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Application of a Hydroinformatic System for Calibration of a Catchment Modelling System

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강우-유출모형의 검정을 위한 수문정보시스템의 적용

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ABSTRACT

A new methodology for selecting spatially variable model control parameter values through consideration of inference models within a Hydroinformatic system has been developed to overcome problems associated with determination of spatially variable control parameter values for both ungauged and gauged catchment. The adopted Hydroinformatic tools for determination of control parameter values were a GIS(Arc/Info) to handle spatial and non-spatial attribute information, the SWMM(stormwater management model) to simulate catchment response to hydrologic events, and lastly, L_BFGS_B(a limited memory quasi-Newton algorithm) to assist in the calibration process. As a result, high accuracy of control parameter estimation was obtained by considering the spatial variations of the control parameters based on landuse characteristics. Also, considerable time and effort necessary for estimating a large number of control parameters were reduced from the new calibration approach.

KEYWORDS: Hydroinformatic System, Inference Model, GIS, SWMM, L_BFGS_B

요 약

공간적 변수들의 추정에 필요한 유역의 지리수문학적 정보의 효율적인 사용과 모델매개변수들의 보다 정확한 추정을 도모하기 위하여 개발된 수문정보시스템은 지리정보시스템, SWMM, 및 L_BFGS_B 등으로 구축되었다. 여기서, 지리정보시스템은 모델의 검정에 필요한 유역의 지리지형 특성인자들의 자동추출을 위하여 사용되었으며, 수문학적인 모의를 위해서는 SWMM을, 그리고 모델의 매개변수 추정에 필요한 decision support system(DSS)으로 비선형 최적화 기법의 L_BFGS_B 알고리즘이 각각 사용되었다. 본 연구는 또한 토지이용을 주 인자로 하여 개발된 추론 모델들을 통하여 공간변수추정의 정확성을 최대화하는 한편, 공간특성변수들의 추정에 드는 엄청난 시간과 노력을 최소화함으로서 기존의 모델검정방법의 문제점들을 개선하고자 하였다. 도출된 연구결과들의 비교분석을 통하여 모델 예측치의 신뢰성 향상 및 효과적이고 효율적인 모델 변수추

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정을 획득할 수 있음을 알 수 있었다. 따라서 이러한 결과들로부터 수문정보시스템의 매개변수 추정에 대한 적용성을 입증 하였다.

주요어: 수문정보시스템, 추론모델, 지리정보시스템, SWMM, L_BFGS_B

INTRODUCTION

The prediction of rainfall-runoff processes over the catchment is complex, and can be accurately described only using a spatially distributed and temporally varying framework. While many hydrological models have been developed based on conceptual representations of the physical processes, most of them have limited simulation capabilities due to several factors (Liao and Tim, 1994; Liong et al. 1991). These factors are:

- Inability to simulate large areas having heterogeneous properties such as land use, land cover, soils and topography;
- Inability to efficiently handle, manipulate, and manage large volumes of input data and parameters, and to deal with information representing the spatial variability of the catchment;
- Uncertainty in how best to perform the model calibration.

Associated with the need for more information regarding temporal and spatial distribution of water within catchments, the models and the associated software are increasing in sophistication and their demands for and production of information is similarly increasing. Consequently, usage of these models and systems demands a substantial volume of information be processed. This need has resulted in the development of Hydroinformatic systems to store, analyse and use information about the water environment within catchments (Ball, 1994).

The general concept of Hydroinformatic systems, therefore, is the application and manipulation of aquatic environmental information stored in a computerised format. This system can be considered to consist of a number of tools that integrate the various datasets and analysis systems. With the advantage of this integrated system, the role of Hydroinformatic systems in hydrological modelling is substantially important because the system offers an effective mechanism for improving the performance of catchment modelling systems. The typical components of the Hydroinformatic systems that would be expected for a system concerned with the management of a catchment are:

- Information database for storage, retrieval and display of spatial and temporal data,
- Catchment modelling systems for simulating the catchment response to hydrologic events, and
- Decision support system for enhanced modelling and data analysis capabilities.

