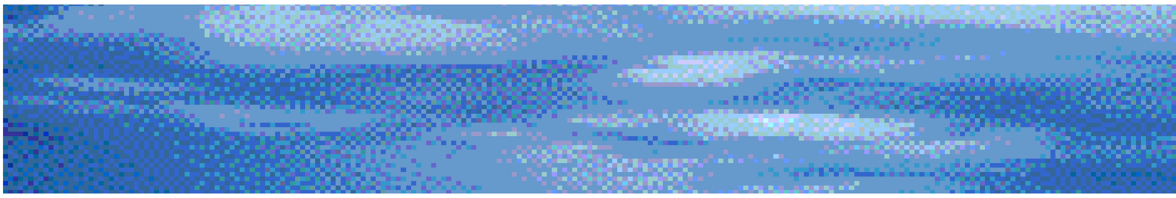
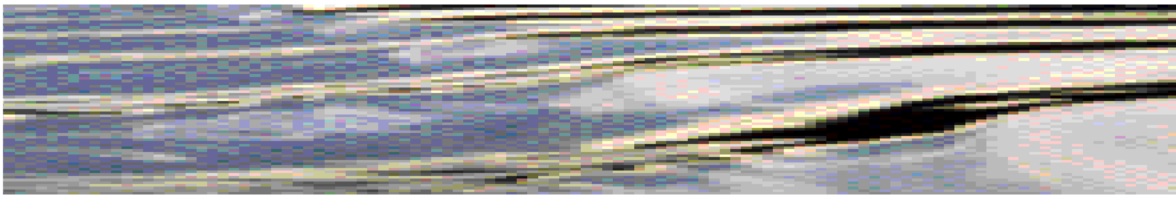
COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

CATCHMENT SCALE MODELLING OF RUNOFF, SEDIMENT AND NUTRIENT LOADS FOR THE SOUTH-EAST QUEENSLAND EMSS

TECHNICAL REPORT
Report 02/1
February 2002

Francis Chiew / Philip Scanlon / Rob Vertessy / Fred Watson





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HEALTHY WATERWAYS
Because we're all in the same boat

SE Qld Regional Water Quality Management Strategy

Catchment Scale Modelling of Runoff, Sediment and Nutrient Loads for the South-East Queensland EMSS

Francis H.S. Chiew, Philip J. Scanlon, Robert A. Vertessy and Fred G.R. Watson

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Foreword

Catchments, streams and coastal waterways of the south-east Queensland region have been degraded significantly since European settlement. Now State Government, Local Councils, Catchment Groups, Community Groups and Industry are working cooperatively to reverse the damage. Under the umbrella of the South East Queensland Regional Water Quality Management Strategy (SEQRWQMS), these groups are working with researchers to discover how to tackle this enormous problem. In a jointly-funded study, the SEQRWQMS and Cooperative Research Centre for Catchment Hydrology developed an Environmental Management Support System (EMSS) to simulate runoff and pollutant movement across the south-east Queensland region. That study benefited from a huge amount of stakeholder input that defined the management problem and specified the modelling needs for tackling it.

This report summarises a vital part of the research that went into the development of the EMSS. It describes the runoff and pollutant load model used in the EMSS and recommends model parameter values for use in the south-east Queensland region.

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Acknowledgements

This study was carried out with funds from the South East Queensland Regional Water Quality Management Strategy and in-kind contribution from the Cooperative Research Centre for Catchment Hydrology.

Many thanks to Eva Abal and Trevor Lloyd for their support in initiating the study. We would also like to thank the many people who assisted us in obtaining the data from the agencies and councils in south-east Queensland.

Executive Summary

This report describes the lumped conceptual catchment scale model used in the Environmental Management Support System (EMSS) to estimate daily runoff and daily pollutant load from 175 catchments in the south-east Queensland region. The model has two components - a hydrologic model and a pollutant export load model. The input climate data into the model are daily rainfall and mean monthly areal potential evapotranspiration and the main model outputs are total daily runoff and total daily pollutant loads (total suspended solids, total phosphorus and total nitrogen). There are seven parameters in the hydrologic model and two parameters in the pollutant export load model.

The report also describes the estimation of parameters for the hydrologic and pollutant load models using local data. The parameter values that are adopted in the EMSS are presented below. Although there are nine land-use categories in the EMSS the limited local data only allow meaningful differentiation between some of the land-use categories.

The hydrologic model has three parts - an impervious area model, a "forest" pervious land-use model and a "other pervious" land-use model. The proportion of catchment with effective impervious area is estimated as **0.4 x proportion of dense urban land-use + 0.25 x proportion of suburban land-use**. Daily runoff from the effective impervious area is estimated as the daily rainfall less a threshold of 1 mm. The natural bush, national park, managed forest and plantation land-use categories in the EMSS are considered as "forest" land-use and modelled using a daily lumped conceptual hydrologic model (see **Figure 3.1**). The remaining land-use categories in the EMSS (grazing, intensive agriculture, broadacre agriculture and the pervious fraction of the dense urban and suburban land uses) are considered as "other pervious" land-use and modelled using the same daily conceptual hydrologic model but with different parameters values. The parameter values for the "forest" pervious land-use and the "other pervious" land-use for nine hydrologic regions in south-east Queensland (see **Figure E.1**) are given in **Table E.1.**

The daily pollutant load is estimated as

Daily pollutant load = surface runoff x EMC + subsurface runoff x DWC

where the event mean concentration (EMC) is defined as the flow-weighted average pollutant concentration over a storm event and the dry weather concentration (DWC) is defined as the pollutant concentration measured during dry weather. The DWC and EMC values for total suspended solids, total phosphorus and total nitrogen used in the EMSS are given in **Table E.2.**

Table E.1 Hydrologic parameters for pervious land-use for the nine hydrologic regions

Region	Forest land use Natural bush National park Managed forest Plantation							Other pervious land use Grazing Intensive agriculture Broadacre agriculture Pervious fraction of dense urban Pervious fraction of suburban						
	INSC	*COEFF*	*SQ*	*SMSC*	*SUB*	*CRAK*	*K*	*INSC*	*COEFF*	*SQ*	*SMSC*	*SUB*	*CRAK*	*K*
1	3.0	200	1.5	29	0.25	1.00	0.008	3.0	200	1.5	29	0.25	1.00	0.008
2	5.0	200	1.5	273	0.35	0.70	0.300	2.0	200	1.5	200	0.35	0.70	0.300
3	4.9	200	1.5	379	0.10	0.25	0.300	3.0	200	1.5	150	0.15	0.00	0.133
4	3.2	200	1.5	320	0.10	0.20	0.300	3.1	200	1.5	200	0.20	0.00	0.300
5	5.0	200	1.5	190	0.50	0.43	0.165	5.0	200	1.5	190	0.50	0.43	0.165
6	4.4	200	1.5	165	0.30	0.40	0.127	4.4	200	1.5	165	0.30	0.40	0.127
7	5.0	200	1.5	319	0.07	0.23	0.003	5.0	200	1.5	262	0.13	0.18	0.067
8	3.5	200	1.5	355	0.48	0.65	0.150	3.5	200	1.5	355	0.48	0.65	0.150
9	1.7	200	1.5	94	0.25	0.37	0.300	1.7	200	1.5	94	0.25	0.37	0.300

Figure E.1 Regions for hydrologic modelling

Table E.2 Recommended DWC and EMC values for TSS, TP and TN for the EMSS

Land-use		**TSS (mg/L)**		**TP (mg/L)**		**TN(mg/L)**	
		DWC	**EMC**	**DWC**	**EMC**	**DWC**	**EMC**
Dense urban	Lower	5	60	0.06	0.20	1.1	1.3
Suburban	**Median**	**7**	**130**	**0.11**	**0.28**	**1.5**	**1.6**
	Upper	9	200	0.16	0.36	2.0	2.1
Natural bush	Lower	5	10	0.01	0.05	0.3	0.4
National park	**Median**	**7**	**32**	**0.03**	**0.10**	**0.5**	**0.8**
Managed forest	Upper	9	57	0.07	0.20	0.8	2.0
Plantation							
Grazing	Lower	8	25	0.02	0.08	0.4	0.6
	Median	**10**	**140**	**0.07**	**0.34**	**0.7**	**2.7**
	Upper	11	350	0.12	0.70	0.9	4.2
Intensive agriculture	Lower	8	60	0.02	0.20	0.4	1.5
Broadacre agriculture	**Median**	**10**	**200**	**0.07**	**0.50**	**0.7**	**4.0**
	Upper	11	550	0.12	1.5	0.9	9.0

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1. Introduction

1.1 Background

Catchments, streams and coastal waters of the south-east Queensland region have been significantly altered since European settlement, resulting in the degradation of aquatic and marine habitat and water quality (Neil, 1998). The South-East Queensland Regional Water Quality Management Strategy (SEQRWQMS) is a major environmental management initiative, involving participation by various councils, State government departments, private companies and community groups operating in south-east Queensland. The aim of the Strategy is to provide the knowledge and coordination for stakeholders to achieve the following vision:

"South-east Queensland land catchments and waterways will, by 2020, be a healthy living ecosystem supporting the livelihoods and lifestyles of people and will be managed through collaboration between community, government and industry".

The SEQRWQMS has commissioned and funded a range of research projects since 1993, dealing with topics as diverse as coastal zone hydrodynamics and nutrient processing, catchment sediment sources and freshwater stream ecology. A staged approach has been used by the SEQRWQMS to conduct research to achieve the desired outcomes. Stage 1 commissioned a range of specialist scoping studies and general background studies of the study area. Stage 2 focused on the estuaries and bay and included the delivery of a water quality strategy and monitoring program for Moreton Bay and estuaries. Stage 3 includes new studies in fresh water zones and issues identified in Stage 2 requiring further investigation.

1.2 Study objectives

Two of the Stage 3 tasks are undertaken as associate projects of the Cooperative Research Centre for Catchment Hydrology (CRCCH) - "Development of an Environmental Management Support System for Catchments in South-east Queensland" (Project 1.3) and "Modelling and Estimating Sediment and Nutrient Loads in South-east Queensland Catchments" (Project 1.4)

This report describes the development of the catchment scale model and the estimation of model parameters (Project 1.4). The lumped catchment scale model estimates the runoff components and pollutant loads (total suspended solids, total phosphorus and total nitrogen) from about 175 catchments of about 100 km^2 each in the south-east Queensland region (see **Figure 1.1**). The model is part of the Environmental Management Support System (EMSS) developed in Project 1.3.

1.3 EMSS and catchment scale model

The Environmental Management Support System (EMSS) is developed to assist the management of water quality across the south-east Queensland region. It estimates daily runoff and daily pollutant loads from 175 catchments in the 23,000 km^2 region, and the storage and transport of runoff and pollutant loads to the receiving waters. The model estimates are sensitive to changes in climate, storage operations, land-use and land management practices. The main use of the EMSS is to estimate present runoff and pollutant loads and to assess the impact of changes in land-use and land management practices on runoff and pollutant export loads. There are nine land-use categories in the EMSS excluding water (see **Figure 1.2**).

The EMSS is composed of three linked models. A runoff and pollutant export model (referred to as 'Colobus') operates on each sub-catchment, providing daily estimates of runoff, total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN). The sub-catchments are linked to one another using a 'node-link' system to represent the river network. Flow and pollutant loads are conveyed down the river network using a routing model (referred to as 'Marmoset'). There is also a storage model (referred to as 'Mandrill') in the EMSS that regulates river flows, traps pollutants and accounts for evaporative losses from large storages in the region.

This report describes the development of the catchment scale runoff and pollutant export model (Colobus) and the estimation of model parameters. The software development and other technical aspects of the EMSS are described in Vertessy et al. (2001) and in the EMSS Assistant.

1.4 Outline of report

Section 2 provides a brief review of catchment scale modelling. Section 3 describes the lumped catchment scale model (Colobus) adopted for the EMSS. There are two components in the model - a hydrologic model and a pollutant export model.

Section 4 describes the calibration of the hydrologic model to estimate model parameters for the different land uses and geographical/climatic regions. Section 5 describes the estimation of water quality parameters for the different land uses for the pollutant export model.

Section 6 presents some summary results from the EMSS simulation of runoff and pollutant loads for present land-use conditions.

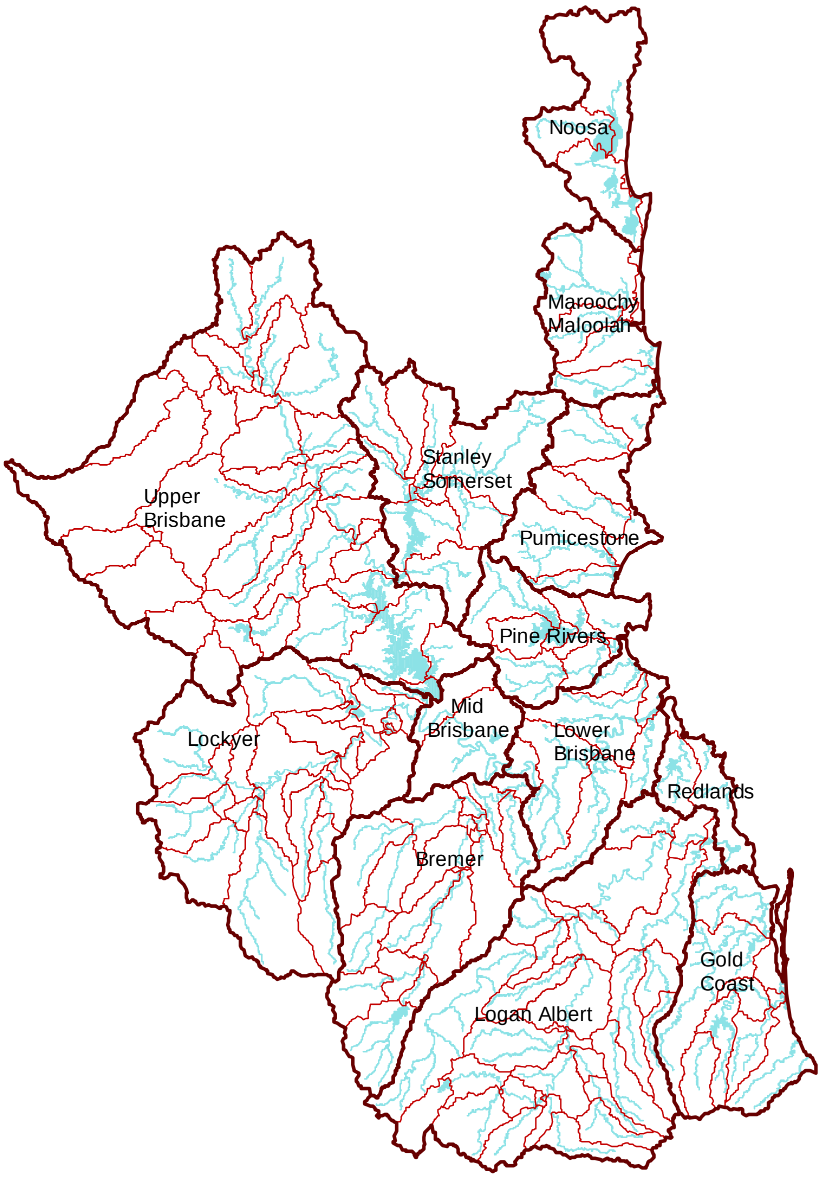


Figure 1.1 EMSS catchments and sub-catchments

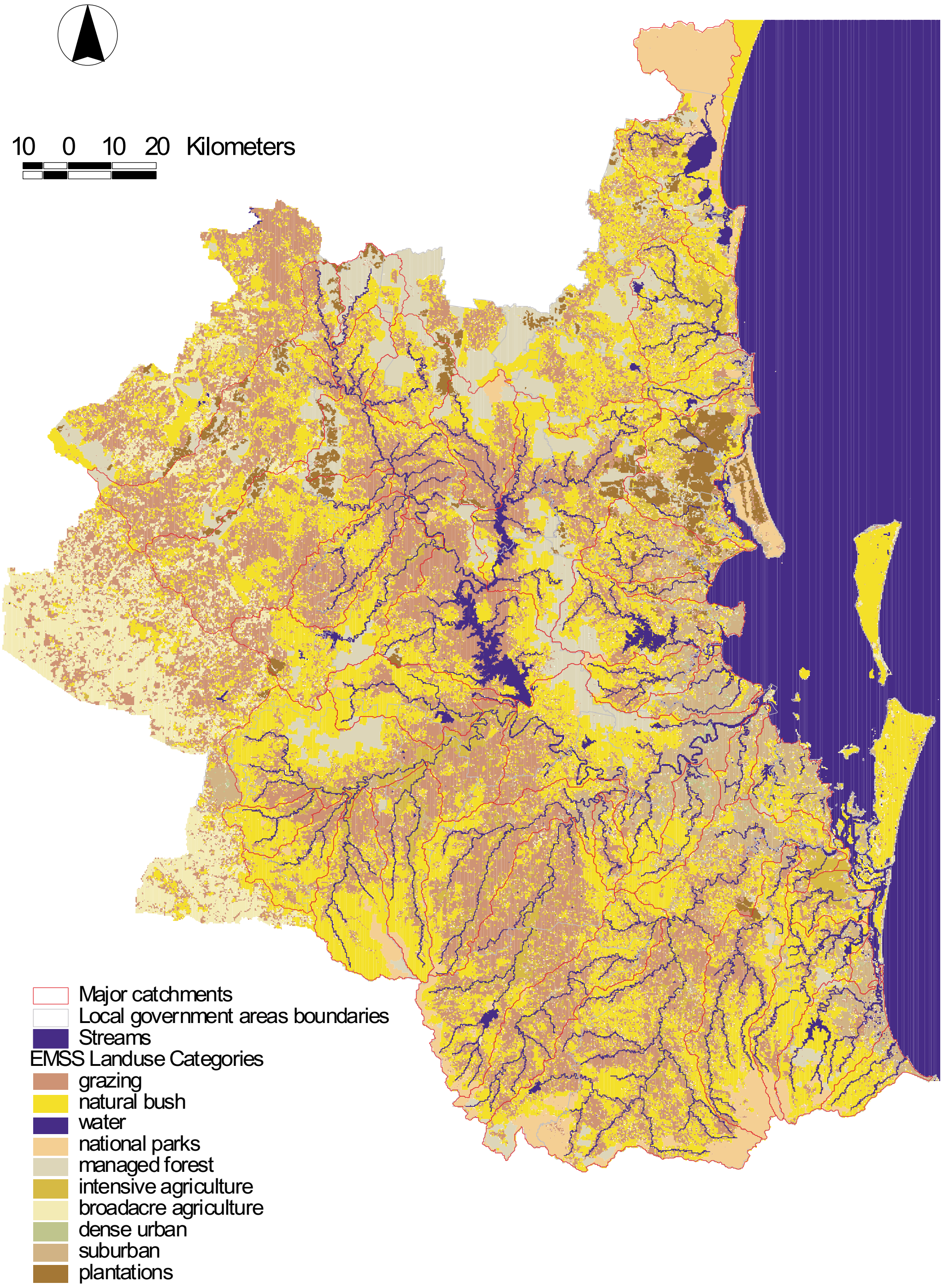


Figure 1.2 EMSS Land-use categories

2. Catchment-Scale Modelling

2.1 Monitoring and modelling

The most direct and accurate method for estimating pollutant loads is to monitor runoff and water quality concentration at the location of interest. However, monitoring is expensive, and pollutant loads are more commonly estimated using models, with some monitoring undertaken to support the modelling efforts.

A properly calibrated model can also be used for sensitivity and scenario studies of issues such as the impacts of changes in land-use practices or impacts of climate change. However, local data must be available to support the modelling because the model simulations can only be as good as the data used to calibrate the model. Sensitivity runs using a model can also indicate where additional local data is required.

There are numerous rainfall-runoff and water quality models, and the choice of the model should ultimately depend on the objectives of the study and the available resources and data. This report presents only broad concepts in pollutant load estimation, and for more detailed discussion on model types and selection, the reader should refer to these papers (Grayson and Chiew, 1984; McMahon and Chiew, 1998; and Chiew and McMahon, 1999).

