# ASSESSING RELATIONS BETWEEN WATER SUPPLY AND DEMAND IN THE ODRA AND MORAVA RIVER BASINS

# POSOUZENÍ VAZBY VODÁRENSKÝCH ZDROJŮ A NÁROKŮ NA VODU V OBLASTECH POVODÍ ODRY A MORAVY

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**Abstract**

Periods of drought represent a serious problem in the management of water resources. Currently used climatic models assume the onset of major climatic changes and periods of drought. Irrespective of whether the forecasts will be fulfilled or not, it is essential to prepare measures to ensure the supply of drinking water in dry periods. This paper deals with the preparation of water balances for the areas of the Odra and Morava River basins and the prediction of relationships between water supply and water demand in the given area.

**Abstrakt**

Suchá období představují závažný problém v nakládání s vodními zdroji. Současné klimatické modely předpokládají nástup velkých klimatických změn a s tím nástup suchých období. Bez ohledu, zda se tyto prognózy naplní nebo ne, je třeba připravovat opatření k zajištění zásobování pitnou vodou v suchých obdobích. Tento článek se zabývá zpracováním vodohospodářských bilancí vodárenských zdrojů oblastí povodí Odry a povodí Moravy a predikcí vazby těchto vodárenských zdrojů a samotných nároků na vodu v daném prostoru

**Key words:** Climate change, drought, water management, drink water, water supply

## 1 INTRODUCTION

The European Environment Agency has been emphasising changes in climate for a long time. The whole society has been considerably affected by climate changes. There is much interaction between physical and chemical phenomena in the atmosphere between the biosphere and other components which create a complex system of climate. This puts the complex process of water mass circulation into motion. A chemical response in the troposphere results in reactions influencing, in turn, changes in climate. Development of water management should be assessed in a rather wide context which is given by social economic parameters, changes in living environment and, last but not least, demands relating to water systems and individual sources of water supply. The Czech Republic depends entirely on rainfall – this is the consequence of the Czech Republic's position and hydrobiological balance. Lack of rainfall in the Czech Republic may deteriorate supply of water to people from water systems. [1,2]

In the Czech Republic, about 90 % of population is supplied with water from public water mains. These are, in particular, extensive water supply systems. The Czech Republic undertook to develop and improve the water system in line with the European Parliament and Council Directive No. 2000/60/EC. Attention is paid, among others, to securing sufficient and sustainable sources of water for water systems which should be able to supply water even in case of negative phenomena which shall accompany changes in climate. [3]

The goal of long-termed forecasts and planning is to find suitable measures being able to arrange that people and other consumers will be supplied with water in case of drought. Area water networks and group water networks which supply drinking water to people should be operated within an organisational and legislative framework and technical conditions so that the water could be supplied smoothly, even in a restricted scope. A wide range of measures should be taken to protect people against drought and it is necessary to have an overall strategy of protection as well. The proposed measures should be a general solution of the issue. In case of long-lasting drought, there might be a big difference between water supply and demand. In that case, it is essential to restrict consumption of water in order to keep basic quantities without restricting operation of important facilities. Changes in environment which affect quantity of water can, no doubt, influence quality, and vice versa. Knowledge of such measures and forecast should be the basis when making decisions on water demand and satisfaction of needs in terms of quality and quantity. [1]

We focused on water management relations in water supply systems which exist in the Odra and Morava River basins. Attention was also paid to the assessment of the data from water sources in terms of water supplies for people and industries. The goal was to identify areas where water deficit might occur in the future use of water sources.

## 2 SUSTAINABILITY IN MANAGEMENT OF WATER SOURCES AVAILABILITY

Sources of water rank among important elements which need particular responsible management in any place and in any point of time.

They are important for the development of all economic and other activities and influence balance between eco-systems (hydrological regimes). Because sources of water were regarded as sufficient ones for the satisfaction of needs of inhabitants and industry, an unbalance between the demand and availability of water in water distribution networks has been becoming more and more evident. In many regions, this unbalance reaches the critical level of sustainability.

