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Discussion of "Revisiting the Resilience Index for Water Distribution Networks" by Gimoon Jeong; Albert Wicaksono; and Doosun Kang. DOI: 10.1061/(ASCE)WR.1943-5452.0000792.

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Discussion on "Revisiting the Resilience Index for Water Distribution Networks" by Gimoon Jeong; Albert Wicaksono; and Doosun Kang. DOI: 10.1061/(ASCE)WR.1943-5452.0000792.

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The discussed article proposes a new resilience index based on the required nodal pressure necessary to reach the standard minimum pressure in the whole system. This interesting reflection leads to this discussion, with three objectives. 1) to emphasize the need to unify terminology and working hypotheses in any energy analysis, 2) to revise the concept of resilience within the framework of climate change, and 3) to propose a calculation of the new nodal pressure excess using a more hydraulic processing method.

Calling surplus head (H_{surp}) (equations 3 and 8) the difference between the piezometric height (H_{total}) and the required height (H_{req}) could lead to errors. In our opinion, surplus (or excess) H_e, should be associated with surplus energy, sometimes non-existent. As the authors define it, there will always be a surplus.

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The discussers believe that, in addition to being key concepts for the alternative calculations of the nodal pressure excess, the concepts of topographic energy and reducible topographic energy (Cabrera et al., 2014), clarify this matter. Topographic energy ΔH_t is the difference, when only the necessary energy is delivered (with no surplus, Figure 16.a), between the piezometric height H and the minimum height required by users H_{uo} (= z + p_o/γ = z+ΔH_o), with p_o being the minimum pressure to be supplied according to standards and z the height of the node. In Figure 16.a, the piezometric and topographic lines coincide. If there is an energy surplus (more energy than necessary is delivered to the least favourable node), these lines are different (Figure 16.b). It is called topographic because it depends on the topography and, although to a lesser extent, on friction. The concept of reducible topographic energy $\Delta H_t'$ arises when the least favourable point is not at the end of the system. Located, for instance, in the middle (Figures 16 and 17 b) or at the beginning (Figure 19), from this point on, part of that energy $\Delta H_t - \Delta H_t'$ can be reduced (e.g. by means of a PRV, Pressure Reducing Valve). Therefore, that difference is also an excess of energy that does not exist when the least favourable point is at the end of the system (Figure 17a or 18).

Fig. 16. Proposed terminology: Ideal system, no surplus. (a) and real system with surplus (b)

Taking these concepts into account, equation 3 leads to:

$$H = z + \frac{p_o}{\gamma} + \Delta H_t = H_{uo} + \Delta H_t \ \ (without\ surplus, Figure\ 16.a)$$
$$H = z + \frac{p_o}{\gamma} + \Delta H_t + \Delta H_e = H_{uo} + \Delta H_t + \Delta H_e \ (with\ surplus, Figure\ 16.b) \qquad (9)$$

For the sake of clarity, all heads referring to the horizontal axis (z, H_{uo} and H) are not preceded by Δ. That is not, indeed, the case (Figure 16) of ΔH_o, ΔH_t, $\Delta H_t'$ and ΔH_e. Taking all into account, equation (8) can be rewritten as:

$$H_{surp}(conventional) = H - H_{uo} \qquad (10)$$

$$H_{surp}(proposed) = \Delta H_e + \Delta H_t'$$

Other minor differences (minimum pressure standard, $p_o/\gamma = \Delta H_o$, called in the paper, H_{min}, minimum required head, or natural energy, E_n, called E_{source}, or input source), although they do not lead to confusion, it would be convenient to unify them.

Any resilience index is linked to the surplus pressure and is therefore an inefficiency. The analysis starts with the pioneer Resilience Index (RI), Todini (2000), which synthetizes the capability the whole system has to respond to an emergency event. Later, the Modified Resilience Index (MRI), a more local (nodal) index, Jayaram and Srinivasan (2008), is reviewed. From this analysis, a modification of the MRI, the MMRI (revised MRI), is proposed. Instead of using $H - H_{uo}$ as nodal pressure surplus, $\Delta H_e + \Delta H_t'$ is used to guarantee that H_{uo} will be reached in all nodes.

All three indices have advantages and disadvantages. The RI, weighting the relevance of the nodes with their demand, offers a global vision of the network response capability, without reporting possible faults in some nodes. The MRI, with a very simple calculation, provides a local nodal resilience. However, as H_{uo} is not imposed in the whole system, some results can be wrong. Finally, the revised MRI (MMRI) is the most conservative (Figure 5) because the adopted excess of pressure takes into account that H_{uo} is always reached. The calculation effort is higher, although a hydraulic analysis does make it easier.

In any case, we wonder if it would make sense to refine the MRI calculation using a demand driven approach simulation (instead of the pressure driven one) that furthermore ignores the existence of leaks. These two drawbacks, although not mentioned in the paper, are very important to correctly model pressure networks and have been recently (Creaco et al., 2016) analyzed in depth. If the final goal of this work is to calculate MRI correctly, we are missing a sensibility analysis to assess the impact of any potential inaccuracy, i.e. the one explored in the discussed paper and the two pointed out by Creaco et al. (2006).

