WMO PROJECT ON INTERCOMPARISON OF CONCEPTUAL MODELS USED IN HYDROLOGICAL FORECASTING

Report by WMO to the International Symposium on the Application of Mathematical Models in Hydrology and Water Resources Systems, Bratislava, 11 September 1975

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This project had its beinning in 1967 at the Symposium on Hydrological Forecasting held at Surfers' Paradise, Australia, and sponsored by WMO, UNESCO and the Federal Government of Australia. It was recognized by this group that the advent of electronic computers had made possible a new and higher level of complexity in catchment modelling, and that many rather sophisticated models were being developed. It was further recognized that, this development had been independent and uncoordinated and that as a result, services needing to choose a forecast model, lacked information on which to base a choice. The type of information needed was in regard to what models existed and to the accuracy of those models relative to each other and relative to the hydro-climatic characteristics of the area in which they might be used. It was therefore recommended that WMO conduct a project to collect this type of information.

The concept on which the project was based was that it should provide an inventory of existing conceptual models including information on such characteristics as physical concepts, data requirements and computer requirements and that it should also provide information about their accuracy relative to each other and relative to hydroclimatic conditions. It is emphasized that no attempt was to be made to identify a 'best' model, but rather to provide a prospective user with the information he would need to decide which model is 'best' for his purposes.

The project was to be limited to conceptual models which enjoy an operational status. These terms are defined for the purposes of this project as follows:

> A conceptual hydrological model is one which represents a concept of either the whole or a part of the physical process of the hydrological cycle, expressed by either simple or complex mathematical formulations. The output of such models is deterministic.

> An operational model is one which is at present being used or actually tested by national services for issuing public hydrological forecasts for the use of consumers such as river authorities, civil defence agencies, the general public, etc.

Another project constraint was that it was to be restricted to models used for forecasting rather than for prediction. For the purposes of this project, these terms are defined in this way:

> Forecasting is defined as being related to the occurrence of hydrological phenomena in real time (e.g., from hour to hour or from day to day). Prediction is de-

fined as statements regarding the future occurrence of hydrological phenomena without regard for their actual time of occurrence (e.g. probability distribution of future discharges, return periods of floods, etc.)

Models which were actually used for forecasting were not to be disqualified however simply because they were also capable of use for prediction.

The project was also to be limited to models which provide a continuous simulation of discharge and which use meteorological variables as input although, observed river discharge at upstream points could be used as an auxiliary input.

Additionally, there was no requirement that the model must have been devised by the national service using it or contemplating its use. The project was originally intended to consider three classes of models, 'hydrological', 'hydraulic' and 'combined'. It was soon realized that any model must involve both hydrological and hydraulic aspects. The 'combined' classification was therefore eliminated and all models classified as either hydrological or hydraulic depending on which process was predominant in the formulation. Later, the hydraulic model portion of the project was, for various reasons, dropped and the work was restricted to hydrological models in which the predominant process was a rainfall to runoff transformation.

Actual work on the project began in 1969 with three informal study group meetings held in Washington, USA, Paris, France and Tokyo, Japan. These meetings resulted in a plan of implementation and a questionnaire on operational conceptual models, and on the project itself. This information was circulated, in March 1971, to all WMO member countries concerned. In October 1972, a meeting of experts was convened in Geneva. This group, after considering the conclusions of the study groups and the questionnaire replies, set down in detail the manner in which the project would be conducted. Some of the more significant decisions made at this time are as follows:

(1) Each model owner would calibrate his model on all data sets. An alternate method, in which each data supplier would calibrate all models to his data, had been considered.

(2) Split sample testing was to be used with a six-year calibration period and a two-year test period. The reason for not splitting the eight-year data sets into halves was that a four-year calibration period was considered as being unlikely to contain sufficiently varied hydrological activity for a good calibration. Due to the statistical limitations of the short two-year test period, it was decided to compute all verification criteria for both the calibration period and the test period.

