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A.S.A.P.

Actions for Systemic Aquifer Protection

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Hydraulic model. Technical report

ASAP - Actions for Systemic Aquifer Protection - Implementation

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(i) Thanks

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We thank Acque Spa that has supported the work and it has given his contribution to create the final document.

Finally, we thank all the people who have offered their support in the difficult task to analyse every matter and they discussed them patiently because of the connection between their activities and ASAP Project.

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Ing. Oberdan Cei
(o.cei@acqueingegneria.net)
Project manager

(ii) Contents

(iii) Document ‘s aim

The aim of this document is to describe the ASAP Hydraulic model.

(iv) Warnings

1. You have always to control the more recent version in ASAP Project page at the web address you can find at the top of the first page.

1 ==> PRELIMINARY REMARK

This report is one of the deliverable foreseen by ASAP Project that is centred in Bientina 's aquifer (Pisa, IT).

Particularly, the document is related to the *Task 4.- Engine tuning of the executive plan to optimize the collection – Activity T4.3 – Constant calibration of precision of the system (fine tuning).*

In fact, the aim of the task is to proceed with an optimum calibration of the pressures system.

AIM

The aim of this report is to describe the ASAP Hydraulic model.

EXECUTION AND RESPONSIBILITIES

Acque Ingegneria (ACQING) is responsible for the report version and for his analysis.

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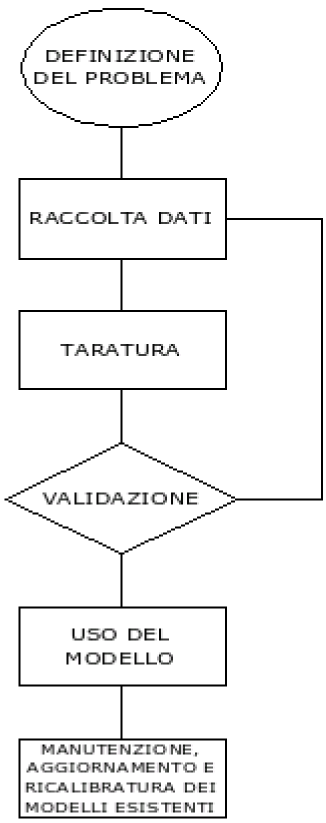
2 ==> INTRODUCTION

Simulation models represent a fundamental instrument either to the correct plan of characteristic elements of the net, such as pipes, tanks, lifting plants, etc., or to its optimum management, allowing to value system behaviour in different situations, to determinate working conditions in these parts not provided with instruments of tele-control and to put in evidence at the same time critical areas characterized by strong pressures and on the contrary suffering areas characterized by low pressure.

The development of mathematical model determinate a sequence of activities which started by the relief and acquisition of the net through telematic supports GIS and later continued with elaboration phases, telematic modelling and restitution. The detail level to reach in each previous phase and consequently the final intrinsic error of the model is strictly related to the use for which it is constructed.



Some characteristic errors of a mathematical model concern the geometrical schematization of the net (diameters, elements shares, plant 's schemes, etc.), the definition of hydraulic parameters (roughness), mechanism of control working and finally the definition and the georeferenciation of users.

3 ==> NET ACQUISITION

The net acquisition is preceded by the recognition, by the georeferenciation and by the characterization of all these elements that constitute an hydraulic disconnection working (tanks, lifting plants, treatment plants, etc.) or that whatever represent incoming points of flow in the system, such as wells or regulation valves.

The correct known of the net and particularly of primary distribution net, is very important to the subsequent development and interpretation of the model; consequently, the simple acquisition in shape file format of the map-making SIT, has to be joined with a direct known in the field.

The net is represented through a succession of arches and knots so that each arch starts and finishes in a knot and it is characterized by as a whole of geometrical and hydraulic attributes, such as typology, length, nominal diameter (DN), internal diameter (Di), material of which the single piece is composed and the roughness that in this first phase is unequivocally assigned for the material without considering neither the age of the supply, nor the water quality that is circulating there.

Only in a second moment, during the calibration we are going to analyse specifically each single piece by the output given by the model and by the data of flow and pressure collected.

