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The Impact of the Water Consumption Regime on the Work of Reservoirs

Bojan Đurin [a]*, Jure Margeta [b], Davor Bojanić [b]

[a] Faculty of Geotechnical Engineering, University of Zagreb, 42000 Varaždin, Hallerova Aleja 7, Croatia

[b] Faculty of Civil Engineering, Architecture & Geodesy, University of Split, 21000 Split, Matice Hrvatske 15, Croatia

* Corresponding author. *e-mail address:* bojan.djurin@gfv.hr

Abstract

Reservoirs in water supply systems have technological, energetic and security functions which are very important for the overall sustainability of water supply. The change in water consumption regime and/or flow of water into the reservoir affects the water balance in the service reservoir and water pressure in the water supply network. This paper analyzes the changes that occurred in the water consumption regime in Croatia and their effect on the water supply system and its sustainability. It has been found that the changes are significant as well as impacts on energy use, water losses and reliability of water supply. Based on the analysis, the functional dependencies between the key input variables and the operation of the system have been defined and recommendations given for practice.

Key words: water supply; reservoirs; water consumption regime; specific consumption; water losses; potential water loss.

1. INTRODUCTION

Croatian society is in a kind of transition from the former system of planned economy to market economy (Rafajac, 2007), and there is a growing trend towards urbanization of major cities and depopulation of large rural areas. In addition to these changes, there is a strong trend of declining population, aging population, reduction in economic activities and standards of living (Radman et al, 2011, Croatian geographic society, 2014). All these changes result in changes in the regime of water consumption in residential areas. We should not forget climate changes and increasingly pronounced climate extremes that also gradually affect the water consumption regime as well as water availability.

These changes affect the work of water supply system and especially conditions in the water service reservoirs. Reservoir has an important role in regulating the water regime in the water supply system. That why, it is necessary regularly analyse changes in water consumption and impact on reservoir behaviour. The paper analyzes the impact of the change in water consumption regime on the work of reservoirs, as well as on pressure changes in the water supply network.

Water reservoir is a facility of the water supply system that has the function of storing water, providing operating pressure and safety of water supply (Margeta, 2010). It significantly affects the economic efficiency of the water supply system and is important for its overall sustainability. It equalizes the water inflow and water outflow (consumption) and provides a reserve of water for fire or other incidental situations. On the other hand, the reservoir regulates energy and pressure relationships in the water supply system and therefore affects the energy and economic efficiency of the system as well as environmental impacts. The pumping system that pressurizes water in the reservoir is the largest consumer of energy in the water supply system (Sanders and Webber, 2012). Exceptions are water supply systems that use sea desalination for drinking water (Sanders and Webber, 2012, Koutsoyiannis, 2011). Another exception is fully gravitational systems that do not use pumping stations. The position of the reservoir is a boundary condition for hydraulic relations in the water supply network and the related potential losses of water and energy. Altitude position in relation to water intake and supply areas and the available volume are variables that determine the framework where we seek to achieve economic efficiency of the pumping system operation.

Water supply areas are dynamic socio-economic systems that are permanently changing with the changes in socio-economic conditions, urbanization, employment etc. The climate and water needs, the importance of water and water availability, and the cost of water and energy are also changing (Kundzewicz, 2008). Annual and daily regime of water consumption in the water supply area has a large impact on performance and sustainability of the water supply system. It determines the required pipe dimensions, water reservoir volume and hydraulic characteristics of the system. The system must not be oversized because it would be irrational in terms of investment (unused capacity and capital) and operating (high pressure, system load and losses of water and energy), but neither should it be undersized, because then it would not provide satisfactory water supply.

Therefore, a good estimate of the annual and daily water consumption regime has always been a challenge for designers. The system is designed for long periods of time, a minimum of 20 years, and the water consumption regime in the water supply area is possibly known from the previous period. Therefore, designers seek to estimate as best as possible the possible water consumption regime for different development periods of the system. Phased construction of key facilities aims to rationalize investments, reduce risk and increase efficiency. This primarily relates to the water reservoir and the capacity of pumping stations and main pipes, while the water supply network is mostly built for the final period of development.

The issue addressed in planning and design of water reservoirs is to define the optimum volume and altitude in relation to the planned arrangement of users in an area for the water pumping regime into the reservoir and water consumption in the supply area, and the required level of security of supply and working pressure. The aim is to obtain the minimum possible pressure in the water supply network that meets the constraints related to fire protection, and minimum pressure at the water outlets. This provides good prerequisites for reducing uncontrolled water losses and damages in the water supply network. It directly affects water pumping efficiency into the reservoir and total energy consumption. We should not forget that reduction in energy consumption has a direct impact on reducing greenhouse gas emissions. Optimum reservoir volume is the result of economic analyses related to the costs of building a reservoir and pumping system, and the costs of water pumping. When planning all is analyzed based on the expected working conditions in the planning period, with more or less reliable data (Margeta, 2010; Narodne Novine, 2006).

Most of the existing water supply systems in Croatia were designed for the socialist socio-economic system where planned economy and social cost of water dominated. Since the 1990s we have been in transition from the previous system into a market economy in which the water is a commodity like any other, with the appropriate social function. The same applies to energy and other resources. As a result of the changes, we are faced with the change in water consumption regime, i.e. specific consumption and unevenness of water consumption. These changes were caused by the introduction of economic price of water, changes in working hours in public institutions, trade and industry, and educational and other institutions. A logical question is how these changes affect the operation of the existing reservoirs and whether the available capacity of reservoirs is sufficient under the new circumstances, and how this affects the sustainability and energy efficiency of the system. In this paper, we will try to provide some possible answers to these questions.