(3) All error analyses were to be based on the differences between the simulated and observed values of either mean daily discharges or monthly volumes, but not on ordinates representing instantaneous discharge. The reasoning here was that timing errors, even if small, would affect the error functions based on mean daily values since the time of occurrence of runoff events is, in general, randomly distributed throughout the day. Timing errors were therefore not to be considered, explicitly.

(4) No provision was to be made for up-dating. While it was recognized that up-dating is necessary in operational forecasting and that it does increase the accuracy of simulation, it was felt that because of the self limiting nature of models of this type, the use of up-dating would not appreciably affect their accuracy *relative* to one another.

(5) Five numerical verification criteria, either decided upon at this meeting, or introduced later, were used. They are:

(a) The coefficient of variation. This is the ratio of the root mean square error to the average of the observed values of the variable.

(b) The ratio of the absolute error to the mean. This is, the ratio of the arithmetic average of the errors to the average of the observed values.

(c) The ratio of the relative error to the mean. This is the algebraic average of the errors divided by the average observed.

(d) The phasing coefficient, the number of times that the simulated and observed peaks are more than one day apart.

(e) The coefficient of persistence, the sum of the squares of the positive and negative run areas divided by the sum of the squares of the individual errors.

These statistical quantities were computed from four flow variables, mean daily discharge, monthly volume, maximum mean daily discharge for each month, but only for those values which exceeded the mean flow for the period of record, and also from mean daily discharge for low flow days, those below the level not exceeded during a period of 130 d in the verification period. Some of the numerical functions described are obviously not applicable to some of the flow variables and hence were not applied to them. For instance, the phasing coefficient was applied only to mean daily discharges and not to monthly volumes.

Graphical error displays consisted of linear scale plots of simulated and observed mean daily discharge, double mass plots of simulated *versus* observed monthly volumes, flow duration curves of simulated and observed daily discharges and scatter diagrams of simulated *versus* observed monthly maximum discharges.

The group which met in 1972 also studied the various models which had been submitted by the respondents to the questionnaires and selected eleven for inclusion in the project. Four of these later dropped out voluntarily for various reasons. Three newer models were introduced subsequent to the meeting, and so, a total of ten models from seven countries actually took part. Since these models demonstrate a great diversity of concepts and approaches, a very brief description of each will be given.

The CBM Model was submitted by the Commonwealth Bureau of Meteorology, Melbourne, Australia. The input to the model is average catchment rainfall. An initial loss is determined by application of a modified API (Antecedent Precipitation Index) technique. The API recession function is based either on an empirically derived seasonal parameter or on normal evaporation and current moisture status. Excess rainfall is predicted using a loss rate which is a function of storm duration. The storm hydrograph is calculated from the excess rainfall using a unit hydrograph. Nonlinearity is introduced into this function using a peak-trend diagram and an index for the storm centre position.

The Tank 1 Model, sometimes known as the Serial Storage Type Model, was submitted by the National Research Center for Disaster Prevention, Tokyo, Japan. As its name implies, it conceives of water being held in storage in a series of tanks, arranged one above the other. Each tank has an opening in the bottom and one or more openings in the side at some distance above the bottom. Rain, or snowmelt, enters the top tank. Water which leaves any tank through the bottom hole enters the next lower tank. Water leaving any tank through a side hole enters the river channel system. The individual tanks represent the various storage zones in the soil mantle. The number of tanks and the size and positions of their outlets are defined by the model parameters.

The temporal distribution function, representing channel storage, is a modified first-order lag system.

The Tank 2 Model, sometimes referred to as the Kizugawa Model, or as the Composite Tank Model, is intended for use in arid or semiarid regions. It consists of a series of two or more Tank 1 models arranged side by side in rows, with the outflow from each row feeding into the adjacent row. The outflow from the last vertical row supplies the channel system. The several rows represent zones in the catchment, the lowest corresponding to the zone nearest the channel system. As hydrological conditions make their seasonal progression between wet and dry, the zones nearest the channel system may be more moist than those further away. This condition is modelled by having the vertical rows of tanks representing the wet zones full while the other rows are less than full.

