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Daniele Laucelli

Luigi Berardi

Orazio Giustolisi

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## **WdNetXL: Efficient Research Transfer for Management, Planning and Design of Water Distribution Networks**

DANIELE LAUCELLI (1), LUIGI BERARDI (1), ORAZIO GIUSTOLISI (1)

*(1): Department of Civil Engineering and Architecture, Technical University of Bari, via E. Orabona 4, Bari 70125, Italy*

The WdNetXL system ([www.hydroinformatics.it](http://www.hydroinformatics.it)) is aimed at promoting transfer of research achievements in water distribution network (WDN) analysis, planning and management to practitioners, students and researchers. In order to facilitate the technology transfer, the WdNetXL functions are integrated into the worldwide known MS-Excel data-management environment. Advanced hydraulic modeling and topological analyses of WDN are combined with efficient optimization strategies to make readily available the latest, even customized, decision support tools for planning and management of WDNs. All these features make WdNetXL of practical support for technicians as well as a privileged platform to test innovations coming from research in WDN analysis, planning and management area. This, contribution illustrates the WdNetXL research transfer paradigm and its architecture, providing also few details about the main advancements in WDN analysis, which represents the primary support for engineers' activities and the base component for other functions.

### **INTRODUCTION**

Environmental, financial, social and normative constraints are increasing the complexity in managing water distribution networks (WDN) and engineers at water companies are asked to provide reliable indications for the effective allocation of capital investments.

In recent years the rapid changes and pervasiveness of information technology, as well the increasing computational capabilities, has motivated researchers in developing advanced analyses tools and strategies to support WDN planning and management activities. However, direct transfer of innovations from scientific/technical research to the intended recipients is often hampered by many practical constraints. On the one hand, incorporating new methodologies in existing commercial packages might imply modifications of complex codes and investments by software houses. On the other hand, technicians are often reluctant to change their consolidate practices in favor of new tools, although they would permit more advanced and targeted responses to technical problems. This makes difficult the transfer of research achievements to daily real scale applications.

The WdNetXL system ([www.hydroinformatics.it](http://www.hydroinformatics.it)) [5] has been recently developed to fill this gap entailing a research transfer paradigm which makes readily available the most advanced analysis and decision support methodologies into a worldwide known data-

management environment (Excel in Microsoft Office® - MS-Excel). The versatility of the WDNNetXL system is demonstrated by a number of functions already implemented to support technicians in various practical problems ranging from WDN hydraulic simulation under failure scenarios, to design of segments (e.g. district metering areas), asset design/requalification, or optimal operations of pumps and valves. In addition, the WDNNetXL architecture makes easy to develop new and customized functions tailored for peculiar needs of water utilities.

This paper provides an overview of the WDNNetXL research transfer paradigm as an example of integration between research achievements and their deployment to assist water engineers, as one of the mission of *Hydroinformatics*. Next, some details on advanced WDN analysis are provided, as key components for other functions.

## **RESEARCH TRANSFER PARADIGM OF WDNNetXL**

Effective paradigm to transfer technical research in WDN analysis and management field should fulfill some key requisites: (a) the final tools should be easily used by engineers, (b) the transfer strategy should make innovations immediately usable on real scale applications and (c) it should be versatile enough to match peculiar analysis and management needs.

(a) WDNNetXL is conceived as a collection of MS-Excel add-in functions exploiting all its functionalities and interoperability with other applications that are commonly used by technicians (e.g. text editing, multimedia presentations, etc.). Using a worldwide known data-management environment greatly simplifies the training of users and facilitates visualization and manipulation of input/output data, permitting also to add comments, notes, external links and graphs. In addition, MS-Excel permits to easily import and visualize as simple tables any data format, thus also facilitating the integration with other software applications.

Results of functions are provided as separate MS-Excel files which can be easily customized and manipulated based on peculiar needs. This, in turn, permits to keep all input data into a unique MS-Excel file while results can be immediately verified/re-used by simple copy/paste actions.

(b) Each WDNNetXL function is developed in a high-level programming environment which is widely used in technical/scientific research (Matlab-TheMathworks®); thus innovations or new/customized functions can be quickly implemented and tested using the latest effective computing methods. Once the testing phase is completed, each function is deployed as MS-Excel add-in which use does not necessarily require the full Matlab software to be installed on the running machine. In addition, new functionalities/upgrades of WDNNetXL are usually less than 3Mb in size, thus being easy to share among users.

