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Intermittent urban water supply under water starving situations

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Rapid population growth in urban areas exerts negative pressure on existing water supply systems, whilst developing additional water sources is unrealistic option for many water companies in developing countries facing limited financial resources. As an alternative, intermittent water supply has been implemented there in attempt to distribute available water to as many people as possible, despite considerable negative impacts such approach is carrying. This paper summarises the main issues associated with intermittent supply, focusing to the importance of categorising the emerging problems. Required measures to improve the water supply situation of certain urban area should therefore differ according to the category of the problems. Moreover, these measures should also be realistic in meeting the consumers' needs. New design guidelines, which could enhance equitable distribution and convenience for consumers, are suggested as a tool for design optimisation of urban water distribution systems with intermittent supply.

Introduction

Conventional urban water supply system, with treatment facilities, service reservoirs and distribution network, is commonly applied for provision of safe water with adequate quantity to people, both in developed and developing countries. Nevertheless, this service is in many developing countries not continuous, most frequently resulting from scarce water sources and/or poor operation and maintenance practices. This situation is causing serious quantity and quality problems, linked occasionally to fatal health hazards. Despite such risks, intermittent water supply is reluctantly applied in many cities in order to distribute limited water quantities to as many people as possible; 'full-pressure, "24-7" water supply remains a pipe dream in many cities' (World Bank, 2004).

Nature of Intermittent Water Supply

Already in the last few decades, intermittent supply is prevalent among developing countries, specifically in arid and densely populated areas of the world. In 1995, around 50% of water utilities in fifty Asian cities supplied water for less than 24 hours; in six out of these, the water was provided only for six hours or less per day. (McIntosh & Yñiguez, 1997). Worldwide investments in water supply services in the last fifteen years brought only partial improvement, mainly due to accelerated growth of population in urban areas of Africa and Asia. More recently, in South Asian countries, above 90% of the population with a piped water supply still receive water for less than 24 hours (McIntosh, 2003). Conditions are similar in most African countries. In Zaria, Nigeria, only 11% of consumers with a piped supply receive water one day in two. In Mombassa, Kenya, average service hours are 2.9 per day. (Hardoy et al., 2001). The long list of examples also includes many countries in The Middle-East, where this problem penetrates deeply into overall political environment.

Consequences of Intermittent Water Supply

Intermittent water supply is usually associated with reduced water quantities conveyed through pipes at relatively low pressures. Hydraulic impact on the reduction of leakage out of such supply conditions is well known as well as those conditions would raise a water conservation sense of consumers. Most usually the result will be in reduced specific demand per capita compared to continuous water supply systems, leaving in theory a room for savings in investment and operational costs. Yet, such situation is much more result of limitations rather than a smart strategy and negative consequences of intermittency readily prevail over the positive factors. The most typical problems are listed bellow.

Inequitable distribution within a network

Intermittency generates inequitable water distribution due to pressure dependent flow conditions, with obvious disadvantages for consumers located faraway from the supplying points or at higher altitudes in the area. In distribution systems designed based on the same concepts as those for 24-hour supply, the consumers exposed to intermittent supply conditions are likely to keep their taps open to obtain as much water as possible whenever the service resumes (IWWA, 2000). As the amount of water flowing out from taps comes to depend on the pressure head, once the supply has been restored the larger peak flows than expected will occur in the pipelines, increasing the pressure losses in the network. Consequently, those consumers furthest away from supply points will always collect less water than those nearer to the source. The most frequent outcome of this problem is in constructing a household (roof) storage but this may help only partially; those at the end of the system are always affected, more or less (Trifunovic & Abu-Madi, 1999).

Water contamination and health hazard

Intermittency entails a high risk of contamination, which creates substantial health hazards. The first route is the ingress of contamination through broken pipes or joints. Interruption of supply can create low pressures or even a vacuum condition in pipelines that last for a significant period of time. Consequently, the contamination readily enters through leak points on pipes. Furthermore, the contamination at household tanks is another type of risk as such storage is rarely constructed under supervision of the water company or according to certain standards with prescribed prevention of contamination. According to a water quality test in Istanbul, Turkey, 24 % of samples from consumer storage tanks were found to be positive for colliforms, while only 4% taken from the pipe network presented positive (Yepes et al., 2001).

