Discussion of "Reliability as a Tool for Hydraulic Network Planning," by Rudy Gargano and Domenico Pianese

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The authors should be congratulated for presenting a thought provoking paper. Reliability analysis of a water distribution system (WDS) has been an area of active research for water supply engineers during the last decade and a half. It has been more or less accepted by the researchers that reliability analysis should be used as a tool and design aid while planning a WDS.

The authors have presented another simulation-based methodology for the estimation of hydraulic and so-called overall reliability index of a WDS. The present discussion is aimed at highlighting the basic philosophy of reliability based WDS planning and the areas that need more focus so that it can be accepted by the practicing engineers for its incorporation in practical design.

The basic goal of planning a WDS is so that the network will adequately serve its intended purposes. The effective planning of a WDS can only be achieved with due consideration to the safe quality of drinking water, in addition to adequate quantity at desired pressure. From the water supply scheme point of view, the reliability would be a measure of supplying desired quality of water in required quantities at desired residual pressures at the demand nodes for the entire design period.

Recent studies have shown the negative impacts of components (pipelines, storage structures, etc.) and hydraulics (mixing, water age, residence time, etc.) of the network, on the water quality (Clark et al. 1993; Boulos et al. 1996; Grayman et al. 1996; Gauthier et al. 2000). The water quality models such as EPANET (Rossman 1994) are based on the hydraulics of the network. In spite of close coordination between the water quality and the hydraulics of flow, the reliability computations for water quality and hydraulics are carried out in isolation. It would be a job half done if the hydraulic planners of the distribution system ignore the water quality aspect. A network may ensure the supply of adequate water at various demand nodes but may fail in supplying the same of desired quality. Thus, in the writers' opinion, the overall reliability index computed for hydraulic planning of the WDN should include the reliability of water quality at the consumer's tap.

The second part of the present discussion is related to the methodology presented by the authors. The authors highlighted that the suggested methodology will help in ensuring adequate design and also identify the repair works to be carried out on existing systems. However, the authors seem to have missed their objectives of linking reliability with effective planning, adequate design, and the identification of the repair works of an existing WDN. For augmentation of existing networks, the capacity-weighted reliability surface provides better guidelines (Sue et al. 1993; Kansal 1996).

The small WDS considered by the authors in the case study, does not seem to be adequately designed and planned as the overall reliability index of the nodes closer to the source is very low (refer to column 2 of Table 4) despite high mechanical availability. Also, the writers disagree with the inference deduced by the author that the almost negligible difference between the values of $HRI^{(0)}$ and ORI is due to the small size of the WDS. The small difference is definitely because of high component availability values. The same applies to the statement that the events such as link, pipe, and valve failure have small influences on overall system reliability. In developing countries where the pipes and pumps are subject to frequent breakdowns and have low availability values, such assumptions do not apply. Under such circumstances, even the assumption of only one component failure at a time cannot be justified and the simulations required for assessment of reliability indices will be very high. Thus, such inferences are not general but are specific to the case study presented by the authors.

The writers would like to suggest the following additions for the effective hydraulic planning of WDSs:

- The abundance of valid methodologies available in the field of topological and hydraulic reliability of WDSs can allow the researchers to focus more on issues related to estimation of component availability. A better coordination between the researchers and field engineers will be well worth the effort and a step towards implementation of reliability tools by the practioners.
- The water quality reliability measures are the best representative of overall reliability. Further research should be carried out to study the impact of pipe and other component failures on water quality since water age (or residence time in various components of the distribution system) and the residual concentration of disinfectant get affected by such failures. Issues like disinfectant types, their effects on water quality and suitability for specific water supply schemes (source, treatment technologies and state of distribution system) should occupy the forefront in the millennium for environment.

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"Closure to Reliability as Tool for Hydraulic Network Planning" by Rudy Gargano and Domenico Pianese

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The writers would like to thank the discussers who, with their very precise and pertinent observations, will enable the writers to better define certain aspects of the methodology proposed in their paper.

The writers fully agree with the discussers that, in principle, the study of the overall reliability of a water distribution system should include the analysis of the capacity of the hydraulic system to supply the consumer demand not only with the adequate residual pressure, but also with the appropriate quality characteristics. Nevertheless, the complexity that is involved in the study of each of the aforementioned aspects led the writers to limit themselves, for the moment, to only one type of reliability, which is nonetheless able to take into account not only the random variability of the customer water demand (hydraulic reliability), but also the working state of the electromechanic components (mechanical reliability), which is also random. In this regard, it should be observed that: (1) notwithstanding the very modest dimensions of the network examined in this paper, the hydraulic and mechanical reliability study alone, using a simulation based methodology, required the analysis of 156,000 different possible working conditions of the network and (2) there are still few models in the technical literature that are capable of analyzing the hydraulic and mechanical reliability together (e.g. Fujwara and Ganeshrajah 1993; Gupta and Bhave 1994, 1996). In any case, it is the opinion of the writers that the available models are not capable of examining both of the aforementioned aspects of the system reliability in an exhaustive manner.