A detailed study of either Tank model discloses that the mathematical formulations defining the flow of water from tank to tank closely resemble the classic hydrological concepts of interception, infiltration, percolation, aquifer storage, etc.

Both Tank models are extremely flexible since changes in the values of model parameters can acutally change the structure of the model.

The IMH Model, also known as the Flood Forecasting Model, was submitted by the Institute of Meteorology and Hydrology, Bucharest, Romania. In this model, the catchment is considered to consist of two reservoirs representing upper and lower soil layers. Rainfall excess is developed by moisture accounting in the reservoirs. Conversion of runoff volumes to hydrograph ordinates is accomplished with a unit hydrograph expressed mathematically as a gamma distribution function involving two parameters.

The HMC Model is from the Hydrometeorological Centre of the USSR, Moscow. Input data consist of precipitation, and also certain meteorological variables such as wind speed. Mathematical formulations which model evaporation and infiltration result in two runoff components, surface and subsurface. These runoff volumes are converted separately to discharge by the use of gamma distribution functions.

The Girard Model was submitted by ORSTOM, the Office of Atmospheric Research, Paris, France. This is a distributed parameter model with a fairly simple vertical structure. The mathematical formulations are linear and involve threshold values and rates defined by model parameters. The model uses both precipitation and evapotranspiration data as input, and yields a water balance for the catchment.

The CLS Model, Constrained Linear System, was developed by the Hydraulics Institute of Pavia University and the IBM Scientific Center, Pisa, Italy. The model uses as input a time series of precipitation data. These are operated on by a series of kernel functions which transform the inputs into a hydrograph of outflow, accounting for hydrological losses as well as for the temporal distribution of the runoff volumes.

In application, the number of kernel functions to be used for a particular catchment and therefore the number of corresponding inputs are determined subjectively by a consideration of the characteristics of the catchment. After this is done however, the evaluation of the parameters in the kernel functions is performed by a fully objective procedure which ensures minimum variance, subject to physical constraints.

The NWS Model was submitted by the Hydrologic Research Laboratory of the US National Weather Service. It is a modification of the Stanford Watershed Model. The model conceives of water being retained in interception storage and in four zones in the soil profile. The mechanics of the various processes taking place utilize a distribution graph technique to model the areal variation of catchment characteristics and conditions.

The model uses both precipitation and evapotranspiration data as input. It generates four components of runoff which are summed and applied to a unit hydrograph. Provision is made for applying a variable storage reservoir routing to the resultant hydrograph.

The Sacramento River Forecast Center Model was developed and submitted by the US National Weather Service River Forecast Center at Sacramento, California.

The basic subdivision of the soil mantle involves two zones with two types of water, tension water and free water in each zone. A percolation function defines the flow of free water from the upper to the lower zone and, indirectly, controls the movement of water through all parts of the soil profile and on the surface.

The model uses evapotranspiration and precipitation as input. It is of the lumped parameter type but has provision for varying, with time, the size of an impervious area which has runoff characteristics different from the remainder of the catchment.

There are five components of runoff. Two of these, from groundwater, are added directly to channel discharge. The other three are summed and applied to a unit hydrograph. Provision is made for routing the resultant hydrograph with variable routing coefficients.

The SSARR Model (Streamflow Synthesis and Reservoir Regulation Model) was submitted by the US Army Corps of Engineers, Portland, Oregon. This model involves a mathematical moisture accounting which results in three components of runoff. Both precipitation and evapotranspiration data are used as input. The evapotranspiration data can be either the actual value for the day being analysed or a long-term average for that date. The model distinguishes between the two types of input and treats them in a different manner.

The three runoff components are converted to discharge hydrographs individually using 'multi-phase routing', a method similar to the instantaneous unit hydrograph. The three resultant hydrographs are then summed to determine the catchment outflow.

Following the 1972 meeting, descriptions of all available data sets were distributed to all participants, who then proceeded to rank them in order of their desirability for the project. Based on these rankings and on other considerations, six data sets were selected. They are:

(1) Bird Creek near Sperry, Oklahoma, USA. The catchment is small, 2 344 km^2 and consists of rolling terrain. The stream is rather fast acting however. The climate is generally humid, although extended dry spells are not uncommon. There is a one and one-half year severe drought in the early part of the record.