Using the Hazen-Williams formula for distributed load losses, roughness used values are:

$$J = \frac{10.675\,Q^{1.852}}{C^{1.852}\;D^{4.8704}}$$

105 for pipes concrete
110 for pipes steel
135 for pipes cast iron covered
145 for pipes copper, inox
145 for pipes PE, PVC and PRFV

The subsequent elaboration, made using a GIS program (Arcview 3.2), involves the individuation and the correction of isolated pieces of the net, which couldn‘t allow to close the calculation process, the unification of pieces with the same diameter and roughness and the “skeletonization” of the net, substituting final pieces with a diameter lower than 32mm with knots in which concentrate opportunely the request.

Finally, it is distinguished between distribution net and adduction, in order to make easier users aggregation and consequently the request only to distribution pieces.

4 ==> DISTRICTUALIZATION OR ZONIZATION

Within the framework of water resources planning instruments and management of water main supply net, the districtualization is one of the most suggested method by technical literature and national prescriptive, (Galli law of 05/01/94 number 36 and subsequent regulation defined with the Decree of the Ministry of Works of 08.01.1997 number 99), in order to reduce the losses and to safe not invoiced water through the pressure regulation and the search/reparation of hidden losses.

With this method the water net is divided in more districts, each of them can be hydraulically separated from others and they are all characterized by one or more alimentation points tele-controlled or whatever measurable.

In the hydraulic model each district is characterized by specific curves of consumption.

In this way the hydraulic simulation allow to value the effects on the service level of interventions turned to modulated regulation of pressure and to estimate the volume of water saved and not invoiced on every single district through specific analysis.

5 ==> ASSIGNATION SHARE KNOT

The subsequent passage in hydraulic model creation is the share assignation to the net knots.

Starting with a digital terrain model (DTM), through a projection procedure, it is automatically attributed the z share to careful elements.

The DTM can be achieved interpolating with various methods (TIN, Kriging, Veronoi etc.) the careful data of share or the level curves.

The correct share assignation is very important to obtain pressure values in real knots; so it is necessary to have at disposal a fairly careful terrain relief in scale 1:2000.

6 ==> REQUEST ASSIGNATION

The request estimate that has to be assigned to a model knot can be based on several methods.

In ASAP protocol we refer to two different indicators: the building area on plan and the annual turnover of each user. The first date is simply to obtain by the regional technical map-making and the second has company origin.

With the first method the single user and the building georeferenciated centre of gravity coincide and the request that has to be associated is proportionally taken by the building plan area. So it necessary to distinguish almost two different kind of users, civil and industrial one, to which different shares of the total net request have to be associated considering social and economical data on the zone productive tissue.

This method is based on the hypothesis according to which civil buildings have comparable heights and industrial ones have an homogeneous use destination on all the territory. Obviously this hypothesis failed if we have the single civil building volumetry or the use destination of the industrial one.

Defining Q_{tot}(L/s) the medium flow in the simulation day, obtained by water balance-sheet on each district, and A_{tot}(mq) the whole area of dealt buildings, we have:

$$Q_{tot} = Q_{civile} + Q_{industriale}$$

$$A_{tot} = A_{civile} + A_{industriale}$$

The value that has to be assigned to Q_{civ} e Q_{ind} is function of the social-economical territory stratum dealt by the water main supply, object of simulation.

Generally, it is put Q_{ind}=20%Q_{tot}.

Consequently, the base request to assign to the single centroid considering the typology is:

$$q_{i_{civile}} = \frac{a_{i_{civile}}}{A_{civile}} Q_{civile}$$ for civil users

$$q_{i_{industriale}} = \frac{a_{i_{industriale}}}{A_{industriale}} Q_{industriale}$$ for industrial users

In that way:

$$\sum_{i} q_{i_{industriale}} + \sum_{i} q_{i_{industriale}} = Q_{tot}$$

To apply the second method it is necessary to have at disposal not only the georeferenciated users, which coincide with estate unities meters, but also the data banks of invoiced consumption and interval between two subsequent measures.

