MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION

Rocznik Ochrona Środowiska

Volume 22. Year 2020 ISSN 1506-218X 593-604

Assessment of Security of Water Supply for Benissa Municipality, Spain Employing the Shannon-Weaver Model

Maciej Miazga, *Jadwiga Królikowska*
Cracow University of Technology, Poland
corresponding authors' e-mail: maciej.miazga@yahoo.com
jadwiga.krolikowska@pk.edu.pl

1. Introduction

A water supply system is a set of devices that operate closely together, namely water intakes, raw water transmission pipes, water treatment plants, retention tanks and water mains distribution pipes and related accessories.

As these elements belong to a city's critical infrastructure and play a key role in their operation, in addition to technical, technological, and economic criteria, reliability criteria must be formulated. Given that critical infrastructure protection is one of the priorities facing state authorities, the importance of tasks related to critical infrastructure not only constitute protection against threats but ensure any damage and disruption in its functioning is as short as possible, easy to remove, and does not cause additional losses to citizens and the economy.

By reliable operation of Collective Water Supply Systems (CWSS) one means the probability of supplying drinking water in the correct quantity, of a quality in accordance with accepted standards, under the required pressure at a convenient time for the consumer, and at a socially acceptable price per cubic meter (Rak 2008).

Depending on the size of the city, an external water supply system can operate in conditions in which it is within range of several water intakes, with different capacities and carrying water reserves accumulated in a tank, connected to collected water source and distributing it in a specific systematic way in terms of the water supply.

Although water supply systems are biotechnological devices with a specific structure, they stand out from other systems by being susceptible to the random nature of events which affect the functioning of a dynamic system, namely through work parameters (efficiency, pressure).

The basis for an analysis of the reliability of water supply systems, subsystems, or individual elements, depends on one's knowledge of the parameter values (estimators) from a quantitative description of their horizontal values (Wieczysty 1990). An example of assessing the one-parameter reliability of a water supply taking into account the diversification of water resources is a generalized indicator of determined *Ku* values. It is recommended to specify the required value of water shortage and the stage of completion of the system's requirements when determining the efficiency standard.

In this study, an attempt will be made to assess the security of the water supply for the coastal municipality of Benissa, Spain, as well as to determine the factors for the diversification and allocation of CWSS resources serving the municipality.

2. Analysis

Benissa is located in the province of Alicante within Valencia region on the Costa Blanca (Figure 1). The town has 10,768 inhabitants (2018 census) with a territory of 69.71 km^2 (Instituto Nacional de Estadistica 2018). Benissa's drinking water supply and sanitation network belong to the Municipal Water Supply Council of Benissa.

Fig. 1. Municipality of Benissa, Spain (City Counsil of Benissa)

The urban area presents a diverse orography in which the following landforms stand out: a four-kilometer coastal strip, characterized by cliffs and small bays; and a mountainous area featuring Sierra de Oltá (586 m), Solana (652 m), Mallá Verda and Sierra de Bernia (1,129 m).

Benissa, like most coastal municipalities, is characterized by a dispersed population living in several urbanizations located along the coast, with a higher population density (50.11%) concentrated in the administrative area of the town located in its northern part.

There are no significant industries in the community. Although in 2012 the population of Benissa was approx. 13,808 inhabitants, in the summer months the number increased by 73%, reaching 23,935 inhabitants (Pro Aquas Costa Blanca S.A. 2013). The seasonal increase in the number of inhabitants is caused by an increase in tourist traffic and the temporary occupation of homes during the summer holidays.

Between the winter period and the summer months, there is a significant difference in the quantity of drinking water distributed. Indeed, this amount can double from approx. 4,000 m^3/d to 8,000 m^3/d.

To supply water, the area has six deep wells (the use of two of which were discontinued in 2017 and nowadays constitute a reserve source), located in the mountain river valleys outside the community. The water is supplied under pressure by a pump to overflow tanks located in the hills. From here, it is directed by gravity through the distribution system with a mains diameter of 300-700 mm to three retention tanks.

Additionally, the location of three river basins, namely the: Gorgos, Girona, Bararanc de la Garganta; and two separate water divisions, are separated by the hills of Llosa de Camacho.

