STREAM Perfume

Calibration and validation for the wider Perfume River Basin in Vietnam

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Contents

1. Introduction

The RIKZ / Coastal Zone Management Centre of the Dutch Ministry of Water and Transport has requested to investigate the hydrology of the Perfume River in Vietnam and the Krishna River in India with the STREAM water balance model. The results for the Krishna River are discussed in a separate report (Aerts and Bouwer 2002b).

This report presents the results of calibrating and validating the hydrological model that was set up for the wider Perfume River Basin in Thua Thien Hue Province, Vietnam including the rivers Huong, Hue Trach, Ta Trach, Bo and O Lau. Additionally, it presents the results of analyses of a selected dataset of monthly and hourly meteorological and hydrological parameters, in particular from October and November 1999. These analyses are the first step of investigating whether this data might be suitable for calibrating and validating the STREAM Perfume water balance model. These modelling activities are undertaken by IVM under project 1005.

The STREAM instrument can be used to give insight in the long-term impacts of land-use change, climate change, river basin management, population pressure, economic development and on the future water demand and water availability in the Krishna basin. Additionally, STREAM can, contrary to many other hydrological models, give insight in the spatial variation of the changes, and complement research the interaction of rivers with coastal processes. Currently, a team has been set-up by RIKZ / CZMZ and IVM comprising other institutes as well, for a broader application of the STREAM model.

In the following chapter the analysis of the selected data will be presented. In the chapter thereafter the actual calibration and validation will be presented. Both chapters conclude by listing some conclusions and remarks.

2. Preliminary analyses of meteorological and hydrological data of the Perfume River

2.1 Introduction

This chapter provides a preliminary analysis of selected meteorological and hydrological data sets for the River Basin in Thua Thien Hue Province, Vietnam. The monthly averaged data of precipitation and temperature of three meteorological stations, river water level (Phu Oc, Kim Long) and discharges and water (Thuong Nhat) for the period 1980 to 2000 (see Table 3.1) were provided by the Hydrometeorological Service of Vietnam (HMS) and Mr. Lie (University of Hue). These data were delivered through the Viet Nam Netherlands Integrated Coastal Zone Management (VN–ICZM) project office in Hanoi. This data was preliminary analysed before the calibration and validation of the STREAM water balance model (see Chapter 3). Additionally, hourly data for the period 15 October to 15 November 1999 were also made available. During this period, a typhoon passed the city of Hue (see Figure 2.1).

The VN-ICZM Workshop on Mathematical Modelling that took place in April 2002 in Hue, concluded that the outputs of STREAM-Perfume could be considered as valuable input for lagoon modelling. Furthermore, the next versions of the STREAM model may provide estimations of water availability and water demand of the TT Hue Province taking into account long-term impacts of climate change and socio-economic development scenarios. Future versions of the STREAM model may indicate on impacts of human interactions in the mountainous areas of TT Hue, such as construction of dams, and de- and reforestation.

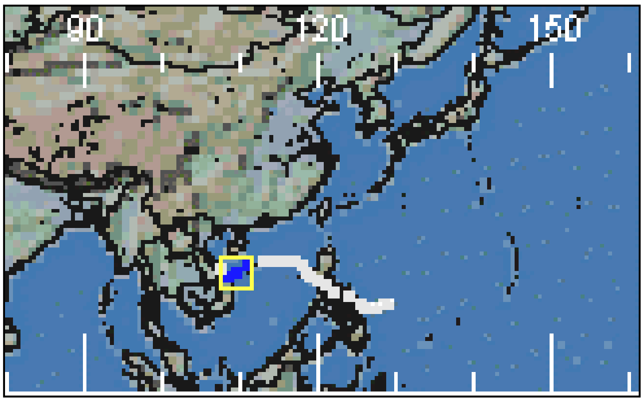

Figure 2.1. The path of the typhoon during late October and early November 1999, and which hit Hue. (picture from NASA PM-ESIP http://pm-esip.nsstc.nasa.gov/)

2.2 Station locations

The monthly averaged data of precipitation and temperature of three meteorological stations were provided; for the stations of Nam Dong, A Luoi and the city of Hue. Monthly data for the period 1980 to 2000 for averaged river water level was available for the stations of Phu Oc and Kim Long, and discharge data was available for the station of Thuong Nhat. Hourly data for the same stations was available for the period 15 October to 15 November 1999. The locations of the meteorological (▮) and hydrological stations (▼) within the basin are shown in the map below.

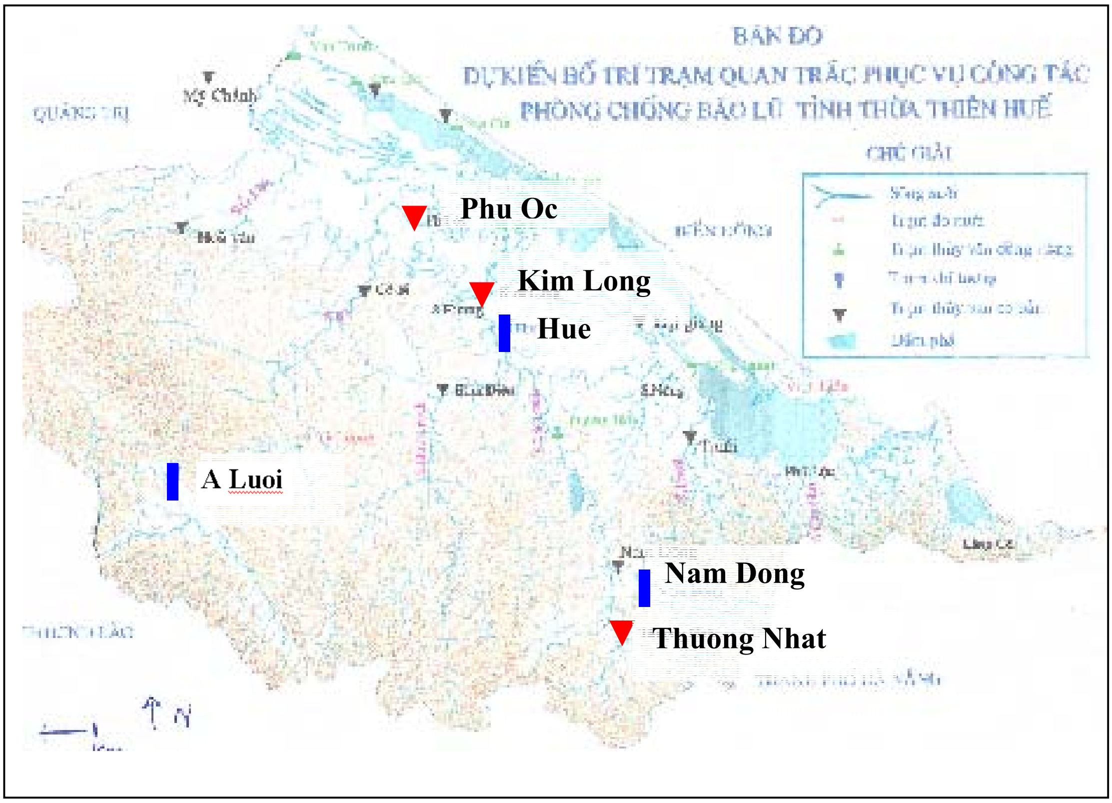

Figure 2.2. Locations of the observation stations in the Perfume River Basin.

2.3 Observations

Figure 2.3 describes a 20-year record of monthly discharges of the Ta Trach River at the station of Thuong Nhat, associated with the precipitation in the upper Perfume River catchment at the station of Nam Dong. The maximum precipitation and associated high river levels occur during October and November. Drier autumns do occur and but never last more than one year.

A typhoon was hitting the coast of Hue during the first week of November 1999 (see also Figure 2.1), resulting in sudden peak discharge of the Hue River. Heavy precipitation both in the city of Hue and the surrounding mountains caused flooding of the city of Hue and its surroundings. The coincidence of the high precipitation in the TT Hue mountains with the very exceptional high rainfall during the first week of November 1999 in the surroundings of the city of Hue, gave rise to exceptional flooding. Analyses of occurrence of such coincidence should be the base of risk assessments in order to better define and design adaptive measures.

Figure 2.4 and Figure 2.5 show the daily and hourly precipitation and responses of discharges of the Ta Trach Rive at the station of Thuong Nhat between October 15 and November 1999. The daily discharges and precipitation data were derived by summing up the hourly data. The discharge curve in Hue is asymmetrical; a very fast rise in discharge resulting from a quick response to the peaks in rainfall, followed by long tail due to the fact that part of the rainwater is absorbed by the soil, which provides a slower groundwater contribution to the river discharges.

