© IWA Publishing 2015
152

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

A methodological proposal for the evaluation of potable water use risk

Mario Maiolo and Daniela Pantusa*

Department of Environmental and Chemical Engineering, University of Calabria – Ponte P. Bucci 87036 Arcavacata di Rende (CS), Italy

*Corresponding author. E-mail: dpantusa@libero.it

Abstract

Water shortages are due to a number of factors such as pollution of sources, decrease of water availability, climate change, wrong use of water resources and the inaccurate management of water systems, including the physiological dysfunctions of waterwork facilities. In order to improve the planning of emergency management, forecasting and prevention of this type of risk, it is helpful to address the study of the risk of potable water use. Through the analysis of water systems in all its components, key factors have been identified that influence the incorrect operation of systems and it was possible to define the risk for potable water use in order to formulate an initial proposal for an estimation method.

Key words: potable water use risk, sustainable management of water resources, water distribution systems

INTRODUCTION

Proper management of water resources and water distribution systems assume particular importance today because of the different emergencies related to the use of these resources. These problems require the pursuit of sustainable management and distribution of resources. The concept of sustainability has been addressed at many international conferences and is the basis of many program actions at EU level; different procedures and methodologies for estimating sustainability have also been developed (UNCSD 1996, 2001; World Bank 1997; UN 2001, 2007; IISD 2002; Ronchi *et al.* 2002; WWF 2002; COM 2005a, 2005b; CPS 2005; Esty *et al.* 2006).

The sustainable management of water resources is an essential element for achieving the general objectives of sustainable development and different criteria have been developed for comparing and evaluating different alternatives, including the use of indicators capable of measuring changes in the level of sustainability as a result of the policies undertaken (Loucks 2002; Nachtnebel 2002; Maiolo *et al.* 2005; Maiolo *et al.* 2006). Beginning with the principles and elements constituting the concept of sustainability, water management becomes sustainable if it acquires and uses the same principles and elements. Therefore, the pursuit of sustainable management of water resources requires the improvement of water systems by reducing structural and management deficiencies. Overcoming these flaws requires the study of various aspects of the water service, such as monitoring and control of consumption, water saving, suitable investment policies, and a more efficient management of water systems. Sustainable management of water resources is, therefore, available only through analysis and evaluation, at different scales, of all environmental, social, economic, and infrastructural aspects related to such resources. With regard to environmental aspects, the objective is to restore and/or maintain good levels of quality resources, in order to maintain the integrity of natural systems and habitats, also through the identification of all the external factors that may put pressure on water resources. The social aspect of water resources is linked to the need to satisfy the

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

requirements of a fair and sustainable price for people with an improvement in sanitation issues. From an economic standpoint, the problems are different, in that it is necessary to pursue goals of profitability and return on capital through the recovery of costs for services and appropriate tariff levels with a cost–benefit balance. Finally, the infrastructural aspects are related to the modernization of infrastructure systems, to maintenance facilities, to reliability.

Given the diverse and growing problems related to water resources due to increased demand, the growing competition between different uses, sources of pollution, climate change, time and space variations in precipitation, it therefore seems particularly important the analysis of the different factors that affect the drinking water service and that relate to the correct system design, reliability assessment, leakage analysis, modeling performance indicators (Bao & Mays 1990; Quimpo & Shamsi 1991; Gupta & Bhave 1994; Xu & Goulter 1998; Alegre *et al.* 2000, 2006; Kleiner & Rajani 2002; AWWA 2004; Almandoz *et al.* 2005).

In this context, risk analysis related to the lack of drinking water supply or distribution of water resource of inadequate quality is useful in order to improve the planning of emergency management, forecasting and prevention.

Potable water use risk is a very complex type of risk, influenced by many factors. This risk reflects, in fact, the effects of natural phenomena such as those that determine drought, but is also strongly influenced by problems related to the correct functioning of the structural parts of the water system.