It is calculated such as in the previous case, considering like weight not the building area, but the daily medium consumption of single user, obtained comparing two subsequent measures:

$\Delta V_i = V_i(t_2) - V_i(t_1)$ invoiced consumption by generic users between two subsequent instants of reading

$q_{m_i} = \frac{V_i(t_2) - V_i(t_1)}{\Delta T}$, daily medium consumption by users during the period DT= t_2-t_1

As the medium consumption value is used like weight to calculate the base request to assign to generic users, it is necessary that the reference period of time DT of the reading will be the same for all the meters. If this condition, such as it is common, doesn't occur, it is necessary to uniform the q_{mi} data, bringing it back to the medium annual value.

$Q_m = \sum_i q_{m_i}$ medium daily consumption of all the dealt and active users at the moment of simulation.

The base request associated to generic users is:

$q_i = \frac{q_{m_i}}{Q_m} Q_g$ where Q_g is the medium net consumption in the day of simulation.

As regards the previous method, not imposing base hypothesis not always verified, but basing only on measured data, it allowed a better and more precise attribution of the base request.

The assignation procedure of base request to moulded net knots is very important because of a mistaken spatial aggregation of users can determine a flows distribution in the model not in accordance with real and consequently a simulated service levels not reliable.

Through using the GIS geoprocessing function, all these users situated at a lower distance of 250-300m from the nearest knot are associated to net knots according to a closeness criterion.

It is obvious that considering building centroids it is possible to commit rough errors either in the spatial association, because the distribution water supply nearest to the centroid cannot correspond to the one to which user is really joined, or supposing that to each one of them correspond only one user.

On the contrary, both the problems don 't exist considering georeferenciated users/meters.

During this first modelling phase it is supposed to not distinguish between the invoiced request and not book-keeped leaks. Dividing uniformly the losses on the whole net of water main supplies, the water resource quantity introduced in the system and the total one supplied to single meters consider themselves equal. This hypothesis is important to assure that simulation results are directly comparable to experimental data of flow and pressure gained by measure campaign.

7 ==> PATTERN REQUEST DEFINITION

Water consumption of a district in which there are several typologies of users, is the result of temporal superimposition of single user consumption curves. In fact, supposing that the request is quite satisfied, the consumption depends on several factors:

1. Typology of user: domestic, commercial, industrial, services
2. Social-economical level
3. Month of the year
4. Day and time sounded

If we consider a time interval of a week, typical working days from Monday to Saturday present a characteristic superimpositable state, while on Sunday the consumption curve is one hour on.

In modelling it is made reference on Saturday because we have maximum values on instantaneous consumptions.

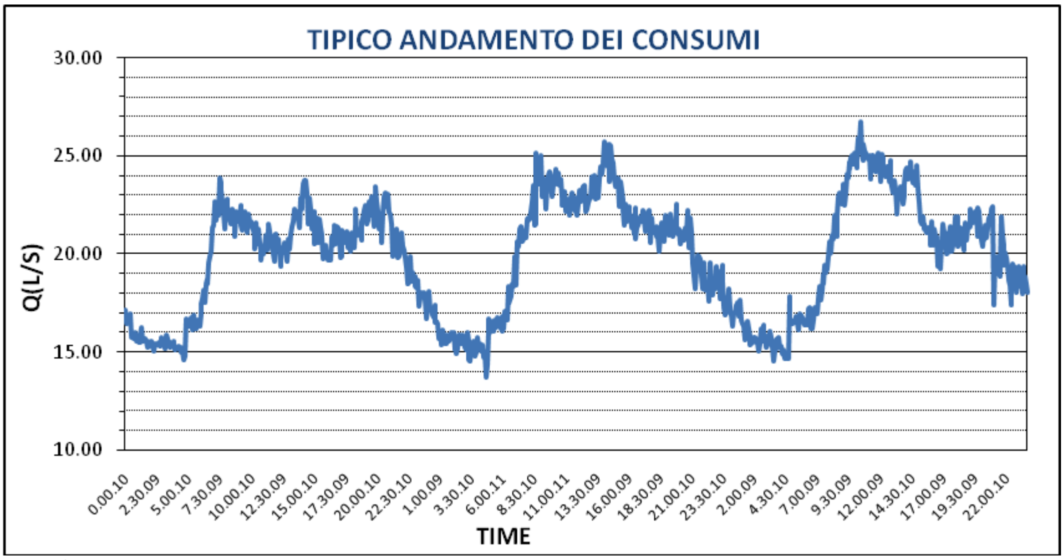


Fig. 1

Generally, civil user is characterized by a consumption curve that present a minimum point during night-hours, an increase during the first hours of the day and three maximum points during day-time. On the contrary, temporal state of industrial request and services in general, depends on user kind.

