A method to improve population access to drinking water networks in cities of developing countries

Thomas Tamo Tatiétsé and Manuel Rodriguez

ABSTRACT

This paper presents an approach to improve the access of urban households to drinking water and to assure continuous distribution without reducing network management performance. It is suggested that households participate in proposing technical solutions for network expansions. The approach is structured on network designs based on relevant variables such as household intake and capacity to pay. Considering costs, this approach will mean better distribution performance at lower rates. Technical responses mainly involve the concept of flexible and appropriate standards, called reference levels. With simultaneous consideration of household effort rate and reference levels, it is possible to define, for each category of area, the appropriate service level, the appropriate type and the optimal dimensions of the distribution network. Three service levels are thus proposed, according to the available resources of households: systematic household connection; connection with a public tap; and combined connection. This approach has been tested in Cameroonian towns. The suggested method allows an improvement in performance using the classic method, by a major increase in served households: network length ratio and a global investment gain in towns under study.

Key words | availability, developing towns, drinking water, distribution network, effort rate, households

Thomas Tamo Tatiétsé (corresponding author)
Laboratoire Aménagement Urbain,
École Polytechnique,
University of Yaoundé, I,
P.O. box 8390 Yaoundé,
Cameroon
Fax: +(237) 23 18 41;
Phone: +(237) 23 12 26;
E-mail: *ttamo@polytech.uninet.cm*

Manuel Rodriguez
CRAD,
Université Laval,
Québec,
Canada

INTRODUCTION

Despite the fact that drinking water networks are vital to preserve the population's health, comfort and activities, access to them is still limited in towns in developing countries (DCs). Providing urban populations with drinking water represents a major challenge—now and in the future—for all DCs, where the average access rate to drinking water is 68% (Navendra *et al*. 1996; World Bank 1999; Tamo Tatietse 1995). In a context marked by economic crisis, urban explosion, low household income and inefficient water network management, supply problems for drinking water in DC towns are due, among other things, to the following two factors.

1. The difficulty of properly applying policies for the planning of drinking water networks and improper evaluation of population water demand. Indeed, up to now, specific consumption (number of litres taken per day per inhabitant) has been overestimated. However, these continue to be the 'standards' used to design distribution networks. This quite often results in the creation of a network whose dimensions have been overestimated for a given sector, to the detriment of the spatial extension in zones that may be solvent.

2. Low commercial and technical performances. The percentage of water losses in networks because of technical blunders or insufficient maintenance is usually two to three times higher in DCs than in developed countries. These losses are mainly due to leaks, pirate connection and water consumption that is not accounted for. These losses also include lost opportunities related to authorities' and municipalities' unpaid bills.

The existence of water-borne diseases is the consequence of insufficient drinking water services. Diarrhoeal diseases affect approximately 900 million people and kill 3 million more each year (Philogene 1992). According to the World Health Organisation, one child out of two dies from diarrhoea before the age of 5 in DCs (Viland 1989). Of course, these water-borne diseases have repercussions on population activities. Apart from the time wasted in the search for water to the detriment of other more productive activities, some households spend around 10% of their income in an attempt to fight these water-borne diseases (SMUH 1971), by buying medication that eliminates the symptoms without, of course, removing the causes.

The approach to the design, extension and/or reinforcement of drinking water distribution networks usually consists of several stages: planning, designing and operating. Planning involves long-term programming of network construction in different stages: choice of population growth scenarios, the short-, mid-, and long-dated identification of water supply sources, and the specifications of supply facilities and equipment components required by the network in question. Network design pertains to evaluation of water needs of a population, calculations of reservoir capacities, choice of network structure, connection sizing and security, and the definition of maintenance mechanisms. This operation consists of insuring the functioning of the drinking water distribution infrastructure and the financial management of facilities.

The use of classic water network methods, designed for towns in DCs, has its limits. These mainly concern model calibration aimed at evaluating the local parameters used to design the networks. Network design rarely considers development in the informal sector, characterised (among other things) by a water re-sale phenomenon, which, none the less, constitutes a tolerated, though illegal, redistribution. It should be noted that household labour and financial contribution is not generally integrated into the network development process. Neither are the economies of scale following an increase in consumption. The other flaws in sizing methods are the absence of household priority evaluation and a poor estimation of water demand. Indeed, the quantity of water used depends on many factors including unit price, connection rate, user density and equipment level. These factors are closely linked to the nature of the urban fabric* under consideration (SMUH 1971). Note that existing literature recommends specific water consumption from 100 litres per person per day to 300 litres per person per day (Grigg 1986; Lauria & Herbert 1981; Gomella & Guerree 1985; Moniteur 1991; Hamou 1983). This value is high for DCs. In the long-term, overestimation of demand for individual connections may result in useless and very costly oversizing of the network. Moreover, not considering household contribution capacity (i.e. financial resources that they can mobilise for their water supply) can lead to an under-evaluation of future needs, which would be an obstacle to network extension. This generally leads to the coexistence of under-equipped zones, which sometimes exhibit high contribution capacities, and over-equipped zones with a limited demand for water.

The purpose of this paper is to present a new approach for network design, to allow not only improvement of urban household access rates to water and a reduction in frequency of cuts on the distribution networks, but also a major increase in network management efficiency without significantly increasing the financial burdens placed on public authorities.