This work presents an analysis of the risk associated with the vulnerability of drinking water systems and suggest a first method of estimation; the developed methodology is a deterministic-comparative type and is easily and immediately usable in management.

METHODOLOGICAL EVALUATION OF POTABLE WATER USE RISK

Potable water use risk can be defined as 'the probability of failure of the water system in ensuring, for a predetermined time interval and under certain operating conditions, the fulfillment of the minimum levels of service and compliance with quality standards, for failure of one or more structural parts of the system, for pollution or depletion of the resource, for deterioration of the water along the path from the point of sampling to the point of use'.

Potable water use risk must therefore be expressed in terms of probability and consequences, considering the various hazard events, all failures of the system and the impact on users and activities in the area. This approach is complex and requires the analysis of many aspects such as probability of contamination of the water source, or probability of failure of specific parts of the system. For these reasons, in order to develop a methodology that can be easily used in management as a decision support tool, the developed methodology is deterministic comparative type. This methodology uses scores and weights to make a comparative assessment of the different drinking water systems in support and guidance of the technical choices and management.

To perform a correct analysis of the factors that influence the risk assessment for potable water use, it is necessary to perform the following activities, listed with specific reference to the proposed methodology:

1. *Gathering general data on the aqueduct*, in order to obtain detailed knowledge of the system.
2. *Surveying activities in the area*, for identification of the economic and productive centres served by the water system, through the characterization of industrial and handicraft activities.
3. *Historical analysis of failures*, in order to acquire and catalog through homogeneity criteria all mechanical failures which occurred in the history of the system.
4. *Assessment of the intrinsic vulnerability index of the water system* through a scores and weights method.
5. *Estimate of damage* through the formulation of damage matrices.

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

6. *Risk assessment for potable water use*. This assessment is carried out on the basis of the vulnerability intrinsic index and the quantity of damage produced by the previous phase.
7. *Assessing quality of management*. The quality of management can be evaluated through the analysis of a set of appropriate parameters and allows comparisons between different managements.
8. *The database of the study*. The dynamic nature of the issues involved implies the need to process all data analyzed using methodologies so as to make them available for further processing and to allow an analysis of the failures in terms of causes and effects.

Below, according to the proposed methodology for risk assessment for potable water use, called **'POTABLE_W.U.R.'** (**POTABLE Water Use Risk**), the different activities are specifically characterized.

Activity 1: Gathering of general data on the aqueduct

This gathering is aimed at the characterization of the water system in terms of number, type and position of intake and accumulation structures and diameters, lengths and materials of pipes, treatment plants, etc. An analysis of the site where the system is placed, can also be useful, regarding meteorology, natural risks, possible sources of pollution and presence of infrastructure that can interact with the system.

Activity 2: Surveying activities in the area

This second task allows economic and productive knowledge of the area serviced by the system.

Activity 3: Historical analysis of failures

The objective of this activity is to highlight all the instances of mechanical failure that can cause hydraulic failure. It is divided into two steps, the first is gathering data regarding mechanical failures that took place in the past. The next step is to process all the data collected to derive general information and identify a number of significant parameters.

Activity 4: Assessment of the intrinsic vulnerability index of the water system

There are various determination methods of the intrinsic vulnerability:

- *Evaluation methods regarding homogenous areas*, that use cartographic references and overlapping for a correct planning of work in the area;
- *Evaluation methods regarding analogical systems*, that use mathematical formulas with great developing complexity of methods;
- *Evaluation methods regarding parametric systems*, that are the easiest to be used and that include:
  - ○ Matrix systems;
  - ○ Evaluation of environment impact systems;
  - ○ Simple point systems;
  - ○ Scores and weights system.

In the proposed methodology, **POTABLE_W.U.R.**, the assessment of the intrinsic vulnerability index of the system is done through a scores and weights method.

