Forecasting Inflows for the Upper Waitaki Storage Lakes in New Zealand

E.J. Peters[1] &
D.J. Painter[2]

An approach linking a climate generator, which utilises multiple discriminant analysis (MDA) and multivariate chaining (MVC), to the University of British Columbia (UBC) Watershed Model was implemented to simulate the response of the Upper Waitaki Watershed, New Zealand. This approach was applied to the catchment for comparing inflow estimates to observed inflows under conditions where a short-term or long-term forecast of flow to the lakes can be obtained by using weather information. This could be as a weather forecast from the local MetService or where a series of daily weather data can be estimated using historic records in addition to local climatic indices in a multiple discriminant analysis routine. The approach was tested on the 1992 drought and showed that had the Electricity Corporation had available such a tool better estimates of the low flows could have been made which would have created the opportunity for improved management of power generation.

Keywords: UBC Watershed Model, multivariate chaining, multiple discriminant analysis,

1. Introduction

The storage lakes of the Upper Waitaki in New Zealand are major components of the Waitaki Hydro Group system which produces an annual average of 9000 GWh from 12 stations with a total installed capacity of 1817 MW. This generation is enough to meet 30% of New Zealand's power demand. The power stations on the Upper Waitaki contribute about half of the total capacity of the Waitaki Hydro Group. About 85 % of the water used in the Waitaki Hydro Group system comes from the catchments of the Upper Waitaki.

The Electricity Corporation of New Zealand (ECNZ) used a variety of methods to optimise the management of its hydro storage lakes (**Halliburton & Truesdale, 1994**). [Since 1999, ECNZ has been split into three separate generating companies.] Improvement in the management of the Upper Waitaki system, to reduce unnecessary spill and to avoid downstream flooding, is possible with improved forecasts of inflows as proposed by **Davison *et al.*, (1992)**. However, traditional methods for forecasting streamflows are not quite suited to the Upper Waitaki because of the sparsity of hydrometeorological stations due to the rugged terrain and braided character of the Upper Waitaki rivers. In this paper, it is demonstrated that more accurate forecasts of inflows are possible by using the University of British Columbia (UBC) Watershed Model (**Quick, 1993**) and multivariate chaining, MVC (**Young, 1988; Peters, 1996**).

2. Forecasting Streamflows

Generally, mathematical models of streamflows can be sub-divided into four classes: purely stochastic representation; stochastic models with hydrologic inputs (typically rainfall); deterministic models giving detailed description of the physical mechanism of the rainfall-runoff process; and deterministic representation with lumped descriptions of the physical mechanism (**Bolzern *et al.*, 1980**). The simplest models involve constant-coefficient input/output formulations and are suitable for temporal resolutions of a month (**Delleur *et al.*, 1976; Tao & Delleur, 1976a**). For shorter intervals, adaptive models of differing complexities provide for time-varying coefficients and can be used for extending current forecasts (**Wood &**

[1] Lecturer, Department of Civil and Environmental Engineering, Faculty of Engineering, UWI, St. Augustine. E.mail: ejpeters@eng.uwi.tt

[2] Associate Professor of Natural Resources Engineering, University of Canterbury, New Zealand. E.mail: david.painter@canterbury.ac.nz

Szollosi-Nagy, 1978; Bolzern *et al.*, 1980; Bidwell, 1992; Bender & Simonovic, 1994; Hisdal & Tveito, 1993 and **Awward *et al.*, 1994**).

Ideally, the best model would be a deterministic description of the rainfall-runoff process using the equations of mass, energy and momentum to describe the movement of water over the land surface and through the saturated and unsaturated zones which could be solved numerically with two or three-dimensional formulations. **Abbot *et al.*, (1986)** reported on Systeme Hydrologique Europeen (SHE), which uses modular construction for the addition of new components. Further, two-dimensional hydrodynamic modelling of runoff routing was used by **Zhang & Cundy, (1989)** and **James & Kirn, (1990). Goodrich *et al.*, (1991)** used a finite element approach for modelling space properties and finite differences to solve the resulting equations in time for modelling surface flow. Notwithstanding the mathematical sophistication of the above models, the spatial variability of rainfall and its influence on surface runoff is inadequately simulated. The cost of the large quantity of data required for these models can be prohibitive.

Although in theory, estimating the runoff given meteorological inputs should be based on the application of these laws, in practice the complexity of natural catchments precludes such a rigorous approach. Consequently, hydrologists have been encouraged to simplify the representation of the elements of the catchment and the description of the physical process into lumped models. This is necessary in order to include, in a limited number of global parameters, all information needed to simulate a quite complexed natural system (**Todini, 1988**). Some of the earliest watershed models [Stanford Watershed Model (**Crawford & Linsley, 1966**), USDA-HL Model (**Holtan *et al.*, 1975**), SCR TR-20 Watershed Model (US Soil Conservation Service, 1965), ANSWERS (**Beasley, 1977**)] enjoyed wide application but were limited to small watersheds.

For large alpine watersheds, models for continuous simulation including snowmelt are relatively fewer. In 1983, the World Meteorological Organisation (WMO) completed a second inter-comparison project that was devoted exclusively to snowmelt-runoff models where model simulation accuracy was a major concern (WMO, 1986). As a follow-up to that inter-comparison, WMO conducted tests of runoff models in partially-simulated forecasts during the period 1987–1990. Seven models [CEQUEAU (**Morin *et al.*, 1981**); ERM (**Turcan, 1981**); HBV (**Bergstrom, 1975**); SRM (**Martinec *et al.*, 1983**); SSARR (U.S. Army of Corps Engineers, 1975); TANK (**Sugaware *et al.*, 1984**) and UBC (**Quick & Pipes, 1977**)] from the 10 used in the previous inter-comparison were used in the 1987–1990 project (**WMO, 1992**). With the exception of CEQUEAU which is distributed, all the models are lumped continuous and use at least the index approach for simulating snowmelt. Although no identifying conclusions were published on particular models, all models' forecast results were more accurate than "no model" forecasts (**Rango & Martinec, 1994**).

3. The Upper Waitaki Watershed

The Upper Waitaki (**Figure 1**) consists of three major sub-catchments: Tekapo, Pukaki and Ohau with a total area of 5995 km^2 and contains large, glacially-formed lakes with the associated rivers running in braided gravel beds. The catchment features sharp relief with high, steep, glaciated mountains with an average barrier height of 3200 m and reaching a highest point at Mt. Cook (3764 mASL). The rivers which flow into the lakes respond quickly to rainfall and rise fast as rainfall commences, falling rapidly as the rain stops.