MATERIALS AND METHODS

The water network designer controls different kinds of variable (the number of physically connected households, the peak flow coefficient, the delivered flow, the minimal pressure, etc.). However, the designer has no control over the population the network actually serves, the potentially solvent households and their future needs. This is why the technical solutions usually chosen for water supply projects—such as the connection of every household—are not always the most suitable for the technical, social or financial context in which the installations have to operate. The lack of reference data, which can be used as a basis for formulating operation plans, is the common denominator for network designers in DCs (OMS 1996). The basic idea is to design and build water distribution networks according to household water consumption and capacity to pay.

*The urban fabric indicates a collection of dwellings, equipment and infrastructure.

 Journal of Water Supply: Research and Technology—AQUA | 50.1 | 2001

Whether the project at hand is the implementation of a new network or the enhancement of an existing one, the network development process requires an approach that is as exact as possible in terms of household capacity to pay, average consumption per sector of activity (industries, services, households) and distribution in time and space. Industry and service consumption are relatively better controlled and their solvency is considered as acquired. The main difficulty for the designer generally lies in demand prediction, including households. Consequently design considerations will be centred on household demands. To assist this reflection, formulation and consideration of two concepts are indispensable: the effort rate and the reference level. The compatibility between these concepts implies the notion of risk related to network design.

Formulation and consideration of the effort rate

The effort rate is defined as what an unconnected household agrees to pay to be connected to the network and for water consumption. In fact, the household can connect to water distribution companies, to other connected households (the person pays a consumption cost to a neighbour who is already connected) or not connect at all. In the last two cases, the household may be solvent, i.e. able to pay the connection and/or the water consumption fees. Two investigation steps can be done to formulate the effort rate: (i) identification of the household's priority according to its access to the drinking water network and, for a positive result, evaluation of the permissible connection cost, which is the cost the household is willing to pay to be supplied with drinking water; and (ii) evaluation of the permissible consumption cost, which is the periodic consumption cost a household is willing to pay once connected to the water network. There is thus a requirement for estimating the household's preferences (priority or desire, financial capacities, etc.). When all criteria can be quantified from field surveys, a household's choice of supply in drinking water can be modelled.

The effort rate components can be calculated for each urban fabric and stratum.*

*A group of homogenous urban fabrics define a stratum.

Let us use the following notation,

CC: Connection cost,
MC: Monthly consumption cost,
CGP: Permissible connecting cost,
CNP: Permissible consumption cost,
N_c: Number of connected households,
Nu: Number of unconnected households.

Let us consider that variables Y_{1s} and Y_{2s} represent respectively connection costs and permissible connecting costs to the drinking water network for stratum s. Variables X_{1s} and X_{2s} represent, respectively, actual consumption costs and permissible consumption costs for stratum s. Evaluation of effort rate consists of determining the supply mode for drinking water, household priorities and actual or potential capacity to pay pertaining to connection costs, permissible costs for connection, periodic consumption costs and permissible costs for consumption. Control of these variables not only allows determination of network organic and functional characteristics, but prediction of their feasibility.

Since statistical variables CC, MC, CGP and CNP are discrete quantitative variables, their total is obtained by adding the different values taken by the variable between two set limits. Thus, the effort rate of a stratum s is defined by (X_{2s}, Y_{2s}) and is calculated as follows:

$$Y_{2s} = \frac{1}{N_u} \sum_{h=1}^{N_u} CGP_{sh} \tag{1}$$

and

$$X_{2s} = \frac{1}{N_u} \sum_{h=1}^{N_u} CNP_{sh} \tag{2}$$

where CGP_{hs} denotes the value of the variable, CGP for household h of stratum s and CNP_{hs} the value of variable CNP for household h of stratum s.

Briefly, the permissible costs for consumption and connection for every household must be determined. These variables can be evaluate from field surveys using a stratified sampling based on three criteria to establish the variability observed in the strata of towns of DCs: (1) dwelling morphology characterised by the external aspect of the construction, by the land-used coefficients, by the dwelling density and by plot size; (2) standard of service for drinking water, sewage, electricity and roadway system, and (3) economic activities dominating the urban fabric (service, agriculture, crafts, trade, etc.). Consideration of effort rate implies the need to define new, more flexible standards called reference levels.

Formulation and consideration of reference levels

Once permissible connection and consumption costs have been calculated, specific water consumption and service levels still have to be determined to size the water networks. The specific consumption and service levels constitute the reference levels for network design. The service level is characterised by the kind of equipment to be built: (a) public tap close to the plots; (b) faucet built on the plot; (c) classic pieces of equipment for sanitary plumbing such as sink, toilet flush, shower, bidet, bathtub, etc. Reference levels are evaluated by means of a deterministic and probabilistic method. The approach is deterministic because it consists of analysing current practices. This implies, for each stratum, studying connection and periodic consumption costs, as well as water quantity consumed (volume of water per day and per person). The averages and dispersions of these variables are deduced from operations statistics when they are the result of household surveys. The approach is also probabilistic since it is based on rapid examination of a broad number of situations (punctual sample) using a survey to produce the variables described above. In this latter approach, particular attention is paid to the sampling technique, on which result reliability depends. In order to set the reference levels, the specific consumption per stratum (X^c_{1s}) and connection costs must be determined. These two variables are respectively defined by the following equations:

$$X^c_{1s} = \frac{1}{N_c} \sum_{h=1}^{N_c} \frac{MC_{sh}}{30 \cdot P_u \cdot n_h} \times 1000 \quad (3)$$

and

$$Y_{1s} = \frac{1}{N_c} \sum_{h=1}^{N_1} CC_{sh} \quad (4)$$

where n_h is the number of people in the household, P_u the price per unit of one cubic metre of water.