2.2 Estimation of long-term pollutant load

Long-term pollutant load can be estimated using areal pollutant loading rates appropriate to the land uses, soil types and other variables in the catchment. The mean annual pollutant load can be estimated as

Pollutant load (t/yr) = catchment area (km^2) x areal loading rate (t/yr/km^2)

This approach is adopted by many models (e.g. ICMS (Croke et al., 2000), NEXSYS (Young et al., 1997), FILTER (Mitchell and Argent, 1999)) to assess catchment management plans. Where local data are available to estimate the areal loading rates, this approach gives reasonable estimates of long-term pollutant loads. Where local data are not available, loading rates from other areas are usually used, introducing uncertainties in the load estimates.

The main disadvantage of this approach is that it does not distinguish between catchments with high rainfall and high runoff which can transport large pollutant loads compared to similar catchments with low runoff which has less transport capacity. This is particularly so when published areal loading rates are adopted because the loading rates may come from areas with different climatic characteristics. Even where local data are available, this approach presents a problem when applied across large regions with varying climatic characteristics.

To overcome this limitation, long-term pollutant loads can be estimated from the average annual runoff and an average pollutant concentration (see Chiew and McMahon, 1999). The mean annual runoff can be estimated reasonably accurately as

Runoff = rainfall x runoff coefficient

The mean annual pollutant load can then be estimated as

Pollutant load = runoff x average pollutant concentration

This approach allows climatic variations across large regions to be explicitly represented. However, it can be difficult to estimate the "average" pollutant concentration, as pollutant concentrations vary significantly from events to dry weather flow (see Chiew and Scanlon, 2001).

2.3 Modelling of daily pollutant load

Shorter term modelling with local data gives more accurate estimates of pollutant loads compared to the long-term average approach discussed above. Daily, monthly or seasonal estimates of pollutant loads are also required to assess shorter term impacts and to evaluate alternative water quality management options. In terms of data requirements and modelling effort, there is little difference between using a daily or monthly model. It is unlikely that there will ever be sufficient data to justify modelling on time steps shorter than a day for the spatial scales considered here.

Daily models usually consist of a hydrologic component that estimates the daily catchment runoff and a pollutant export component that estimates the daily pollutant load transported by the runoff.

2.3.1 Lumped versus spatial modelling

Most daily time step hydrologic models are applied as a "lumped" model over a catchment area. Catchment-average rainfall and potential evapotranspiration are used as the input data to drive the catchment model, which estimates the runoff that would be observed at the bottom of the catchment. The pollutant export model then estimates the pollutant load that would be transported by the runoff. Large catchments can be divided into smaller subcatchments, with a separate "lumped" model representing each subcatchment, driven by different catchment-average rainfall and potential evapotranspiration data and model parameters. The runoff and pollutant load estimated for each subcatchment is then either simply added together, or routed down a stream network to its discharge point to obtain the total runoff and pollutant load from the catchment.

An alternative to the lumped modelling approach is a spatial (or distributed) modelling approach. In the spatial modelling approach, a catchment is subdivided into small grids with runoff and pollutant load for each grid modelled separately. Physically based algorithms are then used to transport the runoff and pollutant load to the drainage system. The spatial modelling approach is intuitively more accurate than the lumped modelling approach, particularly for the generation and movement of pollutants. For example, it is likely that a larger proportion of the pollutants generated close to drainage waterways will find its way to the streams compared to pollutants generated far away from drainage lines.

There is some merit in adopting the spatial modelling approach, but a lot of data is required to fully benefit from this approach. Spatial models also require more computer resources than lumped models, with model run times for spatial models being significantly longer than for lumped models. For these two reasons, a lumped model rather than a spatial model is considered more appropriate for the EMSS.

2.3.2 Daily lumped hydrologic models

There is a plethora of lumped conceptual hydrologic models available that can estimate runoff from rainfall and potential evapotranspiration data. There is little to choose between the various models because once calibrated, most of them can estimate runoff satisfactorily, particularly for the temperate and wet catchments in this region.

Some of the more commonly used models in Australia include AWBM (Boughton, 1993), AQUALM (Phillips et al., 1992), SIMHYD (Peel et al., 2001), HYDROLOG (Porter and McMahon, 1976) and the Sacramento model (Burnash et al., 1973). SIMHYD is adopted here because it has recently been extensively tested and applied to over 300 catchments as part of a National Land And Water Resources Audit to obtain long time-series of streamflow data for catchments throughout Australia (Peel et al., 2001; and Chiew and McMahon, 1994). The simplicity of SIMHYD and the smaller parameter inter-dependency in SIMHYD also increases the likelihood of transferring optimised model parameters from one catchment to other catchments with similar characteristics.

The above models can easily be adapted for use in urban areas and rural townships. Runoff from pervious areas can be estimated using the lumped conceptual rainfall-runoff models mentioned above while runoff from effective impervious areas (impervious surfaces that are directly connected to the drainage systems) can be estimated as (see Chiew and McMahon, 1999),

Impervious area runoff = rainfall - threshold

where threshold represents losses due to water filling the surfaces depressions and pores.

2.3.3 Estimation of daily pollutant loads

Once daily runoff is estimated, the daily pollutant load is usually estimated as

Daily pollutant load = surface runoff x EMC + baseflow x DWC

The event mean concentration (EMC) is the flow weighted average pollutant concentration over a storm event. The dry weather concentration (DWC) is the pollutant concentration measured during dry weather. It is important to differentiate between the EMC and DWC because they can differ by more than an order of magnitude.

Local data may suggest that the EMC and/or DWC should vary as a function of the daily runoff. Apart from this, there are rarely sufficient data to consider more complex water quality simulations to estimate total pollutant loads.

3. Catchment-Scale Runoff and Pollutant Load Model for South-East Queensland EMSS

3.1 Catchment-scale runoff and pollutant load model

The lumped catchment scale modelling is carried out on a daily time step. The model, as used in the south-east Queensland EMSS, is called **Colobus**. The model has two components - a hydrologic model and a pollutant export load model. The input data into the model are daily rainfall, mean monthly areal potential evapotranspiration, parameters for the hydrologic model and EMC and DWC values for TSS, TP and TN. The model outputs total daily runoff and the runoff components, and total TSS, TP and TN loads.

The catchment is divided into two parts for the hydrologic modelling: effective impervious area (impervious surfaces that are directly connected to the drainage system); and pervious area (remaining area).

Runoff occurs from the impervious area when daily rainfall exceeds a threshold. The threshold represents losses to surface depressions and evapotranspiration, and is set to 1 mm (see Chiew and McMahon, 1999).

Impervious area runoff = rainfall- threshold
(must be greater than zero)

The pervious area runoff is estimated using the lumped daily conceptual rainfall-runoff model, SIMHYD, shown in Figure 3.1. The model has seven parameters which are highlighted in bold italics in **Figure 3.1.**

In the model, daily rainfall is first intercepted by an interception store. The maximum daily interception is the lesser of the interception store capacity and potential evapotranspiration. Incident rainfall occurs only when rainfall exceeds the maximum daily interception.

The incident rainfall is then subjected to an infiltration function. The incident rainfall that exceeds the infiltration capacity becomes infiltration excess runoff.

The remaining moisture is subjected to a soil moisture function that diverts water to the stream (as saturation excess runoff and interflow), groundwater store (recharge) and soil moisture store. The saturation excess runoff/interflow is first estimated as a linear function of the soil wetness (soil moisture level divided by the soil moisture capacity). The equation used here attempts to mimic both the interflow and saturation excess runoff processes (with the soil wetness used to reflect parts of the catchment that are saturated from which saturation excess runoff can occur). Groundwater recharge is then estimated, also as a linear function of the soil wetness. The remaining moisture flows into the soil moisture store.

Evapotranspiration from the soil moisture store is estimated as a linear function of the soil wetness, but cannot exceed the potential rate (potential evapotranspiration minus intercepted water). The soil moisture store has a finite capacity and overflows into the groundwater store. Baseflow from the groundwater store is simulated as a linear recession from the store.

There are therefore three components of pervious area runoff: infiltration excess runoff; saturation excess runoff/interflow; and baseflow.

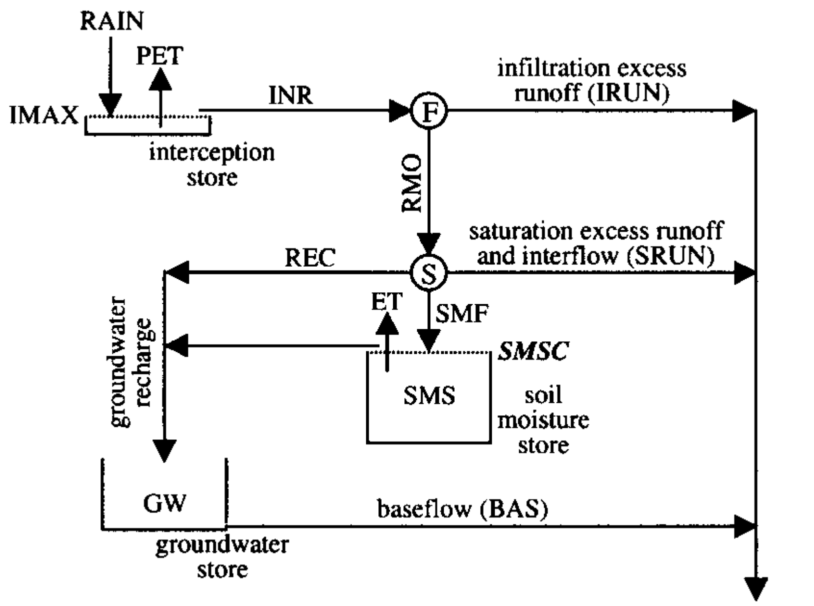
The total surface runoff and subsurface runoff from the catchment is estimated as,

Total surface runoff = fraction impervious x impervious area runoff + (1 - fraction impervious) x (infiltration excess runoff + saturation excess runoff/interflow)

Total subsurface runoff = (1 - fraction impervious) x baseflow

The daily pollutant load is estimated as,

Daily pollutant load = total surface runoff x EMC + total subsurface runoff x DWC



PET	=	areal potential evapotranspiration (input data)
IMAX	=	lesser of { *INSC*, PET }
INT	=	lesser of { IMAX, RAIN }
INR	=	RAIN - INT
RMO	=	lesser of { COEFF exp (-*SQ* x SMS/*SMSC*) , INR }
IRUN	=	INR - RMO
SRUN	=	***SUB*** x SMS/***SMSC*** x RMO
REC	=	***CRAK*** x SMS/***SMSC*** x (RMO - SRUN)
SMF	=	RMO - SRUN - REC
POT	=	PET - INT
ET	=	lesser of { 10 x SMS/***SMSC*** , POT }
BAS	=	***K*** x GW

Model parameters

INSC	interception store capacity (mm)
COEFF	maximum infiltration loss (mm)
SQ	infiltration loss exponent
SMSC	soil moisture store capacity (mm)
SUB	constant of proportionality in interflow equation
CRAK	constant of proportionality in groundwater recharge equation
K	baseflow linear recession parameter

Figure 3.1 Daily conceptual hydrologic model for estimating pervious area runoff

3.2 Time series climate data

Continuous daily rainfall and areal potential evapotranspiration data are required as input into the daily rainfall-runoff model. The source of the daily rainfall data is the Queensland Department of Natural Resources and Mines' (NRM) 0.05° x 0.05° (about 5 km x 5 km) interpolated gridded rainfall data based on over 6000 rainfall stations in Australia (see www.dnr.qld.gov.au/silo). The interpolation uses Ordinary Kriging of monthly rainfall data, and a variogram with zero nugget and a variable range. The monthly rainfall for each 5 km x 5 km point is then disaggregated to daily rainfall using the daily rainfall distribution from the station closest to the point. The lumped catchment-averaged daily rainfall used here is estimated from the daily rainfall in 5 km x 5 km points within the catchment.

Compared to rainfall, evapotranspiration has little influence on the water balance at a daily time scale. The inter-annual variability of areal potential evapotranspiration is also relatively small (coefficient of variation is typically less than 0.05). For these reasons, the mean monthly areal potential evapotranspiration is used here. The 12 mean monthly areal potential evapotranspiration values are obtained from the evapotranspiration maps produced jointly by the Cooperative Research Centre for Catchment Hydrology and the Australian Bureau of Meteorology (see Bureau of Meteorology, 2001). The areal evapotranspiration values are derived using the wet environment evapotranspiration algorithms proposed by Morton (1983) (see also Chiew and McMahon, 1991).

The catchment-average mean annual rainfall and areal potential evapotranspiration in south-east Queensland are shown in **Figures 3.2 and 3.3** respectively.

3.3 Model parameters

The hydrologic model has seven parameters. The estimation of these parameters are discussed in Section 4. The water quality algorithm requires estimates of event mean concentration (EMC) and dry weather concentration (DWC). The estimation of EMC and DWC are discussed in Section 5.

3.4 Runoff data for the calibration of the hydrologic model

The Queensland Department of Natural Resources and Mines (NRM) has streamflow data at about 200 gauging stations in the region. Streamflow data from 58 catchments are used for calibrating the hydrologic model (see **Table 3.1 and Figure 3.4**). The criteria used to select these catchments are

- discussion with NRM officers
- catchment areas between 10 km^2 and 1500 km^2
- at least seven years of historical streamflow data
- the gauge is not located downstream of a major storage which regulates the streamflow
- inspection of rainfall and runoff data indicates no obvious problems with the data set.

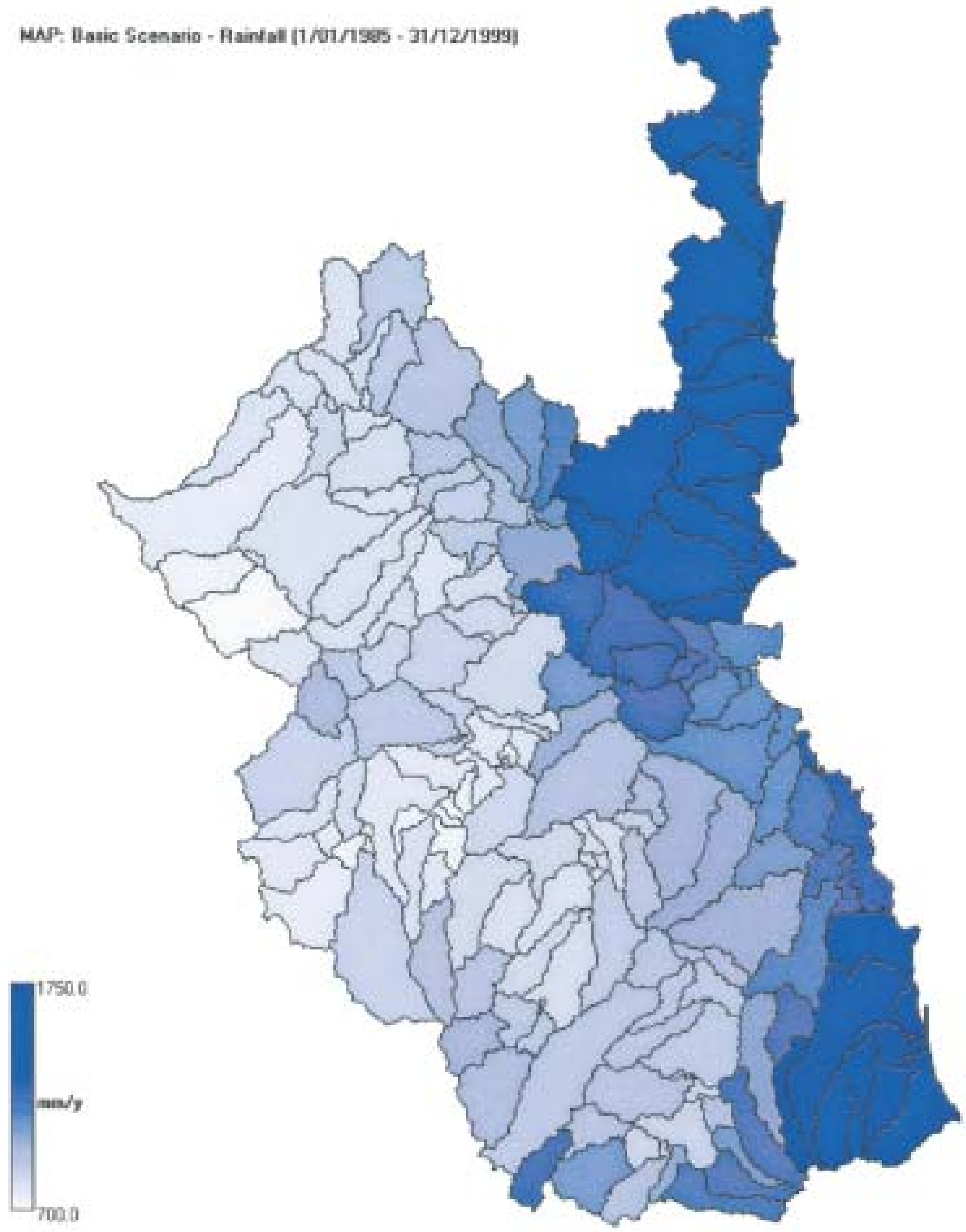


Figure 3.2 EMSS sub-catchment mean annual rainfall

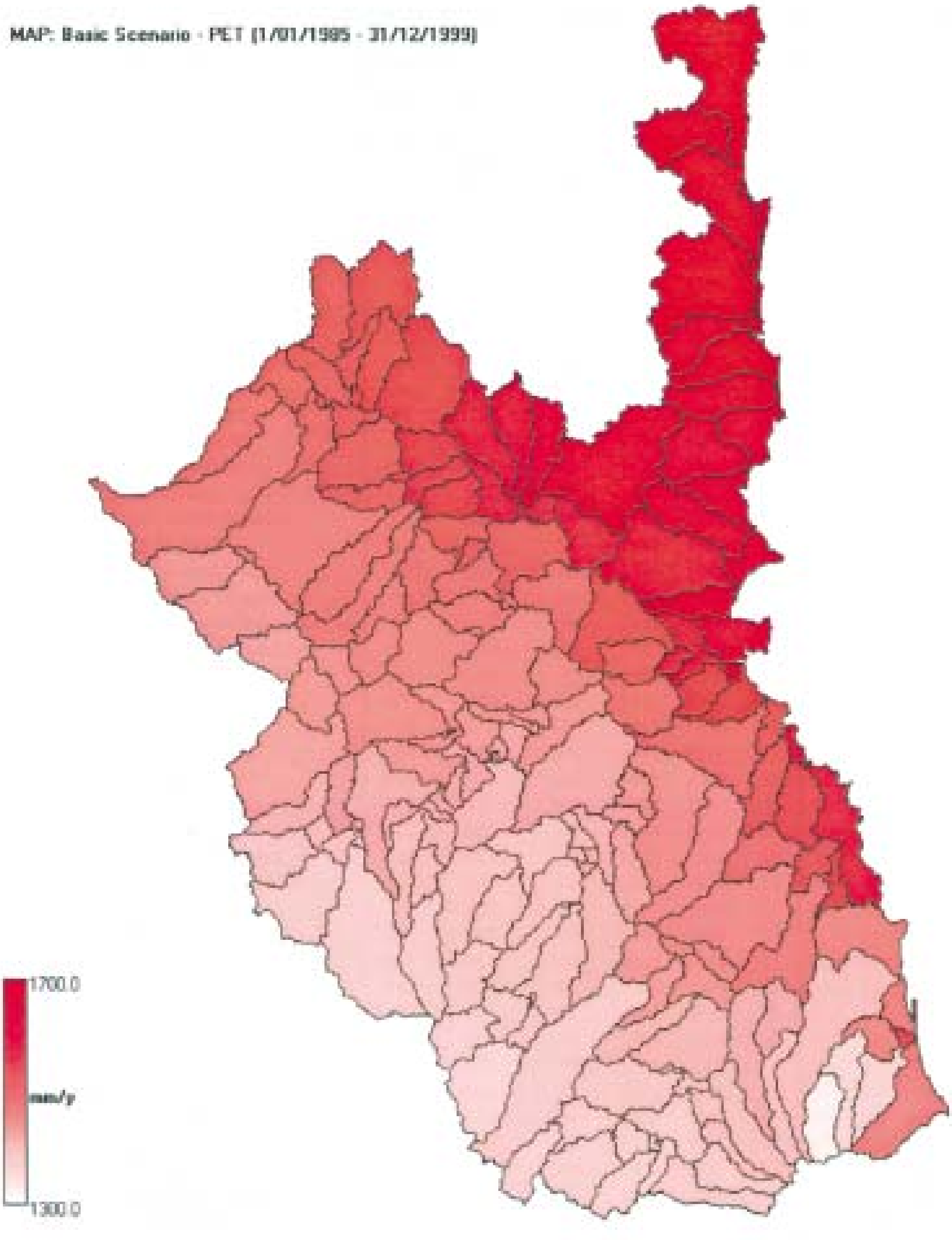


Figure 3.3 EMSS sub-catchment mean annual areal potential evapotranspiration

Table 3.1 NRM streamflow data for model calibration, with catchment land-use proportions