Finally, it is worth rethinking the concept of resilience, as it means designing networks with pressures higher than strictly necessary. It is therefore worth considering a new transient resilience. This concept means equalizing the nodal pressure to the minimum required values, whilst at the same time providing complementary responses that should supply the extra demand for energy during incidents. With flexible energy sources (such as pumps, equipped with variable frequency drivers), the key is to change from permanent resilience to transient resilience.

The article, claiming that network analysis periods are long, ignores tanks in the energy balance. This is correct, although inconsistent with the rest of the paper, which refers to short periods. For hourly intervals, the tank's energy contribution can account for up to 10% of the total (Cabrera at al., 2010). As the MMRI is based on hourly periods, there is a clear inconsistency. The authors also state (equation 2) that losses through leaks are decoupled from friction losses. This is not true however. Leaks, in addition to the energy embedded in them, increase the flow rates, creating additional friction. Whichever the case, these simplifications do not affect the analysed example, although in real networks this cannot be the case.

A considerable part of the paper is devoted to the calculation of the Dependent Minimum Required Head, the MMRI basis. The discussers propose an alternative method, based on the hydraulic lines, which is easier to understand. Figure 17 synthetizes four Figures (2, 3, 4 and 5), dealing with this calculation in the paper. It is more complete, because in addition to the paper's hydraulic gradient assumption j_1, (without surplus), a new smaller loss j_2 (five times less than j_1), is assumed, leading to an energy surplus. It can be seen that the lower the friction is, the lower the gap MRI – MMRI is.

The sub-indices differentiate both assumptions, each with the three energy lines (z, H_{uo}, and H). The first two, independent from friction, do not change, whereas the piezometric lines are different because the surplus differentiates them. On the other hand, the difference between the topographic and reducible topographic lines gives the additional $\Delta H_t'$. The reducible topographic line only makes sense when the least favourable point is not (see the secondary branch) at the end of the system. In this case it is node B (shared).

Fig. 17. MRI and MMRI alternative calculation. Main branch (a) Secondary branch (b)

As far as possible, the calculations in the paper, focused on showing the differences between MRI and MMRI, are replicated. Differences are exaggerated by increasing friction in pipes and the terrain's irregularity. And so, in the uphill network (Figure 18) the pipeline gradient is over 12%, an uncommon value in cities. On the other hand, the network has unacceptable friction levels. For example, during peak hours, in pipeline P1 the unitary loss is 30 m/km, with a head loss of 5.64 m in 188 m. Therefore, the pressure standard of 15 m is not met in N1 (downhill network, Figure 19). Some minor errors and missing data are observed as well. For example, the sum of the modulation coefficients is 24.1, the working pressure is not specified (supposedly 15 m, as in the previous example). Furthermore, nodal MRI and MMRI calculations (with the results depicted in Figures 8 to 13), need some clarification. They appear to correspond to simple average hourly values.

With the hydraulic procedure stated, and with the aforementioned suppositions, similar results are obtained. In the uphill network, for MRI, the average difference between the discusser's results and those of the authors is, 0.06, being slightly higher with MMRI (0.2). These uncompensated errors (always in the same direction) are higher in the nodes with a lower H_{uo}.

As a counterpoint to the descriptive appraisal, the results for the extreme cases, the uphill network (maximum difference between MRI and MMRI) and the downhill network (same values for both indexes), are physically interpreted. Figures 18 and 19 show the values (at peak hour) used for this interpretation. Both figures represent the outer pipes of the network (Figures 18 and 19). In Figure 18, the excess pressure of 2.69 m at N_{25} differentiates the topographic (in this case, the reducible topographic line does not make sense) and piezometric height lines. It is a constant value at all nodes (that will increase in off-peak hours), equal to the MMRI numerator in that time interval.

Fig. 18. Energy lines (uphill network)

The downhill network can be seen in Figure 19. In this case, instead of an excess of energy, there is a fault because in N1 the energy requirement (H_{uo}) is not satisfied. The excess comes from $\Delta H_t'$ and both indexes, MRI and MMRI, are equal because all topographic energy is reducible.

Fig. 19. Energy lines (downhill network)

The authors have made a considerable contribution to a better knowledge of energy performances in networks. But, taking into account that different resilience indexes have been proposed in scientific literature in recent years (Creaco et al., 2016), some important questions arise. First, which form of resilience index better reflects the performance of the network in critical scenarios? Second, which procedure should be used to accurately determine its value? And last but not least, how much energy can be saved per year if we move from permanent to transient resilient networks? These analyses are far beyond the scope of a short discussion paper, which only underscores the relevance of hydraulic analyses in these studies and the need to unify criteria and terminology.