The pattern construction method that has to be used in hydraulic mode, is joined to the kind of information we possess.

Sounding the water request of a representative number of users of each typology it is possible to build a normalized consumption state about this specific kind of user according to a parameter that characterized it.

Known the destination use of the single building/centroid or user/meter, it is assigned the relative request pattern.

Alternately, starting from flow incoming data in each sector, it is determined generally considering a temporal arch of time of 24 hours, the consumption normalized pattern, indirect on one hour or on 5-10 minutes in function of registration data state or of instruments sensibility. In this case, not distinguishing between several user typologies, it is built only one request pattern committing evidently an error for industrial users that generally aren’t active during night-hours.

The use of time pattern, also simplifying calculation procedure, determines maximum instantaneous values annulment in the request, making the simulation not very reliable for particular check sceneries.

During the simulation it is important to consider days with a maximum consumption in order to put themselves in conditions more unfavourable from the hydraulic point of view and the service level reached in the net.

8 ==> ANALISYS

The calculation code used in the analysis is EPANET 2.0 version (Rossman, 2000) developed by EPA U.S. Envirornmental Protection Agency.

EPANET is an hydraulic simulator and of water quality to study net pressure.

The code simulates the presence of hydraulic mechanisms such as pumps, valves, tanks, pressure reducing valve and allow to map principal variables evolution in each knot or part of the net.

Using this software it is possible to execute a conventional kind of analysis or through an opportune use of “emitters” functionality to join the out coming flow by the knot to the pressure.

The conventional analysis or DDA (Driven Demand Analysis) supposes that the piezometric load on the knot (unknown of the problem) is sufficiently elevated to make coincide the flow distributed and the user request (date of the problem).

The result of this kind of analysis is reliable only if for each net knot this condition is respected. On the contrary, in presence of critical knots in which the piezometric load is lower than the necessary, the simulation wouldn’t to be considered correct because the user request would anyway satisfied also with negative pressure and circulating flows in the net wouldn’t result compatibles with loads and consequently with the physic of the system.

If the simulation executed according to DDA methodology doesn’t result adequate, it is necessary to put in relation the flow distributed by the generic knot and the load present in the net.

This kind of approach is indicated in literature with PDA initials (Pressure-Driven-Analysis). In addition to usual equations of movement and of continuity, in each knot in which it isn’t verified the necessary condition to execute the DDA analysis it is introduced another condition:

$$Q_i = f(H_i) = C \ H^{\alpha}{}_i$$

where:

Qi = flow distributed

a= esponent that gives information present in technical literature, it can be 0,5

C = coefficient of outflow

In not verified knots the base demand previously attributed is annulled and they are introduced the “emitters” with coefficient $C_{i,}$ calculated imposing that the flow distributed by the device is equal to the user request with piezometric load equal to requested value.

The new simulation will be characterized by circulating flows lower than the previous and consequently we will have less losses of load distributed on the net and consequently major pressures on the knots.

PDA analysis is a repetitive procedure in which at each passage they are eliminated those “emitters” in which the flow distributed results major than the demand or lower than zero.

9 ==> LOSSES SIMULATION IN A WATER MAIN SUPPLIES NET

The hydraulic equation that joins flow and pressure is traditionally represented by Torricelli formula:

$$Q = \mu \ A \ \sqrt{2 \ g \ H}$$

where m is the flow coefficient, A is the forum area and their product mA in presence of plastic material water main is function of pressure.