Station	Station Name	Area (km^2)	Rainfall (mm/yr)	Runoff (mm/yr)	Start	End	Years	Proportion of catchment subject to land use (see notes for explanation of land use categories) 1	2	3	4	5	6	7	8	9
140002A	Teewah Creek near Coops Corner	53	1550	604	1972	1999	28	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
141001B	South Maroochy River at Kiamba	33	1709	626	1986	1999	14	0.00	0.18	0.00	0.45	0.36	0.00	0.00	0.01	0.00
141003C	Petrie Creek at Warana Bridge	38	1683	662	1979	1998	20	0.00	0.00	0.00	0.58	0.26	0.00	0.03	0.11	0.01
141006A	Mooloolah River at Mooloolah	39	1815	676	1972	1999	28	0.01	0.05	0.00	0.62	0.27	0.00	0.00	0.06	0.00
141008A	Eudlo Creek at Kiels Mountain	62	1727	558	1982	1999	18	0.01	0.00	0.00	0.69	0.22	0.00	0.06	0.02	0.00
141009A	North Maroochy River at Eumundi	38	1638	617	1983	1999	17	0.01	0.00	0.00	0.50	0.36	0.00	0.10	0.02	0.00
142001A	Caboolture River at Upper Caboolture	94	1514	449	1966	1999	34	0.00	0.00	0.02	0.49	0.48	0.00	0.00	0.01	0.00
142101A	North Pine River at Young's Crossing	403	1295	301	1916	1977	62	0.01	0.16	0.01	0.47	0.31	0.00	0.02	0.02	0.00
142202A	South Pine River at Drapers Crossing	156	1312	364	1966	1999	34	0.05	0.07	0.00	0.50	0.35	0.00	0.01	0.02	0.00
142901A	Kedron Brook at Osborne Road	34	1188	503	1973	1980	8	0.00	0.24	0.00	0.28	0.19	0.00	0.01	0.25	0.01
142902A	Kedron Brook at Teachers College	59	1204	467	1973	1979	7	0.00	0.14	0.00	0.22	0.13	0.00	0.01	0.46	0.04
143006A	Cressbrook Creek at Tinton	422	1019	109	1953	1985	33	0.00	0.14	0.01	0.51	0.28	0.05	0.00	0.01	0.00
143010B	Emu Creek at Boat Mountain	914	779	35	1977	1999	23	0.00	0.04	0.02	0.37	0.50	0.08	0.00	0.00	0.00
143011A	Emu Creek at Raeburn	439	801	48	1966	1985	20	0.00	0.02	0.00	0.30	0.54	0.14	0.00	0.00	0.00
143013A	Cressbrook Creek at the Damsite	321	1009	74	1966	1980	15	0.00	0.07	0.01	0.51	0.34	0.06	0.00	0.01	0.00
143015B	Cooyar Creek at Damsite	963	761	28	1991	1999	9	0.00	0.11	0.06	0.28	0.47	0.08	0.00	0.00	0.00
143018A	Brisbane River at Avoca Vale	1498	869	96	1971	1985	15	0.00	0.19	0.05	0.28	0.43	0.05	0.00	0.00	0.00
143020A	Moggill Creek at Misty Morn	61	1158	381	1973	1980	8	0.00	0.05	0.00	0.70	0.20	0.00	0.00	0.05	0.00
143022A	Stable Swamp Creek at Interstate Railway	19	1208	889	1973	1980	8	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.78	0.18
143032A	Moggill Creek at Upper Brookfield	23	1104	285	1977	1999	23	0.00	0.01	0.00	0.83	0.16	0.00	0.00	0.00	0.00
143033A	Oxley Creek at New Beith	60	1004	70	1977	1999	23	0.00	0.00	0.00	0.74	0.19	0.00	0.02	0.05	0.00
143094A	Bulimba Ceek at Mansfield	57	1180	482	1972	1995	24	0.00	0.00	0.00	0.23	0.09	0.01	0.05	0.58	0.04
143101A	Warrill Creek at Mutdapily	771	858	110	1915	1953	39	0.08	0.00	0.00	0.29	0.50	0.00	0.12	0.00	0.00
143102B	Warrill Creek at Kalbar No.2	468	957	124	1959	1970	12	0.13	0.00	0.00	0.40	0.39	0.00	0.07	0.00	0.00
143107A	Bremer River at Walloon	620	891	115	1962	1999	38	0.01	0.00	0.00	0.33	0.55	0.00	0.10	0.01	0.00
143110A	Bremer River at Adams Bridge	125	967	160	1970	1999	30	0.06	0.00	0.00	0.34	0.46	0.00	0.14	0.00	0.00
143113A	Purga Creek at Loamside	215	907	84	1974	1999	26	0.00	0.00	0.00	0.36	0.59	0.00	0.04	0.00	0.00
143114A	Bundamba Creek at Mary Street	110	968	158	1973	1982	10	0.01	0.00	0.00	0.49	0.37	0.01	0.00	0.11	0.00
143203C	Lockyer Creek at Helidon Number 3	357	895	84	1988	1999	12	0.00	0.08	0.00	0.71	0.17	0.00	0.01	0.02	0.00
143208A	Fifteen Mile Creek at Dam Site	87	971	63	1957	1988	32	0.00	0.13	0.00	0.76	0.11	0.01	0.00	0.00	0.00
143209B	Laidley Creek at Mulgowie2	167	978	176	1968	1999	32	0.08	0.00	0.00	0.67	0.16	0.00	0.09	0.00	0.00
143211A	Buaraba Creek at 15.8km	251	997	123	1968	1978	11	0.02	0.02	0.00	0.69	0.24	0.00	0.03	0.00	0.00
143212A	Tenthill Creek at Tenthill	447	909	44	1969	1999	31	0.10	0.02	0.00	0.61	0.20	0.00	0.06	0.00	0.00
143214A	Flagstone Creek at Windolfs	142	862	49	1973	1985	13	0.01	0.00	0.00	0.77	0.18	0.00	0.04	0.00	0.00
143219A	Murphys Creek at Spring Bluff	18	876	107	1980	1999	20	0.00	0.00	0.00	0.70	0.23	0.02	0.00	0.05	0.00
143225A	Laidley Creek at Showgrounds Weir Head Water	233	897	101	1985	1999	15	0.06	0.00	0.00	0.59	0.22	0.00	0.13	0.00	0.00
143229A	Laidley Creek at Warrego Highway	449	786	55	1991	1999	9	0.03	0.01	0.00	0.44	0.35	0.00	0.16	0.01	0.00
143303A	Stanley River at Peachester	104	1707	580	1980	1999	20	0.00	0.07	0.09	0.59	0.24	0.00	0.01	0.00	0.00
143306A	Reedy Creek at Upstream Byron Creek Junction	56	1316	115	1976	1999	24	0.00	0.32	0.00	0.52	0.16	0.00	0.00	0.00	0.00
143307A	Byron Creek at Causeway	79	1440	249	1976	1998	23	0.01	0.55	0.00	0.38	0.06	0.00	0.00	0.00	0.00
143932A	Enogerra Creek at Bancroft Park	70	1267	421	1972	1980	9	0.00	0.43	0.00	0.29	0.05	0.00	0.00	0.21	0.01
145003B	Logan River at Forest Home	175	1171	320	1954	1999	46	0.54	0.02	0.00	0.22	0.22	0.00	0.00	0.00	0.00
145007A	Christmas Creek at Hillview	132	1544	361	1955	1974	20	0.12	0.00	0.00	0.43	0.38	0.01	0.02	0.05	0.00
145010A	Running Ckreek at 5.8km Deickmans Bridge	128	1310	356	1966	1999	34	0.37	0.00	0.00	0.37	0.24	0.00	0.02	0.00	0.00
145011A	Teviot Brook at Croftby	83	1090	203	1967	1999	33	0.17	0.06	0.00	0.40	0.36	0.00	0.01	0.00	0.00
145012A	Teviot Brook at the Overflow	503	939	122	1967	1999	33	0.03	0.01	0.00	0.35	0.56	0.00	0.04	0.01	0.00
145013A	Christmas Creek at Rudd's Lane	157	1416	262	1968	1987	20	0.10	0.00	0.00	0.44	0.39	0.00	0.02	0.04	0.00
145018A	Burnett Creek at Up Stream Maroon Dam	82	1425	217	1971	1999	29	0.15	0.35	0.00	0.31	0.19	0.00	0.00	0.00	0.00
145101D	Albert River at Lumeah Number 2	169	1368	301	1954	1999	46	0.26	0.00	0.00	0.39	0.31	0.00	0.04	0.00	0.00
145102B	Albert River at Bromfleet	544	1314	265	1970	1999	30	0.18	0.00	0.00	0.42	0.34	0.00	0.06	0.00	0.00
145103A	Cainbable Creek at Good Dam Site	42	1590	242	1963	1991	29	0.17	0.00	0.00	0.63	0.18	0.00	0.03	0.00	0.00
145107A	Canungra Creek at Main Road Bridge	101	1587	386	1973	1999	27	0.45	0.00	0.00	0.39	0.14	0.00	0.00	0.01	0.00
146009A	Little Nerang Creek at 4.0km	53	2294	861	1963	1973	11	0.27	0.07	0.00	0.55	0.10	0.00	0.00	0.00	0.00
146010A	Coomera River at Army Camp	88	1584	451	1963	1999	37	0.26	0.00	0.00	0.39	0.34	0.00	0.01	0.00	0.00
146011A	Nerang River Whipbird	122	1787	638	1966	1985	20	0.19	0.16	0.00	0.51	0.14	0.00	0.01	0.00	0.00
146012A	Currumbin Creek at Nicolls Bridge	30	2334	867	1971	1999	29	0.10	0.00	0.00	0.74	0.16	0.00	0.00	0.00	0.00
146020A	Mudgeeraba Creek at Springbrook Road	36	1845	480	1990	1999	10	0.10	0.09	0.00	0.62	0.17	0.00	0.00	0.02	0.00
146095A	Tallebudgera Creek at Tallebudgera Creek Road	56	2343	856	1971	1999	29	0.08	0.00	0.00	0.80	0.11	0.00	0.00	0.00	0.00

Notes:
1 National park
2 Managed forest
3 Plantation
4 Natural bush
5 Grazing
6 Intensive agriculture
7 Broadacre agriculture
8 Dense urban
9 Suburban

Figure 3.4 Locations of NRM streamflow stations used for model calibration

4. Determination of Hydrologic Model Parameters

4.1 Calibration of individual catchments

The hydrologic model is first calibrated against streamflow data from each of the 58 catchments separately to investigate whether the model can be calibrated and verified successfully.

For the modelling, dense urban land-use is considered to consist of 40% effective impervious area and suburban land-use is considered to consist 25% effective impervious area (i.e., percentage effective impervious = 40% x proportion of dense urban + 25% x proportion of suburban). As discussed in Section 3, the daily runoff from the effective impervious area is estimated as daily rainfall less a threshold of 1 mm.

4.1.1 Model calibration and cross-verification

A model calibration and a cross-verification exercise are carried out to optimise the seven parameters in the hydrologic model for pervious area. The model calibration is carried out to assess whether the hydrologic model can be calibrated successfully. In the model calibration, the model is calibrated against all the available historical streamflow data.

The k-fold cross-verification method described by Efron and Tibshirani (1993) is used to assess whether the optimised parameter values can successfully estimate streamflow for an independent test period that is not used in the model calibration. This is done by dividing the available streamflow data into three almost equal parts (k=3). Each part is left out in turn, and the model is calibrated against streamflow data in the remaining two parts. The optimised parameter values are then used to estimate runoff for the part that was left out, and the estimated flows are compared with the recorded flows.

In both the calibration and cross-verification exercises, the model is run for one extra year prior to when the streamflow time series starts to remove the effect of initial conditions from the model storage levels. The model runs on a daily time step, but is calibrated against the monthly streamflows.

The seven model parameters are optimised to minimise an objective function defined as the sum of squares of the difference between the estimated and recorded monthly streamflows, with penalties applied if the total estimated and recorded runoff volumes differ significantly (see **Table 4.1**). The penalty attempts to ensure that the total estimated and recorded runoff volumes do not differ significantly, although a good model calibration against the objective function in **Table 4.1** generally leads to similar estimated and recorded total runoff volumes. An automatic pattern search optimisation method (Hookes and Jeeves, 1961; and Monro, 1971) is used to calibrate the model, with ten parameter starting points used to increase the likelihood of finding the global optimum of parameter values.

Table 4.1 Objective function used in model calibration

$$OBJ = \sum_{i=1}^{n} (EST_i - REC_i)^2$$

where EST is the monthly estimated runoff, REC is the monthly recorded runoff and n is the number of months of available historical streamflow data.

Penalties

If the total estimated and recorded runoff volumes differ by

More than 5%, OBJ = OBJ x 5
More than 10%, OBJ = OBJ x 25
More than 20%, OBJ = OBJ x 125

4.1.2 Modelling results

The optimised model parameter values and the objective measures that relate to the objective function defined in **Table 4.1** are given in **Table 4.2** and shown in **Figures 4.1** (model calibration) and **4.2** (cross-verification) respectively.

The coefficient of efficiency, E, in **Table 4.2** is defined as

$$E = \frac{\sum_{i=1}^{n}\left(REC_i - \overline{REC}\right)^2 - \sum_{i=1}^{n}\left(EST_i - REC_i\right)^2}{\sum_{i=1}^{n}\left(REC_i - \overline{REC}\right)^2} \qquad \text{Equation 4.1}$$

where $\overline{REC}$ is the mean recorded runoff.

The coefficient of efficiency expresses the proportion of variance of the recorded runoff that can be accounted for by the model (Nash and Sutcliffe, 1970) and provides a direct measure of the ability of the model to reproduce the recorded flows with E = 1.0 indicating that all the estimated flows are the same as the recorded flows. It relates directly to the objective function defined in **Table 4.1** with a lower objective function value giving a higher E and vice versa. However, unlike the objective function whose value depend on the magnitude of runoff, the coefficient of efficiency is dimensionless and can therefore be used to compare model performances across catchments.

The volume ratio VOL in **Table 4.2** compares the total estimated and recorded streamflow volumes,

$$\mathrm{VOL} = \frac{\sum_{i=1}^{n} EST_i}{\sum_{i=1}^{n} REC_i} \qquad \text{Equation 4.2}$$

Both the calibration and cross-verification exercises assess the model performance against all available streamflow data, and can therefore be compared directly. In evaluating the cross-verification results, the streamflow estimates for each of the three data parts that are not used in the model calibration are combined into a single composite series and compared with the recorded flows.

As expected, **Table 4.2** and **Figures 4.1** and **4.2** show that the E values are higher in the model calibration compared to the cross-verification. The total streamflow volume estimated by the model is also closer to the total recorded streamflow volume (up to within five percent) in the model calibration compared to the cross-verification because of the penalty/constraint used in the objective function (see **Table 4.1**).

Despite the penalty/constraint used in the objective function, the total streamflow volume estimated by the model is more than five percent different from the recorded streamflow volume in three of the 58 catchments. The poor calibration of Catchment 143022A which is almost entirely dense urban and suburban may be attributed to uncertainties in estimating the effective impervious area and the catchment drainage area. There are no clear reasons for the poor calibrations in Catchments 143306A and 145103A apart from potential errors in the rainfall and/or runoff data. These three catchments are excluded from further modelling analyses.

The E values from the model calibration are high in the remaining 55 catchments (greater than 0.6 in all 55 catchments and greater than 0.8 in 51 of the 55 catchments) indicating that the hydrologic model can be calibrated successfully.

It is more important to assess the cross-verification results because they reflect the ability of a calibrated model to estimate streamflow for an independent test period. The cross-verification results in **Table 4.2** and **Figure 4.2** indicate that the total estimated streamflow volume is within ten percent of the total recorded streamflow volume in all the 55 catchments (and within five percent in 40 catchments).

Table 4.2 and **Figure 4.2** also indicate that the E values in the model cross-verification are generally high and not much lower than the E values from the model calibration. The E value is greater than 0.6 in all but two of the 55 catchments, and greater than 0.8 in 39 of the 55 catchments. The scatter plots and hydrographs in **Figures 4.3** and **4.4** respectively compare the estimated and recorded monthly streamflows for several typical E values.

The results therefore indicate that once calibrated, the hydrologic model can usually estimate monthly streamflow satisfactorily (for example, the survey results of Chiew and McMahon (1993) concludes that in general, runoff estimates can be considered "good" where E is greater than 0.8 and "acceptable for most applications" where E in greater than 0.6).

4.1.3 Simulation of daily flows

The hydrologic model runs on a daily time step, but is calibrated against monthly streamflow. The above results therefore indicate that the model can estimate monthly streamflow satisfactorily.

Nevertheless, although it is calibrated against monthly streamflow, comparisons of the daily flow estimates with the recorded daily flows show that the daily flow characteristics estimated by the model are generally similar to the recorded daily flows (see typical example comparisons in **Figure 4.5**). The model estimates the high flows much better than the very low flows (less than

1 mm) because it is calibrated to reproduce monthly flow volumes and because the objective function used here favour the choice of parameters for good agreement between the larger estimated and recorded monthly flows.

4.1.4 Model parameters

In the model calibration with the automatic pattern search optimisation routine, ten different parameter starting points are used to increase the likelihood of finding the global optimum. In most calibration runs, almost all the ten starting points lead to similar objective function values. In many cases, the final sets of optimised parameter values obtained from the ten starting points are similar. However, there are also many runs where the different starting points lead to very different sets of optimised parameter values with similar objective function values. It is not possible to define the one unique set of "best" optimised parameter values because of likely errors in the input and output data and because the hydrologic model is only a conceptual simplification of the actual processes. As a result of this, it is not possible to regionalise the model parameter values as functions of catchment physical and climatic characteristics.

The sets of parameter values presented in **Table 4.2** are optimised values that give the lowest objective function value. Although they lead to the "best" agreement between the simulated and recorded streamflows, they do not necessarily give good estimates of the internal model variables like soil moisture or runoff components. An accurate partitioning of total streamflow into surface component and subsurface component is important here because the pollutant load associated with the surface component is significantly higher than the load associated with the subsurface component. This is addressed further in Section 4.2.