The average specific consumption observed in a surveyed stratum will be assigned to all the neighbourhoods showing the same characteristics as the stratum for evaluation of peak flow and thus pipe sizing. With respect to establishing reference levels for connections, the principle is that a standard piece of equipment (service pipe diameter, volumetric water meter calibre, etc.) corresponds to each connection. Specific consumption will depend on what kinds of connections are available to users who want to be connected to the network. In the context of a town in a DC, service level has to be designed not so much according to a sole ‘standard’ than according to user capacity to pay. The progressive reinforcement of the network represents the appropriate model for drinking water networks in such a context.

Mathematical models used to determine effort rate and reference levels

The models

The use of stratified sampling is the appropriate technique for evaluating household effort rate and reference levels. Whether for consumption, connections, service rates, expenses/incomes, etc., the central trends and dispersions around those values are used to calibrate the model parameters for distribution network development. The notations used to define sample distribution between strata are presented in Table 1.

n_s = number of households in the sample of stratum s for the considered variable,
$\bar{x}_s$ = average of the variable under study in the sample for stratum s,
N_s = number of households of stratum s for the considered variable,
s_s^2 = variance of the variable under study in the sample of stratum s,
m_s = average of the variable under study for stratum s,
σ_s^2 = dispersion of the variable under study in stratum s,
k = number of strata.

Table 1 | Distribution of the sample between strata

	Stratum				
	1	**2 . . .**	***s***	***v***	**Total**
Population					
Size	N_1	N_2	N_s	N_v	N
Average	m_1	m_2	m_s	m_v	M
Variance	σ_1^2	σ_2^2	σ_s^2	σ_v^2	σ^2
Sample					
Size	n_1	n_2	n_s	n_v	N
Average	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_s$	$\bar{x}_v$	$\bar{x}$
Variance	s_1^2	s_2^2	s_s^2	s_v^2	s^2

The mathematical model used to evaluate the average and standard deviation is the lognormal distribution $N(m,\sigma)$. In fact, use of this distribution is adequate in cases where causes of variability are multiplicative (additive for normal distribution). However, the normal distribution $N\left(m, \frac{\sigma^2}{n}\right)$ can be used to calculate the average, except that these models imply sampling with replacement. However, sampling without replacement for households was the selected strategy. The application is nevertheless possible in this case because the sample includes at least 30 surveyed tissues, that is, $n \geq 30$ (Lavoie 1983; Grais 1992).

Calculation processes for effort rate and evaluation of reference levels

The practical evaluation of the different variables at a stratum level is as follows:

$$\bar{x}_s = \frac{1}{n_s} \sum_{i=1}^{n_s} x_{si} \tag{5}$$

and

$$S_s^2 = \frac{1}{n_s} \sum_{i=1}^{n_s} (x_{si} - \bar{x}_s)^2 \tag{6}$$

and at population level, i.e. for each stratum:

$$m_s = \frac{1}{N_s} \sum_{h=1}^{N_s} X_{sh} \tag{7}$$

and

$$\sigma_s^2 = \frac{1}{N_s} \sum_{h=1}^{N_s} (X_{sh} - m_s)^2 \tag{8}$$

where X_{sh} represents the value of variable X for household h of stratum s, and x_{si} represents the value of variable x for sample household h picked at the ith distribution for stratum s.

$\bar{x}_s$ is an unbiased evaluator of m_s because the average mathematical lifetime of an elementary sample equals the population average from which it comes. Thus, equation (5) is the fundamental equation used for setting the effort rate and reference levels following the entrance system variables in each stratum. As an example, the following equations are obtained:

$$CGP_s = \frac{1}{n_s} \sum_{i=1}^{n_s} CGP_{si} \tag{9}$$

$$CNP_s = \frac{1}{n_s} \sum_{i=1}^{n_s} CNP_{si} \tag{10}$$

$$SC_s = \frac{1}{n_s} \sum_{i=1}^{n_s} \frac{MC_{si}}{30 \cdot P_u \cdot n_i} \times 1000 \tag{11}$$

where n_i is the number of people in household i, SC_s the specific consumption of stratum s. Equation (6) indicates its spread around the average.

The variables pertaining to the whole site under study are evaluated using $\bar{x}'$ (equation (13)), which is an unbiased evaluator of average m (equation (12)).

$$m = \sum_{s=1}^{k} \frac{N_s}{N} m_s \tag{12}$$

will be evaluated by:

$$\bar{x}' = \sum_{s=1}^{k} \frac{N_s}{N} \bar{x}_s = \frac{1}{N} \sum_{s=1}^{k} \frac{N_s}{n_s} \sum_{i=1}^{n_s} x_{si}\,. \tag{13}$$

Equation (9) theoretically allows adaptation of results obtained in the strata to the whole town. In practice, equation (13) is used to extrapolate the results obtained to the whole agglomeration under study. This is the case of the network connection rate, the daily consumption per person and the network subscription cost. In any event, compatibility between household effort rate and reference level determines the type of distribution network to install.