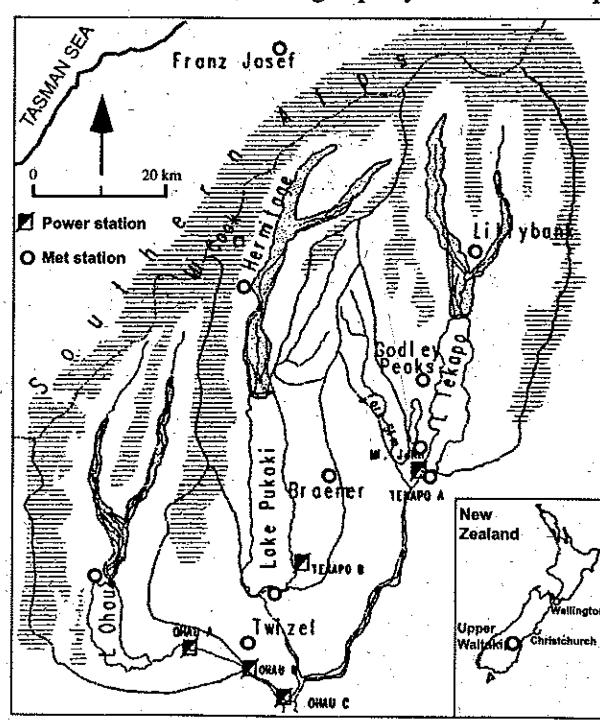

FIGURE 1: *Map of the Upper Waitaki*

The Upper Waitaki's intermontane basin character results in a sub-continental climate in contrast to the overall mid-latitude maritime climate of New Zealand. Precipitation decreases from a maximum of about 4,000 mm/year along the main divide to a minimum of about 600 mm or less in the lower elevations of the intermontane basins. Most forests are below 1000 m and are about 2% (18,680 ha) of the total area.

4. The MDA-MVC-UBC Model Approach

The MDA-MVC-UBC Model approach utilises:

(a) A multiple discriminant analysis (MDA) to estimate a seasonal precipitation amount based on weather indices, and historic records as described by **Peters, (1996)**;

(b) Multiple variate chaining to distribute the precipitation and representative temperatures on a daily basis; and

(c) The UBC Watershed Model to simulate daily inflows in the catchment.

The inflow forecasts are obtained for short-term; one to a few days, or medium-term; in terms of weeks to months. In these forecasts, a three-stage procedure is utilised. First, an estimate of the total precipitation for the region as expected at the individual stations in the catchment is obtained. Short-term estimates are based on Meteorological Service of New Zealand Limited (MetService) one to five-day forecasts for areas on the West Coast, New Zealand, including Franz Josef, in conjunction with probability-exceedence relationships for Franz Josef and stations in the Upper Waitaki. For example, if an extreme storm warning is out for Franz Josef and a precipitation forecast of 125 mm is given, then there is an 80% probability that the precipitation at Mt. Cook would exceed 75 mm. Medium-term forecasts are obtained using MDA of circulation indices and other weather records for the region (**Peters, 1996**) or weather outlooks based on regression analyses of circulation indices (**Cherry, 1992a & b**). Where the preceding estimates are inappropriate or unobtainable, forecasts are based on different precipitation scenarios: very dry, dry, average, wet, very wet. Secondly, the total precipitation for a specified period is distributed on a daily basis using MVC (**Young, 1988; Peters, 1996**). In the case of medium-term forecasting, the total amount is first distributed to the relevant months using the method of fragments (**Valencia & Schaake, 1973; Svanidze, 1980; Srikanthan & McMahon, 1982**). The use of MVC preserves the interdependence between precipitation and temperature.

5. Short-term Forecasting

Based on the five-day weather forecasts available to ECNZ, the integrated model was used to demonstrate a short-term forecast. A case based on an historic weather forecast is used to demonstrate an application of the model. This used a hypothetical "very heavy rain warning" given in February 1989 for the Upper Waitaki and the West Coast Precipitation totals for Franz Josef, Mt. Cook and Ohau are assumed to be 140 mm, 120 mm and 80 mm respectively. The model can be used to simulate a seven-day series of daily weather data where the total precipitation is restricted in a range that includes the forecast total. For example, for Mt. Cook, a series would be accepted if the total is in the range $120 \pm \alpha\,\%$ where the value of α ensures an accurate precipitation total which can be obtained using a reasonable number of chaining simulations. **Figure 2** shows the forecast hydrograph for the first seven days of February based on the hypothetical MetService forecast of total precipitation for those days. Since different combinations of daily precipitation during the seven days could give the specified precipitation, then an infinite number of hydrographs is possible. However, the cumulative

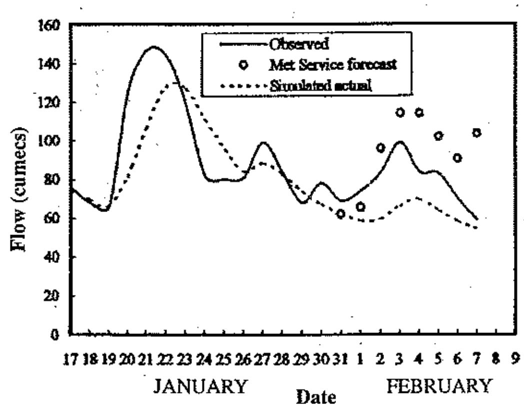

FIGURE 2: *Simulated Infows using a Severe Weather Warning for the Upper Waitaki (Simulated Actual = Flow from using the Actual Observed Precipitation and Temperature)*

inflows over the period should not be significantly different. Simulation results show that the forecasts for the first three to four days are within 10% of the observed values.

6. Long-term Simulations when Estimates of Total Precipitation are available

The model was used to illustrate the simulation of sets of inflows to Lakes Pukaki, Tekapo and Ohau for 1990, and the best estimates of annual precipitation for individual stations in the sub-catchments were obtained **(Peters, 1996)**. In the experiment, the annual precipitation for Mt. Cook from MDA was 4,747 mm, which is close to the observed amount, 4,769 mm. Applying the method of fragments **(Srikanthan & McMahon, 1982)**, the annual total is disaggregated into monthly totals. These monthly amounts are then distributed into daily amounts using the model. Simulations were carried out using either a key site (KS) or selecting a site at random (RS) for disaggregating the annual precipitation amounts. In addition, the simulation was carried out either using one fixed set of daily data from the disaggregation (referred to as continuous) or refining the disaggregation by utilising the monthly precipitation amounts as they became available in the simulation (updating).

Sample results from using the model for the three sub-catchments of the Upper Waitaki: Tekapo, Ohau and Pukaki, for the first three months of 1990 are shown in **Figure 3**. The updating-forecast approach (U) produced higher, final cumulative inflows than the continuous-forecast approach (C).

The simulated inflows from the forecast annual precipitation and the simulated daily weather data were compared to the cumulative mean inflows for the three lakes in the first three months of 1988–1990. In all cases, the forecasted inflows from the model provided cumulative inflows that were closer to the observed. The maximum differences between simulated and observed in the cases for Ohau, Tekapo and Pukaki were 27%, 16% and 14% respectively. The mean differences between the forecasted cumulative inflows and observed cumulative flow for the cases studied were 7.75% and 4.25% for updating-forecast and