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Figure 16

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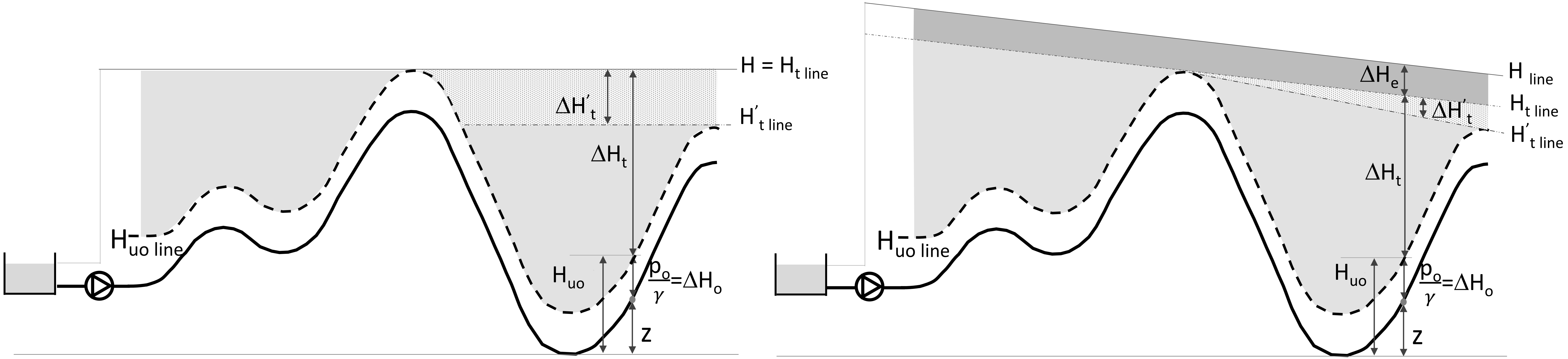

