IWRA - AIRE

IX WORLD WATER CONGRESS
IX CONGRÈS MONDIAL DE L'EAU
MONTRÉAL, CANADA, 1-6 SEPT. 1997

Minimizing Costs for Water Supply in Rural Areas: The Steady-Flow Water System

J.D. Krug and C.R. Goodwin

Ainley Graham and Associates Ltd

Canada

3 D 411-C TP6.2 5

MINIMIZING COSTS FOR WATER SUPPLY IN RURAL AREAS
THE STEADY-FLOW WATER SYSTEM

Krug, John D. [1]

Goodwin, C. Robert [1]

SUMMARY

A "steady-flow" water supply system was recently constructed in the rural community of Carlsbad Springs, saving an estimated 60% in construction costs over conventional technologies. This unique water supply system requires a small storage tank and pressure pump to be installed in each home. Since the in-house tank provides the balancing storage for domestic consumption, high peak flows in the distribution system can be eliminated, and small diameter watermains may be designed. With smaller diameter high density polyethylene pipes, a chain-trencher can be used for watermain installation instead of conventional open-cut methods, significantly reducing construction costs.

KEY WORDS

steady-flow water system, chain-trencher, high density polyethylene (HDPE), directional drilling, electro-fuse, butt-fuse

INTRODUCTION

In many parts of Canada and Ontario, the general condition of groundwater aquifers is deteriorating. In some areas, water table levels are being lowered, and in others, contamination from septic systems and other sources are degrading the quality of the groundwater. Conventional water supply systems, using treated well water and a distribution system consisting of watermains, storage tanks and pumping stations, have been constructed in many of the more heavily developed areas to provide residents with an adequate supply of potable water.

However, residents in smaller rural communities with poor local groundwater are often forced to live with an inadequate or unsafe supply of water from private wells or to purchase drinking water from local distributors. One of the major difficulties in providing potable water to rural areas is the prohibitively high cost of construction of extensive

---

[1] Ainley Graham and Associates Limited
2724 Fenton Road, Gloucester, Ontario, K1T 3T7

distribution system piping and associated infrastructure for these less densely populated areas.

THE CARLSBAD SPRINGS PROJECT

A cost-effective solution to this problem was recently constructed to service the hamlet of Carlsbad Springs, a community of some 1,500 persons, located in the Regional Municipality of Ottawa-Carleton (RMOC), approximately 14 km southeast of the City of Ottawa. This $6 million project will ultimately provide potable water to more than 750 homes along 40 km of roadways.

The majority of residents in the area have voiced concerns about groundwater quality and some have also complained that their wells cannot supply an appropriate quantity of water. Many residents currently purchase bottled water for use in their homes and several households are currently forced to import water during the summer to make up for dry wells.

In response to the problems encountered in Carlsbad Springs, the RMOC (who currently own and operate all parts of the major water supply system in Ottawa-Carleton) undertook preliminary investigations of feasible methods for supplying potable water to the area. Because of the long distance to the RMOC's central water supply system, the costs for extending a standard Regional water service to this area were deemed prohibitively high (up to $35,000/home). A communal well system was rejected because of high costs (up to $38,000/home), and since it would be dependent on poor groundwater quality and would be severely limited by the quantities of groundwater available. For similar reasons, local corrections (up to $15,000/home) would be an impractical solution to solve the problems.

In 1993, an engineering study was undertaken by Ainley Graham and Associates to assess the feasibility of providing potable water to the area using a "trickle-feed" system. Results of this study revealed that significant cost savings could be realized using this water supply technology, in lieu of a conventional extension of regional services. Total costs in the order of $6,000 to $10,000 per home were estimated.

A successful installation of the "trickle-feed" water supply system located outside Edmonton, Alberta was initially investigated. The primary benefit of the system is that long lengths of pipe may be constructed at relatively low cost, using smaller diameter watermains installed with a specially designed trenching machine. No fire-flow or outdoor water use is provided and residents require a storage tank to be located within their dwelling, essential for balancing daily water demands.