In this study, the employed Hydroinformatic tools for calibration of a catchment modelling system were ARC/INFO, SWMM (Huber and Dickinson, 1988) and L_BFGS_B (Byrd et al., 1994) designed for solving large nonlinear optimisation problems with single bounds on the variables. A decision support system was developed using L_BFGS_B to support decisions regarding appropriate values for the catchment modelling system control parameters, while the SWMM was used to simulate the response of an catchment to storm events, and ARC/INFO was employed to handle spatial and non-spatial attribute information.

Presented herein is an approach based on application of a Hydroinformatic system and, in particular, a decision support system for selecting values of the catchment modelling system control parameters. The purpose of this paper is therefore to demonstrate that spatially variable control parameter values can be selected by a Hydroinformatic system, reducing the time and effort required for model calibration and improving a catchment modelling system in terms of accuracy and efficiency.

CALIBRATION PROCESS

Control parameter values for a catchment modelling system typically are determined by one of two alternative methods; these alternative methods are:

- Modification of control parameter values until the simulated and monitored hydrographs or other catchment response measure, are similar; and
- Selection of control parameter values based on some hydrological, hydraulic or other characteristic of the catchment.

The first of these alternatives can be described as a trial and error method whereby the values of the control parameters are modified in a systematic manner to achieve correlation between the monitored parameters and the predicted parameters describing the catchment response. This is the common approach when calibrating a catchment modelling system with recorded information. In practice, however, many catchment are not monitored and consequently information necessary for implementation of the trial and error approaches used in the above studies is not available. A similar situation occurs when the catchment modelling system is intended to assess the implications of a changed management strategy prior to its implementation. An alternative approach for evaluation of the control parameters is therefore necessary. In these circumstances, the second of the two generic control parameter evaluation methods can be used.

The traditional calibration process, whether it is a trial and error technique or an optimisation technique, consists of modifying parameter values until satisfactory simulation is achieved as shown in Figure 1. When this approach is being applied for determination of spatially variable control parameters, the modeller is faced with the problem of distinguishing between a significant number of variables and, in many cases, inadequate information to ascertain values of individual variables.

An alternative approach is to adopt the concept implicitly implemented with the use of inferred control parameters; this concept is based on the application of inference models to determine the values of the control parameters. Inclusion of these inference models in the calibration process results in the approach shown in Figure 2. This approach is the basis of the study reported herein.

The proposed evaluation of control parameters during the calibration process uses inference models within a Hydroinformatic system. Control parameters are influenced by many factors related to characteristics of the subcatchments. Transformation of this information stored within the spatial database

