METHOD OF FORECASTING WATER DEMANDS ON THE EXAMPLE OF A FEW SETTLEMENTS

By

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The basis for a reliable forecasting of the expected municipal water demands is the knowledge of the factors which modify the demands on water supply both in space and in time. Water demand is in itself a kind of social requirement, therefore it is function of social development.

According to the materialistic conception, the decisive impelling force of social development lies in the production. Relying on the strength of this ascertainment, the magnitude of the municipal water demand can be stated to be defined in the first line by the degree of evolution of the productive forces.

1. Definitive and affecting factors of long-range municipal water demand

The change in water demand is the result of the simultaneous effect of a great number of factors. These factors may be grouped according to their evident appearance or concealed effects. Accordingly, they can be distinguished as [1]:

— fundamental determinants, and

— operative factors, affecting the former ones.

The fundamental determinants are

— expected number of the inhabitants (N_i), and

— expected per capita water demand (q_i).

The operative factors have been summarized in *Fig. 1.*

2. Investigations on, and results of forecasting the probable water demand

Investigations were carried out in order to establish forecast of water demands to be expected in selected agglomerations, by using various research methods. In the research investigations, so-called *mechanical* procedures have been applied, mainly as a check, as well as analytic methods which permitted

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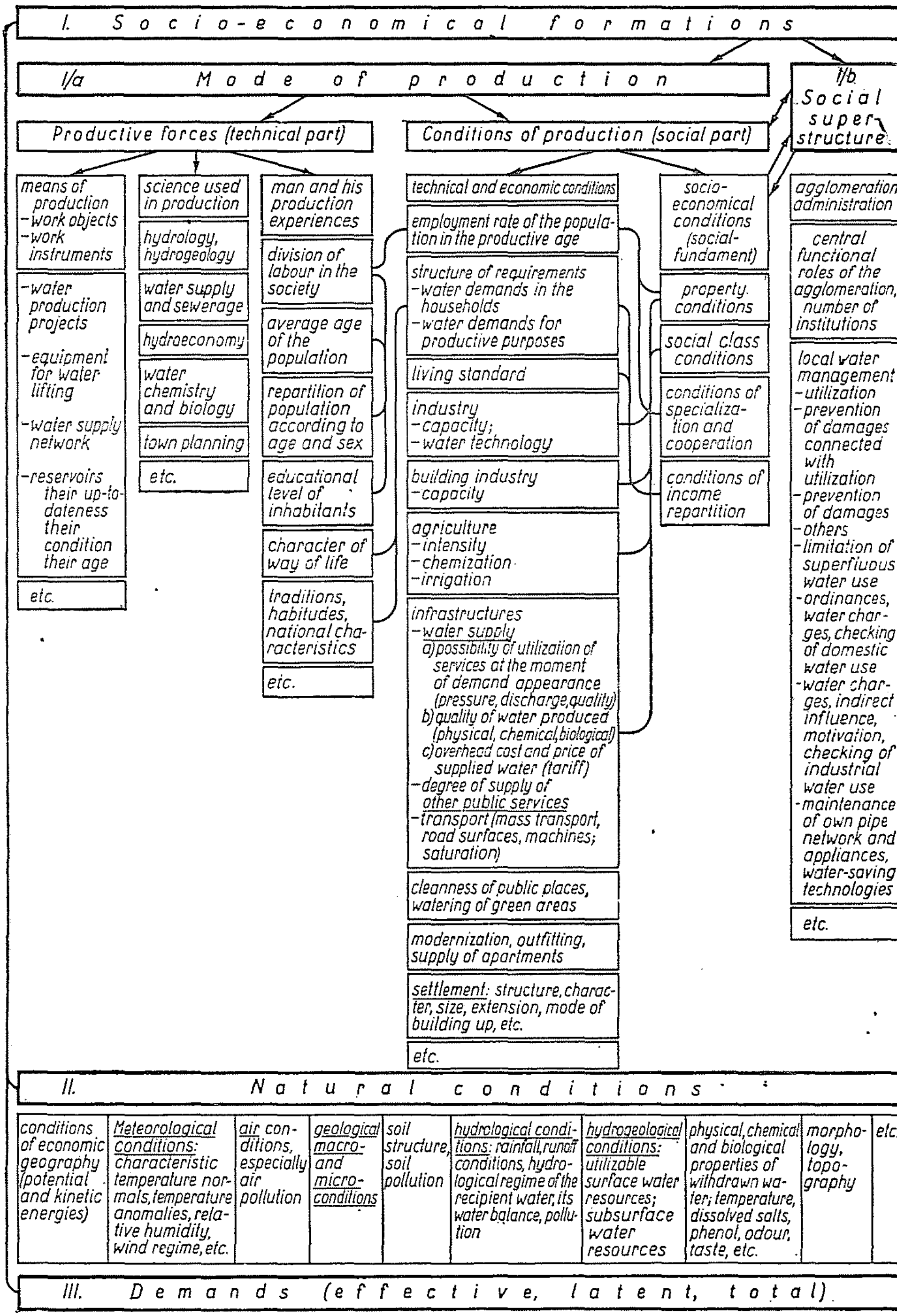
I. Socio-economical formations
I/a Mode of production
I/b Social superstructure
Productive forces (technical part)
Conditions of production (social part)
means of production -work objects -work instruments
-water production projects
-equipment for water lifting
-water supply network
-reservoirs their up-to-dateness their condition their age
etc.
science used in production
hydrology, hydrogeology
water supply and sewerage
hydroeconomy
water chemistry and biology
town planning
etc.
man and his production experiences
division of labour in the society
average age of the population