In September 1994, the provincial government of Ontario, under the Ontario Clean Water Agency (OCWA), approved funding for the design and construction of a trickle-feed system for Carlsbad Springs under the provincial Municipal Assistance Program. "Trickle-feed" is considered an alternative technology for supplying potable water in

Ontario since it is new, and thus, the implementation of this system in Carlsbad Springs is considered a demonstration project by the province. It is noted that the trickle-feed system was modified to suit the specific needs of the Carlsbad Springs area and that the word "trickle" was renamed to "steady-flow", primarily to mitigate potential public perception problems associated with the project.

FEATURES OF THE STEADY-FLOW SYSTEM

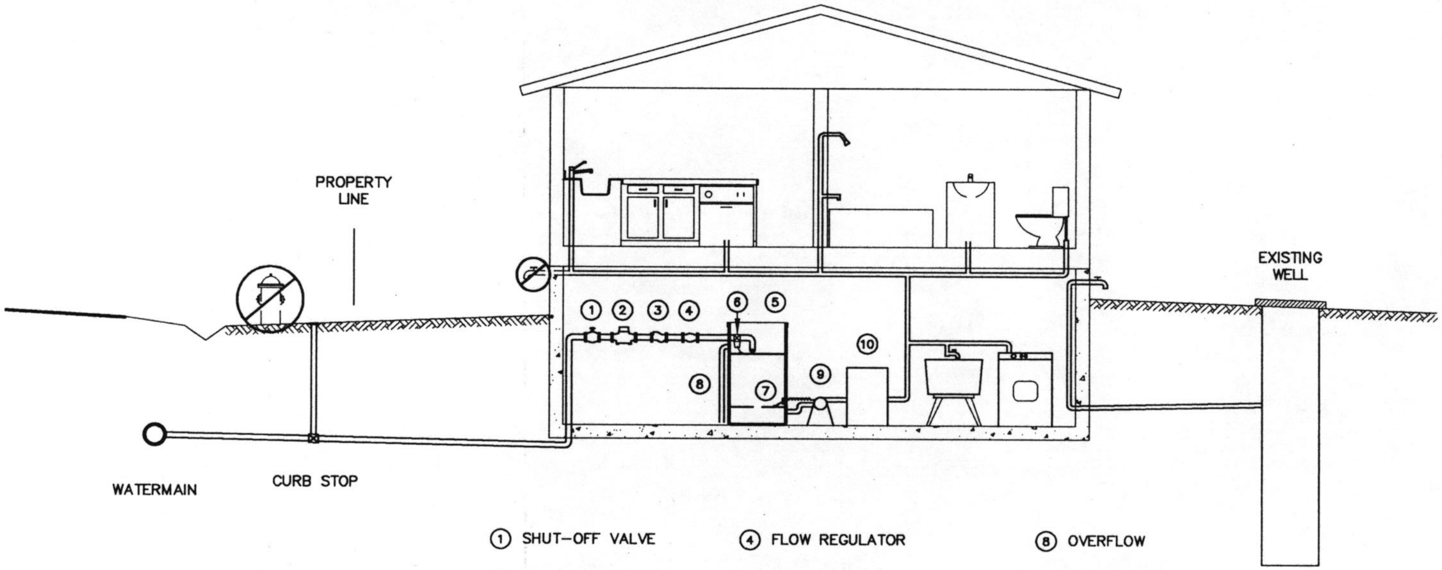
The steady-flow system is unusual in that a small storage tank and pressure pump are required inside each individual dwelling. Water is provided from the distribution system as required to each home at a constant or steady flow rate. It is directed to the tank (or cistern) and then pumped from this tank to the in-house fixtures. The tank is thus filling and draining throughout the day, and any outstanding shortfall is replenished at night. The in-house tank therefore acts as balancing storage for the system.

