FORECASTING METHODS FOR FUTURE MUNICIPAL WATER DEMANDS

by

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Water demands are connected with human activity in a general sense. These demands may be classified as:

— serving directly the survival of mankind, or

— serving this purpose indirectly, meaning water demands for the sake of producing various goods.

Water demands are usually detailed (also involving certain quality criteria) according to the following consumers:

a) municipal demands, including domestic uses, public institutions, public services, watering of streets and parks, fire extinguishing, etc.,
b) industry,
c) building industry,
d) transport and telecommunication,
e) commerce,
f) agriculture, and
g) miscellaneous,

expressed in units of lit per capita per day or cu.m per hectare per day, etc., to be secured in a function of time.

As far as the order of magnitude of these demands is concerned, municipal and industrial demands are of outstanding importance in planning water supply.

The present paper is intended to describe certain methods to forecast municipal demands.

These methods may be divided into *mechanical* and *analytical* ones.

The underlying principle to *mechanical* methods [2] is the projection of past trends into the future, assuming the future to be direct function of the past.

Analytical methods [1] on the other hand do classify and analyze the factors having an influence upon specific water demands playing a role in shaping historical trends. Simultaneously, these methods also give consideration to factors promoting or inhibiting development, the importance of which will increase or decrease in future. (Analytic methods are based on the recognition of considerable errors that may result from simply extrapolating past development.)

1. Mechanical methods

1.1. The use of an index of correlation

Its main feature is the *comparison* of growing water demands with the *growth of other factors* (like the national income, total national gross product, or e.g. the development of gas and heat supply). The method can usually be adopted on a national scale only, since mostly there are no sufficient and reliable data available for smaller areas.

1.2. The use of an analogy

Analogy is a *relationship* or *similitude between things*, not referring to the things themselves but to one or more of their properties, circumstances or effects. Essential is the *identity of proportions.*

Analogy may prove helpful e.g. in forecasting the expected development of an industrial or agricultural town of 25,000 inhabitants when compared with another industrial or agricultural town counting today already more inhabitants, supposing the development conditions and structure of the two towns being nearly the same at the time both had a population of 25,000 (analogy in time and space).

1.3. Determination and extrapolation of a lasting trend of development

In possession of a sufficient number of data it will be possible to determine the trend of past development. If this rate is assumed to prevail also in the future, then the data available will make the forecasting of future demands feasible.

Generally, there are various methods for determining trend functions. This can be performed *graphically* (graphical smoothing, plotting of an average curve), *analytically* (by establishing the regression equation) or by applying *statistical methods.*

The correlation between development and time may be linear, progressively or degressively growing.

2. Analytical methods

The basic feature of analytical methods is the separate investigation of development trends of the three *basic determinants* and the subsequent correction of their future trends by means of *operative factors.*

Basic determinants:

ΔP, the change in population [in capita];
Δr, the change in the ratio of population supplied with tap water to total population [in per cent];
Δq, change in the individual water ration [in lit/day per capita].

Operative factors:

- socio-economic conditions of the country (region);
- degree of completeness, development and state of the water supply network;
- changes in the socio-economic structure of the country, municipalities, regions;
- changes in population density, industrial development;
- quality of supplied water (e.g. warm and cold water, sanitary facilities);
- traditions and habits, etc.

2.1. Advancing projection of the trend determining the total average water demand

$\Sigma\bar{Q}$ (extrapolation of the compound trend)

If there is a sufficient number of data available for the extrapolation of the basic determinants, then these can be projected ahead — by using any of the known methods of trend calculus. After this being done, an identical base period should be taken into account for the trend functions of all three basic determinants over the planning period and the reference bases P_0, r_0, q_0 have to be confined. Then the total water demand Q_t expected at the end of the planning period is to be calculated as

$$Q_t = \frac{P_t}{P_0} \cdot \frac{r_t}{r_0} \cdot \frac{q_t}{q_0} \cdot Q_0$$

where subscripts t and 0 refer to values at the end of the planning period, and those of the reference year, respectively.

Thus a curve, or in some cases, a straight line is obtained for the whole planning period, showing the forecast values for every year.