Figure 17a

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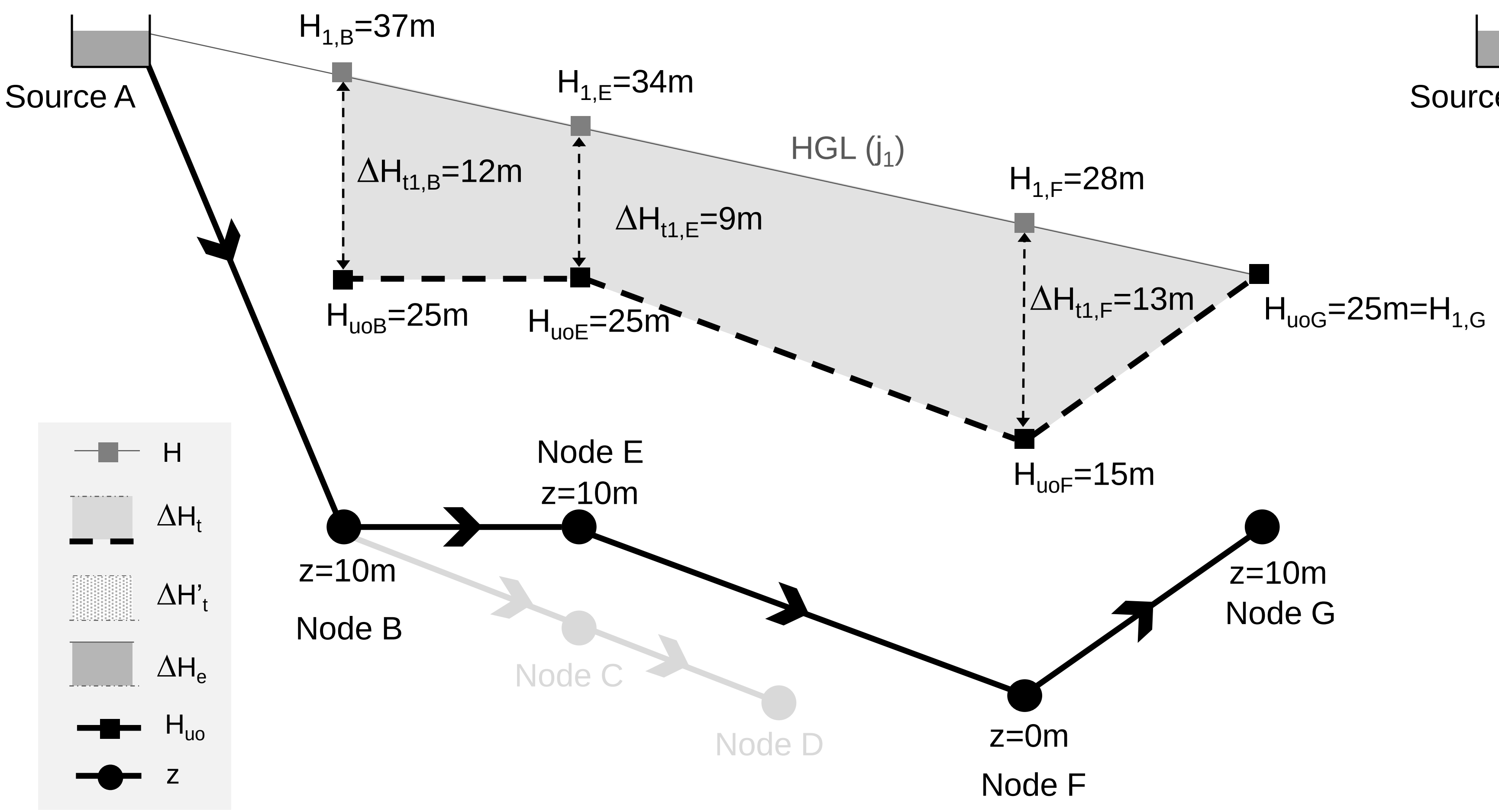