2. THEORETICAL AND ENGINEERING BASIS OF SIZING WATER RESERVOIRS

Total reservoir volume V_U (m^3) consists of volumes (Margeta, 2010):

$$V_U=V_1+V_2+V_3+V_4+V_5 \quad (1)$$

where various values are volumes for:

- equalization V_1 (m^3);
- fire extinguishing V_2 (m^3);
- incident situations V_3 (m^3);
- ensuring the minimum level of water required to maintain the pressure V_4 (m3);
- interruption of inflow to support the flow of water into the water supply network V_5 (m^3).

The largest part of the reservoir volume consists of volumes (V_1 + V_2 + V_3), while volumes (V_4 + V_5) are relatively small compared to the total volume.

Reservoirs are typically sized for one-day equalization of supply and consumption of water in a day of maximum consumption, and volume for incidental situation is added to the calculated values, Figure 1. The required size is determined for the initial period of reservoir operation and final planning period, and typical development interim periods where a significant change of the required reservoir volume is expected (change in water consumption regime). It is also necessary to analyze the operation of reservoirs for seasonal variations in water consumption, if these are significant, such as in our coastal tourist areas.

In relation to the time intensity of water changes, reservoir volume is divided into:

- regular daily exchangeable volume V_A;
- occasionally exchangeable volume V_B.

Volume V_A primarily consists of volume V_1 which changes regularly every day in the reservoir. Volume V_B is a more or less randomly renewable reservoir volume and consists of volumes V_2, V_3,

V_4 and V_5. Due to the stated properties, this paper will analyze only the volume V_A, referred as V hereinafter.

Volume V is determined by graphical or numerical procedure by integral curve methodology (Margeta, 2010). It is a simple methodology which is based on the fact that in the period of exchange all water that flowed into the reservoir flowed out of it.

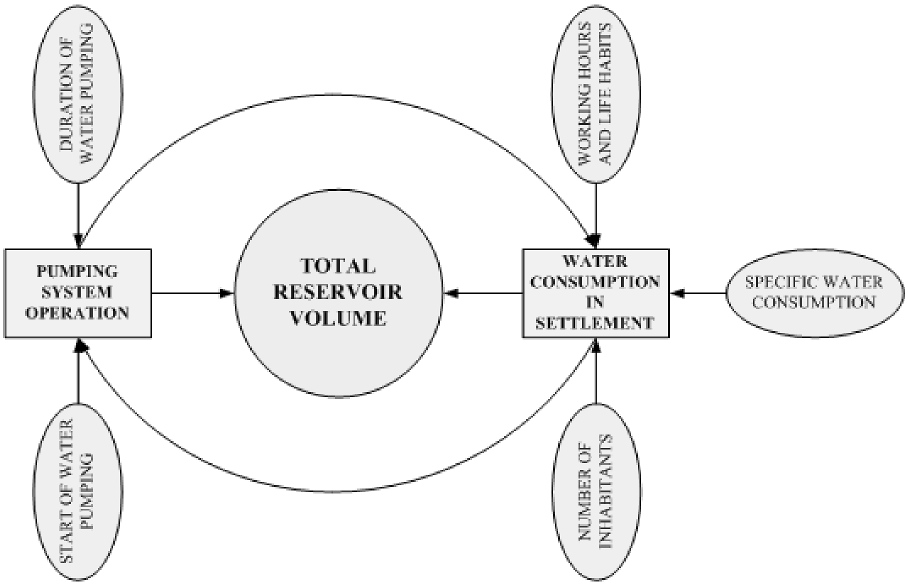

Figure 1. The system within which urban water supply occurs

The flow of water into the reservoir is realized by pumps. In practice the work of pumps is mainly planned in two ways:

- by continuous work of pumps in duration of t = 24 hours with a flow rate which is equal to the medium flow in the maximum daily consumption;
- by intermittent pump operation, typically in periods of cheaper electricity (from 21 to 7 or 22 to 8) or in another period, according to the available volume and needs (Hrvatska Elektroprivreda, 2014).

Intermittent work of pumps in the period of cheap energy results in higher dimensions of the pumping system, higher installed power of pumping generators, shorter duration of pumping and usually lower overall energy costs. Continuous 24h pump work results in the lowest possible installed capacity of pumps and power, dimensions of pressure pipe and all other elements of the pumping system, but with higher energy costs. There are various possibilities of work according to the characteristics of the water supply system.

Due to a big impact on operating costs, the system "pumping station-reservoir" is usually optimized. It is a water infrastructure system with clearly defined boundaries, inputs, outputs and constraints, where the altitude position of facilities determines the hydropower potentials of the system, Figure 2. Water flow into the reservoir and pumping station operation are a controlled input, i.e. control variable controlled by the operator. Water reservoir must not have uncontrolled inputs. Reservoir output is the water consumption in the supply area, preferred or planned output, which is an uncontrolled variable because it is more or less constantly changing, due to water consumption in a settlement and water losses in the water network. In the calculation it is used as default value of hourly water consumption in the supply area. Adverse output is uncontrolled leakage in the water supply system, such as ruptured pipeline, water theft and similar.

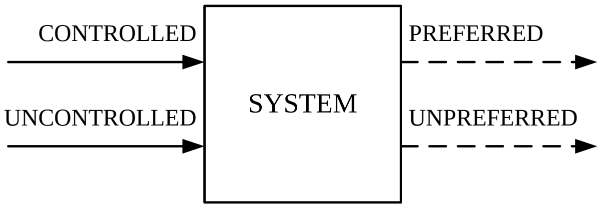

Figure 2. The concept of the system state model

The system has its limits, constraints and objectives. In this case the limits are built parts of the system "pumping station-water reservoir." Constraints are related to the allowed state of reservoir volume *V*:

$$V_{min} \le V \le V_{max} \tag{2}$$

the pumping station capacity Q_{PS}:

$$Q_{PS\,min} \le Q_{PS} \le Q_{PS\,max} \tag{3}$$

and the capacity of the output/supply pipeline $Q_{out,pipe}$:

$$Q_{out} \le Q_{out.pipe} \tag{4}$$

The objective of managing the system is to achieve the greatest possible economic and functional efficiency, i.e. to minimize operating costs and water losses. Precisely because of the fact that water consumption is constantly changing, the system operation cannot be uniquely determined in advance. Therefore, it is necessary to continuously analyze and optimize the operation of the "pumping station-reservoir" system, especially in situations where change occurred relatively quickly.

