



Acceptable and Economic Leakage Levels in Water Supply Systems [†]

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Abstract

Definitions of Non-Revenue Water (NRW), the Economic Level of Leakage (ELL), and their components are well-established and extensively documented in the literature. However, their practical calculation is often complex, typically requiring data that may not be readily available, or which must be estimated. In particular, the methodology used to determine the ELL is frequently subject to debate. All water supply systems (WSS) seek to minimize water losses, but the key challenge lies in identifying the optimal level of loss reduction. Beyond purely financial considerations, leakage reduction activities can have significant operational, social, and environmental implications for WSS. The broader environmental context in which a WSS operates can also shape the acceptable level of NRW. In this paper, the Acceptable Leakage Level (ALL) is defined as the level of NRW that is considered acceptable for a given WSS within its societal context, but is not universally quantifiable. The ALL can differ from the ELL, and this paper presents examples from Serbia and other countries. Factors influencing ALL are also discussed, including the underlying reasons for its divergence from ELL.

Keywords: water supply systems; non-revenue water; economic leakage level; acceptable leakage level

1. Introduction

Factors influencing the magnitude of non-revenue water (NRW) are numerous [1] and can be grouped into two categories: technical and non-technical factors.

The main technical factors include the accuracy of water meters, the number of illegal connections, unbilled authorized consumption, the age and type of pipe materials, the number and condition of service connections, the quantity of available water (sources), and the topography and composition of the terrain [2]. High and, particularly, fluctuating pressures are a major cause of leakages and high losses in many systems [3].

The main non-technical factors include population density, climate, user habits, and the level of importance assigned to maintaining NRW below a certain threshold. The water price (WP) affects water consumption and, consequently, losses in water supply systems (WSS). These factors do not have the same level of importance, as is discussed later. Some have similar implications for WSS, such as climate and user habits (often related to water availability), or topography and pressure levels, including variability in pressure. Moreover, most of these factors vary from country to country and even between systems



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within the same country. Certain factors are strongly correlated with NRW; however, none of these can be defined with precise mathematical relationships.

The Economic Level of Leakage (ELL) represents the optimal point at which the cost of leakage control equals the value of the water saved. The Apparent Level of Leakage (ALL) is a much more dynamic category, and depends on several factors.

The paper presents WP, NRW, and additional descriptive data for 19 cities in Serbia, along with the national average. Data at the average national level for 14 European countries, each with more than 20 constituent cities, are also provided.

The Section 3 analyzes the potential impact of different factors on NRW.

The Section 4 summarizes the findings, highlights selected correlations, and aims to identify the most influential factors affecting NRW levels and the relationship between ALL and ELL. It should be noted that the conclusions derived are specific to the countries examined and may not be universally applicable.

2. Materials and Methods

For the purpose of this study, available data sources for Serbia and other European countries were examined for data on WP (for both drinking water and sewerage) and NRW, as defined by the International Water Association. These data were then collected and analyzed.

Data were collected for a total of 19 Serbian municipalities/cities, along with average values for Serbia as a whole. Data were also collected for a total of 14 European countries, namely, Italy, Montenegro, Croatia, Bulgaria, Romania, Hungary, Greece, Spain, France, Czechia, Germany, Netherlands, Denmark and Norway, along with mean values for the European Union (EU).

Additional technical data regarding NRW targets, pipe materials, pressures in WSS, maintenance and other factors were also collected.

3. Results and Discussion

Collected data are summarized in Table 1, while the data sources are listed below the table.

Table 1. Water price and NRW (%) in some European countries and cities *.

N _o	Country	City (or Country Average)	WP ¹ (€/m ³)	NRW (%)	Goal and/or Note	Remarks
1		Average	1.1	43	To reach EWP which is ≈2 times higher. To reduce NRW by 5–6% ²	Much better rating when classified with ILI than through NRW%
	Serbia	Beograd	1.1	32	NRW → 30% ² variable P in WSS	Belgrade NRW has decreased by a few % in the last several years
	Majority of WSS have insufficient investments in maintenance and development. Significant presence of asbestos cement (ACC) pipes older than 40 years—average share of ACC pipes in Serbian WSS is about 25%. In one WSS, high percentage of malfunctioning flowmeters evident.	Novi Sad	1.3	30	NRW → 29% ²	Relatively uniform P in WSS
		Niš	1.0	52	NRW → 43% ²	Very extensive network
		Kragujevac	1.3	45	NRW → 40% ²	Very extensive network
		Čačak	1.1	46	NRW → 40% ²	Relatively extensive network
		Leskovac	1.3	44	NRW → 39% ²	Uniform P in WSS, very extensive network
		Kraljevo	1.1	39	NRW → 36% ²	Relatively extensive network
		Sombor	1.5	26	To keep NRW stable	Uniform P in WSS
		Knjaževac	1.1	50	NRW → 42% ² , Replaced 15 km of pipelines (9 km main)	Replaced 10% of flowmeters, too. In total, NRW has decreased 16% in the last 8 years
		Lajkovac	1.3	59	NRW → 46% ²	Low level of maintenance
		Titel	1.0	20	To keep NRW stable	Uniform P in WSS