The reason for this situation is, in most cases, a frequent alteration of periods of drought and those of flood. The unbalance of water in water sources is connected considerably with the quality of water. All those phenomena influence significantly territories where sources of water are supplied mostly from rainfall. Unbalance in water quantities and, in turn, consumption of water, play a major role in decision-making and management within water companies which take measures in water collection and waste water processing. The processing and treatment of water is a key prerequisite for maintaining the water balance for long-termed sustainable use of water. [4]

Those parameters influence water management and became the basis for creation of recommendations, the purpose of which is to ensure efficient and sustainable water management within EU. Sustainability and creation of conditions for efficient water management can result from the below described relation between potential water capacities, consumers and internal relations. Relations and cooperation of individual areas in water supply for heavily populated territories are shown in Fig. 1. [5] Assessing individual emergencies in water supplies should not be based on specific elements of the system such as a water supply system, catchment or water-treatment system. This should be a comprehensive assessment of the entire system which comprises water in catchment and urban water. Looking for joint goals should help evaluate efficient solutions in water supplies from sources of water. This should be the principle of cooperation for all stakeholders.

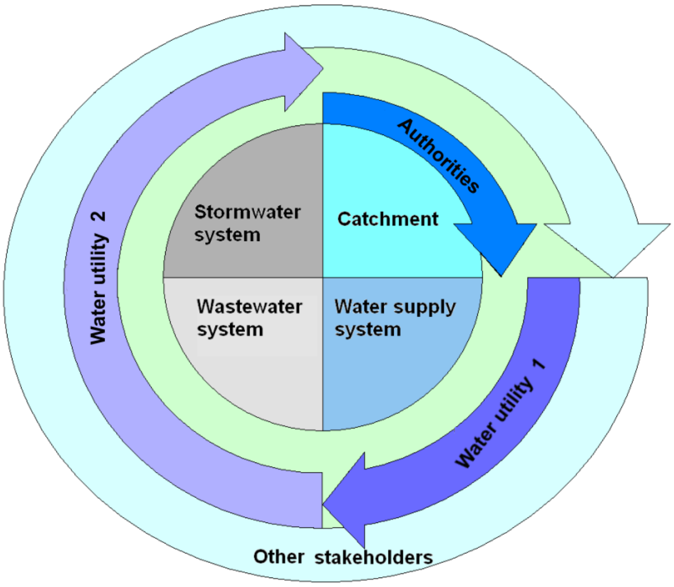


**Fig. 1** Relations in a water supply system in heavily populated territories [5]

## 3 WATER BALANCE

Demands for sources of water have been becoming more and more extensive. One of key roles of the water management is the assessing of possible coverage of water needs from respective sources of water. Water balance characteristics can be defined as relations between potential consumption of water and demand for water. The relation is based on the fact that the demand for water is the sum of all demands for water in that place or territory in a specific point of time and for a specific quality and quantity of water. The quantity of water in a specific place and time can be defined, as Kos and Říha suggest, using the following formula [6]:

$$Zm = Zp + Zn + Zpr - Zt - Od \qquad (1)$$

where in [m$^3$/s]:

*Zm* - total strength of water source,

*Zp* - strength of water in a place,

*Zn* - improvement thanks to tanks,

*Zpr* - improvement thanks to transfer,

*Zt* - losses,

*Od* - water takeoff.

The balance of water quantity in a specific place and time can be described as follows:

$$Bs = \frac{Zm}{(P + Om)} \qquad (2)$$

where in [m$^3$/s]:

*Bs* - strength balance of a water source in a specific place and time,

*Zm* - total strength of water source,

*P* - requirements for use of water in water courses,

*Om* - water takeoff (water supply systems).

The analysis of relations above is an important part of the analysis of water quantity which is needed for water management. At the same time, the analysis provides conditions for a forecast of an available quantity of sources of water which are needed for the coverage of water demands.

## 4 PROGNOSES AND FORECASTS IN WATER MANAGEMENT

In most cases, the supplies of water which can be used for forecasts resulted from long-termed observations and analyses of the current situation. Several water management tasks have to rely on prediction, quantification and assessment of possible scenarios which could influence the decision-making process in complex water management systems. For purposes of the forecast, it is essential to evaluate and apply an educated qualitative estimate with quantitative data for current development of water needs and water consumption. As it is difficult to include all variables in individual models, it is necessary to make an early preparation and time-optimised planning of water demand for the sources of water. For this, all available means should be used. A theoretical basis for all estimates and plans is the prognostic work which considers trends in water economy and water supplies for that territory. An important part is the statistics which makes it possible to forecast the future situation with a certain degree of probability for a certain phenomenon. [4,7]