The rate of flow to each home is maintained at a constant rate with a flow regulating device on the tank supply line. By maintaining a constant demand on the supply system, all peak flows in the distribution system are effectively eliminated, resulting in a steady-flow in the watermain network. The maximum design flow in the steady-flow distribution system can be as low as 20% of conventional design flows. In addition to the significantly smaller distribution system flows, higher-than-normal pressure losses can be tolerated in the distribution system, since domestic pressure is provided by the in-house pump. Therefore, booster pumping requirements can be reduced, since lower than normal system pressures may be tolerated in the system. Since there are no peak demands in the distribution system and fire flows are not provided, large centralized storage facilities are not required for balancing or for fire flows.

In order for the steady-flow system to function, each household requires several plumbing components. The following items are required within each household (see Figure 1):

- Backflow Preventer (to prevent any contamination from the household system from entering the regular distribution network)
- Pressure Regulating Valve (to control the pressure upstream of the flow regulating valve to its effective operating or rated pressure)
- Flow Control Device (to control the flow rate to each dwelling to a preset value)

CARLSBAD SPRINGS WATER SUPPLY



① SHUT-OFF VALVE
② FLOW METER
③ BACKFLOW PREVENTER
④ FLOW REGULATOR
⑤ STORAGE TANK
⑥ FLOAT CONTROL VALVE
⑦ LOW WATER CUT-OFF SWITCH
⑧ OVERFLOW
⑨ PRESSURE PIPE
⑩ PRESSURE TANK

TRICKLE FEED SYSTEM COMPONENTS

FIGURE 1

Ainley Graham and Associates Limited
Consulting Engineers and Planners Ottawa

- Storage Tank & Controls (to provide balancing storage for individual homes with high water cut-off and low level cut-off controls)

- Pressure Pump/Tank (to provide water at adequate pressure to indoor fixtures)

By maintaining small diameter watermains and by using high density polyethylene (HDPE) watermain pipe material, a chain-trencher (similar to the equipment sometimes used to install drainage piping) can be used for the watermain installation, instead of the conventional open-cut method of construction. Prior to installation, the HDPE pipe lengths are butt-fused to form long continuous sections which are initially placed on the ground adjacent to the road shoulder. The watermain is then installed in the bottom of the trench by feeding the pipe through guides on top of the trencher and then down through the specially designed chute at the rear of the machine, which fits into the narrow trench excavated by the chain.

A further advantage of the small HDPE watermains is that directional drilling under roads and streams can be more easily undertaken. This installation method can also be very cost-effective, eliminating the need for restoration of paved roadway surfaces and avoiding detrimental impacts of construction on sensitive stream banks.

DESIGN OF THE STEADY-FLOW SYSTEM

Water Consumption

The first step in determining the steady-flow system design needs was to develop appropriate water consumption estimates for the users of the system. Because of the unique design of this system, existing water consumption standards may not be applicable. Typical water demand standards represent daily averages calculated over a period of time. Higher daily water consumption must be used for the design of the steady-flow system to account for individual days where more than the average daily water use may occur. For example, an average day demand may account for a single washing machine use every two days, so the resulting usage would include only half the washing machine usage each day. It is thus appropriate to estimate high daily and high hourly (or high instantaneous) usages to determine the most appropriate flow rate and tanks size for each home. The terms "high daily" and "high hourly" will be used to avoid confusion with the common terminology maximum daily and peak hourly, which refer to demands which include summer outdoor water use.

In addition to estimating the magnitude of the high daily and high hourly flows, design of the steady-flow system also requires an understanding of when, during the day, water use occurs. Typically, system wide peak hour demands occur in the evening when lawnwatering and other outdoor uses are at a maximum. However, for steady-flow systems, the high hour may occur at other times of the day, when indoor uses are maximized (ie. combined morning toilet flushing and shower use).