Evaluation of risks linked to network design

Adaptation of service level to the household's capacity to pay is analysed from the point of view of the implied risk. For Blancher & Lavigne (1989), the risk is the meeting of a disturbing factor and vulnerable element. The risk is also the probability of the two elements occurring (Tamo Tatiétsé 1995). Such a definition leads to the identification of three risk categories in network design: intrinsic, extrinsic and eventual users-related. The intrinsic risks are due to network implementation techniques and technologies. The extrinsic risks are due to environmental perturbations and natural phenomena. The risks linked to eventual users are due to their solvency, i.e. the financial profitability of urban water services. In this last category, it is possible to identify two risk sub-classes: insolvency towards network connection cost and insolvency towards monthly consumption costs. The control of user-related risks implies satisfactory intrinsic prevention and management linked to the networks. Consequently, evaluation concerns the third category. The risk consideration process consists, for each stratum in the urban fabric, of comparing the effort rate at the reference levels quantified in money value to reduce the risk linked to household solvency. It is now possible to determine low-risk solvency zones, moderate-risk solvency zones and high-risk solvency zones.

The basic principle for considering risk in network design is: the optimal equipment level of a given agglomeration depends on its households' capacity to pay (Table 2). A variety of research has shown a correlation between urban fabrics and incomes (especially purchasing power) (Tamo Tatiétsé 1995; ENSP 1986–95). Given these results, three network service levels were identified according to set risks.

Table 2 | Drinking water supply system according to risk

Service level	Risk	Connection level
High standing	Lower risk	Systematic connection
Medium standing	Moderate risk	Combination distribution (PC & PT)
Low standing	Higher risk	Collective distribution (PT)

PC, private connection; PT, public tap.

The risk evaluated per stratum indicates the network configurations to be installed in the neighbourhoods under consideration. The three service levels determined in this way correspond one-to-one to the financial resources the households can mobilise. Irrespective of service level, drinking water has to meet quality standards, respect minimum pressure in faucets and be permanently available. The following experimental study permits a locking-in of fundamental parameters (effort rate, reference and risk levels) for the new method.

RESULTS AND DISCUSSION

The proposed approach for network design has been experimented in three urban Cameroonian agglomerations (Appendix). However, the results presented hereafter concern Obala's case. Obala is a medium size town of approximately 16,000 inhabitants covering an area of almost 262 hectares. About 50% of all households in the town get their drinking water from the distribution company (SNEC) (Tamo Tatiétsé 1995). Unprocessed water for Obala drinking water supply is drawn from river Afamba. A pumping station forces back an average of 780 m^3/day of treated water per day and feeds a raised reservoir. The collected water is treated by natural sedimentation and brought to the reservoir by two pumps (capacity of 25 m^3/hour). Distribution is done by gravity water supply; the network is ramified with a few links.

To generate the information required to apply the proposed network design method in Obala, the stratified sampling survey method was used. The town was divided

Table 3 | Main results from the survey on households in relation to water supply

Stratum	1	2	3	4	5	6	7	8
Households	412	289	714	395	181	604	376	169
Subscribed	78%	68.2%	30.4%	35%	30%	42.9%	80%	97.5%
Income (CFAF)	128,630	131,000	72,500	72,525	75,460	106,700	49,500	95,760
CNP (CFAF)	2,300	1,920	2,033	2,260	1,855	1,680	1,905	1,335
CGP (CFAF)	36,760	42,500	33,500	40,000	30,070	46,760	31,030	55,000

1 FF = 100 CFAF; 1 US$≈700 CFAF.

into homogenous urban fabric blocks and groups of similar blocks were put together in strata. The sectors under survey were selected by random number generation. Eight strata were identified:

Stratum 1: Old structured urban fabric;
Stratum 2: Recent structured urban fabric and commercial administrative fabric;
Stratum 3: Regular recent urban fabric (structured as low standing);
Stratum 4: Very dense old spontaneous fabric;
Stratum 5: Spontaneous rural fabric, in the course of densifying;
Stratum 6: Medially dense and improving hybrid fabric;
Stratum 7: Peri-urban fabric;
Stratum 8: Half-rural fabric, buffer between urban and rural fabrics.

Three hundred and forty-seven households (average of 5.2 inhabitants per household) out of 3,140 making up the town, at the time of the survey (1992), replied to a survey questionnaire containing various questions about drinking water (daily consumption, willingness to pay for water connection, etc.) (response rate of 0.11). The information from this survey forms the basis of evaluating the effort rate and the reference levels for network development.

Evaluation of the effort rate

As mentioned above, the permissible connecting costs (CGP) and permissible consumption costs (CNP) are the variables describing household effort rate. The average values obtained for the town in question are presented in Table 3.

Table 3 presents, among other things, the two components of the effort rate for each stratum. It shows that *the average household income* does not alone account for the households' capacity to pay. Figure 1 presents the part of each stratum in the total number of households that do not have a private connection, as well as the distribution of permissible connection cost categories inside each stratum.

Results show that no household in the town under study is ready to pay more than 100,000 CFAF (1US$ = 700 CFAF) for its subscription to drinking water.

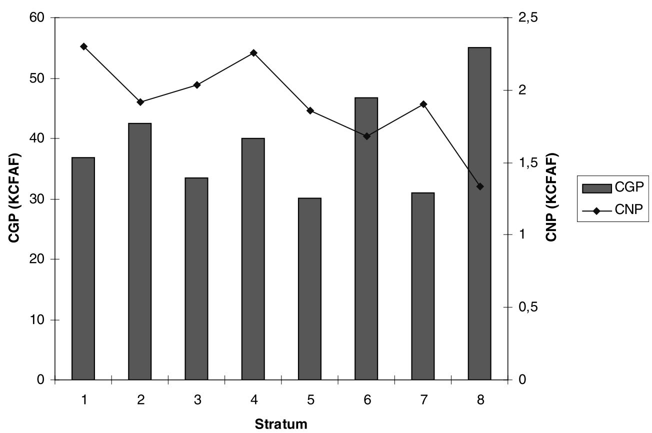

Figure 1 | Effort rate: permissible connecting cost and permissible consumption cost.