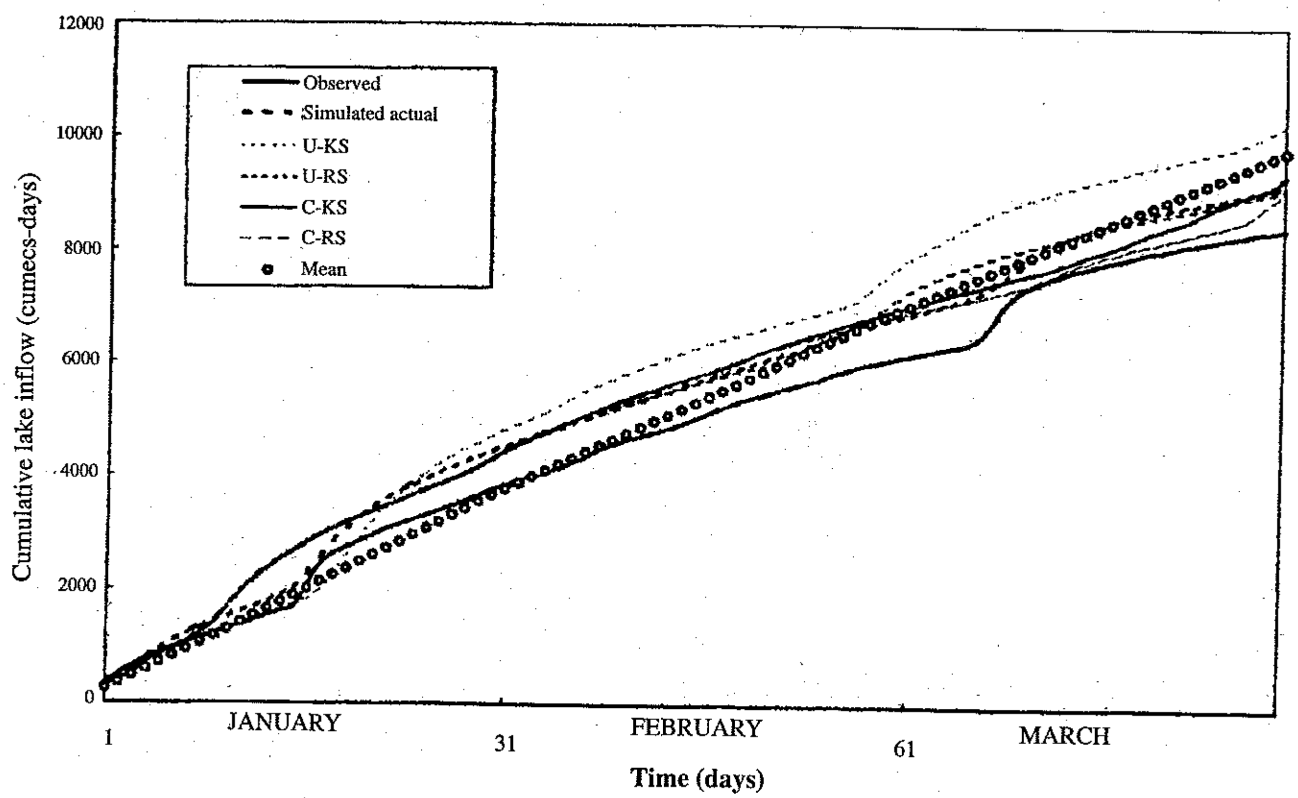

FIGURE 3 (a): *Cumulative Inflows to Lake Tekapo for the First Three Months of 1990*

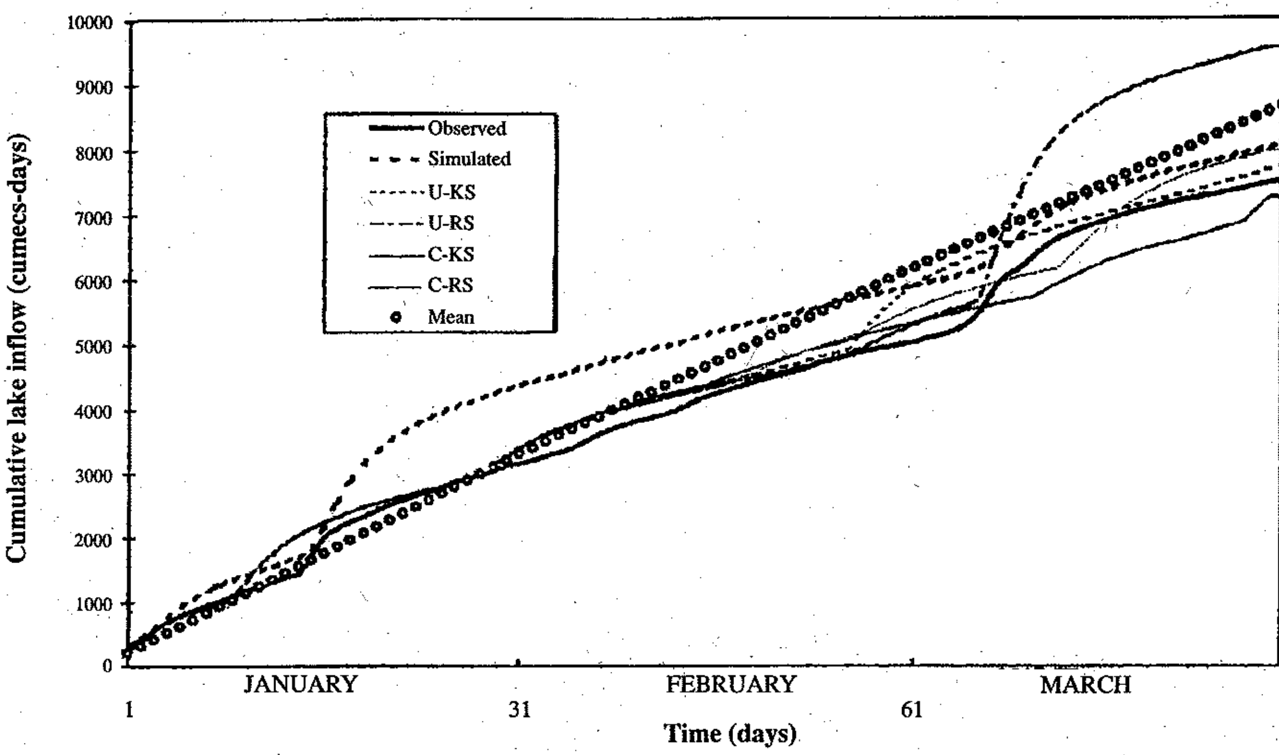

FIGURE 3 (b): *Cumulative Inflows to Lake Ohau for the First Three Months of 1990*