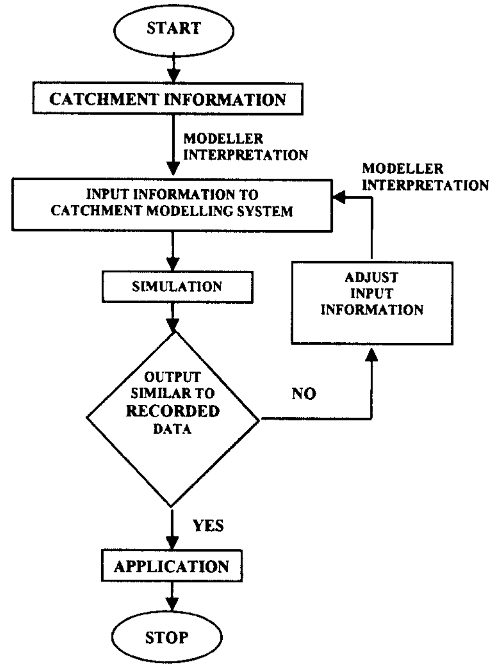

FIGURE 1. Traditional calibration procedure

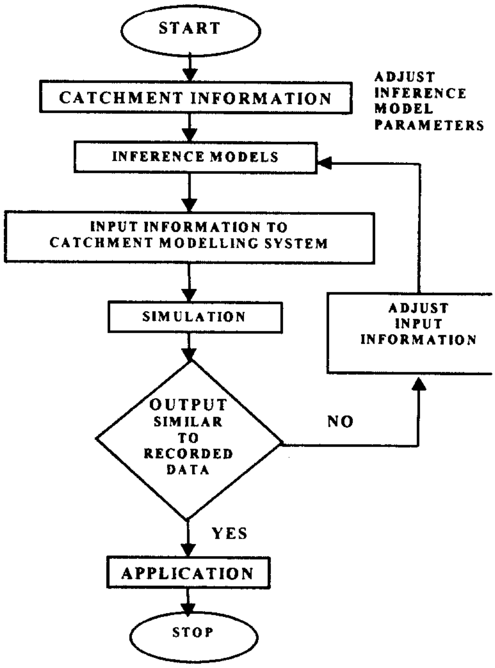

FIGURE 2. Proposed calibration procedure

requires inference models which are the models used to infer the control parameter values. The selection of control parameter, therefore, utilises inference models derived based on their influential factors stored in a GIS database related to the characteristics of the subcatchments. This calibration of the catchment modelling system consists of adjusting the parameters in the inference model until satisfactory agreement between the predicted and the recorded hydrograph characteristics is achieved as shown in Figure 2. The physical influential factors for inferred parameters, such as area of each subcatchment, channel length, and slope, can be known from GIS database and only inferred influential factors, which are assumed based on catchment characteristics, are adjusted in the calibration process. The details of development of inference models are described in Choi (2003). One advantage of this approach is that when recorded information is not available, the inference models can be used to obtain values of the control parameters based on the catchment characteristics. Secondly, the number of control parameters optimised can be reduced significantly as the proposed method only requires determination of control parameters associated with each land use of the catchment while a traditional approach needs to assign a number of control parameters for a number of subcatchments where a spatially distributed catchment model is employed. An effective calibration process, therefore, can be achieved by use of simple inference models.

CASE STUDY

The Centennial Park catchment was used as a case study catchment in application of inference models for determination of the control parameter values. The Centennial Park catchment, which is also referred to as the Musgrave Avenue Stormwater Channel catchment, is located in the eastern suburbs of Sydney, Australia as shown in Figure 3.

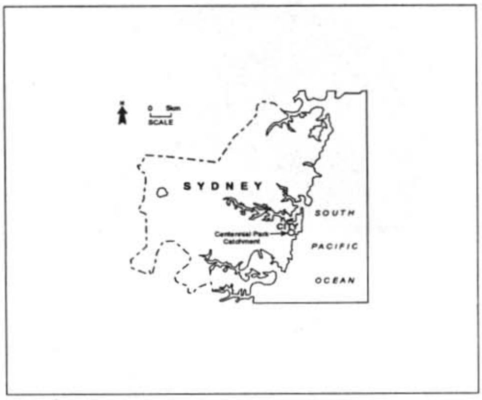

FIGURE 3. Location of Centennial Park catchment

1. Spatial Characteristics of the Catchment

The total area of the catchment is 132. 7 ha, and is comprised of highly urbanised residential areas served by separated drainage systems. The geological composition of the catchment is Botany sands containing mainly two sand soil types which are the Hammondville Soil (85%) and Moore Soil (15%). The number of subcatchments employed for this study was 42 with their size varying from 0. 50 ha to 27. 3 ha. The length of stormwater channel in each subcatchment is between 24. 1 m and 258. 2 m, with most of the pipe system being less than 1000 mm diameter. The main drainage system of the catchment is presented in Figure 4.

The catchment consists mainly of urbanised residential areas with light commercial development, and the overall percentage of impervious area in