Figure 2.6 and Figure 2.7 depict the hourly water level (above national datum; ND) of the Perfume River in Hue at the station of Kim Long, as a response to the precipitation that fell from October 15 to November 15 at the stations in Hue (Figure 2.6) and higher in the mountains at Nam Dong (Figure 2.7). The three peaks in the water level curve in Hue follows the main precipitation pattern in Nam Dong. However, the exceptional heavy rainfall in Hue largely contributed to the enormous increase of water level in Hue of 5.5 m in a few hours time. The exceptional coincidence of heavy rainfall in Hue caused the severe flooding of the city of Hue and the areas surrounding the lagoon. This was an exceptional occurrence, the normal pattern of rainfall is characterised by a high level of precipitation in the mountains and a lower level in the city of Hue (see Figure 2.14).

It can be seen in Figure 2.8 that the onset of the increase of the water levels in Hue has a lag of approximately 9 hours with respect to the onset of the precipitation in the mountains at Nam Dong station. This leads to the conclusion that the water that falls in the mountains reaches within ~9 hours the city of Hue. The contribution of rainfall in Hue, however, must not be disregarded.

The effect of upstream tidal influence is clearly visible in the hourly observations of the water levels at Kim Long station during periods of low river level from Figure 2.6, Figure 2.7 and Figure 2.9). The diurnal tidal range is about 20 cm at the station of Kim Long, which is located about 15 km upstream of the lagoon. This means that the hourly water level observations are made in very accurate way and secondly that the tidal influence by means of a brackish to fresh water tidal progradation is reaching upstream of the city of Hue. This means that the tidal range at the coastline of TT Hue could be a multitude larger than 20 cm, in order to be able to penetrate the station Kim Long having passed the large TT Hue lagoon. In absence of systematical tidal range observations in TTHue province, these Kim Long water level observations can certainly contribute to a long term extrapolation in combination with the hourly water level observations to be erected during the months August to October 2002 (CCP2002 Task7).

Figure 2.10 shows the asymmetrical water level curve of the Bo River at the station of Phu Oc, as a response to the rain falling higher up in the mountains at the station of A Luoi. A similar three-peak water level pattern corresponding with rainfall is distinguished as for the other two river observation stations. Figure 2.11depicts the onset of the water level response in the Bo River due to precipitation at the station of Al Luoi. Like in Hue, the response time is also in the order of 8 to 9 hours.

In Figure 2.12 the relationship between water level (in cm) and discharge (in $m^3 s^{-1}$) at the mountain station Thuong Nhat for the monthly data over the period 1980 to 2000, as wella s for the hourly data between October 15 and November 15, 1999. Both parameters shows a high correlation, possibly because of the use of water height as a proxy for the discharge at Thuong Nhat station. Figure 2.13 shows data on the relationship between water height and discharge of the Perfume River in Hue based on long term average monthly data depicted from the Vietnam Vulnerability Assessment report (1995). This enables a reconstruction of the discharges at water levels for longer time series from Kim Long station, using the formulas that are shown in the graphs. However, more observations of extreme water levels and discharges – if available – would certainly contribute to an increasing accuracy at the extreme high end of the curve.

Figure 2.14 depicts the relationship between precipitation amount and station height for the average months over the period 1981–2000. The general picture is that during the high level of precipitation (October, November, September) the two mountain stations are receiving more precipitation than the low-lying Hue station. However, there are exceptions. During the Hue extreme event in November 1999 a coincidence of high rainfal in the mountains with an extraordinary high rainfall in Hue occurred. The frequency of these coincidental occurrences should be calculated in more detail in order to take them into account in the design of adaptive measures.

Figure 2.15 depicts the relationship between daily precipitation amounts at the different stations in the Perfume River basin between October 15 and November 15 1999. The highest correlation coefficient is found between the precipitation amounts at the mountain stations of A Luoi and Nam Dong. The daily correlation between the mountain stations and the station in Hue is lower during the same period.

2.4 Questions

The answers on the following questions are relevant in order to improve the calibration and validation of the STREAM water balance:

- Can the VN-ICZM team provide more data on the Perfume river discharges in Hue-city?
- In order to construct lines of equal rainfall and temperature for STREAM input data, we would need assistance of the VN-ICZM team and Vietnamese HMS.
- We would like to obtain more information about the tidal influence in the Perfume river.

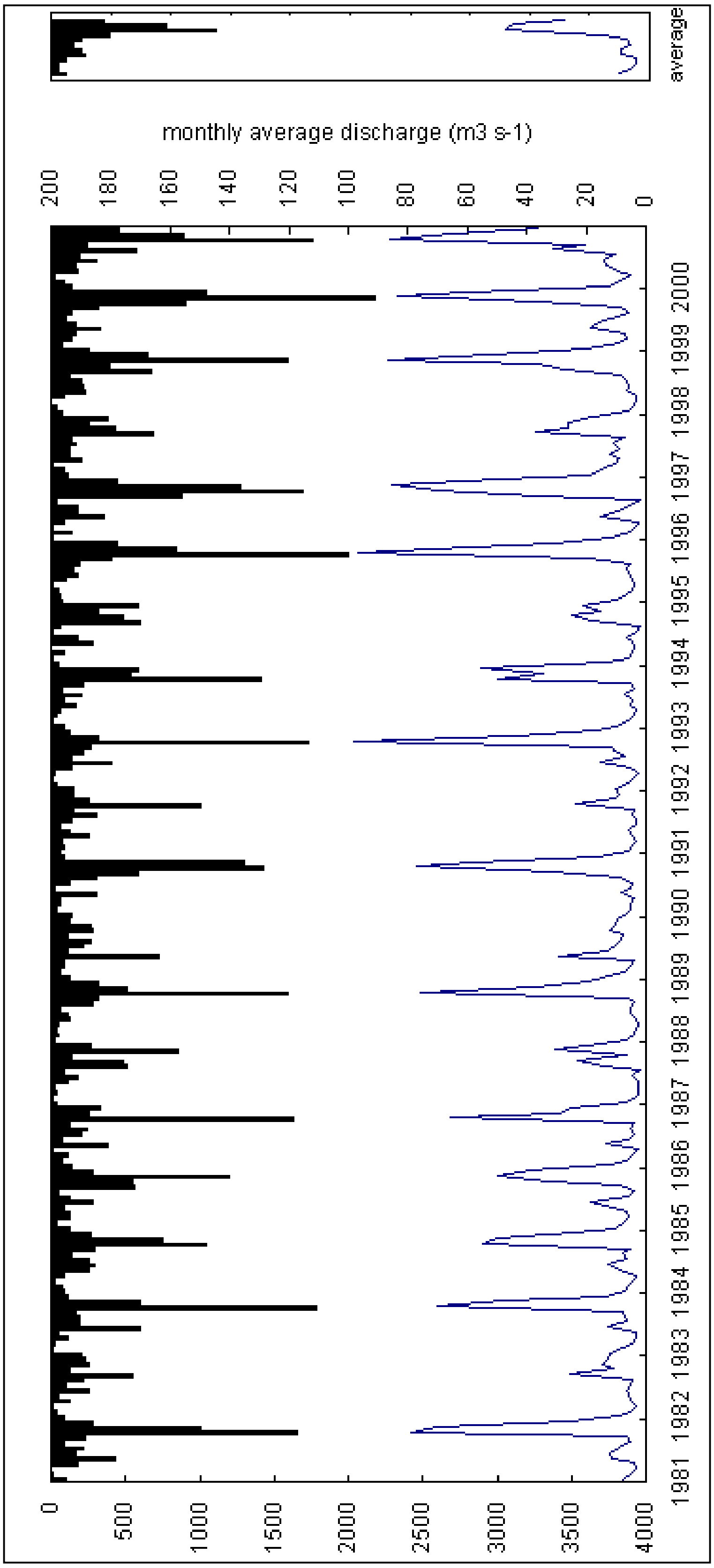

Figure 2.3. Monthly total precipitation in Nam Dong and monthly average discharge of the Ta Trach River at the station of Thuong Nhat 1981-2000. The averages for both precipitation and discharge are depicted on the right side of the graph.

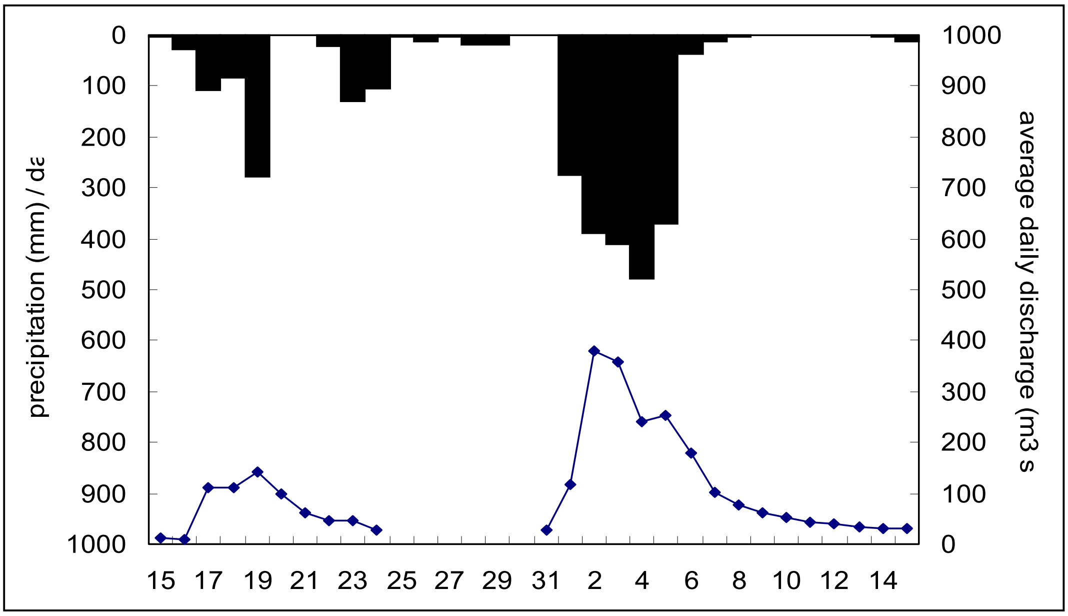

Figure 2.4. Daily precipitation at the station of Nam Dong and discharge response of the Ta Trach River at the hydrological station of Thuong Nhat from October 15 – November 15 1999. There is no discharge data shown between October 25 and 30.