Coping costs of consumers

Resulting from intermittent supply, the consumers have to pay the costs, so called coping costs, for additional facilities, such as storage tanks, pumps, alternative water supplies and household treatment facilities. The poor who cannot afford such facilities spend their time to fetch water from public taps or vendors at comparatively high total costs. Choe et al. (1996) estimated the annual household coping costs through sampling survey in Dehra Dun, India, as summarised in the following table.

Table 1. Annual Coping Cost for Intermittent Supply in Dehra Dun in India (US$ at 1996/year)

Type of Expenses	House connec.	Public taps	Wei'ted average
Water tariff	18.0	0.0	11.7
Total coping cost	13.3	69.3	22.1
Total annual cost of water	31.3	69.3	33.8

Note: per capita consumption: Household connection, 137 l/c/day; Public tap, 46 l/c/day

Source: Adapted from Yepes et al. (2001), Summarised from Choe et al. (1996)

The table clearly shows the high coping costs paid especially by public tap users, who are usually the poor. Another study in Tegucigalpa, Honduras estimates that coping costs of poorest families with an intermittent household connection is around 180 % of water tariff (Yepes et al., 2001). Consumers with interment supply may also spend money to obtain water of potable quality by boiling it or purchasing bottled water.

Wasting water

Once there is sufficient quantity at the source, consumers with intermittent water supply service are likely to waste more water than those who can receive it during 24 hours; from the fear of shortage, they will tend to store as much as possible. Unfortunately for the less favourable rest, they may not use all of it and this water becomes replaced by the fresh supply of the next day (McIntosh, 2003; IWWA, 2000).

Coping costs of water providers

Water supply company also incur additional costs to cope with intermittency. For instance, such supply involves more frequent valve operation, and therefore requires more manpower than in case of continuous supply. According to the multi-regression analysis of 45 utilities in Peru, 'the number of staff per thousand water connections increased in inverse proportion to the hours of service' (Yepes et al., 2001). More frequent operation would also result in more frequent maintenance and replacement of valves (McIntosh, 2003). Regarding the pipe condition, intermittent flow generates repetitive pressure fluctuations that potentially accelerate deterioration of pipes and joints; the consequence would be in higher maintenance costs. An intermittent supply, with higher possibility of contamination, would also require additional cost for pipe cleaning and chlorination. These costs should affect water prices, and eventually be borne by consumers.

Inconvenience to consumers

The time when water is available is not always convenient for users. Alternatively, they will have to go to public taps, sometimes quite faraway and even during midnight, to collect water. Long distances and queues are typical problem of women and children from underprivileged areas, taking lots of productive time from them.

Meter malfunctioning

Intermittent water supply would cause inaccuracy of meter reading. Meters might reverse during vacuum conditions, and the air in a pipe might drive meters at excessive speed during the charging stage after the service has been resumed. Undesirable environment, such as repeated dry and wet conditions, would accelerate the performance deterioration of water meters. Meter malfunction brings difficulties for water providers to monitor the water use and collect accurate tariffs. Furthermore, it makes consumers sceptical to the accuracy of their water bills. (IWWA, 2000).

Two concepts of Intermittency

Intermittent water supply is widely agreed not to be an ideal form of supply. There are two major views amongst water distribution experts on how this problem should be considered.

Direct transfer to 24-hour service

The first view looks at intermittent supply as 'a failing water service', which should be tackled by all means until the 24-hour supply has been restored (World Bank, 2004). A lot in this respect can be achieved by looking into overall water services management and scrutinising bad governance. Examples include inadequate tariff structure, poor financial accountability and revenue collection, poor organisation of preventive maintenance, low level of workmanship, poor education of consumers, etc. As a consequence, the water company will be facing an increase of unaccounted-for water, low bill collection efficiency, and a decline of consumers' willingness-to-pay; it is after some time forced to switch to an intermittent supply conditions.

Combined management- and technical measures, such as improved revenue collection through strict metering and reduction of unaccounted-for water, is the priority to avoid such situations. In addition, a room to increase the water tariff exists in high coping costs for intermittent water supply (McIntosh, 2003). Furthermore, the investment in upgrading to a 24-hour supply is also comparable to the coping costs for intermittent supply. Hence, with sufficient capacity of the source and after enabling proper water services management, any justification for intermittent supply is false, according to this view.