The total water recovered from the Water Intake System travels a distance of 11.9-16.2 km to reach the retention tanks As this helps to improve its quality, the intakes do not require pretreatment. The water is stored in three tanks whose names and capacities are as follows: Salvador 2,500 m^3, Ibiza 5,000 m^3, Europe 10,000 m^3. Located in the same facility as each other, the tanks are hydraulically connected at the same level of the water table for everyone. The water is protected against secondary contamination by dosing it with chlorine gas at the tank inlet.

The distribution of the water is carried out by gravity from three retention tanks, located at an altitude of 309.9 m.s.l. to the receivers which provide pressure to the in-line supply system with a range of up to 26 atm. The pressure of the water in the network is variable due to varying levels of consumption during the year, with a decrease in its consumption being observed during the winter by houses occupied on a seasonal basis. Changes in pressure during periods of higher temperatures from spring to fall create more major failures in the ductile iron piping system.

The water intakes have a cyclical variability in terms of the dynamic level of the water table, with this value fluctuating by approximately 100 m. The periodic water demand does not show any decrease during the rainy period from May to September, which contributes to the water table. The average immersion depth of a submersible pump during the summer months increases to an immersion depth of approximately 250 m below ground.

The "cold drop" (literally translated from the Spanish *gota fría* as "cold water drop") is a well-known phenomenon in the Marina Alta area. This climatic anomaly occurs when, at the end of summer, there is a contrast between the temperature of the sea and cold polar air. Consequently, the hot air rises rapidly to form a low-pressure, humid mass or high-altitude cyclone that moves in line with the topography and when cooled, causes this phenomenon.

In the Marina Alta area, the mountains create a barrier when the rainstorms occur along the coast. The porosity of the earth helps rainwater quickly reach the aquifers and thus the "cold drop" recovery of water levels is spectacular. Apart from causing floods, the *gota fría* usually generates strong winds of up to 150 k.p.h. provoking damage inland to trees and buildings. The phenomenon also causes storms at sea with waves that damage beaches, promenades, and boats moored in the ports (Carmen 1991, Water Office of Benissa 2020).

As the water supply system analyzed here has many variable factors in various conditions which affect its proper operation, the system requires its operators to make constant efforts to increase its reliability.

The quantity of water distributed from each water supply source in the years 2016-2019 is shown in Figure 2.

The data presented highlights the cyclically increased values of water distribution to its recipients in the summer months, July-August, and a decrease in demand in the winter months.

The percentage of water received by individual intakes has been variable during the last four years (Fig. 3), due to the exhaustion of two local wells called Canor and Benimallunt. However, these inlets remained in the water supply system as a backup in times of crises. In subsequent years, similar amounts were obtained from the exploitation of other water sources, with an increase in the share of the Corrales intake.