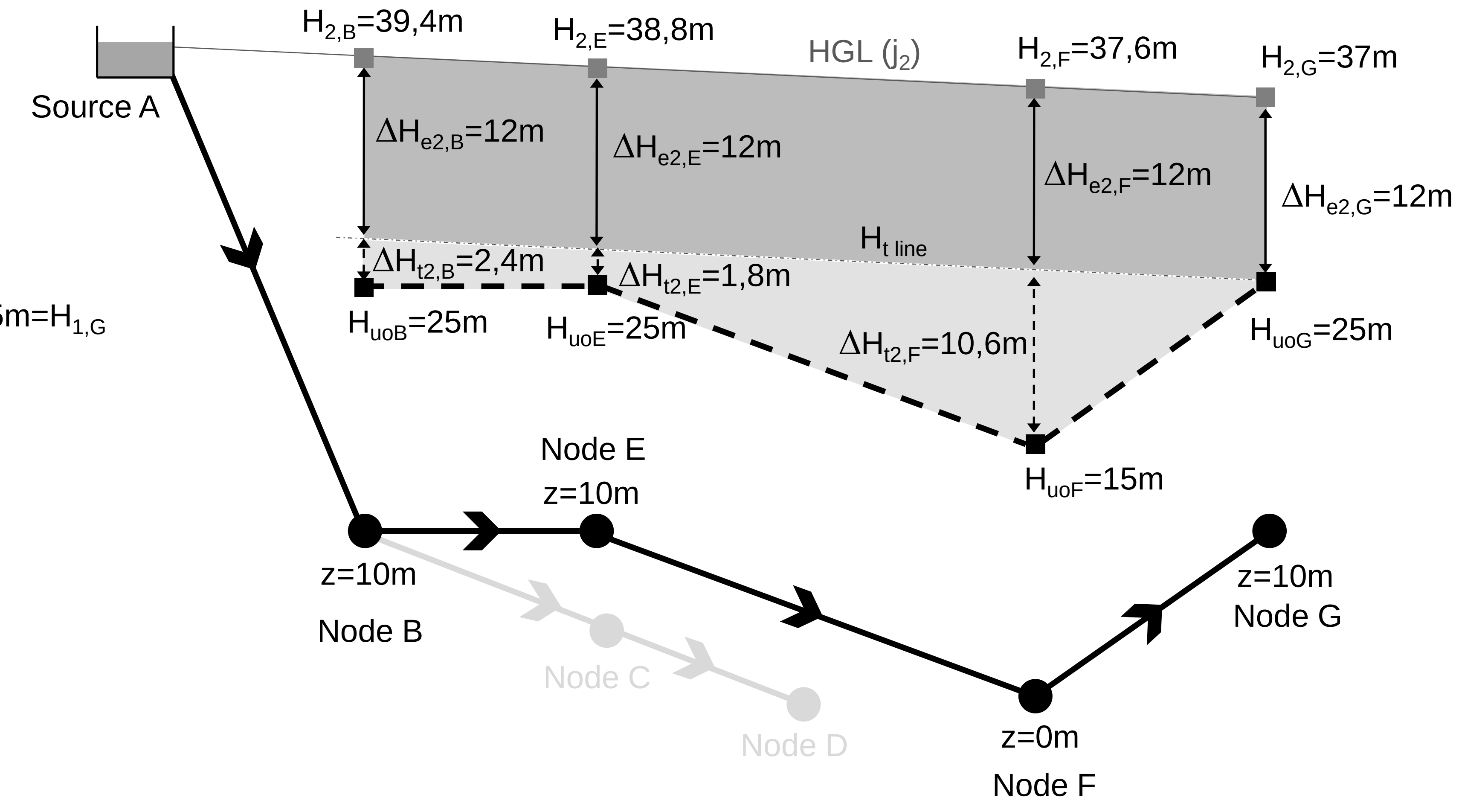
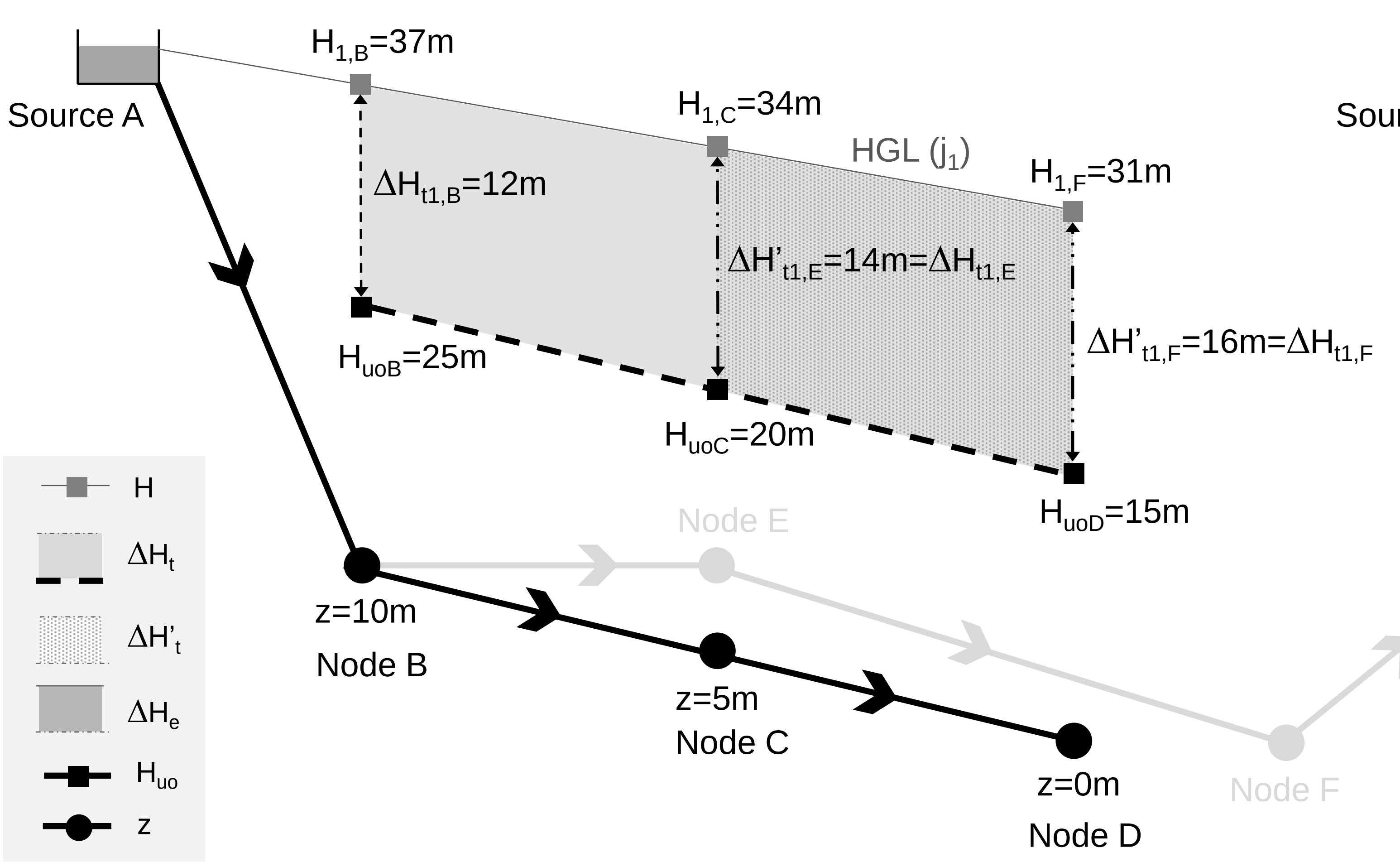
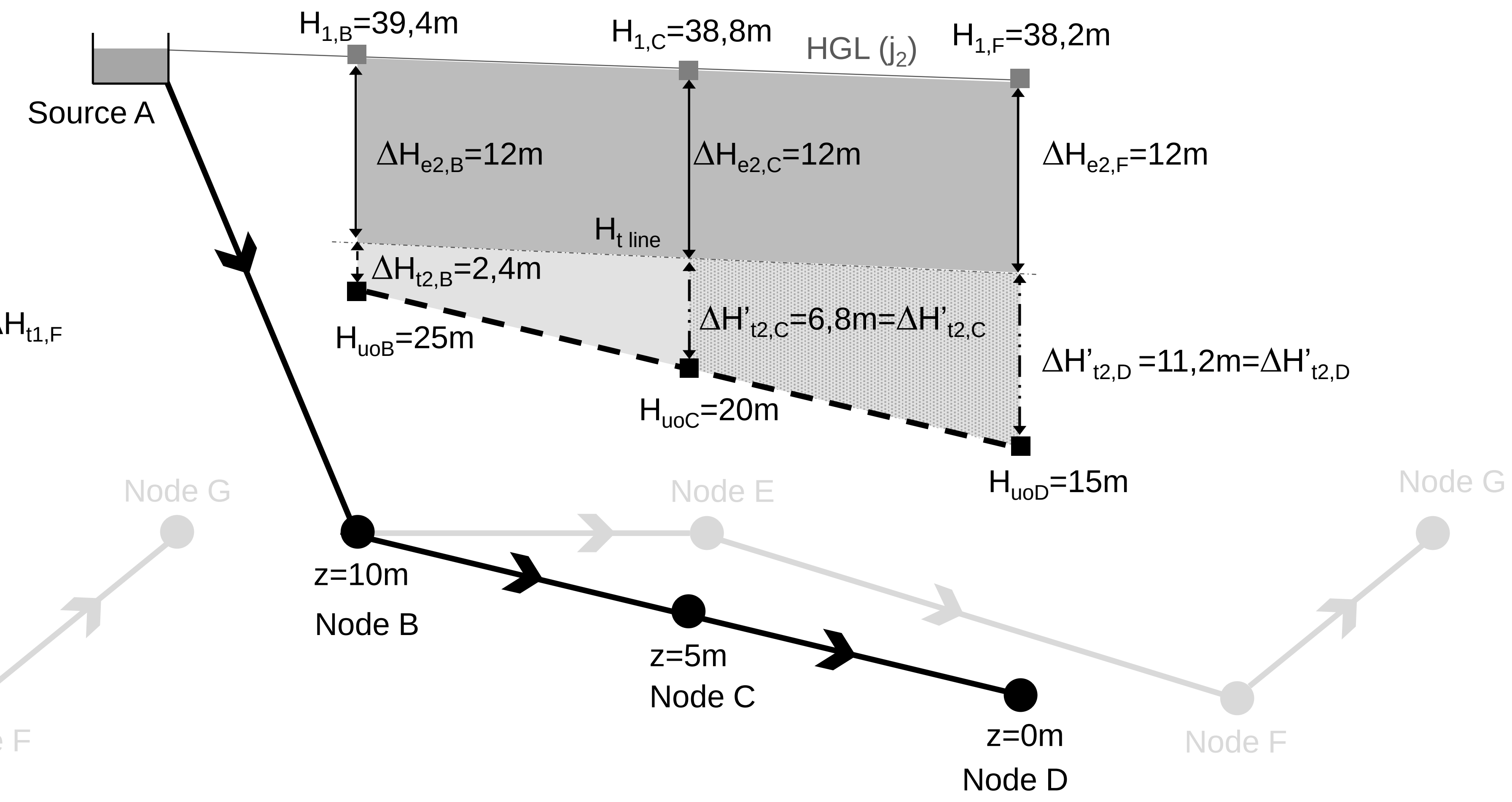