Following is the analysis of the effect of changes, as well as changes in general, in water consumption regime in a settlement on the required size of the reservoir volume V. In addition, we analyze the impact of the change in water consumption regime on hydraulic characteristics of the water supply system and possible losses of water and energy.

3. ANALYSIS OF THE IMPACT OF THE CHANGE IN WATER CONSUMPTION REGIME ON RESERVOIRS CAPACITY

3.1 Analysis of the change of working hours and habits of life on the required reservoir volume

Over the last 20 years, Croatia has been faced with the trend of changes in economic activity, working hours and habits of the population in relation to water consumption. In the former socio-economic system the usual working hours were from 6 to 14, while today they are mostly from 8-9 to 16-17. It has changed the habits of the population which affects the regime of water consumption. The standard water consumption regime during the day was characterized by three distinct extremes of peak water consumption (morning, early afternoon and evening), which were more pronounced in smaller towns than in larger ones (Figure 3). By switching to new work hours, the three extremes of water consumption gradually disappear, and only two are expressed, morning and evening, which are also smaller in larger settlements than in smaller ones (Figure 4). Three daily consumption peaks are mainly retained in rural areas.

At the same time, there is a reduction in water consumption in this transitional period. This is due to the increased cost of water, but also to the replacement of old irrational household appliances with new ones which use significantly less water (e.g. toilet flush). The result is that the average domestic requirement (q_{spec}) is at least halved compared to the period before 1990 and today it is from 100 to 150 l/capita/day (Margeta, 2010). All these changes affect the work of the water supply system and the availability of capacity, due to which the operation of the system should adapt to new conditions in order to be sustainable. The objective is to make maximum use of the available infrastructure in order to reduce energy costs and water losses. To determine the size and impact of changes on the operation of the system, a hypothetical example of a village of mixed type construction, of M = 8970 inhabitants has been analyzed.

3.2 Change in water consumption variation

3.2.1 Example I - Previous period

Average water demand of q = 250 litres/capita/day has been adopted, as well as constant flow of water into the reservoir. The usual daily water-use patterns in this period had three daily extremes (Figure 3). The results are shown in Table 1.

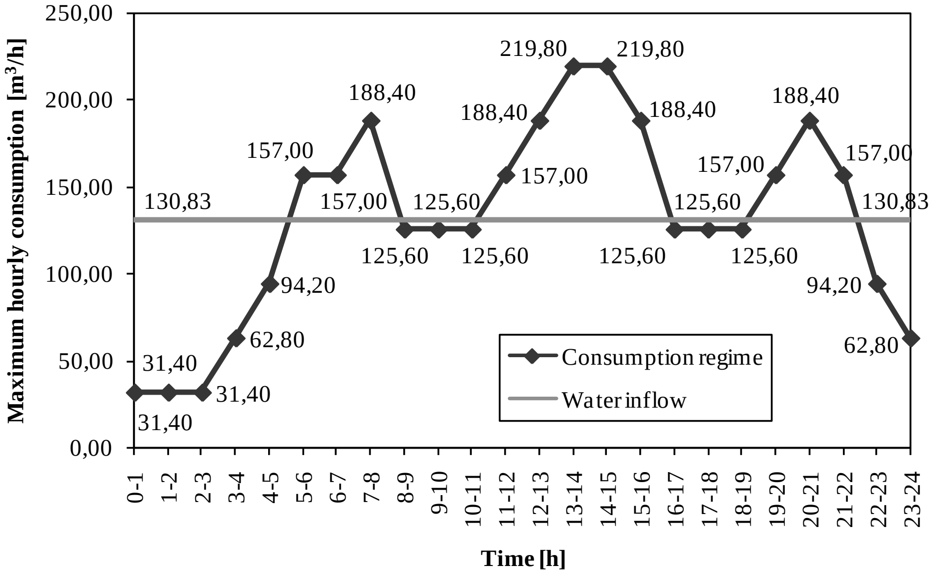

Figure 3. Water inflow and daily water-use pattern for Example I

3.2.2 Example II - Current and future period

The current average water demand is about q_{spec} = 140 l/capita/day, which is usual for the urban settlements in European Union (EU). The flow of water into the reservoir is constant and the daily water-use pattern is characterized by two water consumption extremes (Figure 4). The results are shown in Table 1. where $K_{D,max}$, $K_{,H,max}$ and $K_{H,min}$ are coefficients of maximum daily consumption, maximum daily and minimal daily variations of water consumption. Q_{max}^{daily} is maximum daily consumption, Q_{PS} is pump station capacity, Q_{max}^{hourly} and Q_{min}^{hourly} are maximum and minimum hourly consumption and ΔQ^{hourly} is difference between Q_{max}^{hourly} and Q_{min}^{hourly}.