The factors considered are linked to the different kinds of mechanical failures and to each of them a relative 'weight' (importance) that varies on a scale of 1–6 is assigned (Table 1):

The scores are assigned according to the characteristic parameters of each factor. The sum of the products of the scores and the weights assigned to each parameter of the factor allows of the

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

Table 1 | Factors related to the intrinsic vulnerability index and relative weights

	Factor	Weight
P	Pollution of source	6
O	Obstruction or dysfunction of water intake structure	3
T	Troubles or failures of pumping system	3
A	Alteration of quality of water along system	5
B	Breakage of artworks present along pipes	3
L	Low pressure in water distribution network	2
E	Eccessive annual temperature variations	1
W	Water treatments malfunctioning	5
U	Unavailability of water	6
R	Reduction of availability of water due to leaks	4

calculation the vulnerability index:

$$V = \mathrm{P}_s \cdot \mathrm{P}_w + \mathrm{O}_s \cdot \mathrm{O}_w + \mathrm{T}_s \cdot \mathrm{T}_w + \mathrm{A}_s \cdot \mathrm{A}_w + \mathrm{B}_s \cdot \mathrm{B}_w + \mathrm{L}_s \cdot \mathrm{L}_w + \mathrm{E}_s \cdot \mathrm{E}_w + \mathrm{W}_s \cdot \mathrm{W}_w + \mathrm{U}_s \cdot \mathrm{U}_w + \mathrm{R}_s \cdot \mathrm{R}_w$$

where the subscript '*s*' indicates score and the subscript '*w*' indicates weight. Following are the criteria to assigning scores and relative graphs.

– Determination of score according to factor P (Pollution of source) and factor A (Alteration of quality of water along system).

Italian regulations require the analysis of a series of parameters in order to estimate the quality of water; such parameters are unified so as to form a certain number of groups. These groups are indicated as follows: **SF** (Substances that refer to fecal contamination), **ST** (Toxic substances), **SR** (Radioactive substances) **SM** (Substances that refer to water mineralization), **CF** (Chemical-Physical parameters), **PO** (Organoleptic parameters).

Each group consists of a certain number of parameters and for each of them it is necessary to evaluate the sampling results. In particular, for each parameter it is necessary to calculate the following:

– the number of times that the concentration of the parameter was greater than the guideline value of the regulation;
– for every non-conformant event, the ratio of the obtained concentration to the guideline value C/GV, in percentage, that is called I_{ps} *(Deviation Percentage Index)*.

The average of the Deviation Percentage Index, I_{ps}, regarding each non-conformant event, represents the *Average Percentage Index of Deviation of the Parameter,* IM_{ps} *(name or symbol of parameter)*. Such a value must be determined for each parameter in each group.

The average of the Average Percentage Index of Deviation of the Parameter, IM_{ps}, regarding each parameter of the group, determines the *Average Percentage Index of Deviation of the Group,* IMG_{ps} *(name of group)*. Depending on the value assumed by each IMG_{ps} a value obtained according to the following scale, V_{IMG}, will be attributed to each group (Table 2). By convention, the values that coincide with the boundary between a class and the next will be included in the previous class.

For each group the percentage ratio between cases of non-compliance of the group and the total number of samples which do not comply will be assessed. Depending on the percentage value a specific value denoted by 'P' will be assigned to each group (Table 3).

Each group will be assigned a weight according the following scale (Table 4)

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

Table 2 | Scale of values of V_{IMG}

IMG_{ps}	V_{IMG}
100–120	0.1
120–140	0.2
140–160	0.3
160–180	0.4
180–200	0.5
200–220	0.6
220–240	0.7
240–260	0.8
260–280	0.9
> 280	1.0

Table 3 | Scale of values of P

Percentage	P
0–10	0.1
10–20	0.2
20–30	0.3
30–40	0.4
40–50	0.5
50–60	0.6
60–70	0.7
70–80	0.8
80–90	0.9
90–100	1.0

Table 4 | Scale of values of W

Group	W
SF	4
ST	3
SR	3
SM	2
CF	2
PO	1

The product of $V_{IMG\ (group)}$, $P_{(group)}$ and $W_{(group)}$ is called I

$$I = \sum_{i=1}^{6} V_{\mathrm{IMG(group}_i)} \cdot P_{(\mathrm{group}_i)} \cdot W_{(\mathrm{group}_i)}$$

The value of I is between 0.15 and 15. The score P_s for the factor P (Pollution of source) is attributed according to the following values (Table 5).

