Discussion of "Energy Metrics for Water Distribution System Assessment: Case Study of the Toronto Network" by Rebecca Dziedzic and Bryan W. Karney. DOI: 10.1061/(ASCE)WR.1943-5452.0000555.

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The paper under discussion presents a metric that allows auditing the energy performance of pressurized water networks. This same metric (except for the period used to perform the audit) was already presented by the discussers in this journal (Cabrera et al., 2010). In our opinion, this is a minor difference from a conceptual point of view; while in our proposal the integration was extended to longer periods (days or years) to gain a general understanding of the issue, the paper under discussion uses shorter periods of time similar to those used to analyze network behavior with extended period simulation. The increased time resolution allows a greater depth in the assessment as well as the development and comparison of different scenarios (e.g. winter vs. summer).

The value of energy simulation in extended period lies in understanding the operational advantages at the expense of missing the greater picture. Both time scales are, as a matter of fact, complementary and supported by the same equations. However, the metric is identical and therefore we cannot share the statement that the authors make referred to our work: "Although

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these indicators can be used to assess modeled improvements to the systems, they do not reveal where and which types of modifications are most beneficial. Although the forms of energy use are distinguished, the system is largely seen as a black box".

This statement seems to undermine the usefulness of the indicators defined back in 2010 (Cabrera et al., 2010); on the contrary, the information provided by these earlier indicators allows synthesizing the behavior of the system, a piece of relevant information not obtainable from the extended period simulation. For instance, the indicator addressing the energy loss linked to leakage (I_4) includes both the energy embedded in leaks as well as the additional friction loss energy created by the increased flow rates resulting from leakage. This second component, which may be relevant in high-leakage / high- flow velocity networks, is not considered in the paper under discussion, stressing the importance of a broader view of the problem as a complementary strategy.

The case study presented in the paper (the energy analysis for the Toronto network) reinforces this idea. Given the hourly variation of the emission rate (CO_{2e}/kWh), following its time evolution allows a precise calculation of GHG due to energy inefficiencies. However, the discussers were also able to relate leakage and emissions in a simple case study (Cabrera et al., 2009). In that occasion, where longer periods were used, the annual average rate of the emission factor was used for the estimations.

Leaving aside time resolution, the proposal from the authors (and therefore, from the discussers as well) presents two main obstacles: the availability of the network model and the potential complexity of the calculations (at least when working with EPANET, as certain programming with its Toolkit is necessary; a problem which may not exist using commercial solutions like WaterGEMS, better suited for energy calculations). In any case, the detailed analysis requires a significant effort. Are the benefits worth such effort? The answer to this question lies in performing a diagnosis (Cabrera et al., 2014). If the result of this diagnosis shows that the energy efficiency is poor and a much better value can be achieved, the results justify the effort of a deeper analysis regardless of the time period used. This previous diagnosis can be obtained from the demands and the topography of the network, and can be achieved in an hour using a tool like EAGLE, developed by the discussers (ITA, 2015).

In addition to the previous considerations, we believe that some concepts linked to Figure 1 and Equation 3 in the paper under discussion need some clarification. The presence of a leak does not justify a steep descent in piezometric head as shown in Figure 1. This type of discontinuities can only be originated by hydraulic elements present in a pipe (e.g. pumps or valves) that decouple a point into the upstream and downstream values finally represented. The correct equivalent of a leak is a pressure-driven demand node. It is also incorrect to represent as a step (as Figure 1 does) the energy lost embebdded in leaks, as this value is proportional to the product of head and flow rate and it is incorrect to solely associate it to the first factor. Only in the case of a constant flow rate (prevented here by the leak itself) energy and head can be directly linked. These minor mistakes were not present in previous papers from the authors (Colombo and Karney, 2002), in which the piezometric head line is correctly represented. The attached version of Figure 1 amends these innacuracies.