repartition of population according to age and sex
educational level of inhabitants
character of way of life
traditions, habitudes, national characteristics
etc.
technical and economic conditions
employment rate of the population in the productive age
structure of requirements -water demands in the households -water demands for productive purposes
living standard
industry -capacity; -water technology
building industry -capacity
agriculture -intensity -chemization -irrigation
infrastructures -water supply a) possibility of utilization of services at the moment of demand appearance (pressure, discharge, quality) b) quality of water produced (physical, chemical, biological) c) overhead cost and price of supplied water (tariff) -degree of supply of other public services -transport (mass transport, road surfaces, machines; saturation)
cleanness of public places, watering of green areas
modernization, outfitting, supply of apartments
settlement: structure, character, size, extension, mode of building up, etc.
etc.
socio-economical conditions (social-fundament)
property conditions
social class conditions
conditions of specialization and cooperation
conditions of income repartition
agglomeration administration
central functional roles of the agglomeration, number of institutions
local water management -utilization -prevention of damages connected with utilization -prevention of damages -others -limitation of superfluous water use -ordinances, water charges, checking of domestic water use -water charges, indirect influence, motivation, checking of industrial water use -maintenance of own pipe network and appliances, water-saving technologies
etc.
II. Natural conditions
conditions of economic geography (potential and kinetic energies)
Meteorological conditions: characteristic temperature normals, temperature anomalies, relative humidity, wind regime, etc.
air conditions, especially air pollution
geological macro- and micro-conditions
soil structure, soil pollution
hydrological conditions: rainfall, runoff conditions, hydrological regime of the recipient water, its water balance, pollution
hydrogeological conditions: utilizable surface water resources; subsurface water resources
physical, chemical and biological properties of withdrawn water; temperature, dissolved salts, phenol, odour, taste, etc.
morphology, topography
etc.
III. Demands (effective, latent, total)