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

Table 5 | Score of factor P, Pollution of source

I	P_s
0.15–1.5	1
1.5–3	2
3–4.5	3
4.5–6	4
6–7.5	5
7.5–9	6
9–10.5	7
10.5–12	8
12–13.5	9
13.5–15	10

The procedure for attributing the relative scores regarding factor A is the same as the one proposed for factor P considering these groups: **SB** (Substances referring to biofilm formation), **R** (Ripe release), **DBP** (Disinfection by-products), to which the following weights are given (Table 6)

Table 6 | Scale of values of W for parameter A

Group	W
SB	3
R	1
DBP	2

The value of $I = \sum_{i=1}^{3} V_{\mathrm{IMG(group}_i)} \cdot P_{(\mathrm{group}_i)} \cdot W_{(\mathrm{group}_i)}$ is between 0.06 and 6. The score of factor A is given according to the following values (Table 7):

– Determination of the score relating to factor O (Obstruction or dysfunction of water intake structure), T (Troubles or failures of pumping system), B (Breakage of artworks present along pipes).

Dysfunctions of water intake structure, failures of pumping system and breakage of artworks present along pipes, cause interruptions of service water supply, so the procedure for attributing the relative scores is the same for these three factors.

Table 7 | Score of factor A, Alteration of quality of water along system

I	A_s
0.06–1.0	1
1.0–2.0	2
2.0–2.5	3
2.5–3.0	4
3.0–3.5	5
3.5–4.0	6
4.0–4.5	7
4.5–5.0	8
5.0–5.5	9
5.5–6.0	10

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

For the factor O, for example, the score is awarded based on the average of the water supply service interruptions that occur in a year, due to dysfunction of water intake structure (Table 8).

Table 8 | Scale of values of $O_{(n.interruptions)}$

n. interruptions/year	$O_{(n.interruptions)}$
0–3	1
3–6	2
6–9	3
9–12	4
Greater than 12	5

It is nevertheless necessary to take into account the duration of interruptions. With reference to the average annual duration of interruptions a specific value according to the following classification will be assigned (Table 9).

Table 9 | Scale of values of $O_{(duration)}$

Average duration of interruptions (hours)	$O_{(duration)}$
0–6	1
6–12	2
12–18	3
18–24	4
Greater than 24	5

The product of $O_{(n.interruptions)}$ and $O_{(duration)}$ is called O:

$$O = O_{(n.\text{interruptions})} \cdot O_{(\text{duration})}$$

The value of O is between 1 and 25. The score O_s for the parameter is attributed according to the following values (Table 10)

Table 10 | Score of factor O, Obstruction or dysfunction of water intake structure

O	O_s
1–3,4	1
3,4–5,8	2
5,8–8,2	3
8,2–10,6	4
10,6–13	5
13–15,4	6
15,4–17,8	7
17,8–20,2	8
20,2–22,6	9
22,6–25	10

The same procedure is valid for the other two factors.

– Determination of the score relating to factor L (Low pressure in water distribution network)

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

The parameter used takes into consideration the time interval with a pressure below the minimum. The score attributed is based on the percentage ratio of the summation of the times with a pressure below the minimum forecasted each month (Figure 1).

