Battle of Background Leakage Assessment for Water Networks (BBLAWN)
Water Distribution Systems Analysis Conference 2014
Bari, Italy, July 14-17, 2014 www.water-system.org/wdsa2014
Detailed Problem Description and Rules
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1. Introduction

The Battle of Background Leakage Assessment for Water Networks (BBLAWN) is the fifth in a series of "Battle Competitions" dating back to the Battle of the Water Networks (BWN) in 1985 and more recently the Battle of the Water Sensor Networks (BWSN) in 2006; the Battle of the Water Calibration Networks (BWCN) in 2010 and the Battle of the Water Networks design (BWN-II) in 2012.

The BBLAWN calls for teams/individuals from academia, consulting firms, and utilities to propose a design methodology for reducing water losses due to background leakages and apply it to a real water distribution system. The results of the BBLAWN will be presented at a special session of the upcoming 16th Water Distribution Systems Analysis Conference in Bari, Italy in July 2014 (www.water-system.org/wdsa2014).

It should be emphasized that none of the BBLAWN organizers is taking part in the BBLAWN as participants. The organizer's responsibility is to assemble the methodological approaches and results, make sure that the BBLAWN is objectively assessed, organize the session at the WDSA2014 event, and prepare a manuscript (as warranted) to be submitted to the Journal of Water Resources Planning and Management Division, ASCE, to summarize the outcomes and results of the competition.

The rest of this document describes the BBLAWN competition rules and framework.

2. How to participate

Each participating team/individual must submit on-line, by December 15 2013, an abstract for the WDSA2014 conference that discusses briefly the proposed solution approach (e.g., trial and error with simulation, evolutionary computation, heuristics, etc.). When submitting the abstract (http://www.water-system.org/wdsa2014/?q=content/abstract-submission) the corresponding author must tick the box "Battle of Background Leakage Assessment for Water Networks" – this will identify your team of authors as participants in the BBLAWN. Notifications of accepted/rejected abstracts will be made by January 15, 2014. Each successful team must summarize their final results in a conference paper; these must be uploaded to the WDSA2014 website by May 1, 2014. All conforming designs will be included in the public presentation of summary results at the conference and will be published as part of the conference proceedings. Selected participants will present their results at a special session of the conference.

Authors who wish to submit an abstract before the due date of December 15, 2013 are welcome to do so. The organizers will evaluate abstracts as they are submitted and will notify the authors of acceptance/rejection as soon as possible (upon submission at the conference website please forward a copy of the submitted abstract to the BBLAWN organizers at battlewdsa2014@water-system.org).

Submitted papers describing the final solution from each team should be brief and to the point. It is not necessary to describe the BBLAWN background. To allow efficient and fair assessment of contributed results, papers submitted to the BBLAWN are asked to include the following sections: Abstract; Introduction (brief); Methodology (whether qualitative or quantitative); Summary of design results for the tested network; Discussion of Results; Conclusions; and References.
In addition to the submission of the paper through the conference webpage, participants are requested to email the BBLAWN organizers the conference paper and supporting materials at battlewdsa2014@water-system.org.

Supporting files (www.water-system.org/wdsa2014/?q=content/battle-water-networks) are:
- (i) the file **C-Town_Leaks_04122013.inp** file of the considered network for an Extended Period Simulation (EPS) of 168 hrs containing the network topology, demand patterns, pump curves, data of tanks and so on;
- (ii) the MS-Excel file **Town-C_battle_data_04122013.xlsx** containing the same data of the network in table format; pipe-by-pipe parameters of the leakage model and the Tables reported in this document;
- (iii) the MS-Excel file **BBLAWN-Results.xlsx** where the competitors must report the solution options adopted in the network and the associated cost.

The Discussion of Results section should emphasize the generality of the proposed strategy and the technical reasoning emphasizing benefits of the adopted strategy. Results submitted with incomplete information may be excluded from the competition.

3. Event schedule

Table 1 lists the schedule for the **BBLAWN**.

Table 1. **BBLAWN** schedule

Deadline for submission of abstract	15 December 2013
Notification of acceptance of abstract for the **BBLAWN**	15 January 2014
Final date for upload of submissions	1 May 2014

The competition winner(s) will be declared at the WDSA conference and results will be presented at a special session of the conference.