2.2. Determination of the expected average water demand model $\Sigma\bar{Q}_t$ and the per capita demand q_t by means of the actual water demand model

When using the actual water demand model, the taking into account of the following points is recommended:

a) It is not enough to depart simply from population changes since it is well known that the *non-uniform population density* will lead to distortions in the further development of a water model, with regard to the establishment of new residential and industrial areas, recreational and education centres.

These facts show the inadequacy of a single *growth factor.*

b) Also the changes in per capita demands are not uniform and hence, not to be modelled by means of a single growth factor. Here, the following facts should be kept in mind:

— *in built-in areas, the following development trends may be realized:*

1. in new residential areas where there was a possibility to develop all public facilities, the growth factor will, after having passed a threshold value, increase but slowly (it is probably close to the completeness level but the per capita demand is relatively high);

2. in areas under reconstruction, where restraints from e.g. monuments preservation do not allow a degree of amenities similar to the preceeding ones, the growth factor is increasing more powerfully but still attaining a lower final value;

3. in areas with a sparse population density, where for a long time to come a full sanitation will remain un-economical, there will be three characteristic stages for the growth factor of per capita demand:

— the stage of standpipe supply,

— the stage of water tap in the courtyard,

— the stage of full comfort.

These three stages are separated by two thresholds as a consequence of jumps in quality changes.

— *In designated residential areas the growth factor is of a threshold character* (its absolute value being perhaps near to saturation).

2.2.1. Determination of the growth factor for per capita demands. The numerical solution of this problem has been studied by DIETRICH and REINEBECK [3] for conditions prevailing in the German Federal Republic.

In the authors' opinion, this method is a very significant one for its being based upon a great number of actual data. At the time of its publication it called general attention to the fact that per capita demands must not be looked upon as if they were static features. A certain criticism is needed before applying this method to other countries.

According to his investigations, Dietrich has found a relationship between the *growth factor of per capita demand* (civilization factor) and time.

2.2.2. Analytic calculation of the growth factor [4]. If a municipality has an actual population of P_0 then t years later it will grow to P_t, to be expressed as

$$P_t = \sum_{i=1}^{n} (P_{0i} \cdot f_t^{Pi})$$

if the area can be subdivided into n districts with different development characteristics. In this formula

$$f_{Pi} = 1 + \frac{p\text{‰}}{1000} = \frac{P_{ti}}{P_{0i}}$$

is the growth factor of population in the i-th district.

The population P_{rt} enjoying the benefits of a central water supply will be after t years

$$P_{rt} = \sum_{i=1}^{n} P_{0i} \times f_{Pi}^{t} \times r_{0i} \times f^{t}$$

with r_{0i} being the ratio of people enjoying water supply to total population in the i-th district and the year of reference and f_{ri} the growth factor of this ratio for the i-th district.

The average per capita water demand of the population after t years will be:

$$\bar{q}_{ti} = a_1 \times P_{ti}^{a2} \times f_{qi}^{t}$$

f_{qi} denoting the annual growth factor of per capita demand in the i-th area, and a_1, a_2 being inherent constants of the method.

Hence, the future average water demand may be expressed as

$$\bar{Q}_t = \sum_{i=1}^{n} a_1 \times P_{0i}^{a2} \times f_{Pi}^{a2\cdot t} \times r_{0i} \times f_{ri}^{t} \times f_{qi}^{t} .$$

This method has a drawback in common with all mechanical methods, development factors being calculated through a mathematical formulation describing average development, where a stochastic function becomes replaced by a simple analytical one.

2.2.3. The ratio of water-supplied population and its growth factor. As already stated, this ratio expresses the proportion between population with central water supply and total population. From the aspect of water supply degree, there are four classes of population:

— people supplied from standpipes (where some doubt may arise whether such people should be considered as being supplied with water);

— people using a tap in the courtyard;

— people enjoying full comfort;

— people enjoying a high degree of comfort.

When determining the *growth factor of supply ratio*, attention should be paid to the following circumstances:

— in newly built residential areas or reconstructed areas the factor should be assumed as being 1.0, since, owing to the high degree of comfort, the ratio is almost equal to 100%;

— in residential areas still not completely built in a 100 per cent supply ratio is to be assumed for the time of completion;

— in lower-value areas with mixed types of buildings, characterized by a low density of population, a steep rise of the growth factor of the supply ratio may be expected today as well as at the end of the planning period.