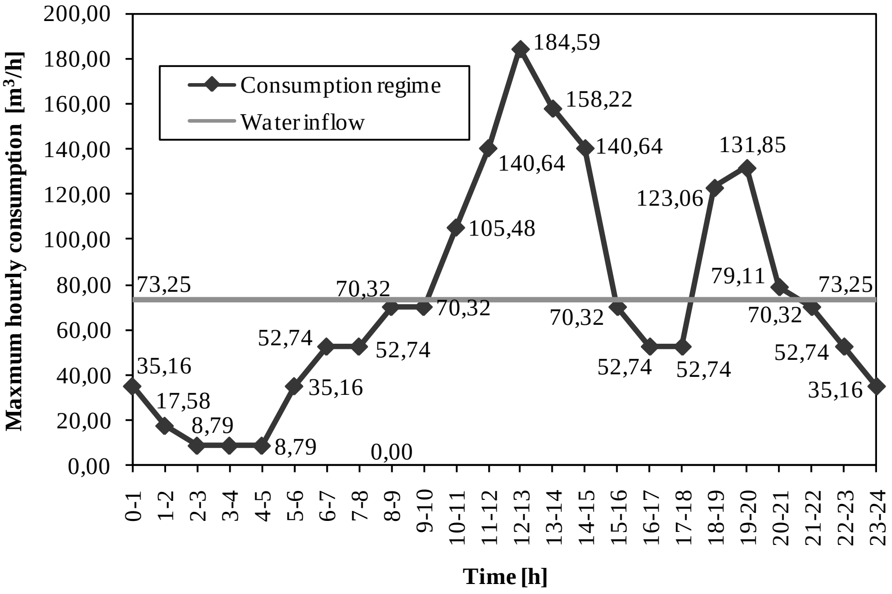

Figure 4. Water inflow and daily water-use pattern for Example II

Table 1. Typical values for Examples I and II

Typical values	Example I	Example II
Number of inhabitants M	8970	8970
q_{spec} [l/capita/day]	250	140
$K_{D,max}$, $K_{H,max}$, $K_{H,min}$	1.4, 1.68, 0.24	1.4, 2.52, 0.12
Q_{max}^{daily} (m^3/day)	3140	1758
Q_{PS} (m^3/h)	130.83	73.25
Q_{max}^{hourly} (m^3/h)	219.80	184.59
Q_{min}^{hourly} (m^3/h)	31.40	8.79
ΔQ^{hourly} (m^3/h)	188.40	175.80
V_A (m^3)	507.69	433.64

From these results it is clear that the required volume in the new conditions is lower, although a higher coefficient of maximum hourly unevenness is used. It is also evident that the required pumping station capacity is significantly less. This result was expected and is the result of a significant reduction in average domestic water consumption. Thus, we can conclude:

- That the changes in society most likely generate excess available capacity of reservoirs (about 15%), therefore the existing reservoirs will be able to satisfy the needs longer than originally planned.
- That the necessary pumping system capacity decreases (by about 44%) and that it will meet the needs over a longer period of time than planned.

The results were expected because the decrease of specific water consumption is big and therefore the required capacity of the water supply system has decreased. The reduction of the required reservoir volume is small, about 15%. However, if this reduction is compared to the reduction in mean daily water consumption, by about 44%, it is evident that the new regime of water consumption demands greater volume for levelling flow than the previous one, so that these two trends of change partly cancel each other out. This is the result of increasing the coefficient of hourly unevenness as a result of an increase in water consumption in two daily periods instead of three.

3.3. Influence of hourly unevenness coefficient

It is known that hourly consumption of water is most influenced by the size of a settlement. Where a settlement is larger the maximum hourly consumption is relatively smaller, and the minimum consumption is relatively higher. The maximum and minimum hourly consumption are significantly affected by economic activities in the area of consumption, so that there is no reliable rule which would determine them. Various guidelines from literature are most commonly used, (Margeta, 2010; Swamee and Sharma, 2008).

The impact of the coefficient on the required reservoir volume is analyzed in the following example. While retaining the same daily consumption of water, the hourly maximum and minimum for example II were changed, so in addition to example IIa, two examples, IIb1 and IIb2, were analyzed. The results are shown in Figure 5 and Table 2.

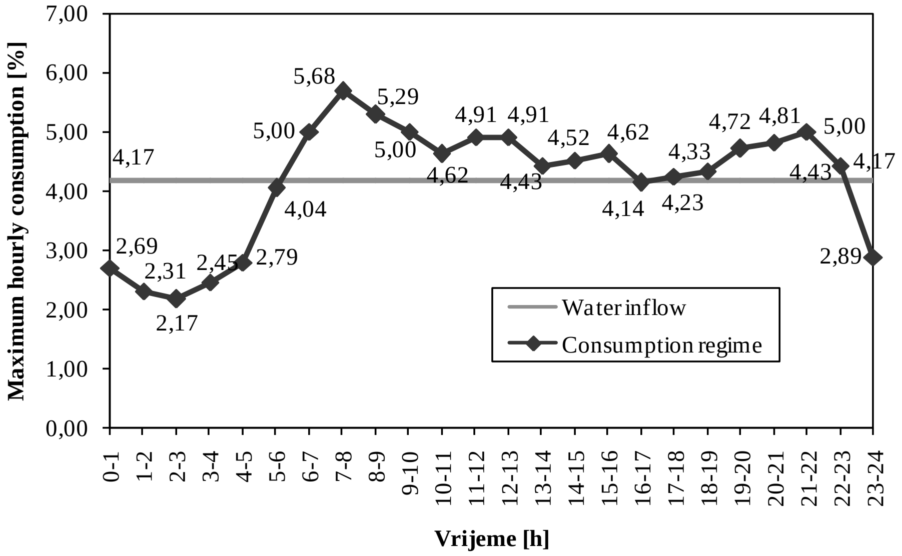

Figure 5. Normal regime of water inflow and daily water-use patterns typical of settlements with industry - Example IIa

Table 2. Typical values for the analyzed variants of the system operation

Typical values	Examples			
	II	IIa	IIb1	IIb2
Number of inhabitants *M*	8970	8970	8970	8970
q (l/capita/day)	140	140	140	140
$K_{D,max}$, $K_{H,max}$, $K_{H,min}$	1.40, 2.52, 0.12	1.40, 1.36, 0.52	1.40, 1.68, 0.43	1.40, 2.00, 0.35
$Q_{\max}^{daily}$ (m^3/day)	1758	1758	1758	1758
Q_{CS} (m^3/h)	73.25	73.25	73.25	73.25
Q_{max}^{hourly} (m^3/h)	184.59	99.62	123.06	146.50
Q_{min}^{hourly} (m^3/h)	8.79	38.09	32.46	25.64
ΔQ^{hourly} (m^3/h)	175.80	61.53	90.60	120.86
V_A (m^3)	433.64	172.65	259.83	308.76

It is evident that in the case of minor extremes (difference) the required reservoir volumes are significantly lower, i.e. available reservoir surpluses are higher when compared to Example II.