(c) The architecture of WDNNetXL is based on combining advanced WDN analysis tools with efficient optimization strategies into various functions to support technicians in peculiar planning and management activities. It can be argued that the range of possible variants based on such architecture is potentially unlimited and permits to devise customized functions to match specific requests. In this framework the functions already implemented in WDNNetXL also stimulate users in asking for specific changes/upgrades, thus triggering a virtuous cycle that poses new research challenges and promotes new solutions.

## **SUPPORTING WDN PLANNING AND MANAGEMENT WITH WDNNetXL**

Water companies need effective support for taking the right course of actions that should improve the system in short/medium-term while being effective also for long-term horizon.

Short/medium term actions are intended to mitigate the consequences of failures which happen under normal system functioning (e.g. single pipe failures, pump outages, increase of leakages and energy consumption). Such actions might involve system requalification (e.g. asset reinforcement, tank upgrade) and/or optimal operational strategies (e.g. pressure control for reducing leakages and energy consumption). In this framework, improved system knowledge by effective pressure/flow monitoring and reliable WDN models are crucial elements.

Long-term actions are intended to reduce system vulnerability in face of extreme and unpredictable events (e.g. sabotages, droughts) that are likely to result into severe consequences on supplying water to population. In such cases, the mitigation actions should improve the preparedness to extreme events in terms of minimization of failure consequences.

Conjugating the abovementioned perspectives is a complex task, since interventions have to be planned under uncertain WDN conditions and future monetary budget. Accordingly, the decision support tools should permit a dynamic planning to point out the sequence of interventions to be executed as financial budget will become available.

The WDNNetXL system already implements various functions to assist technicians in such phases. Figure 1 reports a pictorial representation of some functions which are available by combining advanced WDN analysis and optimization in WDNNetXL. Most of them are already implemented, while other might be developed based on end users' needs.

For the sake of brevity, and because of the crucial importance in the WDNNetXL architecture, the key features of advanced WDN analysis are reported in the following. They are the base “ingredients”, together with the optimization strategies, to develop all other functions.

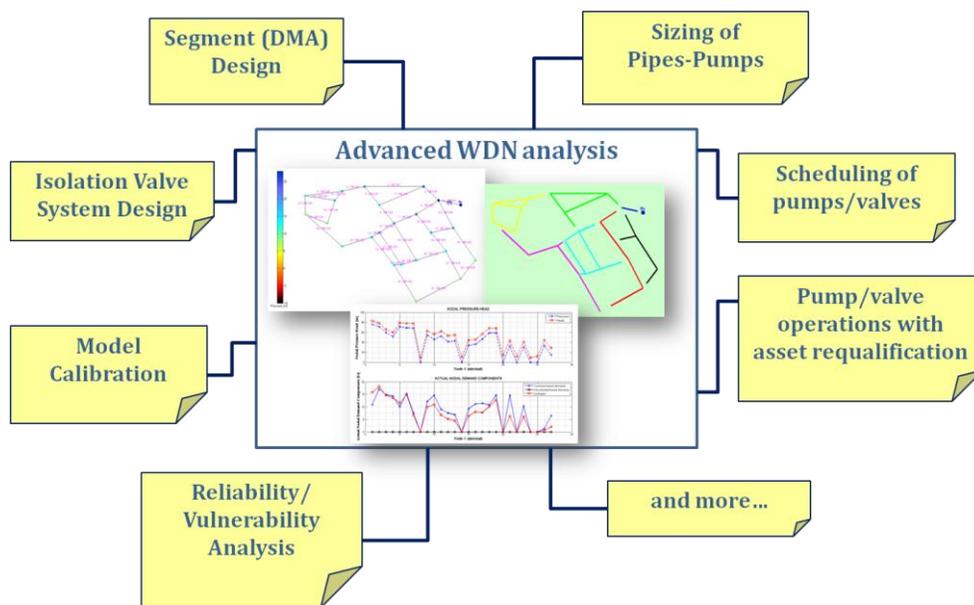


Figure 1. WDNNetXL architecture.

### ADVANCED WDN ANALYSIS WITH WDNNetXL

WDN hydraulic and topological analyses are of primary importance to understand WDN hydraulic behavior, point out major criticalities and simulate the system under real and

hypothetical functioning scenarios. Thus they are the first diagnostic tools to support engineers in management and planning activities and need for robust and computationally effective network hydraulic model.

The model implemented in WNetXL entails the latest advancements in hydraulic and topological analysis suited to support technicians in all planning and management phases. Some key features of the model used in WNetXL are reported in the following sections.