(2) The Bikin River in the USSR is a 12 100 km^2 mountainous catchment. It is 95 per cent forested and has a wet climate. Snow is a factor in this record and only 4 months of data, June-September, are available for each year.

(3) Wollombi Brook at Bulga, Australia, is a small stream, having a catchment area of 1 580 km^2, consisting of forest and grassland. The climate is semiarid and the river often goes dry.

(4) The Kizu River at Kamo, Japan, is the smallest of the six catchments, draining 1 445 km^2. The terrain is hilly and the river is fast acting. The climate is humid and there is usually abundant rainfall throughout the year.

(5) The Sanaga River at Edea, Cameroun, is the largest catchment, 131 500 km^2, involving mixed topography of forest and grassland. The climate is wet, having the characteristics of both tropical and equatorial areas. Although the precipitation pattern exhibits pronounced seasonal characteristics, there is virtually no seasonal variation in the runoff charcateristics of the catchment. It lies only about 300 nautical miles from the equator. Due to the great size of the catchment, and the large amount of channel storage, the river responds very slowly.

(6) The sixth data set is the Nam Mun River above Ubol, Thailand. This is also a very large catchment, draining 104 000 km^2. The climate is humid and is influenced by monsoons.

These six data sets represent a wide variety of hydro-climatic conditions. It is therefore hoped that conclusions resulting from the testing of models on them will be generally applicable.

During the fall of 1973, the data were distributed to all of the modellers, either on punched cards or on magnetic tape. Those data suppliers who had the necessary facilities sent data directly to the modellers. Those who did not have such facilities sent their data to WMO who in turn converted it to the form required by the modeller and sent it to him. All data, whether supplied on cards or on tape, were in card image and in the format used by the data supplier. It was felt that it was easier for each modeller to adapt his read routines to each format than for each data supplier to convert his data to a different format for each modeller.

Each modeller was supplied, for each catchment he wished to model, input data for the entire period of record, but output data for the calibration period only. He was required to simulate both the calibration and verification periods and forward the results to WMO.

Each modeller was encouraged to work with as many data sets as he could, but there was no requirement that he work with all six. Out of a possible maximum of 60 simulations, there were in fact 39, an average of four data sets per model. Two models, the Italian CLS and the Japanese Tank 1, were applied to all data sets and no model worked with less than two.

Following the receipt by WMO of the simulations, early in 1974, the error statistics and graphical displays were prepared at the Laboratory of Hydraulics, Hydrology and Glaciology of the Federal Institute of Technology in Zürich, Switzerland. This rather formidable task was performed under the direction of Mr Felix Naef of that Laboratory.

In July 1974, a second conference was convened in Geneva for the purpose of studying the results of the simulations and making recommendations to WMO regarding the content of the final report on the project. This conference was attended by WMO personnel, by at least one representative from each modelling agency, and by several invited experts. The remainder of this report will be devoted to the conclusions and recommendations decided upon at that conference.

Considering the rather wide diversity of concepts and approaches exhibited by the various models, it was felt that the task of reaching conclusions could be expedited if the models were classified as to the general manner in which they expressed the physical process. The classification system decided upon consisted of three categories, explicit moisture accounting, implicit moisture accounting, and systems approach. Since a model can display characteristics of more than one category, the conference found that for some models it could not agree unanimously on the classification. For this reason and because it was felt that each modeller knew his own model better than anyone else, the following classifications are, for each model, those decided upon by the model owner. In the explicit moisture accounting category are the three United States models, NWS, Sacramento and SSARR, the HMC model from the USSR, and the French Girard model. The only models classified as implicit moisture accounting are the two Japanese models, Tank 1 and Tank 2. The remaining three models, the Italian CLS, the Romanian IMH and the Australian CBM, were classified as systems approach.

The conference also attempted to not only document the performance of specific models on specific data sets, but to generalize the results and attempt to reach conclusions regarding the relationship between a model's general structure and its performance under various types of hydroclimatic conditions.

