity of data is a primary requirement. For the decision making to be efficient it is an essential requirement. The UKWIR Common Framework for Capital Maintenance also placed great emphasis on availability of sufficient historical data on asset failures and recognised that practical application of the Common Framework has certain constraints like limited data available in the short term which will restrict it from full application (UKWIR, 2004a). Therefore, in order to increase availability of data on the reliability of equipment there is an existing 'Water Industry Database of Equipment Reliability' (WIDER) database and further research is ongoing to modify the protocols and develop a web-based common data base for all participating utilities to enable them to make informed decisions on purchase and maintenance strategies of equipments in the light of Common Framework. The estimated cost for database administration and support is between £55,000 and £75,000 per year with additional cost from £40,000 to £60,000 for data enrichment (UKWIR, 2004a).

Apart from the survey of available literature on the subject, interviews with serving water utility managers revealed that in England, the data available with water utilities for pumping machinery is for the composite unit of 'Pump house' and not for individual pumps. The data generally recorded is hour run, volume of water pumped per unit time and energy consumption7.

Since the basic principles of asset management remain same for all categories of assets, a generic model for above-ground asset management model for M & E assets of a water supply system similar to the asset management model for underground assets presented in Table 3-4 has been developed with minor variations based on the above discussed information through literature and interviews. This model is presented below.

---

[6] Franceys, R., (2007) Personal communication

[7] Everest, M., Meniscus Systems Limited, Personal communication , 30/3/07

Table 3-5 Generic asset management model for above-ground (M & E) assets of a water supply system

A. Define asset management objective	
B. Document asset information	
	a. Attributes i.e. manufacturing material, age, design parameters (discharge flow, head), horse power
	b. Geographic location
C. Serviceability (asset performance, service performance) assessment	
	a. Selection of indicator(s), for example LCC, MTBF, hydraulic and energy efficiency
	b. Service performance / asset performance / asset condition observation &/or assessment including energy consumption
	c. Identification of gaps in objectives and existing serviceability
D. Identification of possible intervention options	

3.8 Summary of the chapter

Most of the literature available regarding asset management in water utilities has a focus on regulation or financial reporting requirements. Another category of the literature that is available focuses on various modelling methods for predicting future performance of assets and risk analysis for optimisation and prioritisation. The literature about the process of asset management was obtained from conference proceedings and most of the papers are by water sector professionals providing a very useful practical perspective of the application of asset management.

Overall the literature review has identified the following key aspects with respect to this study:

There is a lack of clear definition of the concept of *sustainability of water service*, which raises the need to derive an explicit definition based on the context under consideration.

From the utility's perspective, sustainability is therefore defined in terms of the requirements of the utility to provide service. In the context of the three-pillar definition of sustainable water service (Environmental, Functional and Financial) it has been demonstrated that asset management contributes to all three dimensions of sustainability, though with varying relevance. The focus on the functional dimension of sustainability is justified by water service being essentially dependent on the physical infrastructures owned, operated and maintained by the water utility and the role of asset management in procuring, operating and maintaining these infrastructures. Since the procurement, operations and maintenance of physical infrastructure entail significant costs within a long-term perspective, there is evidently an impact of asset management on the financial sustainability of service. The discussion has further demonstrated the contribution of asset management towards environmental sustainability of water service by controlling physical loss of water through leakage. The discussion, as demonstrated through this review has endorsed the choice of asset management as a tool to address all three aspects of sustainability of water service.

From the professional literature the underlying principles and methods of asset management that have been used by the water utilities regarding underground pipe networks have been identified. By integrating these principles a unique and generic asset management model for underground pipe network is proposed. The review also helped in identifying data requirement to be able to address the research objective 4.

A series of literature based case studies describing how utilities have been using these asset management principles in practice can be found in Appendix 1 – for Severn Trent, Northumbrian and an unnamed utility.

In summary the literature review has helped to address the first three research objectives as detailed in Chapter 2. The review has therefore helped to establish the desired generic asset management model (objective 3) for underground and above-ground (M & E) assets that in subsequent chapters will be used to test the viability of the application of asset management in the context of an urban water utility in India. It also confirms the validity of the research questions and justifies the use of the proposed conceptual framework, described in the next Chapter, for assessing the adaptability and potential contribution of asset management towards functional sustainability of the water service provision in an urban centre in India.

Chapter 4: Research methodology

4.1 Introduction

Following a description of the conceptual framework which underlies this research, this chapter presents the methods used to collect information and data required for this study and their respective data sources and the associated sampling strategies. The research roadmap is presented in the logical flow diagram of the methodological framework along with techniques for data analysis, interpretation and the subsequent linkage to the formulation of the proposed asset management model applicable to Indian urban centres are also described. The chapter further presents the critique of the methods used, high-lighting the limitations.

4.2 Conceptual framework

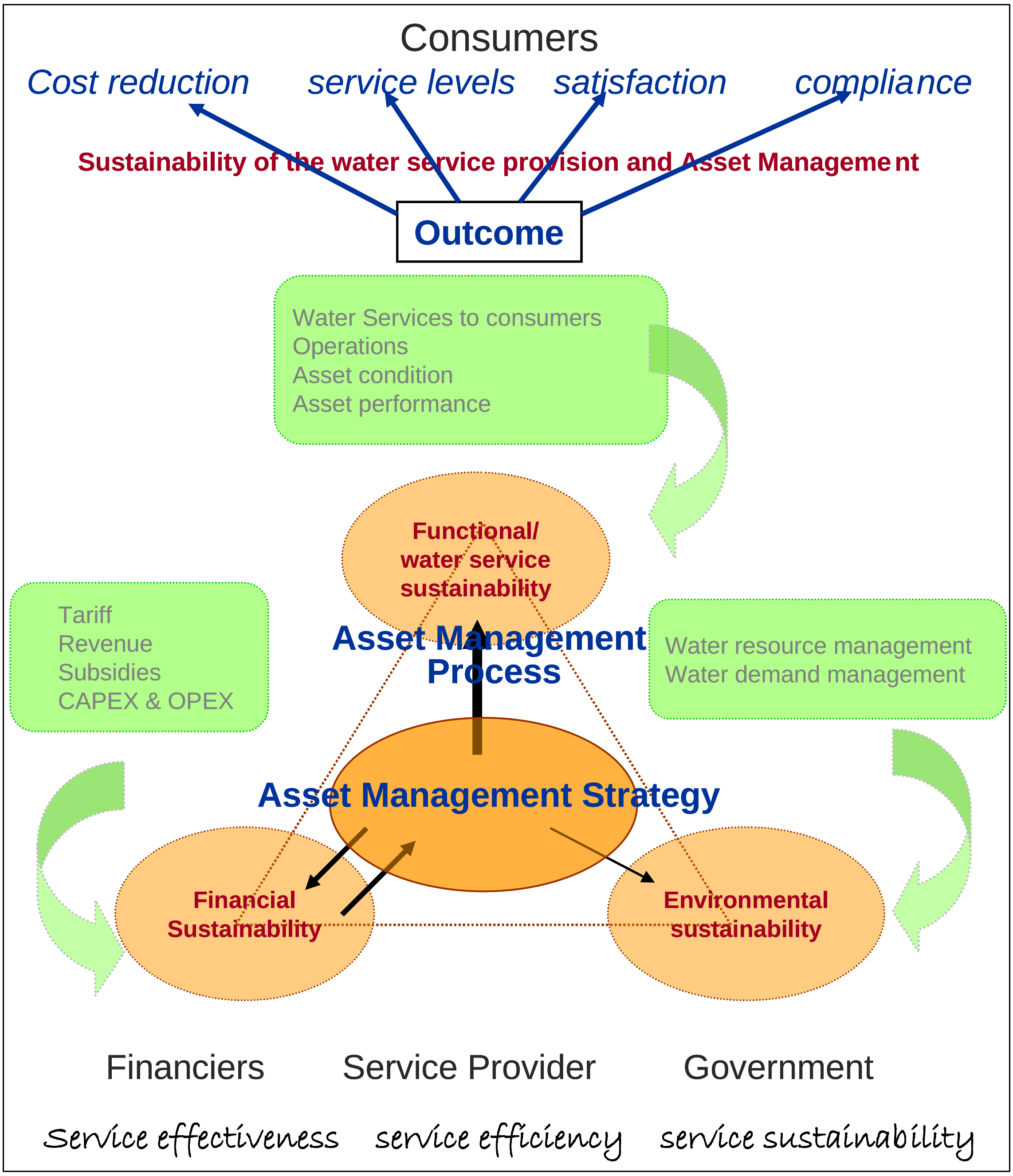


Figure 4-1Conceptual framework

Asset management strategy: *Overall long term plan for the asset(s)/asset types/asset system. (BSI, UK)*
Asset management process *links from the highest level of strategic planning through to day-to-day operational activities.*

The conceptual framework shown above in Figure 4-1 represents an outline of this research enquiry. It informs the formulation of the research approach.

It firstly and necessarily recognises the stakeholders in the process. Stakeholders are defined as “person or group or organisation having an interest in the performance or success of an organisation” (ISO, 2007). There is a broad array of types of stakeholders that can play a role in activities related to water services. Primarily there are four primary stakeholders in the water service delivery system, the consumers, service provider(s), government (policy-maker) and financiers. The International Standard on ‘Activities relating to drinking water and wastewater services’ (ISO, 2007) advises that all the stakeholders should be involved in both setting the service objective and assessing the adequacy and efficiency of service.

Although the consumers *per se* play a passive role in the water service delivery they have a vital stake in the entire process because ultimately the service providers exist only to provide water service to the consumers.

Government determines national policies on different aspects of planning and the rules that govern the functioning of water service provision to communities. To manage water services properly, it is necessary to incorporate a balanced set of policies and institutional reforms and therefore the role of government as stakeholder is a prominent one.

The service provider is basically the nuts and bolts deliverer of the system i.e. the service provider who is responsible for the entire process, from production to delivery of water. This role is normally played by the various water utilities, which could be either entirely in the public sector domain as is the case in India or they could be entirely in the private domain as is the case in England.

The principal benefits of asset management, as discussed in the previous chapter, are enhanced customer satisfaction from improved performance and control of service delivery with subsequently improved health, safety and environmental performance; optimised return on investment and best value for money through efficiency measures within a constrained funding regime; and evidence to demonstrate statutory and regulatory compliance in addition to consideration of sustainability of service. Asset management also contributes to an improved image of the utility and the subsequent potential benefits in terms of enhanced shareholder value and improved marketability (BSI, 2004; Lewis, 2006). Asset management can affect a *change* in the working culture/ethos of the water utility functioning and the way that water utility managers manage their assets (Lewis, 2006; Sklar, 2006).

Cost reduction is the biggest commercial effect of asset management. In England and Wales, asset management practices have contributed to significant savings in capital expenditure in addition to savings in operational costs (Aikman and Doherty, 2006). The Environmental Protection Agency (EPA) in the US estimated a 20% reduction in asset-related costs through adopting effective asset management practices. Clarke (2005) reported a 10% reduction in operation and maintenance budgets of the Seattle Public Utilities due to an asset management programme.

An effective water service is a system that provides adequate, as defined by legislation or regulation, quantity and quality of water to the customers or consumers so as to ensure previously defined standards of public health. Effectiveness measures the extent to which outputs achieve original objectives. From the point of view of customers, effectiveness is measured by the quality of the water supply they receive, in the form of water availability, water quality and consumer satisfaction (Nickson and Franceys, 2003).

Efficiency measures the relationship between resource inputs and outputs, both in operational and financial terms (Nickson and Franceys, 2003). An efficient water delivery service system makes optimum use of its resources, minimises the cost of service delivery by removal of system inefficiencies and provides the best possible service within the existing constraints.

As discussed in Chapter 3, asset management contributes towards all three aspects of sustainability of water service i.e. the environmental, financial and functional sustainability in differing magnitudes because a key element of the asset management process, apart form the optimal use of the resources, is to maintain water service in such a way so as the burden of under-investment is not transferred to the future generations and maintenance of assets and serviceability whether in the immediate or in the future is also factored into the asset management process.

As informed by the literature review presented in Chapter 3, asset management has the potential to make a meaningful contribution to all the three that is effectiveness, efficiency and sustainability of the water service thereby forming the broad premise of the conceptual framework.

4.3 Formulation of research methods

4.3.1 Overview of the methodologies and the theoretical frameworks

The purpose of this research enquiry could be classified as exploration. An exploratory purpose of enquiry is to assess phenomenon in a new setting or light (Robson, 1993). This research enquiry is initially designed to investigate the viability and adaptability of asset management in the context of urban water utilities in India, then to develop a model to suit this context and assess it for wider application.

Case studies are considered appropriate for exploratory work and the development of detailed, intensive knowledge about a case (Robson, 1993). Therefore the ‘case study’ research strategy was adopted, designed by developing the conceptual framework above, covering the main features of asset management and its relationship with various aspects of water service.

Table 4-1 illustrate the logical methodological framework showing the research steps taken to achieve the key objectives of the study. An overview of the factors affecting institutional activities was carried out regarding an urban water utility in India. Literature and electronic sources were the main sources of information regarding asset management and sustainability of water supply systems. Discussions with water supply sector professionals from England provided relevant practical information on asset management from a practitioner’s point of view. The representative water service provider i.e. Public Health Engineering Department, Jaipur was the main source of primary and secondary data collection for the initial case study. The whole process of data collection from a public sector utility in India had its unique challenges as described in section 4.6.

4.3.2 Data needs and information sources

Following the identification of the conceptual framework for research the next stage was to determine data needed for the study, their sources, and collection methods. Table

4-1 presents the detailed description of the type of data, their sources, collection methods, analytical techniques for each of the corresponding research objectives.

Table 4-1 Research objectives, data needs, sources and collection methods

S. No.	Objectives	Data needs	Data sources	Collection methods
1	To describe sustainability in the context of water supply systems and assess the role of asset management regarding sustainability of water service	Descriptive information on various issues related to sustainability of water supply systems	Library and electronic sources	Literature review
2	To determine the key drivers of the asset management in water utilities in high-income countries and assess their relevance in Indian context	Descriptive information on drivers of asset management in water utilities	Library and electronic sources Water utility professionals	Literature review Interview water utility professionals in England
3	To determine the asset management principles, methods and data requirement with reference to water service and develop a generic asset management framework	Descriptive information on practices of asset management in water utilities	Library and electronic sources Water utility professionals	Literature review Interview water utility professionals in England
4	To apply the generic framework in order to assess the viability and adaptability of asset management in an Indian urban water utility and identify constraints	Data on assets, water service levels and present capital maintenance practices in Indian urban water supply sector	Case study water utility. Customer survey	Interview water supply professionals in India Historic records Observations Questionnaire survey
5, 6	To propose an asset management model adaptable to Indian context and assess the potential relevance of it	Information on availability of data within other water utilities. Opinions of Indian water supply practitioners	Water utilities, Water sector practitioners from India	Questionnaire survey Interview urban water supply professionals in India

4.4 Research stages

4.4.1 Literature review

From the initial literature review, information regarding the concepts of sustainability of water supply systems and the role of asset management towards sustainability was collated in order to address the research objective 1. The information was used to categorise sustainability in the context of water supply systems. Then to address the research objective 2, the key drivers of asset management were identified from the literature review. Further, the generic framework from the International Infrastructure Management Manual, presented in Figure 4-2 was adopted for reviewing the factors affecting the organisational activities of an Indian urban water utility. The review provided a basis for understanding the issues affecting the water service provision in Indian urban centres. This part of literature review also helped address part of the research objective 2, to assess the relevance of the asset management drivers in the context of Indian urban water supply sector.

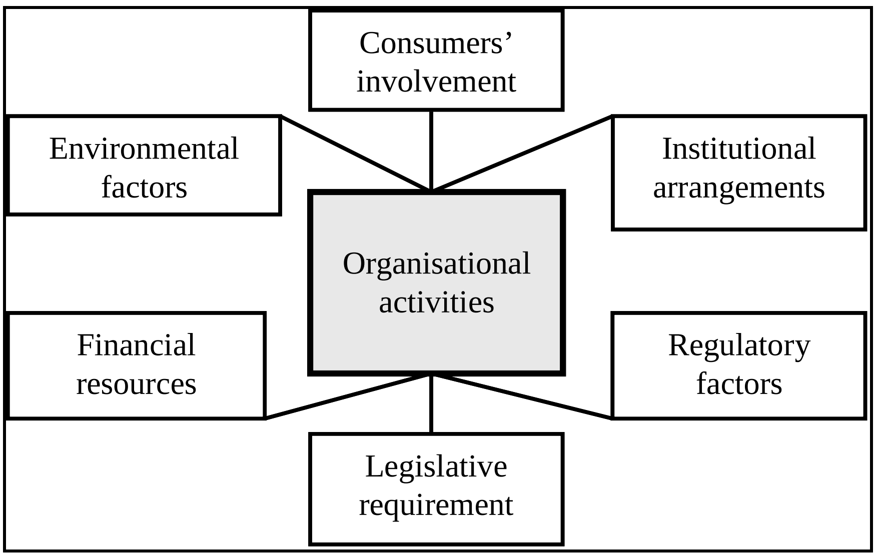


Figure 4-2 Factors affecting organisational activities

Source: NAMS and IPWEA, 2001

The next stage of the literature review was focussed on achieving the goals set in objective 3 i.e. to determine the asset management principles, methods and data requirement with reference to water service. This phase of the literature review was complemented by interviews with water utility professionals from England. These interviews provided details on practical application of asset management process. (See Appendix 1)

At the end of this phase the researcher was conversant with the asset management process and the requirement of data for the same as illustrated in Table 4-2. It enabled the researcher to develop a sampling strategy and detailed methodology for carrying out the field work in India described in Section 4.3.

Table 4-2 Data requirement to test the generic asset management model

Objective	**Methods**	**Data required**
To identify the suitable asset categories to be observed and relevance to serviceability	Analysis of historic capital maintenance expenditure	Financial statements
Preparation of asset register	Data on asset attributes, location, condition, performance	Network drawings, Main burst records, Water quality monitoring records, Repair maintenance records
Level of service observation/Selection of performance indicators	Identification of service level indicators required	Customer complaint records Customer survey records
Optimisation and prioritisation	1.Analysis of historic performance data and performance forecast modelling 2.Modelling relationship between factors affecting structural condition of the assets and remaining age of the asset 3. Financial rate of return analysis or risk analysis considering probability of performance failure and consequences thereof	1.Specific asset category historic performance data such as main burst data 2.Coupon sampling data, Opportunity sampling data 3.Historic performance data, various cost associated with consequences of failure, Modern equivalent asset costs, inflation rates, interest rates etc.

Life cycle costing of pumping machinery	Life cycle costing	Purchase cost, operating cost, maintenance cost, mean time between failure (MTBF), time period between overhauls, mean time to repair (MTTR), repair cost and energy use rates, inflation rates

4.4.2 Testing exercise for viability of application of generic asset management model for assets

The generic asset management models for underground and above-ground assets (See Table 3-4 and Table 3-5) was tested for it its applicability, in the context of an Indian urban water utility, by quantitative and qualitative analysis of the fieldwork data. While testing the generic model, the constraints regarding its applicability were identified. Recognising these constraints, an asset management model adaptable to the Indian context was proposed.

4.4.3 Assessment for wider application of the proposed asset management model for Indian urban water utilities

Subsequent to the formulation of the asset management model adapted to the Indian context, the next phase of the research was designed to ascertain whether it could be *generalised* with respect to Indian urban water utilities. Some level of validation of the proposed asset management model was required to confirm whether other similar utilities would be in a position to use this model. Part of this confirmation exercise was to determine the quality of data available with other utilities in India. This was sought from different water utilities in different States using a questionnaire survey. To assess the potential relevance of the proposed asset management model, the views of urban water sector managers were also sought, through semi-structured interviews, on the potential use and benefit of the proposed model and also to identify the potential challenges in practical application of the model.

4.5 Fieldwork methodology

The fieldwork was divided into three distinct phases (See Table 4-3). The first phase of the fieldwork was designed to gather preliminary information regarding the effectiveness of the service, especially in the context of low-income groups (the main justification for a public water supply) and to gain a background understanding of the issues related to financial sustainability of the utility. Within this stakeholder context, the second and longest phase of the field work was undertaken to collect information and data regarding the *detailed case asset management study. T*he third phase of the fieldwork considered the wider *application of the proposed model*.

Table 4-3 Fieldwork phases

Fieldwork phase	Data collection	Place	Time frame
Phase 1 A **Preliminary research**	Focus group interviews	Jaipur	07/ 2005
Phase 1 B **Preliminary research**	Annual financial statements	Jaipur	12/ 2005
Phase 2 **Detailed case study**	Office based data collection, interviews of water utility personnel, field observations, and customer survey	Jaipur	03/2006 to 09/2006
Phase 3 **Validation exercise**	Questionnaire survey and interviews of water utilities professionals	Mohali, Panchkula, Chandigarh, Shimla, Patna and Jaipur	12/2007

4.5.1 Preliminary research (Phase 1 fieldwork)

The first phase of the fieldwork was further divided into two parts, 1 A and 1 B. Phase 1 A of the fieldwork was undertaken in July 2005, before this research study formally started. Phase 1 A was aimed specifically at understanding the effectiveness of water services with a special focus on low-income areas. Focus groups were conducted in selected low-income areas and information was collected regarding water service levels, coping strategies adopted and their satisfaction levels with service provision.

Phase 1 B (December 2005) was specifically aimed at determining the issues related to financial sustainability and the current capital maintenance strategies in practice with regard to functional sustainability of water service. Informed by the OFWAT historical performance approach, the first step was to analyse historical capital maintenance spending and assess the current level of expenditure across various asset categories to identify the suitable asset categories to be observed. For this purpose the annual financial statements were sought from PHED Jaipur and analysed to identify the asset categories to be observed. This analysis also illuminated the financial context within which any enhanced asset management might be promoted.

4.5.2 Detailed case study (Phase 2 fieldwork)

During the phase 2 of the field work (March 2006 through September 2006) data about the water supply system of one particular Indian urban water utility was collected. Two approaches were employed for primary and secondary data collection, as both were required. ‘Primary’ refers to the information that has been collected first hand through interviews, questionnaires, observations and ‘secondary’ refers to the data collected by others to be re-used by the researcher. A detailed description of each element of the second phase of the fieldwork is provided in Chapter 6.

Selection of the study area

Due to past experience, the researcher was well aware of the particular challenge of data collection from a public sector service provider in India. The researcher was particularly aware of the importance of social networking to gain access to relevant officials and the information they controlled. This was the main reason to choose Jaipur as the primary study area as the researcher has been working there for the last thirteen years and could rely on good social network to gain access to data and co-operation from the main service provider, the Public Health Engineering Department (PHED). A single agency, PHED Rajasthan, is responsible for management of water supply in all 32 districts of Rajasthan, rural as well as urban. Therefore all the districts follow (are meant to follow) a similar pattern of information management and policies. This was another reason to select Jaipur as the study area as this would be representative of all these districts. The extent to which other districts did in fact use the same information management system was verified by visiting another urban centre in Rajasthan, Jodhpur, during the third phase of fieldwork.

Efforts were made to collect data from another city, Delhi. Apart from two interviews, no further co-operation was extended by members of Delhi Jal Board staff and data regarding distribution network was denied citing ‘security threats’. These two interviews were also the result of accessing a social network but the ‘social capital’ did not appear to be high enough to release further information.

Sampling strategy

Sampling is undertaken to make an estimate about the information of interest, which in this study is particularly focused upon capital assets: their age, condition, and performance. The accuracy of the estimates largely depends on the heterogeneity of the study population with the characteristics that have a strong correlation with what one is trying to ascertain (Kumar, 1996). Lindley (1992) advocates adaptation of stratified random sampling to produce data that would represent the region as a whole in case of limited resource availability. He further stresses the need for a clearly identifiable basis of stratification and that it should be related to the main variable being explored. So to reduce the heterogeneity in the population for the greater accuracy in the estimate, initially stratified random sampling was proposed to be implemented. In this case study the main variable is capital maintenance investment and service levels, which are known to be related to assets condition and performance. Condition and performance can further be related to age and material of the pipe material among other things. It was proposed to stratify the whole water supply system on the basis of the age and material of the network, mainly for infrastructure assets (underground assets). However the challenge of obtaining details regarding attributes of assets i.e. age and material for all the distribution zones was insurmountable in practice and therefore stratified random sampling could not be undertaken. The approach then taken was to choose representative distribution zones for sampling. Three distribution zones were selected on the basis of representing three different age groups and three different types of pipe materials for collection of information and data.

Data collection

Utility staff at all levels i.e. field engineers, operating staff, decision makers and policy makers of PHED Jaipur were interviewed to collect information regarding the present approach to asset management. (See Appendix 3 for list of interviewees). Kumar (1996) advocates unstructured interviews carried out in a one to one situation along with an interview guide in situations where in depth information is needed and little is known about the area. The interview guide used for unstructured interviews is given in Appendix 4.

The second step, as shown in the generic asset management model for underground assets (presented in Table 3.5), is document asset and its environment information. To achieve this, available data regarding asset attributes (age, material and diameter), asset location (distribution network drawings), main burst records, customer complaint records, repair maintenance records, operations data, water quality monitoring data were sought from PHED Jaipur.

The next step is service level observation i.e. review the historical service performance. This requires identification of service level indicators. In England the indicators used so far have been service interruptions, properties subjected to low pressure, quality compliance identified and defined by economic regulator. To identify the service level indicators affected by asset performance, the available records such as complaints registers, or any other records reflecting on performance of assets and service levels, were sought from PHED, Jaipur.

For optimisation and prioritisation, which is the next step of the asset management process, the required information is the forecast of future performance or probability of failure, consequences of failure and the cost implications of various intervention options. Optimisation, based on financial rate of return of investment or based on risk analysis, require a future performance forecast or probability of failure. Effective optimisation is feasible only with a good quality and quantity of historic performance data being available. Utilities in high-income countries have found this to be a major handicap in the application of asset management processes. Data employed for the process of optimisation has been historic asset failure data, such as main bursts, and data for modelling the relationship between factors affecting the structural condition of the assets and the age of the asset. Random sampling has been used as one of the methods to model the condition of the asset over its lifetime. Physical access to the underground assets is a challenge in itself. It is disruptive and expensive to carry out and also requires permission from the local authorities. Therefore random sampling was beyond the scope of the research and a low-cost opportunistic sampling approach was adopted. Lindley (1992) endorses opportunistic sampling stating that such samples are invaluable with respect to supporting remedial recommendations for a given system. The case studies from English utilities in Chapter 4 demonstrate this approach being widely used. Field data on assets condition and failure mechanisms were therefore collected at the sites where repair work was going on in the selected distribution zones to determine if a correlation between the assets various attributes and environmental factors and performance failures could be identified.

> A field research meeting with an Assistant Engineer was interrupted by news of a significant burst on a 36”’ transmission main, connecting the distant reservoir to the treatment plant serving the Walled City. Following the ‘opportunistic’ sampling approach, the researcher followed the AE to the site of the burst. Most impressively a mechanical excavator was very quickly on site to uncover the pipe. However, before the necessary ‘asset investigation’ could take place it was revealed that the ‘burst’ was in fact the result of a local drilling contractor starting to drill a new tubewell, unfortunately for him, choosing a location directly on the line of the main. Apart from the ‘drilled’ hole, illustrated, the ’50 year old’ steel main appeared to be in good condition.

Although the emphasis in the literature cited above has been on underground assets, initial survey work in Jaipur demonstrated both the importance of, and easier accessibility to, above ground assets. In particular, the shorter life of electrical and mechanical equipment, and therefore the earlier need for capital maintenance, raised the priority of this asset class in a relatively young system. Data regarding above ground assets was therefore incorporated into the study, following the approach outlined in Table 3-5.

The life-cycle costing (LCC) method is commonly adopted for management of pumping machinery. The data required for LCC are costs incurred on the assets from the time of design to the time of disposal. For pumping machinery LCC, the required data include purchase cost, operating cost, maintenance cost, mean time between failure (MTBF), time period between overhauls, mean time to repair (MTTR), repair cost and energy use rates. Historical maintenance records of the mechanical and electrical machinery assets were therefore collected to apply the LCC approach of asset management.

To assess the condition of service reservoirs, a significant asset class for systems based upon groundwater abstraction, physical observations are supplemented with results of drop tests. Drop tests are well defined methods to estimate the loss of water from a service reservoir over a certain duration of time. The PHED Jaipur was requested to conduct drop tests on service reservoirs and they complied with the request and provided results of drop tests conducted.

For estimating a first approximation of cost and benefits of adapting asset management, time and resources utilised by the researcher were noted down throughout the fieldwork. A customer questionnaire survey (See Appendix 6) was carried out to estimate the order of magnitude of benefits. This survey also provided information regarding service levels experienced by the customers and reliability of those service levels, that is 'serviceability'.

4.5.3 Assessment for wider application of the proposed model (Phase 3 fieldwork)

The phase 3 field work was undertaken to assess the wider application of the proposed asset management model, investigating the extent to which it might be applicable to other/all Indian urban water utilities. Two approaches were employed. The first investigated the level of data available in other similar urban water utilities in India, to determine whether the data required for the proposed model would be available. Secondly, opinions and comments of sector professionals in these water utilities were sought regarding the proposed asset management model.

Selection of study area

A list of States with similar institutional arrangements to Rajasthan i.e. State government managed Health Engineering Departments (PHED), was prepared. The PHED is the water service provider to all districts (urban centres) in these States and so all the districts in each of these States would have similar data management practices.

Geographically India is a very large country and data collection in other States involves very significant travel. In view of the limited resources, in terms of finance and time, the cities chosen were those which were close to each other but were in different States such that a greater number of States could be represented. (See Figure 4-3) The validation exercise was thus undertaken in five cities, namely Shimla (Himachal Pradesh), Mohali (Punjab), Chandigarh (Union Territory), Panchkula (Haryana), Patna (Bihar) and Jaipur (Rajasthan). The urban population represented by these States is approximately 38 million, approximately 13 % of the urban population of India (derived from GoI, 2003a).

Figure 4-3 States in which cities were surveyed for assessing the wider application of the proposed model

Data collection

To determine the availability of data with respect to the proposed model, a questionnaire was prepared. The questionnaire was completed by the researcher herself in consultation with the field staff in all the cities. (See Appendix 8 for details) A sample copy of some of the available data was made available by the utilities staff.

The second approach for the assessing the applicability of the proposed model involved seeking opinion/comments of the proposed asset management model. In the selected cities the utility professionals were interviewed in a one-to-one situation. An interview guide (See Appendix 9) was used to conduct the interviews. One professional at the rank of Executive Engineer was interviewed in each of the cities. One professional from the detailed case study city i.e. Jaipur was also interviewed. Before the interview the concept of asset management and infrastructure renewal/capital maintenance was explained to them. Notes were taken during the interview because permission to record the interviews was universally denied.

Table 4-4 summarises the data collected during the above mentioned three fieldwork phases.

Table 4-4 Data collection details

		Fieldwork phase	Remarks
1	Focus group interviews	Phase 1 A (July 2005)	Focus group interviews were conducted in four selected low-income areas and information was collected regarding water service levels, coping strategies adopted and their satisfaction levels with service provision. See Appendix 10.
2	Annual financial statements	Phase 1 B (Dec. 2005)	The annual financial statements of PHED, Jaipur over a period of ten financial years from 1995-96 to 2004-2005 were procured to understand and identify issues regarding the financial sustainability of service provision in Jaipur and functional sustainability in the context of capital maintenance investments. See attached CD for details
3	Interviews with PHED, Jaipur professionals	Phase 2 (Mar. 2006-Sep.2006)	Nine PHED, Jaipur and 3 Delhi Jal Board personnel were interviewed. For details see Appendix 3.
4	Network drawings	Phase 2 (Mar. 2006-Sep.2006)	Net work drawings (design drawings/blueprints) were procured from three sampled distribution zones. Updated AUTOCAD drawing of distribution network of whole of Jaipur city was also procured. See attached CD.
5	Customer complaint records	Phase 2 (Mar. 2006-Sep.2006)	Customer complaints records for the year 2005 from the three sampled distribution zones were procured. See attached CD.
6	Repair and maintenance history sheets of submersible pump and motor sets	Phase 2 (Mar. 2006-Sep.2006)	One hundred and twenty one history sheets of submersible pumps from four distribution zones were collected. See attached CD for details.