The mathematical-statistical approach comprises several alternative methods which can be used for forecasts. They can be divided into three groups:

- extrapolation (the normative method)
- synthesis (the morphological method)
- intuition (the theoretical method)

The most frequent combination is the method which combines normative and theoretical solutions. Detailed analyses and long-termed concepts use a number of basic statistical and prognostic tasks (such as projection, linear programming, regression, estimates...). Totals of all quantitative and qualitative parameters are taken into account as a total of a certain point of time. Fig. 2 summarises basic assumptions needed for the assessment of water management in a specific place and time, making the process more simplified. In order to make decisions, it is important to summarise trends in water demands from the point of view of all consumers. Available information indicates that in EU member states the intensity of use of the sources had been increasing gradually until the values became stable. There are also clear changes in individual EU member states. [4,7]. It is evident from historic trends in use of water in the EU member states, that the demand for water has been becoming stable and that the consumption is becoming stable as well.

This change is shown in Fig. 2 as a red frame field. This change is based on the development of a country, development of technologies and price of consumed water. It proves that the development of a country causes first the water consumption to increase. The reason are such pieces of equipment as dish washes (households, food processing industry), washers (households and industries), bathrooms or commercial car washes. Once the maximum value of water consumption is achieved, several scenarios are possible. The first scenario is a long-termed stagnation (trend 1). Changes in technology may result in savings and in different needs of and demand for water. The water consumption shows then a decreasing trend (trend 2). The development of technologies can be accompanied with socio-economic phenomena (changes in water tariffs, income of households). In that case, the decrease in total demand for water is the highest of all (trend 3). [4]

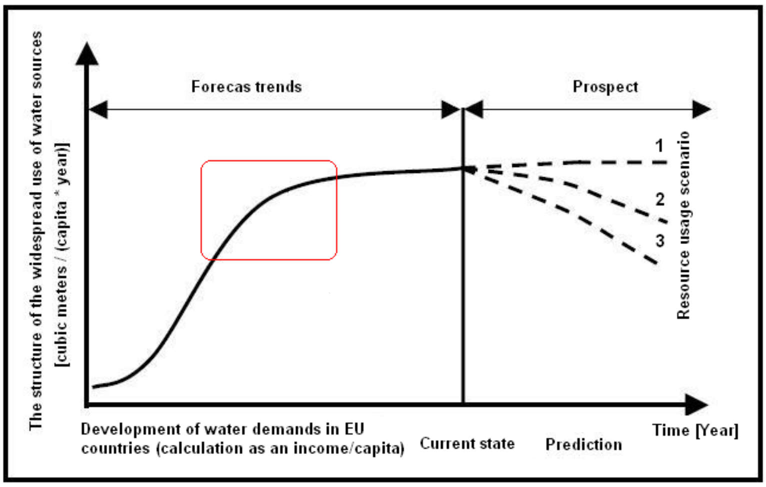


**Fig. 2.** Trend in use of water sources in EU [4,7]



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## 5 RELATIONS BETWEEN WATER SUPPLY AND DEMAND IN CERTAIN TERRITORIES WITHIN THE ODRA AND MORAVA RIVER BASINS

The sources of water and requested quantity of water was analysed in order to summarise average sources of water in the water basins of the Odra and Morava Rivers, evaluating the average consumption of water from the point of view of water which is handed in the water network. The results are based on the observations made from 1990 to 2010. The values include the information about current conditions and maximum values which were taken from previous models and forecasts made in 1993. The following water supply systems and major takeoff of water were taken into account for the Morava River basin: the Vír Water Area Network, Hodonín Water Supply System, Boskovice-Blansko Water Supply System, Štítary, Výškov, Mikulov Water Supply System, Olomouc Water Supply System, Luhačovice Water Supply System, Prostějov Water Supply System, Přerov Water Supply System, Šumperk Water Supply System, Zlín Water Supply System and Kroměříž Water Supply System. The most important source of water which covers the water demand is the Vír Reservoir. Regarding the water basin of the Odra River, the following water systems were included into the analysis: the water system of the Ostrava Area Water Network and Bruntál water supply system. The most important sources of water are the Kružberk Dam, Šance Dam and Morávka Dam.