The obtained results are shown on Figures 6 and 7. The functional connection between the coefficients and the required volume V_A is approximately linear, as the correlation coefficient R^2 = 0.99. Clearly, the value of the coefficient of hourly consumption has a major impact on the condition and needs for water volume in the reservoir. This means that this problem should be approached seriously and that changes in consumption regime during the day should be regularly analyzed according to the changes that occur in the water supply area.

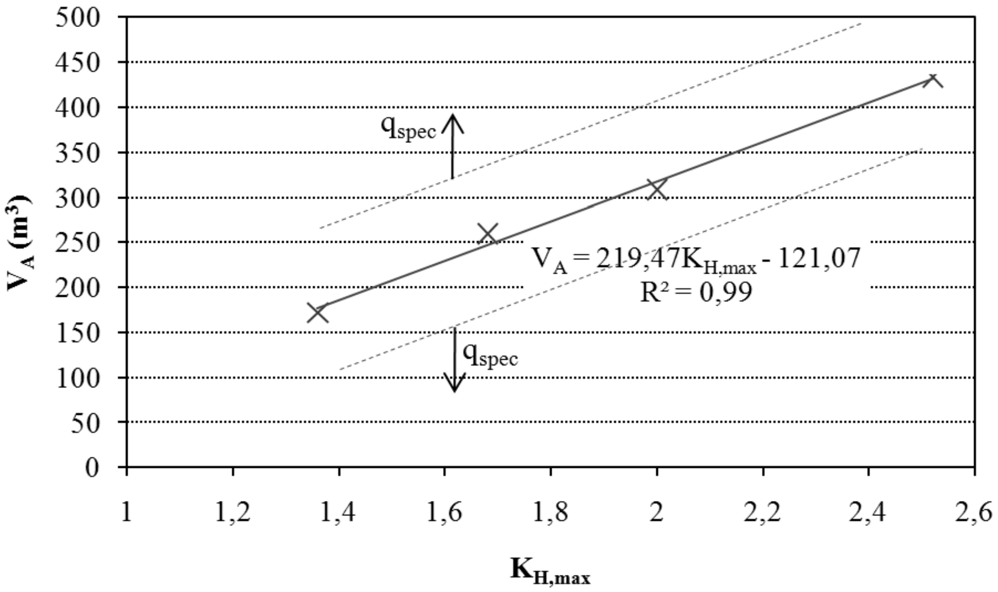

Figure 6. The required reservoir volume *V* as a function of maximum hourly unevenness coefficient $K_{H,max}$ in a maximum day of water consumption

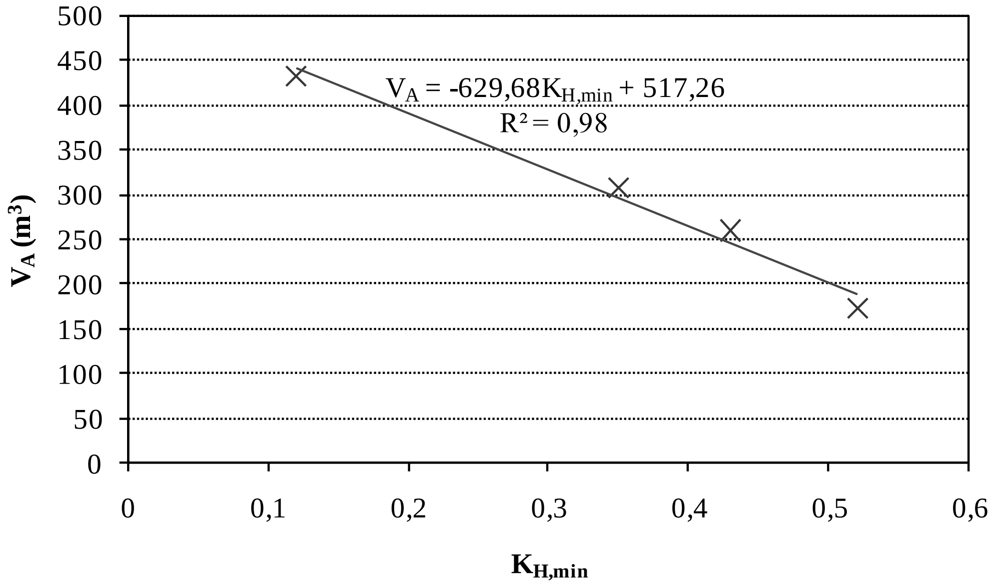

Figure 7. The required reservoir volume *V* as a function of $K_{H,min}$ in a maximum day of water consumption

This brief analysis shows that the current decreasing trend of specific water consumption q_{spec} has a very significant impact on the required reservoir volume. The change of V is proportional to the change q_{spec} for the same daily water consumption regime:

$$\frac{V_1}{q_{spec,1}} = \frac{V_2}{q_{spec,2}} \quad \Rightarrow \quad V_2 = \frac{q_{spec,2}}{q_{spec,1}} V_1 \tag{5}$$

where V_1 and V_2 are the required reservoir volumes for equalizing water inflow and consumption in a given day, along with the associated values of specific water consumption $q_{spec,1}$, i.e. $q_{spec,2}$.