	H	H_{uo}	ΔH_t	$\Delta H'_t$	$\Delta H_e = H-\Delta H_t-H_{uo}$	MRI= $(H-H_{uo})/H_{uo}$	MMRI = $(\Delta H_e+\Delta H'_t)/H_{uo}$
B	37	25	12	0	0	12/25=0,48	0/25=0
E	34	25	9	0	0	9/25=0,36	0/25 =0
F	28	15	13	0	0	13/15=0,87	0/15=0
G	25	25	0	0	0	0/25= 0	0/25 =0

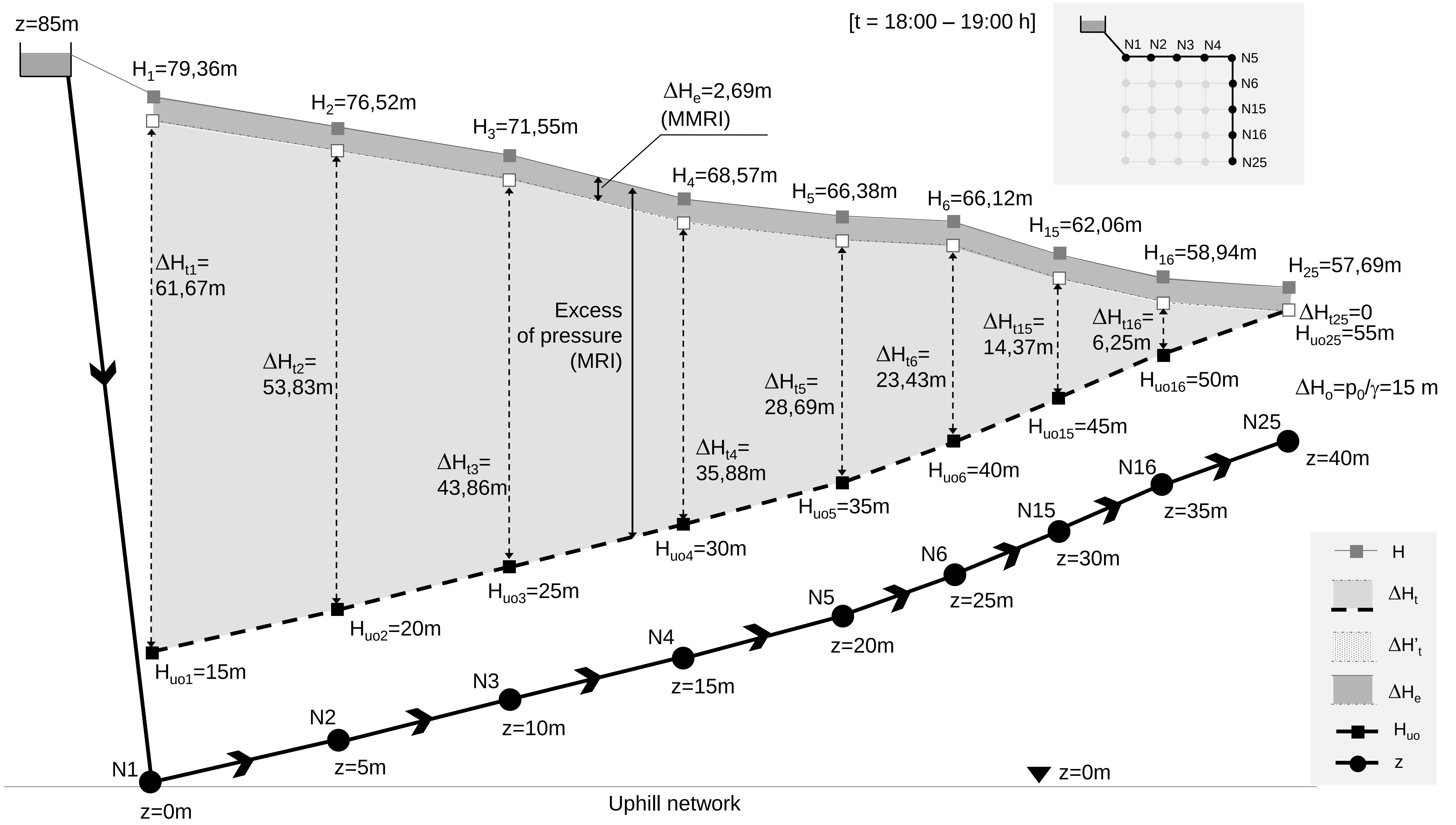
	H	H_{uo}	ΔH_t	$\Delta H'_t$	$\Delta H_e = H-\Delta H_t-H_{uo}$	MRI= $(H-H_{uo})/H_{uo}$	MMRI = $(\Delta H_e+\Delta H'_t)/H_{uo}$
B	39,4	25	2,4	0	12	14,4/25=0,58	12/25=0,48
E	38,8	25	1,8	0	12	13,8/25=0,55	12/25=0,48
F	37,6	15	10,6	0	12	22,6/15=1,51	12/15=0,8
G	37	25	0	0	12	12/25=0,48	12/25=0,48