One such conclusion was that the accuracy of simulation among different types of models differs less in humid regions than in semiarid regions, and that in semiarid regions, the more complex, explicit moisture accounting models perform in a manner which is demonstrably superior to the simpler, implicit moisture accounting types. Furthermore, this superiority may also be noted in humid regions during and immediately after a long dry spell. This is felt to be an extremely important conclusion because it indicates that the extra complexity in the soil moisture accounting of the explicit models is worthwhile if the user is obliged to work in any area other than one which is continuously humid.

Another effect noted was a tendency for the explicit moisture accounting models to under-estimate the peak flow during extreme runoff events. This is thought to be due to precipitation being under-measured during heavy storms. A simple model might, during the calibration have its parameters adjusted to compensate for this undermeasurement. The explicit models however must be calibrated to represent the water balance during the entire period of record and hence cannot accomplish this type of compensation. It was noted that this tendency can be alleviated in actual practice by modifying reported precipitation input values during extreme events. A second factor which may be involved in this effect and which was discussed by the conference is the fact that the temporal distribution function, that is, the unit hydrograph or some variation of it, is, in the case of the explicit models, calibrated to all events, both large and small, and hence cannot duplicate the nonlinearity of the physical process.

The simulations of the Wollombi Brook record by the various models disclosed another interesting effect. This record is thought to contain rather large data errors. It was noted that the NWS and Sacramento models which are classified as explicit moisture accounting had larger errors during the verification period than the implicit moisture accounting Tank model, and much larger errors than the systems approach CLS model. During the calibration period however the NWS and Sacramento models had smaller errors than either the Tank or CLS models. To explain this seeming inconsistency it was suggested that models such as Tank and CLS may be better able to filter out noise in the calibration data and more closely approximate the true parameter values. The conference therefore concluded that in the presence of poor quality data for model development, implicit moisture accounting models and in particular, systems approach models, may have a better capacity to cope with this deficiency and therefore may give better forecasting results than explicit moisture accounting models. It should also be noted in regard to this matter that through an oversight in the distribution of the data sets, calendar year 1970 observed discharge was supplied to the owners of the Tank and CLS models and used in calibration. This year of data was not available for calibration of the NWS and Sacramento models. The magnitude of the effect of this discrepancy is not known.

It was also concluded that, in general, implicit moisture accounting models are very flexible and adaptable. The Tank model in particular is extremely flexible since, as noted earlier, the number of tanks may be changed, both vertically and horizontally, as necessary to reflect the conditions which are predominant in a particular catchment.

In addition to the foregoing conclusions of the conference, each modeller was requested to prepare a statement on the limitations of his own model as they appeared to him, based on the material presented and discussed at the conference. Time does not permit the inclusion of the full text of these statements in this report, but they can be summarized as follows:

The owners of the NWS model, the SSARR model and the two Tank models all seemed to feel that the limitations noted by the conference of certain types of models *did* fully describe the capabilities and that there were no *additional* limitations which would apply to their models specifically.

The owner of the Sacramento model discussed a number of limitations which he felt applied not only to his model but to the present state of the art of hydrological modelling. These limitations took the form of thoughts concerning future refinements and improvements. These include thermal computations within the soil mantle for the purpose of frozen ground evaluation and consequent modification of percolation, drainage and evapotranspiration computations, a more flexible method for loading the lower free water aquifers with water which is subject to deep percolation, a means of modelling the spatial variation of the catchment characteristics, a means of modelling the nonlinearity introduced by the areal variability of rainfall, and the development of techniques to determine optimal parameter values.

The owner of the Girard model felt that his model's results were compromised because of the lack of an automatic optimizing procedure and because of an insufficient quantity of daily rainfall data.

The owner of the HMC model discussed the fact that this model does not incorporate a function to compute groundwater flow and hence will yield accurate results only under those conditions where such flow can be neglected. That is, during extreme runoff events, and/or in comparatively small basins. Also noted was the limitation imposed by the use of lumped input. The belief was expressed that the model should probably not be used for catchments larger than 10 000 to 15 000 km^2.