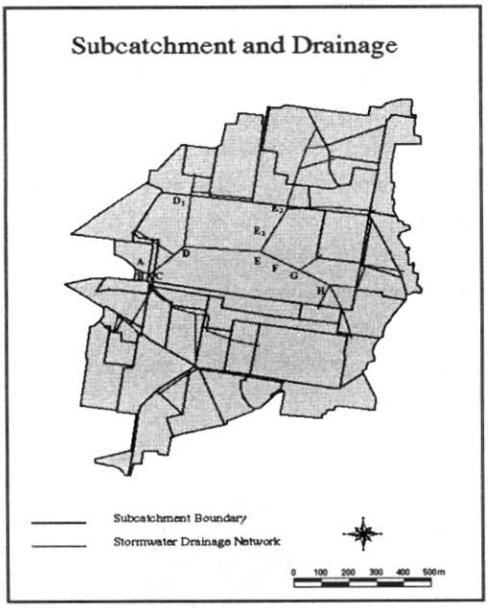

FIGURE 4. Subcatchment and main drainage system

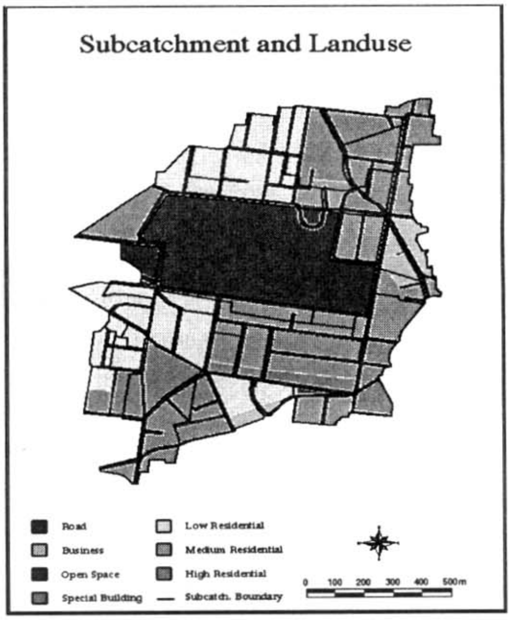

FIGURE 5. Landuse within the catchment

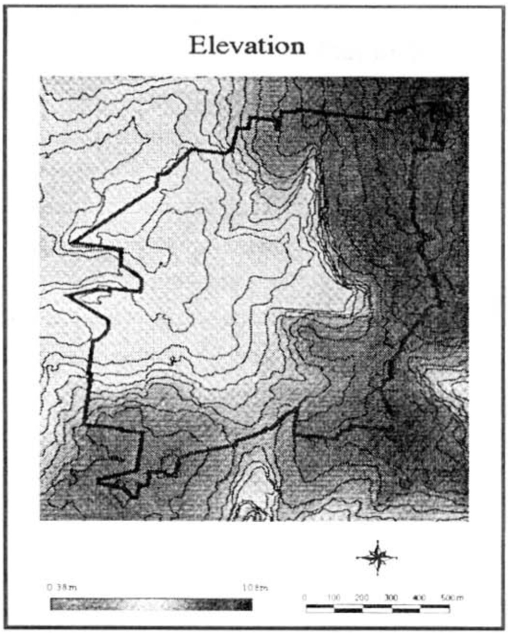

FIGURE 6. Elevation of the catchment

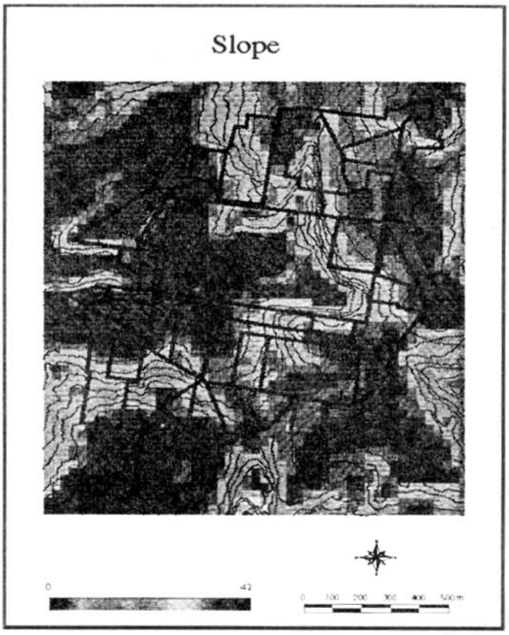

FIGURE 7. Slope of the catchment

the catchment is 35.2%. The landuse within catchment are shown in Figure 5. As can be seen in Figure 6, the eastern and north-eastern regions of the catchment are at a higher elevation with the highest point being 98.0m Australian Height Datum (AHD), while most of the area in the west and north-west are situated at a lower level but with a slight gradient heading down towards the outlet of the catchment at 43.2m AHD. Presented in Figure 7 is the slope of the catchment. Using this information, the average slope of the subcatchment was calculated. The slope of the subcatchments varied from 0.49 % to 12.4 %, with the average slope for the whole catchment being 5.3 %.

2. Temporal Information

Temporal information within the catchment was available in HYDSYS which is a computer system used to store, process, analyse and report hydrometric time series database system. For this study, rainfall and flow information were extracted from HYDSYS in the form of instantaneous value at the end of a time interval. Both single and multiple peak events were selected with data available of a time step of 5 minutes. Four events were selected for calibration process. The details of these events are shown in Table 1. The significance of antecedent conditions was tested by dividing the storm events into categories based on the antecedent wetness of the catchment, which was adapted from Abustan (1997).