		Fieldwork phase	Remarks
7	Water meter readings records	Phase 2 (Mar. 2006-Sep.2006)	Available water meter reading records were procured in the three sampled distribution zones. See Table 6-5
8	Asset attributes, geographic location, condition and cause of failures	Phase 2 (Mar. 2006-Sep.2006)	To assess asset condition and cause of failures, opportunistic sampling was undertaken at 98 repair sites in the three selected distribution zones. See 6.2.3, Table 6-2, 6-3, 6-4, Appendix 5 and 6 for details
9	Drop test	Phase 2 (Mar. 2006-Sep.2006)	Drop tests were conducted on service reservoirs in the selected distribution zones on requests by the PHED staff and results were procured. Physical inspection of these service reservoirs was also conducted. See Table 6-10.
10	Customer survey	Phase 2 (Mar. 2006-Sep.2006)	To assess the current service levels and to estimate the cost incurred by customers to cope with the present service levels, a random customer survey was undertaken. One hundred and two questionnaires were completed by the customers from various distribution zones of Jaipur city other than the sampled zones. See 6.1.2, Table 5-1,Table 6-1 and Appendix 6 for details
11	Modern equivalent asset costs	Phase 2 (Mar. 2006-Sep.2006)	Copies of the purchase orders for pipelines and pumps were procured to find out the modern equivalent asset costs. See Appendix 11.
12	Questionnaire survey	Phase 3 (Dec.2007)	To assess the wider application of the proposed models a questionnaire survey was undertaken in Shimla (Himachal Pradesh), Mohali (Punjab), Chandigarh (Union Territory), Panchkula (Haryana), Patna (Bihar). See Table 7-1 and Appendix 8 for details.
13	Interviews with urban water utility professionals	Phase 3 (Dec.2007)	Eleven urban water utility professionals were interviewed in Shimla, Mohali, Chandigarh, Panchkula, Patna and Jaipur, to seek their opinions and comments regarding the practical application of the proposed asset management models. See 7.3.2 and Appendix 3.

4.6 Data analysis

4.6.1 Qualitative information

Descriptive information was subjected to qualitative analysis aimed at establishing links between the concept of sustainability of water supply and asset management being investigated. The information obtained was used to describe and categorise sustainability with respect to water supply services and issues relating to various categories of sustainability. The descriptive analysis then paved the way for the interpretation of these issues particularly on how they relate to or influence the sustainability of the urban water supply sector in India.

Content analysis of the notes taken during discussions with water utility professional assisted in bridging the gaps in information and understanding and provided a practical perspective of asset management.

Qualitative analysis was very useful in understanding the existing asset management process and the sustainability of the water supply systems and in preparing the proposed generic asset management model.

Field work data analysis is discussed in detail in chapter 5, 6 and 7.

4.7 Critique of the methods

Despite the effort to ensure that the chosen methods are relevant and effective in adapting asset management for the functional sustainability of the water supply, there are limitations that need to be considered when interpreting the results of this research work.

4.7.1 Primary data collection errors

Primary data collection had its difficulties. There was a particular difficulty with the forms completed at the underground pipe failure sites by the Jaipur PHED staff. In a few forms information recorded was incomplete, particularly in the distribution zone where the forms were completed by a field supervisor. Not enough attention to detail was paid. However this did not affect the analysis significantly since the number of such forms was limited. However, it indicates the training and monitoring challenge faced by a utility in implementing enhanced asset management.

The consumers' survey, undertaken to assess the coping cost of inadequate water supply, did not include sufficient samples to be representative of all classes of society. This error occurred due to the limited co-operation from customers in completing the questionnaires. Customers did not understand the relevance when their overall level of service was so poor – another issue to be addressed if future implementation.

There is therefore a need for caution in interpreting the results and such errors have been highlighted in the analysis section.

4.7.2 Case study research strategy

India is a very large country and as mentioned previously there are a variety of institutional arrangements vis-à-vis urban water utilities, affecting organisational activities. Due to resource constraints, only one Indian urban water utility was studied in detail and it may not be representative of the general group of Indian urban water utilities. The issue of generalisation of this case study was addressed by gathering information about availability of required data with other urban water utilities with similar institutional arrangements which were surveyed for the confirmation of the wider application of the proposed asset management model.

4.8 Challenges faced during fieldwork

Field work in India had its own share of problems and systemic challenges. In particular, there are challenges because of negative perceptions of the value of research. Further to these challenges are the specific problems that being an *Indian woman researcher* had to face in data collection in an organisation with predominantly male members of staff. There are internal dynamics which are not apparent at the surface level. These can be categorised as follows-

Seasonal

The main fieldwork, because of the timing of the PhD award, had to be undertaken during the Indian summer. This summer season, especially in Rajasthan, is a harsh and an unforgiving one where the day time temperatures range between the 43-47 degree Celsius and there is a tremendous demand for water. This causes it to be the peak season for those involved in the supply of water. Access to the supply of the limited available volume of water is also governed by extraneous conditions such as politics, or who is a voter for the minister, who is likely to be a voter etc. This leads to all the PHED personnel being fully stretched to the level of their efficiency and competence. Thus there was less cooperation on display and the researcher was frequently rebuffed in her pursuit of data by personnel at all levels who were simply not available or who, on being available, claimed they had more important things to do. To obtain information it was often necessary to make more than three to five visits to an office, in spite of prior confirmed appointments.

Poor time management

During the summer period PHED staff were working well beyond their normal working hours. But still it was very clear that time, in the opinion of the personnel needed to be interviewed, is an elastic concept and the researcher could spend many hours waiting for a person to show up for his appointment. It was particularly frustrating to be told by the attendants or assistants that the location of the person concerned was not known and his time of arrival could be within minutes or never, leading to one having to sit and wait because the possibility of setting up another appointment with better results were bleak. This resulted in the researcher's own time scheduling constantly having to be changed. It was not all downhill, sometimes she got a large amount of data in a short period of time and so overall was able to meet dead lines but the anxiety always remained.

Procedural

The PHED department is highly bureaucratised and a whole army of assistants and subordinate officers have to be persuaded to allow you to meet the relevant person. The 'buck was repeatedly passed' where who had the information appeared to be an enigma and some not so kind-hearted personnel directed the researcher to other personnel in spite of having the data required themselves. This led to a huge amount of time being spent in trying to track down the relevant person and persuading their staff to allow a meeting and then 'hoping for the best'.

It might be noted in passing that international researchers appear to be accorded a privileged status and therefore relatively easy access to information. Hence they are less likely to understand the everyday realities, 'the costs', of undertaking fieldwork in a low-income country.

General apathy

As previously mentioned, researchers are not viewed kindly. They are assumed by some of the members of staff of the water utilities to be a nuisance, potential troublemakers, who are likely to leak information to investigative journalists and so cause them problems. And so cooperation was at a premium.

Being a woman in a predominantly male organisation led to peculiar behaviour patterns wherein some people were excessively formal and uncomfortable and others tried to be over familiar. There was always an undercurrent of discomfort as women in the department are rare.

Getting the questionnaires completed by the consumers was also an uphill task as most of those persons felt that they were doing the researcher a favour, others felt that it was an utter waste of time. It required a lot of coaxing and persuasion by the researcher and was a huge hurdle to overcome.

The problems mentioned above were not insurmountable, over a period of time the researcher developed a degree of familiarity and friendship with most of the personnel and gradually as both sides realised the bona-fides of the other and had some extremely insightful, interesting and fruitful interactions. The researcher became aware of the constraints in both trained manpower and infrastructure being faced by the department and they in turn became quite interested and animated in the research. There were persons who went out of their way to assist and guide her and their experiences were illuminating.

The researcher acknowledges the efforts of the fellow professionals both in their everyday attempts as sustainable service provision as well as in their generous commitment to this research with grateful thanks.

However all these issues are indicative of the challenges which would be faced by the implementers of any improved asset management process.

4.9 Summary of the chapter

The chapter presents the conceptual framework and the logical methodological framework used for this study, including the methodologies used for data collection, analysis and interpretation. This chapter also describes main stages of the research process and the fieldwork of the research.

The chapter also presents the critique of the methodologies, which highlights shortcomings that may affect the interpretation of the results of this research work. Although efforts have been made to minimise the effect of these limitations, caution is needed when interpreting some of the results of this study. However, it is considered that the limitations and cautions do not unduly compromise the general outcome and subsequent recommendations drawn from this research work.

Chapter 5: Water supply, Jaipur

5.1 Introduction

Based on the background understanding of sustainability in the water sector and relevant asset management principles and practice gained from the literature review (Chapters 2 & 3) and the resulting conceptual framework underlying this research (Chapter 4), the main features of water service provision are discussed in this chapter for the water utility serving Jaipur, in the Indian State of Rajasthan. Following a brief introduction to the case study city, the chapter presents a first set of fieldwork results and analyses, concentrating on the role of stakeholders and the issues associated with environmental and financial sustainability of the water service in Jaipur in accordance with the conceptual framework (See Figure 4-1) to help address the research objective 4. This sets the scene, the very necessary context, for the strongly associated issue of functional sustainability based upon asset management planning, which is the core subject of this research and will be discussed in the following Chapter 6.

5.2 Case study background

India is a Union of States i.e. the Constitution of India has certain federal characteristics. The constituent states of the union have independent law-making abilities in certain specific areas as demarcated by the constitution. One of the constituent units of the Polity is the State of Rajasthan. In terms of land area (342, 236 km^2), Rajasthan is the largest state in India with an area approximately equivalent to that of Germany. Rajasthan is largely an arid zone with the Thar Desert forming more than 35% of the land area.

Jaipur is the capital city of state of Rajasthan, founded as the capital of the erstwhile princely state of Shekhawati, by Sawai Raja Jai Singh II. He is reputed to have been an enlightened ruler who believed in town planning (Sarkar, 1984). The buildings in the city of Jaipur are built of pink sandstone and so the city itself has the title of ‘the Pink City’. Jaipur became the capital of Rajasthan after independence and the amalgamation of all the princely states in 1947. This resulted in a massive influx of population to the city. Today, because of the proximity to the national capital New Delhi and progressive state government policy with respect to the encouragement given to small businesses, the population is increasing at the rate of 4.5% per annum (GoI, 2006c). The population of Jaipur in 2001 according to Census of India 2001 was 2.32 million persons (GoI, 2003). This continuing growth in the population has resulted in severe challenges being placed on the basic infrastructure because the demand for services, especially for water, has far out-run the present supply.

Service levels are defined as service quality for a particular service area (water in this case) against which service performance may be measured. Service levels usually relate to quality, quantity, reliability, responsiveness, environmental acceptability and cost (NAMS and IPWEA, 2001). In this case study water quantity (volume, flow pressure), quality, duration and reliability were considered to assess current water service levels.

The guidelines prepared by the Expert Committee, constituted by the Government of India, recommend that water supply systems should be designed for a 24 hours continuous supply. These guidelines are enunciated in the revised and updated edition of the Manual on Water Supply and Treatment, 1999. However during the fieldwork it was found that water supply in Jaipur can be best described as intermittent in the sense that it is not continuous or regular. The average water supply duration was found to be 2-3 hours every day. There is an inequitable distribution of water supply and only in certain areas where the Very Important Persons (VIPs) live, is service regular.

Eighty four per cent of the population of Jaipur uses water that is supplied by the PHED – 76% through individual connections, 5% through hand pumps and 3% through public taps. 16% are supplied by other systems – 6% by private systems, 8% by private wells and the rest by various other means (SAFEGE, 2000).

The production of water from all the formal recognised sources in the beginning of the year 2006 by PHED, Jaipur was 380 million litres per day (MLD). From the projected population of Jaipur for the year 2006 as 2.66 million persons, the per capita water produced for the population served by PHED (84% of the total) is 170 litres/capita/day.[8] This does not include institutional demand, industrial demand and

[8] Proposal report for augmentation of water supply scheme for Jaipur city, South, 2006, PHED Jaipur

demand on account of a floating population. Jaipur is a very popular tourist destination and so has a large floating population. This level of production could be seen as acceptable – however, it may hide the extent of leakage and disparity in supply amongst various segments of the population.

The interviews of the PHED personnel in charge of water quality monitoring revealed that to ensure quality control, water quality testing is carried out on the water from all the clear water reservoirs (CWR), service reservoirs (SR) and random water samples are collected from consumer taps in all different distribution zones for testing. The frequency of conducting these tests is once every six months for CWR and SR water. Random sampling is generally carried out in those distribution zones where complaints of poor water quality are reported by the media. In the absence of any media reporting, five samples are collected from different distribution zones by rotation. CWR and SR water is tested for chemical parameters such as Chloride, Nitrate, Fluoride and Total Dissolved Solids (TDS). It was further reported by them that the water samples from consumer taps are tested for biological water quality and residual chlorine concentration. One sample record of all the CWR water quality parameters was provided to the researcher and it indicates that out of 80 samples, 59 samples exceeded the acceptable standard for Nitrate that is 45 mg/l. All other parameters were well within the specified standards. The increasing level of nitrates in the groundwater might be a function of the limited sewerage system for wastewater disposal in the city. Declining water tables and water quality from significant self-supply should, though with an unknown time frame, deliver pressure for upgrading the pipe network through asset management.

5.3 The stakeholder context

Government

The Government of Rajasthan is responsible for financing and tariff-setting. The PHED is funded from the common budget pool of the state government. The state government procures funds through revenue sources, taxes, loans and assistance/grants from the Government of India.

In Rajasthan, according to the State government annual budgetary allocations, the supply of water comes under the heading of 'social services' along with family welfare and health and it is not considered to be an economic service in the same way as power supply (GoR, 2007). This implies that the State government is committed to providing water service without necessarily considering the economic viability or financial sustainability of the service. This objective is further reflected by the fact that the department responsible for water supply is named the Public Health Engineering Department, that is a government department with no specific reference to water. This policy followed by the government of Rajasthan is akin to the maintenance of the National Health Services in the UK where 90% of the spending comes from general taxation and insurance. Only a small amount comes from charges (Guardian 2002). In the case of Jaipur's water supply, there is a charge for water which bears little relationship to the cost but which consumers can only presume is the cost for which they receive a very limited service. To mislead key stakeholders in this way is not conducive to sustainability.

Efforts were made to find out what institutional mechanisms for the supply of water were in place before 1947, by interviewing older residents as well as engineers in the field. The responses were not very satisfactory in that they were conflicting and inconclusive. In response to direct questions with regard to when the piped water supply began nobody was able to give an accurate time. Between the years 1947 to 1963 water was supplied through the auspices of an omnibus body, the Public Works Department (PWD). In 1963, a specialised agency exclusively dedicated to water supply was formed, that is the still ongoing Public Health and Engineering Department . Since the PHED department was formed by splitting the PWD in terms of both manpower and resources, the organisational sub-culture with regards to service delivery continued to focus on engineering works rather than service to the customers. This work ethic or culture is still prevalent. It is an *output* based approach rather than an *outcome* based one. The changing nature of the requirements of the job is now being addressed by formulating a policy to report on outcomes after the completion of the engineering work[9].

Service Provider

The water service provider in Jaipur is a public sector agency - the Public Health Engineering Department (PHED). The PHED is responsible for planning, development, operation and maintenance of the water supply system. There are other agencies such as the Jaipur Development Agency and the Rajasthan Housing Board which are also involved in capital works, mainly in laying the water distribution network in newly developed areas.

Considerably more detailed information regarding the service provider, both as a stakeholder and as the key delivery agency is presented subsequently. However, it should be noted that a key aspect of the service provider as stakeholder are the interests of the staff. Both the professional engineer administrators and the front-line technicians/workers have a considerable influence on performance of supply and management of the assets. Reference has been made in the previous chapter with regard to styles of working in the context of the researcher seeking to engage with the professional staff. Overall it appears that the poorly paid, limited opportunity for advancement, always ready for crisis management solutions approach of the professional staff is not conducive to forward-looking asset management. Similarly the very poorly paid, very limited access to training and equipment situation of the front-line staff, tempered by having privileged permanent employment, is equally distant from any asset management involvement and responsibility.

Financiers

In Jaipur, because of below-cost pricing of water service, user charges, as demonstrated by the analysis below, are insufficient to cover the operating costs of the water service much less being enough to include capital investments that are required to meet the challenge of a constantly growing demand (See Figure 5-6). The supply of water is therefore subsidised by the State government of Rajasthan. As a result, the

[9] Personal communication, Chief Engineer, PHED, Jaipur, 2006

financial resources of the PHED Jaipur are largely dependent on budgetary allocations from the State government of Rajasthan (GoR, 2007). Some finance for new works is obtained from the Government of India through the Ministry of Urban Development and also obtained as loans from the Life Insurance Corporation of India (LIC), which is reflected in the annual financial statements of the PHED Jaipur. The ongoing Bisalpur Water Supply Project, to augment the present water supply of Jaipur, worth $379million is financed jointly by Asian Development Bank (ADB) and Japan Bank for International Cooperation (JBIC).

The key interest of financiers as stakeholders is to see efficient investments made with their finance such that they will be repaid. There is little evidence of these key stakeholders for a capital asset intensive business having their loans serviced directly by the service provider, let alone any amortisation of the capital amounts.

Consumers

During fieldwork it was observed that consumers, as a stakeholder in water service provision have a passive role in Jaipur. PHED personnel informed that consumers are not in a position to seek any legal redress to grievances that they may have with regard to water quantity, quality or pricing. They further reported that there is no formal mechanism for community involvement in Jaipur. The only interaction of the consumer with the utility determined by this study is through lodging complaints regarding poor service levels. The guidelines regarding the specific time limits to address consumer complaints are in place. However, citizen welfare groups are practically absent in Jaipur, unlike in some other, larger, cities like Delhi or Mumbai. The collective community demand is exercised only when service levels hit ‘rock bottom’, especially in terms of biological water quality parameters consideration, when there are health-related concerns. It was seen during the fieldwork, on more than two occasions, that there was a public outcry with regard to the supply; this public complaint was in the form of large number of women gathering on the main streets and blocking the flow of traffic as well as protesting by breaking earthen pots. Once the agitation took a violent turn with the Junior Engineer of the PHED being assaulted and police intervention was required to normalise the issue. In the researcher’s view it tends to result in the PHED resorting to crisis management and ‘fire-fighting’ approaches rather than moving towards permanently improved management.

Within the proposed asset management model, serviceability of a water supply system relates also to customers' experience of, and views on, the supply. Information about water service levels obtained through the consumer survey, conducted in the second phase of the fieldwork, revealed that water quality was reported better than water supply pressure by the consumers.

Table 5-1 indicates the serviceability of the water supply as responded by the sample population. Almost 60% of the samples rated water pressure as average and only 6% of the samples rated water pressure as poor. In the researcher's personal experience and opinion, this is a response induced due to low expectation, conditioned over a long period of poor water service, compounded with the awareness about water scarcity in a desert region. Out of 102 samples, 89 samples reported to have PHED water supply and of those 89 responses, 71% reported water supply to be reliable. (In the context of intermittent supply, the understanding of reliability is to have no variation in terms of duration and timings of the limited hours of supply, rather than the normal expectation of continuity)

Table 5-1 Customer survey results for water service levels

Water Quality	
Responses received	85
Acceptable water quality	72 (84.7%)
Unacceptable water quality*	13 (15.3%)
Water supply pressure	
Responses received	89
Good water pressure	31 (34.8%)
Average water pressure	53 (59.6%)
Poor water pressure	5 (5.6%)
Water supply reliability	
Responses received	89
Reliable water supply, positive responses	63 (71%)
Reliable water service, negative responses	36 (29%)

*Out of 13 responses for unacceptable water supply, 3 were for fluoride, 4 for hard water, 2 for muddy water and the rest did not specify.

Source: Researchers' fieldwork, Jaipur, (July, 2006)

For a public water supply in a city with a significant proportion of low-income consumers there is a particular need to assess serviceability for all customers. To assess the water service levels in very low-income areas, focus group interviews were conducted during fieldwork phase I A. (see Appendix 10: for details) These revealed that different low-income areas had different mechanisms provided by the PHED, such as piped supply, public standposts, hand-pumps and static tanks for water supply. Low-income areas with piped supply generally had unreliable and insufficient supply and in all cases additional, private, sources always had to be used. The reported prices from private suppliers were much higher than the existing PHED tariff. Most of the public standposts were directly connected to the pipeline from a borewell to the reservoir and therefore had 24 hours supply. However there was no disinfection, which is a minimum treatment requirement for good quality groundwater according to the water supply manual guidelines (CPHEEO, 1999). Static tanks kept in these areas were generally filled twice a day. It was reported that during summer months the scheduled frequency of twice a day supply and timing were both unreliable. Some low-income areas reported failing supply from the hand-pumps, especially in summers. This confirms the data presented earlier regarding falling groundwater levels.

5.4 Environmental sustainability

As previously mentioned, Rajasthan is entirely in the arid zone and the water supply in Jaipur has always been dependent on the monsoons which recently have been even more sparse and irregular than 'normal'. In the past the population of the city was limited and the supply of water was dependent on traditional rainwater harvesting structures. Due to the migration of people from the rural areas to Jaipur, seeking better job opportunities and lifestyles, the supply of water through these traditional methods were insufficient to meet the needs of the growing population of the city.. The State government has invested heavily in infrastructural expansion to supply water to meet the growing population needs.

At present the city's water supply is largely dependent on groundwater (97%) and supplemented by a surface water source, Ramgarh dam (3%) (SAPI, 2004). It used to be the other way round in the past i.e. a water supply was largely dependent on the surface water sources supplemented by groundwater. Over a period of time due to the increase in population and subsequent demand and erratic rainfall patterns there has been an increasing dependence on groundwater. Local residents around the Ramgarh dam hold the view that because of small check-dams being constructed in the catchment area of the river Ban Ganga there is now only a limited supply of water to the dam resulting in an increased dependence on the groundwater. This claim however is yet to be researched or verified.

In order to augment the water supply from the PHED, many ’better-off’ families arrange for the drilling of private bore-wells. So, other than the bore-wells owned by PHED, there are an estimated 20,000 extra private bore-wells drilled for domestic, industrial and commercial uses[10]. The fieldwork found that permission to drill a bore-well, or any documentation in this regard, is not mandatory. Therefore no valid data on actual number of private bore wells is available. There is no restriction on the volume of water to be extracted from these bore wells. According to the PHED , there is a hydro-geological constraint in having two bore-wells within a radius of 300 metres of each other because they would affect the draw down zones. However, the PHED sources further explained that since the private bore-wells were not operational for 24 hours and their size or capacity to draw water was not large these private bore-wells did not affect the PHED bore-wells and so as far as the PHED was concerned these bore wells could be ignored. The researcher however argues that the cumulative suction power of upwards of 20,000 bore-wells is going to seriously impact the limited groundwater supply and in the long run is going to cause further incalculable depletion to an already overstretched resource. The groundwater which in the past had been carefully harvested is subjected to indiscriminate and non-replenishable use. As a result of which the water table is dropping at an alarming rate of a metre every three years[11].

Recently, to reduce the city's dependence on its ground water resources, the Bisalpur-Jaipur Water Supply Project (BWSP) consisting of the construction of a water supply system for bringing water (340 MLD) from a new surface water source to Jaipur city has been designed. The construction work is in progress and is expected to be completed by December 2008.

[10] Personal communication, Executive Engineer, South Division, PHED, Jaipur

[11] Personal communication, Chief Engineer, PHED Jaipur, 2006

These environmental factors, that is availability and the reliability of water resources, have a critical impact on the water supply systems, particularly in terms of water pricing and leakage management. In Jaipur, there is a mismatch in functional responsibility and fiscal autonomy since water tariff-setting is a political decision. Development of new water sources has further financial implications. Presently there is no concerted effort being made to control leakage in the distribution network, an indicator of a very limited approach to asset management. Indeed it was not possible for the researcher to obtain even a rough estimate from the PHED of leakage levels in the city. However, it may be presumed that unaccounted for water will not be less than the 31% average for seven utilities in India (ADB, 2007) and may well be closer to the 48% average for the 'top' three utilities.

Therefore with continuously increasing demand, groundwater levels going down steadily, with no control over water pricing for managing the demand and no leakage management programme, the availability of a reliable water source is a serious concern for the utility to address. This concern should provide some sort of impetus within the organisation to engage in efficiency improvement programmes such as reduction in unaccounted for water. The fieldwork did not find evidence of any such change. It appears that the ready access of consumers to these other sources of water, the private bore-wells, has 'blinded' all stakeholders to the necessity of addressing this critical issue of environmental sustainability for the city.

Environmental factors such as availability and reliability of water resources, water pollution and now climate change are presumed to be responsible for bringing about change in the functioning of water utilities. Globally, these have led to concepts based on integrated water resource management and demand management. Jaipur has a semi-arid climate and is therefore deemed to be a water-scarce city (NCERT, 2006). For Jaipur the future availability of potable water is of growing concern. Rainfall during the monsoon has always been erratic, the groundwater levels are going down every year yet the number of homes and individual demand is rising and water sources are already fully exploited and stretched. Managing the impact of climate change will also be an important consideration. In such a scenario, though a new water source is being developed, a comprehensive water resource strategy is required for the environmental sustainability of the water supply system. The importance of leakage reduction (a critical asset management issue), water reuse and demand management cannot be over emphasised here in view of the marginal costs involved with developing a new source in a predominantly arid state like Rajasthan as the Bisalpur scheme illustrates.

5.5 Financial sustainability

Financial sustainability of a water utility implies that the utility is able to generate sufficient revenue (or access reliable and on-going fiscal transfers) to support the overall financial needs of the utility. The financial health of the utility is best reflected by its income and expenditure accounts which are the primary sources of information regarding the inflow and outflow of financial resources. The financial statements of PHED, Jaipur over a period of ten financial years from 1995-96 to 2004-2005 were procured during the phase I B of the field work (December 2005) to understand the issues involved in the maintenance of financial sustainability of the water service. Of particular concern was the ability of the service provider to access adequate funds for capital maintenance, a critical aspect of asset management planning. During the subsequent phases of the fieldwork the researcher was unable to procure the latest financial statements for the financial years 2005- 2006 and 2006-2007.

The financial statements (general revenue account) of the PHED Jaipur contained information about the water utility's expenditure, income, capital, liabilities and assets in a consistent format. These also included detailed depreciation statements as well as capital works in progress. The statements had standard commercial accounting details on cash receipts, cash payments and net changes in cash resulting due to operations. The balance sheet presented detailed information with respect to fixed assets, capital works in progress, government capital, loans, depreciation reserve fund, accounts payable and accounts receivable. All the photocopied records were transcribed to Excel and analysed.

The annual balance sheets of the power utility for Jaipur were also procured to compare the approach to capital maintenance for two similarly capital intensive, infrastructure based, public service utilities in the context of a low-income country. The power utility is now subject to an economic regulator whilst the water provider is still seen as a 'social service', which could be expected to make a difference in the pattern of costs and particularly revenues.

Water services the world over require an extensive infrastructure which is largely buried underground and is invisible. Capital costs are concentrated in fixed assets for sources of supply, water treatment facilities, transmission and distribution networks and pumping equipments. Hence water services are understood to be the most capital intensive of all networked services (See Table 5-2). The capital intensity (ratio of fixed assets to total revenue) was calculated for the power and water utilities of Jaipur for the financial years 2000-2001 to 2004-05 (See Table 5-2). The results indicate that in Jaipur the water service is nine times more capital intensive than the power service. However, this comparison of *capital intensity* does not present an accurate picture because the water tariffs in Jaipur are so low that the utility's revenue earned is extremely low (as noted previously). On the other hand power service tariffs are more cost-reflective as the power utility recovers more than its operation and maintenance costs from the revenue. The capital intensity of the water services of England and Wales and Jaipur also cannot be compared directly because in England the fixed assets represent the present value of the asset and not the historical cost which is the case in the PHED Jaipur balance sheets. No meaningful comparison can also be made because in England and Wales the revenue generated includes operation and maintenance cost, capital maintenance cost, cost of water supply security and water quality enhancement and cost of capital whereas as previously mentioned the water utility in Jaipur is unable to recover operation and maintenance costs of the service from the revenue generated. But the ratios are indicative of the relative capital intensity within India.

Table 5-2 Capital intensity

Utility	England [12]	US [13]	Jaipur (India)
Water	12.2	3.45	3.6
Power	4.1	1.61	0.4
Telecom	2.8	1.11	
Gas	2.1	0.94	

[12] Source: (Franceys, 2005)

[13] Source: (Kathy, 2007)

The water utilities in developed countries such as UK, US and Australia exist in what has been termed to be "*an infrastructure renewal era*"[14]. That is the infrastructure owned by the water utilities has reached or is nearing the end of its useful life and renewal is essential to maintain the water service. Infrastructure renewal or a capital maintenance programme involves a large investment. The infrastructure managed by water utilities in low-income countries is, usually, relatively younger and therefore less likely to need immediate renewal. However the physical assets owned by the PHED, Jaipur will eventually come to the end of their useful lives which will then require significant investment to maintain a sustainable water service. The extent and timing of that required investment is the core of asset management planning. As a first step it is necessary to determine what capital expenditure has been undertaken to date.

5.5.1 Historical expenditure review

An historical expenditure review was undertaken to quantify the historical capital maintenance spending and assess the typical current level of expenditure across various asset categories based on guidelines provided in the Common Framework (UKWIR, 2002a). This review was to form the basis for identification of the asset categories which involved significant expenditure by the PHED Jaipur to maintain the service. Subsequently the review was to act as a basis for a projection of the required capital maintenance in the future when the assets that are presently functioning come to the end of their useful life. An ancillary advantage of conducting a historical review is that other financial issues regarding sustainability of the service are examined and compared.

To counter the impact of inflation, all financial figures years were converted to year 2007 real values i.e. all the nominal values for the years (1994 to 2007) were converted to real values (2007). Table 5-3 details the RPI (Retail Price Index) used for the conversion from nominal to real values.

[14] Source: Urquhart, T., Oral presentation at LESAM, 2007, Lisbon, Portugal

Table 5-3 Inflation rates and retail price index (1994-2004)

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Inflation rate *		10.3	10.1	9.2	7.2	13.1	4.7	4.0	3.8	4.3	3.8	3.8	4.2	6.2	6.4
RPI	100	110.3	121.4	132.6	142.2	160.8	168.3	175.1	181.7	189.5	196.7	204.2	212.8	226	240.5

* Source: GoI, 2003b; IMF, 2008

Capital expenditure

The capital expenditure review showed that during the financial year 2004-05, the fixed asset base was $93.2million[15]. The fixed assets had increased by 67% over a period of 9 financial years from 1996-97 to 2004-05. From financial year 1996-97 to 2000-01 assets were created steadily and then for the next three financial years, capital expenditure to create new assets reduced significantly before rising again in 2004-05 (See Figure 5-1).

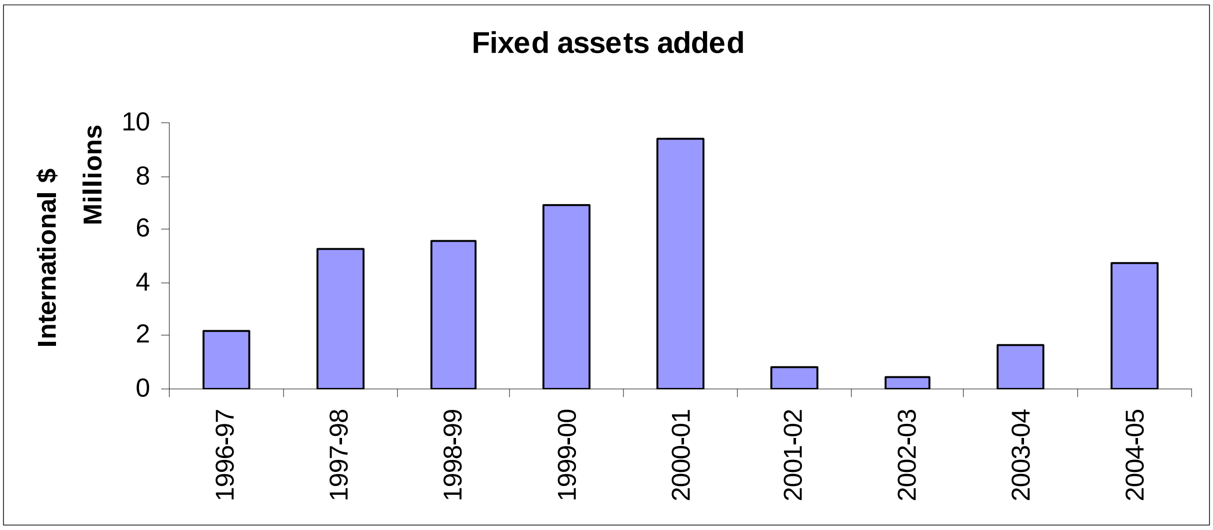


Figure 5-1 Fixed assets added (1996-97 to 2004-05) at 2007 prices

The distribution of the investment made to create assets over the period 1996-97 to-2004-05 is as shown in Figure 5-2. 'Other' in the figure implies buildings and other

[15] $=14.67 INR, Conversion rate at purchasing power parity is used (Source: 2008 World Development Indicators, pp 9)

civil works, loose tools, furniture and fixtures, office equipments, computers and a sewerage treatment plant. Out of the $31.6million capital expenditure over the 10 year period 67% has been spent on assets for water production and distribution. A major share of the investment was made in procuring pipelines, sinking boreholes, wells and installing water meters. The investment on water meters (18%) has been made recently in the most recent two financial years (2003-04, 2004-05) for which information is available.