Table 4.2 Results from calibration of individual catchments

Station	Calibration		Verification		Fraction	Parameters (see Figure 3.1)						
	E[1]	VOL[2]	E	VOL	impervous	INSC	COEFF	SQ	SMSC	SUB	CRAK	K
140002A	0.85	0.95	0.80	0.98	0.00	0.5	400	0.0	500	0.83	1.00	0.006
141001B	0.97	1.00	0.95	1.01	0.00	5.0	400	0.0	103	0.78	0.00	0.064
141003C	0.94	0.99	0.92	1.00	0.03	4.7	400	6.4	305	0.63	1.00	0.056
141006A	0.96	1.03	0.94	1.04	0.01	5.0	400	7.0	493	0.00	1.00	0.155
141008A	0.95	1.03	0.92	1.03	0.01	5.0	400	4.4	298	0.00	0.78	0.138
141009A	0.90	0.99	0.88	1.00	0.01	3.4	190	6.3	500	0.00	1.00	0.066
142001A	0.94	1.05	0.93	1.05	0.00	2.2	120	1.0	263	0.75	0.00	0.003
142101A	0.93	1.03	0.93	1.04	0.01	4.2	400	4.8	395	0.00	0.80	0.215
142202A	0.95	1.03	0.94	1.03	0.00	5.0	400	8.5	500	0.36	0.44	0.096
142901A	0.94	1.01	0.93	1.01	0.07	0.5	400	10.0	500	0.82	0.60	0.021
142902A	0.96	1.03	0.93	1.04	0.13	0.5	380	1.3	83	0.55	0.00	0.035
143006A	0.84	1.05	0.78	1.05	0.00	4.6	235	2.5	371	0.24	0.30	0.163
143010B	0.85	1.05	0.65	1.10	0.00	5.0	83	2.4	500	0.34	0.00	0.300
143011A	0.90	1.05	0.79	0.98	0.00	0.5	400	6.3	500	0.18	0.00	0.033
143013A	0.91	1.05	0.60	1.06	0.00	5.0	335	1.4	303	0.30	0.00	0.040
143015B	0.94	1.05	0.75	1.08	0.00	4.6	400	6.0	415	0.01	0.23	0.128
143018A	0.90	1.05	0.80	0.99	0.00	4.2	400	10.0	370	0.10	0.60	0.040
143020A	0.97	1.01	0.93	1.02	0.01	0.5	400	10.0	500	0.00	0.60	0.190
143022A	-0.50	0.70	-0.52	0.70	0.27	0.5	400	0.0	20	0.00	1.00	0.003
143032A	0.94	0.98	0.91	1.00	0.00	5.0	209	10.0	303	0.00	0.04	0.012
143033A	0.60	1.05	-0.12	1.10	0.01	2.4	110	0.9	445	0.20	0.00	0.003
143094A	0.96	0.95	0.94	0.98	0.16	5.0	65	1.5	235	0.00	1.00	0.158
143101A	0.85	1.05	0.81	1.03	0.00	4.8	400	0.6	242	0.43	0.60	0.240
143102B	0.89	0.96	0.79	1.01	0.00	4.1	308	1.7	180	0.00	0.61	0.238
143107A	0.93	1.05	0.91	1.09	0.00	5.0	270	7.7	270	0.43	0.13	0.018
143110A	0.93	1.05	0.90	1.04	0.00	5.0	93	0.6	216	0.76	0.15	0.183
143113A	0.85	1.05	0.60	1.03	0.00	4.8	360	0.9	305	0.45	0.00	0.003
143114A	0.86	0.99	0.81	1.01	0.03	0.5	400	8.2	500	0.15	0.31	0.018
143203C	0.95	1.01	0.87	1.02	0.01	5.0	400	3.5	234	0.08	0.08	0.300
143208A	0.84	1.05	0.82	1.02	0.00	4.6	400	0.0	223	0.26	0.00	0.300
143209B	0.94	1.03	0.90	1.04	0.00	0.5	400	7.6	500	0.00	0.36	0.053
143211A	0.91	1.05	0.74	0.99	0.00	2.1	400	6.8	479	0.25	0.23	0.009
143212A	0.68	1.05	0.26	1.09	0.00	0.5	359	4.2	490	0.03	0.10	0.053
143214A	0.81	1.05	0.76	1.10	0.00	5.0	263	2.5	155	0.13	0.03	0.003
143219A	0.85	1.02	0.73	1.00	0.01	5.0	400	2.5	238	0.21	0.34	0.003
143225A	0.96	0.98	0.92	1.05	0.00	2.3	400	5.3	313	0.05	0.13	0.006
143229A	0.99	1.04	0.98	0.99	0.00	4.2	158	2.4	250	0.01	0.20	0.110
143303A	0.95	1.02	0.93	0.99	0.00	5.0	375	0.8	231	1.00	0.40	0.014
143306A	0.83	1.20	0.81	1.40	0.00	3.6	259	1.9	476	0.01	0.00	0.003
143307A	0.96	1.05	0.96	1.08	0.00	5.0	400	3.8	395	0.19	0.00	0.300
143932A	0.97	1.01	0.94	0.98	0.06	0.5	400	8.2	500	0.10	0.20	0.098
145003B	0.87	1.02	0.86	1.02	0.00	3.6	400	10.0	500	0.43	1.00	0.061
145007A	0.75	1.05	0.62	1.07	0.00	5.0	135	0.0	433	0.00	0.48	0.143
145010A	0.87	0.97	0.82	1.01	0.00	5.0	400	0.5	429	0.23	1.00	0.171
145011A	0.82	0.95	0.78	1.00	0.00	2.7	355	1.3	150	0.00	0.53	0.243
145012A	0.96	1.05	0.95	1.04	0.00	4.8	400	7.5	390	0.00	0.65	0.180
145013A	0.80	1.05	0.60	1.03	0.00	3.4	253	0.0	500	0.40	0.00	0.003
145018A	0.69	1.05	0.63	1.09	0.00	4.1	340	2.2	420	0.20	0.00	0.003
145101D	0.90	1.05	0.87	1.06	0.00	5.0	140	0.0	488	0.16	0.80	0.159
145102B	0.91	1.05	0.82	1.09	0.00	5.0	175	0.0	310	0.60	0.00	0.004
145103A	0.53	1.20	0.35	1.23	0.00	5.0	265	1.4	438	0.00	0.05	0.003
145107A	0.88	1.05	0.78	1.06	0.00	2.1	85	0.1	365	0.25	0.00	0.003
146009A	0.95	0.96	0.91	0.97	0.00	0.5	92	0.9	238	0.18	0.00	0.133
146010A	0.97	1.04	0.96	1.03	0.00	2.3	358	4.2	500	0.07	0.47	0.115
146011A	0.97	1.05	0.96	1.06	0.00	4.5	110	1.4	420	0.00	0.80	0.144
146012A	0.96	1.03	0.95	1.03	0.00	2.3	400	0.0	262	0.78	0.03	0.009
146020A	0.97	1.05	0.96	1.06	0.01	2.1	391	1.9	308	0.20	0.20	0.269
146095A	0.94	1.05	0.93	1.05	0.00	1.6	196	1.4	210	0.60	0.00	0.003

Notes:
1 Coefficient of efficiency, E (see Equation 4.1)
2 Volume ratio, VOL, compares the total estimated and recorded streamflow volumes (see Equation 4.2)

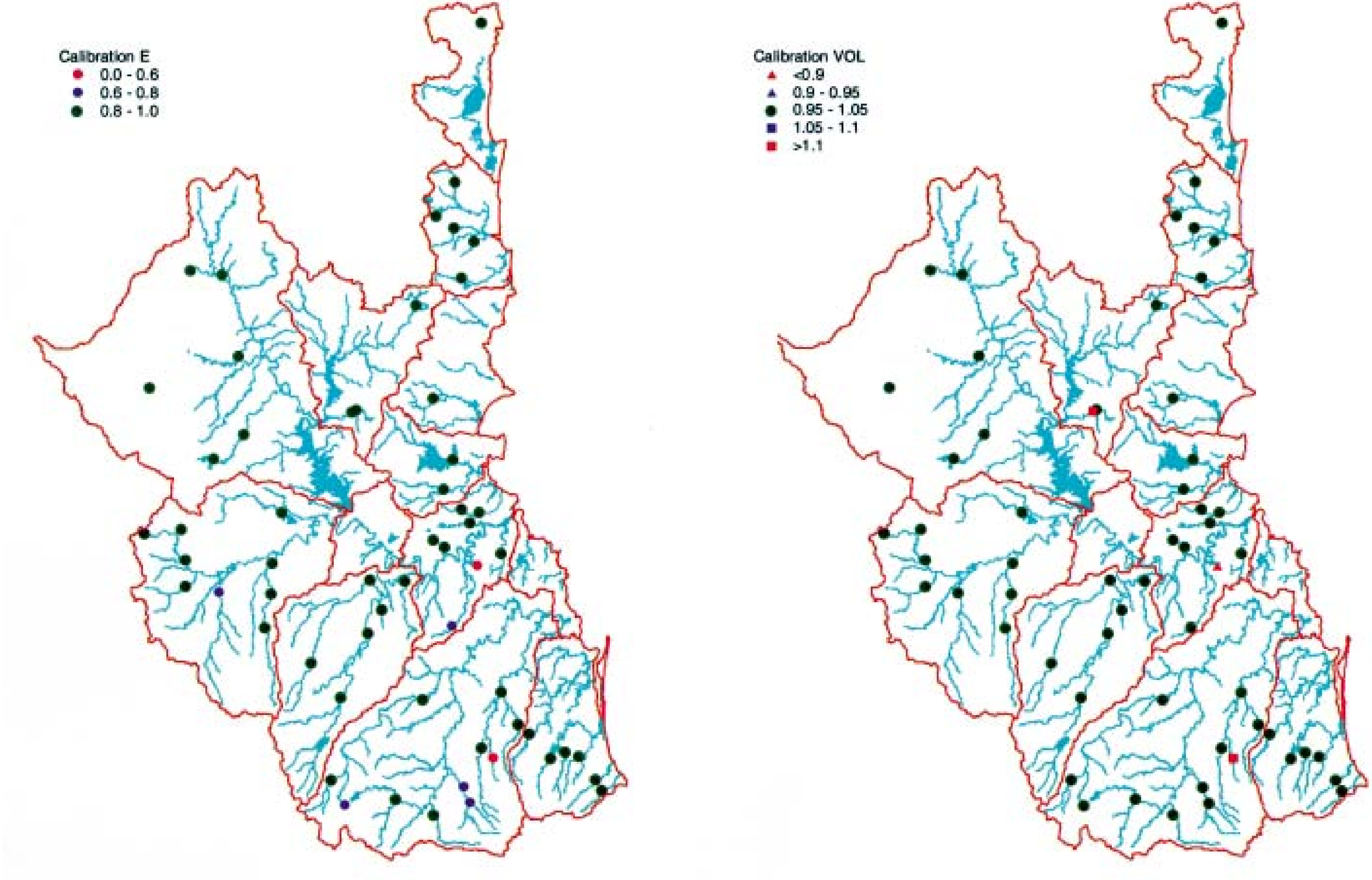


Figure 4.1 Calibration coefficient of efficiency, E, and volume ratio, VOL

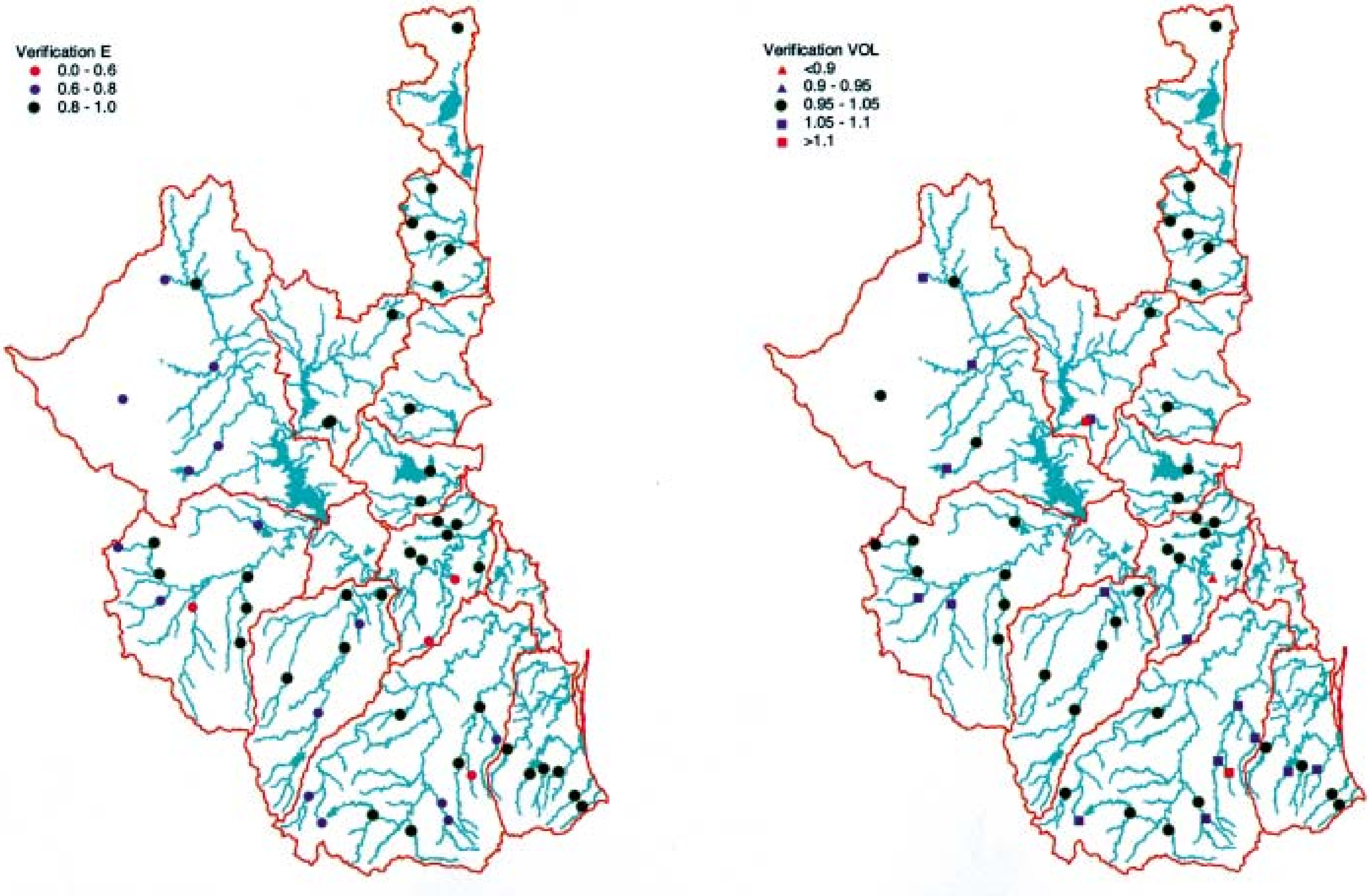


Figure 4.2 Cross-verification coefficient of efficiency, E, and volume ratio, VOL