Measures for design and control of intermittent supply

The other view looks at intermittent supply as a reality, be it from scarce quantities at the source or from un-affordable price consumers would have to pay for continuous supply. This view assumes that intermittency will remain to exist for foreseeable future and therefore advocates the necessity of providing appropriate design and operation methods and technologies that can minimise negative impacts of intermittency on consumers.

Hence, water distribution systems under intermittent supply conditions should be designed and operated on the principles other than those for 24-hour supply. Establishing of such methods is the first priority according to this view. Other tools, such as appropriate valve selection and leak detection methods suitable for flow characteristics in intermittency should also be provided (IWWA, 2000).

Categorising problems

In search for solution, the emerging issues are further categorised based on the types i.e. causes of water scarcity, and origin of the major problems resulting from intermittency, discussed above.

Categorising the water scarcity

The common concept on the cause of intermittency is that the amount of water is not sufficient for supplying continuously. Three main types of scarcity with causes of similar nature can be distinguished.

Type 1: Scarcity from poor management

Both capacity of existing distribution system and the available water quantity abstracted at sources is sufficient for covering the present level of demands. The intermittent water supply is caused because of mismanagement of water supply, which was described with the first concept of intermittency (high leakage and wastage, poor O&M, etc.). In addition, a poor electricity supply, often beyond any control of water utility, can be a major source of intermittency. In general, an improvement of water utility management and good governance are the key to achieve more efficient water use, sound financial performance, and ultimately a 24-hour supply. This is achievable within the capacity of existing water supply infrastructure.

Type 2: Economic scarcity

With the increase of population and per capita consumption, the availability of water becomes stressed by the overall demand increase. At the initial stage, the water cannot be supplied continuously to all consumers because demands and the number of connections have exceeded the existing hydraulic capacity of the distribution system. At the latter stage, the desired demand of consumers exceeds not only the capacity of distribution systems but also of the existing water source for abstraction (e.g. wells, river intakes, dam reservoirs, etc.). Water is felt scarce because financial capability of a utility or government is not strong enough to expand existing infrastructure.

This type of scarcity can result from poor planning and water demand forecasts, which in essence can be associated with Type 1. Although improving the management performance of water utilities and governments can help, a 24-hour supply cannot be achieved without physical expansion and/or development of infrastructure, in this case.

Scarcity Types 1 and 2 can occur simultaneously in some cases. In developing countries that have limited financial resources, enhancing the utility management within the capacity of existing physical infrastructure should be considered as a priority.

Type 3: Absolute Scarcity

The water scarcity is caused by insufficient quantities at the source. This may be the most complicated problem to solve, as the alternative sources may be located at far distances. Stringent measures of water conservation are to be applied in order to mitigate the problem. Both the water company and the consumers should share responsibility in this case.

Categorising the origin of problems

The problems mentioned while discussing the consequences of intermittent supply can be classified in two groups.

The first type of problems (Problem Type A) is led by the fact that distribution systems originally planed and designed for a 24-hour supply are operated as intermittent. This type of problems could be eliminated, or can be alleviated to negligible level if appropriate design, technologies and equipment suitable for an intermittent supply could be provided, even if a supply itself remains intermittent. Among problems described earlier, those that fall into this category would be: inequitable distribution of water due to pressure dependent flow, inconvenience to consumers, and meter malfunctioning.

The second group of problems (Problem Type B) arise genuinely because a supply is intermittent. The problems that belong to this category would be: water contamination and health hazard (e.g. ingress of contamination); coping costs of consumers; wasting water; and coping costs of water providers. This type of problems cannot be resolved as long as the water supply remains intermittent.

Appropriate measures

Each problem associated with an intermittent water supply can be allocated to one of cells in the matrix in Table 2.

Table 2. Matrix of Problem Categories Associated with Intermittent Supply

Water Scarcity	Type 1: M'ment	Type 2: E'nomic	Type 3: Absolute
Problem Type A: Using 24-hour supply Systems	Category 1A	Category 2A	Category 3A
Problem Type B: Genuine intermittent problems	Category 1B	Category 2B	Category 3B

The diversity of indigenous conditions signifies that issues around intermittency in separate areas or cities cannot be compared directly with each other and cannot be discussed within one framework, especially when areas or cities have the different types of water scarcity. Therefore, in order to develop constructive and realistic arguments over the improvement of present situations regarding intermittent supply, the type of the water scarcity in a particular area or city should be clarified in the first place, followed by the list of problems emerging from intermittency.