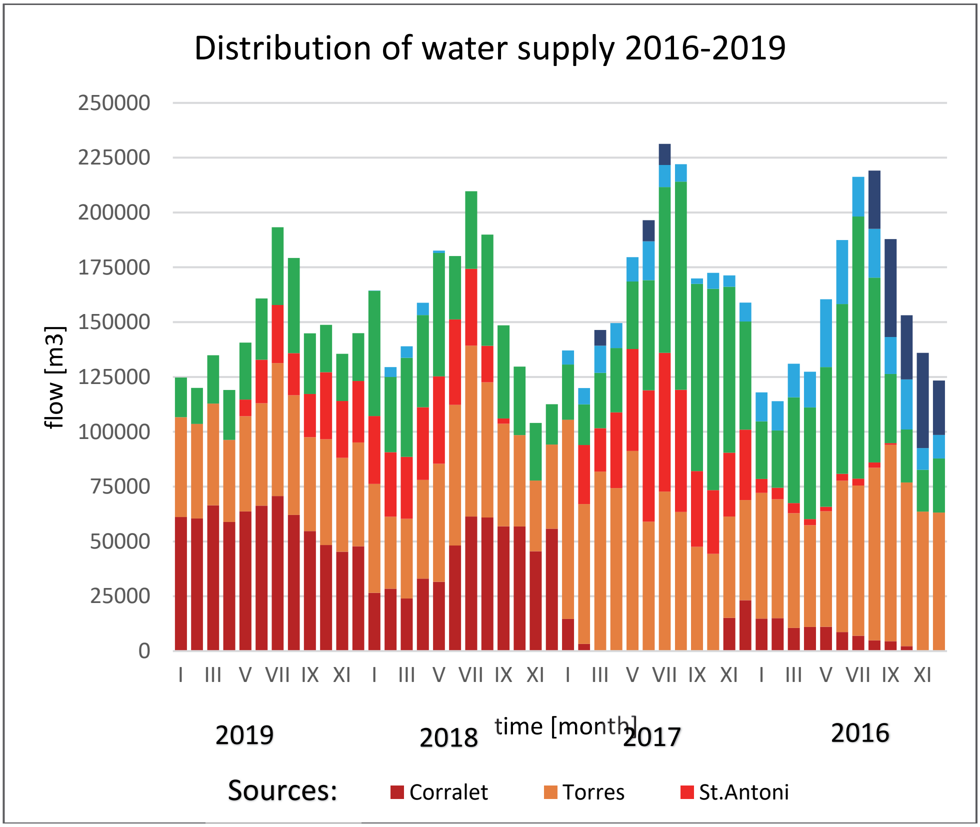

Fig. 2. Distribution of water supply 2016-2019 year (author)

3. Methods, calculations and results

The main point of this work is the calculation of the water diversification index, which is described below: The data from the collected flow tanks were analyzed using the Shannon-Weaver model.

Claude Elwood Shannon was an American mathematician and electrical engineer who laid the theoretical foundations for digital circuits and information theory, a mathematical model of communication. In 1948, Shannon published a paper entitled "A Mathematical Theory of Communication". He established the basic results of information theory such a comprehensive way that its framework and terminology are still used.

Shannon's information theory and its formulae were immediately accepted by communications engineers and continue to prove useful (Piore 1979).

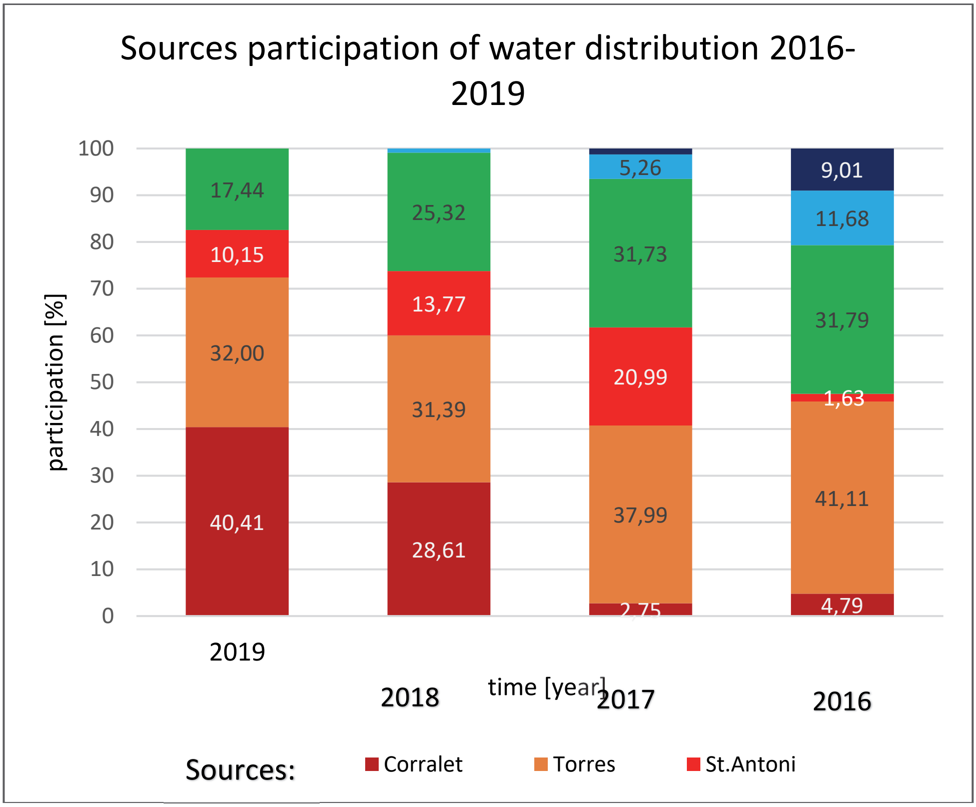

Fig. 3. Sources' share of water distribution 2016-2019 year (author)

Warren Weaver was an American scientist and administrator. He is widely recognized as one of the pioneers of machine translation and as an important figure in building support for science in the United States (Shannon 1948).