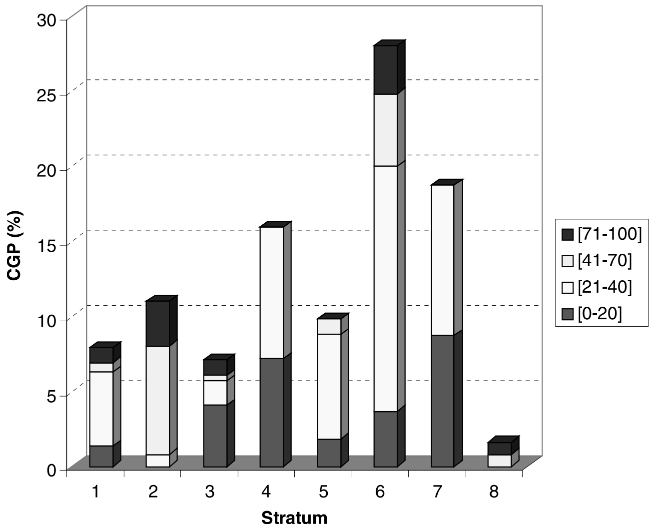

Figure 2 | Household distribution per stratum and according to permissible connecting cost category.

For example, in stratum 3, which contains 7% of all households in the town wanting a domestic connection, households willing to pay a sum inferior to 20,000 CFAF for their subscription represent 4% of the non-subscribed households of the town, whereas those willing to pay an amount between 21,000 and 40,000 CFAF, 41,000 and 70,000 CFAF and 71,000 and 100,000 CFAF respectively represent 1.6, 0.4 and 1% of the non-subscribed households in the town. In stratum 4 and stratum 7, no household is willing to pay more than 20,000 CFAF. Only 9% of the households are willing to pay more than 71,000 CFAF to acquire a private connection; they are distributed in five strata at the rate of 3.2% for stratum 6, 3% for stratum 2, 1% for stratum 3, 1% and stratum 1 and 0.8% for stratum 8.

Figure 2 presents the distribution of household effort rate in each stratum and highlights the relative importance of effort rate per stratum. The higher the effort rate linked to connection, the more the household can subscribe. Moreover, a household with a low connection effort rate will not be able to pay for the private connection cost. However, such households will be able to pay fees for water provided by public taps. Identical observations can be made for water consumption effort rate.

These effort rates correspond to the following service levels.

- The first service level is the creation of collective water sources or public taps on a radius of between 200 and 300 m.
- The second service level is characterised by the implementation of public taps and private connections.
- The third service level, as with cities of industrialised countries, is defined by the systematic level of private connections in every house.

Strata solvency can only be determined by examining the two effort rate dimensions according to the reference levels defined above.

Evaluation of reference levels

As mentioned above, evaluation of reference levels consists of determining the type of equipment for connection to the network, as well as the specific water consumption.

Reference levels for connections

Connection costs depend on the distance between the distribution network and delivery point to the subscriber. The prices charged by the company in charge of water management (SNEC) vary from 35,000 CFAF to a few hundred thousand. For every connection, the possibility of additional connections on existing delivery points is considered. This innovative proposal of regularising water 'resale' to the neighbours is realistic and relevant. Indeed, water 'resale' is not profitable to households buying water at a higher price from the subscribed neighbour; the resale is conducted to the detriment of the SNEC dealer, whose profit would be at least the monthly fees of the water speedometer rental relative to the subscription. Moreover, because specific consumption was found to be limited, it is technically possible to use such a solution (the connection of two subscribers on one delivery point fed by a 15 mm diameter pipe). This strategy is particularly appropriate for a pipe supplying a faucet located on the plot.

Table 4 | Reference levels for connections to the drinking water network

Diameter of pipe (PVC) (mm)	Fixed charges for 5 m of connection (CFAF)	Cost per linear meter (CFAF)	Additional connection cost (CFAF)	Connection from a delivery point (CFAF)
15	46,585	1,720	22,450	34,520
20	53,510	2,080	28,755	41,085
40	78,650	3,125	52,110	65,380

Source: Tamo Tatiétsé (1995); SNEC (1981). 1US$≈700 CFAF.

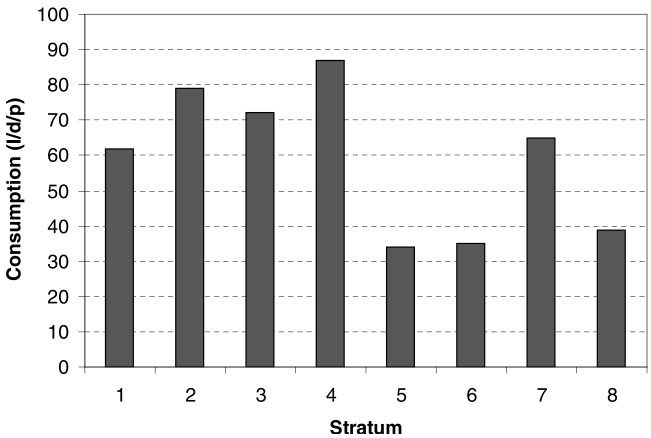

Figure 3 | Reference levels related to specific water consumption for subscribed households.