Averaging of the growth factors (area analysis) [5] is made by dividing the area to be investigated into districts of different character (residential area, reconstruction area, designated residential area, etc.) and calculating the following growth factors:

$$\frac{P_{tk}}{P_{0k}} = f_{P_k}; \qquad \frac{q_{tk}}{q_k} = f_{q_k}; \qquad \frac{r_{tk}}{r_k} = f_{r_k}$$

k denoting one of the n various types of districts.

By weighting these growth factors for the individual districts by the area of districts of the same type, one will obtain the average growth factor $\bar{f}$ as:

$$\bar{f} = \frac{\sum_{k=1}^{n} f_{P_k} \cdot f_{q_k} \cdot f_{r_k} \cdot A_k}{\sum_{k=1}^{n} A_k}$$

A_k being the area of the k-th district.

In knowledge of the average growth factor one obtains the expected average water demand at the end of the planning period as

$$\Sigma \bar{Q}_t = \bar{f} \Sigma \bar{Q}_0 .$$

Essentially, this method enables a dynamic averaging for a time interval, taking development into account.

2.3. *Application of analogies*

Through the averaging method of growth factors and the component analysis it also becomes possible to reliably determine the average water demands of future residential areas, industrial centres or existing unsupplied villages by analogy.

2.4. *Econometric forecasting*

Economic analyses resulted in the realization of water being a commodity of value and hence, a category of economics [7]. Thus, econometry may be used in forecasting water demands that are governed by laws of economics.

The meeting of water demands behaves exactly as the meeting of any other demand where the means are limited.

But in spite of these general features, one part of the demands (those serving survival and health) must be met unconditionally, irrespective of the price of water. The absolute value of this demand is always growing but its relative share within the total demand is decreasing.

According to references, 70 lit/day per capita is the upper limit of consumption still unaffected by water price. The rise of water price has a restrictive effect upon water consumption, hardly perceptible slightly above 70 litres but asserting itself powerfully around 500 litres per day and capita [8].Accordingly, demands can be divided into a *rigid* part covering vital demands and a *flexible* part containing everything else.

Together with growing water consumption, the tariff system assumes a greater complexity too. Water supply becomes a sort of industry selling its product in the market, influenced by the law of offer and demand. The analysis of investment and efficiency becomes then inevitable and this fact is creating the basis for establishing an econometric model for water demand forecasting.

2.5. Simulation models

The forecasting of water demands requires a mathematical or physical model reliably reflecting the substantial properties of the development process. By simulating quality conditions, the model [9] should include the given *initial conditions* (social, technical and natural) and being an operational system, the received *impulses* have to trigger off such *responses* that correspond to real changes in demands.

Such a model enables the reproduction of development processes corresponding to sets of impulses generated artificially or by nature. The construction and operation of simulation models is performed on digital computers, owing to the extremely voluminous calculations involved.

If there is a sufficient amount of observation data available, covering the whole development process, including impulses, responses and the intermediate systems of events, then of course, a theoretical model may be replaced by the actual data. Such cases occur, however, less and less frequently, due to the growing importance of changes induced by human interference.

The evaluation of a simulation analysis is based upon the theory of the Monte-Carlo method, and in course of the simulation process the *number of occurrences* of situations are counted that are decisive from the point of questions to be answered. When using data series of adequate length, this is equivalent to the *probability of occurrence* of these situations.

Summary

Up-to-date methods enable the forecasting of water demands for the long run. The accuracy and usefulness of a forecasting is widely influenced by the selection of the length of planning period. Generally, a period of 20 to 30 years, usual in Hungary, is coinciding with the economic life span of structures and enables a forecasting of desired accuracy. Longer periods of planning require a re-adjustment of figures from time to time.

Any of the usual methods can find application only if there is a sufficient number of reliable data available. This also involves a circumspect collection and processing of data.

Uncertainties inherent to forecasting make it necessary to increase the reliability by the simultaneous application of several methods and by comparing and evaluating the results obtained. This can be done the more easier since all methods described are applicable to the computer technique.

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