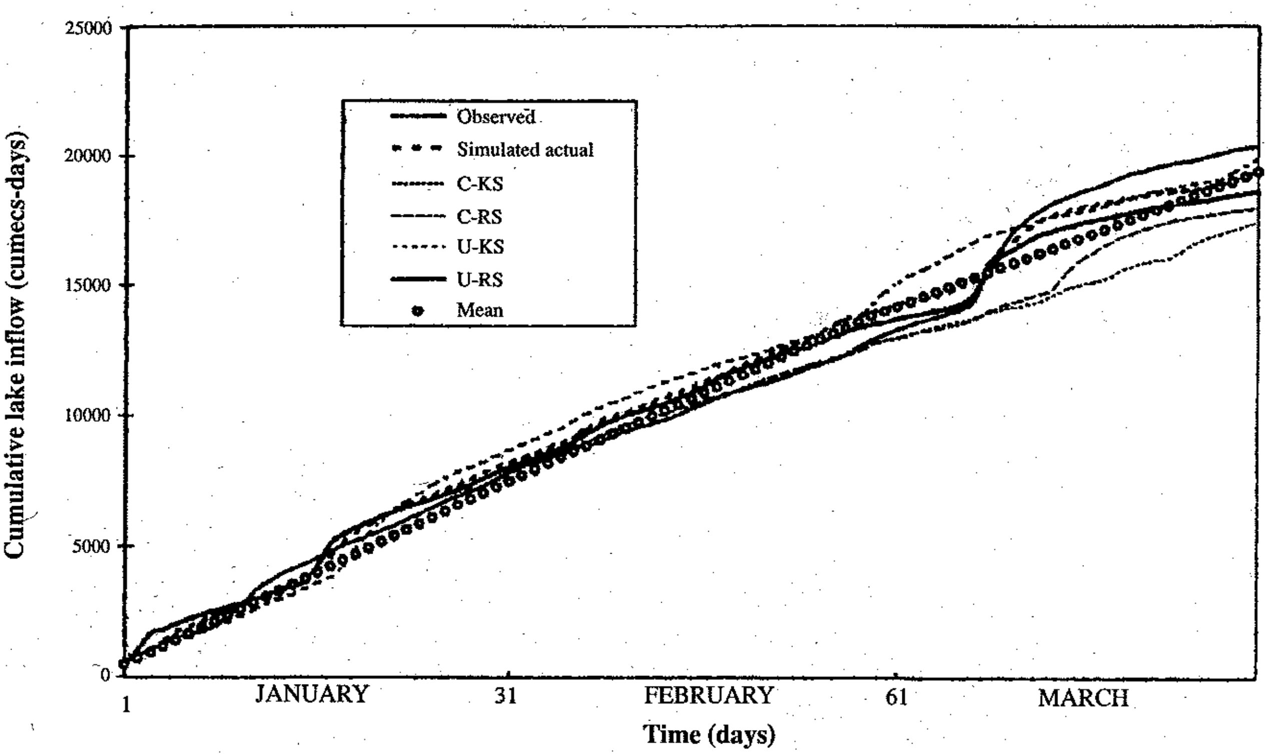

FIGURE 3 (c): *Cumulative Inflows to Lake Pukaki for the First Three Months of 1990* continuous-forecast options respectively. Simulated-actual cumulative inflows for individual lakes were found to be in the range of ±10%–15% of the observed cumulative inflows over this three-month period for the years 1988–1990.

7. Simulating the 1992 Drought

It is of interest to demonstrate what effect, if any, the availability and application of the model might have had in mitigating the severity of the '1992 Electricity shortage' (**Davison *et al.*, 1992**). Two scenarios were tested for the first seven months of 1992 (i.e., the mid-summer to mid-winter seasons). First, the estimates of the total annual precipitation at selected meteorological stations in the Upper Waitaki obtained from MDA were used to simulate inflows. This scenario represents a case where an estimate of the total precipitation in the period is known *a priori*.

The second scenario represents the case where there is no prior information on the expected total precipitation for the forecast period. In this second case, five levels of 'wetness' for the year in which inflow estimates are required are set and used in generating appropriate sets of daily weather. The 'wetness' levels specified as: very dry, dry, average, wet, and very wet were approximated by the minimum, first quartile, median, third quartile and maximum totals from the historic records, respectively.

7.1 The 1992 Drought with Predetermined Total Annual Precipitation

For the first scenario, MDA estimates of the expected total annual precipitation for the selected sites in the Upper Waitaki (**Peters, 1996**) were applied with the MVC to simulate daily weather data for January to July 1992. This data set was used to extend the data series known up to December 31, 1991, and then applied in the UBC Watershed Model to simulate daily inflows to the storage lakes.

Four sets of simulation results, for predetermined total annual precipitation, are shown in **Figure 4a**, and compared to the observed and 'simulated actual' simulation (using the actually observed weather data). The estimated cumulative inflows to Lake Pukaki for the first seven months are all higher than the observed and 'simulated actual' inflows. The 'simulated actual' results indicate that even if the daily weather data were known exactly at the beginning of 1992, there would have been an overestimation of inflows to Lake Pukaki by about 10%. The overestimation from the use of the model is in the range of 10%–37%. The overestimation of cumulative inflow increased progressively as expected to 37% after 6 months. The model provided better estimates of the 1992 flows than using mean monthly flows which were the operational forecast estimates at the time.

Simulation experiments for lake inflows using model-simulated weather data which were updated with observed weather data as they became available were carried out. The particular case using the set of simulated weather data that produces the largest estimates of inflows was considered. The results are shown in **Figure 4b**. Although by the end of March there was a reduction in the difference between the final observed and simulated inflows, there is no significant improvement in the net estimate of the remaining period. By using a large number of weather simulations of daily weather data for a selected season forecast, probabilities for different cumulative total inflow can be estimated.

7.2 The 1992 Drought using Different Levels of 'Wetness'

In cases where there is no prior information on the expected total precipitation during a forecast period, the integrated approach can still provide useful inflow estimates by assuming different levels of 'wetness' based on average precipitation for stations in the watershed. In the following example, five levels of 'wetness' using minimum, lower quartile, median upper quartile and maximum historic values as identifiers are used to demonstrate the approach. The precipitation amount for a particular level of wetness is obtained by randomly selecting the identifier amount plus or minus a%, where a is an integer from 0 –5. For example, for a very dry year the precipitation at Mt. Cook with an identifier amount of 2848 mm (minimum annual precipitation 2848 mm) would be one of the following: 2706, 2734, 2762, 2791, 2822, 2877, 2905, 2933, 2962 and 2991 [mm].

The simulation results for the different levels of wetness for the individual sub-catchments and their combinations are shown in **Figures 5 a–d**. The simulation results for the very dry year total precipitation at the Upper Waitaki stations estimated extremely low flows for the first six months of 1992.