To develop appropriate "high day" and "high hour" water use figures and to aid in determining the daily "time of use" estimates, consideration has been given to estimating daily water usage based on end uses. This involves determining the amount of water used by each fixture in typical dwellings, and adding these together to determine the overall demand.

To determine the high hourly usage and the diurnal variation on water consumption within a single home, estimates were made of how often and when certain fixtures would be used during a "high day" for different size households. The following table presents the results of this assessment considering a six person home (estimates were also made for other home sizes). It is noted that this table represents a "worst case" scenario for high hourly usage, where water demand is very high in the morning. This has significant implications on the design of the steady-flow system, especially the indoor storage volume.

NUMBER OF WATER FIXTURE USES - HIGH DAY - 6 PERSON HOME						
Time of Day	Shower/ Bath	Lavatory Faucet	Kitchen Sink	Flush Toilet	Washing Machine	Dish Washer
7	3	6		6		
8	1		1			
9						
10						
11		1		1	1	
12		4	1	4		
13		1		1		
14					1	
15					1	
16		5		5		
17		1		1		
18		4	1	4		
19	1	2		2		
20	1					1
21		1		1		
22		5		5		
23						
24						

The system design is based on the high day demand scenario. The end uses for this scenario for a 6 person home for a single day are as follows:

- 30 toilet flushes
- 6 showers/baths
- 3 kitchen sink usages
- 30 bathroom faucet usages
- 1 dishwasher usage
- 3 washing machine uses

Flow Rate and Tank Size Design

The total water used in an individual 6 person home has been estimated to vary from 1670 to 2400 L/day, depending on the water efficient fixtures used. These quantities can be delivered easily with a very low flow rate. However, if the flow rate is too low, the required storage capacity to meet peak demands becomes too large. The type of tank, cost of the tank, width of opening in the home, the effect of increased flow on the size of the main and the special needs of certain customers are only a few of the factors to be considered when matching the flow rate to the storage facility. The flow rate delivered to each home and the individual storage tank volumes are highly dependent on each other. Thus, both these design parameters must be addressed together.

A computer model was developed to compare flow rates and storage facility capacities for various household sizes. Detailed analyses were carried out to determine the minimum household storage requirements. Hourly demands were calculated using the hourly usage distribution and individual fixture consumptions discussed previously. These were completed for various size homes (1 to 6 person), various supply rates (1800 to 3600 L/day) and with consideration of water efficient fixtures (1991 and 1996 plumbing codes). A sample of the computer simulation results is shown in Figure 2, which presents the results for a typical 6 person home using the 1991 plumbing code at a supply rate of 2700 L/day.

From the graphs it is clear that with a supply rate of 2700 L/day and with the 1991 plumbing code fixtures, a storage volume of 550 litres will be sufficient to meet the high day needs of a six person household. A smaller tank may be adequate for a 3 person household, although the 550 litre tank will provide a contingency supply and allow for increased temporal flexibility for water use in the home.

Because of the importance of the storage tank size for the individual dwellings, a second method was used to verify the recommended tank volumes. This analysis determines the required storage volumes considering specific end uses in a given time period (ie. 4 showers and 6 toilet flushes in a 1 hour and a 3 hour time period). Specifically, these were developed for the "worst-case" scenario of indoor fixture uses, with a supply rate of 2,700L/day. The results suggest that the recommended storage volume is similar to the