During analysis phase the losses in the net are considered such as unknown flows depending on the pressure, positioned in correspondence of knots for simplifying reasons. The reached experience allow us to say that more than 50% of losses are on fastenings and the other part is distributed on nets.

The equations used to resolve the system are still those of movement and continuity ones. Epanet allows water losses modelling in a water main supplies, using the emitters function, which joins flow and pressure through two k coefficients and to variables depending on pipes characteristics and on the loss kind:

$$Q(t) = K \ P(t)^{\alpha}$$

Exponent a value changes from 0.5 for losses in iron pipes to 2-2.5 for losses in plastic materials ones. In big systems where they have several typologies of losses, from those to fix area, to those on special pieces, on fastenings or on flexible pipes a has a 1-1.5 value.

On each knot of the model it is applicable the $qlos(t)_j = K_j \ P_j(t)^{\alpha}$ relation so that the addition extended on all the net in the generic instant t provides the lost loss by the system in the same instant:

$$\sum_j qlos_j(t) = \sum_j \left(k_j \ P_j(t)^{\alpha} \right) = Q_{loss}(t)$$

To determine the K_j value that has to be assigned to the generic knot, they resort to a water loss estimate according to the minimum night flow (MNF):

$$MNF = HNU + NHNU + ONU + WL$$

With:

- MNF: Minimum night flow
- HNU: Household night use
- NHNU: Non-Household night use
- ONU: Operational night use
- WL: Water losses

During night-hours which coincide with the minimum of consumptions and with pressure values of more important buildings, it is realized the higher proportion between water loss value and the consumption.

The WL estimate is more precise when is more careful MNF measures, the estimate of HNU, of NHNU and of ONU. Generally, the night-hours consumption value of domestic users can be valued restoring to methods reported in technical literature. A first method consists on considering a consumption value of 1.7l/property/hour for each user served. Alternatively, we can consider a 6% active population in the moment in which we have the minimum consumption and assign a water provision of 9l/inhabitant/hour for person. In this way it results:

$$HNU = 0.06 \quad N_{ab} \quad 9 \frac{l}{ab \quad ora}$$

where Nab is the number of inhabitants served.

The estimate of not domestic users (NHNU) can be obtained by values reported in technical literature in function of the activity typology made or preferably by direct measures. On the contrary, it is necessary to execute a measuring campaign in days in which they don’t make net interventions in order to annul ONU term.

Defining $Q_{los}(t)$ all real loss value on net and TMNF the instant in which it is recorded the minimum night-hour consumptions value and considering that, over than the losses distributed on water mains, an elevated per cent of water losses happen near the users fastenings, because their particular vulnerability, it can be supposed a direct proportionality of the loss in a knot of the net with the number of users positioned and the semi-addition of water mains converging to the knot.

Consequently, the whole water loss in the generic instant can be viewed such as the addition of two flows, one depending on the number of present fastenings in the net and other depending on the net extension, according to two coefficients a and b to define in function of sensibility and historical data possessed by the modeller:

$$Q_{los}(t) = Q_{los}{}^{N}(t) + Q_{los}{}^{L}(t)$$

where:

$Q_{loss}{}^{L}(t) = \beta \quad Q_{loss}(t)$ loss attributable to net extension

$Q_{loss}{}^{N}(t) = \alpha \quad Q_{loss}(t)$ loss attributable to the number of present fastenings

$\alpha + \beta = 1 \qquad \alpha \quad 0.5$

Similarly, the loss for j-hypothetical knot can be represented by:

$$qlos_j(t) = qlos_j{}^{N}(t) + qlos_j{}^{L}(t) \qquad {}_{j}\, qlos_j(t) = {}_{j}\, qlos_j{}^{N}(t) + {}_{j}\, qlos_j{}^{L}(t) = Q_{loss}{}^{N}(t) + Q_{loss}{}^{L}(t)$$

Supposing that for the j-hypothetical knot the losses caused by fastenings is proportioned with fastenings density present in that respect to the semi-addition of converging water mains, we have:

$$\frac{qlos_j^{\,N}\left(t=T_{MNF}\right)}{Q_{loss}^{\,N}\left(t=T_{MNF}\right)}=\frac{\dfrac{\left(\sum n_i\right)_j}{\left(\sum\dfrac{l_i}{2}\right)_j}}{\dfrac{N}{L}}$$