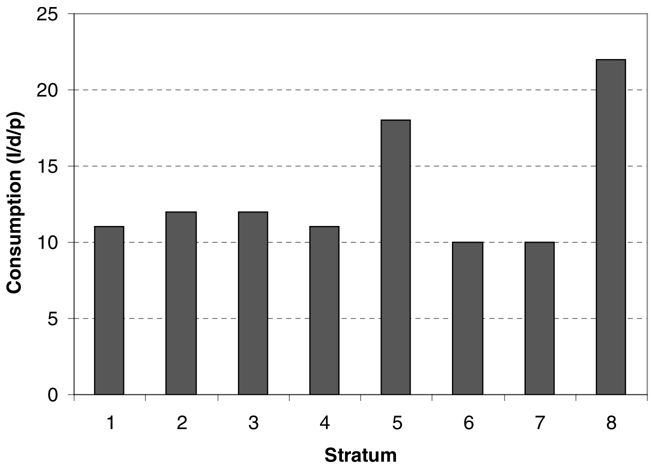

Figure 4 | Reference levels related to specific water consumption from public taps.

Experience and surveys in the field show that low cost connections – 5 m long, 20 mm wide polyvinyl chloride (PVC) pipes – cost about 40,000 CFAF. This is in fact very close to the fixed charge set by the water management company (42,400 CFAF). Thus the threshold $CC_2 = 40{,}000$ is an indicator of operation profitability. Exceptionally, a 15 mm wide PVC pipe can be used, at a cost of 35,000 CFAF (SNEC 1981). This threshold, $CC_1 = 35{,}000$, is a strict vulnerability indicator for profits. Consequently, when permissible connection cost is lower than CC_1, the public tap will be the connection form privileged over every other domestic connection for drinking water network connections.

Reference levels for consumption

The cost thresholds above or below which households are or are not solvent are determined by the following values: cost for each cubic metre of water: 255 CFAF ($WC_m > 10\ m^3$);* 205 CFAF ($WC_m \leq 10\ m^3$), average size of household: 5.17; speedometer maintenance costs: 500 CFAF/month. By using equation 11, the reference levels for subscribed households (Figure 3) and for those taking water from public taps (Figure 4) are determined. The average monthly cost for water for the subscribed households is 4,120 CFAF 3,169 CFAF of which correspond to water consumption. The remainder is a fixed charge used for water meter maintenance. The average of the various specific consumption strata is 60 litres per day per person with a standard deviation of 18 litres per day per person. The result obtained in Obala reveals, in our opinion, the level of typical consumption in other Cameroon towns. The low dispersion around the average confirms the relevance of the obtained specific consumption. The study conducted on the basis of SNEC management statistics in 1989 (Tamo Tatiétsé 1995) shows that in Cameroon it is on average 66 litres per day per person for households with private connections. Specific consumption determined on a monthly water bill basis shows that the level of consumption varies considerably depending on the stratum: the range of this variable is 53 litres per day per person.

*WC_m is the volume of water consumed per month.

Journal of Water Supply: Research and Technology—AQUA | 50.1 | 2001

The average consumption obtained at the public taps was 13 litres per day per person. It is important to note that this water is mostly used for drinking and rarely for cooking food. Well water, springs or rivers are used in this case for cooking, washing clothes, dishes and bathing.

Risk evaluation

It is possible, after determining household effort rates and reference levels, to predict the risks linked to network design and/or enhancement. For this, household effort rate has to be simulated from a precise evaluation of daily water consumption per inhabitant and be compared to the experimental results. In the light of the results presented above, it is reasonable to think that specific consumption in a household with a domestic connection is higher than 40 litres per day per person (it must not be under 30 litres per day per person). This consumption equals a monthly cost of 1,770 CFAF. For an effort rate that is inferior to this limit, it is very likely that consumption is higher than the monthly permissible consumption cost and that the insolvency risk is not to be ignored. If, on the contrary, the monthly permissible cost is higher than 1,770 CFAF, then the insolvency risk is almost non-existent. If the effort rate is less than 1,450 CFAF, this same reasoning shows that households could hardly pay their water bills if they have taken out a subscription for the service. This is because it is not very likely that specific consumption will be less than 30 litres per day per person. These limits let us determine three risk zones corresponding to the three service levels presented in Table 2.

1. CNP≥1,770 CFAF and CGP≥40,000 CFAF: the risk linked to the effort rate in network operation is almost non-existent. The specific consumption equals at least the average of 60 litres per day per person.

2. 1,450≤CNP<1,770 CFAF and 35,000≤CGP <40,000 CFAF: this is the buffer zone corresponding to a moderate risk. Water service from collective water sources (public taps) and from individual connections forms the appropriate model for development of the water network.

3. CNP<1,450 CFAF and CGP<35,000 CFAF: this is the high-risk zone. In this zone it is not advisable to proceed with individual connections. Only the exclusive supply for collective water sources is adapted.