	H	H_{uo}	ΔH_t	$\Delta H'_t$	ΔH_e = H-ΔH_t-H_{uo}	MRI= (H-H_{uo})/H_{uo}	MMRI = (ΔH_e+$\Delta H'_t$) /H_{uo}
B	37	25	12	0	0	12/25=0,48	0/25=0
C	34	20	14	14	0	14/20=0,70	14/20=0,70
D	31	15	16	16	0	16/15= 1,07	16/15 =1,07

	H	H_{uo}	ΔH_t	$\Delta H'_t$	ΔH_e = H-ΔH_t-H_{uo}	MRI= (H-H_{uo})/H_{uo}	MMRI = (ΔH_e+$\Delta H'_t$) /H_{uo}
B	39,4	25	2,4	0	12	14,4/25=0,58	12/25=0,48
E	38,8	20	6,8	6,8	12	18,8/20=0,94	18,8/20=0,94
G	38,2	15	11,2	11,2	12	23,2/15=1,56	23,2/15=1,56



z=85m
[t = 18:00 – 19:00 h]
N1 N2 N3 N4 N5 N6 N15 N16 N25
H1=79,36m
H2=76,52m
H3=71,55m
ΔHe=2,69m (MMRI)
H4=68,57m
H5=66,38m
H6=66,12m
H15=62,06m
H16=58,94m
H25=57,69m
ΔHt1= 61,67m
ΔHt2= 53,83m
ΔHt3= 43,86m
Excess of pressure (MRI)
ΔHt4= 35,88m
ΔHt5= 28,69m
ΔHt6= 23,43m
ΔHt15= 14,37m
ΔHt16= 6,25m
ΔHt25=0
Huo25=55m
Huo16=50m
ΔHo=p0/γ=15 m
Huo15=45m
Huo6=40m
Huo5=35m
Huo4=30m
Huo3=25m
Huo2=20m
Huo1=15m
N25 z=40m
N16 z=35m
N15 z=30m
N6 z=25m
N5 z=20m
N4 z=15m
N3 z=10m
N2 z=5m
N1 z=0m
z=0m
Uphill network
H
ΔHt
ΔH't
ΔHe
Huo
z