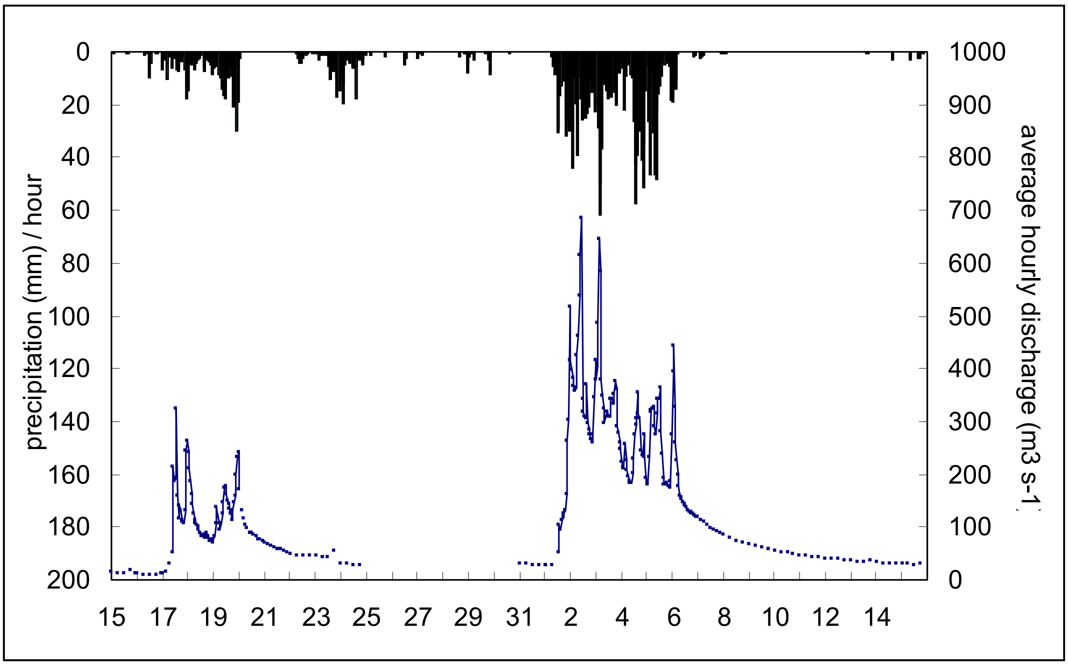

Figure 2.5. Hourly precipitation at the station of Nam Dong and discharge response of the Ta Trach River at the hydrological station of Thuong Nhat from October 15 – November 15 1999.

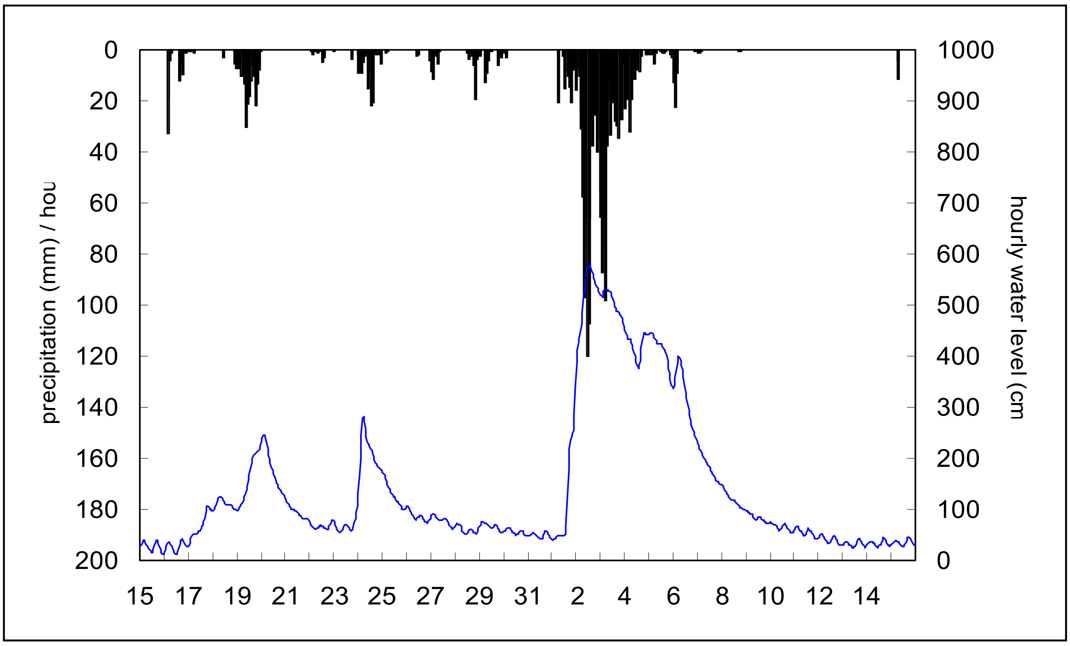

Figure 2.6. Hourly precipitation at the station of Hue and water level response of the Perfume River at the hydrological station of Kim Long (in Hue) from October 15 – November 15 1999. Levels above National Datum (N.D.).

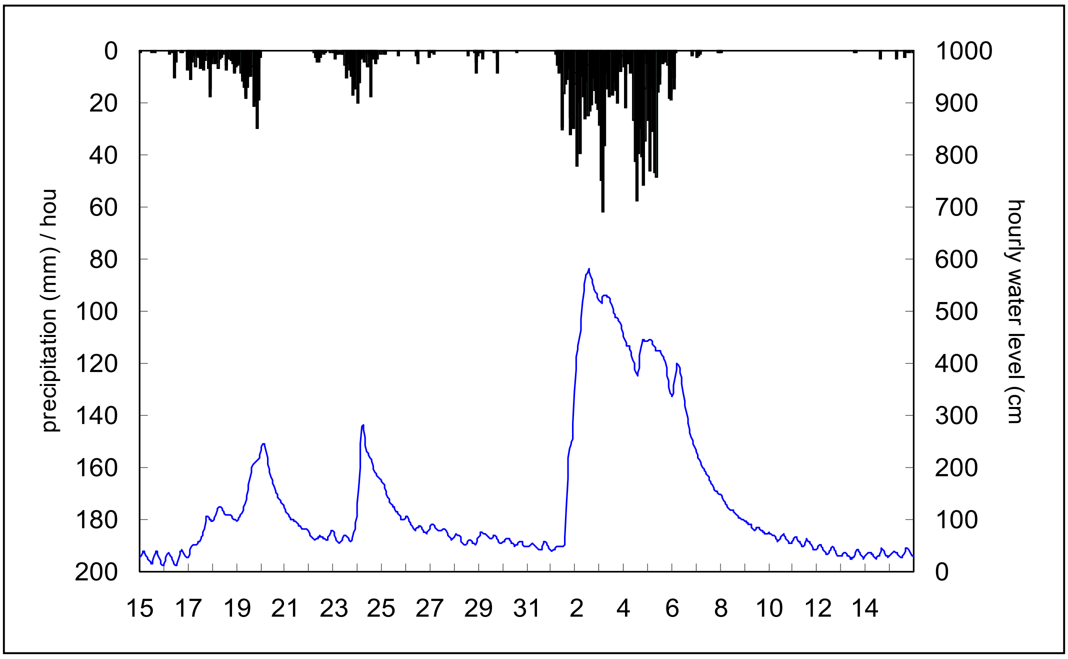

Figure 2.7. Hourly precipitation at the station of Nam Dong and water level (above N.D.) response of the Perfume River at the hydrological station of Kim Long (in Hue) from October 15 – November 15 1999.