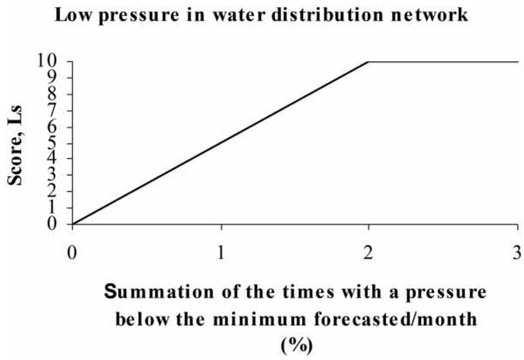

Figure 1 | Score of factor L, Low pressure in water distribution network.

– Determination of the score relating to factor E (Eccessive annual temperature variations)

Since an annual temperature range of 2–3 °C is acceptable, for these a value at 0 score will be assigned, and a score varying according to a linear scale will be assigned to variations between 3 and 10 °C. Above these values the score will be maximum (Figure 2).

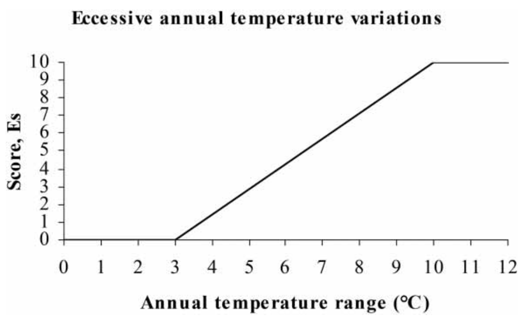

Figure 2 | Score of factor E, Eccessive annual temperature variations.

– Determination of the score relating to factor W (Water treatments malfunctioning)

The parameter used to represent such a factor is the percentage of samplings at the end of the potabilization plants non-compliant with Italian regulations. The threshold mark considered, for the maximum value, is 50% (Figure 3).

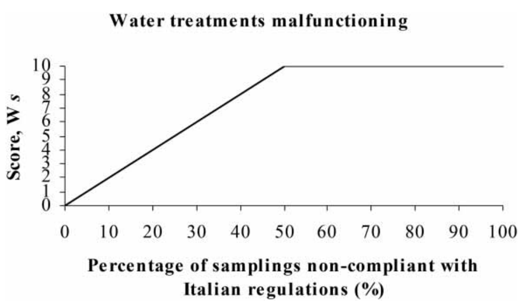

Figure 3 | Score of factor W, Water treatments malfunctioning.

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

– Determination of the score relating to factor U (Unavailability of water)

For this factor the score is given according to water daily availability guaranteed when there is a shortage. Since the Italian regulation requires a minimum of 150 l/inhabitant/day, the water deficit represents a risk factor when the water daily availability guaranteed is below that level.

The score is given according to a scale represented by the following diagram (Figure 4).

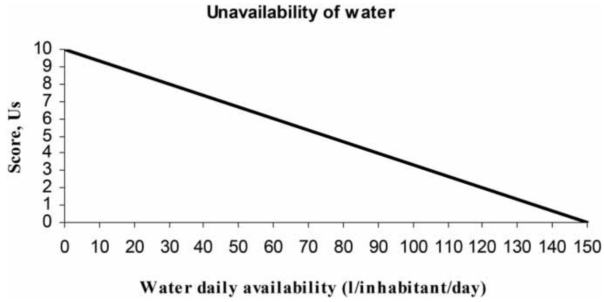

Figure 4 | Score of Factor U, Unavailability of water.

– Determination of the score relating to factor R (Reduction of water availability due to leaks)

The necessary steps to determine the score are

- calculation of the water daily availability guaranteed in the event of physiologic leaks, d_f (l/inhabitant/day);
- calculation of the water daily availability guaranteed, considering leaks (leaking pipes and tank seal imperfection), d_p (l/inhabitant/day).

If d_f and d_p are both greater than or equal to the minimum value of water daily availability requires by the Italian legislation the score given to the factor in question is zero, if, instead d_p is lower, it means that there is a situation of potable water use risk, and the score will be assigned on the basis of the value assumed by the ratio d_p/d_f (Table 11).