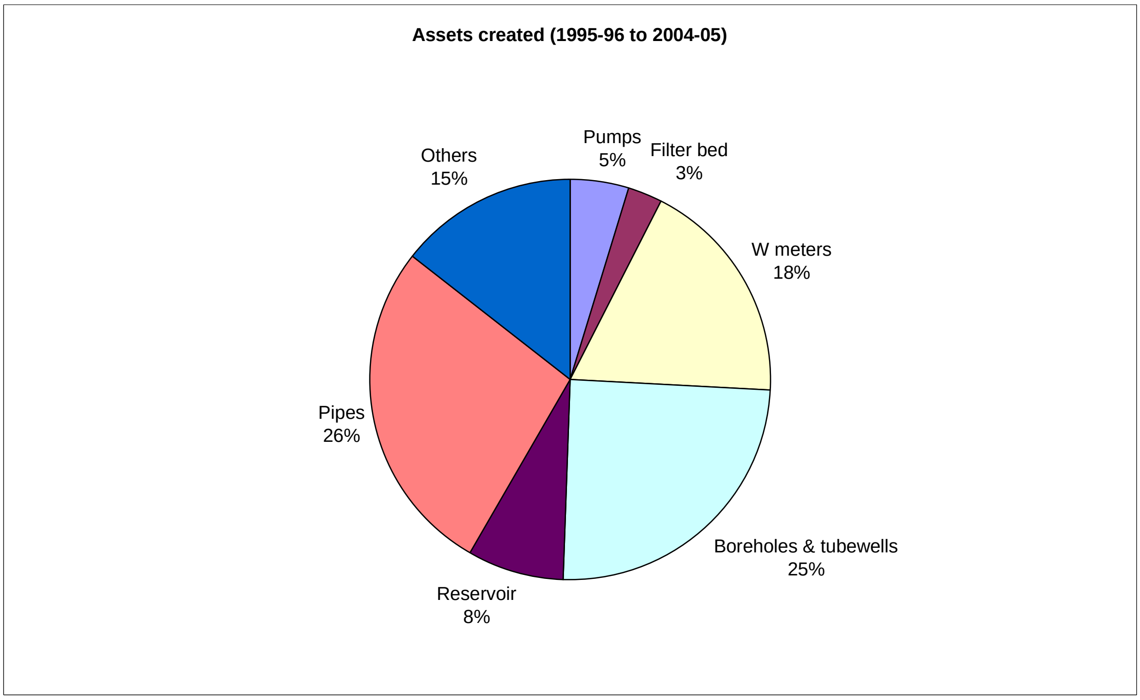


Figure 5-2 Distribution of assets created during financial years 1995-96 to 2004-05

5.5.2 Financial overview

Financial ratios illustrate various areas of business management and allow a comparison of results against industry averages. Financial ratios can be the means to measure a utility's financial performance with identification of norms, benchmarks or long-term trends. The following table provides values of various financial ratios calculated for the PHED, Jaipur over the review period.

Table 5-4 Financial ratios (1997-2004)

	Target value [16]	2004	2003	2002	2001	2000	1999	1998	1997
Profitability ratios									
ROFA	6-8%	-33.7%	-28.5%	-45.2%	-39.6%	-43.7%	-55.9%	-49.6%	-86.2%
ROCE	6-8%	-24.8%	-21.3%	-34.7%	-30.6%	-33.8%	-42.2%	-29.2%	-41.1%
Liquidity ratios									
Current Ratio	1-2	424.8	244.6	50.8	108.2	204.8	22.6	132.4	332.0
Quick Ratio	Approx. ≤1	4.41	11.66	2.97	8.22	20.08	3.03	29.96	247.14
Creditworthiness (gearing) ratio									
DER	100-200%	2.9%	3.4%	4.6%	2.3%	2.8%	3.5%	3.8%	2.5%
Efficiency ratio									
Days Receivable Ratio	60 days	611	435	441	382	337	501	328	344
Operating Ratio	0.6	228.7	172.2	261.1	216.3	219.4	356.2	237.3	232.3

The return on fixed asset (ROFA) and the Return on capital employed (ROCE) are indicative of the profitability of a water utility. In the case of PHED Jaipur both the ratios are negative over the review period indicating that the water utility is experiencing huge financial losses. The profitability indicators do not appear to follow any particular trend. In spite of the sustained financial loss incurred by the water utility the water utility continues to function, in fact it has expanded its service coverage as well as increased its fixed asset base. This apparent dichotomy is possibly due to the fact that the water utility is a state owned public service and financial loss is not critical to its existence and operation.

The *liquidity ratios* of the PHED were calculated and again no particular trend could be established over the review period. The values of these ratios however were found to be extremely high during the entire review period indicating that the PHED was maintaining a very high level of liquidity. This position was however found not to be

[16] Source: (Franceys, 2005)

the case because the *accounts receivable* in the balance sheets were shown to be extremely high figures and payments were to be received from other government or public sector undertakings. As these undertakings were unlikely to make the payments or even if they did make payments the payments would be *book transfers* it would not improve the actual/real liquidity of the PHED.

The *gearing ratio* of a utility is calculated to assess its credit worthiness. The Debt Equity Ratio (DER) was found to be extremely low throughout the review period indicating that the PHED Jaipur was taking loans which were very less in value compared to the equity that it had at its disposal. This position is again a deceptive one because the actual position is that almost the entire equity of the PHED is based on funds that are provided by the State government. This however is not reflected in the balance sheet as a loan or a debt. It is depicted as a *Capital Reserve*. The only loans that are shown are from public sector undertakings to whom the PHED pays interest. If the funds of the State government are considered to be loans then the gearing ratio would alter considerably, but they are ‘owners capital’.

There are two types of *financial efficiency ratios* which were calculated and both were found to be much higher than the target values. However the results in the case of the *days receivable ratio* portray an untrue picture because as previously mentioned the *accounts receivable* which form an important component of this ratio are unlikely to be received. A perusal of the financial statements revealed that one of the agencies from which the PHED Jaipur is to receive money is the Jaipur Municipal Corporation (JMC). The JMC has not paid all its dues during the review period. This has caused a cumulative effect on the *accounts receivable* which has resulted in the high values of the DRR. The operating ratio is also very high as compared to the target value but this is a correct representation of the facts. The operating ratio is high because the operating revenue is very low due to non cost-reflective water tariffs.

Operating expenditure

The main components of operating expenses are disbursement of salaries, payment of electricity bills, purchasing chemicals, repair and minor maintenance (R & M) and overheads. The staffing and power costs contributed to an average of 89% of the total operating expenditure (OPEX) (Figure 5-3). Operating expenditures have been rising continuously between the financial years 1995-96 to 2004-05 by 61% over this 10 year period (Figure 5-6), primarily driven by increasing energy costs.

Energy costs have increased steadily and in ten years have cumulatively increased by 108% (Figure 5-4), partly driven by the effect of the electricity sector being required to move towards cost-reflective pricing. One unit of electricity has increased by 102% in real terms over the review period. The expenses due to disbursement of salaries have increased by 38.7% (Figure 5-4), still a significant increase, remembering that the figures quoted are in real terms. The repair and maintenance expenses and chemical expenses have decreased by 23% and 35 % respectively (Figure 5-5).

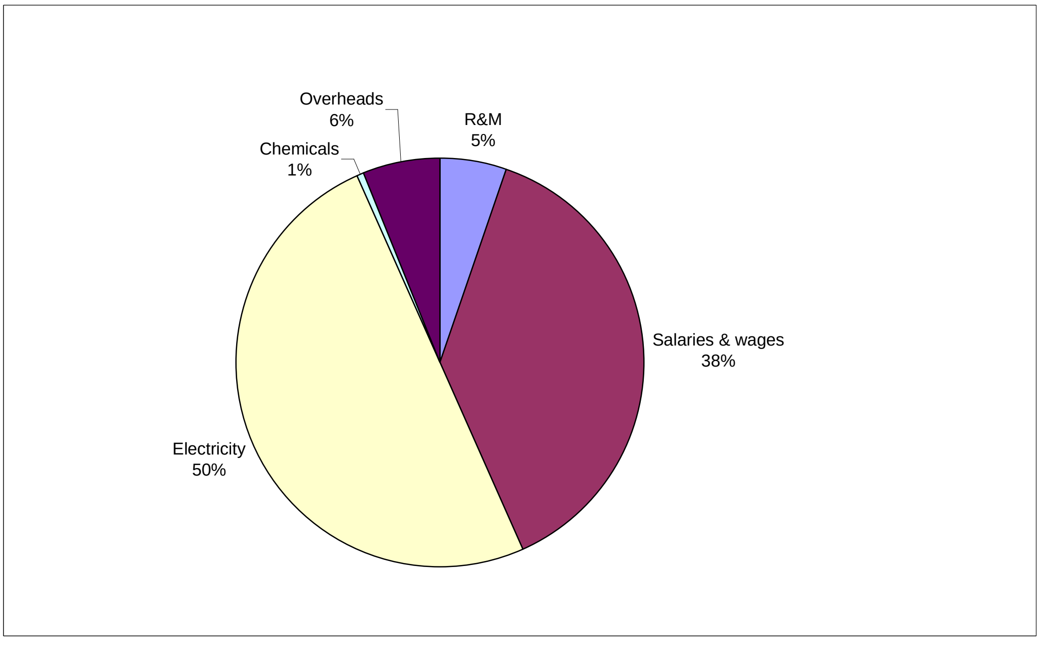
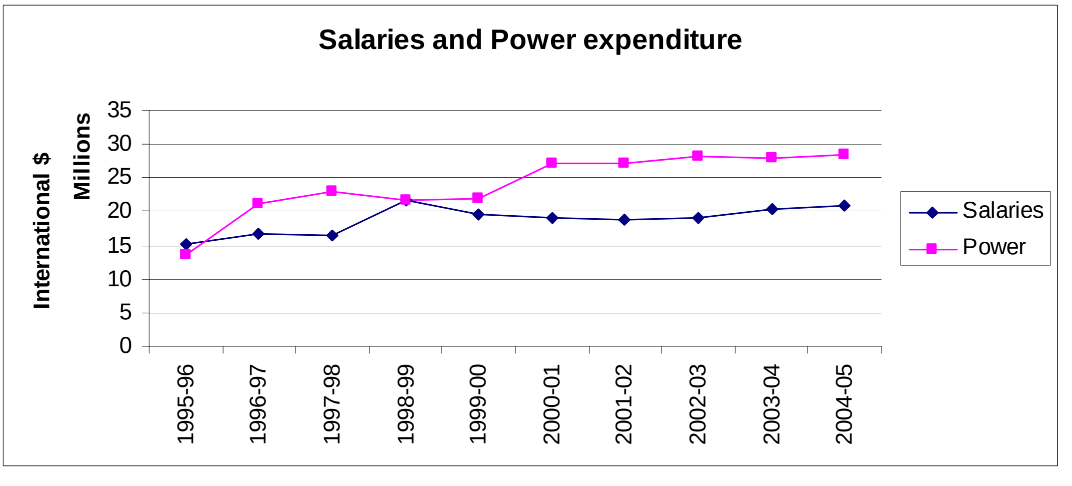


Figure 5-3 Average OPEX distribution (1995-96 to 2004-05)



.

Figure 5-4 Salaries and power expenditure at 2007 prices

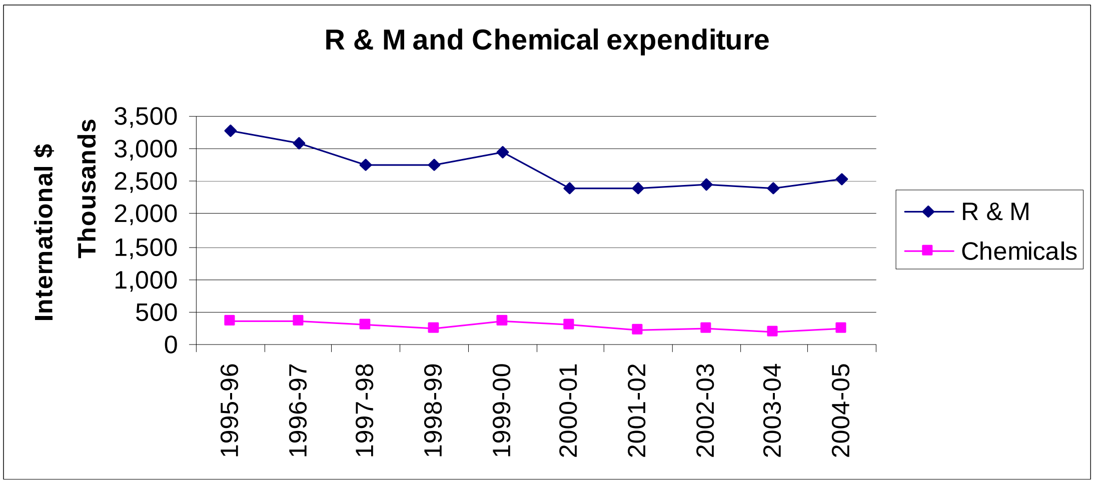


Figure 5-5 R & M and chemicals expenditure at 2007 prices

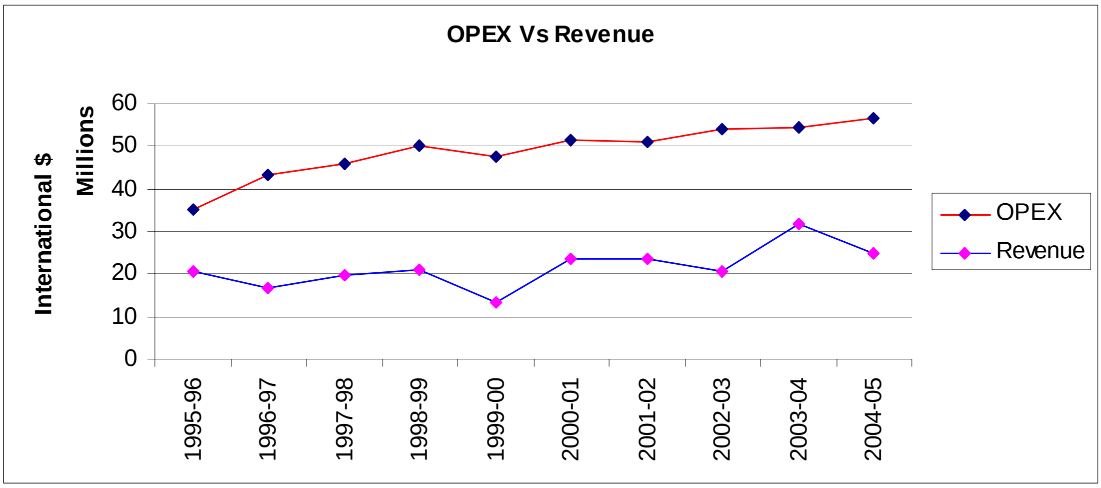


Figure 5-6 Operating expenditure against operating revenue at 2007 prices

The reduction in chemical expenses can possibly be explained by a reduction or little change in prices of the chemicals purchased over the review period. This would be unusual when the cost of chemicals is usually dependent on energy costs. The reduction in chemical expenses can also be possibly explained by the increasing dependence of the utility on groundwater resources where the only chemical required is disinfectant unlike in the past where surfacewater, requiring the use of both disinfectant and coagulant, formed a higher proportion of the total. There appears to be no other explanation for the reduction in chemical expenses as it is an essential element of water supply - except by presuming that adequate chlorination was not being undertaken. During interviews the field engineers stressed the fact that there had been no drop in quality standards of the water supplied. It was not possible to access sufficient records to confirm this point. The field engineers explained the drop in chemical expenses by suggesting that chemicals were being shown under another heading in the accounts. But this appears to be incorrect as there is a specific head in the accounting procedure dedicated to chemical expenses.

The repair and maintenance item is not part of any planned capital maintenance programme. There is no budgetary allotment for any regular repair and maintenance in the budget. Repair and maintenance is carried out as a reactive response which is treated as minor maintenance. The annual R & M expenses have decreased from 7.2% to 4.5% of the annual operating expenses from 1996 to 2004. Over the period 1995-96 to 2004-05, average 5.3% of the annual operating expenses is spent on repair and maintenance of various categories of assets.

Repair and maintenance expenditure was further analysed to identify historical maintenance expenditure for different asset categories. It revealed that most of the expenditure is being made on maintenance of pumps and pipelines.

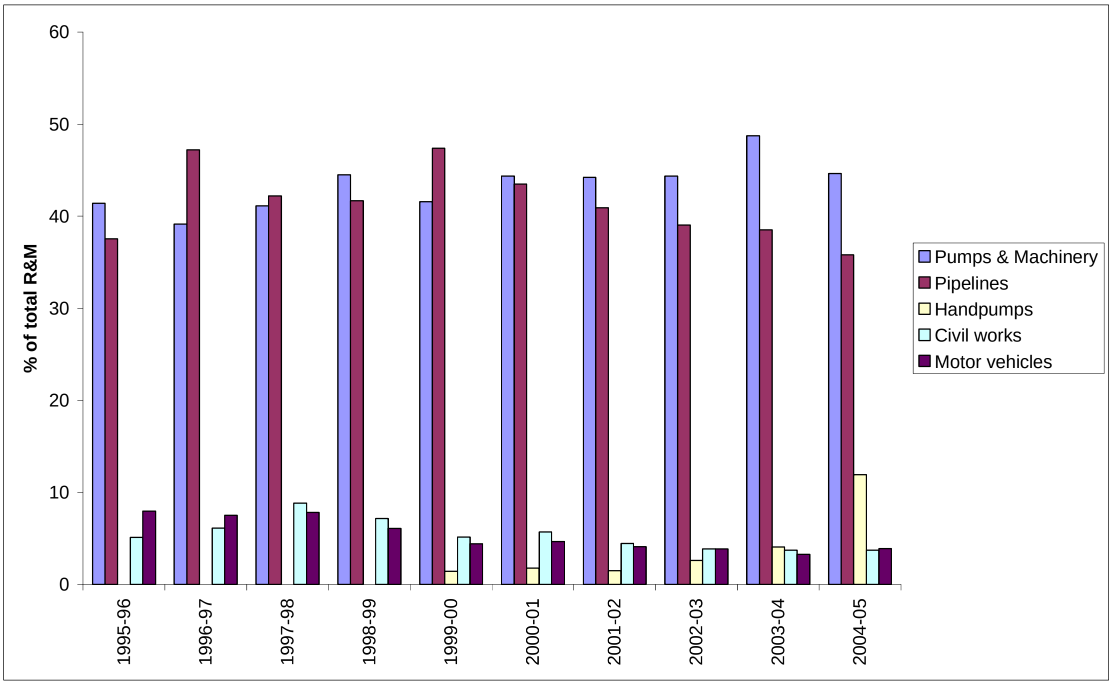


Figure 5-7 Distribution of R & M expenditure

An average of 43% and 41% of the total R&M expenditure has been spent on 'pumps and machinery' and 'pipes' respectively consistently over a period of 10 years (Figure 5-7).

Historical R & M expenditure was further reviewed to identify whether there have been any one-off significant expenditures due to any particular weather variation effects so as to derive a result following the trend observed across the review period to assess the typical level of current maintenance expenditure. No such one-off significant expenditure was observed.

Revenue

For a water service to be financially sustainable, the service provider should, advisedly, recover at least operating and minor maintenance costs and some level of capital maintenance charge through user charges. In Jaipur it was observed that not only was the operating cost not being recovered from the user charges but there was a constantly widening gap between OPEX and the revenue collected throughout the review period. It was observed that OPEX increased by 61.4% but the revenue collected increased by only 19.6% over the review period (Figure 5-5). In Jaipur with the exception of two years (1995 and 2003) when the revenue realised was 59% and 58% of OPEX respectively, in all the other years it consistently remained below 50% of the operating expenditure. The average revenue realised was 44.2% of the operating expenditure through 1995 to 2004. Investigating further, beyond the reported 'accrued revenue', analysis of the annual accounts receivable demonstrates that average bill collection efficiency was 89%. Further improvements in tariff recovery will not be able to reduce the gap between OPEX and revenue significantly even with 100% recovery. Supplementary examination of the accounts receivable illustrate that 71% of the cumulative accounts receivable has to be recovered from Jaipur Municipal Corporation for water supplied through public standposts and 28% has to be recovered from customers.

The gap between the operating expenses and the revenue generated can be reduced by either reducing the operating expenses or increasing the revenue generated. A reduction in operating expenses can be achieved by increasing the operational efficiency of the water supply service, or alternatively, as is suggested by the analysis above, reducing the use of chemicals and limiting repairs with uncertain implications for sustainability. The other option, to increase the revenue generated, requires an increase in tariffs. This option however is a political decision and is not within the purview of the decision-making control of the utility.

Overall, this analysis suggests that there is a very limited financial base on which to build a credible asset management plan.

Depreciation

In accounting terms, depreciation is an expense recorded to allocate the cost of a fixed asset over its estimated useful life[17]. Depreciation is a process of allocation and not valuation of assets. A depreciation reserve fund is established to offset the cost of acquiring an equivalent asset, or renewing the existing asset, at the end of its lifecycle period. The accounts of Jaipur PHED show that the fixed asset values are depreciated annually by a straight-line depreciation method. The depreciation rate is taken to be 3% per year for all categories of assets. The annual depreciation sum is recorded in a depreciation reserve fund (DRF) item.

With insufficient revenue charged and collected even to cover operation and minor maintenance cost, this depreciation charge does not make available any funding for ongoing capital maintenance.

As shown in Table 5-3, the annual inflation rate from 1994 to 2004 has always exceeded 3%. The average inflation rate has been 6.75% over the review period. These figures however do not seem to be reflective of the accounts in the water utility because the cost of assets such as asbestos cement pipes and deep well submersible pumps (major water supply assets) have remained static over the last few years[18]. Even if revenues were sufficient to cover the depreciation charge, the depreciation fund that is being set aside will be insufficient to meet future capital maintenance needs unless some form of 'current cost accounting' of fixed assets is used, at least with respect to capital maintenance. Similarly, taking a uniform depreciation rate of 3% for all categories of assets is erroneous because an annual depreciation rate of 3% implies that the useful life of every category of asset is 33 years which is incorrect. Certain assets such as pipes are known to have a useful life of more than 100 years (though with exceptions of the sort illustrated in Fig 3-4) and on the other hand

---

[17] http://www.investopedia.com/terms/d/depreciation.asp

[18] Personal communications , Registered contractors with PHED and Executive Engineer, PHED, Jaipur

certain assets such as electrical and mechanical equipments are likely to have a useful life of only 15 to 20 years.

It is to meet this particular challenge that asset management planning has been developed. The average figure for depreciation used in Jaipur and the lack of any resources to service even this notional figure for capital maintenance might be seen to both justify the application of asset management planning and to explain the existing poor quality of supply.

Summary

The PHED Jaipur is maintaining practically all the financial records that are required to be maintained by a water utility which aims at financial sustainability. However the data that is being shown is not representative of the actual facts because there are headings under which the information is being written are only partially correct e.g. the loans which the department has taken are shown to be of very small amounts. Looking at the ratios would be a nightmare for any management consultant because they would look at these ratios through the coloured glasses of *ring fenced financing* i.e. assuming that the utility stands alone, is capable of increasing water tariffs, is able to choose the service coverage area and is able to recover all the money that is owed to it. This situation is however not anywhere close to reality because the PHED is a *state owned and run public service*. In fact the heading under which funds are allocated to the PHED Jaipur in the Annual Budget of the State are under the head of *Social Service* which means that the State government of Rajasthan is not looking to run the PHED as a corporate business but is determined to provide a service to ensure public health to as many people at as low a cost as possible. Thus the standard definition of financial sustainability as seen through the financial ratios is not relevant to the PHED Jaipur.

An analysis of the accounts reveals that the water provider in Jaipur is faced with a problem that the revenue generated is insufficient to meet the operating expenditure and the capital cost for the infrastructure renewal needs now and in the future. The operating expenditure is largely concentrated on payment of electricity bills and salaries for the employees which have been increasing over most of the review period. Despite the bill collection efficiency being reasonably high, the gap between the revenue garnered and the requirements for a sustainable supply is increasing. There is scope for introducing measures which would assist in reducing a part of the gap but a decision has to be taken at a political level to make water supply cost effective for the system to sustain itself and grow.

5.6 Summary of the chapter

Considering the conceptual framework shown in Figure 4-1, this chapter sets the scene for the adaptation of a realistic approach to asset managing in one Indian city.

In Jaipur water resource reliability is a challenge. From the limited evidence it emerged that comprehensive efforts are not in practice to address the issue of water resource reliability. Water tariffs which were last revised in 1997 are not cost-reflective and do not facilitate demand management which is another way to approach water resource reliability issue. In addition to water resources another feature of environmental sustainability of water supply systems is energy consumption. In PHED Jaipur almost half of the operating expenditures are energy expenditures and there is no energy efficiency monitoring system in place. Both energy and water resources use need consideration for the sustainability of the water supply system in Jaipur. However, in the short term there can be no presumption of any environmental sustainability.

The PHED Jaipur prepares detailed annual financial statements and analysis of those historical financial statements can be useful in studying trends and developing strategies to introduce efficiency measures. Financial ratios are useful indicators of performance and financial situation of a utility however financial ratio analysis in this case needed a critical review since the utility is state owned and managed and the utility’s accounts are not ring fenced. All the indicators suggest that water services in Jaipur are not financially sustainable.

With limited involvement of stakeholders, partial and inadequate attempts at customer satisfaction or compliance, all based upon the ‘absent legs’ of environmental and financial sustainability, it appears that the role of asset management must be very carefully investigated.

Chapter 6: Assets & asset management, Jaipur

6.1 Introduction

Having considered the stakeholders and financial and environmental sustainability context in Chapter 5, this chapter focuses upon investigating present asset management processes in the case study city and looks to adapt global best practices in asset management to enhance the management of water supply fixed assets in Jaipur.

To achieve the research objective 4 of assessing the viability of application of the asset management principles and methods, the generic asset management models for underground and above-ground assets of a water utility, developed and explained in Chapter 3 (See Table 3-4 and Table 3-5) , were applied to the data collected from the PHED, Jaipur during the phase 2 fieldwork. The chapter also discusses the constraints encountered in the application of the asset management model to the case study data.

The phase 2 of the fieldwork, to test this model, was undertaken for a duration of six months from 7/3/2006 to 8/9/2006 with the aim to collect the necessary information from the PHED, Jaipur and from appropriate field sites. The fieldwork was broadly divided into primary and secondary data collection. For this purpose the Public Health Engineering Department's (PHED) offices were visited, PHED personnel were interviewed and field sites were visited to understand the water supply system and to collect data at accessible sites, both above ground and below ground. A questionnaire survey was also undertaken to assess the current service levels and to obtain the costs of coping strategies adopted by the consumers to complement the data collected during the earlier fieldwork phase I A which specifically targeted low-income areas.

6.1.1 Water supply distribution system

The water supply distribution system in Jaipur can be broadly divided into two spatial units. These units are a product of history. Initially Jaipur city was confined within fortified walls, this area now known as the 'walled city' areas. As the city grew the newer parts of the city were classified as 'outside city walls'.

Within the 'walled city'

Within the walled city, water supply depends upon a combination of groundwater and surface water. The surface water source is Ramgarh dam. Water is pumped from Ramgarh dam to Laxman Doongari treatment plant and then from there it flows under gravity to the distribution system pipe network. Groundwater from various transfer stations spread across the city is pumped into clear water reservoirs (CWR) at Amanishah and from there it is pumped into the distribution network of the walled city. There are also 178 tubewells in the walled city which are directly connected to the distribution network. According to PHED officials, the chemical water quality of some of these tubewells does not meet the standards specified in the Manual on Water Supply & Treatment. Water from these tubewells is pumped into the system only after the main supply hours and consumers are informed in advance to use the supply after regular hours for non-potable consumption. It is a very low pressure supply. Using the same pipe network for both potable and non-potable water is an interesting approach to asset management.

During the summer months, to meet the increased demand, water tankers are also used to augment the supply. During field interviews it was reported that 500 trips of water tankers of 4 m^3 capacity are made everyday in peak summer months.

Outside the 'walled city'

Outside the walled city the water supply is, at present, totally dependent upon groundwater. The area is divided into multiple distribution zones (Figure 6-1). Most of the tubewells are located in the southern parts of the city. Groundwater is pumped into clear water reservoirs through a rising main from the borewells. Water is then either pumped to a service reservoir (SR) of that distribution zone and/or transferred to a reservoir in another distribution zone. There is a 257.730 km long network of transfer main lines all over the city with the pipe diameters ranging from 125mm to 675mm (SAPI, 2004).

Apart from some interconnected pipes between the distribution zones, most of the distribution zones' networks are independent and it would be possible to isolate them hydraulically. Each distribution zone outside the walled city has one or two service reservoirs.

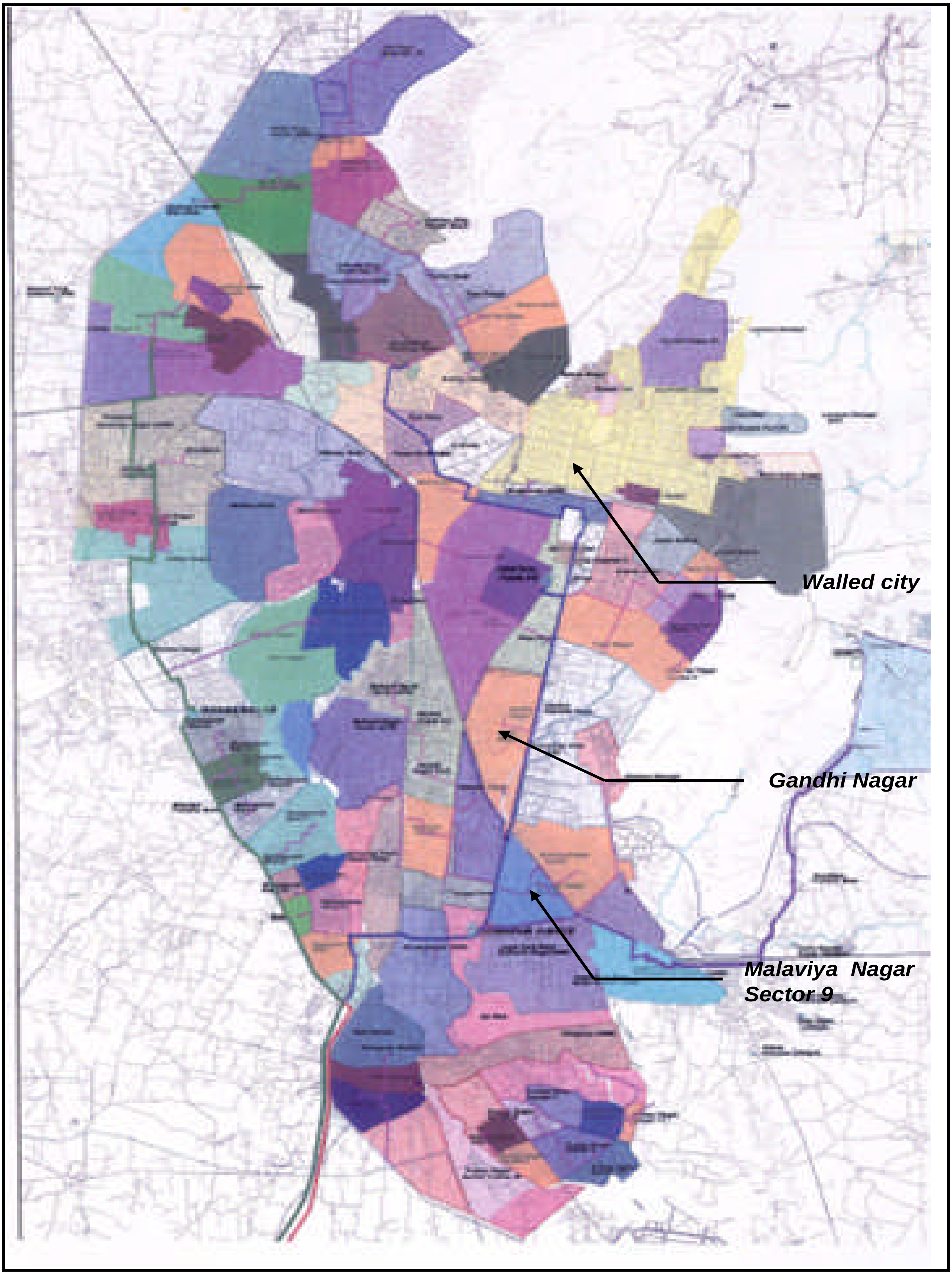


Figure 6-1 Distribution zones

6.1.2 Sampling

Three distribution zones were identified to investigate and develop asset management practices. Identification was based on the criteria of representation of different age profiles of the network and different pipe materials. The 'Walled city' (Distribution Zone 1) is the oldest amongst the three selected zones, being older than 45 years with predominantly cast iron (CI) network. 'Malaviya Nagar sector 9 distribution zone' (Distribution Zone 2) is 11 years old, using asbestos cement (AC) pipes and some polyvinylchloride (PVC) pipes. 'Gandhi Nagar distribution zone' (Distribution Zone 3) is 31 years old with mostly AC pipes, a few PVC and some galvanised iron (GI) pipes. There were no documented records of the specific age of the individual pipes. In two distribution zones, Gandhi Nagar and Malaviya Nagar, the PHED personnel reported the year when the service reservoirs and the network were commissioned. However, with regard to the walled city distribution zone, the commissioning dates of the network were unknown and the personnel could only make an informed guess as to the age of the network, estimating it to be more than 45 years old.