From Table 2, the concept of direct transfer from intermittent- to 24-hour supply seems feasible for all distribution networks that could be classified under Category 1A or 1B. Once a distribution area has experienced the scarcity Type 2, especially when the demand has exceeded the capacity of water sources, achieving a 24-hour supply would become an unrealistic option for most of developing countries, because it inevitably requires high and time-consuming investment for developing additional infrastructure. Moreover, securing additional water sources for urban water supply would require convincing arguments for other water users.

Presently, many cities in developing countries are confronted with demand increase due to rapid urban population growth and the increase of per capita consumption. Under these circumstances, an intermittent water supply inevitably has to be applied in order to enable provision of limited water quantities to as many people as possible, although achieving a 24-hour supply should remain a desirable future goal (IWWA, 2000). Therefore, in the area where the water scarcity can be classified as Type 2, a realistic concept to be applied in order to minimise negative impacts of intermittency over consumers, would be:

- Improving governance to maximise efficient use of limited water and to avoid or at least postpone the outset of scarcity Type 3,
- Providing unconventional methods that can eliminate negative impacts of intermittency caused by provisional use of systems designed with the same method as for 24-hour supply (Category 2A in Table 2), and
- Providing measures to minimise negative consequences of genuine problems associated with intermittency (Category 2B), such as risk management to monitor contamination hazard for drinking water quality.

Strategies regarding water distribution for areas in the water scarcity Type 2 should therefore be determined to cover all the above elements. The two concepts of intermittency discussed above are not necessarily conflicting each other. Rather, in the water scarcity situations, those two different approaches should be applied simultaneously aiming at their best collaboration. Even in areas currently of Type 1, applying such strategies would have to be considered if a supply is predicted to turn to intermittent in the near future. Issues regarding Type 3 are not discussed in this paper because those should be explored in the context of integrated water resources management. Nonetheless, the basic concepts of strategies for Type 2 could be useful for Type 3, as well.

New design guidelines

Providing adequate design guidelines for distribution systems with intermittent supply is one of the first priorities for mitigating problems of Category 2A, and has been researched funded by the Department for International Development, led by South Bank University, in UK in collaboration with the Indian Institute of Technology Madras, and Kerala Water Authority, India.

As a result of discussions with the relevant authorities in certain urban areas in India, it was found that engineers design a water distribution system based on the design method identical with those used for 24-hour supply system in developed countries although they have been aware that the system would be operated as intermittent in the near future according to the estimated available water and the predicted population. They acknowledged that this was not the correct approach, but argued that they had no alternative design methods and guidelines. When a system originally designed for a 24-hour supply is operated as intermittent, a consequence is uneven distribution of water as described in the previous section. But the problem can be mitigated or eliminated up to acceptable level if the distribution system

could be designed based on the reality that the system would be operated less than 24 hours. New guidelines for design and control of intermittent water distribution systems were proposed as an optimal design tool for such cases.
A major component of this new approach is the modified mathematical modelling tool specifically developed for intermittent water distribution systems. These tools combined with optimal design algorithms with the objective of providing an equitable distribution of water at the least cost forms the basis of the new approach.

Basic concept of the guidelines

In developed countries, the importance of the effects of pressure on demand is not critical in the design of water distribution systems, except during periods of drought or under crisis conditions, whereas in developing countries it is a fundamental factor for many distribution networks. Hence, conventional network analysis techniques have rather limited application for cases in developing countries. The modification in the design process requires not only the inclusion of Pressure Dependent Outflow (PDO) functions to model the demand but also a re-definition of the objectives of design.

In general, an optimal design is thought of as being one that can supply sufficient quantities of water to the consumers at adequate pressures and at least cost. In the conventional method, the objective of network design is to find the least cost system, which provides pressure above a specified minimum. However, in water starved systems, the objective might be that the limited quantity of water be distributed as fairly and equally as possible to achieve better supply for people in manners of:

- Equity in supply: Equitable distribution of the limited quantity of water is the keystone of the entire design process outlined in the guidelines.
- People Driven Levels of Service (PDLS): PDLS objectives are central to the design philosophy outlined in all components of this guideline. The PDLS are defined in terms of 4 parameters DTPO: Duration of the supply; Timings of the supply; Pressure (or flow-rate) at outlet; and Others such as the type of connection required and the locations of connections (in particular for standpipes). All parameters of the DTPO are calculated using methods and techniques that recognise the relationship between outflow at a water connection and the pressure experienced at that connection, and
- Meeting the two objectives with the least cost.