### Pressure-driven simulation accounting for background leakages

The hydraulic model in WNetXL permits to perform both classical *demand-driven* simulation, where nodal demands are fixed *a priori* (e.g. as in EPANET [11]), and the more advanced *pressure-driven* simulation, where nodal outflows are defined as a function of pressure. The latter is known to entail a more realistic representation of WDN functioning [12], especially under abnormal scenarios causing pressure-deficient conditions, where WDN is unable to fully satisfy water requests.

Besides the improved hydraulic consistency of *pressure-driven* simulation with respect to water delivered to customers, it also permits to assess the effects of distributed background leakages which normally occur along pipes depending on asset conditions, external stresses and WDN pressure [4]. In WNetXL the pressure-leakage model [2] is implemented and fully integrated with pressure-driven analysis.

Such innovation actually distinguish the WNetXL systems from other similar simulation packages where pressure-dependent outflows can be solely simulated as free orifices (e.g. hydrants) which depends only on pressure at a single nodes.

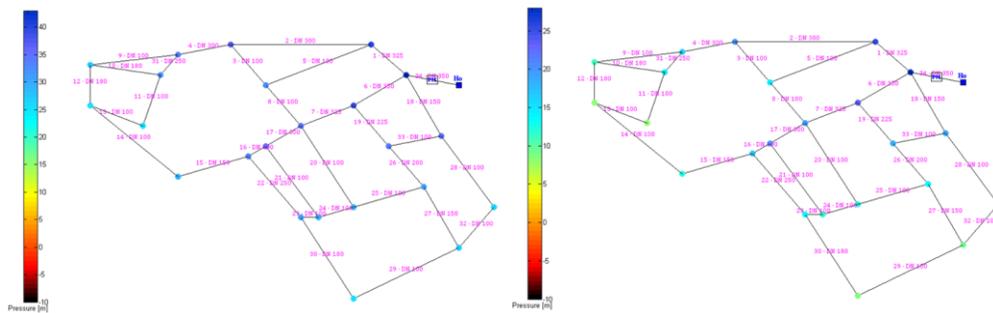


Figure 2. Comparison between WDN hydraulic simulation with and without leakages.

Figure 2 shows an example of comparison between the pressure regime simulated without (left) and with (right) background leakages on Apulian network [3], as resulting from WNetXL analyses. As evident from the color bars on the right of layouts, accounting for leakages results into larger head losses and reduced pressure regime.

The availability of a model for background leakage assessment is of crucial importance for many purposes including, for example, optimal operation of pumps/valves accounting for both energy and water losses reduction [8], as performed in the functions for pump scheduling already available in WNetXL.

### Multi-floor buildings

*Pressure-driven* analysis in WNetXL permits also to simulate, for each single node, water outflows from customers' taps placed at different elevations (e.g. multiple floors with fixed

inter-floor high). This feature permits to assess the customers that would be affected by possible pressure deficit due, for example, to programmed interventions on the network.

### Private local storages

In some peculiar contexts WDN does not feed customers' taps directly but water is stored in local private tanks, placed at building basement or roof, from which customers bring water by pumping systems or by gravity. Local storages are filled from the top by an orifice which is controlled by water level in the tank. Such a configuration is traditionally adopted in Mediterranean cities to cope with droughts.

WNetXL model permits to define the maximum volume of local tanks as well as the type of volume-controlled orifices for each single connection node. It was recently demonstrated [9] that results obtained by accounting for private local storages are different from those using *pressure-driven* analysis based on Wagner's model [13] only.

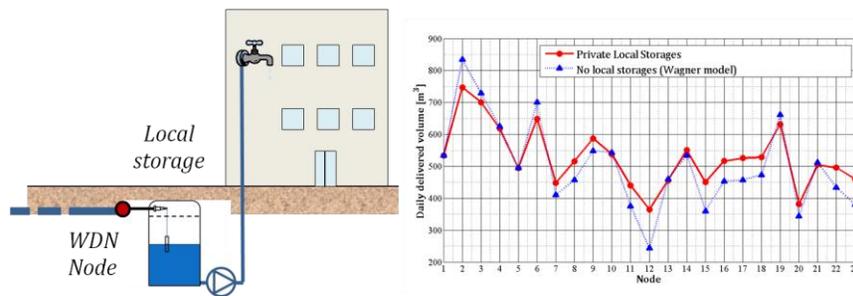


Figure 3. WDN hydraulic simulations accounting for private local storages of not.

For example, Figure 3 shows that accounting for local private storages (with 1 hour demand volume) in Apulian network results into a more equalized water volumes delivered during the day. Accordingly, such a feature permits to realistically assess WDN actual supply capacity as an essential pre-requisite to plan, for example, enhancement works or efficient operational strategies (e.g., pump scheduling).