4. Problem description

The municipality of C-Town is in need of a design project **to meet the minimum pressure for a sufficient service at 20 m and to control background leakages**.
To accomplish this task the city has already commissioned the development of a calibrated hydraulic model of the actual network so as to better evaluate its present state and its future behavior. Therefore, the network model includes the network layout, the demand patterns and the background leakage model parameters. It also contains existing pump and tank characteristics and the controls of pumps and valves referred to tanks.
The existing infrastructure is not able to meet pressure performance targets when future demands are considered. The situation is compounded by excessive background leakage and, thus, **the water utility is interested in minimizing operational, capital costs and background leakages.** The utilities is also concerned about environmental and financial

damage caused by water loss as **the environmental penalty for one cubic meter of water lost is fixed at 2 €.**

4.1 Design Requirements

4.1.1 Costs

The water utility desires a low operational and capital cost solution. In particular, the operational costs are a result of pump operations and background leakages, while capital costs are associated with the pipe and tank material and construction, and any upgrades of the existing pumping stations.

As capital and operational costs occur at different time points during the lifetime of the project, annual costs are provided for the new possible components of the network in the section *Design Options*. These costs take into account the lifetime of each specific component and the discount rate. Consequently, the total cost requiring minimization is the sum of the annual capital costs and of the annual cost of pumping operations and water losses.

To account for the annual cost of pumping operations and water losses, the weekly cost of the pump power and the volume of background leakages have to be computed and multiplied by the number of weeks in a year (52).

4.1.2 System performance under normal operation

The water utility requires that every demand node of the network has water delivered to it with adequate pressure. **Nodes without demand** only have the requirement of a minimum pressure being **above zero**. The minimum pressure required for **nodes with demands** is **20 m**. An additional requirement of the water utility is that at the end of the extended period simulation (1 week) **each tank has to have at least the same volume of water it had at the beginning of the simulation** (note that this initial volume has to be set equal to half the volume of the tank). Moreover, **during normal operation, tanks are not allowed to empty**.

4.2 Design Options

4.2.1 Pipes

Pipe diameter options and costs for the network expansion are given (see MS-Excel file **Town-C_battle_data.xlsx**). The costs shown are inclusive of pipe construction, transport and installation. According to the water utility, pipes can also be placed in parallel to existing pipes. However, as this implies the disruption and reconstruction of pavement roads, the cost of duplicating existing pipes is given by the costs in Table 2, but an additional cost premium of 20% should be added to the values in the Table. The Hazen-Williams coefficient for every diameter is equal to 120.

The background leakages model for pipes is:

$$d_k^{leaks}\left(P_{k,mean}\right) = \begin{cases} \beta_k L_k P_{k,mean}^{\alpha_k} & P_{k,mean} > 0 \\ 0 & P_{k,mean} \le 0 \end{cases} \quad (1)$$

where:

k = subscript of the kth pipe;

$P_{k,mean}$ = model mean pressure along the kth pipe in [m];

d_k^{leaks} = background leakages outflow along the kth pipe in [m^3/sec];
α_k and β_k = model parameters set as in Table 3, in [-] and [m$^{2-\alpha}$/sec];
L_k = length of the kth pipe, in [m].

The modeling approximation allows to lump pipe outflows in (1) in the ending nodes using Eq. (2), where $\mathbf{A}_{np}$ is the network incidence matrix. For the new pipes (parallel or not) β_k is 20% of those reported in Table 3.

$$\mathbf{d}_n^{leaks} = \frac{1}{2}\left|\mathbf{A}_{np}\right|\mathbf{d}_p^{leaks} = \frac{1}{2}\left|\mathbf{A}_{np}\right|\begin{bmatrix} d_1^{leaks} \\ \cdots \\ d_k^{leaks} \\ \cdots \\ d_{n_p}^{leaks} \end{bmatrix} \quad (2)$$

Table 2. Pipe annual costs.