During the period from 1989 until 2010, there were two big significant changes in the approach to water supplies and water needs. Separate water management companies were established and the price of water increased considerably which, in turn, influenced the total consumption of water. There are studies which mention that the sources of available water (the water for water supplies) have been becoming more and more limited. Considering the geography of the Czech Republic, attention should be paid to those territories where few sources of water are available for water supplies.

The available information about consumption of water within the Odra and Morava River basins as well as the assessment of water supplies in those territories were used as a basis for the creation of two models of water needs and intensive use of water sources. The potential future scenarios were modelled using Statgraphics Plus which is able to evaluate data sets from the point of view of various alternatives.

Two models were chosen for the final assessment – they represented the critical condition and the condition which is compliant with current trends. The model evaluates the behaviour of a time sequence after the last known value with a reliability limit of 67 %. The reliability is regarded as the statistically minimum value of correlation of the model between the time sequences of average sources of water and sequences of water demand in individual areas. The confidentiality limit of 67 % makes it possible to optimise the model and make further comparisons.

After assessing the time sequences, the best models were taken from the predictions. Those models were the models resulted from the Random walk (R-w.) and S-Curve (S-c) relations. The R-w model takes into account the mean values of data and standard deviations in differences between the values. This model shows the maximum values of a trend drop in water sources and water needs in a time horizon of 40 years.

The S-c model shows curves which are placed in partial sections of monitored data, covering future periods. The S-c model is the best one for the input data from the point of view of cyclical changes in values and gradual balancing. The final data are again valid for a 40-year forecast. Tabs 1 and 2 show the forecast values for each model separately.

The figures below show the assessment of the water supply systems for each model. "The current state" in the chart is the border for the data of the water supply systems – it shows capacities of available water quantities for water supplies. For this development, the data for a period of 22 years was used. The values from now onwards represent the forecast values for the next 40 years.

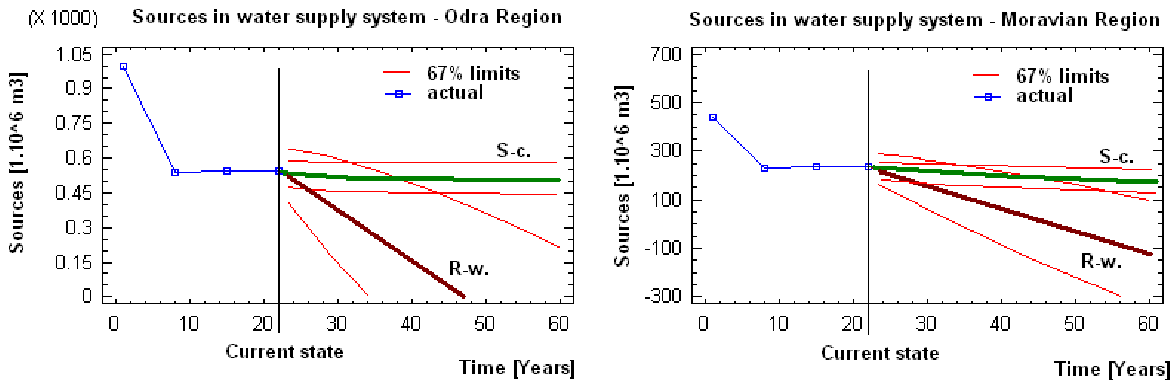


**Fig. 3.** Sources in water supply systems in the Odra and Morava River basins

Two separate trends are clear from the chart. The critical values were achieved in the R-c model where the values for the 20-year forecast indicate a permanent drop in sources in the water supply system. This fact correlates to the trend of drop of available water supplies which is mentioned in the "Climate change and global water resources". [8,9,10,11] Considering local conditions, the S-c trends seem to be more probable - they indicate gradual harmonic balancing of the values with a long-lasting descending trend. The harmonic correlation is rather typical for most water management tasks.