The owner of the CBM model expressed similar views, since the CBM is also an event model. He further pointed out that with such a model, the exclusion of small stream rises from the calibration restricts the information available for calibration. He also stated that the Antecedent Precipitation Index used in this model is only a crude indication of soil moisture status and is likely to give poor results for small floods or for extended periods of rainfall.

In a similar vein, the owner of the IMH model noted that his model was applicable to flood events only and did not do well with small rises. He felt that the largest catchment on which it should be used is 2 000 to 3 000 km^2.

The owner of the CLS model observed that his approach to rainfall-runoff modelling can be regarded as the antithesis of a physics based mathematical model with regard to both computer and data needs as well as in terms of its objective, that is, prediction *versus* understanding. Aside from this observation, however, he did not identify any specific limitations disclosed by the test results.

In addition to studying the test results, the conference also reviewed the manner in which the project had been conducted and drew a number of conclusions which take the form of recommendations to others who may wish to perform similar work in the future. In order to more fully understand and appreciate these recommendations, it may be pertinent to consider some of the problems which arose and some of the mistakes which were made. It must be emphasized that this material is presented for the purpose of illustrating the difficulty of handling, exchanging and processing large volumes of data all over the world. It is not to be construed as criticism of any individual and it is probably safe to say that everyone involved made his share of mistakes.

For one of the data sets, that for the Kizu River in Japan, it was discovered during the testing that the first 30 months of record contained some inconsistencies, and a revised version was sent to all modellers. Still later, it was found that this version also contained obvious discrepancies, but of a different type. As time did not permit an investigation to reconcile the matter, these 30 months were excluded for the purpose of computing error statistics. They were, however, used for calibration, some modellers using one version and some the other.

In one data set, a mis-punched card, having all the numbers shifted to the left, was read in such a manner that a non-existent flood was used in the computations.

As was noted earlier, the Wollombi Brook data set was distributed to some modellers directly by the supplier and to others from Geneva. This resulted in the year 1970 being in the calibration period for some modellers and in the test period for others.

The supplier of the Bird Creek data sent reels of magnetic tape to five modellers with covering letters stating that the data was in EBCDIC coding. It was later discovered that due to a mistake in the computer centre, the coding was acutally 'packed binary' It then became necessary to generate and send new tapes with appropriate explanations, which of course delayed the work.

An additional problem with the Bird Creek data was that one modeller was supplied by WMO rather than bilaterally from the supplier. He was inadvertently sent, and proceeded to use, an earlier version which contained slightly different areal mean precipitation figures.

Some of the data sets included, in addition to the mean daily discharge figures, instantaneous discharge data for selected periods. This was intended to aid in the calibration of the temporal distribution portion of the models. In one case, such data were supplied in the form of eight ordinates per day, spaced 3 h apart and with the first at 3 a.m.

The mean daily discharge data however were based on the 24 h period from 9 a.m. to 9 a.m. and this fact was not documented. At least one modeller, attempting to reconcile the 3 h figures with the daily means had a great deal of trouble before establishing, through correspondence, the reason for the discrepancy.

Although the six data sets had been carefully checked and used before by their owners, all of the problems described, and more, did in fact occur. This seems to indicate that in a project of this type, the most extraordinary measures must be taken to ensure the correctness of the data, the correctness of data duplication, the completeness of data documentation, and the complete coordination of all the parties involved. Even if this is done, probably the best that can be hoped for is the minimization of this type of problem rather than its elimination. When one considers the time involved in communicating with a fellow participant half a world away, it becomes obvious that the time spent in planning and executing this phase of the work is time well spent.

As was stated earlier, all data were transmitted in the format used by the supplier. This was considered preferable to having each supplier write his data in each of the user's formats. There is no reason, at this time, to question this decision. There were cases however where users found fault with the formats used by some suppliers. This suggests that in projects of this type, it might be advisable to consider the use of a standard format which would be used for all data exchange.