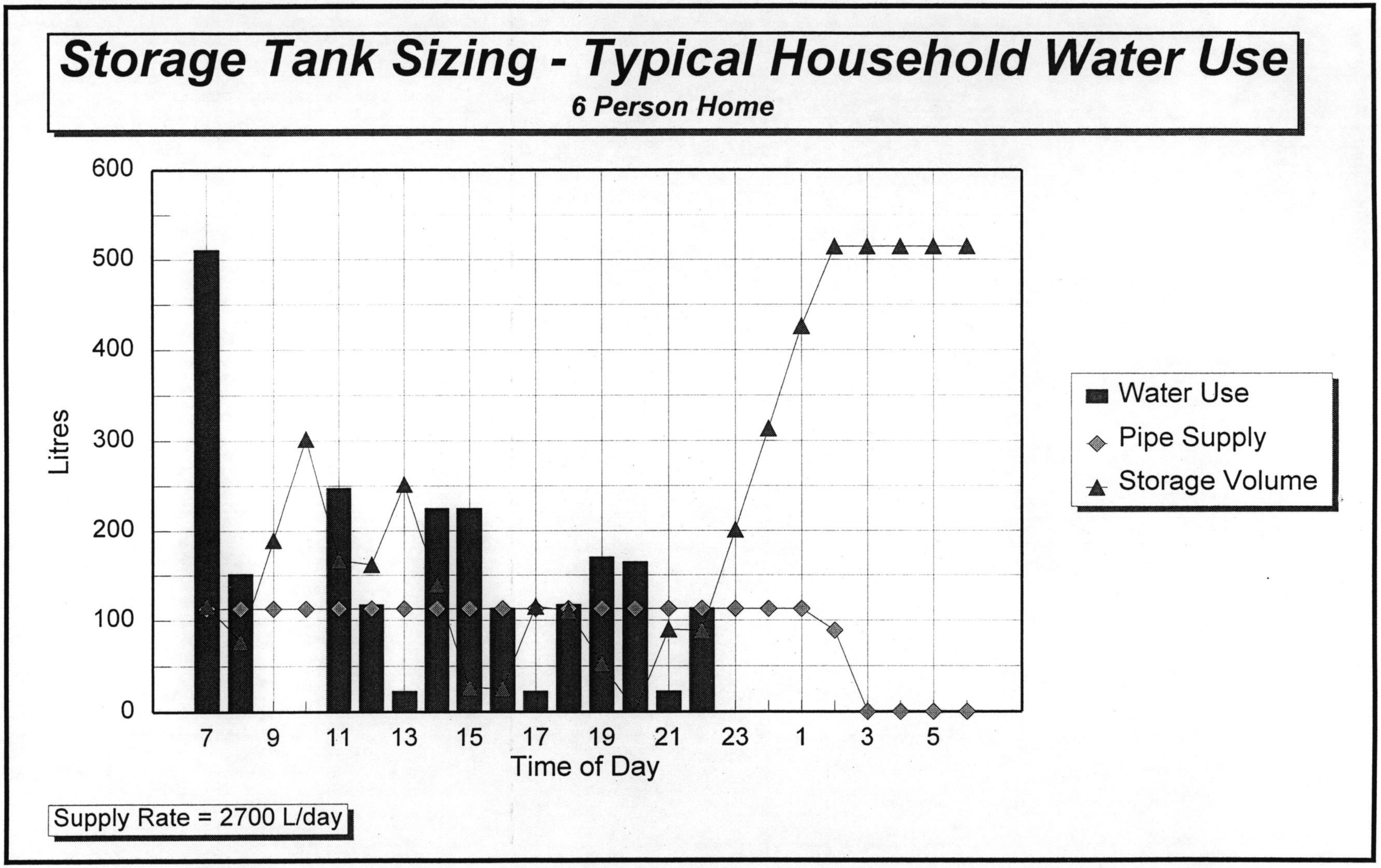

Storage Tank Sizing - Typical Household Water Use
6 Person Home
600
500
400
300
200
100
0
Litres
7
9
11
13
15
17
19
21
23
1
3
5
Time of Day
Water Use
Pipe Supply
Storage Volume
Supply Rate = 2700 L/day

FIGURE 2

previous calculations, in that a flow rate of 2,700L/day (1.89L/min) combined with a 550L tank are sufficient for a 6 person home. For larger families, several options are available, ie, retrofitting with water conserving fixtures, increasing the storage capacity or as a last resort, increasing the flow rate.