These objectives are taken for granted when designing continuous system, but could not be achieved when a system designed for a continuous supply is operated as intermittent. This guideline is provided to fulfil this gap. The guidelines enable engineers to:

- Establish a set of 'People Driven Levels of Service Objectives' (PDLS),
- Develop Design Objectives that incorporate the objective of equity in supply and the PDLS,
- Produce a detailed design of a water distribution system that meets the objectives specified above, and
- Develop operational strategies to ensure that the designed system meets the design objectives throughout its design life.

Components of the guidelines

The guidelines consist of four parts and three supplemental documents. Part 1 gives a General Overview of the entire guidelines. Contents of the subsequent parts are briefly described below.

Part2: Preliminary design

This part of the guidelines describes methods to establish a collection of feasible and practical sets of levels of service objectives for the proposed design. After this collection (5-6 sets) of levels of service objectives, the local community being served by the scheme are consulted (by performing surveys - methods detailed in Part 3), to establish PDLS.
Novel techniques are presented to calculate durations of supply (for a given per capita allocation), for different minimum pressure requirements (minimum pressure requirements are stated in terms of outflow rates at a connection). The calculated duration of supply is then used to generate different timings of supply and this is used to estimate the capacity of water towers (assuming inflow patterns are known).

Part3: Identify people'sneeds

Part 3 describes methods to establish specific People Driven Levels of Service Objectives (PDLS). The PDLS, developed on completion of the activities described in this document, are crucial for the detailed design process presented in Part 4: 'Detailed Design', as they are used to establish the specific design objectives.

Techniques presented in this document are how to design and perform surveys of the people in the supply area, with the main objective of establishing a set of PDLS in terms of DTPO. Initially, it is shown how to prepare and perform a preliminary survey of the local community. From the results of this preliminary survey, methods are presented that show how to select representative samples for a more detailed survey, and how to design questionnaires tailored specifically for the local conditions that exist in the proposed supply area. Methods are also presented on how to analyse this data in order to develop the specific PDLS.

Part4: Detailed design

This enables engineers to produce a detailed network design that ensures an equitable distribution of the limited quantity of water at least cost. Equitable distribution of the limited quantity of water is the keystone of the entire design process outlined in this guideline and is a non-negotiable design objective. As stated before, pressure dictates the quantity of water collected by the consumer, and therefore, inequities in supply can be controlled directly by ensuring the maximum uniformity in pressure distribution throughout the system. This objective is addressed at three stages in the design:

- During the zoning of the distribution system (performed in Part 2), attempts are made to define zonal boundaries to avoid great pressure diversity within a zone (by considering topography – output zonal overlay map)
- During the physical sizing of the distribution system, the main design objective is minimising the diversity in pressure (in addition to minimising cost), and
- After physically sizing the system, valves are strategically located to minimise the diversity in pressure prior to the network reaching its design horizon (in the early life of the network the excess capacity can be controlled in a way that improves the pressure distribution in the network by introducing flow control and pressure devices).

All the above stages are incorporated into the detailed design optimisation model that is formulated and solved using the optimisation software that accompanies this guideline. In the detailed design, PDLS objectives in terms of DTPO are addressed in the following ways:

- From the preferred durations of supply as selected by the people during the consumer survey of Part 3, the minimum acceptable pressure at the water connections is known. This minimum pressure is converted into a minimum pressure constraint for the design model. Any design generated in the design process will therefore ensure that the minimum pressure is provided, and hence ensure that the duration specified is met.
- Using the Timings of supply (again selected during the consumers' survey), the operations of the designed network are established. Exact storage volumes required are calculated and then simulations are performed to ensure that the preferred times can be achieved.

Section 1 of the Part 4 document explains how to convert the PDLS into design objectives. These objectives will then be coupled with the objective of equity in supply all at least cost, to generate a Design Objective data-file for the optimal design program software. Section 2 shows how to generate a Network Link Data-File (pipes, pumps etc.), for the optimal design programme. Section 3 guides how to generate demand coefficients to model the demand in the distribution system. These demand coefficients recognise the relationship between pressure and outflow at connections, and is crucial for the design of intermittent systems. On completion of this component a Network Primary Nodal data-file is generated for the optimal design program. Then, Section 4 shows how to combine these three data-files to generate the optimal design data-file. Also it is shown how to use the optimal design software to produce designs that are both Equitable in the supply of water and meet the PDLS.

