NeatWork, a computer tool for water distribution design

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The countless drinking water distribution networks that exist or need to be planned around the world are designed according to different and multiple criteria and according to specific local conditions such as: the origin of the water to be used; the urban or rural environment of the communities they serve; the geomorphology of the region where the project is located; the cost of the project; the type of buildings requiring access to drinking water and the degree of their dispersal; whether or not houses are already present at the time of project design; the presence or absence of an existing network whose extension must be planned; the presence or absence of local repair technicians to be called upon when necessary; the simplicity and cost of maintenance; the restrictions dictated by urban planning; and, above all, the ease of access by consumers to their drinking water quota.

It is therefore not surprising that computer tools based on mathematical models and computational algorithms have been developed to adapt to these multiple needs. What is more surprising is that, to our knowledge, the tools that are currently used, are based on models whose basic assumptions are not compatible with the conditions of application in the field, which the NGO Agua Para La Vida (APLV) [1], and no doubt many other organizations, are facing. This has led the developers of the NeatWork computer tool to adopt a very different approach from the one documented in manuals and reports such as [5,6].

NeatWork's approach primarily concerns networks for small, poor and dispersed rural communities that need a guarantee of access to drinking water at all times, requiring, beyond the construction period, only an absolute minimum of external intervention. This choice is motivated by the aims of the NGO Agua para la Vida, (APLV), which has been working for over thirty years to help these rural communities fulfill their right to drinking water. In almost all cases, the water supply system is designed for an existing village so that the entire project can be designed. To ensure ownership of the project by the villagers and to promote replication of experiences, APLV is committed to having local technicians trained at the ETAP technical school carry out the project design work. These technicians must be able to do without the supervision of engineers thanks to computer tools developed for their use. In particular, for the design of the distribution network, the NeatWork tool requires only a reduced level of expertise, which makes it easier for ETAP-trained technicians to master it, and makes it popular with this small community. More than 80 water distribution systems have been successfully built using NeatWork in about 20 years. Those systems continue to operate without requiring any maintenance operations other than those routinely performed by local technicians. The efficiency of the tool and its ease of implementation by practitioners were rewarded with a prize at the seventh edition of the Water and Sanitation prize sponsored by IDB and the FEMSA foundation in 2015.

To understand the contribution and originality of NeatWork, it is necessary to specify the exact nature of the networks to which it applies. The purpose of distribution is to connect each user to a tank through a system of protected pipes leading to faucets adjacent to the homes. The inhabitants make basic use of the water supplied by the faucets. They collect the water with containers or use it directly from the faucet to wash themselves or their clothes. The reservoir, which is fed by a spring containing drinking water, is located at the origin of this network, which is tree-shaped, i.e., it has no loop. Water is transported from the reservoir to the faucets by the force of gravity alone. Since the beginning of the network is the free surface of a reservoir and the network ends at the outlet of the faucets, the available energy is simply given by the differences in level between the reservoir and the faucets. The topography of the network, i.e., its spatial arrangement, is established beforehand and is provided to NeatWork as a datum. The design work then consists of selecting the equipment (pipes) to be installed throughout the network to guarantee an adequate service to the users, while minimizing the cost of this equipment.

In order to define what an adequate service to users can be, it is necessary to look at user behavior. To begin with, it is accepted that users withdraw their water quota at any time of the day by turning on the faucet assigned to them. The general rule is that each family is assigned a faucet adjacent to their home. The daily amount of water allocation to the members of each family and therefore to each faucet is a parameter introduced by the designer. It is the same for all members, but the amount taken varies during the day (peak period, average daily period, etc. defined according to the usual usage observed in similar villages). If the amount of water allocated to a faucet is prescribed within a given interval of the day, it does not mean that the withdrawal is continuous and uniform over the time interval in question. For example, if the faucet is used to fill a container of a given capacity, say a dozen liters, it should be expected that the user responsible for the collection wants to do so as quickly as possible. To be concrete, if the container to be filled has a capacity of 12 liters (already heavy for the few steps a child needs to take to carry water from the faucet to the house) a filling time of 4 minutes would be excessive, and a time of 2 minutes would already be long. As a result, the user opens and then closes the faucet, and leaves it closed until the next pass. It follows that the faucet operation is inherently intermittent, with alternating openings and closures. The total opening time will always be less than the duration of the period. It is therefore necessary, in order to limit the filling time, to ensure a minimum flow rate at all times when the faucet is open. The time lapse when the faucet is open can be estimated from the minimum flow rate data. It will always be a fraction less than 1 of the period. However, it is not possible to specify at what times the faucet will open and close. Users' arrivals and departures cannot be predicted precisely; they are typically random. One consequence of this randomness is that at each moment in an observation period, some faucets will be open and others will be closed in a random pattern.

The question that arises is how the system will perform in a potentially very large number of configurations. Will users benefit from a roughly constant flow rate regardless of when they fill their water container, which would be adequate service; or will they face dry faucets at certain times, which would be problematic? This is highly relevant in practice, whether the distribution network was designed by NeatWork or by any other means.