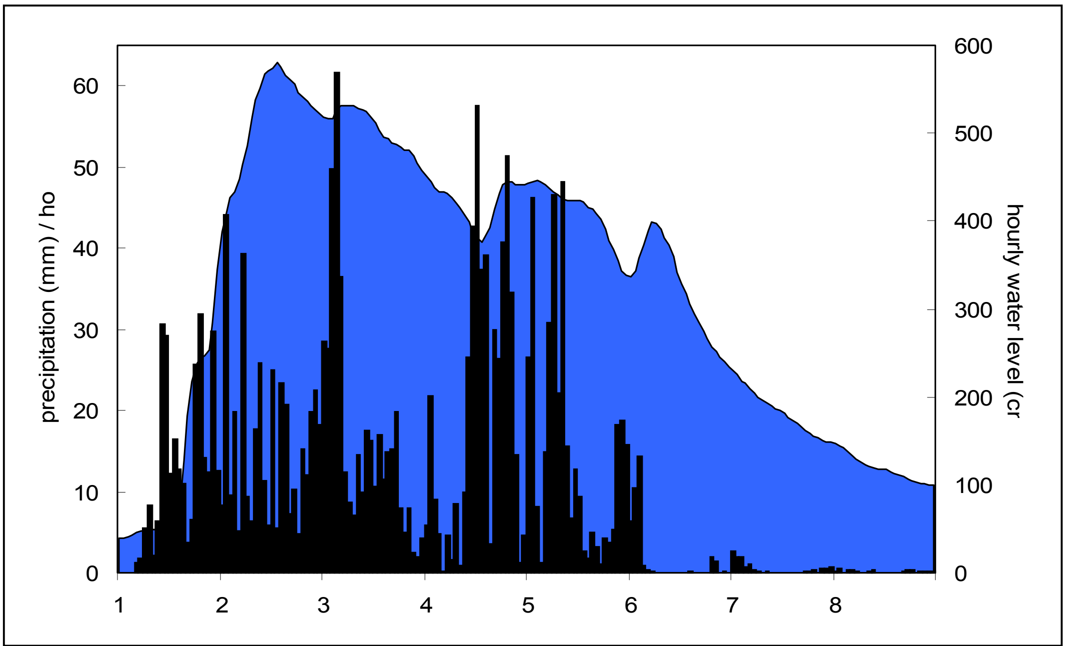

Figure 2.8. Timing of precipitation in Nam Dong and water level response (above N.D.) of the ***Perfume River*** *in Hue during early November 1999.*

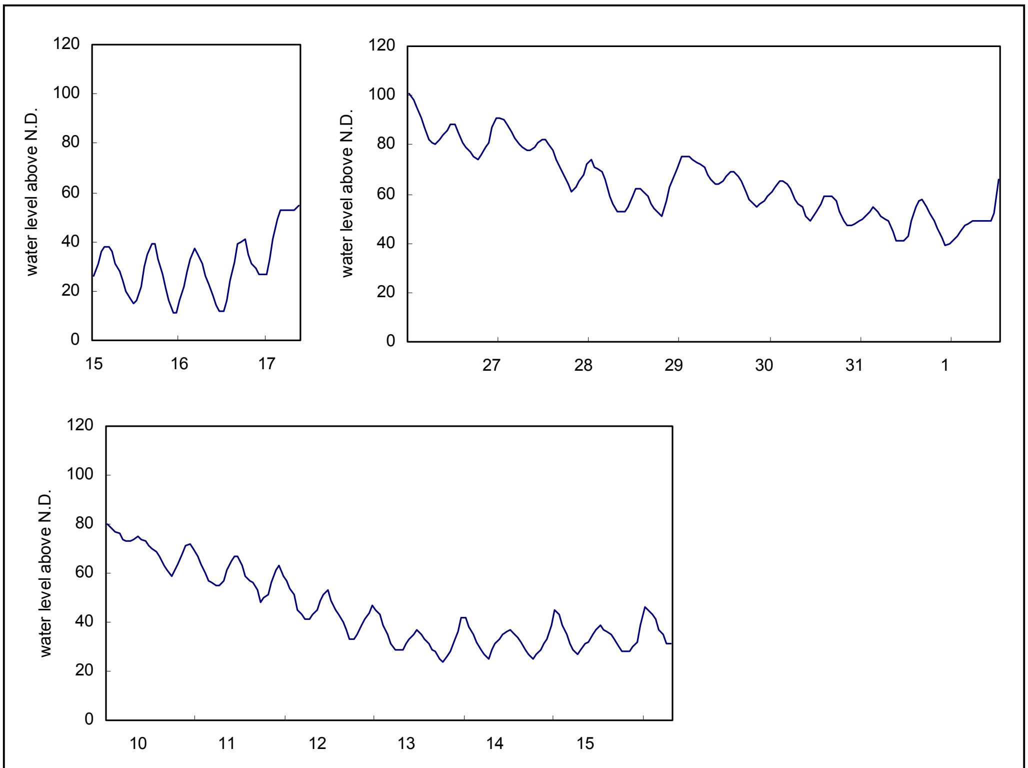

Figure 2.9. Tidal cycle (water level above N.D.) as observed in the Perfume River in Hue at the station Kim Long. Details of the previous graphs.

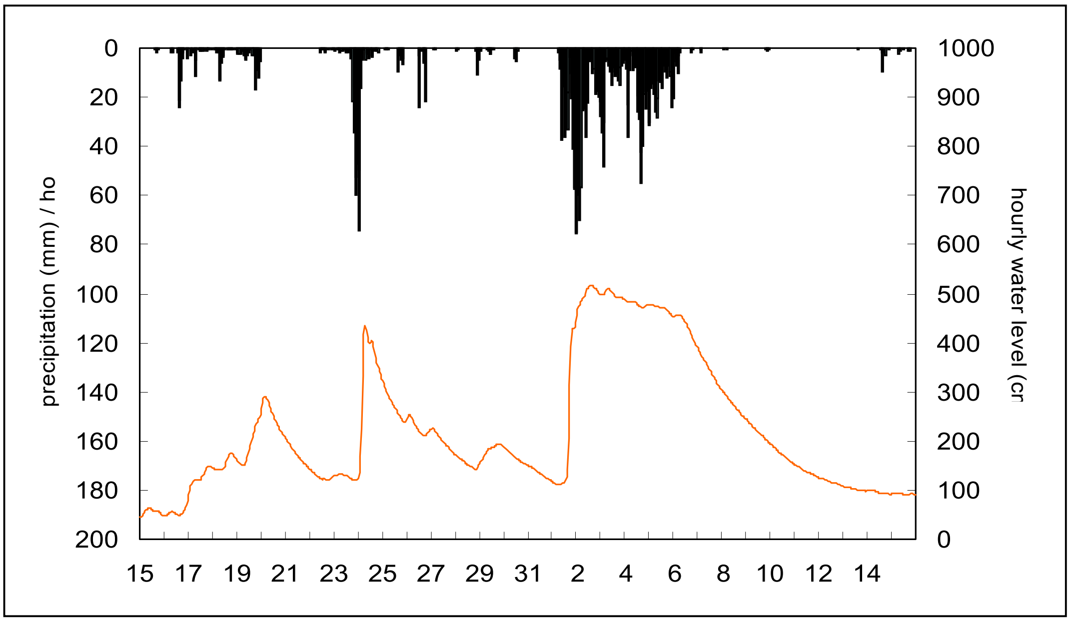

Figure 2.10. Hourly precipitation at the station of A Luoi and water level response (level above N.D.) of the ***River Bo*** *at the hydrological station of Phu Oc (north-west of Hue) from October 15 – November 15 1999.*

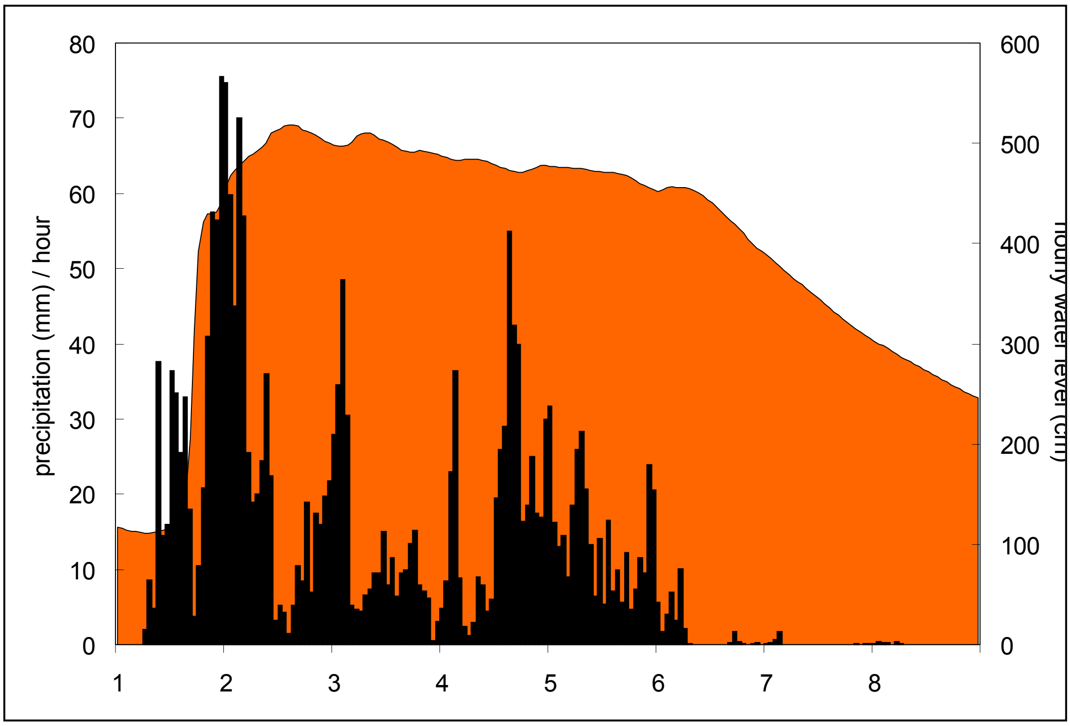

Figure 2.11. Timing of precipitation in A Luoi and water level response (level above N.D.) of the ***Bo River*** *at the hydrological station of Phu Oc early November 1999.*