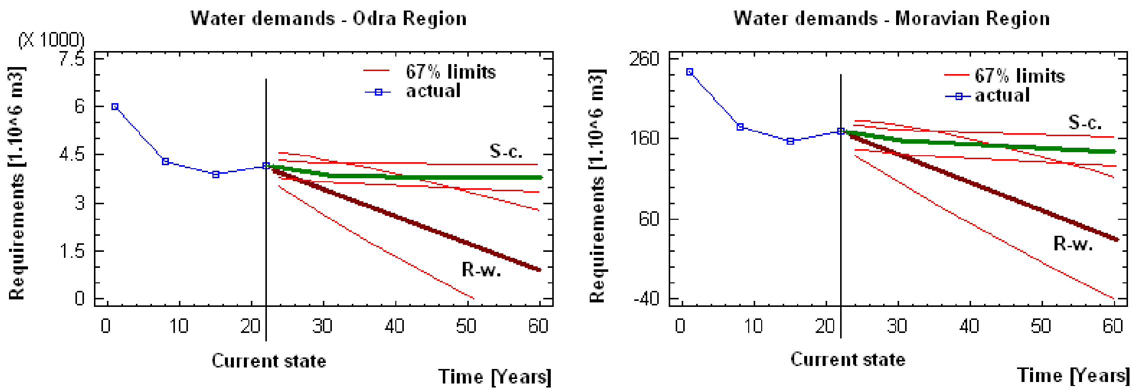


**Fig. 4.** Demands for water supply systems in the Odra and Morava River basins

Let us consider two scenarios of total demand for and consumption of water. The both trends show rather descending tendencies. In spite of this, it is possible to identify sections in the sources within the water supply system (this is, in particular, the task of R-c model) where critical water management is likely. This phenomenon is evident even if the demand for water is going down in both the Odra and Morava River basins. Tab.1 and Tab. 2 show the output values of the R-w and S-c models.

**Tab. 1** Available sources of water in water supply systems in the Odra and Morava River basins

| Period [year] | Sources in water supply system – Odra Region | | | | | |
|---|---|---|---|---|---|---|
| | Model: S-c Trend=exp(8.6 + 0.7/t) t [year] | | | Model: R-w | | |
| | Forecast [$10^6 m^3$] | Lower and Upper Limits 67.0% | | Forecast [$10^6 m^3$] | Lower and Upper Limits 67.0% | |
| 29 | 526 | 501 | 552 | 390 | 177 | 603 |
| 36 | 524 | 499 | 549 | 238 | < S.limit | 539 |
| 43 | 522 | 498 | 548 | 86 | < S.limit | 455 |

| Period [year] | Sources in water supply system – Moravian Region | | | | | |
|---|---|---|---|---|---|---|
| | Model: S-c Trend=exp(5.4 + 0.8/t) t [year] | | | Model: R-w. | | |
| | Forecast [$10^6 m^3$] | Lower and Upper Limits 67.0% | | Forecast [$10^6 m^3$] | Lower and Upper Limits 67.0% | |
| 29 | 229 | 216 | 243 | 170 | 75 | 266 |
| 36 | 228 | 215 | 242 | 104 | < S.limit | 238 |
| 43 | 227 | 214 | 241 | 37 | < S.limit | 202 |

**Tab. 2** Demand for sources of water in water supply systems in the Odra and Morava River basins

| Period [year] | Water demands – Odra Region | | | |
|---|---|---|---|---|
| | Model: S-c Trend=exp(8.3 + 0.4/t) t [year] | | Model: R-w | |
| | Forecast | Lower and Upper Limits | Forecast | Lower and Upper Limits |

| | | | | | | |
|---|---|---|---|---|---|---|
| | [$10^6 m^3$] | 67.0% | | [$10^6 m^3$] | 67.0% | |
| 29 | 403 | 376 | 432 | 356 | 275 | 437 |
| 36 | 402 | 375 | 431 | 295 Limit | 181 | 410 |
| 43 | 401 | 374 | 430 | 235 Limit | 94 | 375 |

| Period [year] | Water demands – Moravian Region | | | | | |
|---|---|---|---|---|---|---|
| | Model: S-c. Trend=exp(5.1 + 0.4/t) t [year] | | | Model: R-w. | | |
| | Forecast [$10^6 m^3$] | Lower and Upper Limits 67.0% | | Forecast [$10^6 m^3$] | Lower and Upper Limits 67.0% | |
| 29 | 164 | 152 | 176 | 145 | 112 | 178 |
| 36 | 163 | 152 | 176 | 120 Limit | 74 | 167 |
| 43 | 163 | 151 | 175 | 96 Limit | 39 | 152 |