Supplemental documents (SD)

The SD of the guidelines provide practical information to users of the guidelines. The SD contains the Field Data Collection and Handling Manual, NEITS-User guide that describes how to use the design software, and two Example Designs, the one is for establishing a new system and the other for reinforcement of existing one.

New models developed and applied

As stated earlier, the major components of this new approach are the development of modified mathematical modelling tools specifically developed for intermittent water distribution systems and the optimal design algorithms with the objective of providing an equitable distribution of water at the least cost. Brief details of the two components are given below.

Modified analysis tools

The overall shortage in water availability necessitates intermittent supply at a low per capita supply rate. These conditions force consumers to collect water in storage vessels to ensure water for non-supply hours. Under the condition, the demand for water at the nodes in the network are not based on notions of diurnal variations of demand related to the consumers behaviour as with networks in developed countries, but on the maximum quantity of water that can be collected during supply hours. In such systems it is logical to assume that consumers will draw water from the distribution system for the total duration of supply and the quantity they collect will be dependent totally on the driving pressure heads at the outlets.

There is a fundamental problem in the assumption made by conventional methods of network analysis, in that the analysis is demand driven, i.e., the demands of the network will be met irrespective of the conditions in the network. As stated above, in intermittent water networks the quantity of water collected by consumers will be dependent on the driving pressure heads at the outlets. Hence, the relationship between the pressures in the system and the demands are important, and it cannot be assumed that demand will be met under all conditions unlike in networks in developed countries.

A modified network analysis programme has been developed that incorporates pressure dependent outflow (PDO) functions to model the "demand" (that is, outflow). The model consists of three main innovative components. The first is the Demand Model. Using queuing theory and reservoir routing, this model forecasts the end-users demand profile (intensity and distribution of usage over a given period of supply), for use with the secondary network model. Data used by this model include: type of connection; time of supply; duration of supply; pressure regime. The second component is the Secondary Network Model. Obviously it is impractical to model networks as far as individual house connection, and therefore methods must be developed to establish lumped PDO functions for a single node (primary node), for a group of nodes (secondary network). Such methods have been developed and take into account the hydraulic behaviour of the secondary network (Vairavamoorthy, 1994). This model initially assumes a primary node to be a constant head (or reservoir) node, supplying water to the secondary network. By performing a series of simulations, varying the pressure at the primary node, flows out of the primary node into the secondary network for these different pressures can be calculated. The Modified Network Analysis Method is the third component. A modified network analysis program has been developed that incorporates PDO functions to model the demand (or outflow). The network governing equations are solved using the gradient algorithm of Todini and Pilati (1987). The program applies sparse matrix methods to improve the computational efficiency of the overall method.

Optimum design

The objectives of any design using the guidelines are: to provide an equitable distribution of the limited quantity of water; to meet the PDLS, and to meet these two objectives at least cost. It may not be possible however, to address the problem of achieving an equitable pressure distribution when sizing the network, since systems are often sized to meet a future forecast demand and therefore will always have excess capacity until the design conditions are realised. To accommodate these conflicting requirements a two-part design approach is proposed. First, the minimum cost design is obtained ensuring adequate pressures throughout the network for the duration of the specified design horizon. Next, the objective to minimise the variability in pressure is addressed by considering the strategic location and setting of valves in the network (Vairavamoorthy and Lumbers, 1998). The inclusion of valves is considered progressively at time intervals between the outset of the operation of the network to its design horizon. The overall best valve locations are established for a case study network in which the valve settings will vary throughout its design life.

As part of the research effort during the production of the guidelines, optimisation methods have been developed based on real-coded genetic algorithms (Vairavamoorthy and Ali, 1999). The particular features of the program include: least cost design objective; optimal pressure management routines to ensure a more equitable distribution of water throughout the network; and multiple objective function routines.