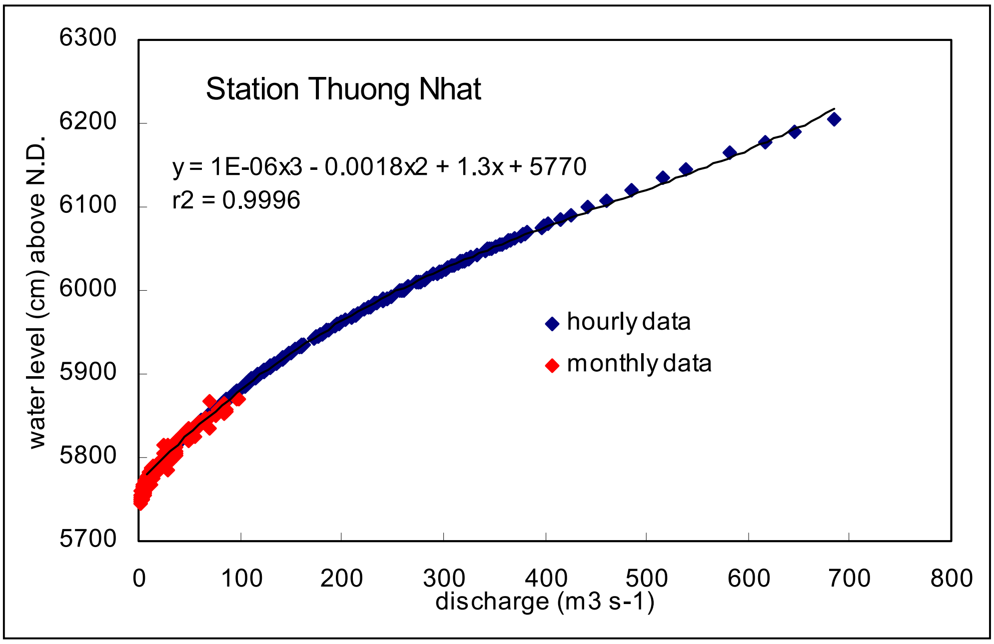

Figure 2.12. Relationship between water level (above N.D.) and discharge of the Ta Trach River at the Thuong Nhat station.

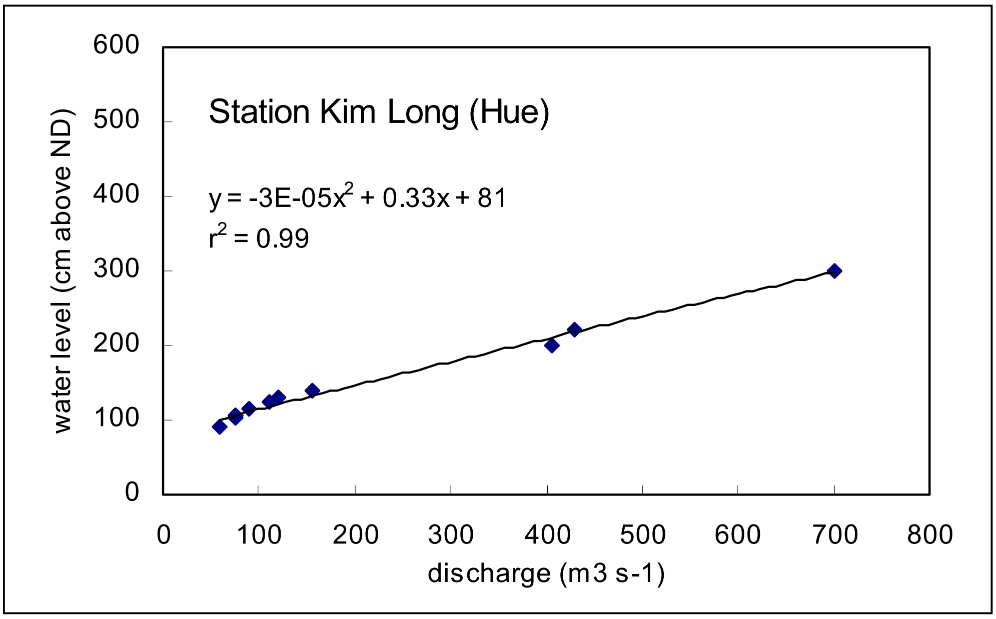

Figure 2.13. Relationship between water level (above N.D.) and discharge of the Perfume River in Hue. The data are from long term monthly averages from the Vulnerability Assessment report (1995).

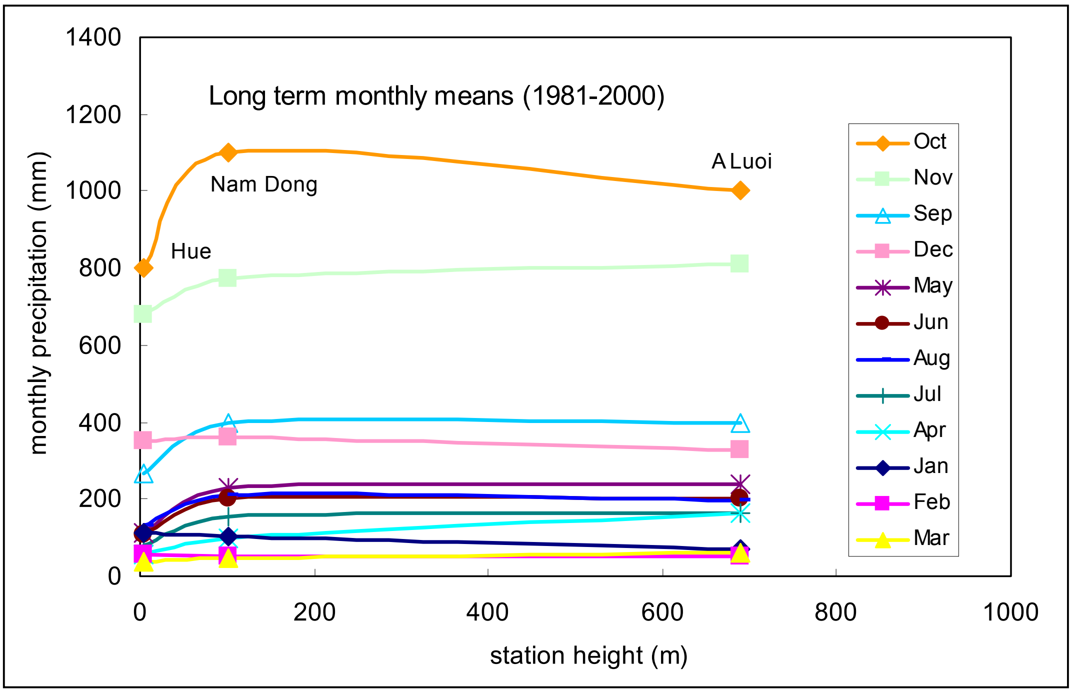

Figure 2.14. Relationship between station height (above N.D.) and monthly amount of precipitation for the stations in Hue, Nam Dong and A Luoi (monthly means for the period 1981-2000).

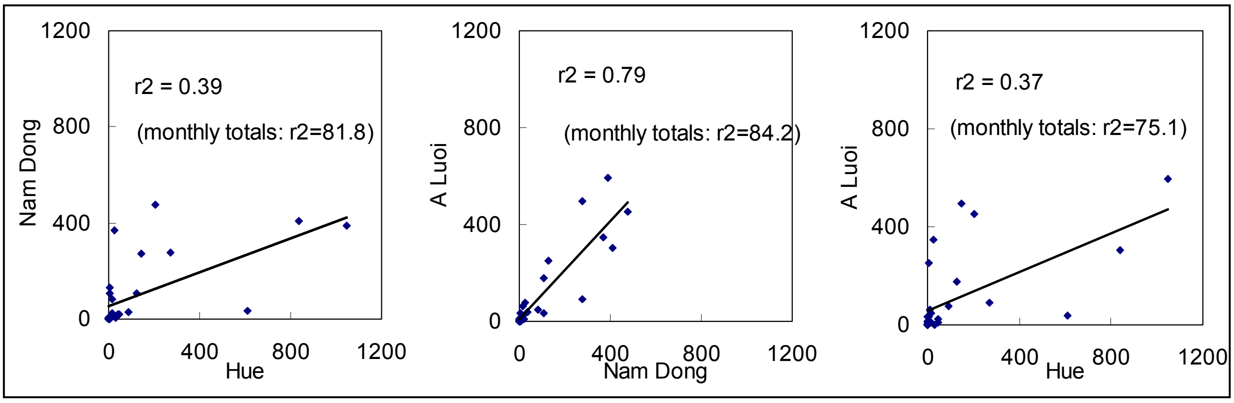

Figure 2.15. Correlation between precipitation at the stations of A Luoi, Nam Dong and Hue; daily totals in millimetres during October 15 – November 15 1999. Also shown are the correlation coefficients for monthly totals over the period 1981-2000.