Pipe Design

To take advantage of the cost savings associated with the trenching methods proposed, a long continuous pipe is required. The only available material that suits this criteria is high density polyethylene (HDPE) pipe. HDPE pipe is available in a large range of sizes and strength classes and is supplied in relatively long lengths for on-site welding (or fusing) into continuous lengths or in rolls in smaller sizes. There has been some reluctance to use HDPE among some watermain utility operators due to a reputation for problems that has evolved over the years. HDPE has a fairly high coefficient of thermal expansion which has caused some problems with mechanical joint pullout in the past. Many of these problems have occurred with exposed installations, rather than buried installations, which are not subject to the same concerns. Since the surrounding ground restrains the pipe, the expansion forces are converted to internal stresses which immediately start to dissipate. Only a large rapid temperature change would be problematic and this is unlikely to occur with a buried watermain. The only unrestrained length of buried pipe is at the end of runs and openings such as valve chambers. The stresses here can easily be absorbed by the use of flanged fittings. Background information on the use of HDPE both for mains and service laterals was gathered through contact with pipe manufacturers, utility operators, regulating organizations (CSA, Plastic Pipe Institute), and utility contractors. Unlike the watermain industry, the gas utility industry has used HDPE successfully in North America for many years.

The normal jointing method for HDPE pipe is butt-fusion. This method requires an area which is relatively flat and unobstructed, with an adequate storage area for the fused pipe. The design team assumed that all the pipe destined for installation by trencher could be fused together on the edge of the road and left there until installation. The only restriction placed on this operation would be the requirement to maintain access to adjacent properties.

At all locations where trenching was stopped for any reason (i.e. at culverts or roadways where a directional bore would occur), a joint between the two sections of pipe would be required. Several options were considered, all of which made use of some type of coupling. Mechanical couplings are available to join HDPE pipe but these devices were deemed to be less acceptable than fusing due to their propensity to failure when subjected to the high thermal expansion and contraction movement of the pipe.

The preferred method of joining these sections together was by a fused joint to allow a continuous pipe. Two options were available: socket-fusion and the newer technique of electro-fusion. Both these methods are in common use in the gas industry, but the current trend is toward electro-fusion. The design team investigated both techniques and felt that electro-fusion provided better control and documentation potential and therefore elected to specify this method.

Similarly, both socket-fusion and electro-fusion were evaluated for use in the installation of service laterals, and again electro-fusion was the selected technique.

Design Constraints

The chain trencher method of installation is not appropriate for all types of ground conditions. Bedrock, boulders, or very coarse gravels may make trenching impractical or increase the cost to a prohibitive level. In Carlsbad Springs, geotechnical investigations confirmed that the ground conditions were suited to the proposed construction methods. Most of the area had damp to wet silts and clays with some areas of sand. The water table was uniformly high which would have provided additional problems for conventional installation methods.

Additional field investigations were carried out to assess the potential of hydrocarbon contamination of the ground water resulting from existing and past fuel handling sites and other land uses. Seriously contaminated soils may have an adverse effect on the plastic pipe and have serious impacts on construction and material disposal. Fortunately, no substantial areas of contamination were identified.

An inventory of the natural environment in Carlsbad Springs found that no significant impacts on the natural environment would occur resulting from construction within the road right-of-ways. The only areas of concern appear to be with respect to the stream and river crossings required for installation of the watermain. This confirmed that directional drilling methods under watercourses were more appropriate to eliminate the possibility of contaminating these more sensitive areas.

Rural roads often have deep ditches. The initial choice for the watermain location is generally in the ditch bottom to eliminate problems with servicing through the ditches, and to minimize the interference with the travelling public. The nature of the chain-trenching equipment precluded this location. It is assumed that the design cover depth of 2.4 metres in Ottawa-Carleton was approaching the practical maximum depth that chain-trenching could achieve with readily available equipment and still provide the cost savings anticipated. Therefore, a relatively flat surface is required for the trenching operation. The only suitable location that satisfied these requirements is the shoulder of the roadways. The drawback to this location is the potential for roadway damage from a trenching operation as close as 0.5 metres from the edge of pavement, as shoulder widths in many rural areas often vary from 1.2 to 3.5 metres.