TABLE 1. Details of events

Event	Rainfall (mm)	Runoff volume (m^3)	Peak flow (m^3/s)	AMC
Oct. 31, 94	5.8	1764.3	0.547	Dry
Nov.29, 94	4.0	1203.6	0.382	Dry
Jan. 02, 95	7.8	786.0	0.512	Rather dry
Jan. 28, 95	8.0	3074.7	0.896	Dry

RESULTS AND DISCUSSIONS

For application of the inference models, it was necessary to develop a new subroutine, PARAM_OP, which contains the mathematical formulas of the inference models, and add to the main program of SWMM. The RUNOFF and TRANSPORT blocks of SWMM were used for simulation of rainfall-runoff process. An objective function selected for this study was mean square error (MSE), which is the most commonly used criterion on which to base the calibration is the minimum average value of the sum of the squares of the differences between observed and simulated discharges as shown in Equation (1) (Fleming, 1975; Nix, 1994; Zaman, 1994).

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (Q_{oi} - Q_{si})^2 \qquad (1)$$

where: Q_{oi} is observed flow rate (m^3/s)
Q_{si} is simulated flow rate (m^3/s)
n is number of observations in the time series

Table 2 lists the measured and simulated values of peak flow and runoff depth, and presented in Figure 8 are the simulated and measured hydrographs of two selected calibration events. From the results shown in Table 2, well balanced results were observed from the proposed approach in terms of runoff volume and peak flow objectives. The response time to peak was very good, and the shape of hydrograph was also well matched between the measured and simulated data as shown in Figure 8.

TABLE 2. Measured and simulated runoff volume and peak flow values

Event	Measured values		Simulated values	
	Runoff volume (m^3)	Peak flow (m^3/s)	Runoff volume (m^3)	Peak flow (m^3/s)
Oct. 31, 94	1764.3	0.547	1794.1	0.545
Nov. 29, 94	1203.6	0.382	1166.1	0.368
Jan. 02, 95	786.0	0.512	807.8	0.486
Jan. 28, 95	3074.7	0.896	3242.3	0.877

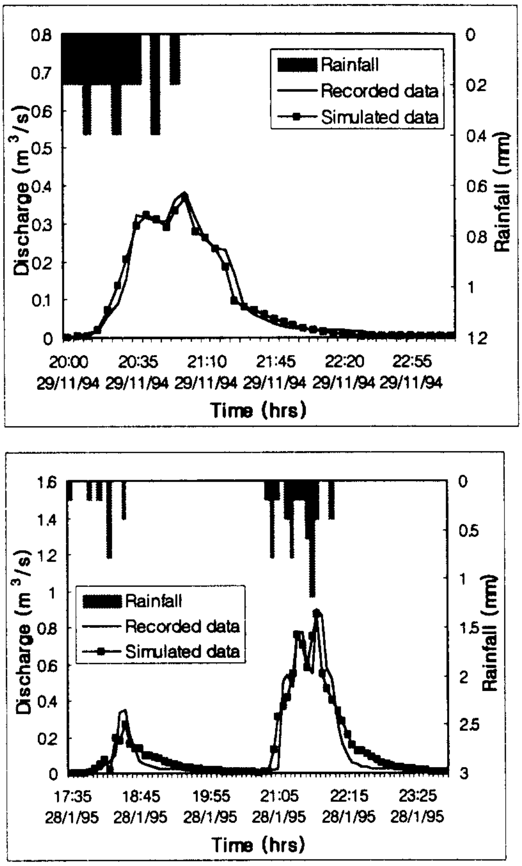

FIGURE 8. Comparison of measured and simulated hydrographs(Storm events on Nov. 29, 94 and Jan. 28, 95)

In order to compare the proposed calibration process with a more traditional calibration process, the evaluation criteria used were the relative error in runoff volume and peak flow, MSE, bias (B), variance (V) and efficiency (E). RE was selected to evaluate differences between the measured and the simulated values of runoff volume and peak flow. Shape of the observed hydrograph against to the simulated one was compared by MSE, while B, V and E were used to assess different aspects of model performances. Algebraically, these criteria were:

- Relative Error (RE) :

$$RE = \frac{(O-S)}{O} \tag{2}$$

where O is observed values and S is simulated values

- Bias (B) :

$$B = \frac{1}{n}\sum_{i=1}^{n} Q_s(i) - \frac{1}{n}\sum_{i=1}^{n} Q_o(i) \tag{3}$$

where Q_s is simulated discharges (m^3/s)
Q_o is observed discharges (m^3/s)
n is number of observations in the time series.