After studying the verification results, the conference concluded that it would be advantageous if the verification and intercomparison of models in general could be carried out in accordance with at least some generally accepted verification criteria. It further recommended that the numerical verification criteria for such general use should, as far as possible, be selected from amongst those used in this project.

A final recommendation concerning future activities of this type is that everything possible should be done to ensure that all models be tested on all data sets. To accomplish this, it is necessary to ensure that all data sets meet the needs of all models. It may be observed that in general the more complex models need a greater variety of data than the simpler types. While a simple model may use only precipitation and streamflow for calibration, a more complex, or explicit moisture accounting model may need in addition such things as evaporation data, topographic maps, soil maps, geomorphological data, land use data, etc. This statement may be misleading unless it is further explained that it is almost always possible to both calibrate and operate the complex models using only precipitation and streamflow data. The difference in data requirements between the simple and complex models is not that the complex model *must have* these additional data types, but that it *can* use them *if* they are available, whereas the simple model cannot. It then follows that if these additional types of data are not available, both types of models can be calibrated and run but the complex model may be deprived of the opportunity to demonstrate a superiority in that particular catchment.

Based on the conclusions discussed earlier and in line with the stated object of the project which was not to select a 'best' model but to give a prospective user the information he would need to select or devise a model which would be best for him, the conference made recommendations concerning the factors which should be considered in selecting a model. These are the climatic and physiographic characteristics of the area in which the model will be used; the purpose of the forecast, continuous or isolated event, floods, low water or both; the data available for development, length of record, quality of the data, types of variables available; the data available operationally, quality and type; ability to transpose model parameters to ungauged or poorly gauged areas; ability to update model output; the computer requirements for optimization and for forecasting in the light of available computer capability; and finally, the training and background of the personnel who will be using the model.

With regard to the relationship between data availability and the data requirements of a model, it should be noted that the application of conceptual models to operational forecasting should also include an updating of the data networks. The models offer the opportunity of analysing the adequacy of the data observation network and of designing an optimum network geared to an efficient operation of the forecasting system as a whole. In this repect, specific requirements of modelling should be borne in mind when the installation or upgrading of data collection systems is being planned. It is therefore not only for purposes of scientific interest but also for very important economic reasons that hydrological forecasting services should consider carefully the advent of the simulation of catchment behaviour by conceptual models.

One of the biggest problems in the use of a model is parameter optimization, or the fitting of the model to a particular basin. Based on the experience of the modellers in the project, the conference noted that two basic methods, manual and automatic, are available.

Manual optimization is a procedure in which subjective adjustments to various parameters are made on the basis of specific characteristics of the output of previous computer runs. With automatic techniques, the computer itself adjusts parameters in a semi-random manner based on changes in the value of a single numerical error function. It is generally agreed that manual methods may produce a good set of parameter values. Such methods do however require a great deal of time in terms of man-hours and a degree of interplay with the computer often not available from the larger systems. In addition, the hydrologist performing the optimization must possess considerable skill and experience with the model being used and with the area in which it is being applied. Automatic methods on the other hand are fast and simple to use. Besides being relatively expensive in terms of computer time however, they have some inherent disadvantages. Some of these are: a complete dependence on one objective function, sub-optimal solutions due to the concavity of portions of the response surface and poorly selected initial parameter values, and failure to recognize the effect of perturbing a group of parameters simultaneously. This may result in a degree of curve fitting and produce a set of parameters which fit the calibration data reasonably well but which are physically unrealistic and which may therefore cause the model to give poor results in actual forecasting. The conference therefore recommended that as far as possible, model calibration should be done with a combination of manual and automatic procedures in which the strong points of one compensate the weak points of the other.

The final act of the conference before adjourning was to formulate a series of recommendations to WMO regarding its future activities in this area. These recommendations are:

First, that the six data sets used in the project be 'cleaned up' and retained by WMO for the use of any parties wishing to test or compare models in the future. The 'cleaning up' of the data sets was to be done by the data supplier and on the basis of deficiencies discovered during the project by himself and by other participants. The archived data sets will be available to all interested parties contingent upon their making the results of their studies available to WMO. This recommendation was accepted by WMO and has already been accomplished.