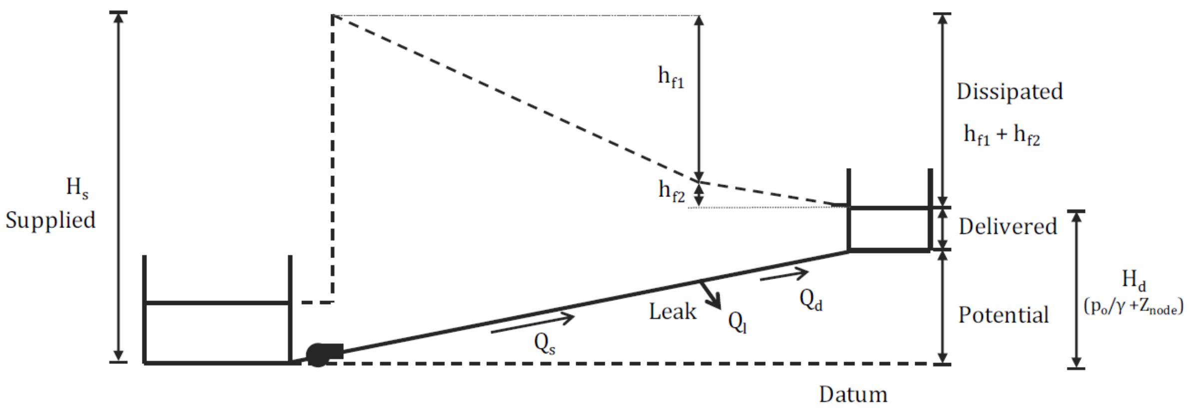

Fig. 1. Schematic representation of a simple system, including the main energy concepts.

It is also convenient to bring attention to the coincidence in the metrics (exceptuating the timeframe). Taking into account that the energy loss due to leaks (mentioned above) can be expressed as the embedded energy plus the additional friction energy, and starting with Equation 3 in the discussed paper:

$$\sum \mathrm{E}_{\mathrm{supplied}} = \sum \mathrm{E}_{\mathrm{dissipated}} + \sum \mathrm{E}_{\mathrm{lost}} + \sum \mathrm{E}_{\mathrm{potential}} + \sum \mathrm{E}_{\mathrm{delivered}} \qquad (1)$$

This same balance can be expressed in energy per time unit (i.e. power) as a function of the variables included in Figure 1; if we group the potential and the delivered energies (thus obtaining what was defined in Cabrera et al., 2014 as "required energy", E_{uo}) the balance can be expressed as:

$$\underbrace{\gamma Q_s H_s}_{supplied} = \underbrace{\gamma\left(Q_s h_{f1} + Q_d h_{f2}\right)}_{dissipated} + \underbrace{\gamma Q_l (H_s - h_{f1})}_{lost} + \underbrace{\gamma Q_d H_d}_{\substack{potential \\ +delivered}} \qquad (2)$$

Where h_{f1} y h_{f2} are the friction loss values upstream and downstream from the valve; Q_l is the leaked volume and H_d, the delivered head, a combination of the node elevation Z_{node}, and the required pressure head (p_o/γ).

The fulfillment of balance (2) is evident. Just by recalling that:

$$Q_s = Q_d + Q_l \qquad (3)$$

$$H_s = h_{f1} + h_{f2} + H_d \qquad (4)$$

The energy lost due to leaks can be obtained from the sum of the embedded energy (in the discussed paper, energy lost):

$$E_{lost\ (embeded)} = \gamma\ Q_l (H_s - h_{f1}) \qquad (5)$$

and the additional friction energy which, suposing friction to be proportional to the square of flow rate with a constant f factor, results in:

$$E_{lost\ (friction)} = \gamma h_{f1}\left[Q_s - Q_d\left(\frac{Q_d}{Q_s}\right)^2\right] \tag{6}$$

Rendering a total energy lost due to leaks equal to:

$$E_{lost(total)} = \gamma\left[Q_l H_s + Q_d h_{f1}\left[1 - \left(\frac{Q_d}{Q_s}\right)^2\right]\right] \tag{7}$$

which will obviously be zero if $Q_l = 0$.