Computation example of the new model

Network analysis was performed for a network in South India (Figure 1), incorporating the developed new model. The results of the simulation corresponded well with the observations made in the field. In the present network, poor pressure conditions and the resulting inequities of supply were highlighted by the analysis. The results of an example application of the proposed methods to the network are shown in Figures 2 and 3. The original network has been reinforced with additional pipes and flow reduction valves strategically placed to minimise the deviation in pressure. In this improved system, pressure showed more even distribution. Figures 2 and 3 show that effective pressure management is possible in the early stages but the magnitude of the improvement in pressure distribution diminishes as the design horizon is approached. This is related to the presence of excess capacity. In the early stages with the greatest excess capacity, there is room to reduce this excess capacity in a way that improves the pressure distribution. As the design horizon is approached, the excess capacity decreases and there is less potential for effective pressure management. However, the process has improved overall pressure distribution in the network and provided a more equitable distribution of water.

The optimisation routines developed as part of this research project have been successfully applied to the design of networks in West Kochi, Kerala. The proposed design has been approved for construction and tenders have been invited. It is interesting to note that the proposed design involves establishing four zones where previously there was only one. These zones where identified using the optimisation programs developed, where the objective of the design was to minimise the diversity in pressure in the distribution system (for equity in supply), at the least cost. An evaluation study of this network will be performed soon to measure the success of designing for equity.

Conclusions

The optimum measures to improve existing situation with an intermittent water supply should be explored based on the careful examination of the water scarcity conditions in the objective area and of the nature of problems to be solved. Achieving a continuous water supply would be of difficulty for developing countries under water starve conditions because it inevitably requires expensive and time-consuming infrastructure development, although it should be remained as a future goal. In areas with such situations, realistic measures

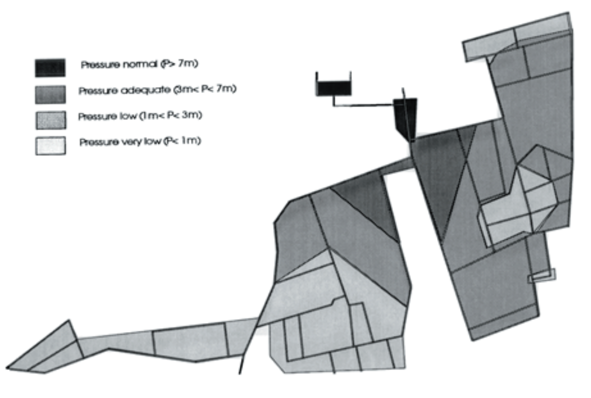

Figure 1. Pressure distribution in the original network (End of supply)

Source: Author

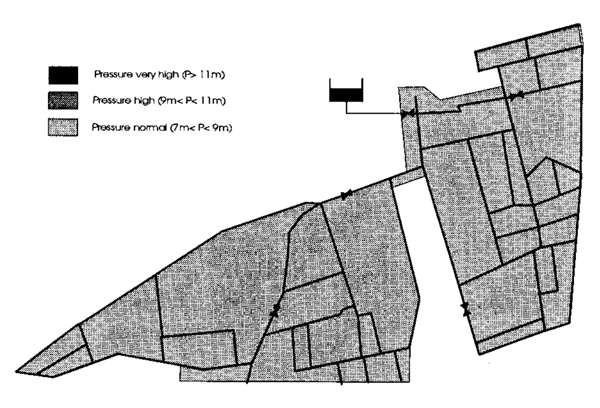

Figure 2. Pressure distribution after applying the new guideline (Year 0)

Source: Author

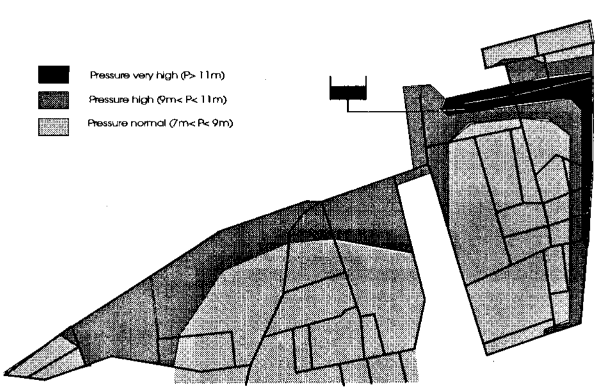

Figure 3. Pressure distribution after applying the new guideline (Year 25)

Source: Author

should be applied so that existing negative consequences of intermittency should be minimised as soon as possible, because consumers need water every day even before supply become an ideal form, continuous supply.

The new guideline for an intermittent supply system design is expected to minimise negative consequences of intermittency and to bring more equal and convenient supply to consumers even under intermittent condition.

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