### Remote control of pressure reduction valves and variable speed pumps

Most existing simulation models permits to simulate pressure control valves (PCV) whose setting point can be fixed right downstream of valve. Nonetheless, modeling such a control scheme requires the prediction of water demand and the hydraulic simulation in the WDN portion downstream the PCV. Today ICT easily provides solutions to transmit pressure reading from remote nodes (where pressure need to be actually controlled) to PLC actuated valves; such kind of control can be also used to control variable speed pumps (VSP).

The WNetXL model permits to simulate PCV and VSP controlled by remote nodes also accounting for pressure-driven simulation and leakages.

Figures 4 and 5 show an example of WNetXL analysis by simulating the effects of remote controlled PCV on Apulian network. Figure 4 (right) shows pressure at nodes 1 and 10 during high (summer) and low (winter) demand scenarios (see left-bottom diagram). The pressure is almost always higher than the value for correct service (12 m), resulting into high total leakage outflows (see right Figure 5). Using a PCV on pipe 34 controlled by node 10 (pressure setting = 12 m) results into lower pressure through the network and less than half total leakage outflow with respect to the uncontrolled scenarios.

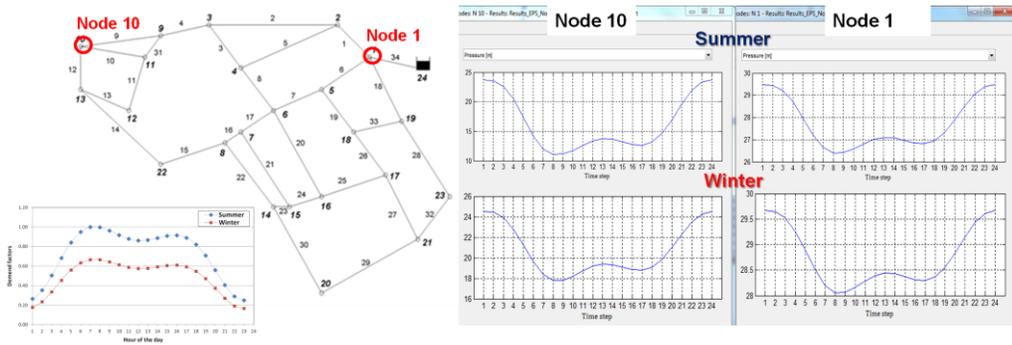


Figure 4. Pressure regimes during high (summer) and low (winter) demand without PCV.

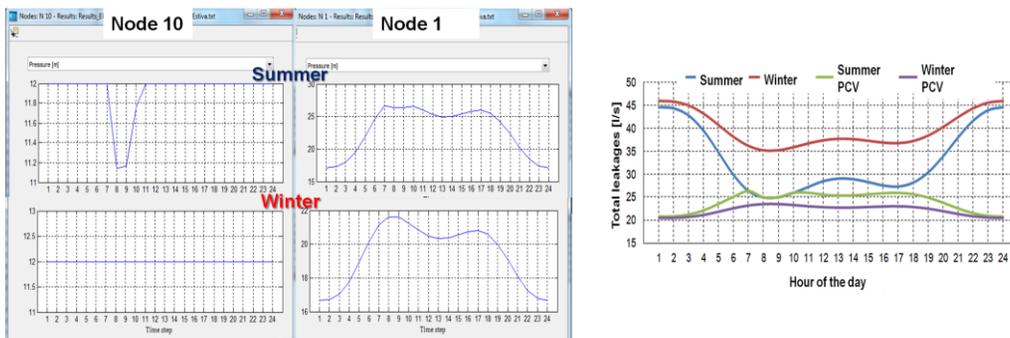


Figure 5. Pressure regime and total network leakages with PCV controlled by node 10.

### Variable topology

Differently from other existing software packages, the hydraulic model in WDNNetXL is fully integrated with the automatic detection of current WDN topology [3][6]. This feature is of key importance since it detects the portion of the network actually connected to water sources (i.e. reservoirs, tanks) both *before* the simulation starts and *during* the simulation run.

The topological analysis *before* the simulation is useful to detect current network portion when one or more pipes are detached (e.g. closing isolation valves). The latter, *during* the simulation run, actually permits to reproduce the closure of check/pressure-reduction valves or pumps (e.g. due to automatic controls) during the steady state simulation by accounting for the topological alterations [7]. This, in turns, permits to avoid heuristic numerical expedients that proved to be non-robust [1] within other simulation packages.