## 6 CONCLUSIONS

The forecast above is based on average values for the locations within the water supply system. The values were prepared using the linear programming and development prediction by means of the S-curve and Random Walk methods. In this comparison, it is possible to address the water management in water supply systems from two different points of view. From the critical assessment point of view, it is possible to consider critical situations in water supply systems. If the descending trend in sources for water supply systems is taken into account, it is likely that critical scenarios will occur within 20 to 30 years in the both Odra and Morava river basins. Regarding the harmonic functions of the S-curves, it should be pointed out that if the current demand for water is maintained it does not necessarily mean that the decreasing quantity of available water from sources for the water supply systems will result in critical scenarios in water management.

Trends in EU show that consumers have started changing their behaviour in consumption of water sources. According to studies, the trend of the changes is similar and is often extrapolated by means of S-curves. The trends have been observed in EU countries for a long time. Considering the changes in the Czech Republic in the 1990s (in particular, from 1990 to 1993), the use of sources diversified and the consumption of water changed. The trend in water consumption and water demand correlates now within EU with the trend of the harmonic development of the S-curves. In case of the S-c forecast, the results of future periods converge now towards the current demand in terms of technology, consumption and available sources of water. This proves that the values within the Odra River basin indicate noncritical water management, if compared with Mediterranean regions. Regarding sub-regions within the Morava River basin, there are territories with a negative water balance for sources of water supply systems for the next 40 years and the deficit of water sources should become evident, with current need during the forecast period of 2012 - 2015. Those sub-regions include the Vír Area Water System, Olomouc Water Supply System and Kroměříž Water Supply System. This trend is stable in the forecast period and converges towards minimum capacities of resources for the water supply systems in a specific place and time.

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## RESUMÉ

Výše uvedené predikce vychází z průměrných hodnot pro jednotlivé lokality vodárenských soustav. Tyto hodnoty byly zpracovány na základě lineárního programování a predikce vývoje pomocí S-křivek a metody Random Walk. Uvedené srovnání umožňuje nahlížet na problematiku hospodaření s vodou ve vodárenských soustavách ze dvou pohledů. Z pohledu kritického vyhodnocení je možné uvažovat s krizovými situacemi ve vodárenských soustavách. V případě klesajících trendů zdrojů vod může docházet s výhledem 20 až 30 let ke krizovým scénářům nakládání s vodou jak v regionech povodí Odry, tak povodí Moravy. Z pohledu harmonických funkcí S-křivek je možné uvést, že v případě zachování současných nároků na vodu nemusí jednoznačně docházet při snižujících se množství disponibilní vody z vodárenských zdrojů ke krizovým scénářům vodního hospodářství.

Trendy v Evropské unii ukazují na fakt, že dochází ke změnám chování spotřebitelů ve smyslu využívání zdrojů vody. Tyto změny mají dle studií podobný trend, který je často extrapolován S-křivkami. Tyto trendy byly v zemích EU pozorovány po delší časové období. Vzhledem ke změnám v ČR v devadesátých letech (tj. především v první polovině v období 1990 – 1993), došlo k diverzifikaci využití zdrojů a k změnám spotřeby vody. V současné době je trend potřeby vody a nároků na vodu v porovnání s EU v korelaci, s trendem odpovídajícím harmonickému průběhu S-křivek. V případě S-c. predikcí je proto patrná oscilace výsledků budoucích období, konvergujících k hodnotám odpovídajícím současným nárokům na technologie, spotřeby a disponibilní zdroje. Zde se ukazuje, že hodnoty ve sledovaných oblastech povodí Odry jsou v současném okamžiku oproti středomořským regionům v režimu nekritického hospodaření s vodou. V rámci sub-regionů povodí Moravy je ale řada oblastí, která vykazuje záporné negativní hodnoty vodohospodářských bilancí vodárenských zdrojů s výhledem 40 let, s deficitem vodárenských zdrojů při současných potřebách na úrovni predikovaného období 2012 až 2015. Mezi takové oblasti patří vodohospodářská soustava Vírského oblastního vodovodu, Olomoucko, anebo Kroměřížsko. Tento trend je v predikovaném období stálý, konvergující k minimálním hodnotám kapacit vodárenských zdrojů v daném místě a čase.