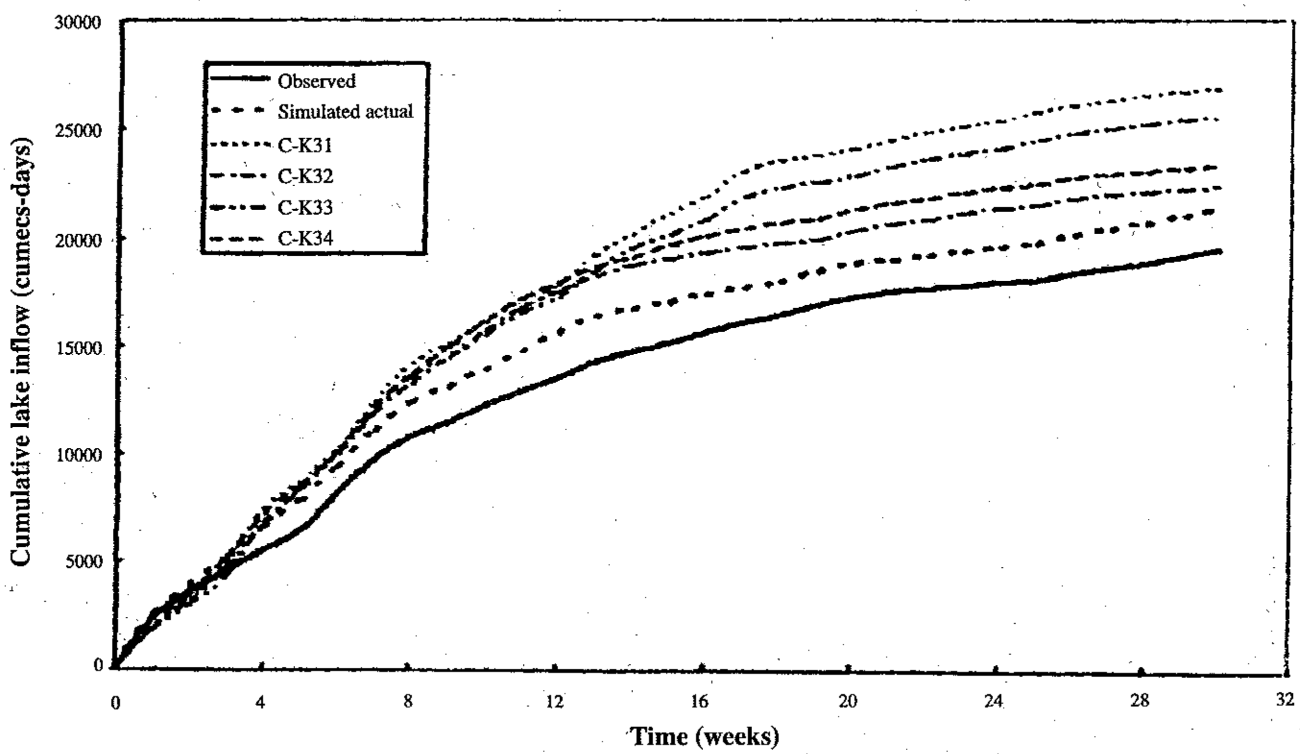

FIGURE 4 (a): *Cumulative Inflow to Lake Pukaki for January - July 1992 (C-K-Sn Simulation obtained at the beginning of the Period using the Key Site in the Catchment for disaggregating Annual into Monthly Values with n being Mt. Cook, Franz Josef, Pukaki or Ohau Station)*

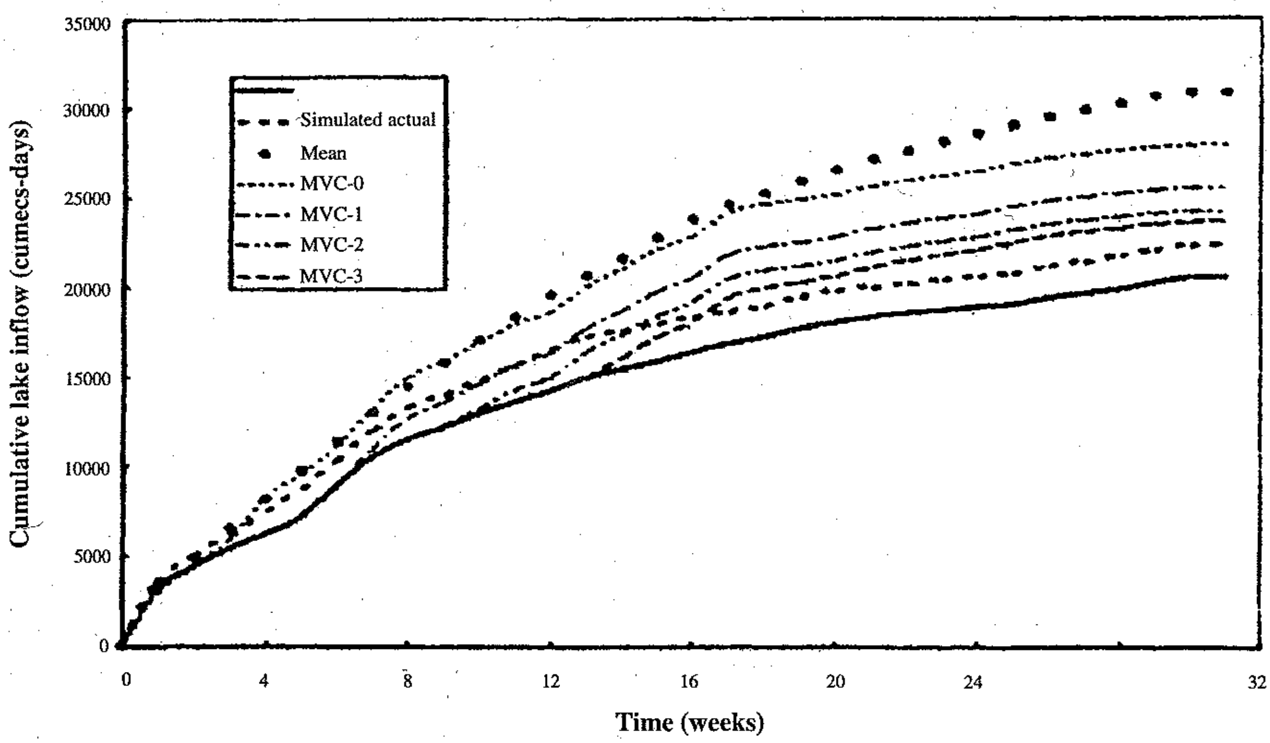

FIGURE 4 (b): *Cumulative Inflows to Lake Pukaki for 1992 using the Maximum Total Inflow Case to demonstrate updating available (MVC-n = Simulation from MVC Weather Data with the First n Months of Data known)*

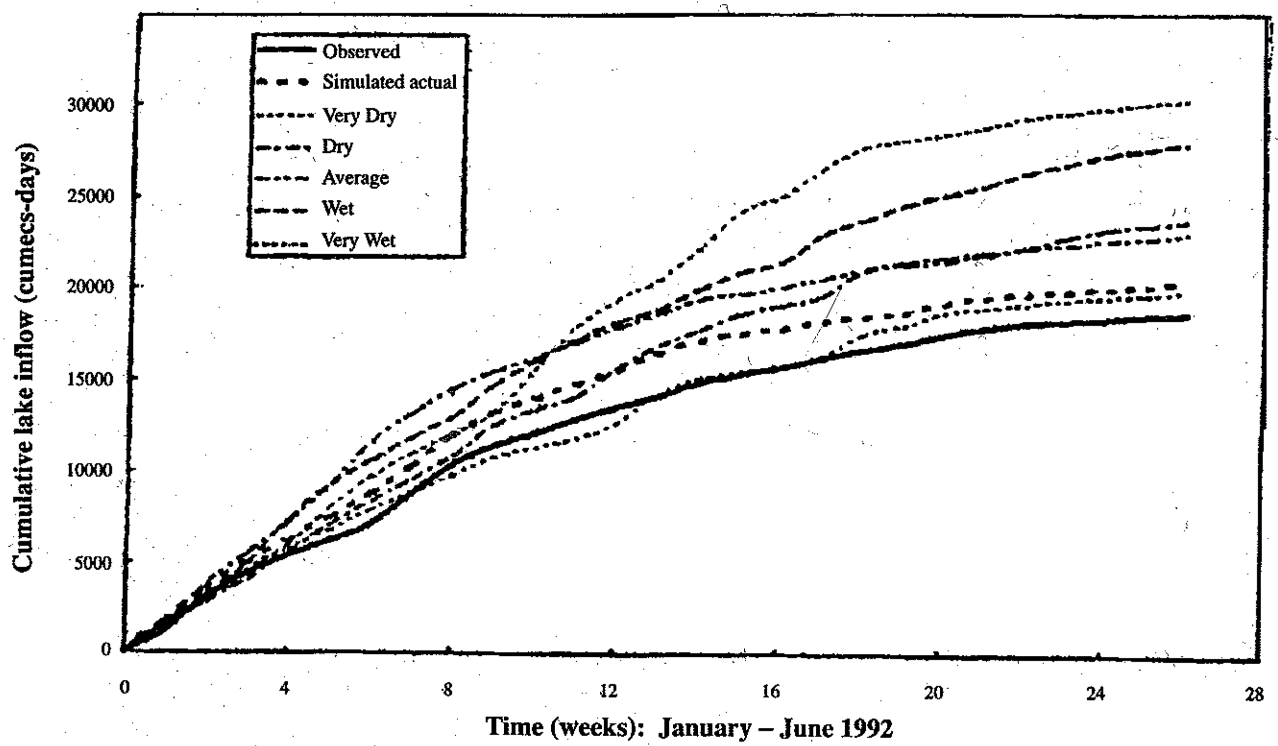

FIGURE 5 (a): *Inflows for Lake Pukaki for the 1992 Drought. Inflow Simulations are based on Five Levels of Precipitation: Very Dry, Dry, Average, Wet and Very Wet*