The resulting mathematical theory was later known as the Shannon-Weaver communication model or "the mother of all models". It also inspired many attempts to apply information theory in other areas, such as cognition, biology, linguistics, psychology, economics, and physics.

The diversification rate was derived from the joint work of Shannon and Weaver (Rak 2017, Shannon 1948, Shannon 1962).

The Shannon-Weaver index was determined in relation to the diversity of water intakes (d_{SWQ}) and the volume of water in networked reservoirs (d_{SWV}), i.e. a two-parameter method for assessing the diversification of water resources.

$$d_{SW} = d_{SW\,Q} + d_{SW\,V} \tag{1}$$

where:
$d_{SW\,Q}$ – an indicator of diversification of water resources,
$d_{SW\,V}$ – an indicator of water volume diversification in water tanks.

The diversification indicator according to the Shannon-Weaver model is equal to:

$$d_{SW} = \sum_{i=1}^{m} (u_i) \cdot (\ln(u_i)) \tag{2}$$

where:
u_i – share of the operating efficiency of the i-th Water Supply Subsystem (WSS) in the total water supply/ share of the volume of the i-th tank in relation to the total volume of the tanks in the network,
m – number of (WSS) tanks / network.

In this analysis, the assessment category of diversification of the CWSS in the municipality of Benissa was based on studies by Professor J. Rak. The categorization and evaluation scale of the degree of diversification of water resources for the *Shannon-Weaver* index is presented below for a one-parameter diversification shown in Table 1, while a two-parameter diversification shown Table 2.

Table 1. Category of one-parameter diversification (Rak & Boryczko 2017)

Category of diversification	Degree of diversification
fail	$d_{SW} = 0$
small	$0 < d_{SW}$ 0.325
medium	$0.325 < d_{SW} < 0.690$
advanced	$0.690 < d_{SW} < 1.390$
very satisfactory	$d_{SW} < 1.390$

Table 2. Category of two-parameter diversification (Rak & Boryczko 2017)

Category of diversification	Degree of diversification
fail	$d_{SW} = 0$
small	$0 < d_{SW}$ 0.65
medium	$0.65 < d_{SW} < 1.38$
advanced	$1.38 < d_{SW} < 2.78$
very satisfactory	$d_{SW} < 2.78$

The calculations for the Benissa CWSS took into account the variable number of water intakes (WSS) and their efficiency in the analyzed period, i.e.:

m = 6, in 2016-2017,
m = 5, in 2018,
m = 4, in 2019.

The values of the Shannon-Weaver index in relation to the diversity of water intakes (d_{SWQ}) are as follows:
$d_{SWQ(2019)} = -(0.40 \cdot \ln 0.40 + 0.32 \cdot \ln 0.32 + 0.10 \cdot \ln 0.10 + 0.17 \cdot \ln 0.17) = 1.27$
$d_{SWQ(2018)} = -(0.29 \cdot \ln 0.29 + 0.31 \cdot \ln 0.31 + 0.14 \cdot \ln 0.14 + 0.25 \cdot \ln 0.25 + 0.01 \cdot \ln 0.01) = 1.38$
$d_{SWQ(2017)} = -(0.03 \cdot \ln 0.03 + 0.38 \cdot \ln 0.38 + 0.21 \cdot \ln 0.21 + 0.32 \cdot \ln 0.32 + 0.05 \cdot \ln 0.05 + 0.01 \cdot \ln 0.01) = 1.37$
$d_{SWQ(2016)} = -(0.05 \cdot \ln 0.05 + 0.41 \cdot \ln 0.41 + 0.02 \cdot \ln 0.02 + 0.32 \cdot \ln 0.32 + 0.12 \cdot \ln 0.12 + 0.09 \cdot \ln 0.09) = 1.41$

The diversification rates received are very similar in each year, and values are high (Table 3).