The answer to this question is twofold. First, the physical laws of flow allow the flow rates to be accurately determined for any given open faucet configuration. There are two such laws, the first one invokes the conservation of mass, the other one invokes the conservation of energy (the latter is equivalent to a principle of minimum energy dissipation). The calculations are performed by a highly efficient optimization algorithm [4], which gives almost instantaneously the solution, allowing its repetition thousands of times on different configurations. Secondly, it is necessary to determine for which open faucet configurations the flows, and thus the service rendered to the users, should be determined. Unfortunately, the potential number of open faucet configurations is astronomical. There is no question of considering them all. A survey must therefore be conducted by randomly drawing a sample of representative scenarios on a sound statistical basis. To do this, NeatWork considers that at a given time, each faucet has a given probability of being open, that this probability is independent of the other faucets and that it is the same for all faucets. Finally, this probability is equal to the proportion of time a faucet is open during the analysis period (peak, low water, in-between periods, etc.). This probabilistic model is compatible with the assumptions made about user behavior: free choice for each user of sampling times, independence between users and same occupancy time for each faucet.

Equipped with this powerful analysis tool, the project designer can address the issue of the choice of adequate equipment for the network. Indeed, the simulation tool will reveal whether the equipment ensures enough stability of the flows at individual faucets, and possibly call for improvement. For this purpose, a second so-called design module is made available to the designer. The mathematical formulation of the design problem is particularly arduous. Indeed, the design work consists in fixing here and now the choice of equipment to cope, in the future, with an almost infinite variety of conditions of use. Formulating this problem in mathematical terms is possible, but solving it would require computing resources that are incompatible with the chosen target of its use. Instead, the authors of NeatWork developed and implemented a heuristic approach that neglects the first of the two laws of flow, that of mass conservation, to focus on energy conservation. This heuristic is driven by the search for a minimum-cost solution, another aspect that traditional approaches neglect or only partially address. The methodology of the heuristic is described in detail in the publication [3]. NeatWork provides almost instantaneously a solution that the user can, and must, test in the simulation module. Simple procedures, described in the user guide and tutorials in progress, make it easy to make adjustments leading to a satisfactory solution.

In summary, NeatWork offers assistance in the integral design of a water supply system at minimum cost, specifying all the equipment to be installed from the reservoir down to each user. The design takes into account the users behavior that result in a random pattern of water withdrawals at each faucet stand. The design is meant to provide a guarantee that regular and sufficient flows will be obtained in real life. This guarantee is obtained thanks to a powerful simulation tool that confronts the system with a very wide representative selection of operating situations. A few remarkable facts should be highlighted in particular.

- The tool is simple and robust enough to be used by the technical community and has been well received by the technical community.
- Once the topographic data set has been entered into the software tool, the creation and completion of the project takes no more than a fraction of a man-hour work.
- The quality of the solutions provided by NeatWork has been massively validated over the last twenty years by the flawless operation of the projects

carried out.

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Post-Scriptum

Since NeatWork offers an alternative to reported practices, it is fair to say a word about those practices. This is not an easy task. It is quite apparent from the above presentation, that NeatWork proceeds on bases never discussed elsewhere in the literature; it is much more difficult to affirm that there is a well-established method for designing the dimensioning of the networks of our concern. The NeatWork approach emphasizes the need for adequate service at individual faucets and the dimensioning the entire network, including terminal branches leading to faucet stands. To do so NeatWork takes into consideration the behavior of the users, which is essentially stochastic. This type of hazard is never described in the literature. All methods we know of ignore it. They substitute to the stochastically intermittent flow resulting from a random manipulation of the faucet a deterministic continuous flow corresponding to the average demand for water during the period under consideration. We argue that this approximation/substitution makes no sense at the ends of the network. Just think of a faucet that is supposed to flow at 0.12 liters per second 10% of the time; it will cause an alternation of 0.12 l/s and zero flow through the pipe adjacent to it. Replacing this situation by a constant average flow rate over time of 0.12 / 10 = 0.012 l/s (a very thin trickle of water) makes no sense and cannot lead to good sizing.

To cope with this deadlock, the standard approaches use a deterministic approximation of the flow rate, only at branching nodes to which at least a dozen faucets are linked. This is somewhat justified by an application of the law of large numbers. The set of nodes that meet the property of serving sufficiently many faucets defines a sub-network, called the main network, which is the focus of the design analysis. The complement of the main network, that is the set of all segments and nodes downstream of the main network is discarded from the analysis. The dimensioning of the secondary parts, which are not included in the main network, seems to be left to the know-how of the technicians in charge of the physical installation of the network. This approach leaves a crucial question in the dark: how can it be ensured that an adequate service will be provided to users when the secondary networks are left in the blue? There seems to be an unwarranted rule that a guaranteed minimum pressure at the nodes where the secondary parts are connected to the main network allows the dimensioning to be easily completed. A second thorny question is how to deal with the case of a user faucet connected directly to the main network. It is not the purpose of this presentation to review the solution methods that are possibly used here and there; it should simply be noted that the two above-mentioned problems are automatically supported and solved with the NeatWork approach.

To illustrate the differences, we have treated a real example [6] using both stochastic and deterministic approaches. The report will be available online very soon.