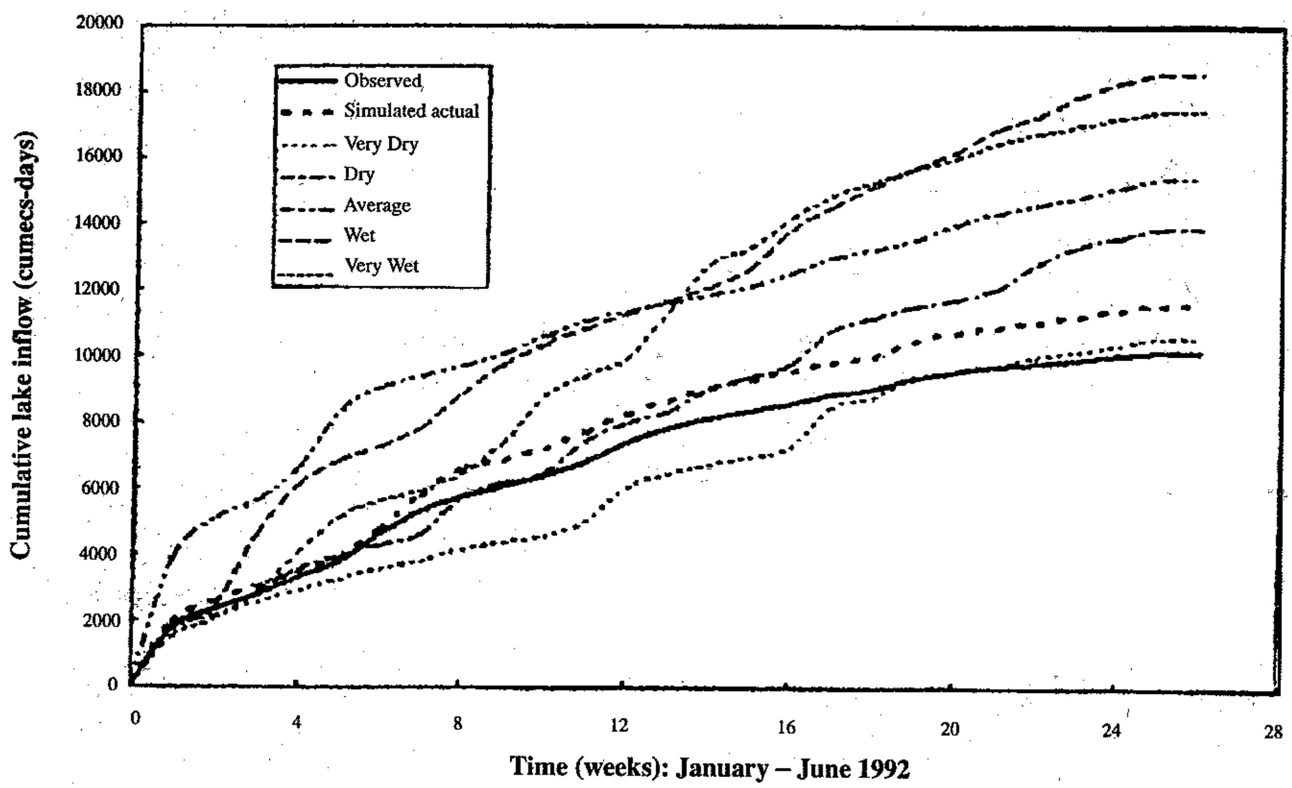

FIGURE 5 (b): *Cumulative Inflow to Lake Ohau during the 1992 Drought using Five Different Levels of Year Wetness: Very Dry, Dry, Average, Wet and Very Wet*

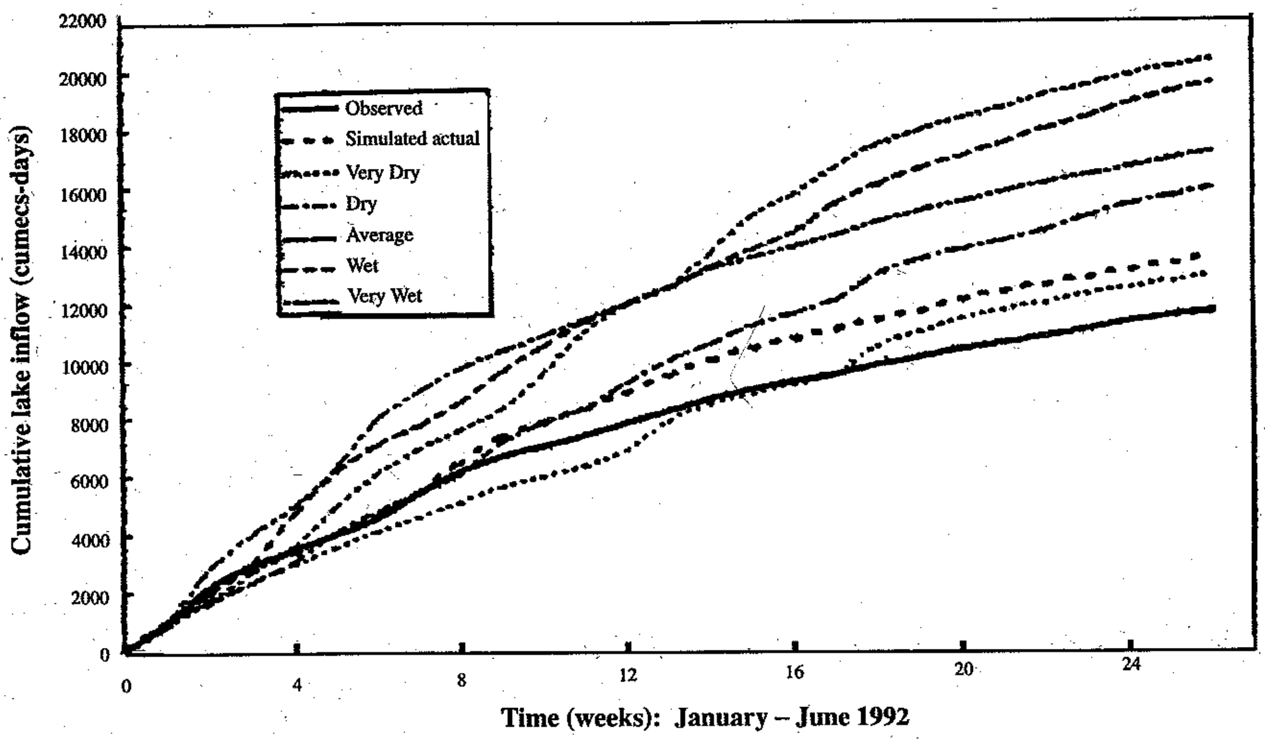

FIGURE 5 (c): *Cumulative Inflow to Lake Tekapo during the 1992 Drought using Five Different Levels of Year Wetness: Very Dry, Dry, Average, Wet and Very Wet*

