PERFORMANCE INDICATORS AND EFFICIENCY ASSESSMENT OF DRAINAGE NETWORKS

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Abstract

In urban drainage networks analysis, as well as in distribution networks analysis, increasing attention is given to the definition of methodologies for assessing the efficiency guaranteed by every element in various scenarios. While in water distribution analysis the concepts of reliability, risk, performance, are frequently applied in order to describe the behaviour of each element and of the whole network, in sewage and drainage systems the same concepts are not so widely diffused. In this paper, by integrating GIS with hydraulic simulation models, a methodology is proposed through which is possible to lead performance analysis of drainage networks applying the same criteria developed for water distribution networks [1]. Thus establishes also a perfect integration of the policy management (Integrated Water Service) required by the existing law in Italy. Particularly we propose a methodology through which it is possible to describe the operating efficiency of drainage networks through global and local performance indicators that summarize the physical characteristics of the system and the operating conditions of the various elements. The indices can be referred to different scenarios to assess the system performance evolutions or to compare different networks configurations [1], [2], [3], [4], [5]. In order to validate the proposed procedure such methodology was applied to the case study of the drainage network of the city of Cosenza (Italy), to localize the critical elements of the network that need priority interventions. In supporting the planning decision processes the same approach could be useful to evaluate the effects that a given design choice will determine in terms of network efficiency.

Keywords
Performance indicators, urban drainage network, Case study.

1. INTRODUCTION

The poor maintenance and the rapid growth of the storm sewer networks, due to the increasing urbanization, point out to the managing authorities, serious infrastructural problems and significant repercussions on urban environments. For example, the recent flooding in Asia, due mainly to the limits in the capacities of the drainage networks, have caused and continue to cause serious damage to infrastructure, interruption of the social and commercial activities and, in the worst cases, loss of human life [6]. Such criticalities are often a result of poor design or structural defects in the sewer networks as well as to their inadequate dimensions, determined by the continuous expansion of existing networks. Moreover, the underground development of the networks and the lack of updated design documents and of computerized management instruments do not permit a comprehensive evaluation of the state of the system [7]. Similar problems are often faced with reactive solutions or, more rarely, long term rehabilitation projects, based on non technical criteria, which only serve to increase the vulnerability of the system as a whole [8].

As described in this work it is evident that introducing a methodology to verify the level of service, granted by the sewer system, could be extremely useful for improving the operating conditions of the networks themselves and to carry out preventive intervention measures based on programmed maintenance plans. Thus facilitate the achievement of the objectives fixed in the most recent laws of water management, including "a balanced economic and financial management of the resources and the creation of an Informative System, that defines technically and qualitatively the infrastructure" as stated by the law decree d.l. 152/2006.

In order to validate the proposed methodology, it was applied to an existing basin (Liguori channel) of about 414 ha, located in the city of Cosenza (Italy), which serves a population of about 50.000 inhabitants. About 48% of the total area is densely urbanized but the remaining 52% is largely covered by vegetation. (fig.1). Greater detail on the physical characteristics of the basin and its drainage system are given in the literature [9]. The basin is served by a mixed sewer system which conveys the whole volume of wastewater to the treatment plant of Montalto. During heavy rain events the flow which exceeds the capacity of the sewer system is released directly without any treatment into the reception water body (the Crati River) by means of diversion structures. The basin is also monitored measuring the precipitations in various points, the flows at the end node of the network and since 2004 wastewater quality during dry periods and during rain events has also been evaluated [10].

Figure 1. The experimental basin of the Liguori Canal

2. METHODOLOGY

To evaluate the degree of functioning of a drainage network and consequently to make decisions about improvement or rehabilitating the system, is necessary to define standards for assessing system performance measures, that should be functions of state variables directly correlated to predefined objectives [11]. In this paper the evaluation of the functioning condition of the sewerage network of the city of Cosenza is assessed through the calculation of two groups of synthetic indicators: physical indicators and hydraulic indicators.