Table 1. Cont.

N _o	Country	City (or Country Average)	WP ¹ (€/m ³)	NRW (%)	Goal and/or Note	Remarks
	¹ / ₃ ACC pipes →	Bor	1.3	55	NRW → 44% ²	Variable P in WSS
	One WSS for whole Munic.	Ruma	1.3	52	NRW → 43% ²	Uniform P in WSS, very extensive network
	One WSS for whole Munic.	Sremska Mitrovica	1.4	51	NRW → 43% ²	Uniform P in WSS, very extensive network
		Šabac	1.0	34	NRW → 32% ² , Uniform P in WSS	Extensive network, good maintenance
		Tutin	0.5	55	NRW → 45% ² , old pipes	Karst, variable P in WSS
		Indija	1.2	30	NRW → 29% ²	Uniform P in WSS
		Kovin	0.9	36	NRW → 34% ²	Relatively uniform P in WSS
		Boljevac	0.8	65	NRW → 48% ² , Main pipeline need replacement, high NLC	Small town with abundant water resources, low level of maintenance
2	Italy Over 60% of pipes are over 30 years old, with 25% over 50 years old.	Average ³	3.1	42	To significantly reduce NRW where are >45%	Data 2022, NRW lower in north Italy compared to other parts
		Milano	2.3	11	To keep NRW stable. One of the lowest WP values, and the lowest NRW in Italy.	
		Bari, Sardinia, Sicilia	2.6 ÷ 3.5	50 ÷ 55	To reduce significantly NRW	Some of the highest NRW in Italy
3	Montenegro	Average ³	1.0	63	To reduce significantly NRW	Real losses are greater, but apparent losses are significant
	Very significant apparent losses	Podgorica	0.8	58	To reduce significantly NRW	NRW varies year to year (49 ÷ 59%)
		Bar	1.3	77		High NRW due to low level of maintenance
		Nikšić	1.1	75		High and variable P
		Herceg Novi	1.0	73		High and variable P
		Tivat	1.0	34	To keep NRW stable	Relatively uniform P in WSS, good maintenance
4	Croatia	Average ³	1.9	49	To reduce significantly NRW	
	Real losses dominant, but apparent losses are not negligible	Zagreb	2.0	48		
		Samobor	1.6	50		
		Split	1.9	60		
		Osijek	1.7	44		
		Rijeka	2.1	31	To keep NRW stable	Relatively good maintenance
5	Bulgaria	Average ³	0.8	60	To reduce significantly NRW	Debatable maintenance
		Sofia	0.9	60	To reduce significantly NRW	Debatable maintenance in the past
6	Romania	Average ³	2.9	44	To reduce NRW	Old pipes, debatable maintenance
		Bucharest	2.1	<40	To reduce NRW further	NRW ≈ 45% before interventions due to aging pipes
7	Hungary	average ³	2.1	28	To reduce NRW in certain cities	
		Budapest	1.7	up to 25	To keep NRW stable	
8	Greece	Average	up to 1.0	29	Keep NRW stable and to optimize water infrastructure [4]	
9	Spain	Average ³	2.3 ÷ 2.4	23	To keep NRW stable	
10	France	Average ³	4.1	20 ÷ 23	To reduce NRW in cities with where NRW (>50%)	

Table 1. Cont.