SUMMARY

Steady-Flow Versus Conventional Systems

To compare typical construction costs associated with the steady-flow system and chain trencher installation to those of a conventional system with open-cut watermain installation, high level estimates of total construction costs for three different housing densities were developed as follows:

TYPICAL COSTS - CONVENTIONAL VS STEADY FLOW			
	300 homes over 5 km	300 homes over 12 km	300 homes over 30 km
CONVENTIONAL:			
Watermains	$1.0 million	$2.4 million	$7.5 million
Booster Pumping	$0.0	$0.0	$0.1
TOTAL	$1.0	$2.4	$7.6
STEADY-FLOW:			
Watermains	$0.4 million	$1.0 million	$2.4 million
Booster Pumping	$0.0	$0.0	$0.0
In-house	$0.6	$0.6	$0.6
TOTAL	$0.4	$1.6	$3.0
Steady Flow Savings	**0%**	**33%**	**60%**

This clearly shows that the steady-flow system is most cost-effective for less dense areas, commonly found in rural communities and strip development lands. The reason for this is that the savings made in installing distribution system piping are offset by the cost of the additional in-house components in denser areas. It is important to note that these are typical costs only, and actual costs may vary from those shown above.

These examples also illustrate the importance of customizing the needs of each community or area to be serviced. Some areas would benefit from a significant cost saving while others may only see moderate reductions in costs when using the steady-flow system and chain trencher.

System Performance Monitoring

Steady-flow represents an unconventional water supply technology and an alternative level of service to customers. Aside from the limited outdoor water uses available to system users, in-house water use may be affected using the steady-flow system. To test the effectiveness of meeting consumer needs in Carlsbad Springs, a monitoring programme was initiated immediately after the system was commissioned. Several monitors were installed in individual storage tanks of volunteers to assess the performance of the system and validate the design assumptions regarding water use patterns.

At the time of this report, all the systems monitored have verified that the flow rate and storage tank volume chosen are adequate for normal indoor use. Figure 3 indicates the results of the tank level monitoring for a typical residence in Carlsbad Springs. However, several residents have demonstrated that some education is required to remind people that the system does have limitations and some planning of their water use may be necessary. The education relates primarily to clothes washing, as multiple washings may consume a significant amount of the available water.