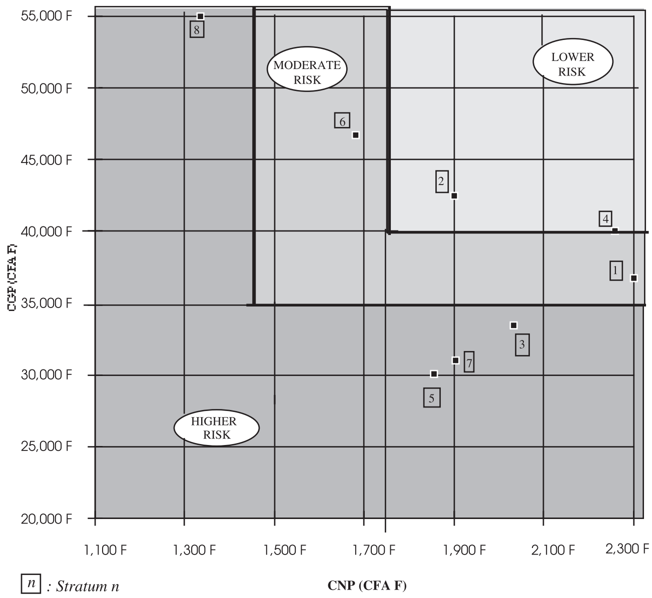

Figure 5 | Diagram for risk related to the households' effort rate.

Figure 5 shows the graphic interpretation of those three zones. This approach allows better prediction and integration of risk in network design and/or enhancement. The correlational analysis between the drinking water service level and the risk associated with household effort rates gives the correspondence described below.

- The first service level corresponds to the higher risk due to an insufficient effort rate on the connection costs as well as the monthly consumption costs.
- The second service level (from public taps and private connections) shows a globally satisfactory effort rate, but with a large proportion of households under the profitability limit for individual connections and thus for consumption. This zone corresponds to a moderate risk.
- The third service level (running water) reveals a lower risk. The relatively high effort rate shows that households in the zone under study can support charges pertaining to drinking water supply.

This graphic evaluation method for risk is a tool designed to help make decisions concerning extending or enhancing a drinking water network. Specific consumption and type of service are defined according to which of the

 Journal of Water Supply: Research and Technology—AQUA | 50.1 | 2001

Table 5 | Comparison of the results obtained according to the method used

Criteria	Classic method	Proposed method	Relative deviations
Length of extension network (km)	4.38	2.25	– 49%
Households served by this network	1,498	1,066	– 29%
Number of households per km in the network	340	474	+ 40%

previously described zones an urban fabric belongs to. It was finally established that drinking water infrastructure service levels should be closely linked to the risk and the latter linked to the households' effort rate. The following network design is a consequence of that conclusion.

Network development trends

The application of the new approach for network design and/or enhancement is completed by the actual sizing of the network in Obala. This last step, performed using the tools presented in the previous paragraphs, has not only made it possible to determine the organic and functional characteristics of extension or enhancement of the network, but also to evaluate its performance compared with the classic method. The new hypothesis used in the network planning process is the risk related to household effort rate and specific consumption per stratum. The other hypotheses, more traditional, are as follows since the consumption increase rate is known, a rapid calculation shows a consumption of 800 m^3/day to which building consumption must be added: student residences, 19 m^3/d; food-processing industry consumption (mushroom growing), 32 m^3/d; administrative centre, 80 m^3/d; shopping centre, 24 m^3/d. A total consumption, Q_t, of 956 m^3/d is obtained, which implies an average flow, Q_m, of 11 l/s; the peak flow factor is thus 26.4 l/s. Hydraulic calculations are performed using, among other things, the Bernoulli Theorem (equation 15) and the following equations:

If Φ_{ij} is the pipe diameter, speed V_{ij} is determined by the following equation:

$$V_{ij} = \frac{4q_{ij}}{\pi \Phi_{ij}^2} \tag{14}$$

Pressure at point j is obtained by the Bernoulli Theorem used between i and j:

$$Z_i + \frac{p_i}{\rho g} + \frac{V_i^2}{2g} = Zj + \frac{p_j}{\rho g} + \frac{V_j^2}{2g} + \Delta H_{ij} \tag{15}$$

Where Z_j is the spot heights for kernels i, j and ΔH_{ij} signifies the hydraulic head loss between i and j; g represents gravity acceleration and V speed. Kinetic energy $\left(\frac{V^2}{2g}\right)$ is not considered because it is relatively low. Pressure, diameter and other flow calculations are classic at this stage of the project.

An example of detailed calculation is presented in the Appendix. The classic and proposed methods have been used to design the drinking water network. The summary of the results is represented in Table 5.

The proposed approach leads to network length that is approximately half of that obtained using the classic method. The extension of these pipes, compared with what was obtained using the classic approach allows the network to serve 1,498 additional households. This corresponds to a drinking water service rate of approximately 100% in the town of Obala. With this method, the extension piping will serve 1,066 additional households in the town, 552 of which will be served by private connection and 514 by public taps. The drinking water service rate upon completion of this extension is 82%. The number of households served per kilometre of network using the proposed method is greater than the one obtained with the classic method.

CONCLUSION

Up to now, the standards used to design water distribution networks have led to an exaggeration of the infrastructure dimensions. Considering the households' participation as part of the network, design process allows an efficient expansion of the water network and rationalisation of the investments pertaining to its extension and enhancement. Following an analysis of the risk linked to the effort rate, three types of service are determined: systematic connection of households, supply by public taps and combined service (coexistence of private connections and public taps). The average specific water consumption in Obala was found to be 60 litres per day per person. This reference level represents less than half of the standard predicted (120 and 300 litres per day per person). The proposed method yields results that go beyond the classic procedure performance, thanks to an increase in the *households served per network kilometre* ratio by 40%. As far as investments go, the global gain obtained in the short-term using the proposed method is 57% according to the classic approach.