Primary and secondary data about the attributes and condition of the underground network as well as causes of failures were collected in the selected three distribution zones.

PHED personnel interviews

Interviews were arranged with PHED personnel at different hierarchical levels of employment. In all, nine PHED personnel were interviewed, Additional Chief Engineer (1), Executive Engineer (1), Assistant Engineer (1), Junior Engineer (3), Supervisor (1), Repair staff (2).

These were relatively unstructured interviews, as this approach to data collection is considered to be useful in situations where in depth information is needed and little is known about the area (Kumar, 1999). Interviews were carried out in a one to one situation with a framework used as an interview guide. Other than the difficulties faced in organizing the interviews there were usually many interruptions while the interviews were being carried out, such as phone calls and visitors and calls from the interviewee's superiors. The researcher had no option but to carry on after every interruption.

Notes were taken during all the interviews. Four interviews were voice recorded with the interviewees’ permission. The rest did not permit recording of interviews.

Customer survey

A questionnaire survey was conducted to assess the current service levels and to estimate the cost incurred by customers to cope with the present service levels. One hundred and two questionnaires were completed by the customers.

To make the questionnaire survey more representative of the spatial considerations of the whole city and inclusive of all the economic classes, it was decided to conduct the survey in public places like shopping areas and offices. PHED offices were excluded to avoid a bias in the responses. People in shopping areas were not cooperative and very few samples could be collected from there. The selection of other offices was based on the social networking links of the researcher. Offices were chosen where the researcher could be introduced to the employees by a senior employee of the organisation and the employees were requested to co-operate in filling out the questionnaires.

Table 6-1Coping strategies’ cost analysis

Coping strategies →	**Water tanker cost**	**Water booster pump cost**	**Operating cost of water booster pump**	**Capital cost for bore well**	**Operating cost of bore well**	**Capital cost of water purifica-tion unit**	**Operating cost of water purifica-tion unit**
	(INR)	**(INR)**	**(INR)**	**(INR)**	**(INR)**	**(INR)**	**(INR)**
Affirmative responses	**9**	**3**	**3**	**10**	**10**	**11**	**1**
	50	4,000	200	25,000	100	6,000	20
	150	1,600	180	25,000	200	6,000	*
	100	2,500	300	40,000	300	6,000	*
	150			50,000	1,250	7,000	*
	38			23,000	400	5,000	*
	800			34,000	300	7,000	*

Coping strategies →	Water tanker cost	Water booster pump cost	Operating cost of water booster pump	Capital cost for bore well	Operating cost of bore well	Capital cost of water purifica-tion unit	Operating cost of water purifica-tion unit
	(INR)	(INR)	(INR)	(INR)	(INR)	(INR)	(INR)
	25			70,000	200	5,000	*
	*			30,000	100	5,000	*
	*			25,000	*	5,000	*
						6,000	*
						7,000	*

* Costs not provided

The survey form can be found in Appendix 6.

The customer survey provided a review of current service levels and a rough approximation of the coping costs incurred by the customers in view of the existing service levels. This information from customer survey indicates that water supply pressure is regarded poorer than water quality by the customers (See Table 5-1 and which is further corroborated by larger no. of positive responses for coping strategies related to augmentation of the existing water supply (See Table 6-1).

6.2 Asset management model - testing

The Generic asset management model for underground assets of a water supply system (See Table 3-4), which is being applied in this chapter, requires the collection of '***Asset information'*** comprising specific attributes, that is the pipe diameter, manufacturing material, age, the geographic location and the number of house connections relating to that asset. In addition ***Asset environment information*** is required including the type of surrounding soil, historic information regarding temperature and other weather variations, the depth of soil cover and the volume and type of traffic details.

It is noted at the commencement of this model testing that the elements regarding temperature and weather may be more relevant where the supply system is exposed to frosts rather than sub-tropical climates of South Asia.

This information then has to be complemented by some measure of '***service performance / asset performance / asset condition observation &/or assessment***'

6.2.1 B. a Asset information,

Preparatory office based data collection

Available network drawings, complaint registers and history sheets of pumps and annual financial statements of the department were procured from the PHED, Jaipur to collect information on the attributes of the assets i.e. age, diameter, material, expenditure and historic performance records of assets. Information/records about the water quality data were also collected.

Network drawings

The designed network blueprint drawings i.e. as initially the network was laid were collected. These drawings however had not been updated with regard to the various changes in the pipe network that had ensued between the time the drawing was made and the time that the drawings were collected. The researcher collected digitised network drawings which have been prepared as a result of a project funded by the Japan Bank of International Cooperation (JBIC).These pipe network drawings have been digitised using AUTOCAD with the satellite image of Jaipur city being used as a base map. The base map that is the satellite image has very poor detailing with no building footprints and no information about the streets or landmark names. It was learnt that the telecom service providers have done a house to house survey and have marked all the details on the base map. Efforts were made to procure these maps but it was not possible for the researcher to acquire these, even following various networking approaches. In Gandhi Nagar distribution zone, it took the researcher more than 10 days to update the original network map with the help of the field staff. In Malaviya Nagar, a print of the AUTOCAD map was provided to the junior engineer (JEn), as the zone office did not have any drawings. The JEn marked the updated details on the hard copy of the AUTOCAD map. A blueprint of the pipe network of the walled city distribution zone was provided by the JEn of the walled city. He said that the pipe distribution network has not been altered with in any way and hence no updates were required. This information could not be verified because other members of staff were non-committal regarding this. All three maps provide information about the diameter, length and the material of the pipes. These maps can be used to prepare an inventory of the assets categories owned by the PHED, Jaipur which may further be used for statistical analysis if and when sampling data about condition of these underground assets is available with the PHED, Jaipur.

Modern equivalent asset (MEA) cost data

The MEA (modern equivalent asset) cost information was also collected for both pipes as well as pumps. There was no readily available consolidated list for all the assets. The researcher found out the cost information for various categories of assets from the latest purchase orders. The researcher procured copies of a few of the purchase orders for pipelines and pumps. A copy of an estimate report made by South division, PHED Jaipur for the financial budget proposal for the year 2005-2006 was procured which had information on present cost of various categories of assets.

This information is collated in Appendix 11.

6.2.2 B. Assets and their environment information

B. a i) Assets attributes

The designed network drawings provide information about the diameter of the pipes and the material used in the manufacture of the pipes. The network drawings are drawn to scale and therefore the length of the segments of the pipe network can be calculated from the drawings. The available information is sufficient to enable the PHED to begin creating an asset inventory. There is tacit knowledge available through older members of field staff who have been working there for very long regarding the age of the underground assets, about the network as laid and subsequent changes.

B. a ii) Assets location

Information about the location of the underground assets in the possession of the PHED Jaipur is maintained in the form of blueprints and network drawings. As explained above, these network drawings are not fully detailed. Hence it is difficult to establish the exact location of an underground asset based on these maps or blueprints. The PHED Jaipur has evolved a unique system of keeping track of the underground assets in its possession, relying on the persons involved in repair of the network who have been posted in that area for years together and have thus accumulated the knowledge and experience which allows them to link immediately a complaint about a network to the actual spatial location of the complaint without needing to refer to the pipe network drawing. However to the uninformed the network drawings do not provide any details regarding the location of service connections and position of the hydrants. There is no reference to either the slope of the pipeline or the depth of the pipe below the ground. Also there are no building footprints or street names mentioned on these drawings, which causes difficulties in being able to relate the data regarding complaints on the network drawings.

B. b Asset environment information

The main environmental factors which affect the underground assets of a water utility are the nature of the surrounding soil, the temperature variation (both at a daily level and at a seasonal level) and the density and type of traffic (where the pipeline is below a road or a railway line). The PHED Jaipur does not maintain either of these records. However information regarding these factors can be accessed from specialised agencies like the Geological Survey of India (GSI) for soil maps, and the Meteorological Survey of India for temperature variations. The researcher obtained the requisite information pertaining to the type of soil surrounding the sample pipe networks from the GSI.

The repair site questionnaire data indicates that the average depth of the pipes from the ground was 85 cm, with maximum and minimum depth being 180 cm and 30 cm respectively. The underground surrounding soil characteristics were found to be sand in all the 98 samples. This was also confirmed by cross-checking the nature of the soil from the soil maps of Rajasthan state accessed at Birla Institute of Scientific Research, Jaipur.

6.2.3 C. b Asset condition observation - field site data collection

Information regarding the cause of failure is especially relevant in addition to information regarding asset performance and service performance for asset management of the underground assets. Since no historical data regarding the causes of underground asset failure was available, the researcher sought to record observations regarding the main causes of underground asset failure in addition to information regarding the condition of the assets at the repair sites (refer 6.2.3).

Information about the condition and/or performance of the pipe network is difficult to obtain, the pipes being deeply buried. Accessing these underground pipes is therefore challenging and expensive. As described in the literature review, information on the condition of the asset can be gathered in a cost effective manner, ‘opportunistically’, when the asset is exposed when being repaired or when new connections are being made.

In practice, primary data on the condition of underground pipes in the selected distribution zones could only be collected at failure points because no new connections were created during the period of fieldwork in the selected distribution zones. The causes of failure were noted along with the information related to the general condition of the pipes.

Records at 98 repair sites were obtained in the three selected zones (48 in Gandhi Nagar, 45 in Walled city and 5 in Malaviya Nagar Sector 9). Two Civil Engineering undergraduate students assisted the researcher in collecting the relevant information. A form was prepared for the information to be recorded at the failure sites (see Appendix 5). The students were trained by the researcher on how to observe and record the information in the field. Due to the limited cooperation of the PHED staff to the researcher’s assistants, they worked only for a week. Later on, the junior engineers in two zones (walled city and Malaviya Nagar) and the supervisor in one zone (Gandhi Nagar) responsible for the pipe repair works offered to complete the forms. A printed questionnaire was provided to the PHED staff and training was provided by the researcher in the field. The researcher had only one geographical positioning system (GPS) unit in her possession and so it was not feasible to record geographical coordinates at all the repair sites. The PHED staff also exhibited reluctance to use the GPS unit. The summary data may be found in Tables 6-6 and 6-7 below with the full information in Appendix 6.

The analysis of the data collected at repair sites revealed that other than service connection failures, all the pipes exposed were in good structural condition. The service connections which are made of galvanised iron pipes however are rusted and decayed. The PHED repair staff interviewed corroborated the observation that the general condition i.e. physical integrity of the underground pipes has been observed to be sound whenever the underground assets have been exposed.

The analysis of causes of failures from the primary data collected at the repair sites revealed that the structural failures (failures related to condition/physical integrity of the asset) were limited to service connection pipes which were because these pipes were made of galvanised iron. This observation was also supported by the interviews with the field engineers of the PHED who stated that the poor condition of the galvanised iron service connection pipes were the causes of service connection failure.

The analysis of the data collected at the repair sites also revealed that most of the failures were related to operational practices, external third party causes and constructional causes. These types of failures cannot be related to the condition of the underground assets. It is recommended not to employ a statistical approach to assess the condition of underground assets when the asset/service failures are operations related or external cause related failures (Ellison, 2001). Therefore on the basis of the available limited data it was concluded that to assess the condition of the underground assets categories other than the service connection pipe category in possession of the PHED Jaipur, statistical analysis was inappropriate since structural failures/asset condition related failures of these assets had been minimal. However, the opportunistic sample size i.e. the number of observations recorded at the repair sites was significantly small therefore the analysis needs to be interpreted accordingly.

Subsequent analysis of the data provided an insight into the common types of failures, failure mechanisms and their causes. (See Table 6-2, Table 6-3, Table 6-4)

Table 6-2 Distribution of types of failures

Total records	100%
Joint failure	45.92%
Pipe failure	19.39%
Service connection failure	31.63%
Valve failure	3.06%

Table 6-3 Distribution of causes of failures for joint failures

Joint failures	
Due to termites	2.2%
Due to decayed rubber rings	42.2%
Due to embedded tree roots	24.4%
Due to bleaching powder deposits	2.2%
Due to bad joining	6.7%
Others*	15.6%
None stated	20.0%

* Others are almost always due to heavy loading

** Some of the joint failures forms reported two causes of failures

Table 6-4 Distribution of causes of failures for pipe failures

Pipe failures	
Due to digging	21.1%
Due to heavy load	36.8%
Due to rusted pipe	5.3%
Due to bleaching powder blockage	21.1%
Due to air lock	5.3%
Reasons not stated	10.5%

Since water supply in Jaipur is primarily dependent on groundwater and the groundwater resources are mainly located in the south zone of the PHED, there is a transfer mainline network for transferring water to various distribution zones across Jaipur city. A transfer main line is a pipeline transferring water from one clear water reservoir (CWR) to another. Normally these are isolated pipelines with no distribution lines connected to them.

There were 52 transfer stations in the south zone of Jaipur city. There are bulk flow meters installed at some places on the transfer main lines but not all the transfer main lines have flow meters installed at both ends. The readings of the quantity of the water transferred are recorded once every 24 hours.

It was observed that bulk meters were installed in the transfer main line networks at some transfer stations and not all. The readings that are recorded by the use of these meters are not collated and analysed for evaluation of performance of the underground assets. The readings were recorded by the PHED personnel to ensure that a certain pre-decided volume of water on the basis of the water demand in each of the distribution zones was being transferred to and from the transfer stations.

Since water auditing and measurement of unaccounted for water (UFW) could be employed to assess the performance of the underground assets/asset categories, meter readings of two such transfer lines which had meters at both ends were obtained for assessing the performance of transfer lines (See Table 6-5) .

Table 6-5 UFW results for transfer lines

		Attributes of transfer line			**Average quantity transferred/ day**	**Average quantity received/ day**
		Length (km)	**Diameter (mm)**	**Material**		
Transferring station (1/6/06 to 20/6/06)	Malaviya Nagar sector-9	10.5	400	Ductile Iron	8.30MLD	7.54MLD
Transferred to	Truck stand					
Transferring station (1/6/06 to 14/6/06)	Durgapura	6.0	300	Asbestos Cement	5.78MLD	2.87MLD
Transferred to	Gandhi Nagar					

The analysis of the observations reveals that the average unaccounted for water (UFW) in the transfer line between Malaviya Nagar sector 9 and Truck Stand is 0.76 MLD (9% of the input volume). In the transfer line between Durgapura and Gandhi Nagar, there is a distribution pipe line of 300 mm diameter connected and 1.3 MLD water is diverted to it. Hence the UFW for the transfer line between Durgapura and Gandhi Nagar is 1.61 MLD (27% of the input volume).

6.2.4 C.c Identification of gaps in existing serviceability

The water service provider, PHED, Jaipur, is a public sector monopoly. It does not conduct customer surveys to assess the level of service provided. Unlike the water utilities in high-income countries, the PHED does not have any mechanism to evaluate the level of service provided like number of water quality violations, water supply pressure monitoring and number of unplanned service interruptions. The only record from which an indirect inference can be drawn regarding water service performance is the complaint register.

The *number of complaints* was selected as an indicator in the absence of data available with the PHED Jaipur regarding serviceability of the distribution network. The choice of this indicator was made because records were available. Another advantage of choosing the number of complaints as an indicator is that this indicator is a measure of both the service levels and asset performance. This indicator was further divided on the basis of the categories of complaints because different categories of complaints required different intervention options.

The unaccounted for water (UFW) was selected as an indicator to evaluate the performance for the transfer main network.

Asset condition and performance assessment

No observations with regard to the condition of the underground assets are made by the PHED Jaipur, hence records pertaining to the condition of the underground assets are not available. Interviews with PHED Jaipur personnel revealed that no attempts are made to evaluate or measure the performance of the underground assets in Jaipur.

Water auditing is not done and there is a very limited number of flow meters in the distribution networks. No readings are recorded for these meters or the very few pressure gauges that are installed in the network. There is no planned leakage management programme. Therefore hydraulic modelling could not be employed to assess the performance of the distribution network.

There is no strict water quality monitoring programme in place. Random sampling is generally carried out in those distribution zones where complaints of poor water quality are reported by the media. In absence of any media reporting five samples are collected from distribution zones by rotation. These water samples from consumer taps are tested for biological water quality and residual chlorine concentration. However the data that was provided to the researcher was very sketchy and could not be used for water quality modelling.

The PHED Jaipur maintains records regarding the complaints received about the performance of the underground assets in the form of a complaints register. So although there is no data recorded or maintained about the performance of the assets or service to consumers, these complaint registers could be used to indirectly infer the performance of the assets and service to consumers.

Customer complaints' records

The data regarding complaints in the three selected distribution zones for the previous year were collected. The existing system being followed in the PHED, Jaipur is that all complaints received in person or by telephone are recorded in a register. The records are all handwritten. The information recorded about each complaint is in the format, Date of the complaint, Address and Details of the complaint.

The researcher sought to collect the complaint records/registers for a period of one year. However since record keeping is not a priority issue with the various distribution zones of the PHED Jaipur, the records provided were for a period ranging from eight to twelve months. The time period for which the records were provided, number of connections in the distribution zones and the number of complaints received of the various distribution zones are shown in the table below.

Table 6-6 Complaints /100connections/year in sampled distribution zones

	No. of connections	No. of complaints	No. of days	No. of complaints/ 100 connection/year
Walled city	15,500	2412	340	16.7
Malaviya Nagar	9,500	1054	247	16.4
Gandhi Nagar	4,087	920	365	22.5

The complaints data was further categorised into the types of complaints commonly received and recorded by the PHED which is shown in the following table.

Table 6-7 Complaint categories

Leakage	A
Low pressure supply	B
No supply	C
Water quality problem	D
Broken pipeline	E
Others	F

Others include hand pump not working, request for water tanker, change the valve, problem in valve rod etc.

A comparative Table showing the number of complaints received in the selected three distribution zones and their category wise distribution is shown below.

Table 6-8 Distribution zone wise complaint categories results

Zone	Walled City		Malaviya Nagar		Gandhi Nagar	
Total	2412	100%	1054	100%	920	100%
Leakage*	1055	43.7%	765	72.6%	304	33.0%
Low pressure supply	88	3.6%	30	2.8%	133	14.5%
No supply	738	30.6%	47	4.5%	316	34.3%
Water quality problem	270	11.2%	7	0.7%	41	4.5%
Broken pipeline*	49	2.0%	7	0.7%	46	5.0%
Others	212	8.8%	198	18.8%	77	8.4%

*The distinction between leakage and broken line is not very clear

The data further revealed that many of the complaint addresses were repeated through the year. For each of the addresses that was repeated, the number of times complaints were received was investigated. The following Table indicates the percentage of the repeated addresses in the three selected zones.

Table 6-9 Results for complaints with repeated addresses

Zone	Walled City		Malaviya Nagar		Gandhi Nagar	
Total complaints	2412		1054		920	
Complaints with repeated addresses	1956	81.1%	317	30.1%	243	26.4%

The complaints from the same address span over several months. The categories of complaints in records with same address are either A/B/C or D or F. In very few instances a combination of A/B/C/D or A/B/C/F is observed. There are many instances of complaints within a span of 2 to 10 days. There could be two possible explanations for that: either the complaint was not addressed or else the quality of the maintenance was poor and the problem resurfaced.

On further scrutiny of the complaints on a monthly basis to see if there is any seasonal variation, it is evident that peak dry season May and June are the months with the maximum number of complaints in all three distribution zones. However in Malaviya Nagar distribution zone the numbers of complaints were fairly uniform over the whole year.

It is not clear from the records if the addresses logged in are the addresses of the reporters or the location of the failure. Many of the addresses that are recorded give no specific information about the location of the failure for example ‘Near Airport’, ‘Near Laxmi Mandir Cinema’, Shiv Shakti Colony’. The staff recording the complaints were interviewed and they explained that they write only whatever information is provided by the complainant at the time of registration of the complaint.

6.2.5 D. Identification of possible intervention options

As the chosen asset management objective is to improve the serviceability by reducing the number of customer complaints received annually, intervention options were identified by using the knowledge gained from the repair site data about the causes of why underground assets failed, in conjunction with the data from the complaints records.

An analysis of the complaints received in the three distribution zones revealed that the single most common cause of complaint from the consumers was leakage. The percentage of complaints with regard to leakage was 44%, 73% and 33% of the total number of complaints in walled city, Malaviya Nagar and Gandhi Nagar distribution zone respectively. If this is coupled with complaints regarding broken pipe lines the figures then read as 46%, 73% and 38%. The distinction between complaints due to leakage and complaints due to broken pipeline was not clear and interviews with the PHED staff also did not clarify the difference. Hence an intervention option which seeks to address the leakage/broken pipeline issues would impact the objective of reducing the number of complaints received quite substantially.

To understand the reasons for leakage, the data regarding most common causes of failure which had been obtained from the repair sites was analysed. The analysis revealed that the most common cause of failure was joint failure due to decayed rubber ring (19.4% of the total failures) and the second most common category is pipe and joint failure due to heavy load (14.3% of the total failures).

Rubber rings are used as washers at the joints of the pipelines to prevent leakages. The interviews with the field engineers of the PHED revealed that the choice of the quality of the rubber rings used in the joints and the manufacturer of those joints is decided on the basis of the least cost quoted. The interviews further revealed that the rubber rings decompose due to continuous exposure to the water flowing through the network over a period of time. Some of the engineers were of the opinion that because the water supply was intermittent the rubber rings were exposed to different moisture and temperature levels causing them to decay. Others were of the opinion that the choice of the rubber used in the manufacture of the rubber rings was poor, using a better quality of rubber ring would prevent the early decay of the rubber rings.

Interviews with the field engineers of the PHED revealed that the broken pipes or pipe leakages were frequently caused by the other utilities especially the telecommunication utilities and the public works department damaging the pipelines while laying their own cable networks or while expanding the width of the road to accommodate increased road traffic. To a limited extent this was supported by the analysis of the primary data collected at the repair sites, as 4% of the total failures were observed to be due to digging undertaken by other utilities. The telecommunication industry in India has witnessed a huge expansion in the last decade and the laying of optical fibre cables has been an almost continuous process which has disrupted both the water supply pipelines as well as the road traffic. In Jaipur the depth at which the optical fibre cable is laid is 1.67 metres and the routes followed are parallel to the routes where the water pipelines have been laid. At the time of the research it was found that water pipe lines are laid at an average depth of 0.85 metres and so it was almost inevitable that while the optical fibre cables were being laid that some of the water pipelines would be damaged due to carelessness causing leakages. Another factor which prevented the issue of leakage or broken pipelines being immediately noticed and addressed was the *intermittent supply of water*. If there were a continuous supply of water any damage to the water pipeline would result in immediate visible leakages. Since there is an intermittent water supply in Jaipur very often the telecommunication utility staff would inadvertently damage the water pipelines and refill the trenches and move on. Only when the water supply was recommenced and if the leakage was substantial would these leakages be noticed. The filling up of the trenches would have to be dug up again to find the exact source of the leak. This is a time consuming process and a substantial amount of water is lost affecting the water supply levels to the consumers. The PHED field engineers also stated that formerly because of the nature of the soil (sandy) used to refill the trenches the leakages would be easily observed so that corrective actions could be taken. Now because the soil was covered by tarmac or asphalt the leakages could not be observed and repeated complaints about the low pressure of the water supply could be deduced to be as a result of leakages but to locate the exact location of the leakage took a much longer time causing substantial loss of water. This was corroborated by the research observations of the Malaviya Nagar distribution zone where the cause of complaints due to pipe leakage and broken pipes was as high as 76%. Malaviya Nagar is a newly constructed residential area where a lot of construction work was being done and the roads were being widened to accommodate the needs of a sudden influx of a large number of residents. After laying the optical fibre cables the trenches are also not adequately back-filled. This leads to water pipelines being inadequately protected from the impact of the load of heavy vehicles especially where the water pipeline is laid under a road. The water pipelines are also affected by the expansion in the width of the road. The heavy rollers that are used to compact the expanded road damage the water pipelines that were formerly on the side of the road but due to road widening are now under the road. These failures are termed as failures due to *heavy loads* in the PHED lexicon. The analysis of the primary data collected at the repair sites also revealed that 14.3% of the total failures were caused due to heavy load.

Approximately 30% of the total failures which was collected at the opportunistic repair sample sites were due to service connection failures. The common cause supported by corroborative statements of the field engineers of the PHED was that the service connection failures were caused due to poor condition of the pipes which were made of galvanised iron.

The suggested intervention options to deal with the problem(s) that have been highlighted are

a) The problem regarding the early decay of rubber rings can be addressed by conducting a study on the comparison of costs and benefits of choosing better quality rubber rings to be used in the joints or by using least cost rubber rings and replacing them when they fail.

b) The optical fibre cables laid by the telecommunication utilities should be laid on the opposite side of the road from where the water pipelines are laid. An analysis of the blueprints maintained by the PHED showing their network drawings revealed that the pipelines are mostly laid on one side of the road. Hence if a copy of the network drawings are provided to the telecommunication utilities before they embark on laying of optical fibre cables (always assuming that these design drawings are sufficiently accurate, not always the case as previously discussed) they could choose to lay their cables in such a manner that it would be less likely to damage the existing water supply network. In such cases where the water supply network is laid on both sides of the road a co-ordination meeting could be organised between the field staff of both the utilities to ensure that damage is kept to the barest minimum. This objective could also be achieved by joint detailed supervision of the digging of trenches (which is done by private contractors) to ensure that the physical integrity of the water pipelines are maintained.

c) In the case of road-widening, again the network drawings should be provided to the engineers of the public works department. Road-widening is inevitable and hence in future when the PHED lays its water pipelines the factor of expansion of roads should be kept in mind while deciding on the location of the pipeline. In this case also the engineers of the PHED should be actively involved when the roads are being expanded to ensure that the damage to the water network is reduced.

d) Reduction in the complaints due to service connection failures due to poor condition of the galvanised iron pipes used in service connections could be more appropriately dealt with proactively by formulating a long term capital maintenance strategy. The present practice followed by the PHED is a form of reactive maintenance. A thorough analysis is needed to study the cost-benefit analysis to find out if a proactive capital maintenance programme vis-à-vis service connection pipes especially in the areas identified with frequent service connection failures and subsequent water quality complaints is more economical than continuing with the present reactive maintenance strategy.

The suggested intervention options are mainly based on either better co-ordination with other utilities or a cost benefit analysis of the existing policy regarding the selection of material of the assets (rubber rings, galvanised iron service connection pipes) and their purchase and utilisation.

This illustrates that, notwithstanding the uncertain stakeholder and sustainability context described in Chapter 5, a pragmatic, cost effective approach to asset management of underground pipes is possible, even with the limited data available.

Transfer main line network intervention option

Based on professional experience in England and Wales, Walton (2006) recommends that if the UFW in the transfer line is less than 10% of the input then it is not economical to investigate the cause of the UFW. However if the UFW is more than 15% of the input flow then it is serious enough to be investigated[19]. The UFW in the two transfer lines observed in Jaipur was 9% and 27% of the input flow. On the basis of the above mentioned criterion of economic level of UFW, the transfer main line between Malaviya Nagar and Truck Stand would not merit further investigation, however it would be economically viable to explore the cause of UFW on the other transfer main line between Durgapura and Gandhi Nagar. In the researcher's opinion the PHED Jaipur may need to develop their own criterion as to what range of UFW warrants further investigations by taking into account the local water scarcity conditions.

An explanation for the high volume of the UFW in the transfer line between Durgapura and Gandhi Nagar was sought. There was no clear explanation given by

[19] Walton, B., (2006), personal communication

the PHED staff but they speculated that it could be because of siphoning off water through illegal connections made on the transfer line.

Suggested intervention option is to collate the readings recorded at transfer stations so as to assess the volume of UFW. On the basis of the volume of the UFW over a consistent period of time an intervention mechanism i.e. investigation of the cause of the UFW could be resorted to. If the average UFW is > 15% of the input volume over a period of one month then remedial action should become mandatory because the volume of water lost would be upwards of 35 million litres on average which can be ill afforded by the water utility of a water scarce city like Jaipur.

6.2.6 E. Optimisation

For a long-term, infrastructural renewal, capital maintenance programme once the assets requiring renewal and possible intervention options have been identified, the next step is to select one of the intervention options based on the criterion of either financial returns or risk costs. Infrastructural renewal decisions normally deal with repair/replacement/rehabilitation of an asset/asset category. Decisions regarding renewal options are taken after the need for extensive capital maintenance programme has been identified based on the assessment of the condition of the underground assets. In the case of assets owned by the PHED Jaipur the structural condition of the underground assets was found to be sound indicating no immediate need for a planned capital maintenance programme. Therefore the intervention options considered and suggested are not related to infrastructure renewal. The intervention options are based on developing co-ordination with the other infrastructure utilities in addition to looking at ‘small’ aspects such as pipe rings and service connections. These intervention options have more limited financial implications but imply significant potential benefits. .

In the case of the transfer main line network supplying water however the cost of intervention options has financial implications because the cost of investigating the cause and location of UFW is high as the assets are underground and the location of the losses could be anywhere on a pipeline which is at the least 5 km long. Subsequent to the identification of location and cause of the water loss, the intervention strategy to prevent the water loss would also have financial implications. During the field work the field engineers revealed that the water losses could be due to illegal connections. Attempting to address this issue especially if it is on a large scale would also have political and social costs which may not be possible to quantify in financial terms but would seriously affect the decision making process of choice of intervention options. The cost of the volume of water lost can be measured in both the production and distribution costs as well as the absolute loss of water leading to poorer service. Both the costs i.e. the investigation cost and the cost of loss of water would have to be compared to choose an optimal strategy for intervention.

6.2.7 F. Prioritisation

Infrastructural renewal works are executed after the assets/assets categories requiring renewal are identified, decisions are taken wherein the most economical intervention option for asset renewal is selected and the subsequent investment needs are identified. Prioritisation is required to decide where the works should be taken up first. The worst affected areas are always given priority in case of limited financial investment availability and all the works in one area are taken up together due to economic reasons. In the case of the PHED, Jaipur, on the basis of the comparison of the number of complaints per connection per year, Gandhi Nagar distribution zone is the worst affected area of the three distribution zones that were part of the study.

The analysis of the primary data collected at the repair sites disclosed that 42% of the total repair sites data collected were because of service connection failure in the walled city distribution zone and 25% in the Gandhi Nagar distribution zone. Hence assuming a limited financial outlay if a proactive strategy for a planned capital maintenance programme of service connection pipes category has to be adopted by the PHED Jaipur, the walled city distribution zone should be the priority amongst the three distribution zones studied.

Moglia, M. et al (2006) advocate that clusters of pipes can be chosen for renewal on the basis of an area with many previous failures or an area which experiences many supply interruptions or zones in which the assets have a high predicted failure rate. In the case of PHED Jaipur it is argued that another way of prioritisation can be utilised which is by identifying *those clusters or groups of addresses from where more than one complaint has been received* from the analysis of the spatial locations of the complaints received and have been recorded in the complaint registers. For example the repeated address analysis disclosed that there were 48 complaints from the area/address Siddharth Nagar in one year, which is 15 % of the complaints with the same addresses in ‘Malaviya Nagar distribution zone’. These pockets or clusters can then be targeted or prioritised for finding the cause of repeated complaints and addressing the problem by choosing suitable intervention options.

Prioritisation of which transfer main line is to be taken up first for further investigation and remedial action is a fairly simple decision because it is based on numbers i.e. the pipeline where the maximum amount of water loss takes place needs to be taken up first. The decision for prioritisation could also be based on the number of customers affected by the water loss leading to less or no water supply. The prioritisation decision criterion could also be the choice of such distribution zones where the number of complaints of low water pressure received is relatively more.