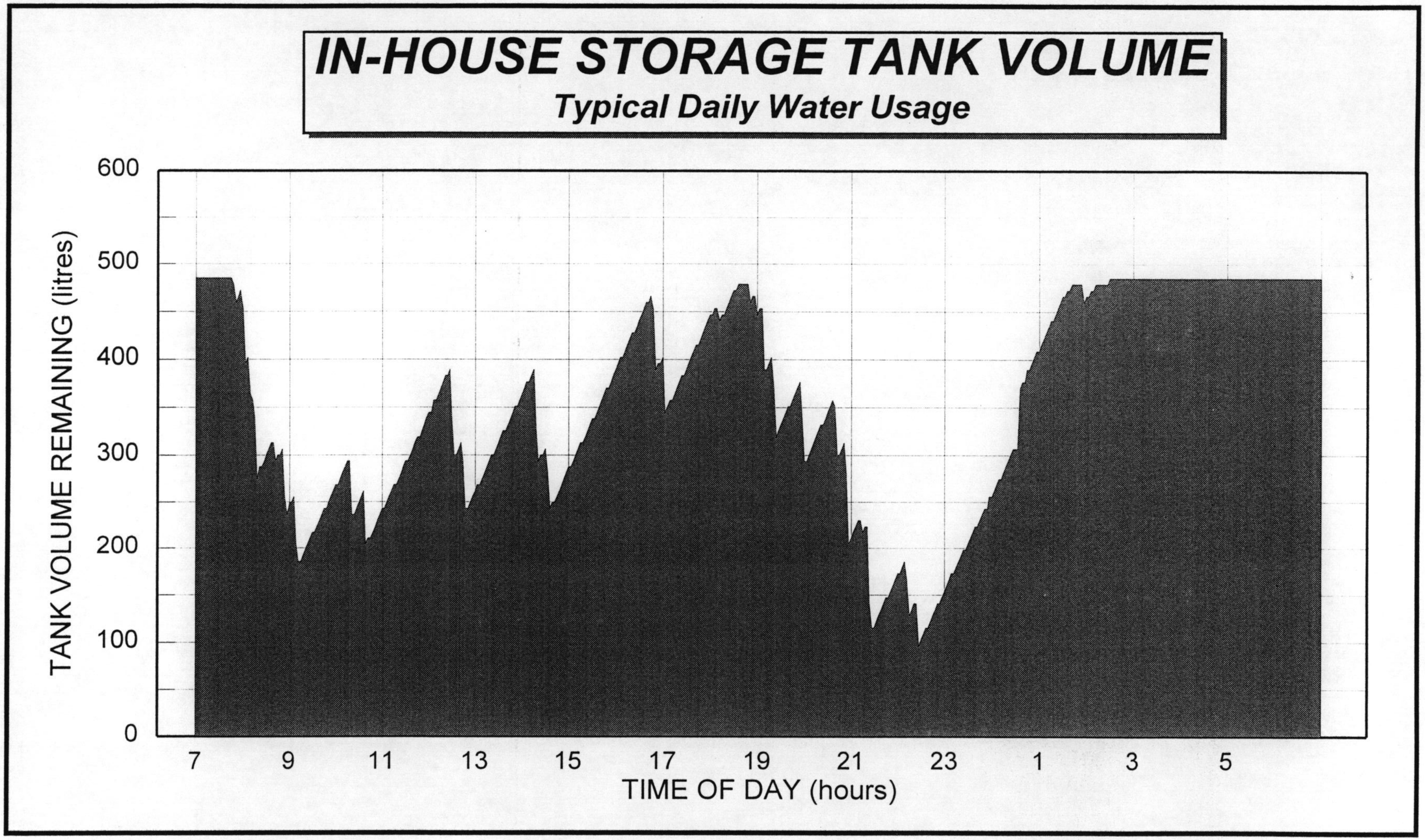
To measure water quality, sampling taps were installed between the meter set and the storage tank. Samples were taken from these taps as well as from a tap somewhere in the house at regular intervals. In this manner, the RMOC was able to ensure that the water delivered to the consumer met their high quality standards and a comparison of the two samples at any one site provides information on length of on-site storage and any detrimental effect this might have.

This sampling operation is especially critical during the early period of operation of the system since the design assumes full participation of all potential users. During the initial usage period, travel times from the source will be much higher due to reduced demands and the system required regular flushing to maintain water quality.

Future Opportunities

The two most notable features of the steady-flow water system are reduced infrastructure needs (smaller diameter watermains, no centralized storage, no booster pumping) and economical watermain installation (HDPE pipe material, chain trencher and directional drilling). The biggest cost savings associated with the steady-flow system are likely to be realized in areas where long lengths of distribution piping are required to service sparsely developed areas.

In view of the potentially high costs of servicing rural and/or remote areas with potable water, this technology could be extremely beneficial in reducing costs to feasible levels. It is anticipated that the unique steady-flow system design and the innovative method of installing watermains will also provide a cost-effective and attractive water supply alternative to other rural areas.



IN-HOUSE STORAGE TANK VOLUME
Typical Daily Water Usage
600
500
400
300
200
100
0
TANK VOLUME REMAINING (litres)
7
9
11
13
15
17
19
21
23
1
3
5
TIME OF DAY (hours)

FIGURE 3