The **physical indicators** rely on the geometric discontinuity of the system, are evaluated using ArcView-GIS and express in dimensionless form the critical degree associated to any elements:

- **Shape Index** (i_f) characterizes the geometric discontinuity associated with changes in shape or diameter between two consecutive links is defined as the ratio:

$$i_f = \frac{D_d - D_u}{D_u} \tag{1}$$

Where, respectively, D_d and D_u represent the downstream and the upstream diameters.

- **Slope Index** (i_s) expresses the criticity due to slope changes that occurs in two consecutive links:

$$i_s = \frac{j_d - j_u}{j_u} \tag{2}$$

Where j_d and j_u are the downstream and upstream slopes.

- **Direction index** (i_α) considering the angle α between two consecutive links it expresses the criticity due to any planimetric deviations

$$i_\alpha = 1 - \frac{\alpha}{180^\circ} \quad (3)$$

The **hydraulic indicators** are evaluated according the simulation analysis (MOUSE-DHI) related to a defined scenario and express in dimensionless form the critical degree associated to any hydraulic behaviour:

- **Velocity index** (i_v), expresses, in term of frequency, the occurrence of velocity exceeding a defined optimal range:

$$i_v = \frac{t^*}{t_{tot}} \quad (4)$$

Where t* represents the total time during which the velocity exceeds the v_{min}-v_{max} range and t_{tot} is the total time of simulation

- **Filling index** (i_φ)likewise to the velocity index expresses, in term of frequency, the occurrence of filling exceeding a defined optimal range:

$$i_\varphi = \frac{t^*}{t_{tot}} \quad (5)$$

Where t* represents the total time during which the filling exceeds the φ_{min}-φ_{max} range and t_{tot} is the total time of simulation.

- **Flood index** (i_{vol}), expresses the magnitude of node overflows that causes flooding:

$$i_{vol} = \frac{V_{flood}}{V_{tot}} \quad (6)$$

Where V_{flood} is the outflow volume that occurs in critical conditions and V_{tot} is the max volume of water that flow through the node.

The indices can be referred to different scenarios to assess the system performance evolutions or to compare different networks configurations [1], [2], [3], [4], [5].

The proposed approach was already stated in former research papers [12] and points to suggest guide lines for the definition of procedures for the optimal management of networks and resources through the use of opportune performance indicators [13]. The study of performance indicators is extremely useful in identifying the sections of the network which require greater and more urgent attention and where available resources should be concentrated [8]. Moreover, this approach also permits an evaluation of the effects that design or rehabilitation choices could have on the network behavior. The indicators can be calculated on the basis of diverse time intervals to evaluate the system's performance evolution over time, or they can be utilized as a common base to compare different networks in terms of performance [1], [2], [3], [4], [5]. For the shape index the threshold value was fixed at zero: if the diameter of the downstream link is the same as the diameter of the upstream link, the level of criticality is assumed to be normal. A negative value for the shape index indicates nodes where the downstream section decrease and overflow phenomena could happen. Consequently the level of criticality associated with discontinuities of this type, is high (level 1). Positive index values show an increase in the downstream section of the link that is a good condition (table 1). Also for the slope index the threshold value was fixed at zero: if the slope of the downstream link is equal to the slope of the upstream link, the criticality level was assumed to be normal (level 2). Negative values of the slope index indicate, on the other hand, nodes where deposition or accumulation of solid substances transported by the current could take place and consequently, the criticality level associated with discontinuities of this nature is high (level 1). Positive index values indicate an increase in the slope of the downstream link which is associated with no criticality level (table 1).

Two threshold values (0.25 e 0.50) are fixed for the direction index. The value 0.25 is obtained by considering a value of α equal to 135°: when the angle α is greater than135° ($i_\alpha < 0.25$) a high level of criticality occurs (level 1), because the insertion of the upstream pipeline into the downstream pipeline takes place in a brusque manner with significant energy loss. The value 0.50 is obtained, on the other hand, by considering a value of the angle α equal to 90°, beyond which energy losses are considered to be negligible (table 1).