6.3 Asset management for above-ground assets

A deep well submersible pump is a mechanical and electrical (M & E) device used for pumping water from aquifers. Its categorisation by virtue of its location would normally cause it to be considered as an underground asset. However because it is an E & M device and a self contained unit it is being regarded as an above-ground asset.

6.3.1 B. Asset information

As mentioned earlier, in Jaipur 97% of the water supply made by the PHED is sourced from groundwater which is pumped into the reservoirs through bore-wells. The PHED Jaipur owns 1240 bore wells. Each bore well has a submersible deep well pump which operates 24 hours a day on electricity.

Interviews with the PHED personnel revealed that the deep well submersible pumps in the PHED are procured in two ways which are firstly when a new bore well is proposed to be dug, in the estimate itself the specifications of the pump is mentioned. The contractor who secures the tender for digging a bore well has to purchase a pump with the same specifications as mentioned in the estimate. He has the choice to select a pump made by certain manufacturers whose names are approved and listed by the department. Secondly if a pump fails and it is to be discarded and replaced, the department can select any pump. The criterion for the selection of the pump is the ‘least cost quoted’

A total of 121 history sheets of deep well submersible pumps were transcribed to an excel spreadsheet for analysis. See Appendix 12 for details. Twenty nine and thirty two history sheets were obtained from ‘Malaviya Nagar’ and ‘Gandhi Nagar’ distributions zones respectively. To increase the sample size, other distribution zone offices were requested to provide history sheets. From two other distribution zones namely ‘Durgapura’ and ‘Sanganer’ 60 history sheets (30 from each zone) were obtained. A total of 121 history sheets of submersible pumps from four distribution zones were collected. History sheets of discarded/unserviceable pumps were not procured. The records were photocopied and returned. Photocopied records were transcribed to an Excel spreadsheet for analysis. The interviews with the PHED staff disclosed that they were inadequately exposed to computing and IT skills and therefore most of the record keeping is done manually.

B. a. Asset attributes

The first page of the history sheet records the specification/attributes of the pump such as type, head, discharge, make, stages, RPM, date of purchase and cost of purchase. The subsequent pages record the details of its description of failure, repair expenses and date of installation and de-installation. The pumps and their history sheets are coded. The records are handwritten.

Most of the history sheets of the pumps did not have information on the date of purchase and cost of purchase of the pump. Only 27 history sheets had information on the cost of purchase. Some records showed guarantee periods and so they did not mention any cost of repair. In some history sheets the specification records were incomplete.

B. b. Asset geographic location

The only information that these history sheet records provide regarding location of the pump is that which distribution zones the bore-well is located at. The pump-sets are coded and accordingly the history sheets are also coded. However the bore-wells are not coded and there was no documented record about the geographic location and depth of bore-wells. The field staff claimed the knowledge regarding the geographic location of the bore-wells and an approximation regarding the depth of the bore-wells. The PHED staff further reported that there are no available records by which the exact location of any specific pump-set can be cross referenced to a bore-well.

6.3.2 C. b Asset performance assessment

The available data from the history sheet records were analysed to approximate life-cycle costs of a pump and were compared against a Modern Equivalent Asset (MEA) cost. It was found that each pump on an average had been repaired five times. The average cost incurred for each repair was INR 4,100 (280 $ at PPP). The average period run between two repairs was 264 days. The maximum number of times that a pump has been repaired was 16 and the maximum cost incurred for a pump's repair has been INR 79,305 ($ 5,406 $ at PPP) in 9 repairs. The maximum life cycle period run has been 15 years 2 months. The maximum period run before the first repair has been 3,599 days i.e. 9years 10months 9 days and the minimum was 6 days.

A survey was conducted in which the field staff of the PHED and the contractors who dug the bore wells and installed the pumps were interviewed to find the present MEA cost for a submersible pump. The survey revealed that the average MEA cost of a submersible pump is INR 18,000 ($1,227 at PPP). The comparable international price of a pump with similar specifications was also found out and it was found that the cost ranges from $750-950 (at PPP)[20] The total cost of maintenance/repair for 52% of the total pumps for which the records were analysed exceeded the MEA cost.

The interviews with the PHED staff revealed that the prevalent practice of the department was to test the hydraulic efficiency of the pump after the pump was repaired. No tests were conducted to check the energy efficiency of the pump. The interviews further revealed that the pump testing records are not maintained.

An independent study on pumps' performance post repair, reported in a proposal report prepared by PHED Jaipur[21], revealed that both the hydraulic and energy efficiency of the pumps were affected after repair. The power consumption by the repaired pumps was reported to increase by 1 to 3 kW, with a reduction in discharge of between 20 to 60% of the design discharge of the pump. Examination of the study report revealed a drawback in the sampling strategy i.e. the specific details about the

[20] Collin, M., Proquip Direct Ltd., Supplier company of submersible bore hole pumps, Personal communication, 12/4/07

[21] Proposal report for augmentation of water supply scheme for Jaipur city, South, 2006, PHED Jaipur

criterion of selection of samples of the pumps was not mentioned. It was not clear if pumps with single repair or multiple repairs were selected to be tested.

The analysis revealed that a pump is repaired after an average period run of 264 days. If one is to consider an average of the reported increase in power consumption after repair, that is 1.5 kWhr, the percentage of pumps whose energy cost and repair cost has already exceeded the MEA cost and still running after multiple repairs is 82.6%. The analysis of the records further revealed that any pump running for more than 86 days after its first repair exceeded the MEA cost.

It was found that the average cost of additional power consumption of a pump repaired at least once is INR 59,130/per pump/year (3.29 times MEA cost). If one assumes that if 50 % of the 1,240 pumps in Jaipur city are repaired at least once, the additional power bill due to decrease in efficiency will be INR 36.66 million/year ($0.815 million/year). Energy cost was calculated on the basis of the unit price of INR 3.56 / kWhr (an average price after combining the fixed charge and energy charges, as calculated for loads varying between 7.5 HP to 15 HP).

6.3.3 D. Identification of possible intervention options

Capital maintenance policy of M & E assets

The analysis of financial data has illustrated that a large part of the operating expense is payment of electricity bills. These electricity bills mainly consist of electricity utilised by operation of the submersible and centrifugal pumps. Since the criterion for replacing a submersible pump is only when the pump loses hydraulic efficiency to an unacceptable level, highly electrically inefficient pumps are in use. The research has also shown that no effort is made to monitor the energy efficiency of the pumps post repair, only the hydraulic efficiency is monitored. Efficiency after repair is dependent on the quality of the repair work. It is possible to maintain design efficiency after repair.[22] Ensuring a high quality of repair and regular monitoring of energy efficiency of the pumps post repair can result in reduced recurring energy expenditure.

[22] Redit, M., ABS Pumps, Personal communication on 2/4/07

The maintenance of records in the PHED, Jaipur with regard to the purchase and maintenance of pump is being carried out on the basis of a uniform format. However various details especially those related to energy consumption are not being maintained. These details are essential to calculate the operating expenses which are an integral part of Life Cycle Cost (LCC). The existing records also do not seem to be a factor in the decision making process regarding capital maintenance of the pumping machinery. The interviews with the PHED staff divulged that the pumps are repaired repeatedly till they are either incapable of being repaired further or the hydraulic efficiency of the pumps is reduced to such an extent so as to make functioning of the pump unacceptable.

By adopting an LCC approach utilising the available historic records of the lifecycle of the submersible pumps, the limited financial resources available with the PHED, Jaipur can be optimised.

Purchasing policy of M & E assets

The purchasing policy of pumps in the department is to select a pump only on the basis of the least cost quoted and not a pump which will ideally have the least life cycle cost. This policy is uneconomical in the long run because a cheaper pump may not have the useful life cycle that a pump chosen on the basis of LCC would have. The repair costs and the increased operating cost due to poor energy efficiency of a pump selected only on the basis of least cost quoted far outweigh the cost of initial purchase price of a pump in which the investment decision is taken on the basis of LCC. Considering the challenges in effecting a policy change so that procurement decisions are based after conducting LCC analysis, an interim solution could be to include energy efficiency specifications for products that the PHED have to purchase.

An analysis of the history sheets revealed that in a majority of the cases of pump failure the reason specified was *'motor burnt pump jammed'*. In the Sewerage Industry in England by far the largest cause of pump breakdown is 'pump blockage' due to inadequate screening (Redit, Marc, ABS Pumps, 2006). The same reason could possibly be applicable to the 'motor burnt pump jammed' pump failure cases in Jaipur which was supported by the interviews with the PHED staff that the most likely cause of this type of failure is clogging due to sand. Investigations could be initiated to ascertain the cause of the most common types of pump failures and measures to prevent these failures could be introduced in the investment decision making process.

The long term impact of purchase of energy-efficient and/or environmentally friendly products presents a substantial opportunity for energy conservation. The PHED can mandate the purchase of energy-efficient and/or environmentally friendly products. It will allow the PHED to lead by example and be a catalyst for market transformation by using its substantial purchasing power to create a market for energy-efficient products. In addition to creating a market, the policy to procure energy-efficient products reduces energy costs without compromising quality.

In summary the PHED, Jaipur has been collecting repair and maintenance expenditure and other information about the pumps; however it is not being used for any decision making. Currently it is in a position to begin applying asset management principles in connection with decision support system regarding the pumping machinery. With some amendments and introducing rigorousness of the already existing data capture process and by introducing energy efficiency monitoring, a better outcome of application of these principles could be achieved.

6.3.4 Service reservoirs

The service reservoirs (SR) are an integral part of the water supply distribution system in Jaipur since most of the distribution zones have water supply under gravity. Six service reservoirs were physically examined to assess their structural condition by observing any evidence of cracking, deterioration of materials and condition of draw-off pipe work. *Drop tests* were conducted to collect the evidence of leakage if any and to assess the extent of the leakage.

Drop tests on service reservoirs

In addition to the underground assets, the above ground assets were also investigated where possible. Of the three selected distribution zones under investigation, the ‘walled city’ does not have any service reservoir (SR) and the water supply is only pumped. ‘Gandhi Nagar’ has two SRs and ‘Malaviya Nagar’ has one SR.

Notes were taken about the structural condition of the SRs. To assess the water loss at SRs, requests were made to conduct the standard drop test. To increase the sample size, a request to conduct drop tests was made to the staff in other distribution zones. Only one distribution zone, ‘Sanganer’, complied with the request and provided results on three SRs.

The drop tests on service reservoirs were conducted by the PHED personnel. At one of the SRs in 'Gandhi Nagar' a water level gauge was not available. To estimate water loss at that SR, it was filled up to the brim until it started to overflow. Then after eight hours it was refilled until it overflowed again. The time taken (t) to refill was observed. A water loss estimate was made by multiplying pump flow discharge rate with the time taken (t). At other SRs, water level gauge readings were observed at the beginning and end of a time interval during non supply hours. The difference in the two readings was multiplied by the surface area of the SR to estimate water loss. Due to intermittent supply the SRs are always either being filled or emptied, so water loss measurement over 24 hours, a requisite for a standard drop test could not be ensured.

Findings

The water loss results as reported by the PHED personnel after conducting the drop tests on the service reservoirs in three distribution zones are presented in a tabular form.

Table 6-10 Drop test results

Distribution zone		Drop test result	Water loss m^3/24 hrs	Observed physical condition
Gandhi Nagar	SR1	100 m^3 in 8hrs	300	Poor
Gandhi Nagar	SR2	Negligible	-	Good
Malaviya Nagar Sector 9	SR1	22.5 m^3 in 5 hrs	108	Good
Sanganer	SR1	1.8 m^3 in 6 hrs	7.2	Good
Sanganer	SR2	15.3 m^3 in 6 hrs	61.2	Good
Sanganer	SR3	11.7 m^3 in 6hrs	46.8	Good

Analysis

1. The structural integrity of the service reservoirs was found to be *good* in five out of six SRs observed because they had been constructed recently (within

the last 15 years). The PHED field staff also reported that the quality of water pumped into these reservoirs was not detrimental to the structural condition of the reservoirs and poor quality construction was responsible for the poor structural condition especially the access i.e. the stairway of the sixth service reservoir.

2. Although the drop tests revealed that there were water losses ranging from 1.8 m^3 to 75 m^3 in 6 hrs in all the service reservoirs examined, the PHED field staff were of the opinion that these losses could not be considered to be a loss to the water supply system because the water loss was due to leakages in the valves which caused the water to enter the distribution network and was very much a part of the total water supplied to the consumers.

The researcher recognises that the investigation of this asset category has not allowed for any meaningful data to be collected and/or conclusions to be drawn with regard to asset management in Jaipur, due to the intermittent nature of water supply and the subsequent limited use of these assets for storage.

6.4 Constraints regarding effective application of asset management framework

An effective application of asset management relies heavily on information and historical data on assets' condition and/or performance. The dearth of the requisite data and poor detailing of the available data was the biggest constraint in effective application of the asset management model. The only information available with the PHED Jaipur relating to underground assets was network drawings. Detailed water quality monitoring data, which could have helped in assessing the performance of the distribution network, could not be accessed – from a customer perspective, perhaps it was not really available.

The available network drawings at the distribution zone offices were the *designed* network drawing and not *as built* network drawings. Recent digitisation of the network drawings was done over a base map which did not have enough detailing such as street names and building footprints. Therefore it was not feasible to make use of it for any visual representation of spatial analysis purposes.

To assess the performance of the underground assets the commonly used data other than service performance indicators is historical mains-break frequency records (Matichich, 2006b), which were unavailable in Jaipur. The other information which assists in assessing the performance of the underground assets is water quality monitoring information. Water quality is, reputedly, being monitored by the PHED, Jaipur on a regular basis. However the information that was provided was for two of the three sampled distribution zones only and even that was very sketchy. The available information could not be cross referenced to any geographic location and did not provide any details about the water quality parameters for example biological/chemical parameters or colour/ odour or their values. The information was made available in the following format which did not help in assessing the performance of assets at all.

Month	No. of satisfactory samples	No. of unsatisfactory samples	Total no. of samples

Since there is no water auditing done, and having no bulk meters in the distribution network, there were no information regarding leakage in the system which could have further assisted in identifying the location of poorly performing assets.

There are practically no pressure gauges installed in the system so hydraulic modelling which is another way of assessing the performance of the underground assets could not be undertaken.

Therefore out of the available information the only data which could indicate performance of the distribution network was the customer complaint records. The complaint records provided in the 'walled city distribution zone' were from January 2005 to December 2005, in 'Malaviya Nagar distribution zone' from June 2005 to March 2006, and in 'Gandhi Nagar distribution zone' from May 2005 to April 2006. The records from the 'walled city distribution zone' for the month of May 2005 recorded complaints for just 10 days and from the 'Malaviya Nagar distribution zone' records there were no records for the month of December 2005; for June 2005 there were records for only one week.

It may be concluded that pages were either torn or complaints not recorded. However it is inconceivable that for the month of May, which is the hottest month of the summer, there are no complaints received for 20 days and also for the whole month of December 2005. It is most likely that the pages or the register containing records were torn and missing and could not be traced. Nobody could explain why the pages were missing. The registers provided were in a very poor condition, pages were coming out, were crumpled and many corners were torn. Handwriting deciphering was another one of the challenges.

The complaints were recorded in the following format.

Date	Address	Details of complaint	Remarks

The categories of complaints identified from the recorded complaints did not make a clear distinction between *leakage in pipeline* and *broken pipeline*.

In these records it was not apparent if the addresses logged in are the addresses of the reporters or the location of the failure. Besides that, as mentioned earlier, many of the addresses that are recorded give no specific information about the location of the failure.

The comments in the "remarks" column were only about whether the complaint was attended to or not. No further details were provided.

Since it was not possible to cross reference or locate any particular house address on these drawings, identification of location/s of clusters or random complaints could not be taken up on maps for visual display of potential areas of concern and instead it was done on a spreadsheet by identifying duplicate addresses.

6.5 Summary of the chapter

The application of structured asset management principles to the fieldwork data highlighted the limitations and the challenges regarding an effective application of asset management with the present-day practices of data management and operational procedures in the urban water utility in Jaipur.

Asset management is totally dependent on a good knowledge of the condition and/or performance of the water treatment and distribution assets. In the PHED Jaipur there is no prevalent practice of monitoring the condition of the physical assets. Also, there is no practice to capture operational data and no water auditing is undertaken which could assist in assessing the performance of the distribution system's assets. Water quality monitoring is undertaken but not consistently and reliably. This chapter demonstrates that in such a case, where there is no recorded data available regarding the condition of the distribution network and no operational data of the distribution network being available, the customers' complaints records can be utilised to assess the performance of the distribution system network. These records can be used to identify the deficiencies and weaknesses of the distribution network and also the potential areas/locations of concern in a distribution zone. This chapter has further highlighted that every opportunistic repair site is a potential information source and demonstrated that the data collected at the repair sites could prove to be extremely useful in providing information about the causes of asset failures and then identifying the intervention options.

There appears to be no coordinated effort to tabulate the physical assets that the PHED Jaipur owns or make use of the data that is recorded to maximise/optimise the utilisation of these assets. Taking a holistic view the agency appears to be virgin territory for the applications of asset management principles. The researcher has examined two specific underground asset categories (distribution network and transfer main network) involved in water supply, collected available data and interviewed relevant personnel from the agency and has applied the asset management model as developed in Chapter 3 with specific objectives of improving serviceability for asset management of distribution network and reduction of unaccounted for water for asset management of transfer mains network.

With reference to the mechanical and electrical machinery, it has established that the application of LCC to the available maintenance records can accomplish one of the objectives of asset management i.e. optimum utilisation of the available resources. The chapter also brings out the issues related to maintenance data management, capital maintenance and purchase policy of the M & E machinery.

This chapter has carried out the objective 4 of the research. It has presented the general overview of the issues regarding the viability of the application of asset management model in an urban water utility in India. It has illustrated how it could be adapted in the context of the limited information and records available with the case study water utility. This chapter has provided a foundation to formulate an asset management model for an urban water utility in India.

Chapter 7: A generic Asset Management model

7.1 Introduction

This chapter addresses the research objective 5 and 6 and presents the proposed generic asset management model for urban water utilities in India which was formulated on the basis of the insights gained from applying the asset management framework to the data collected during the first phase of the fieldwork in Jaipur, Rajasthan. This chapter assess the generalizability and practical application of the proposed model. Potential cost and benefits of initiating an asset management process by the urban water utilities in India are discussed briefly.

7.2 Proposed asset management model for underground and above-ground assets

Since comprehensive asset management requires significant effort, resources and data, Sklar (2006) suggested that utilities may adopt asset management in stages and in a cyclical process through specific initiatives and continuous improvement. The researcher has proposed Phase I and Phase II asset management models for underground assets. The Phase I, asset management model for the underground assets is proposed on the basis of the detailed case study undertaken in Jaipur. In low-income countries limited resources for implementation, mainly in terms of skills and capacity are cited as an obstacle to implementation of new approaches (World Bank, 2004). Therefore the researcher proposes an asset management model to *improve serviceability* with the currently available resources. In addition to improving customer satisfaction through improved serviceability, other expected outcomes are *cost reduction* by improving operational efficiency and suitable capital maintenance planning and bring about *change* such that the focus is on service to consumers and sustainability. Figure 7-1 outlines the 'Proposed asset management model, Phase I' for the underground infrastructure assets of a water utility in India. The proposed asset management model for the distribution network primarily relies on the customer complaints records along with whatever water quality monitoring records might be available and proposes data collection at all opportunistic sites such as repairs and new connections. It is also proposed to utilise the opportunity when other infrastructure utilities' excavation work is in progress, to validate and update network drawings. In England a National Underground Asset Group (NUAG) has been established to improve access to information about buried infrastructure and facilitate a better co-ordination with street-works and traffic management (NUAG, 2006). Along the lines of National NUAG in England, an initiative can be taken up to establish a consortium of the organisations responsible for underground infrastructure, roads and traffic to improve access to information about buried pipelines, cables and water mains.

Proactive customer surveys are suggested to complement the current water service performance assessment. These surveys will also contribute towards a change in organisational culture and pave a way for a consumer centred focus.

Customer complaints records are suggested to be divided into three categories, namely 'low pressure or no supply', 'leakage or broken line' and 'water quality'. A spatial analysis of these complaints and water quality monitoring records should be carried out to identify the location of the assets/assets categories which require intervention. Once the assets have been identified, the next step is to identify suitable intervention options. The tacit knowledge of the field staff regarding the common cause of failures in these asset categories, and the complementary information through the data collection at the repair sites, could then be further used to identify the intervention options.

As shown in Figure 7-1, in the sequence to be followed to identify the least cost intervention option, the first step is to check if any operational improvement can be applied. For asset categories related to low pressure and no supply, it is recommended to investigate illegal connections and suction pumps, in addition to an evaluation of operational intervention. Since in India the water supply is intermittent in most of the cities, therefore for asset categories identified with water quality issues the second step is to investigate if there are any close running sewer lines. Similarly in asset categories with leakage or broken line problems, the second step is to investigate if third party interference is the common cause of failures. The subsequent step is to carry out the repair vs. renewal analysis in all three categories of failures.

Assuming that if the asset management model, Phase I, is adopted and change is embraced by the utility, then over a period of time the utility will have compiled reliable and good quality data about assets, operation and asset failures available to move on to a relatively more sophisticated asset management model. Rather than replacing the Phase I model, the proposed Phase II asset management model (See Figure 7-2) is designed to complement the Phase I model especially for water service performance assessment by incorporating hydraulic and water quality modelling in addition to customer complaints records analysis to identify asset categories requiring intervention. The Phase II model recommends different actions for critical and other assets. Since critical assets failure results in severe consequences, it is advised to first identify critical assets and then undertake a risk analysis to decide a condition assessment strategy and to support renewal decisions. For non-critical assets which are high in number, the same degree of effort as for critical assets will result in extensive resource utilisation which is already at a premium. Therefore statistical forecasting is recommended for these assets to suggest renewal budgets to facilitate planned capital maintenance programmes.

Above-ground, generally Mechanical and Electrical, assets are easier to access and therefore a condition assessment of these assets is not so much of a challenge. M & E asset performance can also be evaluated by energy and hydraulic efficiency measurements. In addition to that, generally M & E asset failure does not affect the service to the customer directly, mainly due to built in redundancy in the system. Therefore a simpler approach of life-cycle costing, a commonly used strategy for management of M & E assets, is proposed for urban water utilities in India. Figure 7-3 shows the proposed asset management model for the M & E assets. Energy costs of operating M & E assets were shown to be a significant proportion of the total operating costs of water service provision. Application of life-cycle costing to the historical maintenance data of these assets demonstrates that the current maintenance policy of these assets is not economic. Asset maintenance decisions of M & E assets, based on the analysis of the historic maintenance records besides an efficiency monitoring programme (post repair), can contribute to reduction of operating and capital maintenance costs of M & E assets. However it is also important to monitor the energy consumption pattern of these assets during operation. Therefore a comprehensive energy efficiency monitoring in addition to compiling repair and maintenance records is advised for lifecycle costing analysis. The expected outcome of the proposed asset management model for the M & E assets is to contribute towards procurement and capital maintenance policy. Initial application of the proposed model is also expected to improve asset data management practices such that information regarding other factors such as mean time between failures (MTBF), mean time to failure (MTTF), asset disposal costs, asset installation and de-installation costs can also be taken into account for a comprehensive application of lifecycle costing.

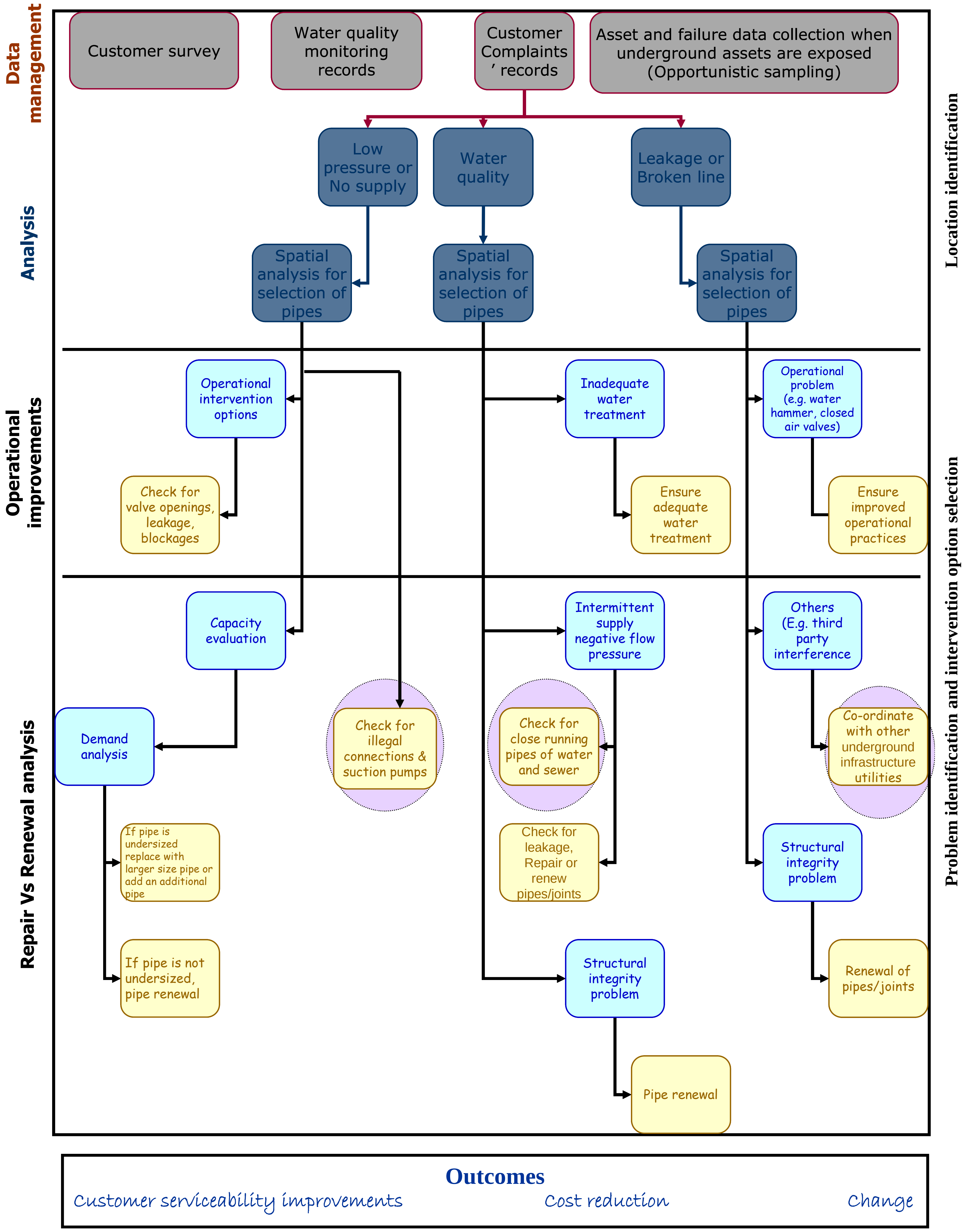
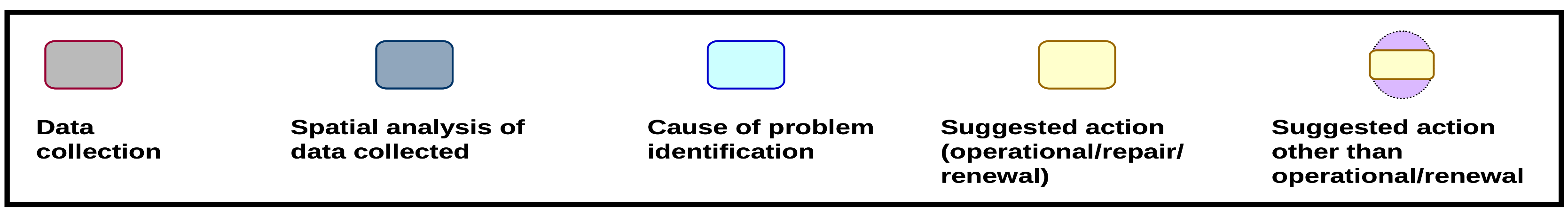


Figure 7-1 Proposed asset management model for underground assets, Phase I

Source: Brighu, U.

Legend



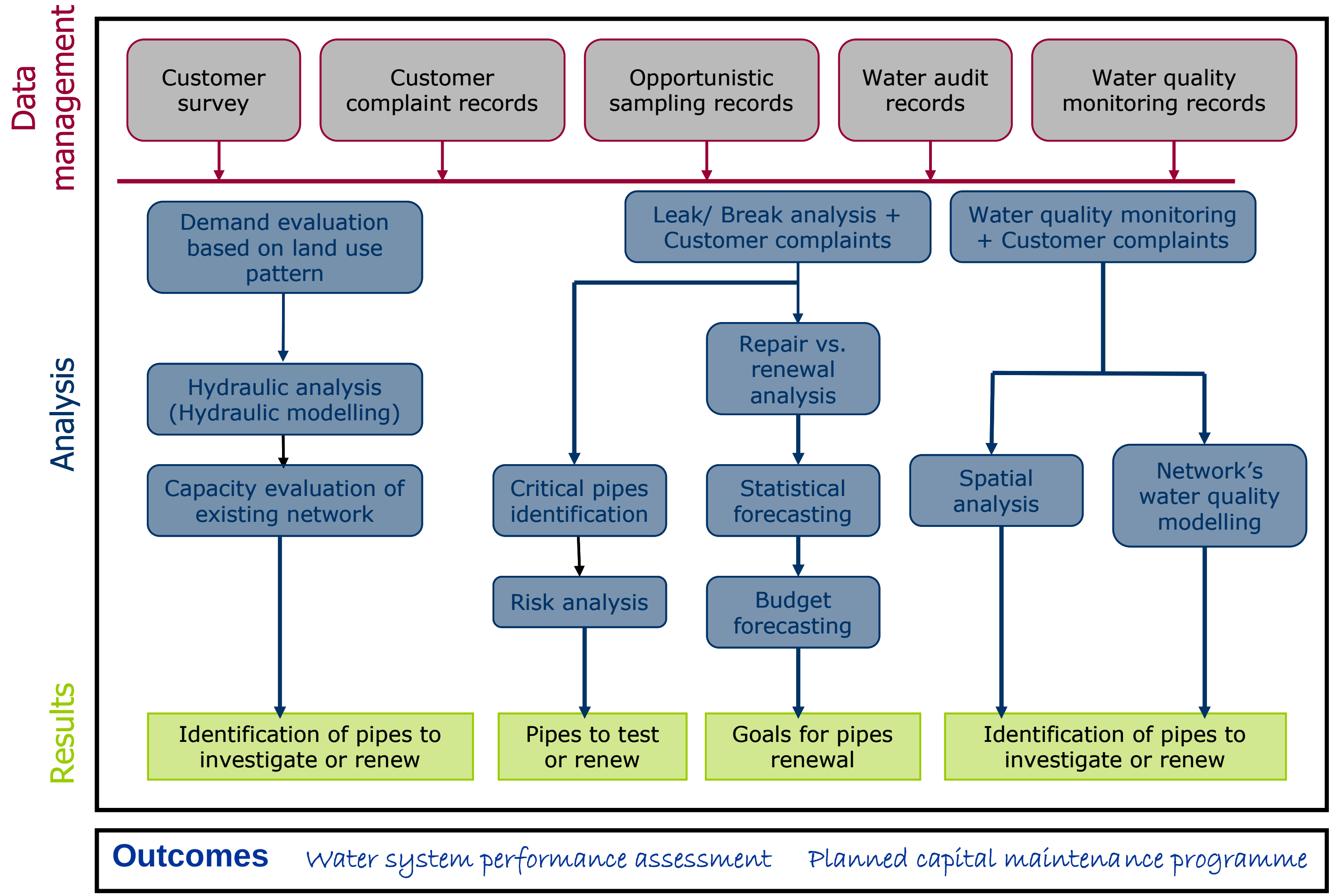


Figure 7-2 Proposed asset management model for underground assets, Phase II

Adopted from Ellison, 2001

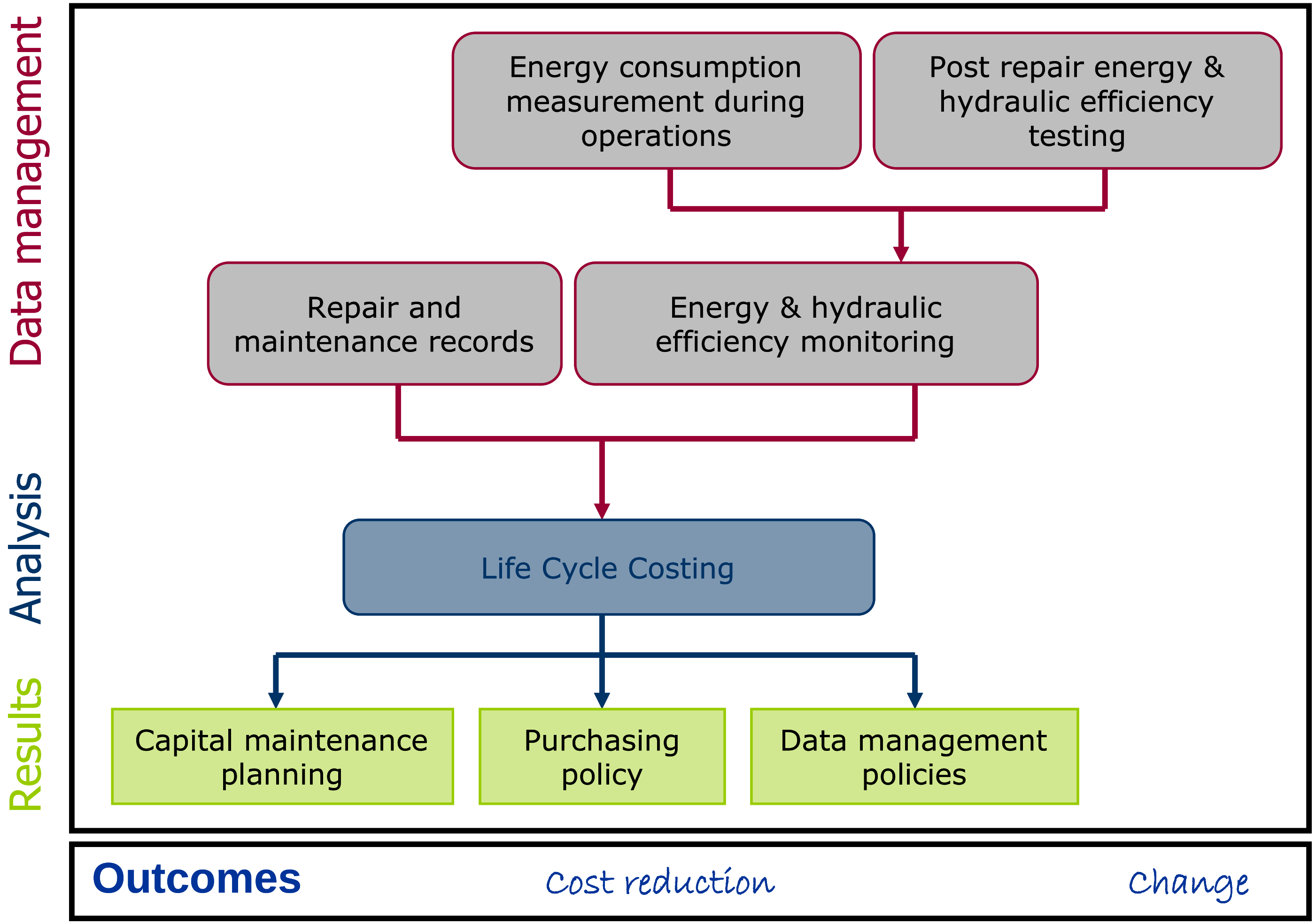


Figure 7-3 Proposed asset management model for M & E assets,

Source: Brighu, U.