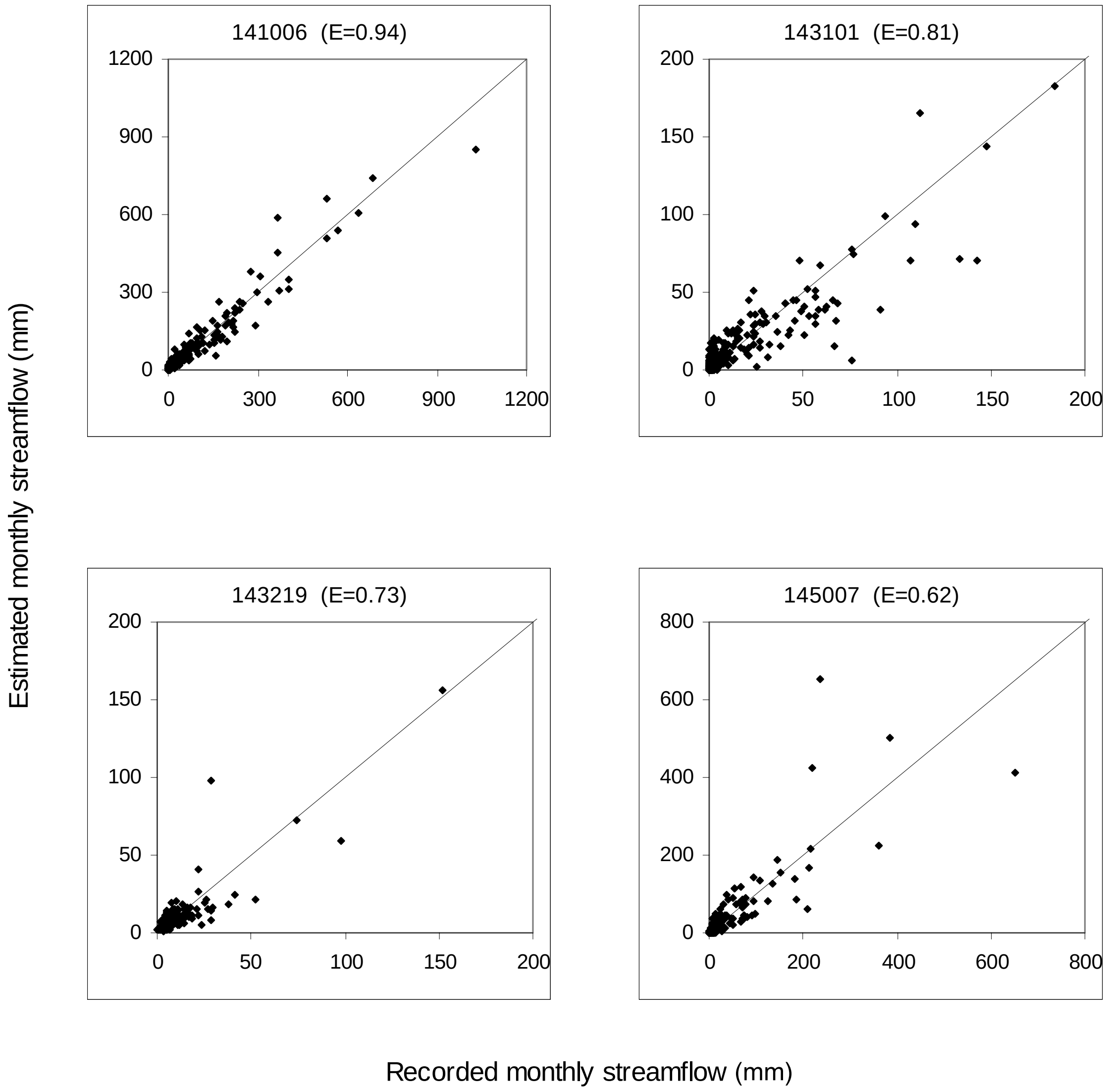


Figure 4.3 Typical cross-verification scatter plots

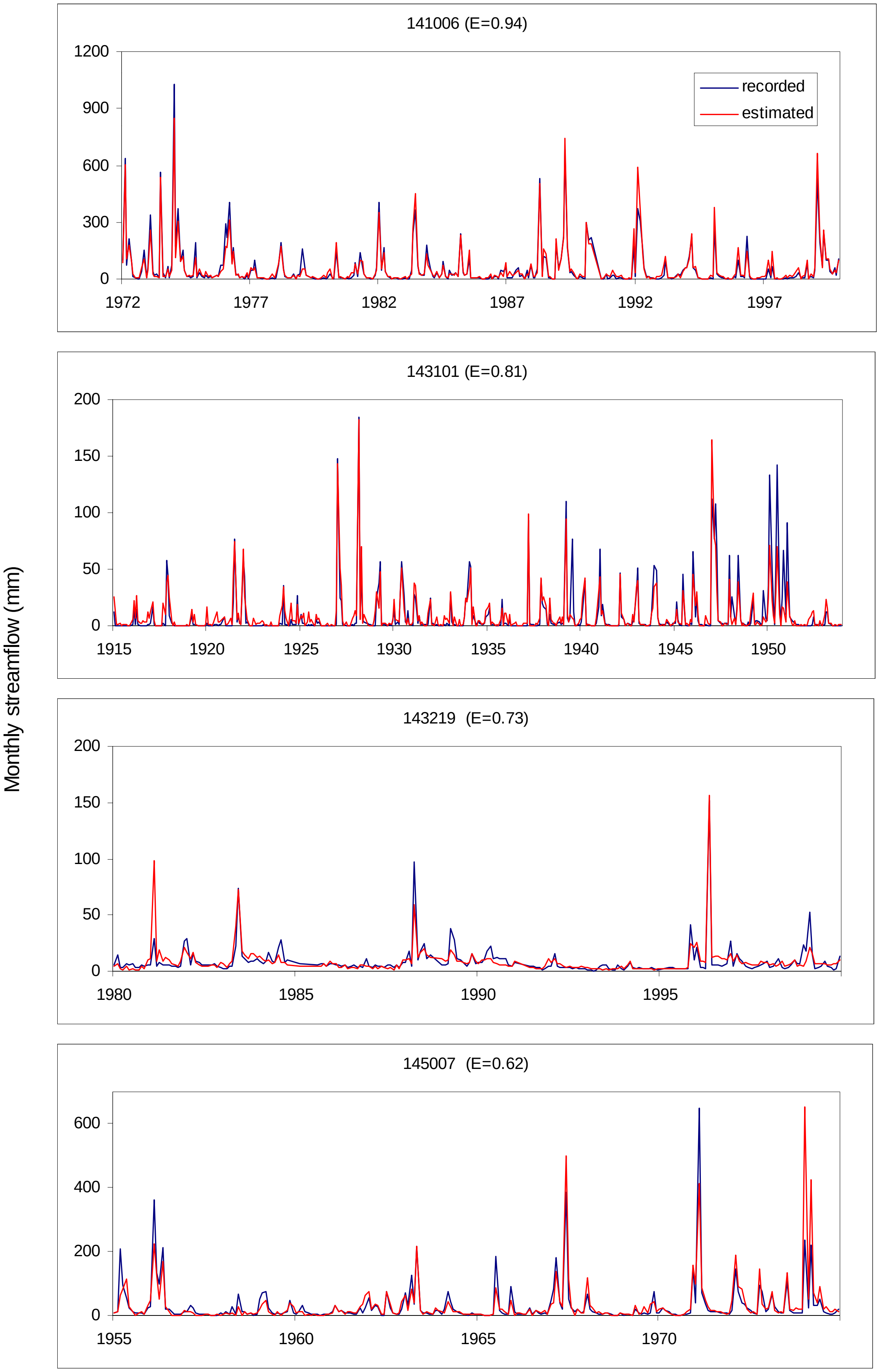


Figure 4.4 Typical cross verification hydrographs

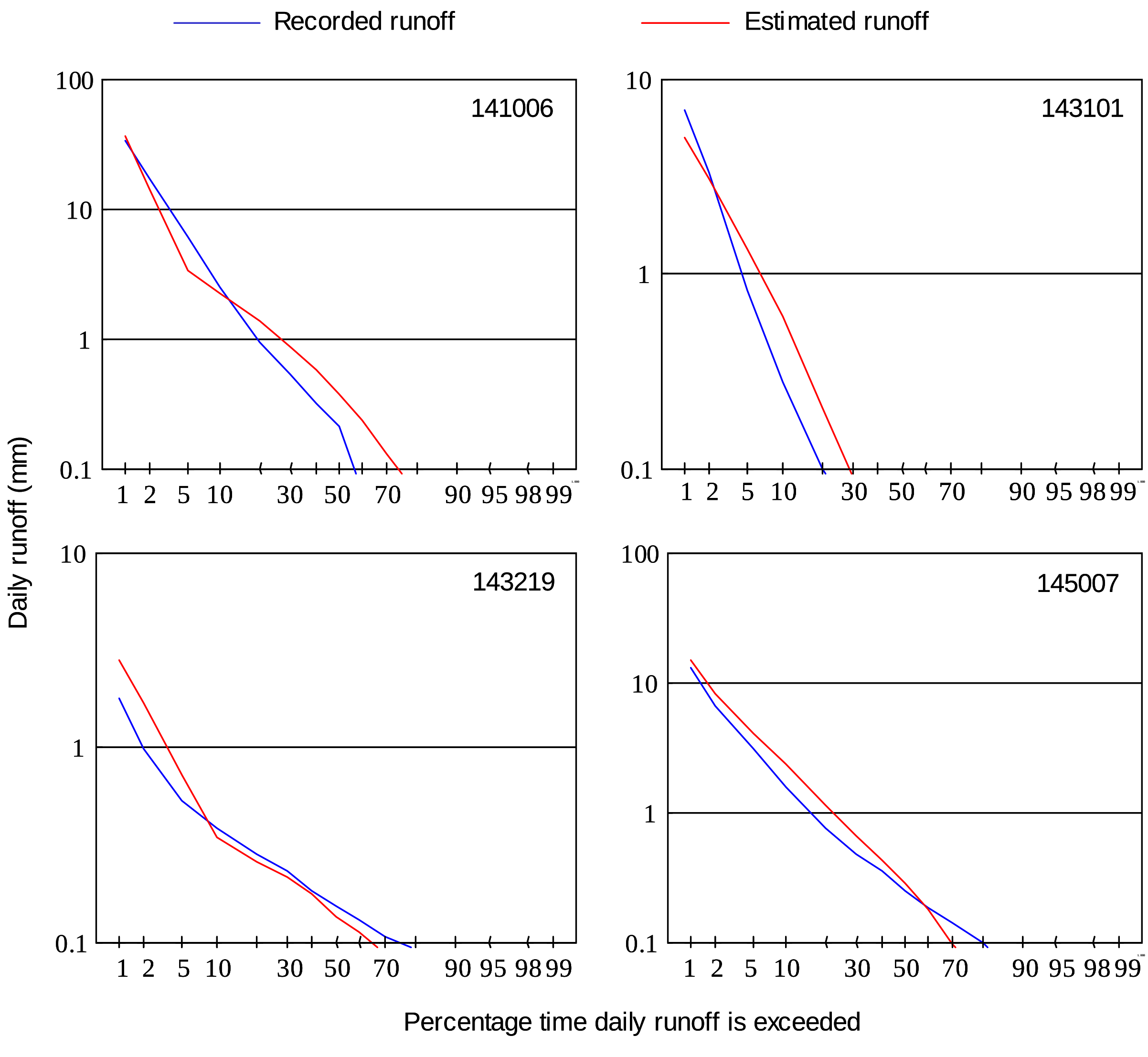


Figure 4.5 Typical comparison of simulated and recorded daily runoff

4.2 Calibration to determine parameter values for catchments in the EMSS

4.2.1 Hydrologic regions for EMSS modelling

Historical streamflow data for model calibration are available only at 58 locations. Only fifteen of these catchments share the same boundaries as the 175 catchments adopted in the EMSS. The modelling exercise in Section 4.1 indicates that while the hydrologic model can be calibrated successfully, it is not possible to regionalise the optimised parameter values as functions of catchment physical and climatic characteristics.

To estimate model parameter values for use in all the EMSS catchments, south-east Queensland is divided into nine hydrologic regions. Model calibration is then carried out separately for each region to determine one set of parameter values for each region. For each region, the historical streamflow data from all the gauged catchments in the region are used in the model calibration, with the parameter values selected to provide reasonable agreement between the estimated streamflow and the recorded streamflow in all the catchments.

The hydrologic regions are determined arbitrarily based mainly on the geographical location and the rainfall and runoff characteristics of the NRM gauged catchments. The final boundaries for the hydrologic regions are also influenced by the results of the modelling analyses discussed below. The hydrologic regions are shown in **Figure 4.7** and discussed in detail in Section 4.2.4.

4.2.2 Modelling in the hydrologic regions

For the analyses here, there are effectively three models for each catchment.

Effective impervious area model

The proportion of catchment with effective impervious area is estimated as 0.4 x proportion of dense urban land-use + 0.25 x proportion of suburban land-use. Daily runoff from the effective impervious area is estimated as the daily rainfall less a threshold of 1 mm.

Forest land-use model

The natural bush, national park, managed forest and plantation land-use categories in the EMSS are considered as "forest" land-use because they are hydrologically similar. The proportion of catchment with "forest" land-use is simply the sum of the proportions of catchment with the above four land-use categories. The "forest" land-use is modelled using the daily conceptual hydrologic model for pervious area presented in Section 3 (see **Figure 3.1**).

Other pervious land-use model

The grazing, intensive agriculture and broadacre agriculture land-use categories and the pervious fraction (1 - fraction effective impervious) of the dense urban and suburban land-use categories are considered as "other pervious" land-use because they are reasonably similar hydrologically and because there are insufficient data to differentiate between them in the model calibration. Like the "forest" land-use, the "other pervious" land-use is also modelled using the daily conceptual hydrologic model for pervious area presented in Section 3, but with a different set of parameter values.

The streamflow data available for model calibration is barely sufficient to differentiate between the two types of pervious land-uses (because there are data from only 58 catchments and all the catchments have mixed land-uses). However, an attempt is made here to differentiate between them because it is generally accepted that there is less runoff from forested catchments than cleared catchments (see Holmes and Sinclair (1986) and Zhang et al. (1999)) and the proportion of surface runoff to total runoff (referred to as "surface flow ratio" here) is lower for forested catchments compared to cleared catchments. Nevertheless, these differences are not obvious in the limited streamflow data from the gauged catchments (see **Figure 4.7**), with the data not showing a clear influence of the forested land-use on the runoff coefficient or the surface flow ratio (estimated using the Lyne and Hollick filter baseflow separation algorithm (see Nathan and McMahon, 1990).

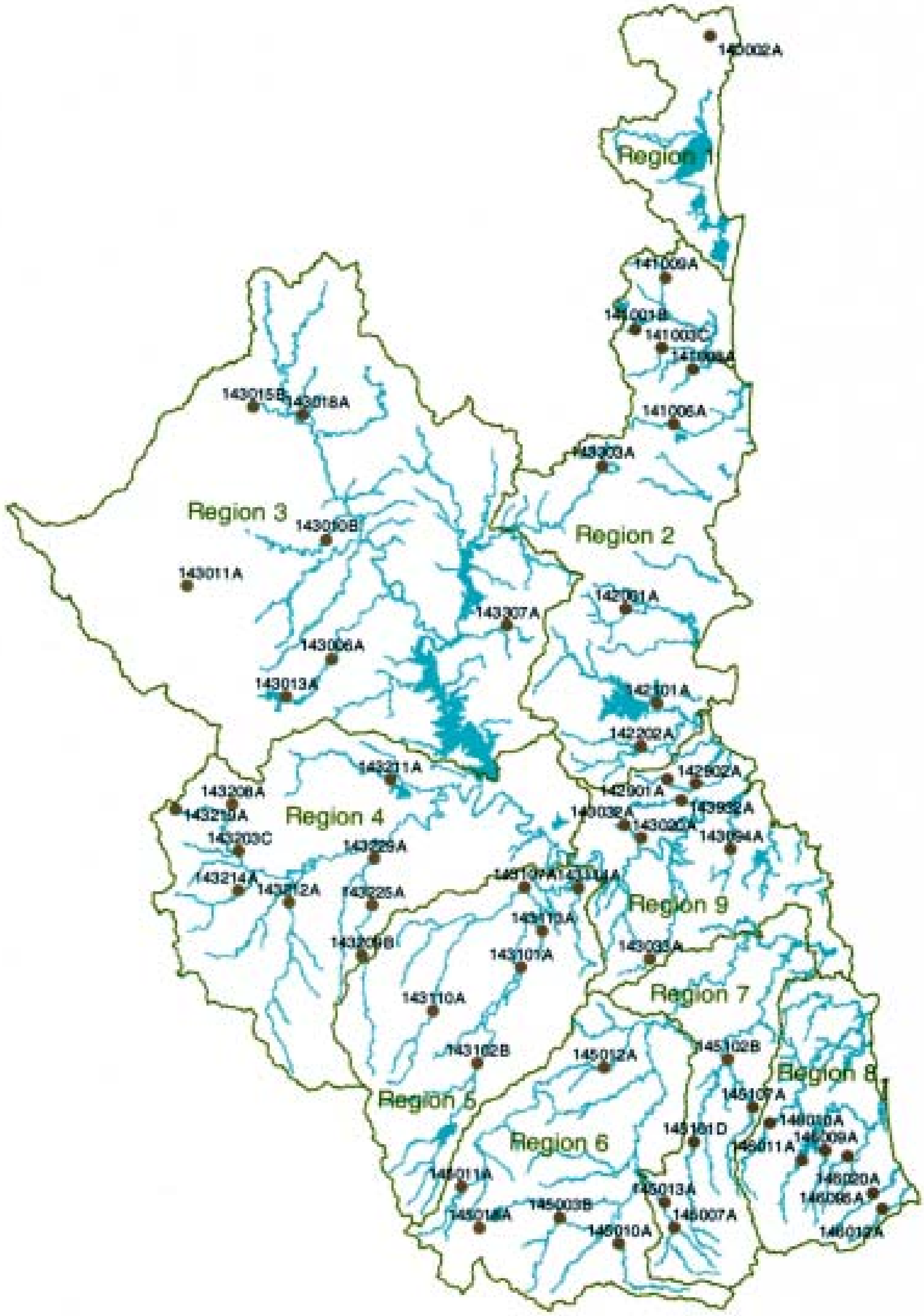


Figure 4.6 Regions for EMSS hydrologic model calibration

4.2.3 Optimisation of model parameters for the hydrologic regions

There are 14 parameters to optimise in the model calibration - seven for the "forest" land use model and seven for the "other pervious" land use model. To prevent problems of parameter cross-correlation resulting from the use of many model parameters, the infiltration capacity parameters, COEFF and SQ (see **Figure 3.1**), are set to 200 and 1.5 respectively (see Chiew and McMahon, 1994) for both land use types. This reduces the number of parameters to be determined for each region to ten (five each for the two land use types). Further analyses indicated that the use of 14 parameters did not give better results compared to the use of 10 parameters.

For each region, all the catchments with streamflow data are optimised collectively. The parameters are optimised to obtain the highest average coefficient of efficiency E (i.e., best "average" agreement between the estimated and recorded monthly streamflows in all the catchments), with penalties/constraints used so that the total estimated streamflow volumes do not differ significantly from the recorded streamflow volumes.

The pattern search optimisation routine is used with more than 10 parameter starting values to guide the determination of parameter values. The internal modelling results obtained from model runs for each catchment in the region using the different sets of optimum parameter values giving similar "best" results in the E values and volume ratios VOL (see Section 4.1.2) are then assessed to identify an appropriate set of parameters for the region. The appropriateness of the set of parameters is assessed in the following order.

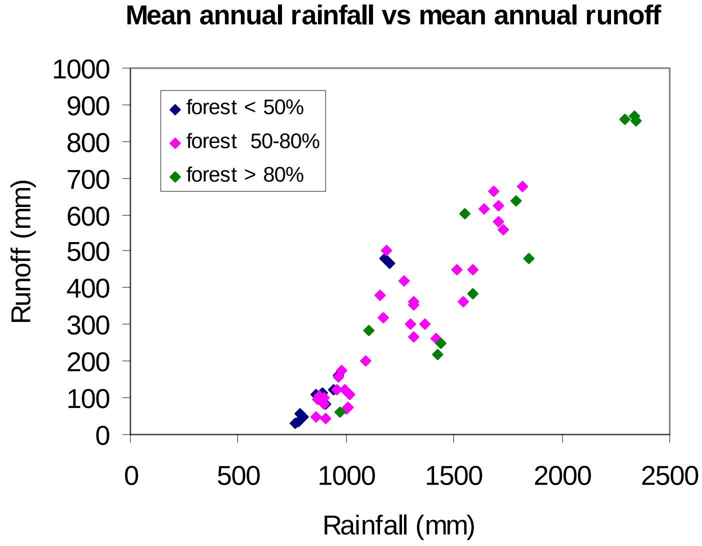
1 High E values in all the catchments, indicating good agreement between the estimated and recorded monthly streamflows.
2 Volume ratios VOL in all the catchments being close to 1.0, indicating that the total estimated streamflow volume is similar to the total recorded streamflow volume.
3 Proportion of surface runoff to total runoff (referred to as "surface flow ratio") estimated by the model being similar to the surface flow ratio in the recorded streamflow data - this is important in the pollutant load export modelling because the pollutant load associated with the surface runoff component is significantly higher than the load associated with the subsurface component.
4 Model parameters and runoff component simulations that realistically reflect the generally accepted differences between forested and cleared catchments - similar or higher value of interception capacity INSC and soil moisture store capacity SMSC in forested catchments, lower total runoff per unit area in forested catchments, and lower surface flow ratio in forested catchments).

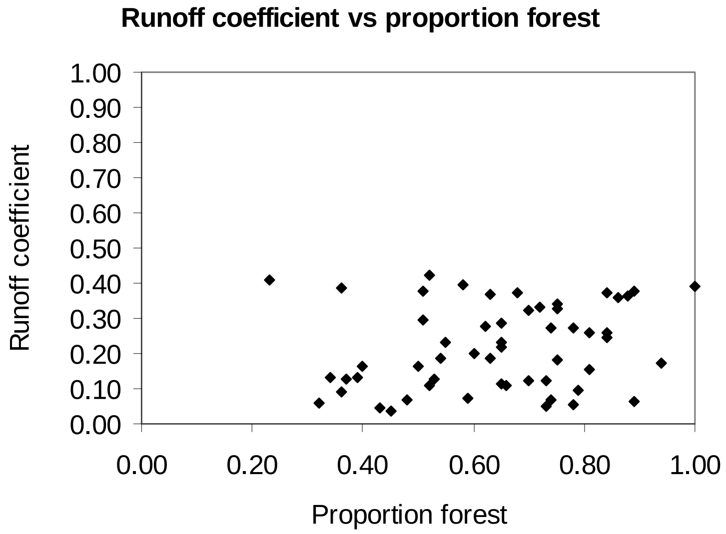
4.2.4 Parameter values for hydrologic regions and modelling results

The nine hydrologic regions are shown in **Figure 4.6** and the parameter values for the regions are given in **Table 4.3**

Table 4.3 Parameter values for pervious land use model for the nine hydrologic regions

Region	**Forest land use**							**Other pervious land use**						
	INSC	*COEFF*	*SQ*	*SMSC*	*SUB*	*CRAK*	*K*	*INSC*	*COEFF*	*SQ*	*SMSC*	*SUB*	*CRAK*	*K*
1	3.0	200	1.5	29	0.25	1.00	0.008	3.0	200	1.5	29	0.25	1.00	0.008
2	5.0	200	1.5	273	0.35	0.70	0.300	2.0	200	1.5	200	0.35	0.70	0.300
3	4.9	200	1.5	379	0.10	0.25	0.300	3.0	200	1.5	150	0.15	0.00	0.133
4	3.2	200	1.5	320	0.10	0.20	0.300	3.1	200	1.5	200	0.20	0.00	0.300
5	5.0	200	1.5	190	0.50	0.43	0.165	5.0	200	1.5	190	0.50	0.43	0.165
6	4.4	200	1.5	165	0.30	0.40	0.127	4.4	200	1.5	165	0.30	0.40	0.127
7	5.0	200	1.5	319	0.07	0.23	0.003	5.0	200	1.5	262	0.13	0.18	0.067
8	3.5	200	1.5	355	0.48	0.65	0.150	3.5	200	1.5	355	0.48	0.65	0.150
9	1.7	200	1.5	94	0.25	0.37	0.300	1.7	200	1.5	94	0.25	0.37	0.300





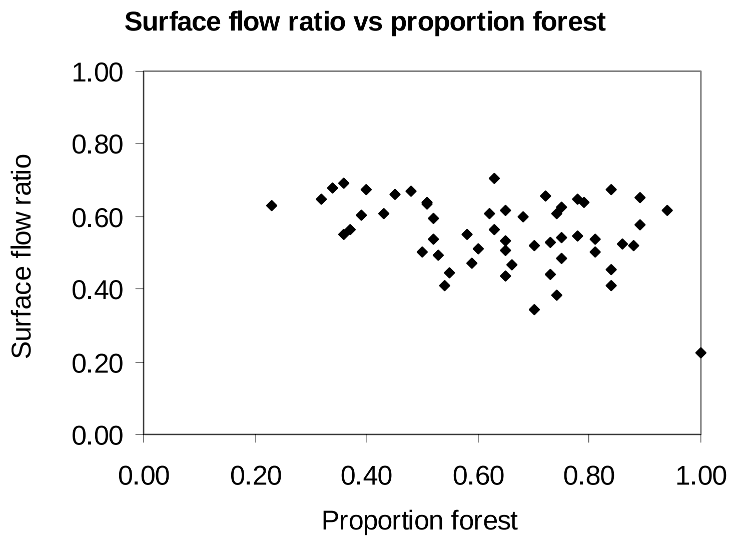


Figure 4.7 Influence of proportion of forest land use on catchment hydrologic characteristics

The modelling results for each of the nine regions are presented separately in **Figures 4.8** to **4.16**. For each region, the E value, volume ratio, surface flow ratio estimated by the model, surface flow ratio in the recorded streamflow data and the modelled runoff components for all the catchments in the region are tabulated. The figures also show scatter plots comparing the estimated and recorded monthly streamflows in all the catchments.

Region 1 (see **Figure 4.8**) covers the Noosa sub-region. The mean annual rainfall in this region is about 1600 mm with a runoff coefficient of about 0.4 (runoff coefficient is defined as the proportion of rainfall that becomes runoff). The hydrologic model parameters for this region are determined by calibrating against streamflow data from only one catchment (Catchment 140002A). As data from only one catchment is used and because the region is predominantly forest, the same parameter values are adopted for "forest" pervious land use and for "other" pervious land use. A differentiation is made between Region 1 and Region 2 because the parameter values determined for Region 2 could not adequately estimate the streamflow at Catchment 140002A. There is also a distinct difference in the soil types in the two regions, with Region 1 having quicker draining soils (evident in the low surface flow ratio in Catchment 140002A).