The economic crisis and the devaluation of the CFA Franc in 1994 have slowed down investments, notably in the water supply sector. As a result, the number of subscribed households for drinking water in the towns studied has remained low. Indeed, the subscription cost and the cubic metre cost of drinking water, though globally constant between 1994 and 2000, saw an increase of about 25% in 1994. The proposed method does not treat the needs of network maintenance. That will be the main point of a subsequent paper.

However, paying public taps, proposed by these research works, have already been applied in Cameroonian towns. That accounts for the multiplication of paying public taps, which rose from 0 in 1992 to 7 in 1999 in Obala (Cameroon). There, installation is widespread in spontaneous neighbourhoods whose anarchic urbanisation does not allow the construction of water mains to serve plots or buildings. In short, the tendencies observed (specific consumption, number of households served in the network) should probably be maintained if the proposed method is to be fully applied. Only the number of connected households could probably decrease—everything being equal—from the growth rate of the subscription expenses, because household income has not increased since 1994.

To sum up, this approach is suitable for most towns in DCs by identifying the zone to which the households belong in the risk diagram associated with their effort rate and thereby using the specific consumption obtained for sizing of water mains.

The optimal drinking water network design or enhancement plan implies consideration of households' capacity to pay, which would lead to investment rationalisation and, on the technical level, reference level adjustment, particularly for specific consumption, as alternatives to the current standards. The originality of the proposed method is the design of the water network according to the compatibility between household effort rate and the quantified reference levels in monetary value, meaning the risk linked to network design and/or enhancement.

LIST OF MAIN INITIALS

CC: Connection costs
CGP: Permissible connecting cost
CNP: Permissible consumption cost
DCs: Developing Countries
MC: Monthly Consumption costs
m_s: Average of variable used in stratum s
N_c: Number of connected households
N_u: Number of unconnected households
n_s: Number of households in stratum s sample for the considered variable
N_s: Number of households from stratum s for the considered variable
PC: Private connection
PT: Public tap
SC_s: Specific consumption for stratum s
SNEC: Cameroon National Water Corporation,
s_s^2: Variance of the variable under study in sample for stratum s
v: Number of strata
X_{1s}: Consumption costs for stratum s

X_{2s}: Applicable consumption costs for stratum s
$\bar{x}_s$: Average for variable under study in sample for stratum s
Y_{1s}: Connection rate to the drinking water network for stratum s
Y_{2s}: Applicable connection costs to the drinking water network for stratum s
σ_s^2: Dispersion of the variable under study in stratum s

ACKNOWLEDGEMENT

The authors thank Professor D. Trystram, Institut National Polytechnique Grenoble.

REFERENCES

Blancher, P. & Lavigne, J. C. 1989 *Risque et réseaux urbains. Génie urbain et état des connaissances et des savoir faire*. Lyon: Institut National de Génie urbain.

ENSP (École Nationale Supérieure Polytechnique) 1986–1995 *Schéma d'aménagement, etude préalable, propositions des villes Akonolinga, Guider, Melong, Akonolinga, Obala, Mbalmayo, Yaoundé 4, Bandjoun*. Yaoundé: ENSP.

Gomella, C. & Guerree, H. 1985 *Guide de l'alimentation en eau dans les agglomérations urbaines et rurales*. Volume 1. *La distribution*. Paris: Eyrolles.

Grais, B. 1992 *Méthodes statistiques*. 3rd édition. Paris: Dunod.

Grigg, N. S. 1986 *Urban Water Infrastructure: Planning, Management, and Operations*. New York: John Wiley.

Hamou, H. 1983 *Les réseaux de distribution de l'eau*. Paris: CATED.

Lauria, D. T. & Herbert, P. V. 1981 *Optimal Staging and Upgrading of Community Water Supplies in Developing Countries. Series Appropriate Technology for Water Supply and Sanitation.* Washington: World Bank.

Lavoie, R. 1983 *Statistique appliquée: auto-apprentissage par objectif.* Quebec: Presse de l'Université de Quebec.

Moniteur 1991 *L'eau et les collectivités locales*. Paris: Éditions du Moniteur.

Navendra, P., Sharma Torbjorn, D., Gilgan-Hunt, E., Grey, D., Okaru, V. & Rothberg, D. 1996 *African Water Resources. Challenges and Opportunities for Sustainable Development*. World Bank technical paper no. 331. Washington: World Bank.

OMS 1996 *Exploitation et entretien des systèmes de distribution d'eau et d'assainissement en milieu urbain,* Genève: OMS.

Philogene, B. 1992 L'eau potable, un besoin fondamental. *Universités* **13** (3), 19–22.

SMUH 1971 *Alimentation en eau*. Paris: Ministère de la coopération.

SNEC 1981 *Convention et cahier de charges, concession de la distribution publique d'eau potable. Avenant no 5 Art. 20, 22, 27, 28*. Yaoundé: Ministère des mines et de l'énergie.

Tamo Tatiétsé, T. 1995 Éléments pour une prise en compte de la participation des ménages au développement des réseaux d'eau potable et d'électricité dans les villes des pays en développement : le cas du Cameroun. Thèse de doctorat, INSA de Lyon, France.

Viland, M. C. 1989 *Eau et santé. Éléments d'un manuel pédagogique pour des programmes d'hydraulique villageoise dans les pays en développement.* Paris: Ministère de la coopération et du développement.

World Bank 1999 *World Development Report 1998–1999*. Oxford University Press.

APPENDIX: GEOGRAPHICAL LOCATION OF CAMEROON AND TOWNS