Table 1. Levels of criticality for shape index, slope index

Level of criticality	Values of i_f	Values of i_s	Values of α	Values of i_α
high	$i_f < 0$	$i_s < 0$	$\alpha > 135°$	$i_\alpha < 0{,}25$
normal	$i_f = 0$	$i_s = 0$	$90° < \alpha < 135°$	$0{,}25 < i_\alpha < 0{,}50$
absent	$i_f > 0$	$i_s > 0$	$\alpha < 90°$	$i_\alpha > 0{,}50$

It is evident that local discontinuities such as variations in slope, diameter, or direction, together with bad choices of design, can bring about conditions of overflow in the drainage network which determine mainly outflows from the manholes or other intake structures, causing local flooding of the surrounding area. For this reason, with the aim of evaluating the correct functioning of the drainage network, a volume index was calculated (equation 6) and two threshold levels (0 and 0.01) were fixed for the volume index: when the excess volume discharged from the generic node was zero (i_v =0), it was possible to associate no criticality level to that node. When the flood volume was different from 0 and more than 10% of the total volume passing through the node under consideration the consequent level of criticality is no longer negligible while normal criticality was associated when the volume index was between 0.01 and 0 (table 2).

Table 2. Levels of criticality of the flood index

Levels of criticality	Values of i_{vol}
high	$i_{vol} < 0{,}01$
normal	$0{,}01 < i_{vol} < 0$
absent	$i_{vol} = 0$

The quantities V_{flood} and V_{tot} for each node of the network were deduced from the results of the simulations carried out by means of a model which had been adequately tested [14].

In general, it is possible to perform evaluations of the hydraulic index by considering both observed and synthetic pluviograms depending on research goals.

In this paper the network response to a simulated pluviometric input was utilized to verify the behavior of each element in specific situations. The design pluviogram was reconstructed by analyzing available pluviometric data and considering a return period of about 10 years.

The evaluated indexes were then integrated in a GIS environment, thus supplying the spatial distributions of the grades of criticality calculated and permitting the immediate localization of the critical elements with respect to the parameter under investigation.

3. RESULTS AND DISCUSSION

For each index are defined three levels of criticality which have been assigned different colors in the graphic representation. Figure 2 shows the criticality levels with regard to each synthetic indexes calculated for every nodes of the network. It is possible to observe that the proposed methodology permits to detect of about 31 out of 48 nodes which could manifest overflow problems (level of criticality equal to1). In fact about 65% of the points highlighted by at least one of the physical indexes correspond to the critical points identified by the volume indexes.