7.3 Assessment of the potential wider applicability and relevance of the proposed asset management model

Since it was not feasible to test the proposed models in the field, an exercise that would have necessarily extended beyond the available duration of the research, an external validity exercise (the degree to which findings can be generalised from the specific sample in the study to some target population) was undertaken. The specific research example is the case city of Jaipur and the target population was other similar urban centres in India. The case study city is considered to be representative in its organisational structure and approach to asset management. In order to confirm the applicability of the proposed asset management model to the other urban water utilities, the availability of data required to initiate the proposed model was determined and the opinions of water supply managers in those cities were sought with an aim to identify any practical difficulties in the application of the proposed model.

7.3.1 Data availability with regard to proposed asset management model with urban water utilities in India

The following table summarises the data that is available from a sample of urban water utilities in India.

Shimla and Chandigarh, both being the capital cities of States, were in the process of adopting accrual accounting systems as one of the reform measures suggested by the Jawaharlal Nehru Urban Renewal Mission (JNURM) and therefore the financial data that was available was a cash-based single entry system whereas the case study city Jaipur started with accrual accounting system much earlier and had historical financial data for a reasonable number of years. In Patna, the utility followed no formal accounting practice at all. However the proposed model for the initial stages is not dependent on the historical financial data and therefore it is not a limiting factor for the application of the proposed model.

As shown in the table, all the utilities surveyed, including the case study city, have similar levels of information available regarding assets and assets' attributes. Only two cities, Chandigarh and Jaipur, had digitised AUTOCAD network drawings which were prepared recently from the similar type of paper drawings available with other utilities. While digitising the network drawings, updating was also undertaken with the help of the tacit knowledge of the utility staff. However no formal procedures had been defined for validation or further continuous updating by these utilities.

None of the utilities, including the case study utility in Jaipur, collect or record information regarding the local environmental conditions in which their assets function. However the national agencies, namely the Geological Survey of India (GSI) and the Central Ground Water Department (CGWD), have the information regarding soil types and the level of groundwater. The scale of the soil data that is available with the GSI is too large for it to be useful for any detailed modelling exercise to be undertaken to assess the condition of the underground assets but is sufficient for the Phase I approach.

Asset condition and/or asset performance information is at the core of any asset management model. None of the utilities had any information available on the structural condition of their assets. The conventional practices from which performance of the assets could be assessed such as water audit, leakage management or main break data were not available with any of the utilities surveyed including the case study utility. Therefore the proposed model is essentially based on the customers' complaints records as a proxy performance measure for the underground assets. All the utilities surveyed had historical records of customer complaints. The available records had a similar format in all the surveyed cities. Water quality monitoring records were also available with all the utilities surveyed. However these records were found to be useful only as supporting information because water quality monitoring is not followed very systematically and the record-keeping is also quite inadequate.

On the basis of the available data with the utilities it can be concluded that the proposed asset management model, Phase I can be applicable in all the utilities for underground infrastructure assets. The challenge which is common to all the utilities is digitisation and subsequent analysis of the historical records. Except for the case study utility, no other utility surveyed keeps any record regarding the maintenance of its M & E equipment. Therefore it can be reasoned that it would not be feasible to apply the proposed asset management model for M & E assets fully and straight-away. However such utilities can begin efficiency monitoring of their M & E assets post repair to help in the decision-making process regarding capital maintenance of these assets.

Table 7-1 Data availability with urban water utilities in India

	State	**Rajasthan**	**UT**	**Himachal Pradesh**	**Haryana**	**Punjab**	**Bihar**
	City	**Jaipur**	**Chandigarh**	**Shimla**	**Panchkula**	**Mohali**	**Patna**
	Urban population represented	**13,203,416**	**808,841**	**594,963**	**6,114,067**	**8,246,216**	**8,677,410**
Financial information	**Accounting system**	Double entry	Single entry system, shift to double entry in process	Single entry system, shift to double entry in process	Single entry system	Single entry system	Detailed accounts are not maintained
	Asset valuation	Historic cost and depreciation	Historic cost	Historic cost	Historic cost	Historic cost	
Asset and asset attributes' information	**Network drawings**	As designed paper drawings and updated digitised AUTOCAD drawings	As designed paper drawings and updated digitised AUTOCAD drawings	As designed paper drawings available, digitisation and updating is presently in process (outsourced)	As designed paper drawings available	As designed paper drawings available	As designed paper drawings available

	State	Rajasthan	UT	Himachal Pradesh	Haryana	Punjab	Bihar
	City	Jaipur	Chandigarh	Shimla	Panchkula	Mohali	Patna
	Diameter of the pipelines	Yes	Yes	Yes	Yes	Yes	Yes
	Material of the pipelines	Yes	Yes	Yes	Yes	Yes	Yes
	Gradient of the pipelines	Not marked, field staff has tacit knowledge	Not marked, field staff has tacit knowledge	Not marked, field staff has tacit knowledge	Not marked, field staff has tacit knowledge	Not marked, field staff has tacit knowledge	Not marked, field staff has tacit knowledge
	Location of the pipelines	Cannot be exactly referenced to the centre line of the street or any other reference point, field staff has tacit knowledge	Cannot be exactly referenced to the centre line of the street or any other reference point, field staff has tacit knowledge	Cannot be exactly referenced to the centre line of the street or any other reference point, field staff has tacit knowledge	Cannot be exactly referenced to the centre line of the street or any other reference point, field staff has tacit knowledge	Cannot be exactly referenced to the centre line of the street or any other reference point, field staff has tacit knowledge	Cannot be exactly referenced to the centre line of the street or any other reference point, field staff has tacit knowledge

	State	Rajasthan	UT	Himachal Pradesh	Haryana	Punjab	Bihar
	City	**Jaipur**	**Chandigarh**	**Shimla**	**Panchkula**	**Mohali**	**Patna**
	Age of the pipelines	Can be estimated from other sources and tacit knowledge of field staff	Can be estimated from other sources and tacit knowledge of field staff	Can be estimated from other sources and tacit knowledge of field staff	Can be estimated from other sources and tacit knowledge of field staff	Can be estimated from other sources and tacit knowledge of field staff	Can be estimated from other sources and tacit knowledge of field staff
Asset environment information	**Type of surrounding soil**	GSI maps	GSI maps	GSI maps	GSI maps	GSI maps	GSI maps
	Depth of soil cover	No recorded information	No recorded information	No recorded information	No recorded information	No recorded information	No recorded information
	Type of traffic	No recorded information	No recorded information	No recorded information	No recorded information	No recorded information	No recorded information
	Volume of traffic	No recorded information	No recorded information	No recorded information	No recorded information	No recorded information	No recorded information
	Surface	No recorded information	No recorded information	No recorded information	No recorded information	No recorded information	No recorded information

	State	Rajasthan	UT	Himachal Pradesh	Haryana	Punjab	Bihar
	City	**Jaipur**	**Chandigarh**	**Shimla**	**Panchkula**	**Mohali**	**Patna**
	Groundwater	Ground water department has information	Ground water department has information	Ground water department has information	Ground water department has information	Ground water department has information	Ground water department has information
Asset performance information	**Water auditing**	Not at District Metering level, only water produced and water billed are recorded	Not at District Metering level, only water produced and water billed are recorded	No	No	No	No
	Flow meters in the network	A few but no reading records are available	No	No	No	No	No
	Flow pressure gauges	A few but no reading records are available	A few but no reading records are available	No	No	No	No

	State	Rajasthan	UT	Himachal Pradesh	Haryana	Punjab	Bihar
	City	Jaipur	Chandigarh	Shimla	Panchkula	Mohali	Patna
	Main break records	None available	None available	None available	None available	None available	None available
	Water quality sampling	Practiced and historic records are available	Practiced and historic records are available	Practiced and historic records are available	Practiced and historic records are available	Practiced and historic records are available	Practiced and historic records are available
	Customer complaint records	Historic records are available	Historic records are available	Historic records are available	Historic records are available	Historic records are available	Historic records are available
	Repair/maintenance records	None available	None available	None available	None available	None available	None available
Asset Condition information		None available	None available	None available	None available	None available	None available
M & E machinery	**Initial purchase records**	Available	Not available	Not available	Not available	Not available	Not available
	Maintenance records	Available	Not available	Not available	Not available	Not available	Not available
	Operational records	Not available	Not available	Not available	Not available	Not available	Not available

7.3.2 Opinions/comments of the Indian urban water sector professionals on the proposed asset management model

Having made her own assessment of the likely fit of the proposed asset management model, the researcher sought the opinions of senior utility managers from each of the following cities: Shimla (Himachal Pradesh), Mohali (Punjab), Chandigarh (Union Territory), Panchkula (Haryana), Patna (Bihar) and Jaipur (Rajasthan). There follows the thematic, qualitative analysis of the interviews conducted to identify the difficulties and limitations in practical application of the proposed asset management model.

Infrastructure renewal needs for functional sustainability of water service and the role of the proposed asset management model

1. Practitioners asserted that infrastructural renewal due to deteriorating infrastructure is not a concern for them at this point of time. In Jaipur and Shimla, due to rapid growth of the cities, meeting increased demand for water by increasing production is their priority. Capacity enhancement is the next concern in Jaipur and Shimla due to the growth of city and change in demographic density due to change in land use pattern, particularly in Jaipur where single house buildings are being replaced by multi-apartment buildings. In Chandigarh the practitioners stated that their priority is to shift to 24/7 water supply which indicates the need for more active asset management. There was little understanding that asset management of ‘small things’ such as ‘O’ rings and connections, could lead to significant additional availability of water to meet growing demand.

2. Some of the practitioners argued that the present practice of informal asset management is quite similar to what has been proposed in the model. The present approach to infrastructural renewal decisions is based on field staff’s knowledge and recommendations which is further based on identification of locations from where there are repeated customer complaints and their causes.

3. With regard to the deterioration of the underground assets over time and the functional sustainability of the water service the response was ‘ *we will see when it comes to that’*.

Data capturing practices and the use of data

1. For the likely requirement of large-scale infrastructure renewal in the future, the usefulness of historic records regarding asset condition, performance and failure records was recognised by the practitioners. However they also cited the current disregard of the available records for any kind of decision-making purposes. They also pointed out the non-digitised format of the records as a reason for non use along with the organisational culture. It was suggested by them that there should be a separate department within the utility tasked with ensuring that useful records are maintained properly and analysed to assist decision-making processes.

2. The field engineers in Jaipur, Patna and Shimla mentioned that the utilities' employees do not have the necessary computing skills. They asserted that recording information regarding asset condition and/or performance may not prove to be a challenge, however analysing it could very well be.

3. Practitioners in Patna were of the view that, in absence of any records, doing any form of asset management in a scientific and systematic manner is practically impossible. Apart from that, due to frequent floods in Patna, the underground pipes are 10-12 feet deep in many places and in their opinion locating such pipelines is not worth the effort.

4. In Shimla there are no records of customer complaints made on the personal telephone number of the field engineer. Also customers file a Public Interest Litigation (PIL) in the courts regarding a water quality problem and do not register a complaint. Therefore the engineers were of the opinion that the proposed asset management model may have limited applicability in Shimla however a beginning can be made and in future all complaints received on personal phone numbers and through PIL may also be recorded in a consistent manner.

5. In Chandigarh the practitioner was of the opinion that the number of complaints received is very small and these are mostly related to water meters and billing (0.01/connection/year). Complaints related to water quality and pressures are minimal and in the opinion of the practitioner the present reactive approach to

address leakage complaints is the most cost effective approach. The practitioner in Chandigarh did not see any benefit in the proposed model vis-à-vis Chandigarh water supply.

The concept of determining asset condition and the collection of failure data at the repair site was considered to be quite useful, not only for the application of asset management, but also to be able to project to their seniors what the field staff already know but are unable to back up with the numbers, such as number of instances of some particular kind of failures e.g. leakage, main breaks etc. Collecting information in a consistent format at the site would have no practical problems but digitisation and then analysis of the collected data would be. According to them, if the working culture is not addressed at the organisation's policy level, this too will end up as another one of those records in the archives.

It was mentioned that in order to do things formally in a systematic manner with a futuristic perspective the working culture of the agency would have to be changed. These practitioners were not very clear by whom and how the change could be brought about. They mentioned that all the employees have been working according to a particular working style for so long that to expect them to change the way they work will be met with resistance. They emphasised the requirement of training and documentation of data capturing procedures if any change is to be brought on.

The practitioners supported the proposed model as a stepping-stone towards bringing in the change. They asserted that the outcomes, in terms of customer satisfaction through improved serviceability and cost reduction, can be achieved more realistically over a long term, citing the challenges associated with bringing in change such as training, documentation, overcoming resistance to change etc.

Another opportunity was presented to the researcher in terms of presenting the research in a Water Safety Plan workshop and to test the proposals with water utility professionals from even more States of India. Most of the audience agreed with the ground realities especially about non-availability of the network drawings, lack of updating, the absence of operation and maintenance procedures documentation, and non-conformation of the standard operating procedures regarding addition of chemicals during coagulation and disinfection processes of water treatment and sample collections for water quality monitoring. They accepted that they were aware of the standard practices and the relevant manuals however they did not respond to why these were not followed in practice.

The practitioners recognised that the working culture of their organisations needs to change and that accountability should be introduced. They did not offer any suggestions regarding how to achieve the same. They debated amongst themselves how the universal ‘carrot and stick’ policy may or may not work.

From the analysis of the two-pronged approach to assess the extent to which the proposed model could be used more widely, it can be concluded that the model can be the starting point for asset management and will be applicable with varying degree of effectiveness in the water utilities surveyed in India. The proposed model is largely based on the existing customer complaint records and water quality monitoring records. The record-keeping procedures and water quality monitoring are followed with different degrees of rigorousness in different utilities. This issue has to be addressed if any form of asset management is to be developed.

Regarding the practical application of the proposed model, concerns were raised by the water utility professionals regarding the digitisation and analysis of the records. The most important concern that was expressed related to the organisation’s willingness to embrace change since they recognise that accepting and embracing change is by far the hardest thing that their organisations face.

7.4 Potential costs and benefits of the proposed asset management model

7.4.1 Potential costs

The proposed model, for good reason, mainly formalises the informal practices that currently happen already. The potential costs involved in terms of infrastructure requirement and man power requirement to implement the proposed model are therefore not very significant, as shown in Table 7-2. It only requires making use of the available resources to begin with and the degree of sophistication can be improved with progressively better and improved data collection over time. However, training of staff for recording information and for the analysis of the data available is essential and would entail certain costs and staff time.

For an effective application of the proposed asset management model for the M & E assets, historical maintenance records, besides energy efficiency monitoring, are fundamental. Except for the case study city, no other city that was surveyed had any of this kind of information available to them. None of the surveyed cities, including the case study city, had any planned efficiency monitoring programme for the M & E assets. It is necessary to develop a suitable method to capture operating and maintenance records of the M & E assets of the water utilities. Monitoring hydraulic and energy efficiencies of the pumping machinery post repair is also vital for the application of life-cycle costing. Therefore suitable procedures are required to be developed, along the lines suggested in Figure 7-3, by all the utilities. Again there would be limited cost implications.

A first approximation of the potential costs involved in the practical application of the proposed asset management model for the underground assets, Phase I, is presented in Table 7-2. The quantitative figures for resource requirement are estimates based on resources utilised by the researcher to achieve these tasks during the research.

7.4.2 Potential benefits

Since the proposed asset management model could not be tested in practice, it is unrealistic to quantify the benefits. However the application of the generic asset management framework to the data collected from the PHED, Jaipur has demonstrated that it can be a used as a tool to further *consumer service satisfaction*.

1. The proposed Phase I asset management model is a first step towards managing the serviceability of assets such that the current water service levels are improved. The main initial driver, as well as benefit, is service improvement in terms of water supply pressure, water quality and leakage aiming for *consumer satisfaction*. Improvements in service levels will also affect the coping costs incurred by the consumers. While estimating the coping costs, investment in storage tanks made by the consumers is not considered as part of the affected coping strategies. This is because although the proposed Phase I asset

management model can support the move from intermittent supply to 24/7 water supply, without parallel water-pricing policy interventions continuous supply remains a distant dream. Also, storage tank construction is a one-time investment which has already been made, that is a ‘sunk cost’. The results of the customer survey that was conducted to assess the coping costs (in financial terms only) incurred by the consumers due to poor service levels is shown in Table 7-3. The average cost of each of the coping actions per month is more than the average cost of water bill per month (INR153 or $10.43). Four of the sampled consumers incurred costs on two coping mechanisms simultaneously; the rest of the positive sampled consumers for coping costs had only one of the coping mechanisms options. Thirty one per cent of the sampled consumers were incurring some kind of costs to cope with the poor water service levels.

2. As proposed in the Phase I asset management model for underground assets, the data collection regarding asset condition and failure mechanisms and its causes, at all opportunities when the underground assets are exposed, will verify and update the available information regarding asset and its environment and capture and document the information regarding the structural condition of the underground assets. This information can then later be utilised for statistical forecasting, as proposed in asset management model, Phase II. It will also support the identification and documentation of the common types and causes of the failures and the selection of the remedial actions leading to improved operation and maintenance procedures initially and capital maintenance decisions in the long term. Proactive improved operating procedures would result in fewer failures, thereby reducing repair and other costs.

3. The proposed life-cycle costing approach, including energy and hydraulic efficiency monitoring for asset management of the M & E machinery, would lead to overall *cost reduction* and facilitate improvements in asset procuring policies for the organisation.

4. The proposed model will facilitate transparency in the decision-making process of the utility by having a structured decision support system and removal of subjectivity in decision making.

5. One of the most important benefits of the adoption of the proposed asset management models is introducing a *change* in working culture of utility and shifting the focus of the utility from infrastructure creation to service provision.

To sum up, the proposed asset management model can deliver the desired outcomes as shown in the conceptual analytical framework (Figure 4-1). Reflecting once more on Lewis, (2006), it has been shown how it is possible, even in the present state of Indian water utilities, to deliver the benefits of *Customer service satisfaction*, *Cost reduction* and *Change*. Since these water utilities in India are under no legal or regulatory obligation for any kind of compliance, the fourth outcome, i.e. *Compliance* is not yet relevant in this case.

Table 7-2 First approximation of the potential costs in adopting asset management model, Phase I

Task	Infrastructure & other requirements	Average Man hour required	Man power requirement	Remarks
Digitisation of historic records	IT equipment	40 man hours for complaints records of one year per distribution zone	One person for one week per distribution zone	There are enough number of computers available and are not being used. Currently the staff ratio is very high and there are personnel available with basic computing skills. Reallocation of jobs can be a solution.
		40 man hours for historic records of 100 pumps	One person for one week	
Updating of network drawings	Drawing equipment	60 hours	Field staff and drawing section staff	Tacit knowledge of the long term field employees need to be captured and documented before they retire from the organisation. Initially the hard copies can be updated and digitisation can be taken up later which would require additional infrastructure such as computers, software and specialised computing skills
Data collection at repair sites and data recording	IT equipment & training		Field staff and record keeping staff	

Task	Infrastructure & other requirements	Average Man hour required	Man power requirement	Remarks
Customer surveys	Training			Currently the staff ratio is very high and therefore reallocation of jobs can be a solution, however training will be required.
Data analysis	IT equipment & training			There are enough numbers of computers available with urban water utilities with MS Office installed, which are not being used.
Training on computing skills	IT equipment			For the analysis of the available data, sophisticated computing skills are required and therefore the training is essential
Training for data collection procedures at repair sites and customer survey				Training of the field staff on how to record information, explaining the technical terms such as failure mechanisms etc and for understanding the importance of the information that needs to be recorded.

Table 7-3 Coping strategies costs

	Bottled water cost/month	Water tanker cost (INR/month)	Water booster cost		Water purification unit		Tube well	
			Purchase (INR)	Running (INR/month)	Purchase (INR)	Running (INR/month)	Capital (INR)	Running (INR/month)
Mean		187.5	2,700.0	226.7	5,417.6	20.0	35,777.8	356.3
Std deviation		274.9	1212.4	64.3	1878.0		15570.6	375.5
Std error		39.3	404.2	21.4	170.7		1730.1	46.9
Count*	0+	9 (8.8%)	3 (2.9%)	3 (2.9%)	11 (10.8%)	1 (0.98%)	10 (9.8%)	10 (9.8%)

* Count is the no. of affirmative responses for the above coping strategies, out of a total of 102 responses

+ Bottled water is purchased when travelling and not for everyday use.

7.5 Summary of the chapter

This chapter has addressed research objective 5 and 6 that is proposing asset management model adaptable in Indian context and its wider application. This chapter also considered the potential relevance of the proposed models in terms of the outcomes such as cost reduction, change, customer satisfaction and compliance, as depicted in the conceptual framework (See Figure 4-1).

Currently asset management decisions in the urban water utilities surveyed have tended to be subjective and most often reactive. There is no planned capital maintenance programme in any of the cities surveyed. A system is not in place to ensure that expenses and impacts of failures are systematically minimised so that the right elements are renewed at the right time. Asset management is basically about doing the right things at the right time and Albee and Byrne (2007) recommend that ‘the best strategy for getting started in asset management is simply to get started’. The proposed model can serve as a starting point and can then subsequently be enhanced over time.

With regard to the asset performance information presently available, there are different mechanisms to register customer complaints. Record-keeping is not followed with the same meticulousness in all aspects of complaints procedures in all the cities that were surveyed. It would be required to improve the customer complaint recording methods, in addition to the format of the customer complaint form, for a better and improved application of the proposed model.

The major challenge for the practical application of the proposed model was identified as the ‘*willingness in the organisation to change*’ and how such change can be brought about. Another impediment for the practical application of the model was cited as the lack of computing and analysing skills of the personnel but this is easier to address.

But for a few cynical remarks such as ‘*presenting the same thing in new packaging*’, the model was considered to be a step forward to improve customer service satisfaction and as a precursor to bring change in the working culture.

A first approximation of the potential costs associated with the implementation of the proposed model based on the resources utilised by the researcher in the various proposed activities makes it quite clear that the costs involved are limited at the very beginning, excluding all training costs. In the researcher's opinion, if the utility is willing to adopt change, it can implement the proposed model with the current available resources.

Change and customer satisfaction are the main outcomes of the proposed Phase I asset management model. Cost reduction in terms of operating cost and capital maintenance cost of M & E assets is another important outcome of the proposed asset management. Apart from these outcomes, these models will also address the issues of transparency by providing a structured decision-support system and elimination of subjectivity in decision-making.

Chapter 8: Conclusion

This chapter presents the conclusions of this study against the six objectives set in Chapter 2. Based on the outputs of the research, conclusions are drawn on each of the research objectives in turn.

Addressing Objective 1: "*To describe "sustainability" in the context of water supply systems and determine the role of asset management with regard to the sustainability of water service"*

In the context of urban water supply, this study has critically reviewed the concepts of sustainable water supply systems, whereby the lack of a clear definition of sustainability was highlighted. The review (presented in Chapter 3) demonstrates that in order to define sustainability, there is a need to derive an explicit definition based on the context under consideration. Therefore, for urban water supply, sustainability of water supply systems is described in terms of the requirements to maintain service today and in the future. The three-pillar definition of a sustainable water supply system (environmental, financial and functional) is considered, whereby it is demonstrated that asset management relates to all three dimensions of the sustainability though with varying relevance.

Currently it is environmental and financial sustainability that attracts attention in the water sector. The study recognises the importance of the environmental and financial dimensions of water supply system sustainability as prerequisites for functional sustainability. From that base it is possible to focus on the functional dimension through the serviceability lens of asset management. This focus is justified by water service being essentially dependent on the physical infrastructures owned, operated and maintained by a water utility and the role of asset management in procuring, operating and maintaining these infrastructures. Since the procurement, operations and maintenance of physical infrastructure entail significant cost there is evidently an impact of asset management on the financial sustainability of services but, as the financial analysis indicated, that financial sustainability also impacts asset management.

The functional sustainability aspect also addresses issues of operational efficiency and asset maintenance and is, again, directly related to financial sustainability through potential cost reductions. The case study findings, which show a complete absence of planned operational efficiency or asset maintenance practices within the surveyed urban water utilities in India, provide further justification for the focus on the functional dimension of sustainability. The process of describing sustainability in the context of the water supply system and determining the role of asset management towards sustainable water supply systems achieves Objective 1 of this study.

The lack of academic literature regarding asset management provided no ready starting point from which to develop an appropriate analytical framework for *asset management and sustainability* of water supply systems. Therefore, this analytical framework was developed (See Figure: 3-1) as part of this research to help confirm the relevance of the research objectives, identify key research issues, and guide the methods for data collection and analysis, especially in circumstances where resources to carry out the research were limited.

Addressing Objective 2: *"To determine the key drivers of asset management in water utilities in high-income countries and assess their relevance in Indian context"*

Following on from the analytical framework, further literature was reviewed to identify the key drivers of asset management. The reason behind this objective was to assess the potential relevance of these drivers in the context of the Indian urban water supply sector during the case study research that followed.

The literature review identifies financial reporting requirements, economic regulation and the increasing awareness regarding the ageing of infrastructure by the water utilities, as well as the enormous investment requirement for rehabilitation. Similarly, environmental factors such as water quality and quantity as the drivers of asset management in the water industry can be seen. Advances in information technology, climate change and community expectations regarding the environment encourage and assist in adopting more sophisticated tools for asset management.

These drivers, when considered in the context of the case study, reveal that they currently have very limited potential to act as drivers of asset management improvement in India. As there is no regulatory or statutory compliance requirement regarding serviceability, limited financial reporting requirements and little active participation or demand from the community, it is the scarcity and unreliability of available water resources in relation to the increasing demand, at least in Jaipur, as well as limited funds that could perhaps trigger off a transformation and pave the way towards enhanced asset management in significant sections of the Indian urban water supply sector.

Addressing objective 3: "*To determine the asset management principles, methods and data requirements with reference to water service and develop a generic asset management model"*

With regard to water supply and wastewater asset management, the approach has been that principles developed in practice (by utility associations and utilities) have advanced the theory (academics and research). Most of the available literature regarding asset management in water utilities focuses on regulation or financial reporting requirements. The professional literature review facilitated the formulation of a generic asset management framework (Table 3-5) with a unique combination of all the underlying principles and methods of asset management that have been used by the water utilities across the world for underground pipe networks.

The literature review also provides an understanding of the evolution of the concept of asset management in the water industry through various stages beginning with informal asset maintenance to a sophisticated risk based asset management.

The literature review, complemented by the information gathered through interactions with water utility professionals in England, helped to identify data requirements for testing the viability of applying this asset management framework to an Indian urban water utility.

Addressing objective 4: "*To apply the generic asset management model in order to assess the viability and adaptability of asset management in an Indian urban water utility and identify constraints"*

The generic asset management model for underground assets was tested for viability of its application with the data and information collected from the PHED, Jaipur, an urban water utility in India. The testing exercise revealed that there were challenges and limitations regarding an effective application of the generic asset management such as inadequate data availability with the PHED, Jaipur and their present-day practices of data management and operational procedures. The details of the challenges encountered during the trial application of the generic asset management model for underground assets are as follows:

Lack of data and the inadequate detailing of the available data is the biggest constraint affecting the application of generic asset management model in the PHED, Jaipur. In addition to that the available data cannot be cross-referenced to a geographic location on the available network drawings. Another challenge is digitisation of hand-written records which are in poor condition and handwriting is mostly indecipherable.

Asset management is totally dependent on a good knowledge of the condition and/or performance of the water treatment and distribution assets. In the PHED, Jaipur there is no prevalent practice of monitoring the condition of the physical assets. Also, there is no practice to capture operational data and no water auditing is undertaken which could assist in assessing the performance of the distribution system's assets. Water quality monitoring is undertaken but not consistently and reliably. Main break data is not captured. Therefore one could say that no information which is conventionally used to assess the asset performance or serviceability is available within the PHED except the customer complaints records.

These customers' complaints records present a starting point to evaluate the performance of the distribution system network. However the format for customer complaints records needs to be improved to avoid confusion regarding the exact location of failures. These records can be used to identify the deficiencies and weaknesses of the distribution network and also the potential areas/locations of concern in a distribution zone. Another very useful opportunity that is available with the PHED, Jaipur is the tacit knowledge of the senior long-serving field staff regarding the asset location, condition, performance and failures which should not be allowed to be missed.

In summary the currently available data regarding the underground pipe network can only be used to primarily identify the areas of concern regarding the poor serviceability and later to prioritise on the basis of identification of relative comparison of serviceability. However if data regarding asset condition and failures recorded at all the opportunities when the underground assets are exposed is used to complement the available data, the application of the framework could be improved. It allows identifying possible intervention options to assist the decision making process for maintaining or improving serviceability.

With reference to mechanical and electrical machinery, the application of life cycle costing (LCC) to the available maintenance records can accomplish one of the objectives of asset management i.e. optimum utilisation of the available resources or cost reductions. M & E asset maintenance policy requires attention since the PHED has already spent much more money on the maintenance of many M & E asset than their modern equivalent asset (MEA) cost and these are still in use. There is a need to develop a criterion to decide when to dump an asset based not just on hydraulic efficiency requirement or subjective decisions (current practice) but also taking into consideration its historic maintenance costs and energy efficiency. For that there is a need to develop and implement an energy efficiency monitoring system.

Addressing Objective 5: “*To propose an asset management model adaptable to Indian urban water utilities*”.