- Variance (V) :

$$V = MSE - B^2 \tag{4}$$

where MSE is mean square error
B is bias.

- Efficiency (E) :

$$E = 1 - \frac{MSE}{V} \tag{5}$$

where MSE is mean square error
V is variance.

Using the criteria selected, the simulation results for the proposed and traditional calibration approaches were assessed as shown in Table 3 and 4. The performance statistic shown in Table 4 is the results obtained from Abustan (1997) which used the trial and error method to estimate model parameters during the calibration process. The performance between the proposed and traditional approaches were evaluated only on the first three events because the last event shown in Table 3 was not included in Abustan (1997).

TABLE 3. Statistical results of the proposed approach

Event	RE (%)		MSE	B	V	E
	Runoff	Peak	(m^3/s)^2	(m^3/s)	(m^3/s)^2	
Oct,31,94	-1.7	0.37	0.0032	0.0014	0.0032	-0.0006
Nov.29,94	3.1	3.7	0.0085	-0.0031	0.0085	-0.0012
Jan.02,95	-2.8	5.1	0.0013	0.0015	0.0013	-0.0016
Jan.28,95	-5.4	2.1	0.0058	0.0086	0.0057	-0.0129

TABLE 4. Statistical results of the traditional approach

Event	RE (%)		MSE	B	V	E
	Runoff	Peak	(m^3/s)^2	(m^3/s)	(m^3/s)^2	
Oct,31,94	-16.0	-1.8	0.0066	0.0170	0.0063	-0.046
Nov.29,94	-4.2	-10.0	0.0017	-0.0075	0.0016	-0.034
Jan.02,95	-3.8	12.0	0.0081	0.0110	0.0079	-0.025

From the comparison between Table 3 and 4, the proposed approach showed better results in terms of accuracy of model prediction. The range of RE in runoff volume and peak flow was -1.7∼-5.4% and 0.37∼5.1% respectively for the proposed approach, while for the traditional approach the range in runoff volume and peak flow was -3.8∼-16% and -1.8∼-10% respectively. From the above results, it was noticed that both approaches tended to produce larger values of runoff volume from the simulation compared to the measured values as most events selected showed negative RE of runoff volume. The average value of MSE was $0.0047(m^3/s)^2$ for the proposed approach and $0.0055(m^3/s)^2$ for the traditional approach, indicating that overall the simulated responses of the catchment for the proposed approach followed a more similar trend to the observed responses of the catchment. The values of B, V and E obtained from the proposed approach were also superior to those obtained from the traditional approach.

From these results, it was found that high accuracy control parameter estimation was obtained from the proposed approach. Furthermore, this approach allowed the development of spatially variable control parameters without the problem of optimising over a large number of control parameters.

CONCLUSION

The definition of control parameter values is an important component of successful implementation of catchment modelling systems. Accurate estimation of the control parameters for a spatially distributed physically based catchment modelling system, however, requires considerable work to establish credibility. To improve this situation, a Hydroinformatic system for estimating control parameters of a catchment modelling system was developed. Catchment information was constructed in an ARC/INFO database, and transformations of this information were made to generate the input information necessary for operation of a SWMM, while the L_BFGS_B algorithm was employed to assist in the calibration process.

It was found that the proposed approach reduced the number of spatially variable control parameters to be considered and, hence, reduced the considerable time and effort necessary for estimating a large number of control parameters. Furthermore, the need for extensive recorded information of the catchment response was decreased due to the lower number of parameters being evaluated. From the comparison of the new and traditional calibration approaches, it was also found that Hydroinformatic systems can be used effectively to evaluate catchment modelling system control parameters, and to improve the accuracy and efficiency of the catchment modelling system calibration process.

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