Foreword

This publication was first written as a report for the Norrköping Conference of the WMO project "Intercomparison of Conceptual Models of Snowmelt Runoff" in September 1983, except for Chapter 7 of Part 2. However, by adding many appendices, this publication can now be used as a handbook or textbook for the tank model. As my papers, reports and books on the tank model have been mostly written in Japanese, I believe that this publication will be of some significance for hydrology.

Readers can get a rough outline of the tank model and its automatic calibration method from Part 1, which is a general description of the tank model with its snow component. Detailed descriptions are given in corresponding appendices while Part 2 gives examples of runoff analysis which will help readers to understand how to calibrate the tank model.

The tank model is usually classified as a deterministic parametric lumped model and it is considered as a black box model by many hydrologists. However, we can ask ourselves, if it is a mere black box, how can such a simple tank model successfully simulate river discharge from high flood flows to low base flows? There must be some physical meaning in the tank model.

The tank model had its origin in the idea that to represent surface runoff and intermediate runoff two water storages are necessary. After a while, two more storages were introduced to represent base flow and the present form of the tank model was obtained. Very recently, we were able to find the phenomenon to prove the existence of two kinds of water storage, by analyzing the record of crustal tilt meters affected by rainfall (Appendix 1, 1.3.3). Also, we could find a phenomenon which can be explained by two water storages for the base flow but which is impossible to explain by a single tank (Appendix 1, 1.3.4). To some extent, these are the physical meanings of the tank model.

On the surface of the ground there are river channels by which the most part of surface water transportation is carried out. However, the area of the river channels is negligibly small compared with the whole area of a basin. Therefore, if we pick up random sample points in a basin, the probability that some sample points fall on a river channel must be very small, probably near to zero, even if the sample size is very large. Similarly, if we select some small random sample area in the basin, the possibility that the sample area would include a river channel is also very small. This means that, by such a random sampling method, we cannot catch the real image of water transportation on the ground surface.

We cannot observe the structure under the ground surface but can imagine that the transportation of groundwater is mostly carried out through some singular domains such as sediment layers, faults, fissures etc. and that the total volume of such singular domains is very small compared with the whole volume. We can find an evident example of such singular structures in karst regions. Even in a homogeneous sediment layer, we can imagine that water transfers mostly through routes of three dimensional networks, which is somewhat similar to river channels on the ground surface. Of course, these water routes are not stable. Some routes will be stopped by sedimentation and other routes will be opened by washing away of sand and silt. In spite of such an unstable micro structure of three dimensional network-like water routes, the sediment layer seems to be homogeneous in macroscopic outlook. The structure of groundwater movement in a basin may be somewhat similar to this but on a larger scale.

In the case of such a structure in which water transfer occurs mostly through a singular domain with comparatively very small volume, research or experiments carried out by sample points or by small sample areas cannot be *reliable. This may be a reason why experimental basins are not so useful and why transfer of the results obtained from experimental basins to large basins is very difficult.*

There is another difficult fundamental problem concerned with such structures. A water route will be stopped when it is blocked only at one point along the route and an impermeable layer will pass water freely when there is only one hole somewhere in it. The total response of such structures is very difficult to analyze from point inspections or small area experiments and it is better to analyze as a total by some macroscopic method. Runoff analysis by the tank model is such a sort of approach by total response. Moreover, we expect that the tank model itself is a sort of structural approach to the discontinuous structure such as faults, gaps and fissures.

When I had the idea of the tank model, I was very anxious about the problem of how to calibrate the model. However, despite my anxiety, calibration of the tank model by the trial and error method was rather easy and interesting. It was a sort of numerical experiment; and much experience and information were accumulated through the trial and error procedures. In the early days, I could not use a computer and so the trial and error procedures were carried out by manual calculation. It was troublesome hard work and it took a very long time but model calibration by the trial and error method was proved possible. For more than twenty years, I have been analyzing the runoff structure of many river basins by the trial and error method. Of course, in later days, we used computers in the trial and error method. A feedback cycle composed of a computer and human judgement was very effective and efficient.

In 1975, I retired from the post of director of the National Research Center for Disaster Prevention. I was to become a professor at the Asian Institute of Technology at Bangkok from April 1976 and I expected to analyze *river basins in various parts of Asia. However, just before I was due to start this job, it was found that I was suffering from gallstones and I was unable to go to Bangkok.*

Then, I considered; what shall I do? I was 59 at that time and I was not young. My knowledge, technique and way of thinking about the tank model would be lost in the not so far future. It should be my duty to translate my knowledge and technique into computer language. This work seemed to be important and interesting both in hydrology and computer software technique. This work was finished successfully without much difficulty in August 1976. The resulting automatic calibration method of the tank model is not a hill climbing method but a sort of feedback method using several criteria RQ(I) and RD(I) defined by the comparison of calculated and observed hydrographs. This method is very effective and efficient and it can give good results after several iterations of the feedback procedure (Appendix 6).

One and half years later, a new method based on the comparison of duration curves was developed and this new method was usually better than the former hydrograph comparison method (Appendix 7). In the runoff analysis of six WMO basins, this duration curve method was used throughout.

These automatic calibration methods were used to determine the runoff and infiltration coefficients of the tank model but there are many parameters other than these coefficients, such as heights of side outlets, parameters of the soil moisture structure, parameters of the snow model etc. Automatic and semi-automatic methods were developed for these parameters using the automatic calibration procedure with RQ and RD as an auxiliary method (Appendix 10).

Even though such automatic and semi-automatic methods have been developed, I still believe that the trial and error method by human subjective judgement is the most important way.

Today, mathematical methods based on the correlogram and the Fourier transformation are used in many hydrological problems. However, I think, though this method is very powerful and effective for oscillating systems, it may not be so effective for exponentially descreasing systems. The correlogram is similar to the diffraction grating as a physical instrument and the Fourier transformation is an orthogonal transformation from displacement coordinates to frequency coordinates. These procedures cannot have a large effect in exponentially decreasing systems which have no frequency component at all. In the automatic calibration method of the tank model, exponentially decreasing components, having their respective time constants, are separated by dividing the whole period into subperiods and then, in each subperiod, adjusting each component using RQ and RD. I have some expectation that such a method may be applicable to other systems composed of exponentially decreasing components.

I would like to express my heartfelt thanks to Mr. I. Watanabe, Miss Y. Katsuyama and Miss E. Ozaki who have been working with me for long time. The results described in this publication were obtained by our group in the Fourth Research Division of National Research Center for Disaster Prevention.

I would also like to express my heartfelt thanks to Dr. Geoff Kite, Chief Technical Adviser of UNDP-WMO project in Kathmandu, Nepal, and Dr. Jiři Haas, National Hydrology Research Institute, Environment Canada, who kindly read the draft and corrected many mistakes and gave me many suggestions and advice.

M. Sugawara