Region 2 (see **Figure 4.9**) is in the north-east and covers the Maroochy/Mooloolah, Pumicestone, Pine Rivers sub-regions and the eastern part of the Somerset Stanley sub-region. The mean annual rainfall in the region varies from 1300 mm in the south to 1700 mm in the north, and the runoff coefficient varies from 0.25 in the south to 0.4 in the north. The hydrologic model parameters for Region 2 are determined by calibrating against streamflow data from nine catchments. The monthly streamflows in all nine catchments are simulated well, with the E values being greater than 0.8 in all catchments, and the total estimated streamflow volumes being within 15% of the total recorded streamflow volumes in all catchments (and within 10% in seven of the nine catchments). The surface flow ratios in the estimated and recorded streamflows in all the nine catchments are also similar. Different parameter values are used for the forest pervious land use and other pervious land use with the model parameters and runoff components reflecting the generally accepted differences between forested and cleared catchments (see point 4 in Section 4.2.3).

Region 3 (see **Figure 4.10**) is in the north-west and covers the Upper Brisbane sub-region and the western part of the Somerset Stanley sub-region. Except for several catchments east of Lake Wivenhoe, the mean annual rainfall in this region varies from 700 mm in the west to 1000 mm in the east, with runoff coefficients of less than 0.1. The catchments east of Lake Wivenhoe have characteristics that are in between Region 2 and the other catchments in Region 3 (mean annual rainfall of about 1400 mm and runoff coefficient of about 0.15). They are included as part of Region 3 because the parameters adopted for Region 3 can estimate the streamflow satisfactorily for the one gauged catchment there (Catchment 143307A). The hydrologic model parameters for Region 3 are therefore determined by calibrating against streamflow data from seven catchments. The monthly streamflows in all but one catchment (Catchment 143018A) are simulated reasonably well, with the E values being about or greater than 0.8 in the catchments, and the total estimated streamflow volumes being within 20% of the total recorded streamflow volumes. The surface flow ratios in the estimated and recorded streamflows in all the seven catchments are also similar. Different parameter values are used for the forest pervious land use and other pervious land use with the model parameters and runoff components reflecting the generally accepted differences between forested and cleared catchments.

Region 4 (see **Figure 4.11**) covers the Lockyer and mid Brisbane sub-regions in the west. The rainfall and runoff amounts are relatively similar throughout the region with mean annual rainfalls of 800 mm to 1000 mm and runoff coefficients of 0.05 to 0.1. The hydrologic model parameters for Region 4 are therefore determined by calibrating against streamflow data from eight catchments. The monthly streamflows in all but one catchment (Catchment 143211A) are simulated satisfactorily. The E values are greater than 0.6 in all eight catchments (about or greater than 0.8 in four catchments) and the total estimated streamflow volumes are within 20% of the total recorded streamflow volumes in seven of the eight catchments (within 10% in four catchments). The surface flow ratios in the estimated and recorded streamflows in all but one of the eight catchments (Catchment 143219A) are also similar.

Different parameter values are used for the forest pervious land use and other pervious land use with the model parameters and runoff components reflecting the generally accepted differences between forested and cleared catchments.

Region 5 (see **Figure 4.12**) covers the Bremer sub-region in the south-west. The rainfall here is similar to Region 4 (mean annual rainfall of 800 mm to 1000 mm), but a much higher proportion of this rainfall becomes runoff (runoff coefficient of 0.1 to 0.25). The hydrologic model parameters for Region 5 are determined by calibrating against streamflow data from seven catchments. The monthly streamflows in all but one catchment (Catchment 143113A) are well simulated. The runoff coefficient in Catchment 143113A (0.09) is lower than the runoff coefficients in the other catchments in this region (all greater than 0.13) suggesting that the recorded streamflow data for Catchment 143113A may have been slightly underestimated. The E values are greater than 0.6 in all the remaining six catchments (greater than 0.8 in five catchments) and the total estimated streamflow volumes are within 15% of the total recorded streamflow volumes in all the catchments (and within 10% in five catchments). The surface flow ratios in the estimated and recorded streamflows are also similar. The same parameter values are adopted for the forest pervious land use and other pervious land use as the model calibration did not lead to significant differences between the parameters in the two pervious land use types.

Region 6 (see **Figure 4.13**) covers the western part of the Logan-Albert sub-region in the south. The mean annual rainfall in this region ranges from 900 mm to 1400 mm and the runoff coefficient varies from 0.15 to 0.3. The hydrologic model parameters for Region 6 are determined by calibrating against streamflow data from five catchments. The monthly streamflows in all but one catchment (Catchment 145018A) are well simulated. The E values are greater than 0.8 in all the remaining four catchments and the total estimated streamflow volumes are within 25% of the total recorded streamflow volumes in all the catchments (and within 10% in three of the four catchments). The surface flow ratios in the estimated and recorded streamflows are also similar. Like Region 5, the same parameter values are adopted for the forest pervious land use and other pervious land use as the model calibration did not lead to significant differences between the parameters in the two pervious land use types.

Region 7 (see **Figure 4.14**) covers the eastern part of the Logan-Albert sub-region. The rainfall here is higher than the western part of the Logan-Albert (mean annual rainfall of 1300 mm to 1600 mm) with similar runoff coefficient as the western part of the Logan-Albert (0.15 to 0.3). The hydrologic model parameters for Region 7 are determined by calibrating against streamflow data from five catchments. The monthly streamflows in all the five catchments are simulated satisfactorily. The E values are greater than 0.6 in all the catchments (greater than 0.8 in three catchments) and the total estimated streamflow volumes are within 20% of the total recorded streamflow volumes in all the catchments (within 10% in four catchments). The surface flow ratios in the estimated and recorded streamflows in all the five catchments are also similar. Different parameter values are used for the forest pervious land use and other pervious land use with the model parameters and runoff components reflecting the generally accepted differences between forested and cleared catchments.

Region 8 (see **Figure 4.15**) covers the Gold Coast sub-region in the south-east. This region and the north-east have the highest rainfall in south-east Queensland with mean annual rainfall of up to 2000 mm and runoff coefficient of about 0.4. The hydrologic model parameters for Region 8 are determined by calibrating against streamflow data from six catchments. The monthly streamflows in all six catchments are simulated well, with the E values being greater than 0.9 in all catchments, and the total estimated streamflow volumes being within 20% of the total recorded streamflow volumes in all catchments (and within 10% in four of the six catchments). The surface flow ratios in the estimated and recorded streamflows in all the nine catchments are also similar. There are no data to reflect the other pervious land use because this region is predominantly forest, and therefore the same parameter values are adopted for the forest pervious land use and for other pervious land use.

Region 9 (see **Figure 4.16**) covers the lower Brisbane and Redlands sub-regions. The mean annual rainfall here varies from 1000 mm to 1300 mm. Unlike the other regions, half the catchments in Region 9 have significant urban areas. Depending on the amount of effective impervious surfaces in the catchments, runoff coefficients vary from 0.25 to 0.5. The hydrologic model parameters for Region 9 are determined by calibrating against streamflow data from seven catchments. Despite the fraction impervious area in the catchments varying from 0 to 0.2 (daily impervious area runoff is estimated as daily rainfall less a threshold of 1 mm), the parameter values adopted can estimate the monthly streamflows satisfactorily in all but one catchment (Catchment 143033A). The runoff coefficient for Catchment 143033A (0.08) is much lower than the runoff coefficients of gauged catchments close to it (runoff coefficients in Regions 7, 8 and 9 vary from 0.15 to 0.4) suggesting that the recorded streamflow data for Catchment 143033A may have been underestimated. The E values are greater than 0.9 in all the remaining six catchments and the total estimated streamflow volumes are within 20% of the total recorded streamflow volumes in all the catchments (and within 10% in five of the six catchments). The surface flow ratios in the estimated and recorded streamflows are also similar. The same parameter values are adopted for the forest pervious land use and other pervious land use because it is difficult to differentiate between the two pervious land use types given the potential errors in estimating the higher runoff from the impervious surfaces.

Region 1

station	E[1]	VOL[2]	SFR[3] (modelled)	SFR (recorded)	rainfall (mm)	runoff (mm)	impervious component (mm)	forest component (mm)	other pervious component (mm)	impervious runoff (mm)	forest model				other pervious model			
											surface	interflow	baseflow	runoff (mm)	surface	interflow	baseflow	runoff (mm)
140002A	0.81	0.98	0.29	0.22	1550	677	0	677	0	1408	0.12	0.17	0.71	677	0.12	0.17	0.71	677

Notes
1 Coefficient of efficiency (see Equation 4.1)
2 ratio of total estimated and recorded streamflow volumes (see Equation 4.2)
3 Surface flow ratio (ratio of surface flow component and total streamflow)

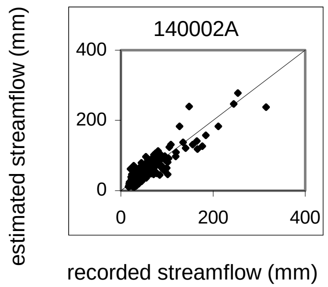


Figure 4.8 Region 1 model calibration results

Region 2

station	E[1]	VOL[2]	SFR[3] (modelled)	SFR (recorded)	rainfall (mm)	runoff (mm)	impervious component (mm)	forest component (mm)	other pervious component (mm)	impervious runoff (mm)	forest model surface	forest model interflow	forest model baseflow	forest model runoff (mm)	other pervious model surface	other pervious model interflow	other pervious model baseflow	other pervious model runoff (mm)
141001B	0.95	0.96	0.55	0.71	1709	598	3	353	242	1566	0.27	0.28	0.45	569	0.26	0.28	0.46	641
141003C	0.92	0.87	0.56	0.55	1620	558	46	292	220	1487	0.23	0.29	0.48	503	0.22	0.30	0.49	567
141006A	0.95	1.01	0.54	0.60	1815	679	23	430	225	1678	0.24	0.29	0.47	643	0.23	0.30	0.48	713
141008A	0.94	1.09	0.53	0.52	1727	607	9	406	191	1583	0.23	0.30	0.48	581	0.22	0.30	0.48	649
141009A	0.89	0.91	0.54	0.64	1638	559	9	266	284	1508	0.25	0.29	0.46	522	0.24	0.29	0.47	586
142001A	0.94	1.10	0.51	0.63	1514	494	3	234	257	1384	0.20	0.30	0.49	459	0.20	0.31	0.50	526
142101A	0.92	1.14	0.47	0.53	1297	351	6	212	133	1164	0.14	0.32	0.54	326	0.14	0.33	0.54	386
142202A	0.93	1.04	0.51	0.61	1312	380	5	224	151	1187	0.20	0.30	0.50	356	0.20	0.30	0.50	412
143303A	0.94	0.95	0.53	0.49	1707	576	0	419	158	1565	0.24	0.29	0.47	558	0.23	0.29	0.47	630

Notes
1 Coefficient of efficiency (see Equation 4.1)
2 ratio of total estimated and recorded streamflow volumes (see Equation 4.2)
3 Surface flow ratio (ratio of surface flow component and total streamflow)

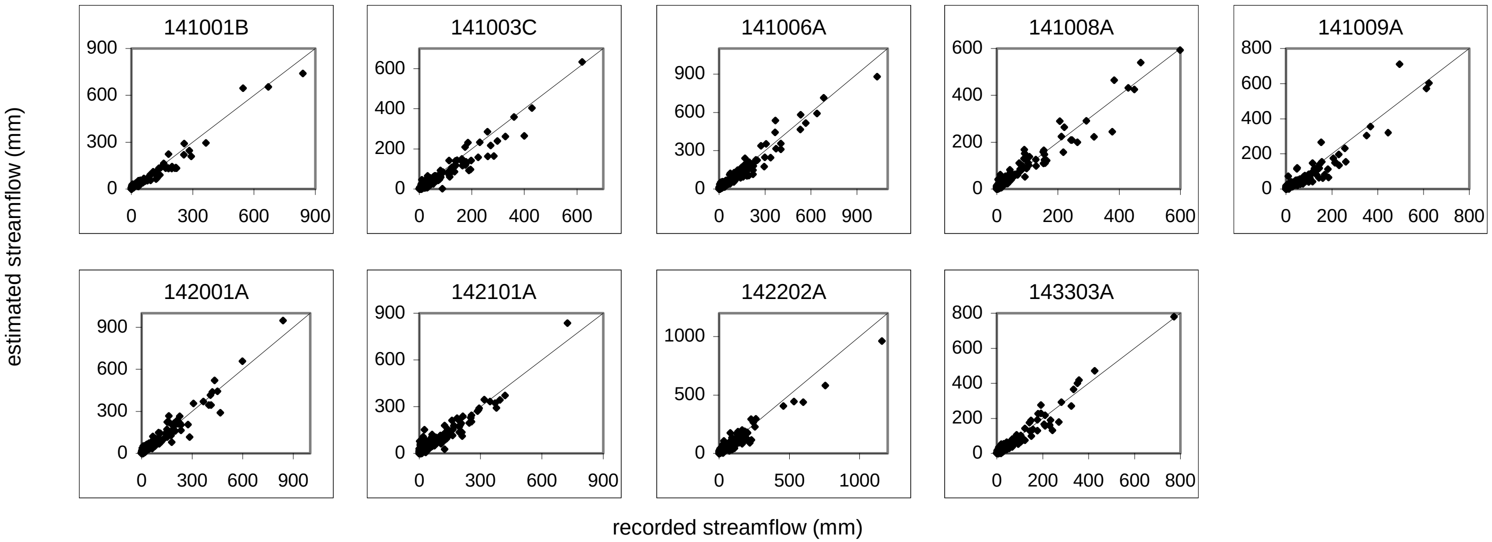


Figure 4.9 Region 2 model calibration results

Region 3

station	E[1]	VOL[2]	SFR[3] (modelled)	SFR (recorded)	rainfall (mm)	runoff (mm)	impervious component (mm)	forest component (mm)	other pervious component (mm)	impervious runoff (mm)	forest model surface	forest model interflow	forest model baseflow	forest model runoff (mm)	other pervious model surface	other pervious model interflow	other pervious model baseflow	other pervious model runoff (mm)
143006A	0.81	0.90	0.43	0.47	1022	92	2	51	39	898	0.09	0.26	0.65	77	0.14	0.36	0.50	115
143010B	0.80	0.92	0.53	0.61	779	35	0	14	21	674	0.04	0.28	0.68	33	0.13	0.54	0.33	37
143011A	0.78	0.85	0.56	0.65	808	41	0	12	29	712	0.04	0.28	0.68	37	0.13	0.53	0.34	43
143013A	0.80	1.19	0.44	0.47	991	82	2	40	41	878	0.09	0.27	0.64	68	0.11	0.39	0.50	100
143015B	0.89	1.06	0.57	0.66	761	30	1	13	16	658	0.00	0.29	0.71	29	0.14	0.65	0.21	29
143018A	0.62	0.48	0.45	0.54	878	47	0	20	26	749	0.01	0.29	0.70	39	0.11	0.46	0.43	55
143307A	0.94	1.12	0.52	0.61	1411	276	0	255	21	1296	0.35	0.16	0.49	272	0.37	0.21	0.42	345

Notes
1 Coefficient of efficiency (see Equation 4.1)
2 ratio of total estimated and recorded streamflow volumes (see Equation 4.2)
3 Surface flow ratio (ratio of surface flow component and total streamflow)

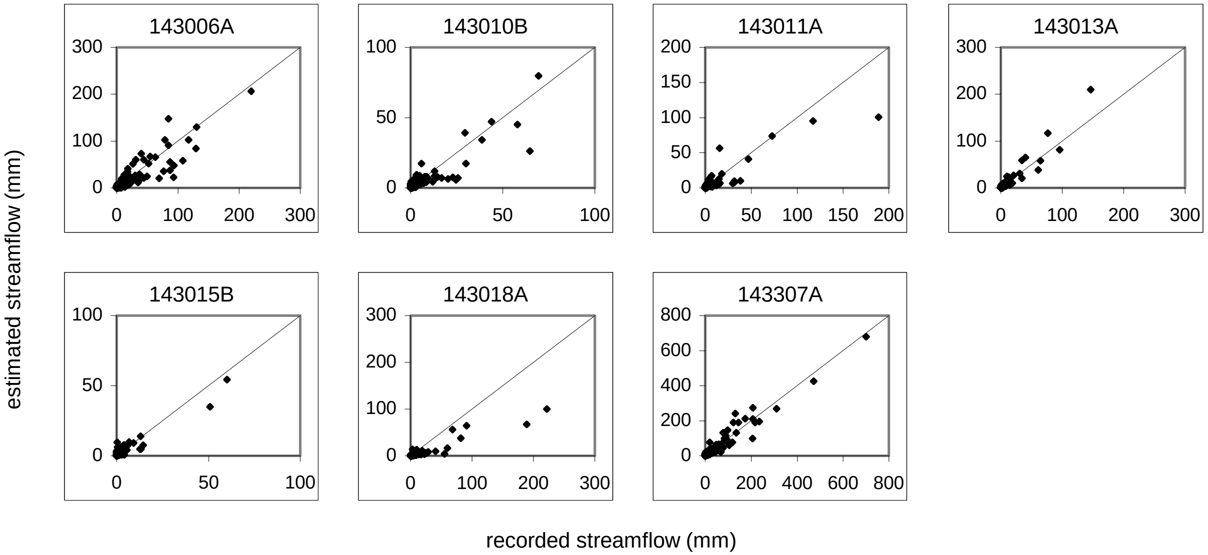


Figure 4.10 Region 3 model calibration results

Region 4

station	E[1]	VOL[2]	SFR[3] (modelled)	SFR (recorded)	rainfall (mm)	runoff (mm)	impervious component (mm)	forest component (mm)	other pervious component (mm)	impervious runoff (mm)	forest model surface	forest model interflow	forest model baseflow	forest model runoff (mm)	other pervious model surface	other pervious model interflow	other pervious model baseflow	other pervious model runoff (mm)
143203C	0.91	1.02	0.56	0.64	895	82	4	60	18	789	0.22	0.25	0.53	76	0.27	0.48	0.25	88
143208A	0.74	1.01	0.43	0.65	971	74	0	65	9	871	0.09	0.29	0.61	73	0.15	0.56	0.29	82
143211A	0.78	0.61	0.53	0.53	998	83	0	57	26	890	0.17	0.28	0.56	78	0.20	0.51	0.29	96
143212A	0.62	1.20	0.50	0.44	909	64	0	45	19	793	0.13	0.29	0.58	61	0.16	0.56	0.28	71
143214A	0.72	0.93	0.47	0.65	876	48	1	36	12	772	0.00	0.34	0.66	46	0.12	0.69	0.19	50
143219A	0.66	0.80	0.60	0.34	876	78	10	47	21	799	0.17	0.27	0.56	67	0.23	0.53	0.24	74
143225A	0.92	0.84	0.57	0.62	897	75	0	47	29	790	0.21	0.25	0.54	72	0.25	0.49	0.26	82
143229A	0.98	1.01	0.64	0.67	786	55	2	24	29	683	0.19	0.25	0.55	50	0.26	0.52	0.22	55

Notes
1 Coefficient of efficiency (see Equation 4.1)
2 ratio of total estimated and recorded streamflow volumes (see Equation 4.2)
3 Surface flow ratio (ratio of surface flow component and total streamflow)