Following Objective 4, asset management models for underground and M & E assets are proposed separately for an urban water utility in India. Recognising data availability and resource limitations in an urban water utility in India, the asset management model for underground assets is proposed in two phases. Phase I model is proposed to be a starting point to initiate asset management with the data that is available and additional low-cost data capture at opportunistic sites. Over a period of time with better data capture practices, improved data formats so as to allow cross-referencing to a geographical location and a change in working culture, it is assumed that the utility may be in a position to move to Phase II of the asset management model. The proposed Phase II model is a graduation to a slightly more sophisticated asset management practice by making use of hydraulic and water quality modelling. It suggests identifying critical assets for optimum use of limited available resources. It recommends an evaluation of the investment requirements to maintain serviceability such as to facilitate improved financial planning.

Addressing objective 6: “*To assess the wider application and the potential relevance of the proposed asset management model for Indian urban water utilities*”

The proposed asset management models were assessed for their wider application by two distinct approaches. Firstly, by finding out if other similar utilities in India have the data required for the proposed asset management model; secondly, by determining the possible practical difficulties in its application by interviewing water utility professionals in India

Historical customer complaints records are the primary requirement for the application of Phase I asset management model for underground assets. All five utilities surveyed have mechanisms in place to register complaints and historical records were available with these. However there are different mechanisms to register customer complaints and the record keeping is not followed with same meticulousness in all the mechanisms. It would be required to improve the customer complaint recording methods besides the format of the customer complaint form for a better and improved application of the proposed model.

All the 5 utilities surveyed had no historical records regarding the purchase, maintenance or energy or hydraulic efficiency monitoring of mechanical and electrical equipment. Therefore the proposed asset management model for the M & E assets cannot be implemented straightaway by any of the utilities surveyed other than the case study city, Jaipur.

8.1 Conclusions about the research problem

This study has made a contribution towards the knowledge of determining the applicability of asset management in urban water utilities in India. The findings of the study discussed above may contribute to the literature on asset management in water utilities in the context of low-income countries. The research revealed that with the level of available data and information with urban water utilities in India, it is not viable to apply asset management comprehensively the way it is practiced currently in high-income countries, however a pragmatic, cost effective approach to asset management of underground pipes is possible, even with the limited data available.. Based on the available limited data and recognising the current context of intermittent supplies, a unique asset management model for underground assets adaptable to urban water utilities in India was developed to be a first step towards asset management with an aim to achieve '*customer satisfaction*' and a '*change*' in working culture. The proposed stage I asset management model for underground assets can then be further modified depending on the data capture practices by the water utilities to attain their strategic objectives through either limited or total asset management practice to achieve the overall goal of functional sustainability of water services.

The research also demonstrated that application of asset management to the above ground M & E assets potentially may contribute to '*cost reductions*' and provide guidelines for capital maintenance and procurement policies of these assets. The research facilitated formulation of an asset management model for the above ground M & E asset with an aim to reduce costs through introduction of efficiency measures in utilisation of energy and available financial resources.

8.2 Implications for theory

The major challenge for the practical application of the proposed model is identified as the '*willingness in the organisation to change*' and how this can be facilitated. In addition to that it was identified that data management practices including the quality and detailing of the available records and updating of these records need to be improved so as to have a more effective application of asset management.

Theoretical frameworks of asset management therefore, in the context of low-income countries, need to incorporate aspects of organisational behaviour in a more systematic manner. Due emphasis is also required to be given to developing realistic data management practices i.e. data collection, record keeping and updating practices.

8.3 Implications for policy and practice

One of the impediments for the practical application of the model was cited as the lack of computing and analysing skills of the personnel. If this is true, in a country as renowned as India is for its computing and analytical skills, then the implications for service providers are very clear: they have to begin to staff their organisations at an appropriate technician and professional level with ongoing capacity-development for all staff.

The proposed model was considered to be a step forward to improve customer service satisfaction and a precursor to change in the working culture. However, it is unlikely that enhanced asset management alone can bring about that change. There is a clear responsibility on politicians, senior government officials and leaders of service providers to start a more committed process of organisational change – beyond the handful of 'metropolitan' service providers which are making progress to serve their customers.

8.4 Limitations

This study could be criticised for taking a limited proposed approach to asset management in India, relative to the complexity found, for example, in the previously discussed Common Framework, now being implemented in England and Wales. However, the researcher, based upon the fieldwork evidence, has tried to be utterly realistic as to what can actually be achieved in India in the short term. She has resisted the temptation to pretend that more can be achieved for the sake of appearing more 'advanced' in this research.

The real limitation therefore is the inability, during the limited study time available, to see the proposed asset management approach implemented and results monitored, even at the Phase I level.

8.5 Implications for further research

Although this study achieved its objective to investigate the viability of the application of asset management there were some issues which were identified as requiring further research. The study has revealed a range of issues that appear to influence, or are associated with, asset management and water service provision in the context of the Indian urban water supply sector. The list of priority areas for future research is presented below:

1. Modify further the generic asset management framework by including asset management practices from other infrastructure services such as roads, construction and energy.
2. Explore the scope for using asset management for comparative competition and benchmarking of service levels in different distribution zones of an urban water utility.

3. Undertake a long term cost benefit analysis of urban water utilities adopting asset management.
4. Develop effective data management systems for asset management
5. Explore ways to promote the concept of asset management to urban water utilities in India.

8.6 Closing Statement

The urban population of India is increasing at a high rate; the availability and reliability of water resources, along with limited available storage capacity, is a challenge. The uncertainty of water availability is even more of a concern due to climate change. For environmental sustainability of water service, optimum use of the available water, leakage reduction and demand management practices are of paramount importance. These issues are required to be addressed in addition to inter-state water transfer conflicts and water resources pollution.

Pricing policies affect the financial sustainability of a water utility. Since cost recovery pricing is still an anathema to the Indian water sector, recovery of even operation and minor maintenance costs is not achieved through user charges. This results in the complete absence of planned maintenance of the existing assets. Deferment of maintenance of assets will affect the functional sustainability of the water service by accepting increased mains breaks with subsequent ever-increasing leakage levels leading to the loss of such a valuable resource, along with increased water quality problems in addition to the inter-generational transfer of costs.

It is apparent that with the current scenario it will be very difficult for the urban water utilities to maintain even present serviceability, as indicated by continuously deteriorating service levels over the past years. There is a need therefore to explore the ways to at least maintain present (albeit inadequate) service levels and to consider to what extent these approaches can contribute towards achieving the goal of sustainable water service.

Getting started is stated to be the best strategy recommended for asset management and the research findings are an encouragement to make a first step. Most importantly the proposed Phase I model is instrumental in shifting the focus of the utility from infrastructure creation to service provision by bringing in a '*change*' in the working culture of the organisation, which should guide the way, eventually, to higher '*customer satisfaction*'. The research findings demonstrate that asset management of M & E assets can achieve '*cost reductions*'. The proposed models are a step forward, despite all the obstacles and limitations that currently preclude 'proper' asset management. Some of the proposed actions may already exist informally but the model formalises and acknowledges these vital contributions. For those service providers which have already begun the process of asset management, the thesis presents a Phase II approach which has the potential to enable the delivery of 'world class water to world class cities'. For such a capital intensive service, good asset management remains the pre-requisite to sustainable water supply.

REFERENCES

Ackerman. (Computer Sciences Corporation), (1999), *Achieving world class asset management* (unpublished The 10th annual water conference presentation, The Economist Conference, Le meridian Piccadilly), .

ADB (2007), *2007, Benchmarking and data book of water utilities in India,* ADB.

ADB (2006a), *Urbanisation and sustainability in Asia,* 051206, ADB, Philippines.

ADB (2006b), *Strategic thinking to achieve water MDGs,* ADB, Philippines

ADB (2002), *Beyond boundaries: Extending services to the urban poor,* ADB.

ADB (2002), "Chapter 3: Universal service obligation and reform", in *Beyond boundaries: Extending services to the urban poor,* ADB, Manila, Philippines, pp. 17-18.

Agrawal, P. C. (2008a), *Performance improvement planning: Designing an effective leakage reduction and management programme,* , WSP, India, New Delhi.

Agrawal, P. C. (2008b), *Performance improvement planning: Upgrading and improving urban water services,* , WSP, India, New Delhi.

Aikman, I. and Doherty, D. J. (2006), "Overview of infrastructure asset management: A view from both sides of Atlantic Ocean", *Water environment foundation: WEFTEC,* Oct. 2006, Dallas TX, Water Environment Foundation, USA, pp. 4151.

Albee, S. (2005), "America's pathway to sustainable water and wastewater systems", *Water asset management international,* vol. 1, no. 1, pp. 9-14.

Albee, S. and Byrne, R. (2007), "A global vision for driving infrastructure asset management improvement", *Leading-edge asset management: Reports and abstracts book,* 17-19 October 2007, Lisbon, pp. 27.

Alegre, H. (2007a), "Strategic infrastructure asset management: concepts, schools and research needs", *Leading edge asset management: Reports and abstracts book,* 17-19 October 2007, Lisbon, LNEC, Lisbon, pp. 48.

Alegre, H. (2007b), "Strategic infrastructure asset management: concepts, schools and research needs", *Leading edge asset management: Reports and abstracts book,* 17-19 October 2007, Lisbon, LNEC, Lisbon, pp. 48.

Alegre, H., Baptista, J. M., Cabrera Jr, E., Cubillo, F., Duarte, P., Hirner, W., Merkel, W. and Parena, R. (2006), *Performance indicators for water supply services,* Second ed, IWA, London.

Amarasinghe, U. A., Shah, T., Turral, H. and Anand, B. K. (2007), *India's water future to 2025-2050: Business-as-usual scenario and deviations,* 123, International Water Management Institute, Colombo, Sri Lanka.

Ashley, R., Blackwood, D., Butler, D. and Jowitt, P. (eds.) (2004), *Sustainable water services: A procedural guide*, IWA Publishing, London.

Araral, E. (2008), *The political economy of urban water in India and South East Asia*, available at: http://www.spp.nus.edu.sg/wp/Araral-Water%20in%20India%20and%20SE%20Asia%20160608.pdf (accessed 28-08-08).

Bajaracharya, S. R., Mool, P. K. and Shrestha, B. R. (Undated), *Impact of climate change on Himalayan glaciers and glaciel lakes,* , ICIMOD and UNEP.

Banyard, J. (2004), *Water for the world - why is it so difficult?* , Institution of civil engineers.

Banyard, J. K. (1996), "Asset management", *Knowledge, Information & Data 1996,* pp. 55.

Banyard, J. K. and Bostock, J. W. (1998), "Asset management- investment planning for utilities", *Proceedings of institution of civil engineers, Civil engineering,* vol. 126, pp. 65-72.

Baptista, J. M. and Alegre, H. (2007), "Target definition and assessment of performance in water services", *Leading-edge asset management: Reports and abstarcts book,* 17-19 October, 2007, Lisbon, pp. 53.

Beck, B., Alam, U., Jeffrey, P., Robertson, K. and Speers, A. (2006), "How many engineers does it take to achieve sustainable water management", *Water 21,* , no. June, pp. 12.

Brandon, T. W. (ed.) (1984), *Water distribution systems,* The institution of water engineers and scientists, London, England, London.

Briscoe, J. and Malik, R. P. S. (2006), *India's water economy: Bracing for a turbulent future,* , World Bank, New Delhi.

BSI (2004), *Asset management, Part-1: Specification for the optimised management of physical infrastructure assets,* PAS 55-1, BSI, London.

Burn, S., Marlow, D., Moglia, M. and Buckland, P. (2007), "Asset management for water infrastructure", *Water asset management international,* vol. 3, no. 1, pp. 12.

Byrne, R., Edwards, R. and Wilson, J. (2003), "Asset management benchmarking to deliver sustainable improvements", *Water 21,* , no. December, pp. 49.

Canning, M. E. (2002), "Field testing of infrastructure for asset evaluation", *American water works association. Journal,* vol. 94, no. 12, pp. 53-57.

Carter and Rwamwanja, R. (Cranfield University, Silsoe), (2006), *Functional sustainability in community water and sanitation: A case study from south west Uganda* (unpublished Consultancy)

Cashin, G. (2006), "Asset management in the context of operation and maintenance contracts", *Water asset management international*, vol. 2, no. 4, pp. 12.

Chakrabarti, P. G. D. (2001), "Urban crisis in India: New initiatives for sustainable cities", *Development in practice*, vol. 11, no. 2 & 3, pp. 260.

Chaudhary, P. K. (2003), “International linkages, economic reforms and democracy: A study of India’s political economy, PhD Dissertation, University of Pennsylvania

Choe, K. (2008), *Raising revenues: Quick solutions for better services*, available at: http://www.adb.org/Water/Articles/2008/Raising-Revenues.asp#a1 (accessed 16-05-08).

Clarke, C. (2005), "The Australian influence: Asset Management - a CEO's point of view", *Water asset management international*, vol. 1, no. 2, pp. 3.

CNN-IBN (2006), *India 360-Consumer the king*, available at: http://www.ibnlive.com/videos/27777/12_2006/india360_0512_1/india-360-consumer-the-king.html (accessed 10/12/2006).

Conroy, P. and Williams, W. (2007), "Engineering developments in asset management: water supply", *Leading-edge asset management: Reports and abstracts book*, 17-19 October, 2007, Lisbon, pp. 131.

Cox, J. (2005), "New developments in investment planning and project evaluation: optimising expenditure to meet multiple objectives with limited resources", *Water asset management international*, vol. 1, no. 2, pp. 9.

CPHEEO, G. (Undated), *Policies of GoI*, available at: http://cpheeo.nic.in/ (accessed 11/6/07).

CPHEEO, G. (1999), *Manual on water supply and treatment*, , GoI, New Delhi.

Cromwell, J., Nestel, G. and Albani, R. (2001), *Financial and economic optimisation of water main replacement programs*, 90821, AWWARF & AWWA, USA.

D'Agata, S. (2003), "The "go with what you know" approach to forecasting future asset replacement expenditure", *Water Science and Technology: Water supply*, vol. 3, no. 1, pp. 51-54.

Day, G. (2007), "Improving water asset management planning in the England and Wales water industry: a regulator's perspective", *Water asset management international*, vol. 3, no. 1, pp. 5-7.

Deb, A. K., Grablutz, F. M., Hasit, Y. J. and Snyder, J. K. (2002), *Prioritising water main replacement and rehabilitation*, 90898, AWWARF &AWWA, USA.

Deb, A. K., Momberger, K. A., Hasit, Y. J. and Grablutz, F. M. (2000), *Guidance for management of distribution system operation and maintenance*, 90803, AWWARF & AWWA, USA.

DEP (2007), *What is a sustainable city*, available at: http://www.dep.org.uk/scities/background/sustainablecity.php (accessed 20/10/07).

DeSilva, D., Burn, S., Tjandraatmadja, G., Moglia, M., Davis, P., Wolf, L., Held, I., Vollertsen, J., Williams, W. and Hafskjold, L. (2005), "Sustainable management of leakage from wastewater pipelines", *Water Science and Technology*, vol. 52, no. 12, pp. 189-198.

Dutta, P., (2006), "Urbanisation in India", *European population conference*, 21-24 June, 2006, Liverpool, UK, available at http://epc2006.princeton.edu/download.aspx?submissionId=60134 (accessed 14/11/08).

Ellison, D. (2001), *Distribution infrastructure management: Answers to common questions*, 90846, AWWARF & AWWA, USA.

Engelhardt, M., Savic, D., Skipworth, P., Cashman, A., Saul, A. and Walters, G. (2003), "Whole life costing: Application to water distribution network", *Water Science and Technology: Water Supply*, vol. 3, no. 1-2, pp. 87-93.

Foley, A. (2005), "Benchmarking asset management", *Water asset management international*, vol. 1, no. 1, pp. 22.

Franceys. (Cranfield University), (2006), *Guidelines for user fees and cost recovery* (unpublished Lecture notes), Cranfield University.

Franceys. (Cranfield University), (2005), *Use and analysis of financial statements* (unpublished Lecture notes), Cranfield University.

Franceys, R., (2002), *Change management forum: for sustainable urban water and sanitation in India*, Change Management Forum, India.

Franceys, R. and Gerlach, E. (eds.) (2008), *Regulating Water and Sanitation for the Poor - Economic Regulation for Public and Private Partnerships*, I ed, Earthscan, UK.

Gangl, G., Fuchs-Hanusch, D., Stadlober, E. and Kauch, P. (2007), "Analysis of the failure behaviour of drinking water pipelines", *Water science and technology: Water Supply*, vol. 7, no. 5, pp. 219.

GAO (2004), *Water infrastructure: Comprehensive asset management has potential to help utilities better identify needs and plan future investments.* GAO-04-461, GAO, USA, USA.

Gessler, M., Brighu, U. and Franceys, R. (2008), "The challenge of economic regulation of water and sanitation in urban India", *Habitat International*, vol. 32, no. 1, pp. 49.

GoI (Undateda), *The Constitution (Seventy fourth amendment) Act-1992*, available at: http://indiacode.nic.in/coiweb/amend/amend74.htm (accessed 10/05/07).

GoI (Undatedb), *The Ministry*, available at: http://urbanindia.nic.in/moud/theministry/ministryofurbandevelopment/main.htm (accessed 12/05/07).

GoI (Undatedc), *Urban scenario*, available at: http://www.urbanindia.nic.in/moud/moud.htm (accessed 11/6/07).

GoI (Undatedd), *Water related problems: water contamination*, available at: http://www.wrmin.nic.in/index1.asp?linkid=145&langid=1 (accessed 12/05/07).

GoI (Undatede), *Water the Resource*, available at: http://wrmin.nic.in (accessed 11/6/07).

GoI (2008a), *Economic survey 2007-2008*, available at: http://indiabudget.nic.in/es2007-08/chapt2008/chap13.pdf (accessed 30/05/08).

GoI (2008b), *Report of the high level group on service sectors*, GoI, New Delhi.

GoI (2007), *Committee on infrastructure*, available at: http://infrastructure.gov.in/ (accessed 4/6/07).

GoI (2006a), *Jawaharlal Nehru National Urban Renewal Mission: Overview*, available at: http://jnnurm.nic.in/nurmudweb/toolkit/Overview.pdf (accessed 2/09/08).

GoI (2006b), *Modified guidelines for projects of Jawaharlal Nehru National Urban Renewal Mission on urban infrastructure and governance*, available at: http://jnnurm.nic.in/toolkit/modified_guidelines.pdf (accessed 4/6/07).

GoI (2006c), Jaipur: City development plan, available at: http://urbanindia.nic.in/moud/programme/ud/CDP_Appraisals_Nipfp/CDP-Jaipur.pdf (accessed 12/06/08)

GoI (2005), *Annual report 2004-05, Ministry of Urban Employment and Poverty Alleviation*, GoI, New Delhi.

GoI (2003), *Census of India*, available at: http://www.censusindia.gov.in/Default.aspx (accessed 21/05/07).

GoI (2002a), *India assessment 2002-Water supply & Sanitation*, , Planning commission of India, India.

GoI (2002b), *National water policy*, , Ministry of water resources, GoI, New Delhi.

GoR (2007), *Statement of revenue and receipts: 2006-07*, available at: http://finance.rajasthan.gov.in/doc/0708/vol1-2.pdf (accessed 18/09/07).

Grigg, N. S. (2006a), "Condition assessment of infrastructure systems", *Journal of Infrastructure Systems*, vol. 12, no. 3, pp. 147-153.

Grigg, N. S. (2006b), "Condition assessment of water distribution pipes", *Journal of Infrastructure Systems*, vol. 12, no. 3, pp. 147-153.

Grigg, N. S. (2004), *Assessment and renewal of water distribution systems,* 91025F, AWWA Research Foundation, USA.

Guardian, (2002), *NHS finance 2002-03: The issue explained*, Guardian, UK.

Harlow, V. K. (2005), "Risky business: two case studies in asset risk management", *Water asset management international*, vol. 1, no. 1, pp. 5.

Harlow, V. K. and Stewart, D. (2006), "Condition assessment: should you risk it?", *Water asset management international*, vol. 2, no. 3, pp. 4.

Heare, S. (2007), "Achieving sustainable water infrastructure", *American water works association. Journal*, vol. 99, no. 4, pp. 24.

Heather, A. I. J. and Bridgeman, J. (2006), "Water industry asset management: a proposed service-performance model for investment", *Water and environment journal*, vol. 21, pp. 127.

Heinicke, G. and Stenstrom, T. A. (2006), "Drinking water treatment and supply", in Malmqirst, P., Heinicke, G., Karrman, E., et al (eds.) *Strategic planning of sustainable water management*, IWA Publishing, London, UK.

Hobson, S. (2005), "Show off your assets", *Utility week*, pp. 21.

Hu, Y. and Hubble, D. W. (2005), "Failure conditions of asbestos cement water mains in Regina", *I CSCE speciality conference on infrastructure technologies, management and policies*, 2-4 June 2005, Toronto, Ontario, Canada, pp. FR135-1.

IMF (2008), *World economic outlook*, IMF.

ISO (2007), *Activities relating to drinking water and wastewater services: Guidelines for the management of drinking water utilities and for the assessment of drinking water services,* ISO 24512, ISO, Switzerland.

Kane, M. J. (1997), "Evaluating condition of underground iron pipes", *The construction and operation of underground utilities conference*, 24-27 February, 1997, Coventry, UK, Scientific survey limited, pp. 1.

Kayaga, S., Smout, I. and Al-Maskati, H. (2007), "Water demand management-shifting urban water management towards sustainability", *Water science and technology: Water supply*, vol. 7, no. 4, pp. 49.

Kleiner, Y. and Rajani, B. (2001), "Comprehensive review of structural deterioration of water mains: statistical models", *Urban Water,* vol. 3, pp. 131.

Kleiner, Y. and Rajani, B. (1999), "Using limited data to assess future needs", *Amerian water works association. Journal,* vol. 91, no. 7, pp. 47-61.

Knudson, M., Gittings, S., Stilwill, R. and Wilson, C. (2006), "Asset management condition assessment for Stockton: To test or not to test", *Water Environment Foundation: WEFTEC*, October 2006, Dallas TX, Water Environment Foundation, USA, pp. 4226.

Kumar, R. (1996), *Research methodology: A step by step guide for beginners,* First ed, Sage Publications Ltd, London.

Kumar, R., Singh, R. D. and Sharma, K. D. (2005), "Water resources of India", *Current Science*, vol. 89, no. 5, pp. 794.

Kulshrestha, M. and Mittal, A. K. (2005), "Water and Sanitation in South Asia in the context of the Millenium Development Goals", *South Asia Economic Journal,* vol. 6, no. 1, pp. 99.

Lewis, M. (2006), "Loopy about assets", *Utility week,* vol. November, pp. 24-24.

Lindley, E. (1992), "Asset management planning: theory and practice", *Journal of international water and environmental management*, vol. 6, pp. 621-627.

Marlow, D. (2005), "Sustainability based asset management", *Enviro-06,* Vol. paper e6190, Melbourne, .

Marlow, D. and Burn, S. (2008), "Effective use of condition assessment with asset management", *American water works association. Journal,* vol. 100, no. 1, pp. 54.

Marlow, et al. (CSIRO Land and water, Highett, Victoria, Australia), (2006), *PARMS-Priority: An advanced asset management software tool for water distribution network* Australia.

Mather, D. (2006), "Captured by data: enterprise asset management systems", *Water asset management international,* vol. 2, no. 2, pp. 14.

Mathur, O. P. (2006), "India", in Roberts, B. and Kanaley, T. (eds.) *Urbanization and sustainability in Asia: Case Studies of good practice*, ADB, Philippines, pp. 135.

Matichich, M., Allen, J. and Allen, R. (2006a), "Asset management planning and reporting options for water utilities", *American water works association journal,* vol. 98, no. 1, pp. 80-87.

Matichich, M., Booth, R., Rogers, J. and Rothstein, E. (2006b), *Asset management planning and reporting options,* 91095, AwwaRF, USA.

McAll, R. and Brooks, S. (ND), *Satisfying capital maintenance planning common framework for asset replacement,* Advantica, UK.

McIntosh, A. C. (2003), "Tariffs, subsidies and development funding", in *Asian water supply: Reaching the urban poor,* ADB, Philippines, pp. 73-79.

Metcalfe, A. V. (1991), "Probabilistic modelling in the water industry", *Journal of international water and environment management,* vol. 5, pp. 439-449.

Moglia, M., Burn, S. and Meddings, S. (2006), "Decision support system for water pipeline renewal prioritisation", *Electronic Journal of Information Technology in Construction,* vol. 11, pp. 237-256.

NAMS and IPWEA (2001), *International Infrastructure Management Manual,* NZ National asset management steering group, Wellington.

NCERT (2006), *Text book in Geography for class 11 India: Physical environment*, NCERT, New Delhi

Nickson, A. and Franceys, R. (2003), *Tapping the market: The challenge of institutional reform in the urban water sector,* I ed, Palgrave Macmillan, New York.

Njiru, C. and Sansom, K. (2003), **"**Strategic marketing approach to urban water services in developing countries*". Proceedings of the Institution of Civil Engineers (ICE,) Municipal Engineer Journal*, Volume 156, no. ME2, pp143-148.

NIUA, I. (2005), *Status of water supply, sanitation and solid waste management in urban areas,* National Institute of Urban Affairs, New Delhi.

NUAG (2006), *Capturing, recording, storing and sharing underground asset information: A review of current practice and future requirements,* UKWIR, London.

Oakes, M. and Phillips, J. (2006), "Cultural challenges of embedding decision technology", *4th Annual CIWEM conference: Emerging environment issues and future challenges*, 12-14 Sep. 2006, Newcastle-upon-Tyne.

OFWAT (2008), *June return 2008 reporting requirements: Chapter 1 Key outputs and service delivery*, available at: http://www.ofwat.gov.uk/aptrix/ofwat/publish.nsf/Content/jr08_reporting_requirements (accessed 5/11/08)

OFWAT (2007), *Understanding OFWAT: A glossary of the most commonly used terms*, available at: http://www.ofwat.gov.uk/aptrix/ofwat/publish.nsf/AttachmentsByTitle/understanding_ofwat220507.pdf/$FILE/understanding_ofwat220507.pdf#page=55 (accessed 18/03/07).

OFWAT (2006), *The development of the water industry in England and Wales, ,* OFWAT, UK.

OFWAT (2000), *MD 161: Maintaining serviceability to customers*, available at: http://www.ofwat.gov.uk/aptrix/ofwat/publish.nsf/Content/maintainingserviceability (accessed 24/01/06).

OFWAT (1998), *Asset inventory and system performance submission. Reporting requirements and definitions.* , OFWAT.

Olsson, G. (2007), "Strategies to close water supply and demand gap", *Water science and technology: Water supply,* vol. 7, no. 4, pp. 103.

Panagariya, A. (2008), *India: The emerging giant*, First ed, Oxford University Press, New Delhi.

Parker, J. (2008), "The repair or replace dilemma for services and mains", *Water 21, ,* pp. 51.

Parsons, D. (2006), *Regulating asset management through serviceability and a common framework for investment planning, ,* OFWAT, UK.

Parsons, D. (1999), "Asset management in water distribution- Part 2", *Pipes & Pipelines International,* vol. 44, no. 3, pp. 17-26.

Pearson, D. and Dewhurst, M. (1989), *Strategic planning of rehabilitation requirements and methods* .

Pollard, S., Hrudey, S., Leiss, W. and Godfree, A. (2007), *Risk analysis strategies for credible and defensible utility decisions,* 91168, AwwaRF, AWWA, IWA, USA.

Rajani, B. and Kleiner, Y. (2004), "Alternative strategies for pipeline maintenance/renewal", *AWWA 2004 annual conference: International overview of pipeline design, installation and maintenance practices*, 13-17 June, 2004, Orlando, Florida, AWWA, pp. 1.

Raven, A. V. (2006a), "Asset management: complex problems require sophisticated analytical approaches", *Water asset management international,* vol. 2, no. 1, pp. 19.

Raven, A. V. (2006b), "An independent review of the EU-funded CARE-W programme", *Water asset management international*, vol. 2, no. 2, pp. 8.

Redit. (Group operations director, Service spares and rental, ABS pumps), (2007), *A practical approach to achieving the benefits of life cycle costs (LCC) in wastewater applications* (unpublished Presentation paper).

Robson, C. (1993), *Real world research,* First ed, Blackwell Publishers, Oxford.

Rogers, P., Silva, R. D. and Bhatia, R. (2002), "Water is an economic good: How to use prices to promote equity, efficiency and sustainability", *Water Policy,* vol. 4, pp. 1.

Rojas, T. and Davis, J.H., (2008), *Implementing an asset maintenance management strategy: Where do you start*, April ed., Water and wastewater international, USA.

SAFEGE. (PHED, Jaipur), (2000), *Feasibility study: Jaipur water supply and sanitation project* (unpublished Consultancy).

SAPI. (PHED, Jaipur), (2004), *Special assistance for project implementation of Bisalpur Jaipur water supply project for JBIC* (unpublished Consultancy).

Sarkar, J. (1984), *A history of Jaipur*, Orient Longman Limited, New Delhi

Savic, D. A. and Walters, G. A. (1999), "Hydro informatics, data mining and maintenance of UK water networks", *Anti corrosion methods and materials,* vol. 46, no. 6, pp. 415-425.

Schulting, F. L. and Alegre, H. (2007), "Global developments of strategic asset management", *Leading-edge asset management; Reports and abstracts book,* 17-19 October 2007, Lisbon, pp. 7.

Shah, T., Makin, I. and Sakthivadivel, R. (2005), "Limits to leapfrogging: Issues in transposing successful river basin management institutions in the developing world", in Svendsen, M. (ed.) *Irrigation and river basin management: Options for governance and institutions,* CABI Publishing, pp. 31-36.

Sharma, A. (2006), *Urban water sector in South Asia: Benchmarking performance,* , WSP, World Bank, New Delhi.

Sklar, D. C. (2006), "Asset management and its alignment with effective utility management", *Water asset management international,* vol. 2, no. 3, pp. 13.

Smith, A. (2007), "A mature relationship: Regulation and innovation in the UK water industry", *Water asset management international,* vol. 3, no. 1, pp. 3.

Sohail, M., Cavill, S. and Cotton, A. P. (2005), "Sustainable operation and maintenance of urban infrastructure: Myth or reality", *Journal of urban planning and development,* vol. 131, no. 1, pp. 39.

Srivasatava, R. and Sasikumar, S. K. (2003), *An overview of migration in India, its impact and key issues*, available at: http://www.livelihoods.org/hot_topics/docs/Dhaka_CP_2.pdf (accessed 29/08/08)

Stephenson, D. (2005), *Water services management,* I ed, IWA Publishing, London, UK.

Tecco, N. (2008), "Financially sustainable investment in developing countries water sectors: what conditions could promote private sector involvement", *International Environmental Agreements,* vol. 8, pp. 129.

Thackray, J. E. (1990), "Privatization of water services in the United Kingdom", *Urban water infrastructure. Proc. NATO workshop, Isle of Man, 1989,* , pp. 33-41.

Thomsen. (Chatham House), (2007), *Infrastructure and Indian development: Reform first, invest later* (unpublished Briefing paper), London.

Tewari, R., (2007), *States invite private players to secure safe drinking water*, Indian Express.

TNN, (2001), *Opposition lambasts water tariff hike*, Times of India, India.

TNS, (2004), *Water tariff hike rocks assembly*, The Tribune, Delhi.

Todinov, M. T. (2006), *Risk based reliability analysis and generic principles for risk reductions,* I ed, Elsevier, GB.

UKWIR. (UKWIR, London), (2007), *Assessing capital maintenance planning* (unpublished UKWIR News), London.

UKWIR (2004a), *Implementing the common framework: Meeting asset data requirement for PR09, Volume 2: Methodology and findings,* 04/RG/05/11, UKWIR, UK.

UKWIR (2004b), *Implementing the common framework: Meeting asset data requirements for PR09 Volume 3 Protocol for the collection and submission of data for water treatment works and sewage treatment works,* 04/RG/05/12.

UKWIR (2002a), *Capital maintenance planning- A common framework. Volume-1: Overview,* 02/RG/05/3, UKWIR, London.

UKWIR (2002b), *Forecasting serviceability and asset performance indicators,* 02/RG/05/2, UKWIR, London.

UN (Undated), Goal 7: Ensure environmental sustainability, available at http://www.un.org/millenniumgoals/environ.shtml (accessed 19/11/08)

UNEP (2007), *Global outlook for ice and snow,* , UNEP.

UNEP (Undated), *Asia Pacific environment outlook*, available at: http://www.rrcap.unep.org/apeo/index.html (accessed 4/09/08).

Urquhart, T. (2006a), "Asset management around the world: the expertise of Australia/New Zealand, the UK and the US", *Water asset management international,* vol. 2, no. 1, pp. 3.