N _o	Country	City (or Country Average)	WP ¹ (€/m ³)	NRW (%)	Goal and/or Note	Remarks
		Paris	3.7	<20	Predominantly real losses	In general, in France the bigger cities have WP and NRW below the French average
		Velizy-Villaco- ublay	5.5	No data	Small city, Paris suburb	
		Lyon	3.2	Below the French average	Predominantly real losses	
		Marseille	4.0			
		Nantes	3.6			
		Strasbourg	2.9			
11	Czechia	Average ³	3.5	15	(NRW) values in Czechia have significantly decreased, from near 40% in the 1990s to around 15% in 2024	
12	Norway	Average ³	free	35	Drinking water is free, while EWP is estimated ≈5.5 €/m ³	Abundant fresh/clean water sources, no uniform P generally, losses are not in focus
13	Denmark	Average ³	9.0 (till 2 years ago 5.0)	8	Uniform P, low NRW in focus. PUCs pay penalties if NRW > 10%. In general, 1/3 of WP is for WS, and 2/3 for wastewater collection and treatment. Consumption has decreased after increasing WP, but bills have stayed about the same	
14	Germany	Average ³	4.5	6	Great care is taken to keep losses low	In majority of cities WP varies from 3.5 to 5.0 €/m ³
15	Netherlands	Average ³	4.0	5	Great care is taken to keep losses low	In majority of cities WP varies from 3.0 to 4.5 €/m ³ . Flat terrain in whole country
16	EU mean	Average ³	3.0 ÷ 3.3	25	WP and NRW vary widely among countries and cities	

* Sources: (a) <https://www.waternewseurope.com/water-prices-compared-in-36-eu-cities/> (URL accessed on 10 February 2026). (b) https://www.udruzenjevodovoda.org/wp-content/uploads/2025/03/Cene-vode-i-kanalizacije_presek-februar-2025-min.pdf. (URL accessed on 10 February 2026) (c) https://www.ttigroup.co.rs/wp-content/uploads/KOMDEL_Istra%C5%BEivanje_cene-u-regionu_2017.pdf (URL accessed on 10 February 2026). (d) Data from the PUC websites of certain cities. ¹ Water prices include price for drinking water and price for removal and purification of wastewater (in whole column). ² Majority data for Serbia are from 2024 or 2025. Goal (estimation) to decrease NRW in Serbia is linked with the goal to decrease ILI, and with established correlation between ILI and NRW (%) [5]. ³ Approximate values for WP and NRW, majority of data are from one of the last five years.

In order to investigate potential relations between collected data, several correlations and dependencies between NRW and selected factors are now analyzed and discussed. The influences of various technical and non-technical factors on NRW are discussed as well.

3.1. Correlation Between WP and NRW

This analysis excludes two outliers: Denmark, which has by far the highest WP, and Norway, where drinking water is free in the majority of WSS. Analyzing data for national average level, the relationship shown in Figure 1 is obtained. As expected, there is a trend that a higher average WP leads to lower NRW values.

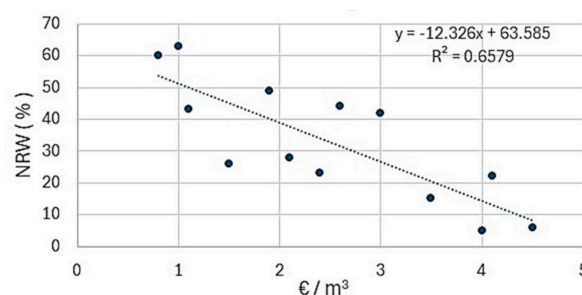


Figure 1. Correlation between average values, at national level, of WP and NRW for 13 countries.

Figure 1 also presents the corresponding linear regression. The coefficient of determination is 0.6579, indicating the presence of a correlation, though only of moderate strength.

3.2. Correlation Between Average Pressure in WSS and NRW

Papers [2,5] provide data on estimated average pressures in water distribution networks and NRW (%) values for 65 WSS in Serbia and Montenegro. Figure 2 presents the correlation between these two parameters for all 65 WSS, as well as for averages calculated for each pressure category.