While for the $qlos_j^{\,L}(t)$ quantity we can suppose this relation:

$$\frac{qlos_j^{\,L}\left(t=T_{MNF}\right)}{Q_{loss}^{\,L}\left(t=T_{MNF}\right)}=\frac{\left(\sum\dfrac{l_i}{2}\right)_j}{L}$$

Where:

$N=\sum_j n_j$ addition of all users served by the net

$L=\sum_j l_j$ length of the net

$\left(\sum\dfrac{l_i}{2}\right)_j$ semi-addition of water main converging in j-hypothetical knot

$\left(\sum n_i\right)_j$ semi-addition of fastenings to j-hypothetical knot

Because of it is valid the general relation $qlos(t)_j=K_j\,P_j(t)^{\alpha}$, k_j of the j-hypothetical knot is:

$$k_j=\frac{qlos_j^{\,L}\left(t=T_{MNF}\right)+qlos_j^{\,N}\left(t=T_{MNF}\right)}{P_j\left(t=T_{MNF}\right)^{\alpha}}=\frac{Q_{loss}^{\,L}\left(t=T_{MNF}\right)\dfrac{\left(\sum\dfrac{l_i}{2}\right)_j}{L}+Q_{loss}^{\,N}\left(t=T_{MNF}\right)\dfrac{\dfrac{\left(\sum n_i\right)_j}{\left(\sum\dfrac{l_i}{2}\right)_j}}{\dfrac{N}{L}}}{P_j\left(t=T_{MNF}\right)^{\alpha}}$$

where $P_j\left(t=T_{MNF}\right)^{\alpha}$ can be obtained using the model previously built and calibrated according to DDA methodology analysis.

In this way we will have: $\sum_j qlos_j(t)=\sum_j\left(k_j\,P_j(t)^{\alpha}\right)=Q_{loss}(t)$

With this method water losses are distributed on all the net knots also in the case of there aren’t positioned users because the $\left(\sum\dfrac{l_i}{2}\right)_j$ term is always different from zero.

The using pattern in Epanet for real users consumptions is obtained by the difference between the volume introduced in the net $Q(t)$ measured, and the volume lose in real losses $Q_{loss}(t)$: $Q'(t) = Q(t) - Q_{loss}(t)$