Urquhart, T. (2006b), "Incorporating condition assessment into a comprehensive asset management programme", *Water environment foundation: WEFTEC,* Oct. 2006, Dallas TX, Water Environment Foundation, pp. 4198.

Van den Broeck, W., Vojinovic, Z., Antonaropoulos, P. and Tselepidis, S. (2005), "Hydroplan - EU knowledge management framework for urban water asset management", *IWA international conference on water economics, statistics and finance,* 8-10 July 2005, Greece, IWA, pp. 67.

Vanier, D. J. (2001), "Why industry needs asset management tools", *Journal of computing in civil engineering,* vol. 15, no. 1, pp. 35.

Vanier, D. J. and Rahman, S. (2004), *Municipal infrastructure investment planning (MIIP) report: A primer on municipal infrastructure asset management,* B-5123.3, NRC-CNRC, Canada.

WHO and Unicef (2006), *Meeting the MDG drinking water and sanitation target: The urban and rural challenge of the decade,* available at: http://www.who.int/water_sanitation_health/monitoring/jmpfinal.pdf (accessed 19/11/08)

WHO (2008)*, Water, sanitation and hygiene link to health,* available at: http://www.who.int/water_sanitation_health/publications/facts2004/en/index.html (accessed 4/09/08).

Walker, Y. V. (2004), "Mind the gaps", *Utility week,* , pp. 20-21.

Water UK (2007), *Water industry finance and investment: Why water services need so much investment,* Briefing note 2, Water UK, London, UK.

Water UK (2002), *Back ground paper: Capital maintenance and national infrastructure,* Water UK.

Wood, A. (2007), "Constructing water main break database for asset management", *American water works association. Journal,* vol. 99, no. 1, pp. 52.

Woodward, D. G. (1997), "Life cycle costing - Theory, information acquisition and application", International Journal of Project Management, vol. 15, no. 6, pp. 335-344

World Bank (2008), *World development indicator database*, available at: http://siteresources.worldbank.org/DATASTATISTICS/Resources/GDP_PPP.pdf (accessed 30-05-08).

World Bank (2007), *World Bank list of economies, April 2007,* available at: http://siteresources.worldbank.org/DATASTATISTICS/Resources/CLASS.XLS (accessed 4/6/07).

World Bank (2006a), *Bridging the gap between infrastructure and service: India water supply and sanitation*, World Bank, http://go.worldbank.org/1Z1E4M9HK0.

World Bank (2006b), *India inclusive growth and service delivery: Building on India's growth, Development policy review*, 34580-IN, World Bank.

World Bank (2005), *India's water economy: Bracing for a turbulent future,* , World Bank, Washington DC.

Worley International (2000), *Strategic municipal asset management*, 21100, World Bank.

WSP (1999), '*Willingness to pay but unwilling to charge: Do "Willingness to pay" studies make a difference?*', field note. New Delhi, WSP- SA

Wu, Z. Y. (2006), "Technological requirements for water system asset management", *Water Science and Technology: Water Supply*, vol. 6, no. 5, pp. 123-128.

Yepes, G., Ringskog, K. and Sarkar, S. (2001), "The high costs of intermittent water supplies", *Journal of Indian Water Works Association,* vol. 33, no. 2.

Yoshino, N. and Nakahigashi, M. (2000), *The role of infrastructure in economic development*, available at: http://www.econ.keio.ac.jp/staff/dikamiya/pdf00/seminar/1205.pdf (accessed 24/08/08).

Appendix 1: Practices adopted by water utilities

In England and Wales, water utilities have developed certain strategies/ methodologies by applying asset management principles taking into account local circumstances. These circumstances such as level of data available within the water utility and prevalent causes of concern in service delivery (water supply pressure problems, water quality problems, leakage problems) have influenced their approach to asset management practices. The water utilities have formulated asset management procedures which are unique to their objectives, circumstances and settings to prepare Asset Management Plans (AMPs).

Some of the asset management procedures developed in England and Wales are enumerated below to address part of the research objective 3 for determining asset management methods and data requirements.

Severn Trent Water Utility

Severn Trent Water utility (serving over 8 million people in the Midlands region of England) used statistical modelling for planning investment for both above ground and underground infrastructure in the preparation of its first AMP. Due to the heterogeneous nature of the above ground assets there were concerns regarding the use of a statistical approach. It was resolved to depart from the statistical approach to plan investments for the above ground infrastructure in the second AMP. Subsequently a Surface Asset investment Model (SAM) was developed (Banyard, 1996).

Severn Trent Water adopted an approach of calculating the serviceability of each asset/asset category as a product of condition grade and performance grade. For surface assets condition grades were assigned after visual inspection, and for underground assets statistical analysis was undertaken to estimate the condition grade. Performance grades were assigned from performance records of the assets held by the company. The serviceability grades were then cross-checked with maintenance records. Assets with good serviceability grades but poor maintenance records warranted further investigations to check if there was any design defect so that pre-emptive action could be taken. A priority matrix for renewal was prepared as shown in the example for Electrical and Mechanical equipment in the following table

Table I: Condition and performance grades matrix for asset serviceability

Source: (Banyard, 1996)

Electrical & Mechanical	**Condition grade**				
Performance grade	1	2	3	4	5
1					III
2				VI	II
3				V	I
4				IV	I
5	IV	III	II	I	I

Severn Trent Water also used remaining life of an asset as a criterion for renewal decisions. The analysis of the remaining useful life was done considering all the factors affecting the pipe condition and thus affecting the remaining useful life of the asset. Random coupon sampling of the underground network was undertaken and opportunistic samples were also taken when the water main was exposed because of operational reasons. Between 1984 and 1997, 4,300 random and opportunistic samples were collected. Both sets of samples were utilised to assess the condition of the whole network and to estimate the residual life of a pipe by application of predictive models (Kane, 1997). Information regarding the samples and the information on the conditions in which the pipe was used such as soil type and water type, internal corrosion rate, external corrosion rate, life after relining, percentage blockage and tuberculation was observed and analysed. These were all time dependent factors and could be analysed because information regarding the time of original laying of the pipe or when they were altered such as when they were relined was accurately known or estimated.

Parsons (1999) reported the method employed by Severn Trent Water when the focus of the asset management planning was leakage control. Each company had their own declared ‘Economic level of leakage’ (ELL) required by regulator OFWAT, and Severn Trent Water’s ELL was approximately 330 million litres per day (MLD). District Metering Areas (DMAs) were grouped into four levels of unaccounted for water (UFW) relative to the company average. Specific assets responsible for UFW and their condition grades were identified from the main burst data and other asset performance records available within the utility. For all condition grades ranging from 1 (good) to 5 (awful), percentages of assets were computed. It was found that 70% of the main bursts were in condition grade 3, 4 and 5 and 50% of the assets responsible for UFW were in condition grade 3, 4 and 5. These two together represented 15% of the total assets of the DMA. The identification of these specific assets and knowledge regarding their condition was utilised to prepare asset management plans to plan future capital maintenance investments.

Northumbrian Water

The aim of preparation of an AMP as understood by Northumbrian Water (serving 2.6 million people in North East England) was only to estimate the capital maintenance investment (Metcalfe, 1991). The water company made use of probabilistic models and statistical inferences. Assets were first divided into two categories i.e. those which would be sampled (local distribution network) and those which would be investigated (dams, raw water systems). Sampling units i.e. zones were defined and classified based on the number of connections, type of supply (rural/urban/mainly rural/mainly urban) and number of water service problems per connection. These zones were then sorted into different strata depending on the type of supply and the identified problems per connection. Random samples were collected from each stratum. The number of samples collected was proportional to the number of connections. Costs of the required renewal work for the selected zones were calculated and then the cost for the entire strata was estimated. The calculation of the renewal investment requirement was made from unit cost data obtained from national data on unit costs or other past records.

The reported shortcoming of the sampling approach was lack of ability to prioritise because the utility could not be certain which zones were in the worst condition and where renewal works were needed the most. Though in practice the utility separately surveyed the worst areas and these were excluded from the sampling population (Metcalfe, 1991).

North West Water

North West Water (NWW, serving 7 million people within the North West region of England) had corrosion of the mains as its main concern, which was leading to failures, leakage, poor water quality and reduced flows. NWW aimed at assessment of long-term investment needs, formulating and implementing plans for water main rehabilitation and system management on a zone-by-zone basis and lastly devising and implementing a leakage control policy. These defined objectives helped in their putting together an Asset Management Plan.

The company adopted a step-by-step approach to devising their AMP. After the objectives were defined, they collected data about the assets in their possession by developing an inventory of their assets. Next, data on condition and performance of these assets was gathered from past records. Data was also collected from repair works on bursts and other ongoing repair works at rehabilitation work sites. Information about the mains pressure survey was gathered. Random water quality sampling exercises were undertaken to assess the condition and performance of the assets. NWW also chose to involve the consumer in its quest for data collection by carrying out customer surveys to assess the service levels. These customer surveys yielded additional information which was used to complement the historic service level information i.e. number of interruptions, flow, pressure and water quality compliance that was available within the utility. After the data was collected reports for each zone were prepared using all the above-mentioned information in a specified consistent format for the purpose of comparison. Each zone was assigned a rank based on a two-tier ranking system. Tier I was based on the water service data available and Tier II was based on the results of surveys. On the basis of these reports investment estimates for rehabilitation were prepared for each zone. The criterion for prioritisation of rehabilitation work was that zones suffering from poorest service were to be resolved first and all the works in one zone were to be taken up together.

The rehabilitation strategy ensured uniformity of approach throughout a large organisation having many operational districts and management teams ((Pearson and Dewhurst, 1989).

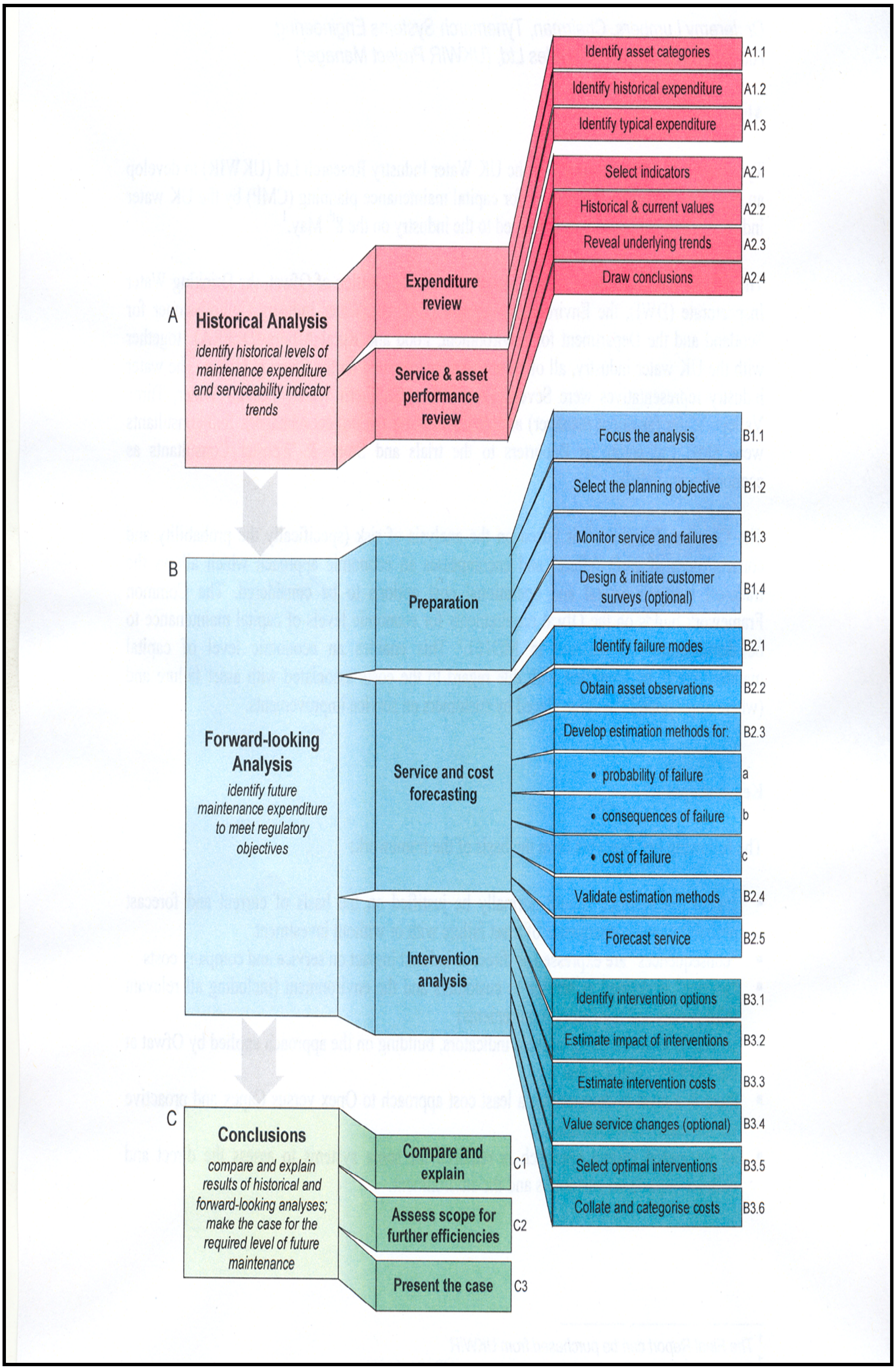
Unnamed water utility

Lindley (1992) has described the asset management planning process embarked upon by an unnamed water utility. The water utility initially stated that its objective to carry out asset management planning was customer satisfaction. As no statutory standards were available on pressure or flow, the next step was to define standards of service and then monitor the performance of the existing system relative to the defined standard of service.

Stratified random sampling was carried out. The strata were classified on the basis of types of water being supplied (soft/medium/hard), the type of network (rural/urban/semi rural) and the age of the network (pre-1918, 1918-1945, post 1945). Study units were selected from these strata and desk studies and field work were undertaken to make an inventory of the system and measure performance relative to the specified standards of service. The local knowledge of problem areas was the basis on which pressure loggings in key areas were employed for study of pressure and flow as network models were not available. Water quality modelling was achieved through using the water quality data and referring to the archives where customer complaints were stored. It was realised that water quality modelling was essential to establish the cause of the problem because it could be a result of poor water treatment, the existing network conditions or other unknown causes.

Further investigations were undertaken for monitoring and assessing the continuity of water supply. Main burst data was studied against the acceptable predefined standard rate of one per year. More than one per year was taken to be unacceptable. A need for structural sampling of sections of mains was identified as an essential requirement to support and augment the desk study of main burst records. Unit costs were used for costing of the renewal programme. The above parameters and the information collected were analysed and employed to assist the unnamed water utility in formulating an asset management plan to achieve their stated objective of customer satisfaction (Lindley, 1992).

Appendix 2: The common framework process



Appendix 3: List of interviewees during the research

England			
Designation	Organisation	Name	Date
		Breach, B.	January, 2006 December, 2006 March, 2007
		Walton, B.	February, 2006 December. 2006
	ABS Group. Global Marketing & Product Management, Wastewater Collection	Redit, M.	April, 2007
	Meniscus Ltd.	Mark, E.	April, 2007
	Proquip Direct Ltd.	Collin, M.	April, 2007

Fieldwork phase II, Detailed case study			
Chief Engineer	PHED, Rajasthan		August, 2006
Additional Chief Engineer, Jaipur Division	PHED, Rajasthan		June, 2006
Executive Engineer, Sub division I, Jaipur	PHED, Rajasthan		March, 2006
Assistant Engineer, Gandhi Nagar, Jaipur	PHED, Rajasthan		March, 2006
Assistant Engineer, Walled City, Jaipur	PHED, Rajasthan		July, 2006
Junior Engineer, Gandhi Nagar, Jaipur	PHED, Rajasthan		April, 2006
Junior Engineer, Walled City, Jaipur	PHED, Rajasthan		April, 2006
Junior Engineer, Malaviya Nagar, Sector 9, Jaipur	PHED, Rajasthan		April, 2006
Water supply supervisor, Gandhi Nagar, Jaipur	PHED, Rajasthan		May, 2006

Line man, Gandhi Nagar, Jaipur	PHED, Rajasthan		May, 2006
Line man, Malaviya Nagar, Jaipur	PHED, Rajasthan		May, 2006
Draftsman, Subdivision South, Jaipur	PHED, Rajasthan		March, 2006
CEO	Delhi Jal Board		June, 2006
Chief Engineer	Delhi Jal Board		June, 2006
Finance Commissioner	Delhi Jal Board		June, 2006
Fieldwork phase III			
Executive Engineer, Jaipur city division	PHED, Rajasthan		December 2007
Junior Engineer, Jodhpur city	PHED, Rajasthan		December 2007
Executive Engineer, Water Supply, Chandigarh	Municipal Corporation, Chandigarh		December 2007
Joint Commissioner	Municipal Corporation, Chandigarh		December 2007
Chief Engineer (Retired)	PHED, Punjab		December 2007
Additional Chief Engineer (Retired)	PHED, Haryana		December 2007
Chief Engineer	Irrigation and Public Health Department, Himachal Pradesh		December 2007
Executive Engineer	Municipal Corporation, Himachal Pradesh		December 2007
Executive Engineer, Patna Water Board	PHED, Bihar		December 2007
Executive Engineer, Drawing and Design, Patna	PHED, Bihar		December 2007
Senior Mechanical Engineer	PHED, Bihar		December 2007

Appendix 4: Interview guide for the fieldwork phase II, the detailed case study

1. What is the policy for infrastructure renewal?
2. Is there any planned infrastructure renewal/capital maintenance programme in practice?
3. What is the criterion for decision making regarding budget planning and funds allocation for infrastructure renewal?

Is the following information about the underground assets (pipe network) available?

1. As built drawings/maps
2. Has the network drawings been updated?
3. Diameter of the pipelines
4. Material of the pipelines
5. Gradient/Slope of the pipelines
6. Age of the network
    a. If not, are their any other records available by which age of the network can be estimated?
    b. Is age of the individual pipelines known?
7. Can the no. of connections along the pipeline be assessed?
    c. Is the location of the connections marked on the network drawings?
8. Is the location of a pipeline marked with reference to the street centre line or any other reference point?
9. Are the network drawings/maps digitised or available in a hard copy?
10. If the network drawings are digitised which software is used? (GIS/ AutoCAD/ others)
    d. How many personnel are capable or trained to use that soft ware?

Is the following information regarding environment of the asset available?

1. Are soil maps available providing information regarding type of the soil surrounding pipelines?
    a. If no, can this information be procured from some other department?
2. Is the information regarding the depth of soil cover over the pipelines available?
3. Is the information regarding the type of traffic and volume of the traffic over the street available?
    a. If no, can this information be procured from some other organisation?
4. Is the information regarding type of surface over the pipelines (streetwise) i.e. paved or bitumen available?
5. Is the information regarding the Groundwater level and its variations (if any) available?
    a. If no, can this information be procured from some other department?

Asset performance information

1. Is there any practice of leak detection programme?
    a. If yes, what records are maintained?
2. Is water auditing practiced? (At distribution zone level or transfer main network or any other)
    a. If yes what records are maintained?
3. Are there flow meters installed in the underground pipelines network?
    a. If yes, how frequently the readings are recorded?
    b. Are historic records of these readings available?
4. Are there flow pressure gauges installed in the underground pipelines network?
    a. If yes, how frequently the readings are recorded?
    b. Are historic records of these readings available?
5. Is their information (location, date, any other including cause of the break) available regarding main breaks?
    a. Are historic records available regarding main break information?
6. Is water quality sampling practiced?
    a. What is the schedule of the same?
    b. Are the historic records of water quality sampling available?
    c. Can these records be cross referenced to a pipeline?
7. Are customer complaint records available?
    a. What information is available in these customer complaint records?
8. What information is available regarding repair work of a pipeline undertaken? (Cost of the repair work, cause of the failure, can the location be cross referenced to a pipeline?)

Are there any direct or indirect information/records available regarding the structural condition of the underground assets?

Is hydraulic modelling of the distribution network practiced and tested?

If yes, which software/model and what records are used?

What is the basis of the selection and prioritisation of the assets for renewal?

Appendix 5: Repair site questionnaire

Date

Name of the distribution zone

Pipe attributes

Rising/supply/transfer

Diameter (mm)

Material

Age (estimate)

Thickness (mm)

Depth from the ground (cm) (soil cover)

Surrounding soil type

Remarks on structural condition/Physical integrity of the pipe

Pipe failure/ Joint failure/ Valve failure/ Service connection

If it is a pipe failure

Is there a crack?

Circumferential or longitudinal

Is it rusted?

External/Internal

Is there any salt deposition

If yes, what is current pipe thickness?

Is there tuberculation of the pipe surface?

If yes, what is current pipe thickness?

Others

If it is a joint failure

Is it due to termite (A)

Is it a rubber ring failure (B)

Is it due to tree roots (C)

Is it due to bleaching powder deposits (D)

Is it due to bad joining (E)

Other (F)

What is the estimated cause of the failure?

Repairing details

How much time was invested (Hrs)?

How many personnel were involved?

What components were repaired or replaced?

How much was the expenditure (INR)?

Loss due to failure

How many water supply connections were affected?

How much volume of the water was lost?

What was the overall impact on the water supply?

Appendix 6: Summary of repair site data

Distribution zone wise records (Total records 98)	
Gandhi Nagar (GN)	48
Walled City (WC)	45
Malaviya Nagar Sector 9 (MN)	5

Distribution of types of failures		
Joint failures	45	45.9%
Pipe failures	19	19.4%
Valve failures	3	3.1%
Service Connection failures	31	31.6%

Distribution of causes of failures in Joint failures (45)				
Due to termite	1	1 (GN)	AC	2.2%
Due to decayed rubber ring	19	9 (WC), 8 (GN), 2 (MN)	15 AC, 3 PVC, 1CI	42.2%
Due to tree roots	11	11 (GN)	6 AC, 5 PVC	24.4%
Due to bleaching powder deposits	1	1 (GN)	1 PVC	2.2%
Due to faulty joining	3	1 (WC), 2(MN)	3 AC	6.7%
others *	7	6 (WC), 1(GN)	4 PVC, 3 AC	15.6%
Reasons not stated	9	9 (GN)	4 AC, 2 CI, 3 PVC	20.0%

* Others are mainly heavy impact or loading

AC-Asbestos Cement, CI-Cast Iron, PVC-Poly Vinyl Chloride

Note: The numbers don't add up to 45 because some of the records reported both types of failures i.e. pipe failures and joint failures. Such records were primarily considered under pipe failure records but also considered for analysis of the causes of joint failures.

Distribution of causes of failures in Pipe failures (19)				
Due to third party digging	4	2 (GN), 2 (WC)		21.1%
Due to heavy loading	7	7 (WC)	5 AC, 2 PVC	36.8%
Due to rusted pipe	1	1 (WC)	GI	5.3%
Due to bleaching powder deposits	4	4 (GN)	4 PVC	21.1%
Due to air lock	1	1 (MN)	1 AC	5.3%
Reasons not stated	2	1 (MN), 1 (GN)	2 AC	10.5%

Service connection failures (31)	
19 in WC	42.2%
12 in GN	25.0%

Appendix 7: Questionnaire for coping strategy survey

Water connection details

PHED

Private

Personal tube well

Do you have a storage tank?

What is monthly average water bill (INR)?

What is monthly average income of the family (INR)?

Water service levels

Duration (hrs)

Pressure (Good/Poor/average)

Water quality (Good/ Bad)

Service failures

Is there a variation in supply duration?

If yes, how many times in a month?

Do you have incidents of no water supply?

If yes, how many times in a month?

Do you have incidents of very low pressure water supply?

If yes, how many times in a month?

Do you have incidents of poor water quality supply?

If yes, how many times in a month?

Coping strategies

When there is a service failure in terms of low pressure, water quality, reduced duration or no supply-

Do you organise a water tanker?

  If yes, how many tankers do you organise in a month

  What is the volumetric capacity of a tanker (l)?

  How much is the cost (INR)?

  How much time is invested in organising a tanker (hrs)?

Do you buy bottled water?

  If yes, how many litres in a month (l/month)?

  How much is its cost (INR/month)?

Do you use a booster pump?

  If yes, how many days in a month?

  What was the purchase cost of the pump (INR?)

  What is the running cost of booster pump (INR/month?)

Do you have a water purification unit at home?

  If yes, what type of water purification unit do you have?

  What was the purchase cost of the unit?

  What is the running cost of the unit?

Do you have a private tube well?

  If yes, what was the installation cost?

  What is the running cost of the tube well?

Do you make any other arrangements for your water needs?

  If yes, what are those?

Appendix 8: Questionnaire to confirm the wider application of the proposed models

(Note: This questionnaire has additional questions which are not specifically relevant for assessing the potential applicability of the proposed model, however helpful to develop a better understanding of the prevalent working culture in the organisation and also to explore if other similar utilities have superior data available than the case study city)

Financial information

1. What is the prevalent accounting practice i.e. Single entry or accrual accounting?
2. How are assets valued in accounts books i.e. are they valued on the basis of historic cost – depreciation or present value?
3. If assets are valued on the basis of historic cost and depreciation, what is the rate of depreciation?
4. Is the rate of depreciation common for all types of assets i.e. pipelines, pumps, bore wells, treatment plants?
5. Could you please provide a sample copy of annual accounts?

Is the following information about the underground assets (pipe network) available?

4. As built drawings/maps
5. Have the network drawings been updated?
6. Diameter of the pipelines; Material of the pipelines
7. Gradient/Slope of the pipelines
8. Age of the network
9. If not, are their any other records available by which age of the network can be estimated?
10. Is age of the individual pipelines known?
11. No. of connections along the pipeline
12. Is the location of the connections marked on the network drawings?
13. Is the location of a pipeline marked with reference to the street centre line or any other reference point?
14. Are the network drawings/maps digitised or available in a hard copy?
    a. If the network drawings are digitised which software is used? (GIS/ AutoCAD/ others)
    b. How many personnel are capable or trained to use that soft ware?

Is the following information regarding environment of the asset available?

6. Are soil maps available providing information regarding type of the soil surrounding pipelines?
    a. If no, can this information be procured from some other department?
7. Is the information regarding the depth of soil cover over the pipelines available?
8. Is the information regarding the type of traffic and volume of the traffic over the street available?
    a. If no, can this information be procured from some other organisation?

9. Is the information regarding type of surface over the pipelines (streetwise) i.e. paved or bitumen available?
10. Is the information regarding the Groundwater level and its variations (if any) available?
    a. If no, can this information be procured from some other department?

Asset performance information

9. Is there any practice of leak detection programme?
    a. If yes, what records are maintained?
10. Is water auditing practiced? (At distribution zone level or transfer main network or any other)
    a. If yes what records are maintained?
11. Are there flow meters installed in the underground pipelines network?
    a. If yes, how frequently the readings are recorded?
    b. Are historic records of these readings available?
12. Are there flow pressure gauges installed in the underground pipelines network?
    a. If yes, how frequently the readings are recorded?
    b. Are historic records of these readings available?
13. Is their information (location, date, any other including cause of the break) available regarding main breaks?
    a. Are historic records available regarding main break information?
        i. Are these records available in paper or digital format?
14. Is water quality sampling practiced?
    a. What is the schedule of the same?
    b. Are the historic records of water quality sampling available?
        i. Are these records available in paper or digital format?
    c. Can these records be cross referenced to a pipeline?
15. Are customer complaint records available?
    a. What information is available in these customer complaint records?
    b. Are these records available in paper or digital format?
16. What information is available regarding repair work of a pipeline undertaken? (Cost of the repair work, cause of the failure, can the location be cross referenced to a pipeline?)

Are there any direct or indirect information/records available regarding the structural condition of the underground assets?

Is hydraulic modelling of the distribution network practiced and tested?

If yes, which software/model and what records are used?

What is the capital maintenance policy regarding underground assets?

About mechanical and electrical (M & E) assets

1. Are historic maintenance records of M & E assets available?
2. Are planned energy audit practiced or energy consumption and efficiency monitoring in practice?

If yes, what records are available?

What is the capital maintenance policy regarding M & E assets?

Appendix 9: Interview guide for assessing the practical application of the proposed asset management model

1. Infrastructure renewal needs

2. Use of historic complaint records

3. Use of water quality monitoring records

4. Recording data at repair sites and its use

5. Customer survey

6. Outcomes of the proposed model
   a. Customer serviceability
   b. Cost reduction
      i. Operational cost
      ii. Capital maintenance cost
7. Change

Appendix 10: Focus group discussion results

Source: Gessler, 2008 with Brighu

	Balmiki Nagar	Kunda Basti	Nirmar Nagar	Lunka Puri Basti
Legal status	regularized	not regularized	not regularized	not regularized
No. of households	800	500	800	1500 in wider area
Household size	5-6	4-7	7-8	10
Age of settlement	12 years	30 years	20 years	25 years
Family income (Rs./month)	1,500-4,000	1,000-4,000	3,000-15,000	1,500-3,000
Rent (Rs./month)	none	minority on rent, 300-400	50% on rent, 500-600	none
Employment	solid waste collection/sweepers	peon	regularly employed	peon
Electrictity	single/shared/none	50% connected/no shared connections	1	single/shared
Illegal connections	not possible		none	still exist
Bill (Rs./month)	300	200-1000	300-750	800-1200
Satisfaction			good	
Water				
Bill (Rs./month)	30-50 (PHED)	none	150 (private)	30-40 PHED / 100 (private)
Satisfaction	yes	no	no	
Supply systems	6 psp+1 tank (25%piped+psp)	3 tanks +handpumps + factory in 0.5km distance	120 out of 800 with private piped supply +2 handpumps +1 tanker	psp+handpumps+40% pipedPHED*(few from private well)*
Duration	30 minutes		20 minutes	
Quality	good	good	good	good
Reliability	bad, problems in summer	bad	bad	bad
Time for collection	1.5-2hrs	without tanks 3 hrs	1-2 hrs	0.5-2 hrs
Willingness to pay for improved service	Rs.50-100 per month, preferably nothing as they can cope with situation as it is	Rs.50, but only for household connection	Rs.150, but only for household connection	Rs.50
Consumption/month	6m³	6m³	12m³	9m³
Household sanitation	pit or poor flush latrines	open defaecation	pit latrines	pit latrine (provided by NGO)
Drainage system	open drainage canals	none	none	none
Roads	good	none	none	none
Major problem	employment, making money for living	people want psp, because water is for free	water	roads, drainage
Overall remarks about services	fear further increase in electricity costs, satisfied with water services as they are for free	given both water and electricity at 200, they would pay for electricty as they think they can organise water somehow	tanker supply started in 2005, once per day, after complaining to local politician, main pipe in 250m distance, no obvious technical reason for not getting connected,	standpost is purely side effect of borehole made to supply elevated water reservoir for better off area

Appendix 11: Modern equivalent assets cost

These costs have been collated from the purchase orders of the PHED, Jaipur and proposal report for augmentation of Jaipur city, South, water supply (2006)

Asset Category: Pipes		
Material	**Diameter (mm)**	**Cost (INR/m)**
Asbestos Cement	80	84
	100	105
	125	143
	150	216
	200	370
	250	532
	300	726
	350	1044
	400	1359
Ductile Iron	200	1109
	250	1419
	300	1845
	400	2748
Asset category: Submersible pump-sets		
		18,000/ Pump-set

Appendix 12: A sample spreadsheet of history sheet records of submersible pump-sets

S. No.	Code	Distribution Zone	Type	Specifications							Date of installation	Date of de-installation	History					Remarks
				Make	HP	KW	Head	Discharge	RPM	Stage			Period run	Expenses	Failure cause	Purchase cost	Time taken for repair	
1	MN-61	MLV NGR S-9	Submersible	KSB	12.5	9.325	76	5000 GPH	2880	11	30/09/2004	15/10/2005	1Y 0M 15D	6,351	Motor burnt			
2	MN-64	MLV NGR S-9	Submersible	Vikas	10	7.46	90	225 LPM		11	20/06/2004	17/11/2004	0Y 4M 27D	Guarantee pd	Motor burnt			
											21/12/2004	30/04/2005	0Y 4M 10D	Guarantee pd	Motor burnt			
											02/06/2005	15/09/2005	0Y 3M 13D	Guarantee pd				
											18/12/2005	15/01/2006	0Y 0M 17D	6,093	Motor burnt			
3	MN-51	MLV NGR S-9	Submersible	Vijay	10	7.46	90	225 LPM	2880	11	29/06/2002	31/07/2003	1Y 1M 02D	5,563	Motor burnt and pump jammed			
											07/08/2003	24/05/2004	0Y 8M 17D	6,658	Motor burnt and pump jammed			
											11/06/2004	24/01/2005	0Y 7M 13D	6,060	Motor burnt and pump jammed			