### Analysis of failure scenarios accounting for isolation valve system (IVS)

Accidental or planned interruption of pipes in real WDN requires the isolation of the network segment(s) the pipe belong to, according to the installed isolation valves which are usually quite less than pipes.

Combining the topological analysis with the hydraulic model, the WDNNetXL permits to simulate the WDN under any pipe failure requiring the isolation of relevant segment(s) and of WDN portions that would be unintentionally disconnected from water sources. Figure 6 (left) shows the segments identified by the IVS and the pipe (4) to be isolated by detaching the whole

yellow segment; this scenario results into the hydraulic functioning represented on the right side.

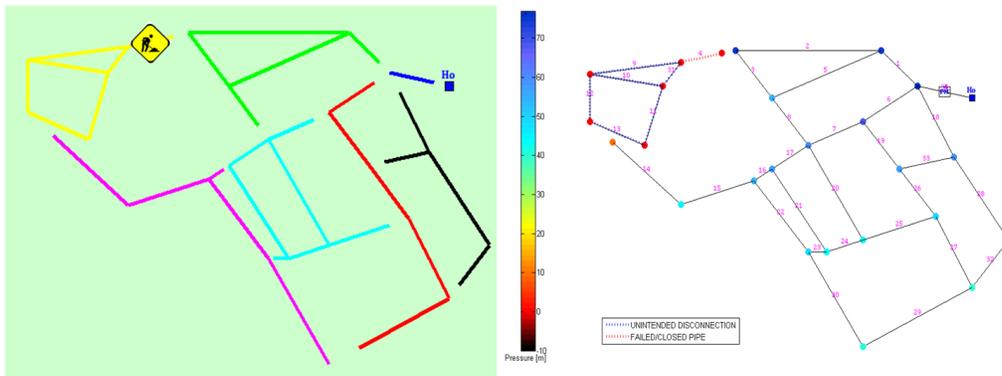


Figure 6. Isolation Valve System (left) and hydraulic simulations under failure of pipe 4 (right).

It can be argued that the analysis of failure scenarios underlies some other functions in WDNNetXL which are aimed at analyzing the reliability/vulnerability of the system under possible (mechanical) failure events. The mechanical *reliability analysis* function permits to analyze WDN behavior under the isolation of each single pipe segment; the *mechanical vulnerability assessment* functions also permits to search for the most disruptive combination of multiple simultaneous segment detachment.

#### Analysis of WDN modules/segments

The identification of WDN segments/modules is an essential pre-requisite for many purposes including monitoring, control and also calibration of WDN model. Then, modules are identified by flow/pressure measures which are available at *ad hoc* meters or other devices.

WDNNetXL automatically detects the modules identified by nodal pressure or pipe flow measures available at all devices including pumps, PCV (and remote controlling nodes), flow control valves, tanks/reservoirs. Figure 7 shows as different colors the 9 modules identified in C-Town network [10] with 1 reservoir, 7 tanks, 11 pumps and 3 PCV.

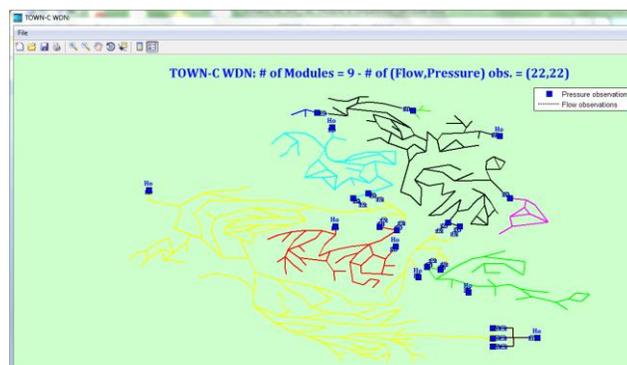


Figure 7. Modules identified in C-Town.

Also the segment analysis is the base component for other WDNNetXL functions suited for supporting design/upgrades of WDN segments according to operational and economic criteria.

## CONCLUSIONS

The WDNNetXL system has been developed as a platform to transfer the latest advancements on WDN analysis, planning and management to students, technicians and researchers. This paper illustrates the research transfer paradigm and the motivations for using MS-Excel as interface environment. The base architecture of WDNNetXL is also described where advanced WDN hydraulic modeling and topological analyses are integrated to provide practical answers to WDN planning and management needs.

The WDNNetXL system is currently used by students in Engineering worldwide, by researchers and is part of international cooperation programs within Europe and between Italy and China.

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