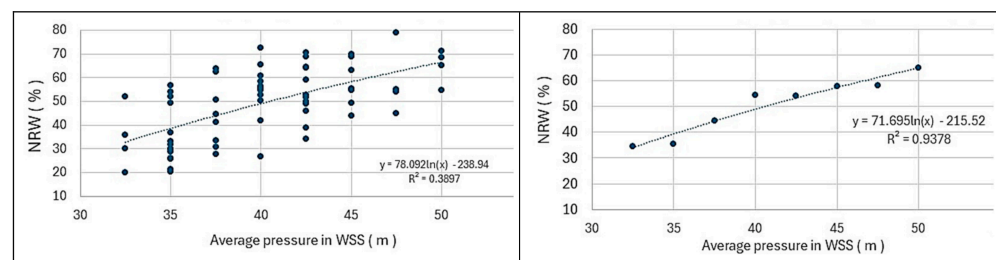


Figure 2. Correlations between average system pressure and NRW for 65 WSS in Serbia and Montenegro, including category-wise averages for 2.5 m pressure intervals.

Comparing losses in Montenegro (predominantly mountainous areas), central Serbia (predominantly hilly areas), and northern Serbia (predominantly flat areas), average NRW values are approximately 60–65%, 45–50%, and 30–35%, respectively [2,5]. In addition to possible differences in user habits and levels of apparent losses, it is noteworthy that with more topographically variable terrain and higher average pressures in the distribution network, NRW also tends to increase. Naturally, conditions differ significantly from system to system within each of the three geographical regions.

The example of the Scandinavian countries Denmark and Norway is also informative. In Denmark, the average NRW is around 8%, whereas in Norway it is about 35%. In addition to differences in WP, a likely differing institutional emphasis on NRW control, and the less favorable climate in northern parts of Norway, the topography of the terrain clearly plays an important role. In Norway, detailed zoning of the network, with smaller pressure ranges per zone, has been adopted as a primary systemic measure.

One important reason for the low NRW in the Netherlands is the fact that the entire country is essentially flat, and maintaining low P in WSS is technically feasible.

3.3. Factors Affecting the Level of NRW in Serbia

The main reasons for the relatively high NRW in Serbia are decades of insufficient investment in WS infrastructure and a low WP which barely covers the operating costs of public utility companies (PUCs). The main specific factors influencing the level of NRW in Serbia are:

- C1. Technical factors: Age of the network and pipe material (particularly critical for the main transmission pipelines), topography of the terrain in relation to network pressure, and spatial dispersion of the network.
- C2. Non-technical factors: Water meter accuracy, authorized but unbilled consumption, institutional capacity of PUCs, and the level of managerial initiative.

C1: Due to long-term underinvestment, the average pipe age is about or more than 40 years. For certain pipe materials, cracking (e.g., ACC) occurs easily under stationary conditions and even more easily under transient hydraulic conditions. The impact of deteriorated main pipelines conveying water from karst springs or reservoirs (predominantly ACC) on NRW is illustrative: the cities of Aleksinac (DN 800, 8 km), Bojnik (DN 300, 13 km),

and Boljevac (DN 250, 7 km) have real losses close to 10% of abstracted water [5]. The city of Knjaževac has reduced NRW from 66% in 2017 to 50% in 2024 by replacing 15 km of pipelines (9 km of mains) and approximately 10% of flowmeters. The city of Bor has reduced NRW by 5 percentage points (from 60% to 55%) by replacing malfunctioning flowmeters. One of the reasons for the still high losses in WSS Bor is the presence of old ACC pipes in about one third of the WSS. Many cities exhibit high NRW due to highly dispersed networks but still have acceptable ILI values [5]; examples include Aleksinac, Knjaževac, Loznica, Sremska Mitrovica, and others.

C2: The influence of water meter accuracy and authorized but unbilled consumption (more pronounced in the past than today) is direct and evident (and was partially mentioned above). The institutional strengths of PUCs and the entrepreneurial attitudes of their staff are also important. In general, smaller WSS tend to have a higher NRW for two main reasons: limited financial resources, and an insufficient number of qualified technical personnel. Although WP is low nationwide (barely covering operating costs), some stronger PUCs have achieved reductions in losses. The cases of Belgrade, Knjaževac, and, especially, Novi Sad are instructive. While PUC Belgrade, as the utility of the capital city, receives substantial support, and Knjaževac has obtained external loans, PUC Novi Sad reduced NRW by 6 percentage points (from 30% to 24%) over two years using only internal resources and without external funding, about 15 years ago [6]. However, without sustained financing, this effort could not be maintained and losses soon returned to previous levels.

3.4. Dependence of NRW on the Priority Assigned to Loss Reduction Within the Water Supply System

Germany, Austria, and the Netherlands are countries in which water losses are not regarded solely as an economic issue, but also as a matter of benchmarking and performance standards; therefore, they maintain very low NRW levels.