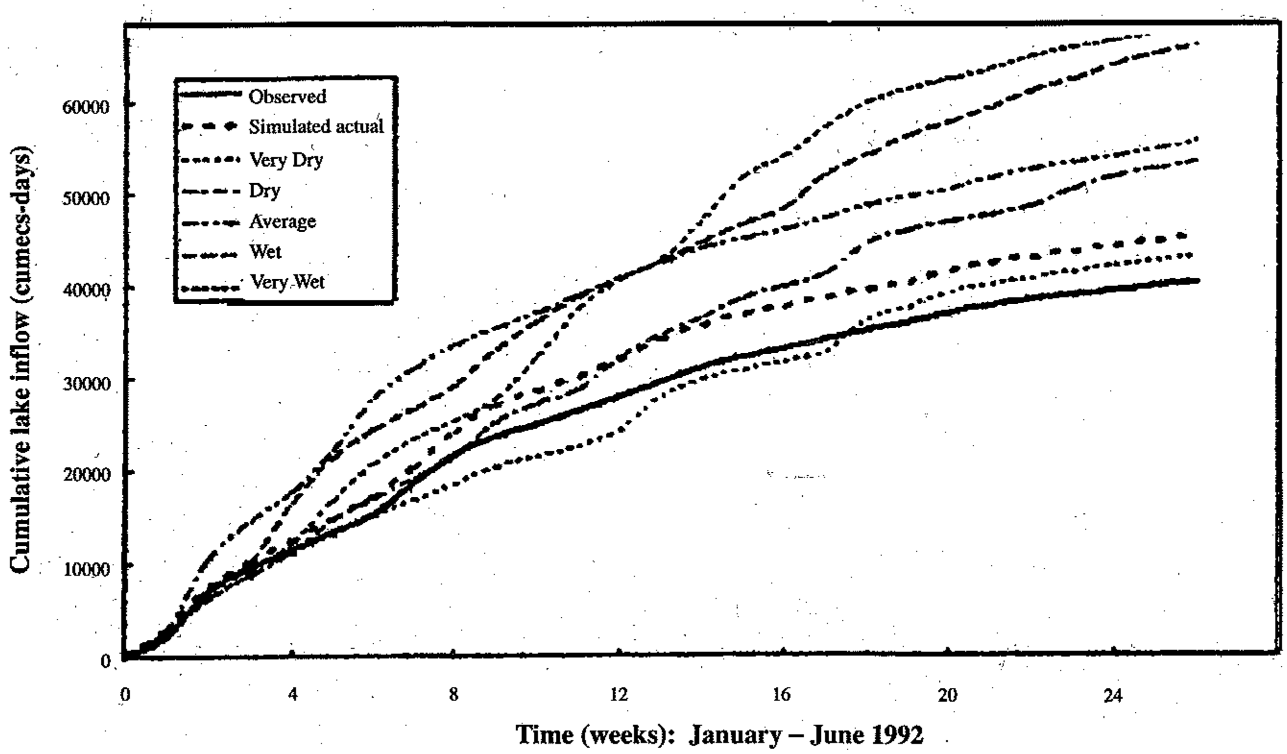

FIGURE 5 (d): *Combined Cumulative Inflow to the Upper Waitaki during the 1992 Drought using Five Different Levels of Year Wetness: Very dry, Dry, Average, Wet and Very Wet*

For Lake Pukaki, there was no difference between the simulated and observed flows up to the beginning of May and only a 6% difference by the end of June. Similar results were observed for Lakes Ohau and Tekapo with differences at the end of June of 4% and 11% respectively.

For the very wet year, the simulated cumulative inflows at the end of June overestimated the observed inflows by 62%, 72% and 77% for Lakes Pukaki, Ohau and Tekapo, respectively. The use of combinations of total precipitation for very dry, dry and average years simulated cumulative inflows that are within 26% or less of the observed inflow.

8. Discussion and Conclusions

In this study, a model is used for estimating inflows to the storage lakes of the Upper Waitaki with particular simulations of the 1992 drought. This proposed approach utilises the catchments' antecedent water storage status at the beginning of the forecast period as part of the initial conditions of a corrected-forecast UBC Watershed Model.

When the annual precipitation is assumed known or can be estimated, for example, by using the MDA approach, inflows for the sub-catchments of the Upper Waitaki can be estimated. The mean differences between the observed and simulated cumulative inflows were 1.2%, 6% and 12.2% for Lakes Ohau, Tekapo and Pukaki, respectively for 1989. These levels of differences would be quite satisfactory for operational purposes. In the case of Lake Pukaki for 1990, the 0.6% mean difference between the observed and simulated cumulative inflows is small, indicative of an exceptionally good forecast . The 1990 results for Lakes Ohau and Tekapo, although satisfactory, are not as good with mean differences of 8.6% and 15%, respectively.

When the model is used in a continuous mode, further improvement in flow estimates can be obtained if the weather data are continuously updated with observed data as they become available. This would create a data set comprising observed data followed by MDA-MVC simulated data.

In the case of the 1992 drought, although the forecasted results were higher than the observed and the simulated actual, they are within reasonable limits. Hence, they would have provided a better indicator of the likely inflows to the Waitaki lakes than the average recorded inflows. Without prior insight into the kind of precipitation regime that is likely for a forecast period, the model can provide useful information for the management of the storage lakes of the Upper Waitaki. By simulating different levels ofwetness from very dry to very wet, it is possible to produce an unlimited number of inflow series to the individual lakes. These inflow series represent upper and lower bounds for inflows during the forecast period. If this approach had been used prior to the 1992 drought, the simulation of inflows for a hypothetically very dry year would have produced cumulative inflows that were representative of the observed inflows.

During the 1992 drought, the best indicator of future inflows available to ECNZ was the average of past inflows (**Davison *et al.*, 1992**). The above analysis has demonstrated that use of the model produced inflows which were closer to the observed than the average inflows. Consequently, it can be concluded that had this model been available prior to the 1992 drought, management would have been better informed on the nature of future inflows. The model has greatest application for inflow forecasts for short periods of up to seven days when estimates can be kept within 10% differences between simulated and observed inflows.

References

[1] Abbot, M.B., Bathurst, J.C., Cunge, J.A., O'Connell, P.E. and Rasmussen, J. (1986). *An Introduction to the European Hydrological System – Systeme Hydrologique Europeen, "SHE."* 2: Structure of a Physically-based, distributed Modelling System. Journal of Hydrology (Amsterdam), 87: pp. 61–77.

[2] Awwad, H.M., Valdes, J.B. and Restrepo, P.J. (1994). *Streamflow Forecasting for Han River Basin, Korea.* Journal of Water Resources Planning and Management, 120(5): pp. 615–673.

[3] Beasley, D.B. (1977). *ANSWERS: A Mathematical Model for Simulating the Effects of Land-use Management on Water Quality.* Thesis PhD., Purdue University, Lafayette, U.S.A.

[4] Bender, M. and Simonovic, S. (1994). *Time Series Modelling for Long-range Stream-flow Forecasting*. Journal of Water Resources Planning and Management, 120(6): pp. 857–870.

[5] Bergstrom, S. and Jonsson, D. (1976). *The Application of the HBV Runoff Model to the Filefjell Research Basin*. Rapporter Nr RH05, Swedish Meteorological and Hydrological Institute, Norrkoping.