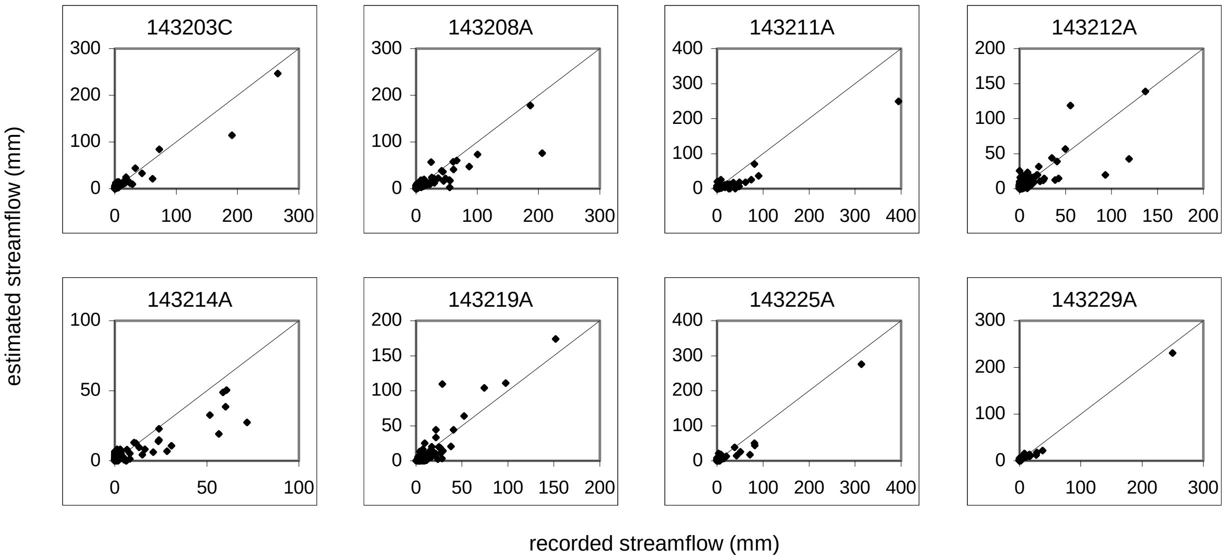


Figure 4.11 Region 4 model calibration results

Region 5

station	E[1]	VOL[2]	SFR[3] (modelled)	SFR (recorded)	rainfall (mm)	runoff (mm)	impervious component (mm)	forest component (mm)	other pervious component (mm)	impervious runoff (mm)	forest model				other pervious model			
											surface	interflow	baseflow	runoff (mm)	surface	interflow	baseflow	runoff (mm)
143101A	0.83	1.05	0.61	0.57	850	115	1	42	72	724	0.04	0.57	0.39	114	0.04	0.57	0.39	114
143102B	0.85	1.13	0.61	0.49	939	132	0	71	61	812	0.03	0.58	0.39	132	0.03	0.58	0.39	132
143107A	0.87	1.04	0.63	0.68	891	129	2	43	84	767	0.07	0.56	0.38	128	0.07	0.56	0.38	128
143110A	0.92	1.05	0.64	0.67	967	176	0	70	106	861	0.10	0.54	0.36	176	0.10	0.54	0.36	176
143113A	0.61	1.80	0.65	0.69	907	147	1	54	92	801	0.12	0.53	0.35	146	0.12	0.53	0.35	146
143114A	0.63	0.91	0.73	0.50	968	204	25	92	87	878	0.23	0.46	0.31	184	0.23	0.46	0.31	184
143209B	0.89	1.01	0.65	0.54	978	176	0	134	42	870	0.12	0.53	0.35	176	0.12	0.53	0.35	176

Notes
1 Coefficient of efficiency (see Equation 4.1)
2 ratio of total estimated and recorded streamflow volumes (see Equation 4.2)
3 Surface flow ratio (ratio of surface flow component and total streamflow)

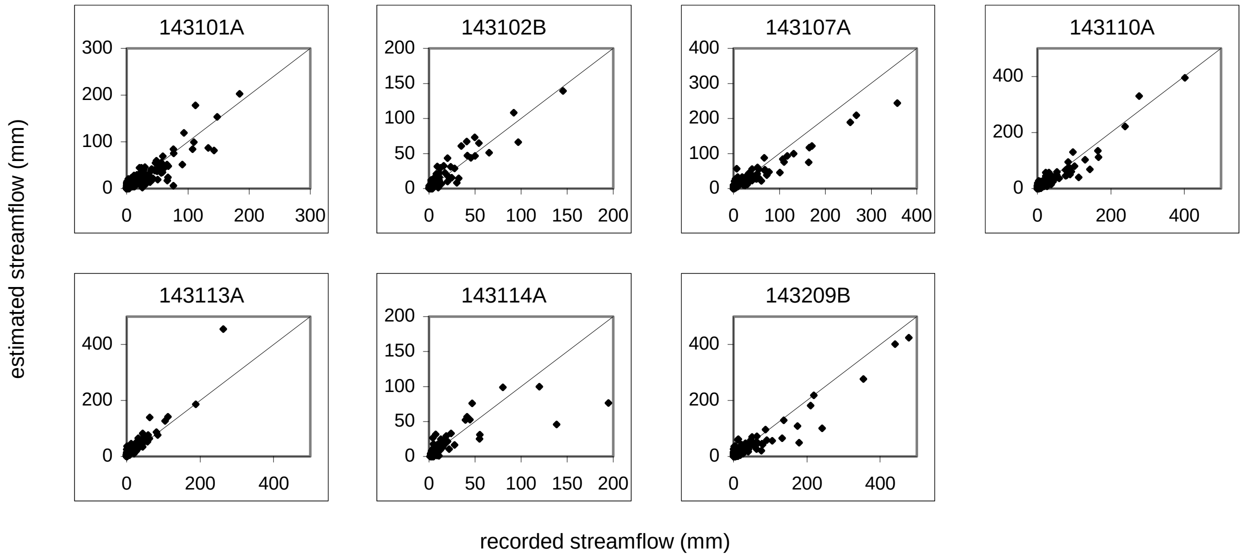


Figure 4.12 Region 5 model calibration results

Region 6

station	E[1]	VOL[2]	SFR[3] (modelled)	SFR (recorded)	rainfall (mm)	runoff (mm)	impervious component (mm)	forest component (mm)	other pervious component (mm)	impervious runoff (mm)	forest model surface	forest model interflow	forest model baseflow	forest model runoff (mm)	other pervious model surface	other pervious model interflow	other pervious model baseflow	other pervious model runoff (mm)
145003B	0.81	0.74	0.52	0.54	1171	237	0	185	52	1049	0.14	0.39	0.48	237	0.14	0.39	0.48	237
145010A	0.80	0.95	0.54	0.38	1310	337	0	249	88	1177	0.20	0.35	0.46	337	0.20	0.35	0.46	337
145011A	0.81	0.94	0.49	0.57	1090	190	0	120	70	961	0.09	0.41	0.51	190	0.09	0.41	0.51	190
145012A	0.94	1.10	0.51	0.60	939	134	2	52	81	814	0.10	0.40	0.50	133	0.10	0.40	0.50	133
145018A	0.28	1.74	0.51	0.50	1425	380	0	308	72	1283	0.13	0.37	0.49	380	0.13	0.37	0.49	380

Notes
1 Coefficient of efficiency (see Equation 4.1)
2 ratio of total estimated and recorded streamflow volumes (see Equation 4.2)
3 Surface flow ratio (ratio of surface flow component and total streamflow)

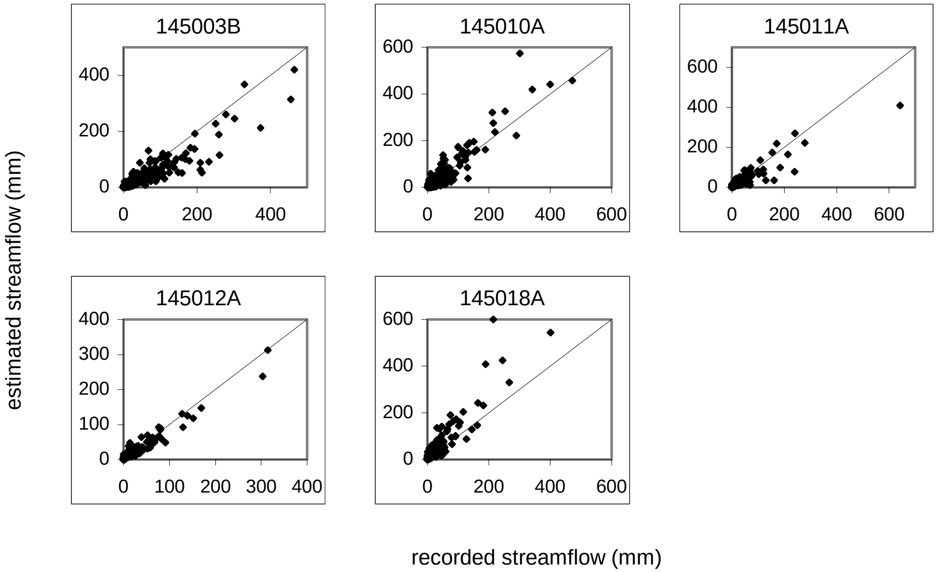


Figure 4.13 Region 6 model calibration results

Region 7

station	E[1]	VOL[2]	SFR[3] (modelled)	SFR (recorded)	rainfall (mm)	runoff (mm)	impervious component (mm)	forest component (mm)	other pervious component (mm)	impervious runoff (mm)	forest model surface	forest model interflow	forest model baseflow	forest model runoff (mm)	other pervious model surface	other pervious model interflow	other pervious model baseflow	other pervious model runoff (mm)
145007A	0.68	1.06	0.48	0.45	1556	392	0	221	171	1421	0.35	0.10	0.54	381	0.34	0.18	0.48	408
145013A	0.60	1.10	0.46	0.41	1397	279	0	154	125	1267	0.30	0.11	0.59	275	0.30	0.21	0.49	284
145101D	0.81	0.82	0.47	0.44	1368	265	0	165	100	1221	0.33	0.11	0.56	258	0.32	0.20	0.48	278
145102B	0.87	0.90	0.47	0.51	1314	235	0	136	99	1156	0.32	0.11	0.56	227	0.31	0.20	0.49	247
145107A	0.86	1.06	0.49	0.41	1587	408	4	342	62	1433	0.38	0.09	0.53	402	0.37	0.17	0.46	420

Notes
1 Coefficient of efficiency (see Equation 4.1)
2 ratio of total estimated and recorded streamflow volumes (see Equation 4.2)
3 Surface flow ratio (ratio of surface flow component and total streamflow)

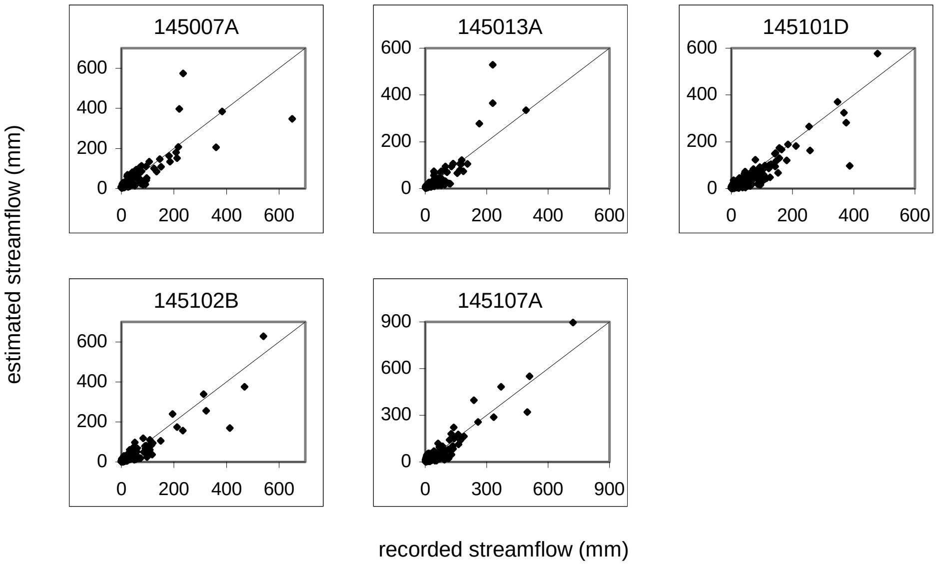


Figure 4.14 Region 7 model calibration results

Region 8

station	E[1]	VOL[2]	SFR[3] (modelled)	SFR (recorded)	rainfall (mm)	runoff (mm)	impervious component (mm)	forest component (mm)	other pervious component (mm)	impervious runoff (mm)	forest model surface	forest model interflow	forest model baseflow	forest model runoff (mm)	other pervious model surface	other pervious model interflow	other pervious model baseflow	other pervious model runoff (mm)
146009A	0.93	1.03	0.60	0.58	1768	701	0	631	70	1617	0.20	0.40	0.40	701	0.20	0.40	0.40	701
146010A	0.95	1.19	0.59	0.51	1584	538	0	350	188	1441	0.19	0.40	0.41	538	0.19	0.40	0.42	537
146011A	0.96	1.10	0.61	0.52	1814	712	0	606	107	1649	0.21	0.40	0.39	712	0.21	0.39	0.39	712
146012A	0.95	1.03	0.63	0.45	1984	909	0	763	145	1858	0.26	0.37	0.37	909	0.26	0.37	0.37	908
146020A	0.94	1.20	0.59	0.54	1660	593	9	476	108	1511	0.18	0.40	0.42	587	0.18	0.40	0.42	587
146095A	0.93	1.05	0.63	0.52	1991	888	0	790	98	1837	0.25	0.38	0.37	888	0.25	0.38	0.37	887

Notes
1 Coefficient of efficiency (see Equation 4.1)
2 ratio of total estimated and recorded streamflow volumes (see Equation 4.2)
3 Surface flow ratio (ratio of surface flow component and total streamflow)

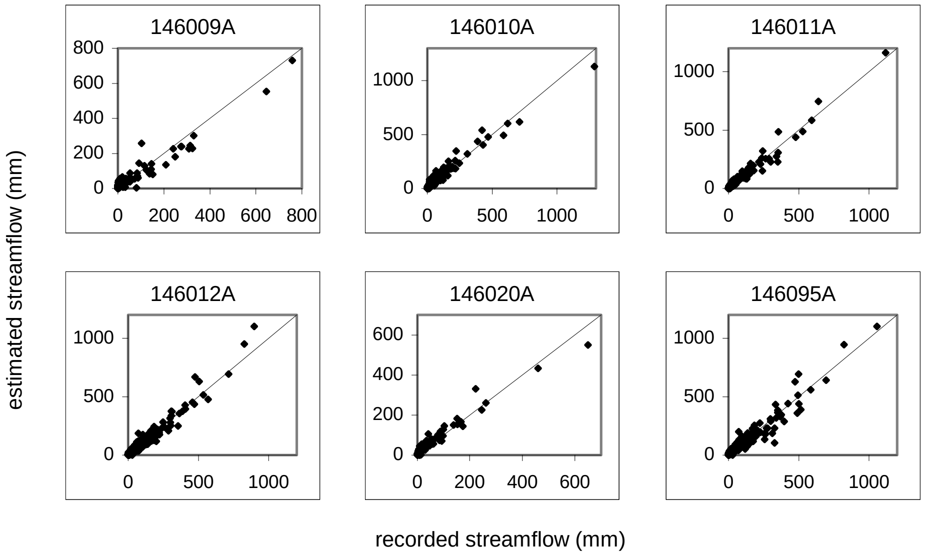


Figure 4.15 Region 8 model calibration results

Region 9

station	E[1]	VOL[2]	SFR[3] (modelled)	SFR (recorded)	rainfall (mm)	runoff (mm)	impervious component (mm)	forest component (mm)	other pervious component (mm)	impervious runoff (mm)	forest model surface	forest model interflow	forest model baseflow	forest model runoff (mm)	other pervious model surface	other pervious model interflow	other pervious model baseflow	other pervious model runoff (mm)
142901A	0.90	0.80	0.61	0.59	1192	410	75	191	144	1080	0.27	0.26	0.47	360	0.27	0.26	0.47	360
142902A	0.93	0.96	0.67	0.55	1204	449	142	128	180	1080	0.26	0.26	0.47	354	0.26	0.26	0.47	354
143020A	0.95	0.90	0.58	0.63	1153	343	12	251	80	1041	0.32	0.25	0.44	335	0.32	0.25	0.44	335
143032A	0.93	1.04	0.52	0.67	1104	300	0	252	48	994	0.25	0.26	0.48	300	0.25	0.26	0.48	300
143033A	-1.60	2.90	0.49	0.61	1004	236	13	168	56	899	0.16	0.30	0.54	227	0.16	0.30	0.54	227
143094A	0.95	0.97	0.68	0.63	1178	451	168	77	206	1059	0.21	0.27	0.52	337	0.21	0.27	0.52	337
143932A	0.94	1.07	0.62	0.66	1277	461	66	301	93	1161	0.31	0.24	0.45	419	0.31	0.24	0.45	419

Notes
1 Coefficient of efficiency (see Equation 4.1)
2 ratio of total estimated and recorded streamflow volumes (see Equation 4.2)
3 Surface flow ratio (ratio of surface flow component and total streamflow)

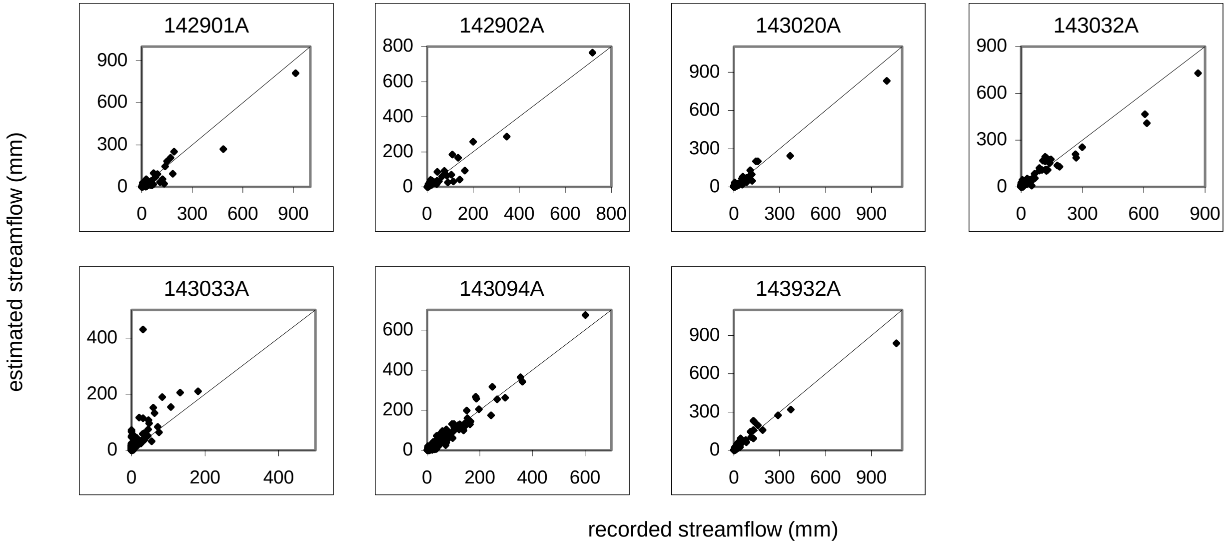


Figure 4.16 Region 9 model calibration results

5. Determination of EMC and DWC For Estimating Pollutant Loads

The determination of event mean concentration (EMC) and dry weather concentration (DWC) for use in the EMSS to estimate total suspended solids, total phosphorus and total nitrogen loads are discussed in detail in Chiew and Scanlon (2001). This section presents only some of the background, main discussion points and the EMC and DWC values that will be adopted in the EMSS.

5.1 Pollutant load modelling and EMC and DWC

The model estimates the daily pollutant load as,

Daily pollutant load = surface runoff x EMC + subsurface runoff x DWC

The event mean concentration (EMC) is defined as the flow-weighted average pollutant concentration over a storm event. The dry weather concentration (DWC) is defined as the pollutant concentration measured during dry weather. It is important to differentiate between the EMC and DWC because the EMC is typically much higher than the DWC. The pollutant loads transported by surface runoff are therefore higher than the loads transported by subsurface runoff because the EMC is higher than DWC and because the runoff volumes are bigger during events.

The EMC and DWC values are highly variable, both within a monitoring location and between monitoring locations. As such, many water quality samples must be taken from a monitoring location to provide an accurate estimate of the average EMC and DWC values at that location. Water quality monitoring should also be carried out at many sites to explain the variability in EMC and DWC values across the region.

5.2 Water quality monitoring and EMC and DWC

Historically most water quality monitoring programs have been developed to monitor the long term health of the waterway at the sampled locations. Grab sampling programs are adequate for this, and so most programs are of this type. As most of the data from grab sampling programs are collected during dry weather, grab sampling data can be used to estimate the DWC.

As the impact of pollutant loads on receiving waters is now a serious issue, more event-based monitoring programs are being undertaken. The pollutant load and EMC value can only be estimated accurately from event-based sampling because the pollutant concentration can vary significantly over an event. There are a lot less data from event-based monitoring programs compared to grab sampling programs because it is much easier and less expensive to collect instantaneous samples.