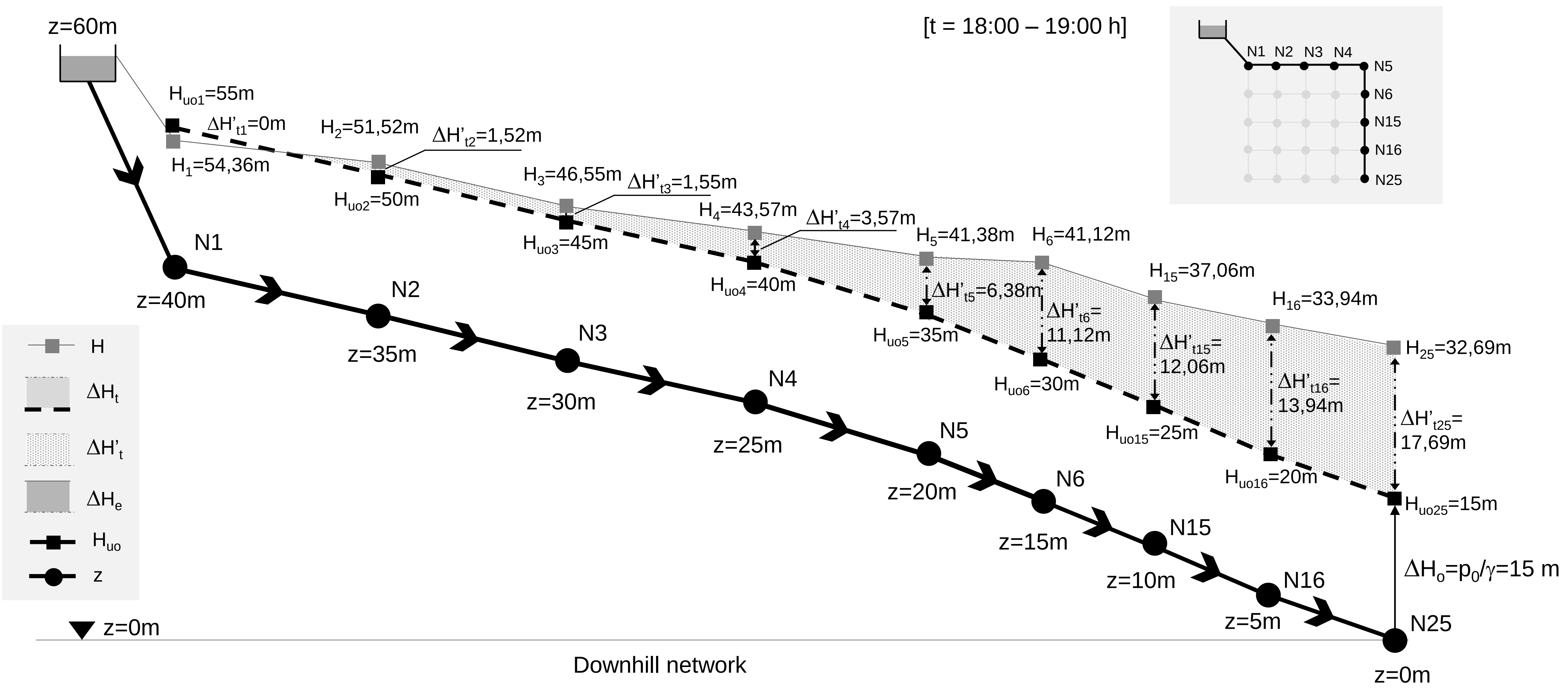

z=60m
[t = 18:00 – 19:00 h]
N1 N2 N3 N4 N5 N6 N15 N16 N25
H_uo1=55m
ΔH'_t1=0m
H_1=54,36m
H_2=51,52m
ΔH'_t2=1,52m
H_uo2=50m
H_3=46,55m
ΔH'_t3=1,55m
H_uo3=45m
H_4=43,57m
ΔH'_t4=3,57m
H_uo4=40m
H_5=41,38m
H_6=41,12m
ΔH'_t5=6,38m
H_uo5=35m
ΔH'_t6= 11,12m
H_uo6=30m
H_15=37,06m
ΔH'_t15= 12,06m
H_uo15=25m
H_16=33,94m
ΔH'_t16= 13,94m
H_uo16=20m
H_25=32,69m
ΔH'_t25= 17,69m
H_uo25=15m
ΔH_o=p_0/γ=15 m
z=40m
z=35m
z=30m
z=25m
z=20m
z=15m
z=10m
z=5m
z=0m
H
ΔH_t
ΔH'_t
ΔH_e
H_uo
z
z=0m
Downhill network

Figure Captions

Fig. 16. Proposed terminology: Ideal system, no surplus. (a) and real system with surplus (b)

Fig. 17. MRI and MMRI alternative calculation. Main branch (a) Secondary branch (b)

Fig. 18. Energy lines (uphill network)

Fig. 19. Energy lines (downhill network)

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To the best of my knowledge the language employed in the text is correct, although no opinion is given about the factual information it contains.

Yours sincerely.

Robin T. Loxley Ward

RT Loxley Ward

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After an analysis of the previous review received, the attached table summarizes the comments and the correspondence actions taken.

Comment	**Action / Answers**
Editor: A review by the associate editor is positive, but authors are requested to address two key comments and provide a response explaining the revisions. In addition, the paper should be carefully proofread by a native English speaker. It is also recommended that the section headings be removed, as these are awkward and not needed in a short Discussion paper.	Below you can find our answers to the associated editor concerns. Furthermore, the paper has been proofread in depth by a native English speaker (the certificate is attached) while section headings have been removed.
Associate Editor: I think that the discussion is technically sound and deserves to be published. However, I would like to make two comments that the Authors should consider before the discussion can be accepted:	Thank you. We have included two new paragraphs addressing both comments in our discussion.
1 - Besides referring to the original index from Todini (2000), the Authors should also mention its upgrade in the pressure driven approach, proposed in the paper Generalized Resilience and Failure Indices for Use with Pressure-Driven Modeling and Leakage". In fact, the upgraded index is more convenient for use when dealing with pressure-driven modeling and capable of including the effect of leakage. In principle, all the energy related indices should now be upgraded to the pressure driven approach.	Indeed, the associated editor is right. However, in such a short discussion paper, we should only focus our assessment on the contents of the discussed paper. We therefore believe performing a state of the art review of the subject in the paper is convenient. In any case, we agree that the advantages of the pressure driven approach versus the demand-driven one should be clearly stated, which in fact has been underlined in the right place (after the MRI and MMRI discussion).
2 - Both the Authors of the original paper and the Authors of the Discussion are developing new formulas for assessing resilience. Though being interesting contributions, none of them showed which form of resilience is able to reflect better the performance of the network in critical scenarios (segment isolation and hydrant activation). Are the new formulas for assessing resilience advantageous compared to the old one? By only analysing the hydraulic grade line, the Authors of the original paper and the Authors of the Discussion do not reply to this fundamental question.	In the discusser's opinion, the authors do not propose a new formula to assess resilience. They analyse the MRI suggested by Jarayam and Srinivasan (2008). They only recommend a more refined procedure to calculate the MRI. In fact, the main contribution of the paper is the comparison between the original MRI and the revised MRI (in our discussion the MRI and the MMRI). From our side, we just underline that resilience, whatever the considered index may be, is ultimately an excess of energy delivered to users, and therefore, in the actual context of climate change we should move on from the current concept of permanent resilience, to transient resilience. In fact, answers to critical scenarios are needed for just some hours (perhaps days) per year. Most of the time (when the system is operating under normal conditions) we are simply wasting energy. In any case, as we fully agree with the associated editor that this is a fundamental question and therefore cannot be either forgotten or skipped, this specific concern has also been included, as a new final remark in the discussion.