As noted earlier, the average NRW in Denmark is around 8%. An important contributing factor is that water utilities are subject to penalties if NRW exceeds 10%.

In recent years, the national average NRW in the Czech Republic has been around 15%, which represents a major success, given that the average level was more than twice as high approximately 25 years ago.

Milan, Italy [7], is another illustrative example. The Milan WSS maintains low losses (11–12%), well below the Italian national average ($\approx 42\%$). NRW in Milan is regularly monitored, and the adopted strategy includes the full range of procedures recommended in the literature—from loss analysis according to the IWA methodology to the implementation of key measures for reducing (or keeping under control) both apparent and real losses.

In several cities in the Balkan region, such as Belgrade, Novi Sad, Rijeka, and Tivat, systematic attention is also devoted to NRW. Although current losses are still around 30%, they have decreased over the last 10–15 years and are now significantly lower than the corresponding national averages.

3.5. Acceptable and Economic Leakage Levels in Water Supply Systems

Depending on the values of the factors influencing NRW% and the prevailing societal attitude toward water, the acceptable level of losses (ALL) may be greater than, equal to, or lower than the economic level of losses (ELL). This is clearly a complex issue that requires more data and resources for thorough investigation; however, at this stage, several potentially most influential factors can be identified.

- (1) *Ratio of the actual water price to the economic water price (i.e., the price that enables full cost recovery).* When the actual water price (WP) is significantly lower than the

economic water price (EWP), the NRW% tends to increase (Figure 1) and the local community—although often criticizing the level of NRW%—is generally willing to accept losses that are lower than the current level but still higher than the ELL, sometimes considerably higher. The opposite is also observed: when WP is significantly higher than EWP (regardless of the reasons), NRW% decreases and the local community tends to favor loss levels that are lower than the ELL, sometimes considerably lower. It may be stated, in an approximate sense, that when $WP \approx EWP$, then $ALL \approx ELL$.

- (2) *Relationship between water availability and water demand.* When water availability (WA) is limited, the tendency to reduce NRW% beyond the ELL increases. Conversely, when WA substantially exceeds the water demand (WD) of the local community, tolerance for higher losses increases, leading to $ALL > ELL$. It may similarly be stated that when minimum WA is close to or slightly higher than maximum WD, then $ALL \approx ELL$ is likely to hold.

In addition, the good technical performance of a WSS (e.g., favorable pressure regime, relatively young network, appropriate materials) and a strong commitment within the PUC and/or the wider community to reduce and control NRW (e.g., through benchmarking) both tend to lower the ALL, in some cases even below the ELL.

4. Conclusions

NRW is jointly controlled by technical conditions and system context: higher tariffs, lower pressures, flatter topography, younger mains and accurate metering are consistently associated with lower NRW, whereas high pressures in mountainous systems, aged and brittle (ACC) transmission mains, and spatially dispersed networks lead to very high NRW, as illustrated by a comparison between Serbian, Montenegrin and Norwegian WSS and the Dutch, Danish and Milanese systems.

Institutional priority and financing are decisive for sustained NRW reduction: utilities operating under strong benchmarking/penalty frameworks and with stable funding (e.g., Germany, Austria, Netherlands, Denmark, Milan, some Czech and selected Balkan utilities) successfully maintain or achieve low NRW, while systems with low tariffs that barely cover operating costs and have weak utility capacity (many Serbian WSS) struggle to preserve achieved reductions once external or temporary support ends.

The practically acceptable loss level (ALL) in many WSS systematically deviates from the economic loss level (ELL) and is largely governed by tariff policy and water scarcity: $WP \ll EWP$ and abundant water drive ALL above ELL, whereas $WP \gg EWP$ and/or limited water availability drive ALL towards or even below ELL, implying that setting realistic leakage targets must integrate hydraulic, economic and resource availability criteria rather than technical factors alone.

Last but not least, the willingness of PUC staff and the wider community to invest effort in reducing and controlling NRW is also of critical importance.

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Abbreviations

ALL	Acceptable leakage level	ELL	Economic leakage level
NRW	Non-revenue water	ILI	Infrastructure leakage index
WP	Water price	EPW	Economic price for water
WS	Water supply	WSS	Water supply system
WW	Wastewater	PUC	Public utility company
P	Pressure	NLC	No-paid legal consumption
WA	Water availability	WD	Water demand

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