Table 3. Calculation of degree of diversification by sources (author)

	Corralet	Torres	St. Antoni	Sanet	Canor	Benima-llunt		
year	u_1	u_2	u_3	u_4	u_5	u_6	d_{SW}	Degree of diversification
2019	0.40	0.32	0.10	0.17	0.00	0.00	1.27	**advanced**
2018	0.29	0.31	0.14	0.25	0.01	0.00	1.38	**advanced**
2017	0.03	0.38	0.21	0.32	0.05	0.01	1.37	**advanced**
2016	0.05	0.41	0.02	0.32	0.12	0.09	1.41	**very satisfactory**

The highest rate was obtained in 2016 and was associated with the distribution of global performance into a larger number of intakes. In 2019, despite the closing down of two intakes, the diversification index slightly decreased compared with the maximum value from 2016. The level of the indicator value depends on both the number of intakes and the performance of individual shares. In the case of the system under consideration, in 2019 the number of deep wells decreased from 6 to 4, while the 2 closed wells are wells with a very low efficiency rate throughout the system.

The water supply system of the community of Benissa analyzed here, consists of three primary network tanks for WSS: m = 3. The water allocation indicator in the water tanks is:

$$d_{SW} = -(14.29 \cdot \ln 14.29 + 28.57 \cdot \ln 28.57 + 57.14 \cdot \ln 57.14) = 0.96$$

Table 4. Calculation of degree of allocation by retention tanks (author)

	Salva-dor	Ibiza	Europa
	u_1	u_2	u_3
Capacity, m^3	2,500	5,000	10,000
Participation, %	14.29	28.57	57.14

The allocation rate of the water supply system obtained is classified as *advanced* (Table 5). Three retention tanks with a gradually varying total capacity ensure a high level of diversification of water resources.

In addition, its hydraulic interconnection provides a guarantee of continuity of water supply in times of crisis with a total quantity of less than 17,500 m^3, which will ensure its delivery to customers in the winter for 3-4 days, and in the summer months for 2 days.

Finally, the two-parameter category of diversification of water resources for Benissa CWWS for each year are as follows:

$$d_{SW(2019)} = 1.27 + 0.96 = 2.23$$
$$d_{SW(2018)} = 1.38 + 0.96 = 2.34$$
$$d_{SW(2017)} = 1.37 + 0.96 = 2.33$$
$$d_{SW(2016)} = 1.41 + 0.96 = 2.37$$

Table 5. Calculation of degree of two-parameter diversification (author)

year	$d_{SW\ Q}$	$d_{SW\ V}$	d_{SW}	Degree of diversification
2019	1.27	0.96	2.23	**advanced**
2018	1.38		2.34	**advanced**
2017	1.37		2.33	**advanced**
2016	1.41		2.37	**advanced**

The results of the diversification indicator represent the *advanced* category (Table 5) at its upper thresholds. A high level of diversification is a component of the high value of the diversification index of the intake and allocation of water resources.

4. Conclusions

The area described here is one dependent on tourism while having variable water consumption. In the municipality of Benissa there is a great need for water at the height of the tourist season which is, in addition, a period of no rainfall. When, during the winter season, this need decreases, rainfall is sporadic. Weather anomalies, the so-called *gota fría*, are becoming more common, featuring heavy precipitation, storms causing the raising of the water table, as well as, unfortunately, the destruction of existing infrastructure. The technical solutions applied to sources of water allow one to adapt the depth of pumps to the significant seasonal changes in ground water levels. Moreover, variable water consumption has an impact on variations in the pressure of the distribution system.

Despite the impact of so many variable factors, a high level of reliability of water supplies is maintained by the system analyzed here. This result is influenced by the large amount of water sources, as well as their separate location in three different river basins. The amount of water collected in active sources possesses a similar proportion of that delivered to the system. This system has three retention tanks of significant capacity built into its structure which ensure there is a high water distribution buffer.

The water distribution system constitutes the application of a system for delivering water to the municipality in variable tourism, weather and hydrological conditions. The structure of the CWSS guarantees a high level of diversification and water supply.

The obtained Shannon-Weaver indicators present values concerning the significant diversification of water sources and the allocation of their resources.

The obtained result of the diversification of water sources in 2019 (2.32) is lower than that of previous years by a very small amount. The previous year, work was halted on two sources, evenly adjusting the constituent parts of the efficiency of the remaining deep-well pumps into the most beneficial position, obtaining similar values in the total daily production of water as in previous years.