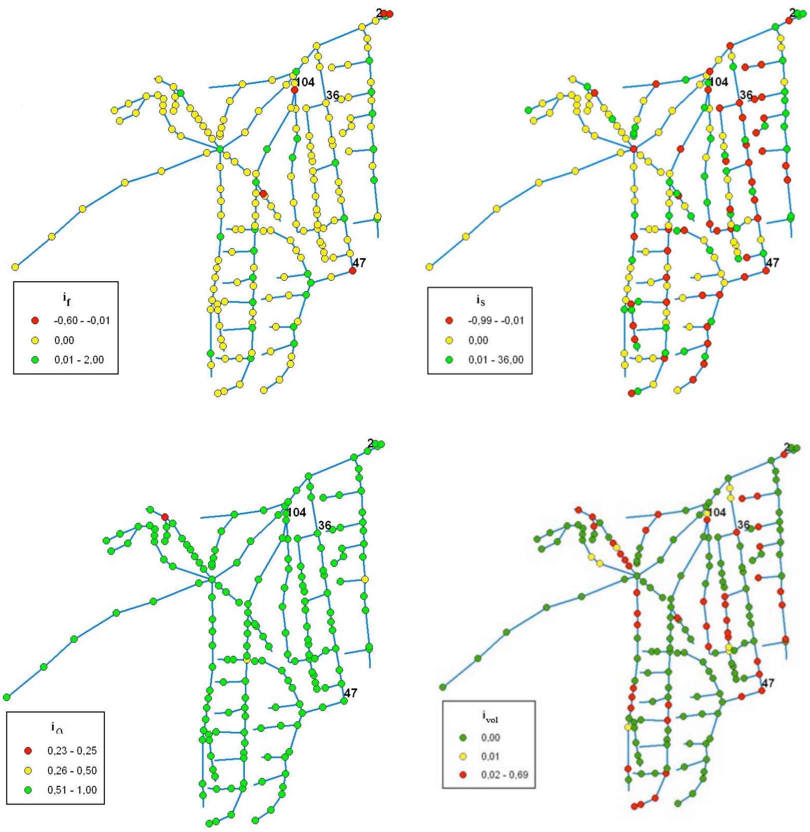

Figure 2. Spatial distribution for the calculated synthetic indexes.

The indicator with major impact on the correct functioning of the network is the slope index: about 75% of the nodes defined as "critical", show deficiencies of this nature (figure 3).

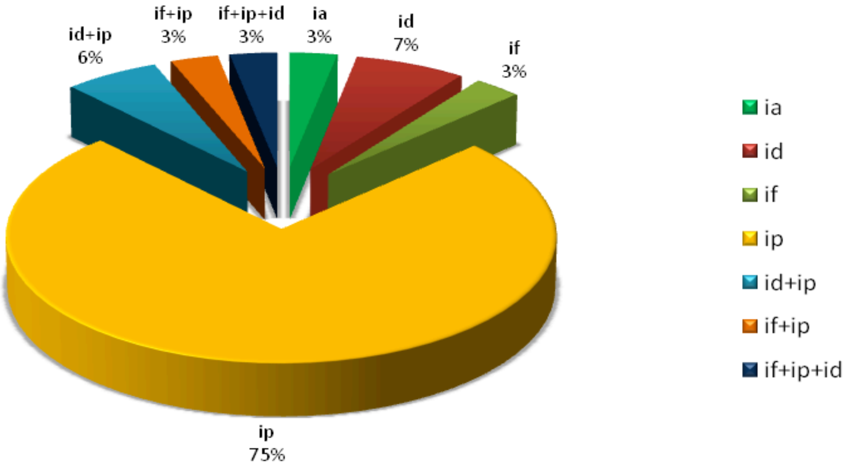

Figure 3. Incidence of various physical deficiencies along the network.

As a result, in order to improve network performance, it is necessary to adapt the slopes of the indicated branches. The most critical nodes are:

- nodes 2 and 36 with criticality in the slope and the sizing;
- node 47 with criticality in the form and in the slope;
- node 104 with criticality in the form, the slope and the sizing.

All the values of the indices are affected by the threshold values adopted in the different indices evaluation, but in a specific network the distribution of the before mentioned parameters, is not influenced by this, except for an obvious scale effect and for the chosen level of sensibility.

4. CONCLUSIONS

The method proposed has permitted an evaluation of the level of efficiency of the drainage network of the city of Cosenza and helps to simply identify the critical points of the system through the calculation of different synthetic indexes. Specifically were considered the indexes regarding the physical characteristics of the network including form and slope, as well as those expressing the level of functioning of the infrastructure itself such as the volume index. Limit values were successively defined for each index so as to be able to assign diverse levels of criticality to any discontinuity.

The graphic representation of the diverse indexes carried out with the aid of GIS, enables us to locate the elements which, due to their physical endemic characteristics, could cause hydraulic criticality. The physical indexes state the endemic conditions of network components and constitute only a potential criticality not represent network inefficiencies except when the same components also manifest critical hydraulic behavior. The numeric value of the indexes only quantifies a parameter (dimensionless with respect to elements characterizing the context in which it is assessed) useful for "relative" evaluations between elements of the same infrastructure, or to compare similar properties of the same contest.

The usefulness of the indexes is to be assessed mainly in the ability they have to provide a synthetic analysis of the potential criticality of the different elements of the infrastructure under examination that could be utilized within a process of topological overlay in creating a graded hierarchy of possible critical zones and thus in driving any design or rehabilitation intervention.

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