Fig. 1

to take into account several operative factors simultaneously. These methods have been treated at length in an earlier paper [2]; in the presented study the authors intend to report on the application of these methods.

2.1. Application of mechanical methods

From among the mechanical methods, trending and extrapolation have been applied.

If, at a time, a suitable number of data are available, one may determine the trend of preceding development. If one assumes the preceding rate of development observed to hold also for the forecast period, then from the data being at disposal one can forecast long-term water demands. As an illustration, the results obtained in establishing the forecast of the water demands of Bratislava are presented. It is to be noted that these results show the development of the total water demand of the city.

The average daily water consumption for each month through 66 months was measured, from June 1967 to July 1972. By making use of the measurement results, the trend of consumption was determined with the help of a computer and the equation of the trend curve was approximated by mathematical relationships assuming the consumption data of the base year to agree with the water demands (Table 1). Extrapolating the trend yielded values of water demands to be expected for the years 1980, 1990 and 2000 listed in Table 2 [3].

Table 1

The trend of water consumption in the city of Bratislava

Number of months I	Correlation index R	Equation Q(m^3/day)
	Linear approximation	
1–66	0.7880	$121\,679.85+510.512 \cdot I$
1–60	0.7710	$121\,171.27+534.214 \cdot I$
1–54	0.7277	$121\,072.34+539.801 \cdot I$
1–48	0.8064	$118\,707.64+675.655 \cdot I$
	Approximation through a progressively increasing curve	
1–66	0.7912	$121\,985.552 \cdot e^{0{,}00373 \cdot I}$
1–60	0.7756	$121\,458.137 \cdot e^{0{,}00393 \cdot I}$
1–54	0.7354	$121\,279.982 \cdot e^{0{,}00401 \cdot I}$
1–48	0.8113	$119\,168.984 \cdot e^{0{,}00502 \cdot I}$

However, this method of forecasting should only be applied with precaution, and after a certain time, the results should be modified by using corrective factors to eliminate the inherent errors of mechanical methods.

Table 2

Forecast water demands of the city of Bratislava

Months involved	Form of approximation	1980	1990	2000
		100 Q (m³/day)		
1–66	Linear exponential	194.7	255.9	317.2
		207.9	325.3	509.0
1–60	Linear exponential	197.6	261.7	325.8
		213.1	341.4	547.2
1–54	Linear exponential	198.3	263.0	327.8
		215.2	348.2	563.4
1–48	Linear exponential	215.3	296.4	377.5
		244.3	446.2	815.0

2.2. *Application of analytic methods*

When using analytic methods, one should investigate separately the development trends of the fundamental determinants defining the water demands and to correct their rate of development depending on the probable effect of the operative factors.

2.2.1. *Investigation of the factor of growth of per capita water demands*

From among the investigations of the growth factors of the fundamental determinants only those of the per capita water demands are reported. The determination of the growth factor of per capita water demands has been dealt with, among others, by *Dietrich* and REINBECK [4]. As a result of his investigations, *Dietrich* found a relationship between the growth factor of per capita water demands and time, in agreement with our own investigations. Analyzing our forecast data on the basis of *Dietrich*'s diagram *(Fig. 2)* the following conclusions may be drawn:

— at the initial segment of the curve a lag of about 10 years may be observed,

— it is probable that the slope of the curve will be steeper than that of *Dietrich*'s curve which proves that the *rate* of development was here more marked than in the F.R.G. during the corresponding period.

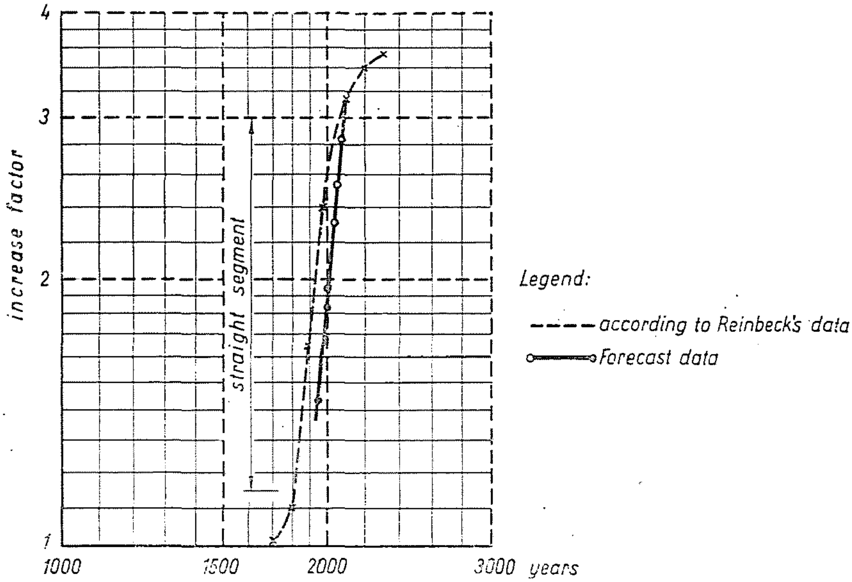

Fig. 2

2.22. Forecasting the development trend of the factors determining the total average water demands (extrapolation of the complex trend)

If sufficient actual data are available for the extrapolation of the fundamental determinants, so they can be forecast separately by using the familiar methods [2]. By taking into account the same basic periods in the trend function of the fundamental determinants, at the end of the planning period, the total water demand to be expected may be determined as follows:

$$\bar{Q}_{t\Phi} = \frac{N_t}{N_0} \cdot \frac{\bar{q}_t}{q_0} \cdot \frac{e_t}{e_0} \cdot \sum_{i=1} \bar{Q}_{0\Phi}, \tag{1}$$

wherein

$\bar{Q}_{t\Phi}$ and $\bar{Q}_{0\Phi}$ — average water demands at the end of the planning period and in the base year, respectively,

N_t and N_0 — number of inhabitants at the end of the planning period and in the base year, respectively,

$\bar{q}_t$ and $\bar{q}_0$ — average per capita daily water demands at the end of the planning period and in the base year, respectively,

e_t and e_0 — percentages of population enjoying central water supply at the end of the planning period and in the base year, respectively.