The second recommendation was that a project similar to this, but involving snowmelt models be undertaken. This has been accepted, in principle, and is presently in the planning stage.

Four additional recommendations were made which involve the adoption of policies to encourage member countries to engage in certain acitivities. One of these relates to the improvement and standardization of instruments and observational methods. The use of the more sophisticated conceptual models in hydrological forecasting makes it necessary to collect more and better data to fully utilize their greater capability. It is necessary therefore to develop network design theory so that a more nearly optimal data base using improved instruments and methods of observation can be acquired.

To solve some of the problems associated with data transmission, especially for hydrological forecasting, WMO has developed computer compatible international hydrological codes and is planning pilot projects in several international river basins to study the maximum possible use of the Global Telecommunications System of the WMO World Weather Watch by national hydrological services.

For hydrological forecasting and warnings, data processing and exchange on a 'real-time' basis is vital. In meteorology there have long been in existence internationally agreed procedures and practices which are embodied in the Global Data Processing System of the World Weather Watch. Provision has already been made within the System to provide a storage and retrieval service for nearly 30 hydrological elements. It is urged that efforts be made to apply to hydrological data the advanced degree of standardization already achieved within the Global Data Processing System.

The second of these policy recommendations is that WMO cooperate with national agencies in the development of a simulation package. That is, a model containing alternative subroutines shown by this project to be best in specific forecasting situations and under certain conditions.

The third recommendation is to encourage activity aimed at the development of an 'on line' model which would combine in one system a data collection, transmission and processing function, as well as a forecasting model. The results of the intercomparison project, particularly with respect to the quality of data used for the intercomparison, indicate that the ultimate solution to the forecasting problem is dependent upon the development of such systems. It is obvious that such a system may, in addition to functions performed for hydrological forecasting, serve other fields of economic activities, in particular, water resources management, agriculture, forestry, environmental protection, etc.

The fourth and last recommendation is that capable agencies be encouraged to provide opportunities for the training of hydrologists in the use of conceptual hydrological forecasting models, in particular within the framework of WMO training programmes.

These four recommendations have been considered and approved by the Seventh Congress of WMO as priority acitivites in the Operational Hydrology Programme for the period 1975-1980.

In conclusion, it should be strongly emphasized that this report is but a very brief summary of the material available from this project. The published WMO report is more detailed and more comprehensive. The conclusions presented in both reports, however, are of necessity, general in nature and it is therefore highly desirable for the user to adapt these conclusions to his own specific set of circumstances. As was stated early in this report, the objective of this project was not to identify a 'best' model, but rather to provide a prospective user with the information he would need to decide which model is best for his purposes. Anyone wishing to select a model is therefore urged to study the published report in detail, both the text and the statistical error summaries.

With regard to the error summaries, this project, considering all data sets and all models, involved the simulation of 277 years of streamflow. The basic error quantity is the difference between the observed and simulated values of an individual mean daily discharge figure. In this amount of record, there were slightly over 100 000 such error quantities. The numerical and graphical displays presented were an attempt to reduce these quantities to a volume which could be grasped by the reader without eliminating too much of the meaning in the raw data. Hopefully a proper balance was achieved, and the displays do contain the essential information. The user is therefore strongly urged to study the error statistics, the model descriptions, and the data descriptions in great detail and attempt to glean from them the specific information which he needs to adapt the general conclusions to his own specific problem.

The successful implementation and completion of this project was made possible by the close cooperation and effective contribution of national services, other institutions and individual experts who participated in it. These include the scientists and experts who participated in the three informal study group meetings in 1969 and 1970 and in the Geneva conferences in 1972 and 1974. In addition there are the model owners and data suppliers and the Laboratory of Hydraulics, Hydrology and Glaciology of the Federal Institute of Technology, Zürich, Switzerland, which prepared and transmitted many data sets to model owners and performed the computations for the numerical and graphical verification criteria used in evaluating the results.

WMO wishes to express its thanks to all of those mentioned and to the other scientists and experts who contributed to the success of this project.