Unevenness coefficients also have a significant impact on reservoir capacity. Larger coefficients, i.e. greater extremes in water consumption result in greater reservoir volumes. This was expected, but this brief analysis also shows for how much:

$$V = 219.47K_{H,max} - 121.07 \tag{6}$$

$$V = -629.68K_{H,min} + 517.26 \tag{7}$$

whereat $K_{H,max} \geq 1$, while $K_{H,min} \leq 1$.

From the abovesaid for the analyzed example results a general expression for calculating the required reservoir volume V as a function of $K_{H,max}$ and q_{spec} (l/capita/day) for the adopted water consumption regime during the day of maximum water consumption:

$$V = (219.47K_{H,max} - 121.07)(q_{spec}/140) \tag{8}$$

The analysis of Figure 8 shows that the difference between maximum and minimum hourly flow of water during the day, ΔQ^{hourly} (m^3/h), also has linear dependence with V, where at $R^2 = 0.99$.

$$V = 2.22\,\Delta Q + 44.42 \tag{9}$$

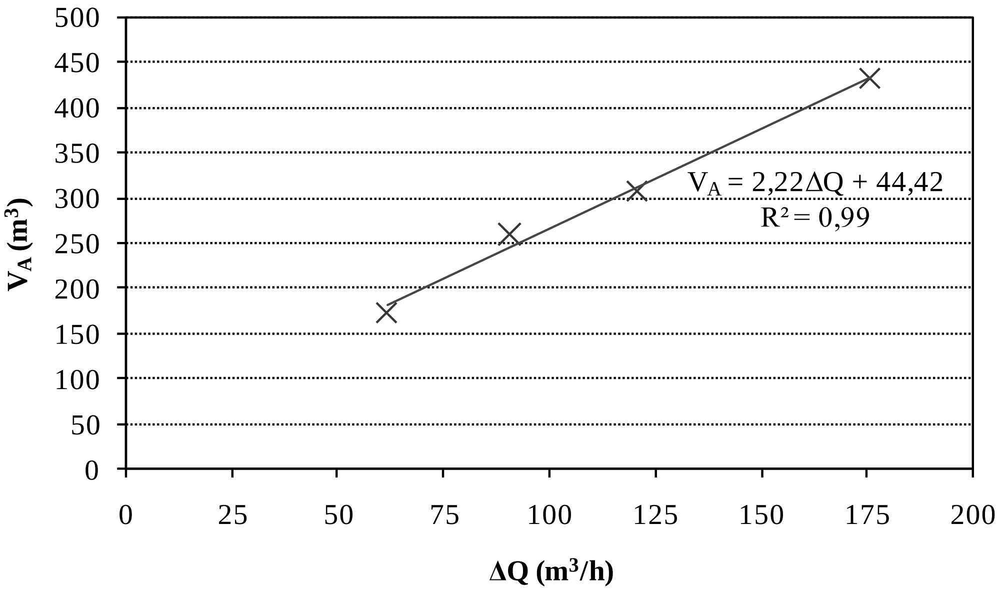

Figure 8. The required reservoir volume *V* as a function of Δ*Q* in a maximum water consumption day

By analogous procedure as in equation (8), a general expression is derived for calculating the required reservoir volume *V* as a function of Δ*Q* (m^3/h) and q_{spec} (l/capita/day) for the adopted water consumption regime during the day:

$$V = (2.22\ \Delta Q + 44.42)(q_{spec}/140) \tag{10}$$

As reservoirs are calculated based on the state in a peak day of the planning year, the available surplus from the peak day in the remaining perioid of the year increases as the daily water consumption in a settlement decreases.

In this example the available surplus V_t in day *t* (maximum water consumption day) of the analyzed year is:

$$V_t = (219.47 K_{H,max,t} - 121.07)\frac{Q_{max}^{daily}}{Q_t^{daily}} \tag{11}$$

or

$$T_{reduction} = V_t / Q_{mean}^{hourly} \tag{12}$$

where Q_t^{daily} is daily water consumption in a settlement in day *t*.

It is obvious that in winter period when the daily consumption is lower, the surpluses are larger, especially in tourist resorts. Monitoring and continuous analysis of the changes in water consumption regime throughout the day and year, and the level of use of reservoir volumes can improve the pumping regime and reduce energy costs. Also, analysis provides a better insight in the available volume surplus for all incidental situations.

If the available reservoir volume surplus V_t is divided by mean hourly water consumption in a particular day Q_{mean}^{hourly}, possible time period $T_{reduction}$ is obtained to reduce pumping during periods of more expensive electricity tariffs:

$$T_{reduction} = V_t \,/\, Q_{mean}^{hourly} \tag{13}$$

The required quantity of water will be pumped into the reservoir during periods of cheaper electricity.

As the daily water consumption decreases, the available reservoir volume surplus from the peak water consumption day in the remaining period of the year increases. The period of pumping water when electricity is more expensive can systematically be reduced and the flow of water can increase in the period of cheaper energy. Obviously, the savings can be huge, i.e. throughout most of the year all necessary water can be pumped with the cheapest energy.

- Possible economic savings ΔTE_t (€) in day t of the year could be approximated with the following expression:

$$\Delta TE_t = TE_t^{existing} - V_t \,/\, Q_{mean,t}^{hourly}\left(CE^{higher} - CE^{lower}\right)N \tag{14}$$

where:

$TE_t^{existing}$ = existing costs of pumping energy (€/day)

CE^{higher} = higher cost of pumping energy (€/KWh) (Hrvatska Elektroprivreda, 2014)
CE^{lower} = lower cost of pumping energy (€/kWh) (Hrvatska Elektroprivreda, 2014)
N = used average power of pumps (kW).

Possible economic savings in water supply systems with extremely high seasonal water consumption are significant. For almost eight months these systems are able to pump water only during periods of cheaper electricity. The savings are particularly large in this case. This should also be applied to drinking water treatment plants if they spend significant amounts of electricity, for example, in the case of desalination.