This method of forecasting is a skeleton to be modified according to the effects of the *operative factors*. From among the investigations performed, an account is given on the results of the analysis made in connection with the city of Bratislava (Table 3).

Table 3

Forecasts of water demands

Method of forecasting		Total water demands to be expected Q m³/day 1980	1990	2000
Analytical method		273.976	407.018	508.997
Trending	linear	215.326	296.404	377.482
	exponential	244.301	446.216	815.012

For the sake of comparison it should be mentioned that when investigating the trend of water demands in connection with Budapest and Miskolc the following results were obtained for the time-dependent average per capita water demands (Table 4) [5], [6].

Table 4

Development of the average per capita water demands

City / Year	Budapest	Miskolc
	average per capita total water demand q_3 (lit/capita/day)	
1972	435	390*
1980	630	540
1990	775	660
2000	850	750
2030	1020	950

*Estimated from data of 1971

2.2.3. Simulation

In order to forecast per capita water demands, from among the fundamental determinants, the deviation from the average and the distribution of the water demands by making use of the available data was analyzed as a first step [7].

In order to characterize the probability distribution of expected per capita water demands, the lognormal distribution function was applied *(Fig. 3)* because computer-made fitting tests have proved that with an increasing

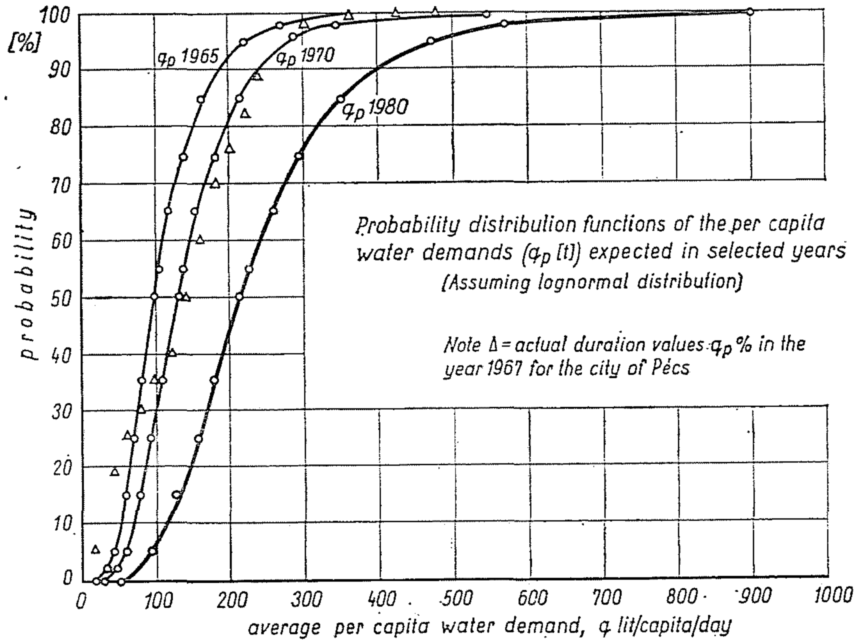

Fig. 3

homogeneity of the data, an increasing area involved an increasing satisfaction of water demands, the demands tend towards the lognormal distribution.

The intention of the present investigations was to simulate the water demands involving the effects of the operative factors. If one knows also the probability distribution function of the development of the population supplied, one can also establish the probability distribution function of total water demands which permits a reliable forecast.

Summary

Forecasting the water demands of a settlement is a technical and in most cases economical problem. From the methods reported herein for the forecast of water demands the authors *consider the analytical methods as the most successful ones*, in all cases where appropriate and reliable data are available. In a number of cases, however, the lack or unreliability of significant data makes necessary to apply other, e.g. mechanical methods which, in certain respect, are less accurate. For instance in the case of the city of Bratislava several forecasting methods were used. The results show that *for a short-range forecast, the mechanical methods e.g. trending give acceptable results, but it is thought necessary to apply simultaneously several methods in the case of long-range forecasting* as well as the *careful consideration of the results from the technical point of view* (e.g. the assessment from the engineering viewpoint of computer outputs) as well as the *revision* at given periods and if necessary, modification of the estimates.

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