Table 11 | Score of factor R, Reduction of water availability due to leaks

$d_p/d_f \cdot 100$	R_s
100–90	1
90–80	2
80–70	3
70–60	4
60–50	5
50–40	6
40–30	7
30–20	8
20–10	9
10–0	10

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

Activity 5: Damage estimate

To estimate the damage two parameters have been selected that are linked to the population and to the presence of industrial and handicraft activities.

The first parameter, D_P, represents the consumers who could be inconvenienced due to potable water use problems. The second parameter, D_A, considers economic losses in industry and in the varied handicraft activities.

In order to evaluate the parameters damage matrices have been created (Tables 12, 13):

Damage is calculated as

$$D = D_P \cdot D_A$$

Table 12 | Scale of value of parameter D_P

Population	Value of parameter D_P
City centre with population less than 10,000	0.25
City centre with population from 10,000 to 50,000	0.50
City centre with population from 50,000 to 100,000	0.75
City centre with population greater than 100,000	1

Table 13 | Scale of value of parameter D_A

Characteristics	Value of parameter D_A
Centre with little industrial presence. Minor damage	0.25
Centre with small to medium industrial presence. In these areas the potable water use problems have limited effects on the economic and productive fabrics of the city	0.50
Centre with vast industrial presence for which the economic damage resulting in the case of no water service is much more important than previous case	0.75
Centre with important industrial activities that need water to manufacture their product.	
A shortage/stoppage of water service, compromises the entire system with enormous economic losses and damage.	1

Activity 6: Evaluation of potable water use risk

The potable water use risk is defined as the product of intrinsic vulnerability of the system and damage

$$R = V \cdot D$$

Activity 7: Evaluation of quality of management

The evaluation of quality of management is done through a series of indicators that allow monitoring of management and maintenance of the system and comparison between different management profiles.

Some examples of these indicators are the average losses in % for distribution water system, absolute average losses for distribution water system, index of average duration of the water supply service interruptions.

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

Activity 8: Database study

Data acquired through the various study phases must be elaborated and organized so as to be easily used and consulted. Besides the parameters previously used to estimate the potable water use risk, it can be useful also extract other information; all aspects of the system that constitute the work and the related fault modes, processes achieved and possible deviations, presence of external events that caused dysfunction must all be examined in detail. Once a list is extracted for all the possible cases of failure, it is necessary to analyze, in a complete and detailed manner, the way the flaw takes place. This will allow the highlighting of the existing cause-effect relation, in order to decide on which corrective methods should be employed.

CONCLUSION

Sustainability of water resources management, the necessity to provide users with potable water with high-level standards, is objectives that can be obtained if sustained by a correct know-how and adequate analysis of the potable water use risk. This study focused on finding the factors that influence such risk and suggest a first proposal for an evaluation method. Such method uses a series of factors that best represent the intrinsic vulnerability of the water system. The evaluation of the entity of risk has been considered to be inseperable from the consequences to the users and the activities present in the area serviced by the system. Besides the value of the index calculated through the estimate procedure, an evaluation of the quality of management has been developed as an extra means of comparison. The POTABLE_W.U.R. method proposes a comparative evaluation procedure of various aqueducts, acceptable in most cases and useful in making technical and management decisions.

REFERENCES

Alegre, H., Hirner, W., Melo Baptista, J. & Parena, R. 2000 *Performance Indicators for water supply systems.* Manual of best practices, IWA Publishing, London.

Alegre, H., Baptista, J. M., Cabrera, E., Cubillo, F., Duarte, P., Hirner, W., Merkel, W. & Parena, R. 2006 *Performance Indicators for water supply Service*, 2nd Edition, IWA Publishing London, London.

Almandoz, J., Cabrera, E., Arregui, F., Cabrera, E. & Cobacho, R. 2005 Leakage assessment through water distribution network simulation. *Journal of Water Resources Planning and Management* **131** (6), 458–466.