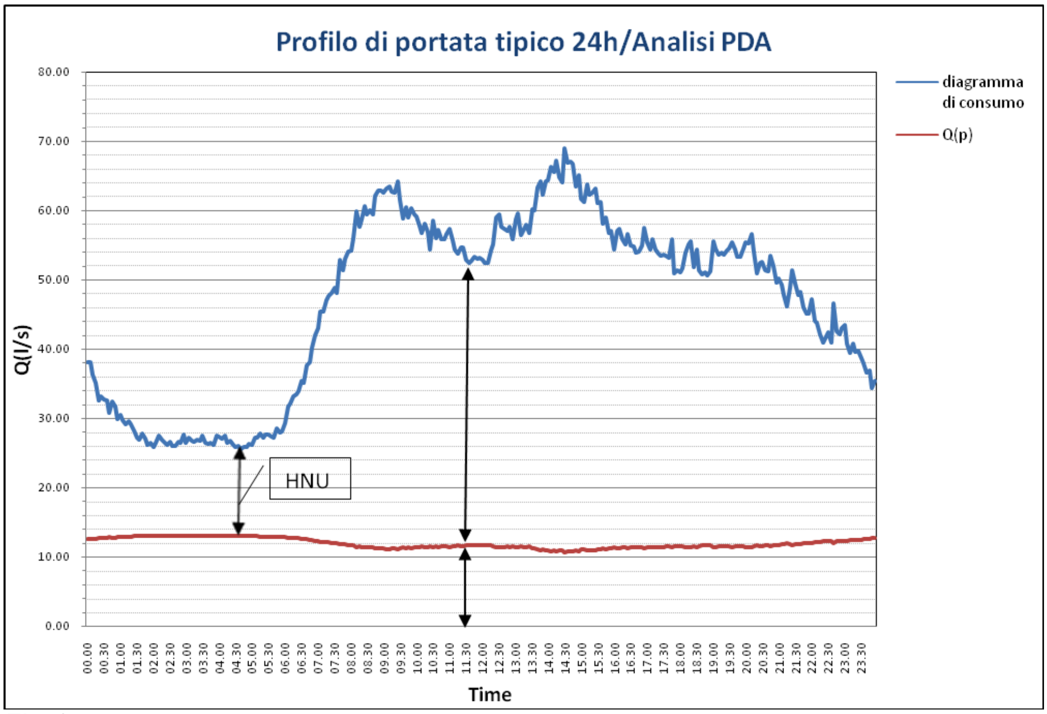


Fig. 2

To value the temporal state of net losses $Q_{loss}(t)$ we use the relation:

$$\frac{Q_{MNF}(t = T_{MNF})}{Q_{loss}(t)} = \frac{P(t = T_{MNF})}{P(t)}^{\alpha} \qquad Q_{loss}(t) = \frac{P(t)}{P(t = T_{MNF})}^{\alpha} Q_{MNF}(t = T_{MNF})$$

where P(t) is the variation of medium plan of piezometric sky calculated starting from the DDA analysis result executed on the model or from the measuring campaign made.

The base demand to assign to each user/meter or building/ centroid is still established with one of the previously method described, provided normalized.

The previously procedure is repetitive; changing opportunely at each simulation the coefficient a value and diagram of temporal losses state in function of the previous simulation they are obtained approximations always more precise.

10 ==> CALIBRATION MODEL

It is necessary to follow a calibration procedure that consists on a progressive adapting of hydraulic and geometrical parameters, such as roughness and spatial distribution of the request, in order that the model can adequately reproduced the system behaviour and predicted the working according to external conditions variations.

The method consists on minimizing the swerve between flow and pressure values measured in several net points and correspondent ones given by the hydraulic model.

Consequently, it has to be previously started a measuring campaign, in order to build a data bank characterizing the system working.

The number of making measures is strictly joined to net dimensions, to the present hydraulic mechanisms and obviously to the approximation degree that they can reach, which will be as greater as the campaign will be larger.

Kind of net	**Nº of measures points**	
	Pressure	**Flow**
Cities with less of 30.000 inhabitants	30-30	2-6
Cities with less of 300.000 inhabitants	30-50	5-15
Cities with a population of about 1.000.000 inhabitants	60-100	10-20

In addition of flow and pressure measures made, it is important to take information about the temporal working of all hydraulic disconnection mechanisms and not, which constitute external conditions, such as: lifting plants, tanks level, regulation valves, etc.

Because of measuring data made in the net are numerically limited and lower than unknown one, the calibration can’t give only one values combination of the system variables: roughness, spatial request dislocation, but only one of them that can better adapt the model to real state.

In Epanet 2.0 it is possible to use the “Calibration” function that punctually permit to compare the population of measured data and the ones given by the program.

11 ==> MODEL VALIDATION

To consider a model valid, the error committed during the calibration phase has to stand inside a maximum limit fixed by the planner according to the use to which the model has been created.

The "Engineering Computer Applications Committee" of AWWA proposes the following table:

Uso del modello	Livello di dettaglio	Tipo di simuzione	Misure di pressione	Errore sulla misura di pressione	Misura di portata	Errore nella misura di portata
Pianificazione	Basso	Dinamica	10% dei nodi	± 3.5 mca pre il 100% delle misure	1% dei tubi	± 10%
Progetto	Medio Alto	Dinamica	5% a 2% dei nodi	± 1.4 mca per il 90% delle misure	3% dei tubi	± 5%
Oprerazioni sullaret	Alto	Dinamica	10% a 2% dei nodi	± 1.4 mca per il 90% delle misure	2% dei tubi	± 5%
Qualità dell'acqua	Alto	Dinamica	2 % dei nodi	± 2.1 mca per il 70% delle misure	5% dei tubi	± 2%

Tab. 1: fonte Engineering Computer Applications Committee" - AWWA

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