3. Calibration and validation of the STREAM Perfume model

3.1 Introduction

The STREAM model is a grid-based spatial water balance model for estimating runoff amounts in river basins (Aerts *et al.* 1999). The model has been applied to many larger river basins, such as the Ganges-Brahmaputra-Meghna, Rhine, Zambezi and Yangtze Basins (Van Deursen and Kwadijk 1994; Aerts *et al.* 1999).

The CZMC has commissioned Resource Analysis to apply the STREAM model to the relatively small catchment of the wider Perfume River in TT Hue Vietnam in the year 2000. From this model (Stream Perfume 4.0), a demonstration cd-rom with the outline of the model and the results has been made available (Resource Analysis 2001). The model for the Perfume River was updated in March 2002 by IVM with two new data sets consisting of both a new land use and soil map. The land-use map was used to calculate the potential evapotranspiration, and the soil map to calculate the maximum water-holding capacity of the basin surface. The results of this modelling exercise are discussed in Aerts and Bouwer (2002a). This model uses a set of input data of long-term averages for monthly precipitation and temperature.

This paper describes the results of a first calibration and validation exercise for the Perfume River Basin in Thua Thien Hue Province in Vietnam, based on observational data over the period 1980–2000. The necessary data on meteorology and hydrology (river discharges) have been kindly provided by the Hydro-meteorological Service of Vietnam (HMS) and Mr. Lieu (University of Hue). This set included information on both monthly discharges and water levels for five stations. The monthly dataset has been previously analysed, together with some hourly data for the period between 15 October and 15 November 1999 including the flooding due to the passage of a on the typhoon (Chapter 2). This preliminary analysis showed that the data was very accurate, and that it provides a promising basis to validate and calibrate the STREAM model. The dataset has been split into two time slices; the period 1981–1990 and the period 1991–2000. The first period has been used to calibrate the model. The second period has been used to validate the model.

Calibration and validation was performed on the basis of discharges. However, some of the stations only provided water levels, and these numbers needed to be converted into discharges using a regression analysis (see Chapter 2). Apart from comparing discharges in calibration - validation exercise, the model was also validated by comparing model drainage patterns with drainage pattern provided in the VA study (Vietnam VA 1995) and by comparing model evapotranspiration amounts with field observations.

Before running the model with the new data, the river basin extent has been slightly modified, as it appeared that rivers in the current model, located in the southwestern part of TT Hue Province, do not transport water to the coastal area but rather to the country of Laos on the eastern border of TT Hue Province. The basin area extent is now about 4066 km^2, compared to the previous 6200 km^2.

3.2 Data preparation

Input parameters for the model are precipitation, temperature, soil and land-use characteristics, next to a number of basic descriptive parameters such as basin outline and flow direction. Table 3.1 gives an overview of the data that was available for this validation and calibration exercise.

Station name	River	Period	Measure	Source
Meteorology				
Nam Dong		1980-2000	temp., precip.	HMS
A Luoi		1980-2000	temp., precip.	HMS
Hue		1980-2000	temp., precip.	HMS
Discharge				
Thuong Nhat	Ta Trach	1981-2000	m^3 per second	HMS
Duong Hoa	Ta Trach	1980-1990	m^3 per second	Mr. Lieu
Binh Dien	Huu Trach	1980-1990	m^3 per second	Mr. Lieu
Kim Long	Huong River	long-term averages; unknown	m^3 per second	Anonymous, 1973
Water level				
Kim Long	Huong River	1980-2000	cm above N.D.*	HMS
Phu Oc	Bo River	1980-2000	cm above N.D.*	HMS
Cross sectional areas				
Hue 3	Huong River	April 5 and 11 1997	water depth, level, and speed	Mr. Lieu

* National Datum

Table 3.1. Monthly datasets available for the Perfume River Basin. (For locations see Figure 2.2)

The precipitation and temperature data have been inserted in the model by first transforming the tabular data into maps using a template for the geographical distribution of both parameters. This process is being described below.

3.2.1 Precipitation

Data on monthly precipitation amounts was available for 20 years. For the entire time-series, see Figure 2.3.

The spatial distribution for the precipitation was estimated using a map of the total yearly precipitation amounts. From this map, three different regions were identified, to which the values of the meteorological stations were assigned (Figure 3.1). This resulted in a series of monthly precipitation maps for the period 1980–2000. These patterns could be refined when taking into account seasonal differences.

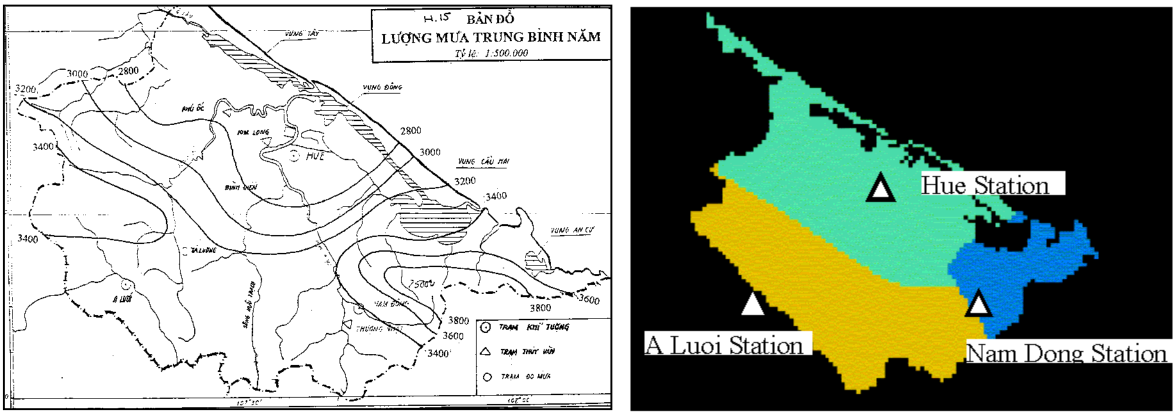

Figure 3.1. Precipitation patterns in Perfume River Basin.

3.2.2 Temperature

Yearly average temperatures over the period 1980–2000 are shown in Figure 3.2. The differences in temperature between the three stations are due to the difference in the height above sea level of the stations. An increase of temperature over time can be observed for the two mountain stations, in particular for the highest (A Luoi).

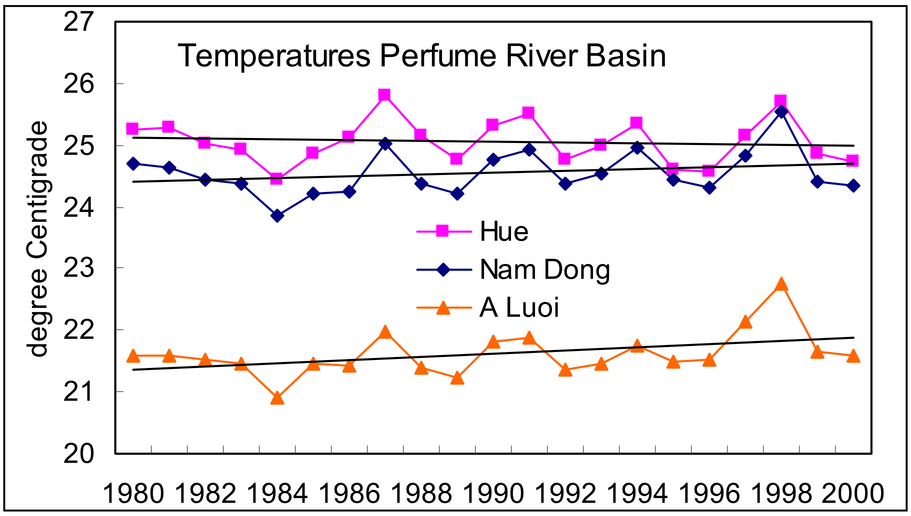

Figure 3.2. Yearly average temperatures at three stations in the Perfume River Basin.

The transformation from tabular data to a spatial distribution of temperatures has been established using a digital elevation model (DEM) of the region. The DEM was derived from the GTOP30 dataset of the United States Geological Service (available from http://edcdaac.usgs.gov/gtopo30/gtopo30.html).