The derived expressions are an approximation for one concrete example that may enable a better and faster perception of the issue concerned. For each individual system these relations should be corrected in accordance with the input data.

4. ANALYSIS OF THE IMPACT OF CHANGES IN WORKING HOURS AND HABITS OF LIFE ON POSSIBLE WATER LOSSES

The water consumption regime in a settlement is determined, as well as its hydraulic properties and changes of water pressure in the water supply network. Pressure, on the other hand, determines the load of the system and water losses. Each water supply system has real water loss, from 6 to 63% (Water and Sanitation Division Utilities - The World Bank, 1996). Unfortunately, losses in Croatia are by an average 46% (Kovačić and Nedić, 2012) and will remain so for a long time, until the systems are repaired. Water loss is also energy loss, which affects the formation of greenhouse gases due to energy production, so this should be considered more widely. Therefore, the reduction of water losses ultimately affects the sustainability of life, locally and globally.

Pressure determines the speed of water at all leaking points in the water network, such as weak (leaky) connections, cracks, fractures and similar. The size of the losses Q_g is proportional to the square root of gross pressure level in the network at a given location:

$$Q_g = A_g \times \mu \sqrt{2gh_{g,l}} \qquad (15)$$

where is:
Q_g = water that leaks through a hole in the pipe (m^3/s)
$h_{g,l}$ =gross pressure height at a given location (m) = $h_{water\ reservoir} - DH_{losses,l} - z_l$
A_g =size of leak hole (m^2)
μ =leakage coefficient
g =acceleration of gravity (9.81 m/s^2).
Available gross pressure height h_l at location l is:

$$h_l = h_{reservoir} - DH_{min,l} - DH_{losses,l} - z_l \qquad (16)$$

where is:
$h_{reservoir}$ = reservoir level
$DH_{min,l}$ = minimum required pressure height at leakage point (hydrant ≈ 25 m V.S.) at location l
$DH_{losses,l}$ = pressure losses at location l as a result of water flow in the system from reservoir to location l (Jeppson, 1976, Jović, 2006).
z_l = pipe level at a given location l.

Pressure loss in a pipe of the water supply system can be expressed through a simple formula:

$$\Delta H_{losses,l} = K_l \cdot Q_l^2 \tag{17}$$

Where is:

K_l = coefficient obtained based on the Colebroock-White equation

Q_l = water flow in the pipe at location *l*.

The pressure in the system is determined by the height position of the reservoir and the water consumption regime in the water supply area, or hydraulic losses as a function of flow rate and characteristics of the pipe system. This means that the water consumption regime diagram in the water supply system is in fact similar to the diagram of water pressure. We distinguish water consumption regime during the year (Figure 9) and hourly regime during an average day (Figure 10).

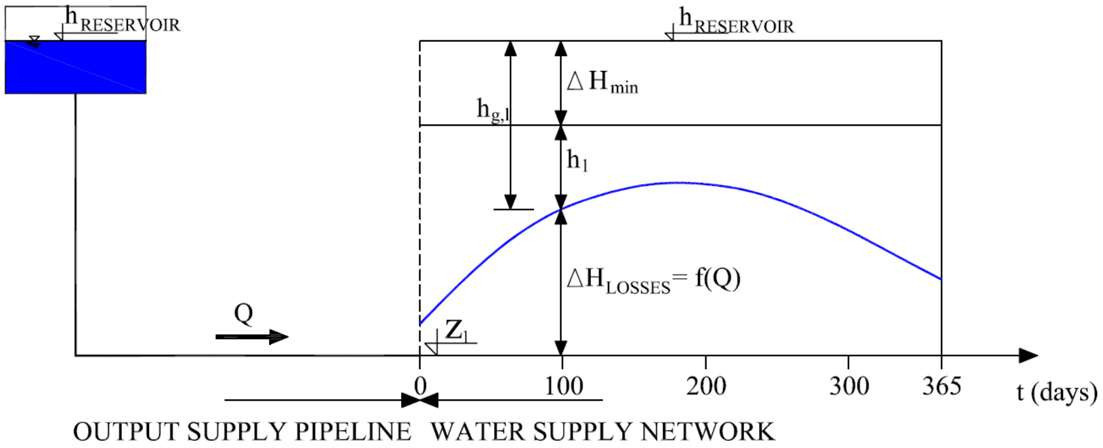

Figure 9. Generalized relation among pressures in the system during the year

Accordingly, we distinguish the respective changes in pressure in the system and possible water loss regimes in the system.

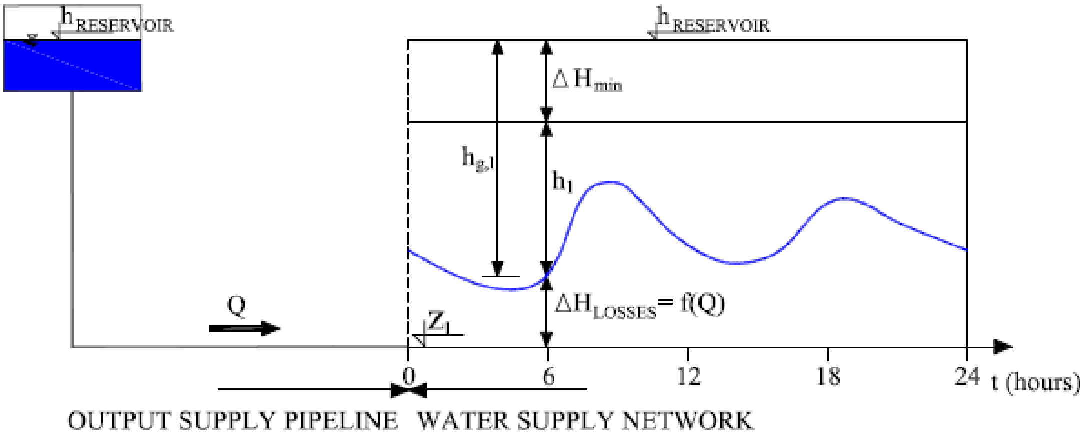

Figure 10. Generalized relation among pressures in the system during the day

In case of reduction of specific water consumption in the current system there is significant excess pipeline capacity, which will result in lower water velocities and less hydraulic losses. This will result in higher pressures in the piping system and thus higher potential water losses, pipeline stress and failures. It is easy to conclude that, due to the reduction of water consumption, the current systems are over capacitated and thus overloaded. Exceptions are the systems or parts of systems that did not have enough capacity in the previous period.

