AGGREGATE URBAN WATER DEMAND FORECASTING USING ARTIFICIAL NEURAL NETWORKS

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The accurate forecasting of water demand is essential to the planning, design, operation and maintenance of drinking water supply infrastructure. Traditionally, this forecasting has been predominantly completed using parametric approaches, such as the multiple linear regression (MLR) method. Such techniques require the development of an equation, or set of equations, to describe the relationship between water demand and the explanatory variables, such as population, land-use, and climate condition. The true form of the functional relationship between demand and the explanatory variables is often unknown and is, at least to some extent, subjectively assumed.

This paper explores the potential use of artificial neural networks (ANNs) to predict long-term urban water usage. Essentially, ANNs are a highly parallel adaptive system capable of self-improvement through an artificial learning process. An ANN is composed of inter-connected basic processing elements called artificial neurons organized into three different kinds of layers, namely the input layer, the hidden layer(s), and the output layer. The input layer receives data from outside of the network and transmits it to the hidden layer(s). The hidden layer(s) does not interact directly with the input layer, but rather enhances network complexity, which gives the network the ability to process complex nonlinear data. The output layer receives signals from the hidden layer(s) and its outputs are the outputs of the ANN. ANNs are increasingly being applied in many science and engineering fields. The wide application of ANN is largely attributable to its ability to handle highly complex and non-linear processes by "learning" through network training. Unlike traditional parametrical approaches, ANNs require no prior knowledge of the true form of the functional relationship.

Based upon data recorded from 1996 to 2001 for seventeen municipalities in the Greater Vancouver region, an aggregate urban water demand model was developed and tested. The explanatory variables (i.e. inputs to the ANN) selected include serviced population, climatic data (precipitation and average temperature during summer), median family income and land-use information for each municipality. The land-use data is comprised of areas of commercial, industrial, institutional, agriculture, high-rise residential, apartment and town house land uses, as well as the numbers of single family dwelling units and the average single family lot size. Thus, the input layer contains twelve neurons, while the output layer contains one neuron representing the response variable of annual average water demand for each municipality.

The data set was arbitrarily divided into two groups, with 83 data sets chosen for network training and 19 data sets used for validation purposes. The optimal number of neurons and hidden layers are determined via the review of results from network training and validation. Four cases of the ANN using a different number of weighted connections were evaluated and compared with MLR. It is shown that the accuracy of the ANN decreases as the number of connections is increased beyond a certain threshold. Fig. 1 shows the most accurate of the four forecasts by the ANN against the observed flows. Overall, 75% of the predicted flows are within 5% of the observed value and 97% of the predicted flow is within 10% of the observed value.

The ANN model is shown to have the flexibility to handle the complex non-linear problem of water demand prediction and to provide better predictions than the traditional MLR approach. The ANN does not currently include all explanatory factors which are known to have the potential to affect regional water demand over the long term. For instance, the consideration of both water pricing and conservation factors are not currently explicitly considered. Most residential single family and multiple family land users are not metered at this time. Many of the users that are metered are presently charged a flat rate for water use. Therefore the financial incentive for conservation, including the incentive at the municipal level to reduce the volume of leakage from municipal watermain systems, is currently relatively small although it will increase over the coming years as the water metering program is formalized and as water prices rise. However, in spite of the limitations of the current ANN, the resulting forecasts are promising, especially if the ANN were to be developed further to include additional explanatory variables as the financial incentive for water conservation increases regionally and as more data becomes available.

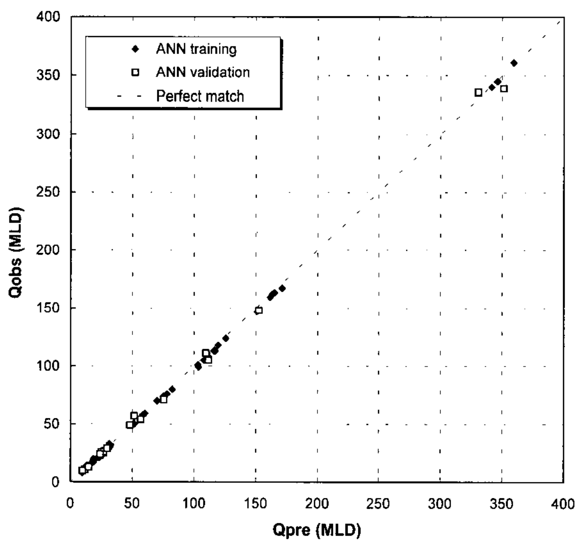

Fig. 1 Results of ANN training and validation (l=10 and m=5), where l and m represent the number of neurons in the first and second hidden layers respectively