Pipe data		
Diameter [m]	**H-W coeff.**	**Cost [€/yr]**
0.102	**120**	9.97
0.152	**120**	12.1
0.203	**120**	14.49
0.254	**120**	15.55
0.305	**120**	18.28
0.356	**120**	19.94
0.406	**120**	23.26
0.457	**120**	26.65
0.508	**120**	29.58
0.61	**120**	42.8
0.711	**120**	48.12
0.762	**120**	51.11
Diameter [m]	**H-W coeff.**	**Cost [€/yr]**
0.102	**120**	8.31
0.152	**120**	10.1
0.203	**120**	12.1
0.254	**120**	12.96
0.305	**120**	15.22
0.356	**120**	16.62
0.406	**120**	19.41
0.457	**120**	22.2
0.508	**120**	24.66
0.61	**120**	35.69
0.711	**120**	40.08
0.762	**120**	42.6

Table 3. Background leakage model parameters α [-] and β [$m^{2-\alpha}$/sec].

Leakage model parameters		
DMA	α	β
1	0.9	4.00E-08
2	0.9	2.00E-08
3	0.9	1.00E-08
4	0.9	2.00E-08
5	0.9	1.00E-08

4.2.2 Tanks

Because of the increased demands, the water utility is also allowing for the addition of new tanks, but only adjacent to the existing tanks, where the water utility already owns sufficient land. New tanks are assumed to have the same height and bottom elevation as the existing adjacent tanks (because the water utility does not want to introduce new valves to control the system). All new tanks are cylindrical and come in pre-specified standard sizes shown in Table 4, together with associated annualized costs. The construction of non-standard tanks is not considered by the water utility because they are regarded as being too expensive.

Table 4. Tank annual costs.

Tank data	
Volume [m^3]	Cost [€/yr]
500	14020
1000	30640
2000	61210
3750	87460
5000	122420
10000	174930

Note that the annual costs shown in Table 4 already include the connectivity costs to link the new tanks to the network. Therefore, the addition of new tanks can be modeled simply by increasing the tank diameters so that the resulting volume is equal to the existing tank volume plus the new tank volume.

4.2.3 Pumps

Existing pump systems can be upgraded by adding new pumps to the pumping stations in parallel to the existing pumps. No additional pumping stations or boosters can be placed into the network as the water utility does not have any available location for these new components. The maximum pump efficiency is equal to 70% for existing pumps, while new pumps have a maximum efficiency equal to 80%. The pump efficiency curve is given as:

$$\eta = -\frac{4\eta_{max}}{Q_{max}^2} Q^2 + \frac{4\eta_{max}}{Q_{max}} Q$$
$$Q_{max} = \left(\frac{H^{pump}}{r}\right)^{\frac{1}{c}} \qquad (3)$$

where η_{max} = maximum pump efficiency; H, r and c = parameters of the pumps. Eq. (3) represents a parabolic function with the maximum value (η_{max}) at $Q_{max}/2$.

Table 5. Pump annual costs.

Pump data				
Ho_k [m]	r_k [$f(c_k)$]	c_k [-]	η_k [-]	C [€/yr]
70	929	1.36	0.8	4133
90	37512	2.15	0.8	3563
120	86972	2.59	0.8	4339
90	187486	2.41	0.8	3225

4.2.4 Valves

The water utility is considering introducing pressure control valves (PRVs) in the system. The target is to maintain the cost low while reducing the background leakages. The PRV costs are reported in Table 6 and it is assumed that they have the nearest diameter of the corresponding pipe.

The pressure set point on controlled nodes can be variable over time.

It is also possible to close one or more pipes at no cost since one isolation valve is assumed to be already present on each pipe.

Table 6. Pressure Control Valve annual costs.

PRV data	
Diameter [m]	Cost [€/yr]
0.102	**323**
0.152	**529**
0.203	**779**
0.254	**1113**
0.305	**1892**
0.356	**2282**
0.406	**4063**
0.457	**4452**
0.508	**4564**
0.61	**5287**
0.711	**6122**
0.762	**6790**

Throttle Control Valve (TCV) controlled by PLC (e.g. by flow or time) are not allowed since they would require real time prediction of demand which was not commissioned by the C-Town municipality. Moreover, controlling the TCV by time is assumed to be less robust in face of uncertainty on boundary conditions.