Using the previous expresions, Equation 1 changes from its qualitative nature into a quantitative one:

$$\gamma Q_s H_s = \gamma(Q_s h_{f1} + Q_d h_{f2}) + \gamma\left[Q_l H_s + Q_d h_{f1}\left[1 - \left(\frac{Q_d}{Q_s}\right)^2\right]\right] + \gamma Q_d H_d \tag{8}$$

An expression which is equivalent to the one previously established by the discussers (Cabrera et al., 2010). In summary, identical concepts that have been structured differently to reach the same conclusions. The only issue missed by the authors is the important concept of topographic energy (Cabrera et al. 2014), which is absent from Equation 8 because the energy balance has been applied to a single pipe with no user demand nodes (leaks are not such nodes). The excess of energy delivered to the users at these nodes with respect to the required energy (= $p_o/\gamma + z_{node}$) is the topographic energy. In the absence of demand from the nodes, there is no such energy.

It is also important to remark that Figure 1 points correctly to the datum in the system. This corresponds to the node with the lowest elevation with either a positive or negative flow rate. Otherwise, the energy balance cannot be fullfilled.

Finally a minor typing mistake needs to be addressed in equation 7. Its correct expression should be:

$$E_{potential} = \gamma(z_{node} - z_{datum})Q_{delivered}\, t \tag{9}$$

The preceding comments are intended to clarify and contribute to the comprehension of the presented study, as well as to demonstrate the need to unify terms, metrics and indicators, as these studies will become more relevant with time. As it has been shown, the concepts are the same, and only the specialists will point out subtle differences in the interpretation; differences that will not matter much when the concepts are applied in practice. Therefore, it seems convenient to make progress in such direction, following the success of previous initiatives to unify water loss terminology, concepts and methods around the world (AWWA, 2003).

TOWARDS A NEW TERMINOLOGY, SET OF METRICS, INDICATORS AND PROCEDURES TO PERFORM GLOBAL ENERGY ANALYSES

There is currently a certain abundance of proposals presenting metrics and indicators aimed at improving the energy efficiency of pressurized water transport. The motivations are obvious, and greater efficiency is needed in the use of two strategic resources: water and energy. The first remarkable warnings were given at the end of last century. Dr. Peter Gleick, a visionary, was the first one to highlight the importance of the water-energy nexus in its energy for water side (Gleick, 1994). Shortly afterwards, Burgi noted the changes in water policies (from water development to water management) clearly demonstrated by the objectives of the Bureau of Reclamation (Burgi, 1998). In the dawn of the 21st century, with an unstoppable population growth and the need to minimize the impact of climate change, these trends have been confirmed.

This change requires new indicators and procedures to assess and improve efficiency (EPA, 2008) and the paper under discussion is a relevant example. The first pieces of work on the topic were aimed at improving the efficiency of part of the system, usually pumping stations (e.g., Brion and Mays, 1991 and Walski, 1993); proposing simple indicators linked to the topography of the system (Pelli and Hitz, 2000); or quantifying the energy intensity (kWh/m^3) of the different stages in the cycle (Alegre et al., 2006).

This kind of studies have evolved into thinking globally while acting locally, and the current trends show analyses considering the joint efficiency of the system (Duarte et al., 2009; Boulos and Bros, 2010; Moreno et al., 2010; Walski, 2011; Gay and Sinha, 2012; Cabrera et al., 2013; Pardo et al., 2013; Mamade et al., 2014; Nogueira-Vilanova and Perrella-Balestieri, 2015; Hashemi et al., 2015; Scanlan and Filion, 2015). All of them, in one way or the other, are aimed to capture the global efficiency of the system, with different approaches that should be unified, or at least organized. New work will continue to appear in journals of different scopes, as energy efficiency is a widely shared concern (for instance, the papers quoted in this discussion have been published in eight indexed journal of very diverse nature). It is therefore quite evident that a unifying initiative is necessary at this stage.

FINAL REMARK

The paper under discussion presents remarkable contributions. By integrating the energy equation with reduced time intervals, it produces an extended period energy analysis, with all its attached operational benefits. Additionally, in the presented case study of a large network, the scenario comparison is particularly interesting.

In any case, by comparing this work and the previously published by the discussers, it would seem clear that many of the ideas and concepts, although different in appearance, are in fact similar and coincident as this discussion demonstrates. Given the increasing number of these analyses and as suggested above, it would seem very convenient to provide unified concepts, procedures and indicators.

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