The second writer, considering the opportunity to also take into consideration the reliability related to the quality of the water being distributed, has already undertaken a series of studies in the last few years related to this subject, focusing for the moment on the modeling of the alteration processes that the water is subject to during its course between the introduction points and the distribution points (Pianese et al. 1995; 1997a,b; Pirozzi et al. 2000). The influence of the quality characteristics of the water distributed on the total reliability of the system is currently the subject of study, and is the theme of a work that is in the process of completion.

Finally, concerning the first part of the discussion, the writers agree with the discussers that more effort should certainly be put forth both to attain a deeper knowledge of the single aspects that make up the overall reliability of a distribution network and to formulate models capable of making a comprehensive evaluation of the reliability.

With regard to the second observation, the writers recognize that in the paper they did not dwell on the illustration of the possible technical solutions that could be adapted to increment the comprehensive reliability of the network in question. This aspect was purposefully omitted in the interest of brevity, in order to focus the attention of the readers on the main goal of the proposed methodology which is that of identifying the points in the distribution network most vulnerable to the risk of water shortages and to furnish an objective evaluation of the reliability for these points. In fact, the proposed methodology, through local reliability indices, provides the possibility to identify the areas in the network that actually require structural repairs or modifications. Furthermore, the results of the analysis performed for each structural working condition allow us to identify the system components that, when not in working order, can cause a notable reduction in the hydraulic performance of the system and need to be either substituted or upgraded, as appropriate.

The writers are sorry that they were not able to read the publications regarding the *capacity-weighted reliability surface* referred to by the discussers. However, the writers point out that the first reference that was cited was not in the bibliography attached to the discussion paper, and that the second bibliographic reference is not easy to obtain.

In regards to the simple study case in the paper, the writers point out that the network was purposefully conceived with some weak points in order to immediately bring to light the capacity of the proposed methodology to identify the less reliable nodes of the distribution system.

In relation to the availability values used in the paper, which were estimated for each conduit based on a MTTF calculated with Eqs. (13) and (14) and a MTTR=1 day, it should be pointed out that these values are in accordance with the available reports and data regarding the times for conduit breaks and maintenance work for distribution networks in several North American and European cities (Gargano and Pianese 1998; Gargano 1999).

It is obvious, therefore, that the availability values in question are overestimated for the reality of aqueducts in developing countries or aqueducts under harsh environmental conditions (Goulter and Coals 1986). However, the writers recognize that, generally speaking, the difference between the ORI and $\mathrm{HRI}^{(0)}$ indices can be justified not only by the high values of availability but also by the size of the network. More precisely, from Eqs. (9) and (11), the difference may be expressed as

$$\mathrm{ORI}-\mathrm{HRI}^{(0)}=\mathrm{HRI}^{(0)}\left\{A_{\mathrm{tot}}\left[1+\sum_{i=1}^{R}\frac{\mathrm{HRI}^{(i)}}{\mathrm{HRI}^{(0)}}\frac{U_i}{A_i}+\sum_{i=1}^{R-1}\sum_{l=i+1}^{R}\frac{\mathrm{HRI}^{(i)}}{\mathrm{HRI}^{(0)}}\frac{U_iU_l}{A_iA_l}+\cdots\right]-1\right\}$$

where the factor A_{tot} decreases with R (number of the components of a network), whereas the factor in the square brackets increases with R.

Furthermore, the writers, sharing the perplexity already expressed some time ago by one of the discussers (Kumar and Kansal 1995), hold that in order to perform a reliability study of a distribution system in a developing country it is necessary to consider the specific conditions under which that system has to operate. To this end, the writers once again point out that their proposed methodology allows for the study of reliability of future or existing hydraulic systems in developing countries where lower standards of service and water distribution may be accepted. With this scope in mind, it is sufficient to appropriately choose the threshold values hpi_j and $\mathrm{hpi}_{\mathrm{net}}$ with which to evaluate the reliability of the distribution system.

The discussion remains open regarding the value to attribute to hpi_j and hpi_{net} in relation to the socio-economic conditions in which the network is inserted.

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