[6] Bidwell, V. (1992). *Adaptive Flood Forecasting. An application to the Waimakariri River*. AEI Science Report, AEI, Lincoln University, Canterbury, New Zealand.

[7] Bolzern, M., Ferrario, M. and Fronn, G. (1980). *Adaptive Real-time Forecast of River Flow-rates from Rainfall Data*. Journal of Hydrology (Amsterdam), 47: pp. 251–267.

[8] Cherry, N.J. (1992a). *Forecasts of the Weather over the Next Three Seasons: Implications for Clyde Inflows*. Consultant's Report for ECNZ Climate Research Unit, Lincoln University.

[9] Cherry, N.J. (1992b). *Long Range Forecast for the Waitaki System: Report for ECNZ*. Climate Research Unit, Lincoln University.

[10] Crawford, N.H. and Linsley, R.K. (1966). *Digital Simulation in Hydrology : Stanford Watershed Model IV*. Stanford University, Dept. of Civil Eng, Tech. Report No. 39.

[11] Davison, R., Carter, R.P. and Gough, M. (1992). *The Electricity Shortage 1992*, The Report of the Electricity Shortage Review Committee, Information Centre, 123pp. Department of the Prime Minister, Wellington, New Zealand.

[12] Delleur, J.W., Tao, P.C. and Kavvas, M.L. (1976). *An Evaluation of the Practicality and Complexity of Some Rainfall and Runoff Time Series Models*. Water Resources Research, 12: pp. 953–970.

[13] Goodrich, D.C., Woolhiser, D.A. and Keefer, T.O. (1991). *Kinematic Routing using Finite Elements on a Triangular Irregular Network*. Water Resources Research 27(6): pp. 995–1003.

[14] Hisdal, H. and Tveito, O.E. (1993). *Extension of Runoff Series using Empirical Orthogonal Functions*. Journal Hydrological Sciences 38(1): pp. 33–49.

[15] James, W.P. and Kim, K.W. (1990). *A Distributed Dynamic Watershed Model*. Water Resources Bulletin, 26(4): pp. 587–596.

[16] Martinec, J., Rango, A. and Major, E. (1983). *The Snowmelt-Runoff Model (SRM) User's Manual*. NASA Reference Publication 1100. Washington, DC, 118 pp.

[17] Morin, G., Fortin, J.P., Lardeau, J.P., Sockanska, W. and Paquette, S. (1981). Modele CEQUEAU: Manuel D'Utilisation. INRS-Eau Quebec, Rapport Scientifique Version ME0681m, 449pp.

[18] Quick, M. (1993). *UBC Watershed Model Manual,* 2nd. Draft, Univ. of British Columbia, Civ. Eng. Dept., Vancouver, BC.

[19] Quick, M. and Pipes, A. (1977). *UBC Watershed Model*. Hydrologic Sciences Bulletin, 22(1): pp. 153–161.

[20] Rango, A. and Martinec, J. (1994). *Model Accuracy in Snowmelt-runoff Forecasts extending from 1 to 20 Days*. Water Resources Bulletin, 30(3): pp. 463–470.

[21] Srikanthan, R. and McMahon, T.A. (1982). *Simulation of Annual and Monthly rainfalls – A Preliminary Study at Five Australian Stations*. Journal of Applied Meteorology, 21: pp. 1472–1479.

[22] Sugaware, M., Watanabe, I., Ozaki, E. and Katsuyama, Y. (1984). *Research Notes of the National Research Center for Disaster Prevention.* No. 65, Japan, 299pp.

[23] Svanidze, G.G. (1980). *Mathematical Modelling of Hydrologic Systems.* Water Resources Publication, Fort Collins.

[24] Tao, P. and Delleur, J.W. (1976a). *Seasonal and Nonseasonal ARMA Models in Hydrology.* Journal of the Hydraulics Division. Proceedings ASCE, 102(Hyl0): pp. 1541–1559.

[25] Tao, P.C. and Delleur, J.W. (1976). *Multistation Multi-year Synthesis of Hydrologic Time Series by Disaggregation.* Water Resources Research, 12: pp. 1303–1312.

[26] Tiao, G.C. (1985). *ARMA Models, Intervention Problems and Outliers Detection.* In Hannan, E. J., Krishnaiah, P.R. and Rao, M.M. (Eds). Handbook of Statistics Time Series Analysis in the Time Domain, Vol. 5 Elsevier Science Publishers B.V., North-Holland.

[27] Todini, E. (1988). *Rainfall Runoff Modelling: Past, Present and Future.* Journal of Hydrology (Amsterdam), 100: pp. 341–352.

[28] Turcan, J. (1981). *Empirical-Regressive Forecasting Runoff Model.* Proceedings of Conference VUVH, Bratislava.

[29] US Army Corps of Engineers (1975). *Program Description and Users Manaual for the SSARR Model.* US Army Corps of Engineers, North Pacific Division, Portland, Oregon.

[30] US Soil Conservation Service (1965). *Computer Programme for Project Formulation-hydrology.* Technical Release No. 20.

[31] Valencia, D. and Schaake, J.C. Jr. (1973). *Disaggregation Processes in Stochastic Hydrology.* Water Resources Research, 9: pp. 580–585.

[32] WMO (1986). *Intercomparison of Models of Snowmelt Runoff.* Operational Hydrology Report No. 23, World Meteorological Organisation, Geneva, Switzerland.

[33] WMO (1992). *Simulation Real-Time Intercomparison of Hydrological Models.* Operational Hydrology Report No. 38, World Meteorological Organisation, Geneva, Switzerland.

[34] Wood, E.F. and Szöllosi-Nagy, A. (1978). *An Adaptive Algorithm for Analysing Short-term Structural and Parameter Changes in Hydrologic Prediction Models.* Water Resources Research, 13(4): pp. 377–381.

[35] Wood, E.F. and O'Connell, P.E. (1985). *Real-time Forecasting.* In Anderson, M.G. and Burt, T.P. (Eds) Hydrological Forecasting. Wiley and Sons. pp. 505–557.

[36] Young, K.C. (1994). *A Multivariate Chain Model for Simulating Climatic Parameters for Daily Data.* Journal of Applied Meteorology, 33(6), pp. 661–671.

[37] Young, P.C. (1988). *Recursive Extrapolation, Interpolation and Smoothing of Nonstationary Time-Series.* In Chen, C.F. (ed.) Identification and System Parameter Estimation. Pergamon Press, Oxford.

[38] Young, P.C. and Benner, S. (1991). *Microcaptain 2 User Handbook, First edition.* Centre for Research on Environment Systems, Lancaster University, UK.

[39] Zhang, W. and Cundy, T.W. (1989). *Modelling of Two-Dimensional Overland Flow.* Water Resources Research, 25(9): pp. 2119–2035.

[40] Peters, E.J. (1996). *An Integrated Approach to Inflow Forecasting for Reservoir Management: The Upper Waitaki.* PhD. Thesis, Lincoln University, New Zealand (Unpublished).

[41] Halliburton, T.S. and Truesdale, J. (1994). *ECNZ Generation Scheduling: Response to the Shortage Review and Future Directions*. In Proceedings of IPENZ Annual Conference "Adding the Value" 2. 238–242, IPENZ, Wellington, New Zealand.

[42] Holtan, H.N., Stittner, G.J., Hanson, W.H. and Lopez, N.C. (1975). US Department of Agriculture H L-79 Model of Watershed Hydrology, USDA – Agr. Research Service Tech. Bull. No. 1518.■