Topographic height was classified into three elevation regions, based on the elevation of the three stations. Temperatures for each month were then assigned to the three regions (Figure 3.3), creating a series of temperature maps for the period 1980–2000.

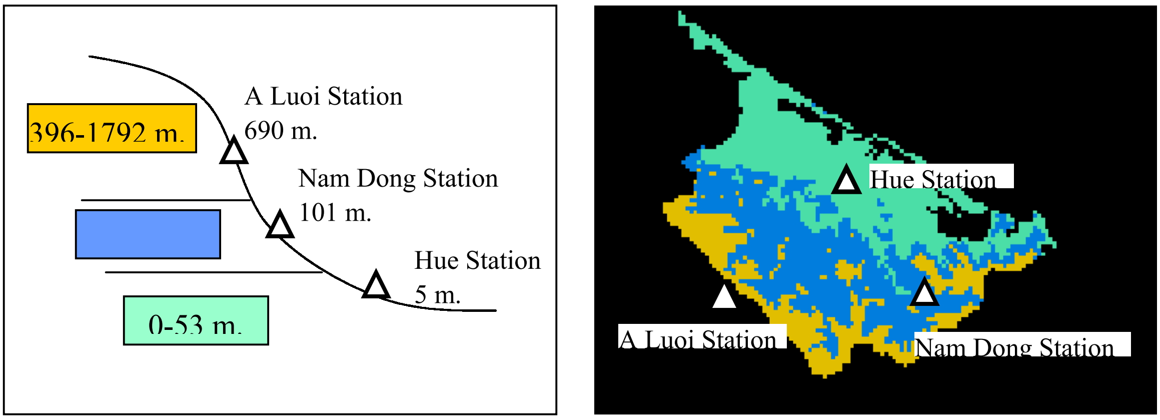

Figure 3.3. Temperature regions identified in the Perfume River Basin.

The calibration exercise focuses on the period 1981–1990 and consists of first making sure that the simulated yearly amount of water in mm that yearly passes a particular point in the basin matches the observed yearly discharges. Next, measured and observed discharge peaks and base levels are compared and calibrated. This is done for the stations for which reliable discharge data are available. These are the stations of Thuong Nhat, Duong Hoa and Binh Dien. For comparison, the calibration results for the stations of Kim Long (Huong River) and Phu Oc (Bo River) are shown as well. However, it must be stated that since the model has been calibrated on the former three stations, the calibrations for the latter two not necessarily needs to yield good results. In other words, discrepancy between simulation and observed discharges at particular stations is possible over the calibration period.

Finally, the validation exercise focuses on the period 1991–2000 and involves the comparison of the simulated discharges with the observed discharges without any further model adjustment. Additionally, the amount of evapotranspiration and the drainage pattern were compared.

3.3 Calibration results

The STREAM model was calibrated using datasets for the three stations of Thuong Nhat (Ta Trach River), Duong Hoa (Ta Trach) and Binh Dien (Huu Trach River). These stations are located higher up the catchment. Only for these stations discharge series were available for the period 1981–1990. Datasets for the same stations for the period 1991–2000 were used to validate the model.

3.3.1 Calibration of the upstream stations

First, the model was adjusted by changing the modelled amount of evapotranspiration until the average yearly amounts of water that passes two stations was equal to the observed average yearly amounts. In Table 3.2 the results from the calibration are shown. Total amounts of water (in m^3 per second) were translated to millimetres by multiplying discharge rates times the surface area of the catchments lying above a station. The model was considered to be performing well once the simulated average amount at the station of Duong Hoa (2136 mm) fairly well matched the observed amount (2168 mm). After calibration, this amount is only being underestimated by about 1.5%. At the station of Thuong Nhat the estimation was about 6.7% too low, on average.

Duong Hoa

surface area (km2)	680		644

	observed average (1980-1990)		modelled average 1981-1990	
	total in m3	total in mm	total in m3	total in mm
Jan	30	114	41.0	165
Feb	21	79	26.1	105
Mar	16	62	17.2	69
Apr	12	44	14.1	57
Mar	23	89	20.2	81
Jun	32	121	16.3	66
Jul	15	58	15.8	64
Aug	17	65	14.7	59
Sep	47	180	37.2	150
Oct	148	562	133.3	537
Nov	144	549	127.9	515
Dec	64	244	66.8	269
total		2168		2136

Thuong Nhat

surface area (km2)	200		234

	observed average (1981-1990)		modelled average 1981-1990	
	total in m3	total in mm	total in m3	total in mm
Jan	9	119	14.2	158
Feb	6	74	9.1	101
Mar	4	53	6.0	66
Apr	4	48	5.3	59
Mar	10	127	7.2	80
Jun	10	125	5.9	65
Jul	6	76	6.3	70
Aug	7	89	5.2	58
Sep	12	162	14.3	159
Oct	48	627	48.1	532
Nov	40	515	46.9	519
Dec	20	264	23.5	260
total		2277		2126

Table 3.2. Calibration results for the stations Duong Hoa and Thuong Nhat (Ta Trach River).

But not only the total amounts were considered, also the yearly distribution of the amounts is important, characterized by ‘peaks’ and ‘base flow’ levels. Hence, the estimated monthly amounts at the three stations were compared to the observed amounts. The results are shown in Figure 3.4, and it can be stated that the model simulations very well match the observed discharges for the two stations of Thuong Nhat and Duong Hoa.

The base flows as well as peak flows are well simulated, except for the peak flow in November 1990, which is too high. Possibly, an incorrect simulation of the rainfall distribution is the cause. Timing of the peak-flow at the station of Binh Dien seems to be simulated a little bit too early. Perhaps there is some lag-effect in the river, like a reservoir, that causes a delay in the actual flow timing.

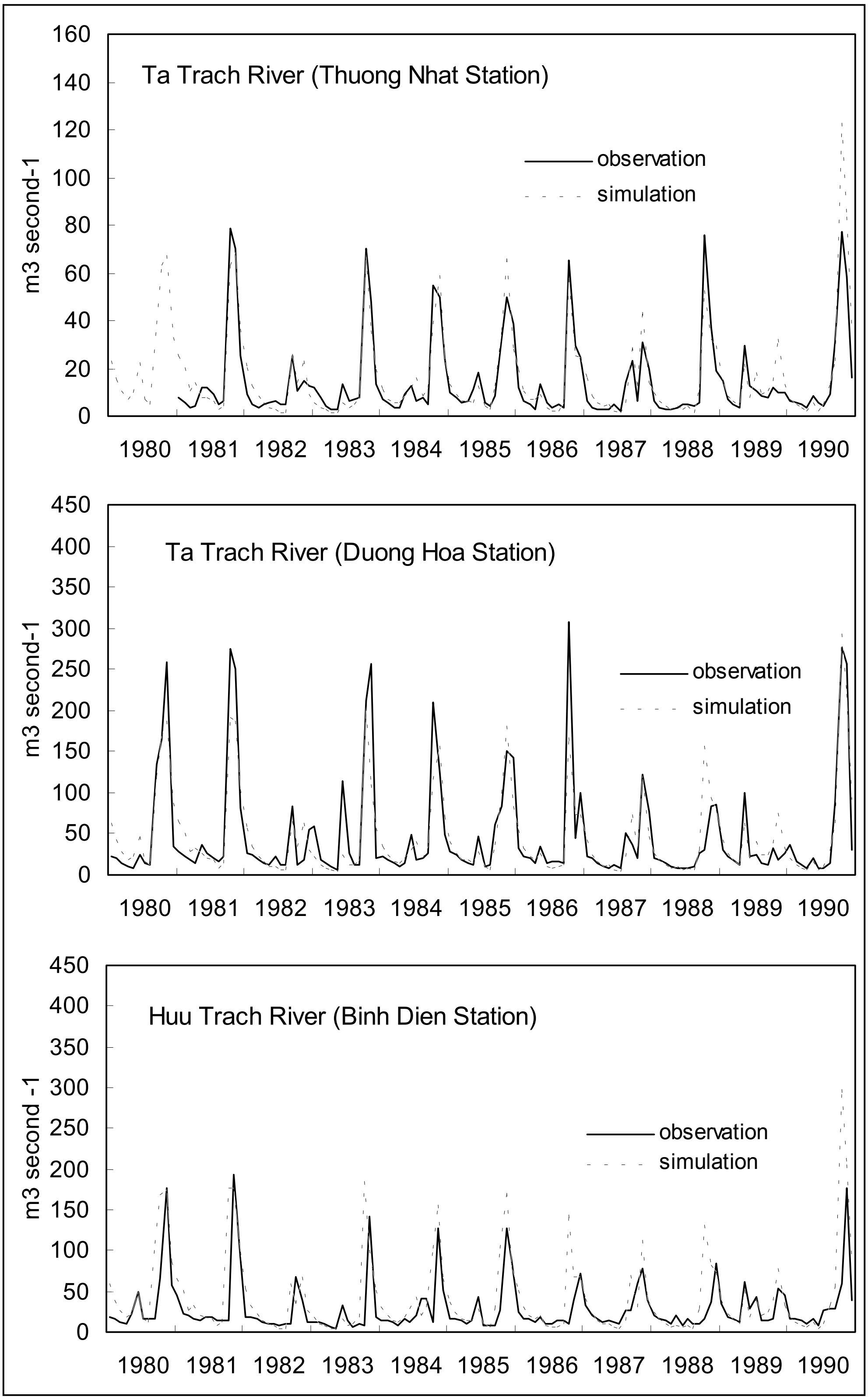

Figure 3.4. Calibration results of the STREAM model for three stations. Note that at Thuong Nhat Station no observational data were available for the year 1980.