AWWA. 2004 Selection and Definition of Performance Indicators for Water and Wastewater Utilities.

Bao, Y. & Mays, L. W. 1990 Model for water distribution system reliability. *Journal of Hydraulic Engineering* **116** (9), 1119–1137.

COM 2005a Communication from the Commission to the Council and the European Parliament - The 2005 Review of the EU Sustainable Development Strategy: Initial stocktaking and future orientations. 37, 9.2.2005.

COM 2005b Communication from the Commission to the Council and the European Parliament - Draft Declaration on Guiding Principles for Sustainable Development. 218, 25.5.2005.

CPS 2005 *Final report of the Sustainable Development Indicators Task-Force* - Theme 70–2005/57/20/EN. 57th Meeting of the Statistical Programme Committee, Luxembourg 29 and 30 November 2005.

Esty, D. C., Levy, M. A., Srebotnjak, T., de Sherbinin, A., Kim, C. H. & Anderson, B. 2006 *Pilot 2006 Environmental Performance Index*. Yale Center for Environmental Law & Policy, New Haven.

Gupta, R. & Bhave, P. R. 1994 Reliability analysis of water distribution systems. *Journal of Environmental Engineering* **120** (2), 447–461.

International Institute for Sustainable Development (IISD). 2002 *IISDnet, Measurement and Indicators for Sustainable Development*.

Kleiner, Y. & Rajani, B. 2002 Forecasting variations and trend in water main breaks. *Journal of Infrastructure Systems* **8** (4), 122–131.

Loucks, D. P. 2002 Quantifyng system sustainability using multiple risk criteria. In: *Risk, Reliability, Uncertainty, and Robustness of Water Resources Systems*. International Hydrology Series, Cambridge University Press, Cambridge.

Maiolo, M., Martirano, G., Morrone, P. & Pantusa, D. 2005 A Sustainability Synthetic Territorial Index (ISST) to assess the sustainable management of water resources. In: *3rd Dubrovnik Conference of Sustainable Development of Energy, Water and Environment Systems*, Dubrovnik, Croatia, 5–10 June 2005.

Water Practice & Technology Vol 10 No 1
doi: 10.2166/wpt.2015.017

Maiolo, M., Martirano, G., Morrone, P. & Pantusa, D. 2006 Assessment criteria for a sustainable management of water resources. *Water Practice & Technology* **1** (1). doi: 10.2166/wpt.2006.0012.

Nachtnebel, H. P. 2002 Irreversibility and sustainability in water resources systems. In: *Risk, Reliability, Uncertainty, and Robustness of Water Resources Systems*. International Hydrology Series, Cambridge University Press, Cambridge.

Quimpo, R. G. & Shamsi, U. M. 1991 Reliability based distribution system maintenance. *Journal of Water Resources Planning and Management* **117** (3), 321–339.

Ronchi, E., Federico, A. & Musmeci, F. 2002 A system oriented integrated indicator for sustainable development in Italy. *Ecological Indicators* **2** (1–2), 197–210.

UN. 2001 *Roadmap towards the implementation of the United Nations Millenium Declaration*. Report of the Secretary General, New York.

UN. 2007 *Indicators of Sustainable Development, Guidelines and Methodologies*. United Nations, New York.

UNCSD. 2001 *Indicators of Sustainable Development, Framework and Methodologies*. UN Commission on Sustainable Development, New York.

UNCSD. 1996 *Indicators of Sustainable Development, Framework and Methodologies*. UN Commission on Sustainable Development, New York.

World Bank. 1997 *Expanding the Measure of Wealth, Indicators of Environmentally Sustainable Development*. Sustainable Development Studies and Monograph Series. No 17 World Bank. Washington, DC.

WWF. 2002 *The living planet report 2002*. Cambridge, UK.

Xu, C. & Goulter, I. C. 1998 Probabilistic model for water distribution reliability. *Journal of Water Resources Planning and Management* **124** (4), 218–228.