The event-based data provide a direct estimate of the EMC. The grab-sampling data can be analysed to provide an estimate of EMC and DWC where flow is also measured at the monitoring site. The flow data provides an indication of whether the sample is taken during dry weather or during an event.

5.3 Water quality monitoring in south-east Queensland and data used to estimate EMC and DWC for the EMSS

There are various sources of water quality data in the south-east Queensland region, such as Brisbane City Council, Department of Natural Resources and Mines, Environmental Protection Authority, South East Queensland Water Corporation, local councils and water watch programs.

The EMC and DWC values for the EMSS are determined primarily from two main sources of data. The EMC and DWC values for the urban land use are determined using data from the event (and inter-event) monitoring program carried out by Brisbane City Council at six urban catchments, two rural residential catchments and three developing urban catchments. The number of event samples in the six urban catchments range from 20 to 90 events, while the number of inter-event samples range from 20 to 130.

The EMC and DWC values for the rural land use categories are determined using mainly grab sample water quality data obtained from the Department of Natural Resources and Mines' data base. To use grab sample data for the analyses, flow data are required to differentiate between samples collected during "events" and samples collected during dry weather conditions.

Altogether, a total of 50 sites with TSS and daily flow data and 20 sites with TP and daily flow data are used for the analyses.

There are other ongoing monitoring programs collecting event-based water quality data that can be used to estimate the EMC for rural land use categories, but at present have limited data available for analyses. These programs are described in Chiew and Scanlon (2001).

5.4 EMC and DWC values for pollutant load modelling in the EMSS

The lower limit, median and upper limit EMC and DWC values for total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN) that are adopted in the EMSS modelling are presented in **Table 5.1.** The limited water quality data only allow meaningful differentiation between four broad land use categories: urban (dense urban and suburban land use categories in the EMSS); forest (natural bush, national park, managed forest and plantation land use categories in the EMSS); grazing (grazing land use category) and cropping (intensive agriculture and broadacre agriculture land use categories).

Where there are sufficient local data, the EMC and DWC values are generally estimated as the 10th percentile, average and 90th percentile of the median EMC and DWC from catchments across the south-east Queensland region. Where there is limited or no local data, values from the literature (in particular values from the CRCCH review of over 500 Australian and overseas data sets - Duncan, 1999) are used as a guide to estimate the EMC and DWC values for use in the EMSS.

Table 5.1 also provides indications of how much local data are used to estimate the EMC and DWC for the EMSS modelling. In general there are some local data to estimate the EMC and DWC values, but a lot more monitoring is required to estimate the EMC values accurately. The report by Chiew and Scanlon (2001) provides recommendations of targeted monitoring programs that can be undertaken to improve the estimates of EMC and DWC values in **Table 5.1**.

Table 5.1 Recommended DWC and EMC values for TSS, TP and TN for the EMSS

Land use		**TSS (mg/L)**		**TP (mg/L)**		**TN (mg/L)**	
		DWC	**EMC**	**DWC**	**EMC**	**DWC**	**EMC**
Dense urban **Suburban**	Lower **Median** Upper	5 **7** 9	60 **130** 200	0.06 **0.11** 0.16	0.20 **0.28** 0.36	1.1 **1.5** 2.0	1.3 **1.6** 2.1
Natural bush **National park** **Managed forest** **Plantation**	Lower **Median** Upper	5 **7** 9	10 **32** 57	0.01 **0.03** 0.07	0.05 **0.10** 0.20	0.3 **0.5** 0.8	0.4 **0.8** 2.0
Grazing	Lower **Median** Upper	8 **10** 11	25 **140** 350	0.02 **0.07** 0.12	0.08 **0.34** 0.70	0.4 **0.7** 0.9	0.6 **2.7** 4.2
Intensive agriculture **Broadacre agriculture**	Lower **Median** Upper	8 **10** 11	60 **200** 550	0.02 **0.07** 0.12	0.20 **0.50** 1.5	0.4 **0.7** 0.9	1.5 **4.0** 9.0

Key: Reasonable amount of local data
Some local data
Little to practically no local data
No local data

6. Summary Results from Catchment Scale Modelling in the EMSS

The input climate data into the catchment scale model are daily rainfall and mean monthly potential evapotranspiration (see **Figures 2.1** and **2.2**). The hydrologic model parameters for different land use categories in different parts of south-east Queensland are presented in Section 4. The EMC and DWC values for different land use categories are presented in Section 5.

The main outputs from the catchment scale model, for present climate and land use, simulated by the EMSS for the period 1985 to 1999, are presented as mean annual TSS load, mean annual TP load and mean annual TN load, averaged over each sub-catchment, in Figures 6.1 to 6.4 respectively.

There is a reasonable amount of streamflow data available to calibrate the hydrologic model. The rainfall-runoff process is also less variable between catchments compared to the water quality characteristic. As such, the EMSS estimates of the mean annual, seasonal and monthly streamflow are reasonably accurate. However, given the large variability in water quality characteristic and the limited event water quality data, the EMSS only gives rough estimates of the TSS, TP and TN loads. Estimates of pollutant loads can be improved considerably as more event data becomes available.

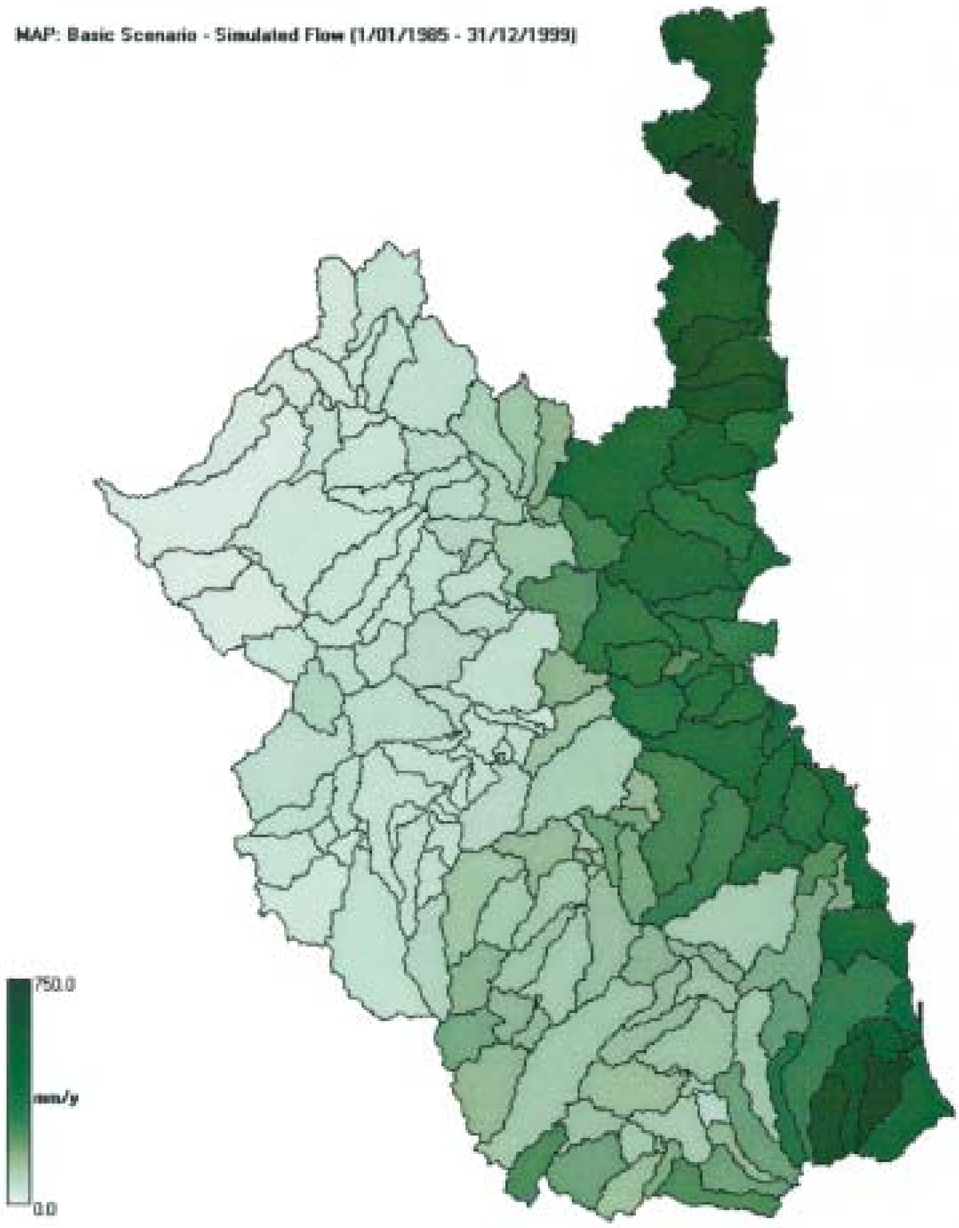


Figure 6.1 Mean annual runoff simulated by the EMSS

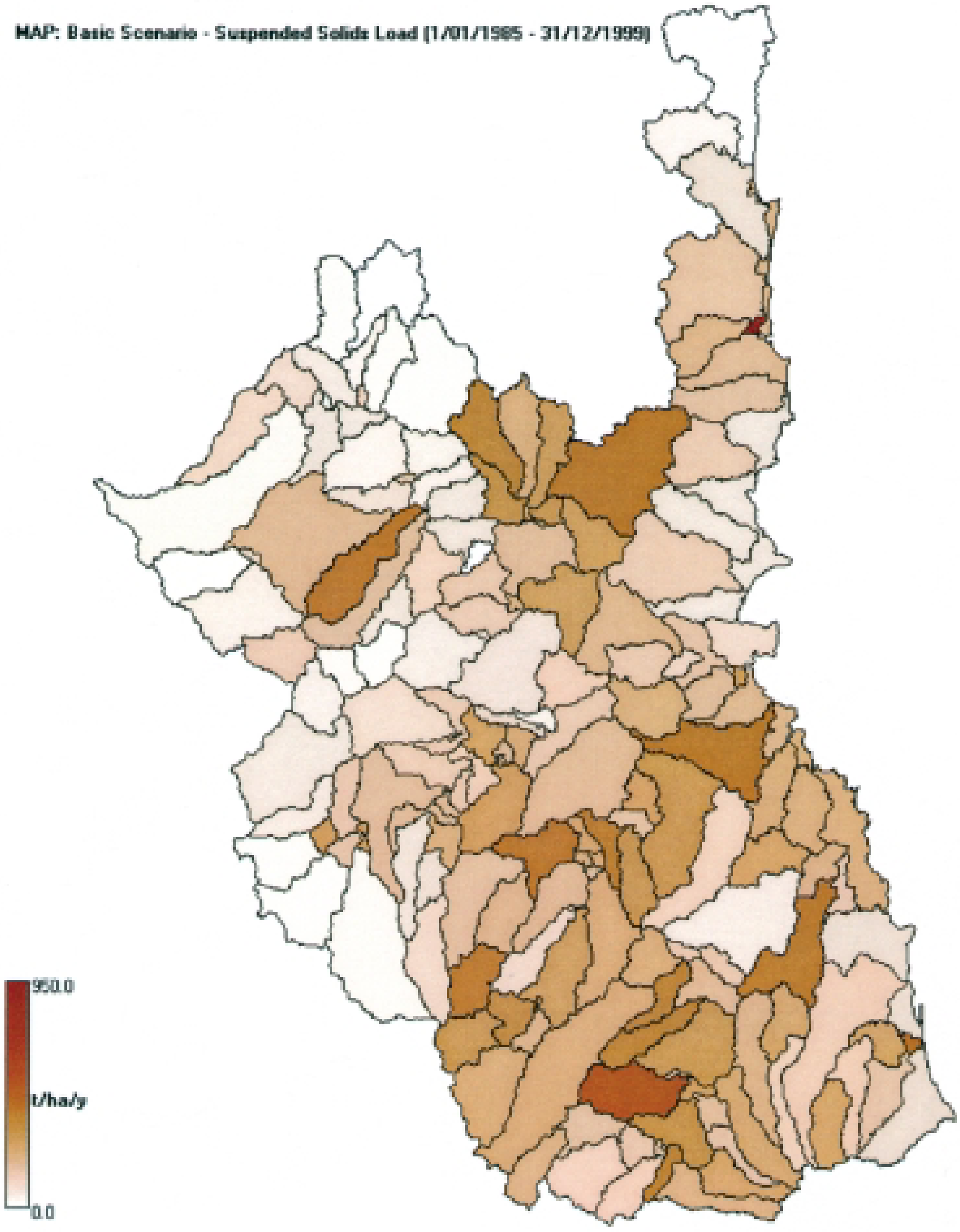


Figure 6.2 Mean annual TSS load simulated by the EMSS

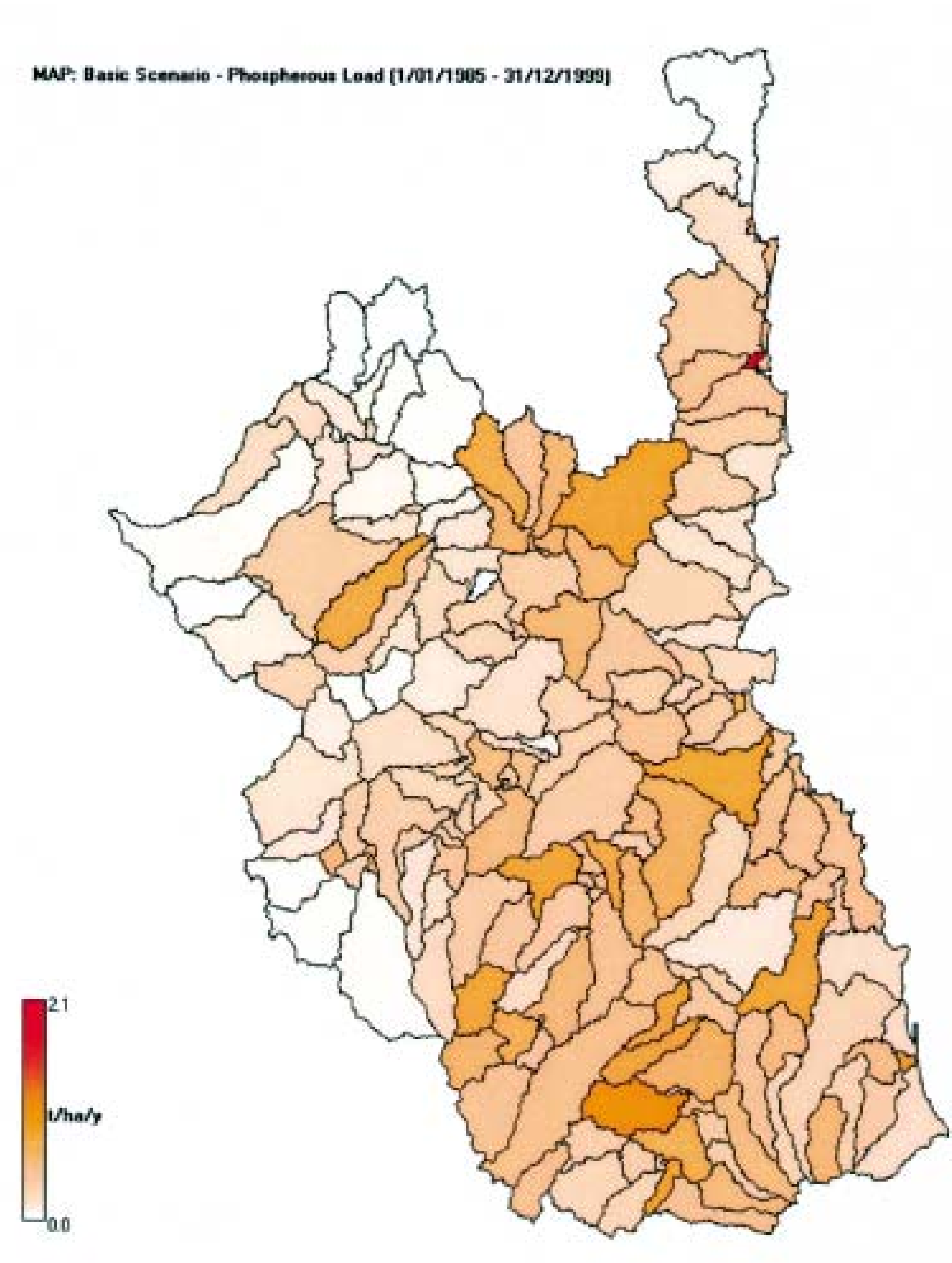


Figure 6.3 Mean annual TP load simulated by the EMSS

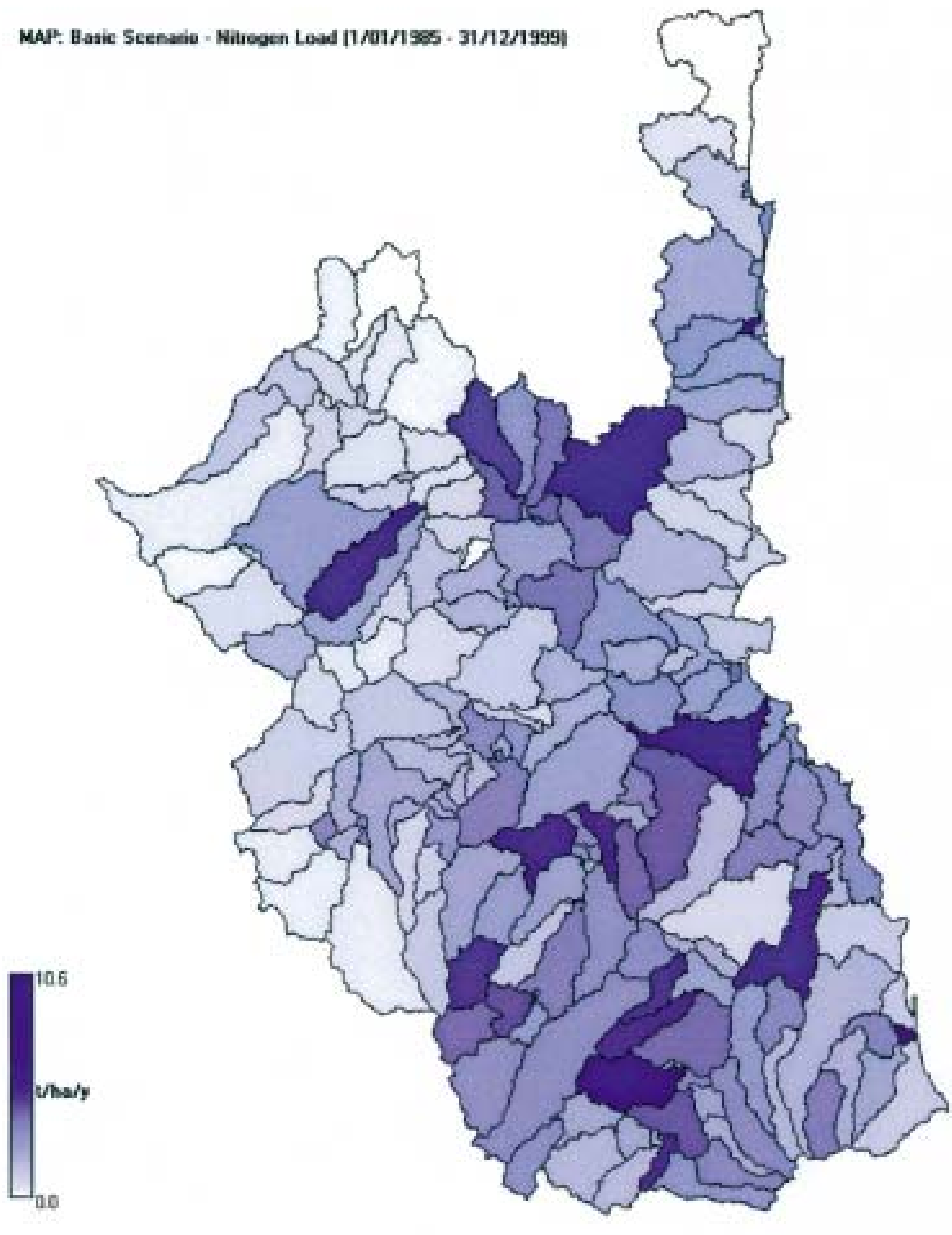


Figure 6.4 Mean annual TN load simulated by the EMSS

7. References

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