4.2.5 Pump controls

The pumps are controlled by water levels in tanks as reported in the *.inp and MS-Excel files since using hydraulic network state is assumed to be more robust in face of uncertainty on boundary conditions. The controls need to be designed also for existing pumps. **It is not possible to install time controlled pumps**

Pumps controller by PLC are not allowed since they would require real time prediction of demand which was not commissioned by the C-Town municipality.

4.2.6 Time step

The municipality requested the use of continuous “hydraulic” controls of any device in the system. However, relevant parameters of the hydraulic simulation and device controls (e.g. pumps and valves) could be provided at 1 hour time step because that step is assumed meaningful enough considering the uncertainty, e.g. of demands, and the steady-state hypothesis behind the hydraulic modeling.

4.3 Electricity tariff

The electricity tariff is shown in Table 6 where the energy prices are shown in cents/kWh. For example, the price applied on Monday is 6.72 cents/kWh from 6:00 am to 7:00 am, while it is 10.94 cents/kWh from 7:00 am to 8 am.

Table 7. Electricity tariff.

Tariff data (€/kWh)							
Hour	**Mon**	**Tue**	**Wen**	**Thu**	**Fri**	**Sat**	**Sun**
0	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672
1	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672
2	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672
3	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672
4	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672
5	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672
6	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672
7	0.1094	0.1094	0.1094	0.1094	0.1094	0.1094	0.0672
8	0.1094	0.1094	0.1094	0.1094	0.1094	0.1094	0.0672
9	0.1094	0.1094	0.1094	0.1094	0.1094	0.1094	0.0672
10	0.2768	0.2768	0.2768	0.2768	0.2768	0.1094	0.0672
11	0.2768	0.2768	0.2768	0.2768	0.2768	0.1094	0.0672
12	0.2768	0.2768	0.2768	0.2768	0.2768	0.1094	0.0672
13	0.2768	0.2768	0.2768	0.2768	0.2768	0.1094	0.0672
14	0.2768	0.2768	0.2768	0.2768	0.2768	0.1094	0.0672
15	0.2768	0.2768	0.2768	0.2768	0.2768	0.1094	0.0672
16	0.2768	0.2768	0.2768	0.2768	0.2768	0.1094	0.0672
17	0.1094	0.1094	0.1094	0.1094	0.1094	0.1094	0.1094
18	0.1094	0.1094	0.1094	0.1094	0.1094	0.1094	0.1094
19	0.1094	0.1094	0.1094	0.1094	0.1094	0.1094	0.1094
20	0.1094	0.1094	0.1094	0.1094	0.1094	0.0672	0.1094
21	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672
22	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672
23	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672	0.0672

5. Design evaluation

Each participant is required to submit one solution only and the used methodology.
The solutions received will be ranked based on:

- Pipe, Pump and Tank upgrading costs.
- Water loss and Energy costs.
- Pressure Control Valve cost.

For the cost evaluation, the committee reserves the right to group the solutions considering that small differences could be not significant from technical point of view and depending on the accuracy of the hydraulic simulation model.

In addition, the number of people involved (i.e., group) will be considered and the groups will be ranked accordingly as surrogate of the consultancy cost. Consistently, a lower sum of ages will be the second ranking criteria, because it is assumed that younger consultants are less expert and expensive.

Finally, during the presentation of the works in Bari, the groups will be ranked by a jury/committee that will take into account the methodology and survey results from the attendees at the special session.

The winner is the group ranked the highest considering the above criteria, summing the position rank of each criteria. The prize for the best group is an iPad mini that will be awarded during the last day of the conference.

Groups from the same university are allowed if they are using different methodologies, but no person can participate in more than one group.

Note that, as outlined earlier, to be eligible to participate, participants are required to submit:

1. a paper describing the approach adopted;
2. the MS-Excel files C-Town_battle_data.xlsx and BBLAWN-Results.xlsx outlining the design decisions and costs;
3. the file C-Town_Leaks.inp with the patterns of leakages concentrated at the nodes according to Eq. (2). **The participants can use any software model, but the pipe Background Leakage, which must be reported in the file of the point 2, must satisfy Eq. (1). Pipe Background Leakages represent the sum of all leakages along a pipe linking two nodes. The selected solution will be independently checked and evaluated by the Committee.**

In addition to the submission of the paper through the conference webpage, participants are requested to email the conference paper and supporting materials at:

battlewdsa2014@water-system.org