This expanded system offers a high level of reliability in adverse local conditions. In addition, it guarantees a continuous supply of water at the required pressure, at the required standard of quality (Markowsky 2020) and at a socially acceptable price (Water Office of Benissa 2020). It should be noted that such diversification and allocation of water resources is a continuous process and has to be constantly supervised.

Regarding the dynamic development of the settlement analyzed here, Benissa's Water Works are currently being expanded to include a new intake, in the form of new well reaching 400 meters underground or 100 m below sea level. Only at this depth can geologists find water of the required quality.

A final definition of the factors influencing the security of water supplies in Spain requires knowledge of the factors in the diversification and allocation of water resources for systems serving settlements with changeable and varied conditions. Further studies by the authors will be aimed in this direction.

The authors would like to express their gratitude to the Municipal Service of Drinking Water Supply of the Town of Benissa for their cooperation and help in putting this article together. In addition, we express a special acknowledgement to its director, Rubén Macho, for his commitment, dedication and sharing his valuable experience in this field.

References

Carmen, Llasat, Botija, M. (1991). *Gota fria.* Barcelona: Marcombo S.A., Collection number 6.

City Council of Benissa. (2020). *Information from the Benissa City Council*. Spain: Ayuntamente de Benisa. Información del Ayuntamiento de Benissa.

National Statistics Institute. (2018). Spain: Instituto Nacional de Estadística.

Markowsky, G. (2020). Edinburgh: *The Information Architects of the Encyclopedia Britannica*.

Piore, Emanuel, R. (1979). *Obituaries: Warren Weaver*. Physics Today.

Pro Aguas, Costa, Blanca, S.A. (2013). *Update of information on minimum hydraulic supply infrastructures in high supply*, Benissa: Alicante Provincial Council. Spain: Pro aguas Costa Blanca S.A. (2013). Actualización de la información sobre las infraestructuras hidráulicas mínimas de abastecimiento en alta. Benissa: Diputación de Alicante.

Rak, J., Boryczko, K. (2018). Diversification of the water supply. *E3S Web of Conferences, 59*, 00006.

Rak, J., Boryczko, K. (2017). *Security of water supply systems. Diversification of water resources*. Rzeszów: Publishing house of Rzeszów University of Technology (in polish).

Rak, J. (2008). *Selected problems of security and reliability in water supply*, Rzeszów: Publishing house Rzeszów University of Technology (in Polish).

Royal Direct 140/2003, of February 7, 2003, *What establishes the sanitary criteria for the quality of water for human consumption*. Spain: Real Directo 140/2003, de 7 de febrero 2003 ańo, Por el que se establecen los criterios sanitarios de la calidad del agua de consumo humano.

Shannon, C. (1948). A Mathematical Theory of Communication. *Bell System Technical Journal*, 27, 379-423, 623-656.

Shannon, C., Weaver, W. (1962). *The Mathematical Theory of Communication*. University of Illinois Press.

Water Office of Benissa. (2020). www.siguesdebenissa.com

Wieczysty, A. (1990). *Reliability of water and sewage systems*, I and II. Cracow: Publishing house of Cracow University of Technology (in Polish).

Abstract

This publication is a presentation of the methodology to determine the degree of diversification and allocation of water resources in water supply systems; with a differentiated level of need based on the example of the municipality of Benissa Spain.

The article shows a frequency of the changes and factors that affect the functioning of the water supply system. Moreover, its presents the calculation of the diversification indices for the selected water supply system while the methodology offers the possibility of evaluating the diversification of water resources in two parameters according to an adapted form of the Shannon-Weaver index.

Keywords:
diversification, allocation, resources, water supply, tanks, distribution, flow, capacity

Ocena bezpieczeństwa dostawy wody dla gminy Benissa z wykorzystaniem wskaźnika Shannona-Weavera

Streszczenie

Publikacja przedstawia metody wyznaczenia współczynnika dywersyfikacji i alokacji zasobów wodnych dla systemu zbiorowego zapotrzebowania wody cechującego się zróżnicowanym jej zapotrzebowaniem na przykładzie miasta Benissa w Hiszpanii. W pracy przedstawiono obliczenia stopnia dywersyfikacji zasobów wodnych, metodą dwu-parametryczną, wg zaadaptowanego wskaźnika Shannona-Weavera.

Słowa kluczowe:
dywersyfikacja, alokacja, zasoby, system wodny, zbiorniki, dystrybucja, przepływ, pojemność