Systems with greater changes in flow, annual and hourly, will have potentially greater losses of water. Hourly water losses increase (if measures to control pressure are not implemented) when daily water consumption is reduced during the year, because water losses are proportional to the system pressure which increases when the flow of water in pipes is smaller, in accordance with the equations (15) and (17).

This means that the coefficient of daily unevenness K_D, as well as hourly K_S, has a direct impact on potential losses. Higher coefficients give potentially greater losses:

$$Q_{max} = K_D \; x \; (K_H \; x \; Q_{D,mean}) \uparrow \Rightarrow Q_g \uparrow \tag{18}$$

Special problem are highly seasonal systems with several times lower water consumption during the winter period than in summer, and therefore with multiple increase of unused pressure in the system, and hence greater losses of water. When seasonal unevenness is greater, probable losses are higher. Reduction of water consumption, i.e. flow Q results in an increase of disposable pressure H and thus water loss Q_g:

$$Q\downarrow \Rightarrow h_g \uparrow \Rightarrow Q_g \uparrow \tag{19}$$

Potential losses are proportional to the area above the curve of the flow in the system, Figures 9 and 10. Therefore, these surfaces are a useful indicator of potential water losses in the system. Average annual loss potential $h_{g,\ mean,\ annual}$ is:

$$h_{g,mean,annual} = \left(\frac{\sum_{i=1}^{365} \sqrt{h_{g,mean,daily(i)}}}{365} \right)^2 \tag{20}$$

where:

$h_{g,\ mean,daily(i)}$ = average daily potential loss for the diagram of hourly water consumption in the i day (Figure 10).

$h_{g,\ mean,annual}$ = average annual potential loss for the diagram of annual water consumption (Figure 9).

Based on this, it may be possible to define the volume of annual water loss $V_{g,year}$ (m^3) for the assumed values of system leakage A_g:

$$V_{g,year} = A_g \times \mu \sqrt{2g \times h_{g,mean,year}} \times 86400 \times 365 \tag{21}$$

The above shows that the current regime of water consumption throughout the day with two extremes, in principle generates greater potential losses than the regime with three daily extremes of water consumption. This also means that the new working conditions of the system have a greater impact on energy efficiency of the system as a function of water loss *EG*:

$$EG = \frac{energy\ consumption\ for\ system\ without\ water\ losses}{energy\ consumption\ with\ real\ water\ losses} \tag{22}$$

By calculating this indicator it is possible to monitor the results of work on improving energy efficiency of the system arising from the reduction of water losses in the system.

5. CONCLUSIONS AND RECOMMENDATIONS

Water utilities strive to provide safe water supply at an acceptable price. However, it is always a big challenge for utilities and their sustainability. The resulting changes in Croatia significantly alter the water consumption regime in water supply systems. The trend of changes that generate changes in water consumption regime are: (i) decrease in population, (ii) reduction in economic activity, (iii) reduction in water consumption, (iv) daily consumption expressed by two peak periods, (v) reduction in the number of users in rural and sparsely populated areas, (vi) increase in the number of tourists in a short period of time during the summer, and (vii) climate changes. The change in the pricing policy of water, from social towards the real full price (no subsidies), has led to a sharp increase in prices. This increase will continue because we still don't pay the full cost of water.

In the future the expected increase in prices of water utility services is inevitable due to construction of sewerages and wastewater treatment plants. This will further affect the rationalization of water consumption by the population, which will result in pressure increase and losses in the built water supply systems. On the other hand, it will reduce the income of the companies, so that they will have less resources to operate and maintain the system.

Water supply network in sparsely populated areas with increasing depopulation and lower water consumption will be areas that are most likely to generate the greatest increase of water losses. A small number of users per km of network means huge economic losses for each company, which will have to be covered by the other users.

Likewise, tourist areas with highly seasonal tourism, which is mainly tourism in Croatia, due to the expected increase in the number of tourists, will have an increasing unevenness of water consumption and thereby potentially increasing losses. A largely seasonal use of water infrastructure should have seasonal water prices if they want to properly cover the costs in relation to the local population and economy that are year-round users of the system. Such pricing services are not permitted and are difficult to implement, although they are fair. As a result of the change, the usability of water intakes, pipelines, pumping stations, reservoirs and water network change. The result is the change in the balance of water and energy consumption in the system. Water and energy are increasingly expensive, so it will be difficult to achieve satisfactory social and economic objectives.

All said changes occur regularly and therefore must be continuously monitored, and the water supply system constantly analyzed. It is primarily the analysis of the use of reservoirs in order to rationalize water pumping and the analysis of pressure in the system to reduce losses and damages. The aim is to improve energy efficiency of the system and reduce water losses. Good analysis requires good data, and the data cannot be obtained without good monitoring system of inputs, outputs and conditions in the system. From the results shown it is evident that the changes are significant, but it can also be seen that the expected and unexpected changes provide a more efficient system operation.

All this is a big challenge for utilities and their sustainability. Experts in water utilities will have to constantly apply new and innovative solutions that would remediate painlessly the consequences of changes in the society. We hope that the presented analysis, derived relations and explanations will be helpful in improving the sustainability of water supply systems.

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