3.3.2 Applying calibration results for the downstream stations

Next, the results were compared to the downstream stations. These are the stations Kim Long (Huong River close to Hue) and Pho Oc (Bo River; in the northeast). However, for these stations only water-level data were available. In order to transform water levels into discharges, we used long-term average discharges for these stations (data from Anonymous, 1973), and compared these long-term average discharges with long-term average water levels (see also Section 2.3). These two series were used in a regression curve, shown in Figure 3.5. Next, the regression equation was used to transform monthly water level data over the period 1981–2000 into discharges. An important note must be made with respect to the long-term discharge data that was provided. It is not known over what period these long-term averages are taken, and over how many years. In other words, the relationship between the time-series of the water level and the long-term averages shown below is uncertain, and they could originate from completely different periods with different seasonal characteristics. Additionally, more information would be needed to verify the quality of these data series.

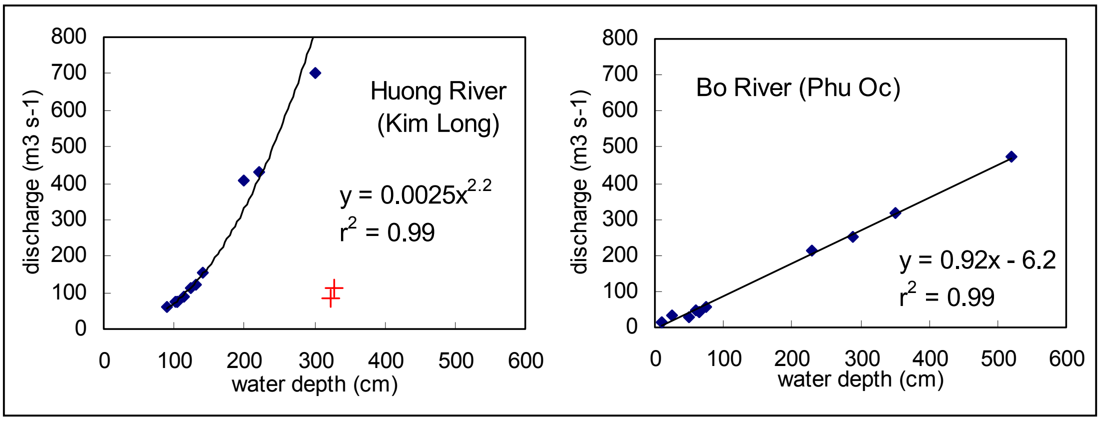

Figure 3.5. Relationship between discharge and water depth for two stations. (Data from Anonymous, 1973 / Hue 13 report, and from two field measurements)

Additional data is available in the form of two field measurements on the river morphology and water depth performed close to Hue. These were kindly provided by Mr. Lieu . These field measurements could provide additional information on the relationship between water depth and discharge near Hue (note that water depth is probably different from water levels). The diagrams from the field observations are provided in Figure 3.6 and Figure 3.7, and show the accompanied estimated discharge. These discharge results are included in Figure 3.5 (red crosses), but they differ quite a lot from the discharges calculated from the water levels, described earlier. Two questions arise when looking at this data: 1) where is the exact location “H3”of the water depth observations, and 2) what is the relationship between water depth at this location and the water depth at the location of the station of Kim Long? The relationship between the water depth at this location and the station in Kim Long and the water levels needs to be further investigated.

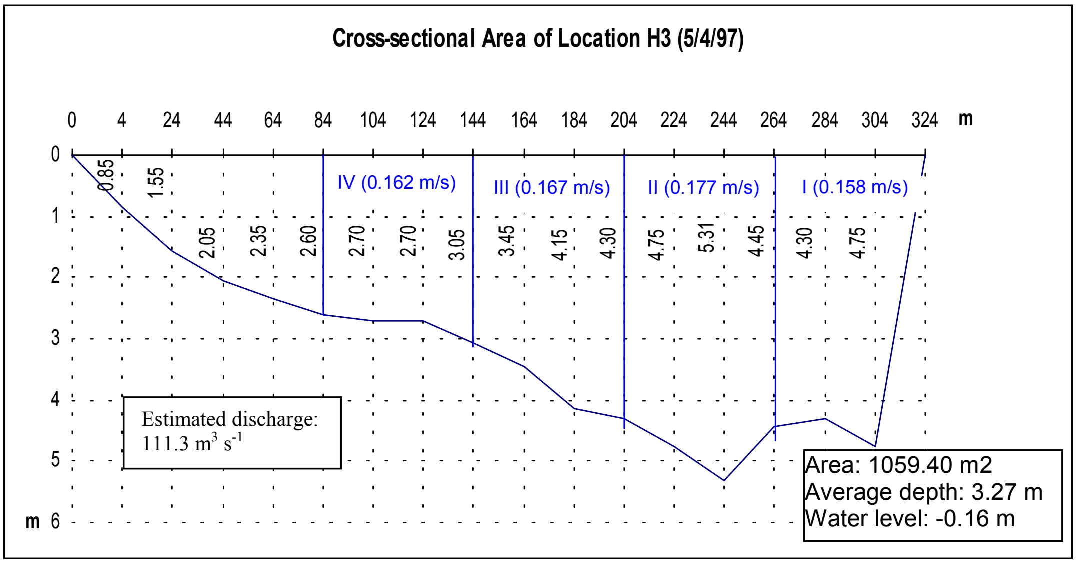

Figure 3.6. Field measurement in Hue at location H3 on April 5, 1997. (Figure courtesy of Mr. Lieu)

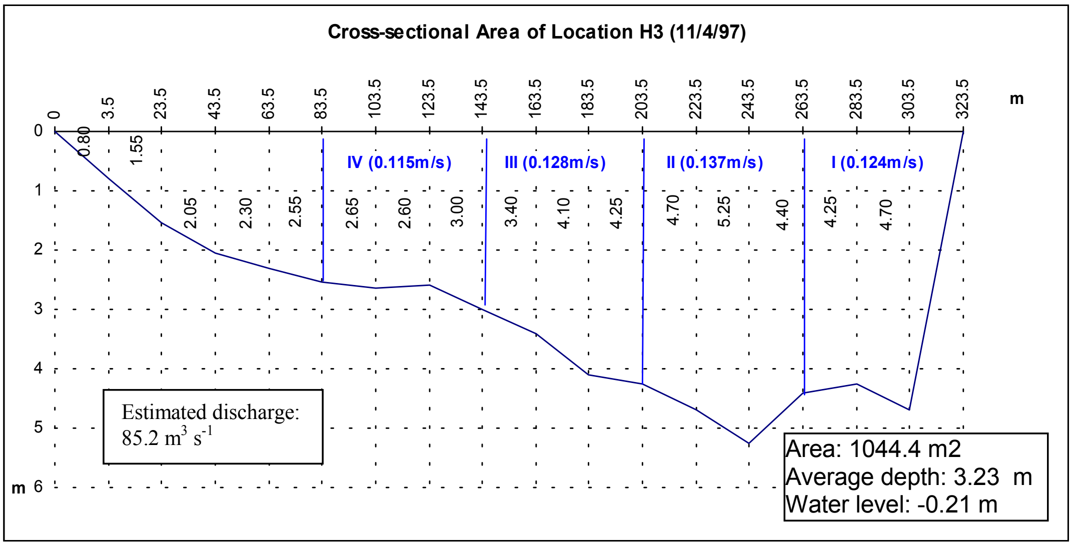

Figure 3.7. Field measurement in Hue at location H3 on April 11, 1997. (Figure courtesy of Mr. Lieu)

From the different parameters given above it was possible to calculate roughly the discharges at the two stations of Kim Long (Huong River) and Phu Oc (Bo River). The dataset contains a large uncertainty since a) it is unknown from what period the average data in the report by Anonymous (1973) were calculated, and b) it is difficult to translate the water depths into water levels.

Figure 3.8 shows the model results for the discharges of the downstream stations of Kim Long (Huong River) and Phu Oc (Bo River) after calibration for the station of Thuong Nhat. From these graphs it is clear that the simulated peaks do not match the observed peak discharges too well, and underestimate base flow at these particular locations, in particular for the Bo River at Phu Oc. Since there are many limitations to the above estimated discharge on the basis of both water levels and water depth, the discrepancy could very well stem from this uncertainty.

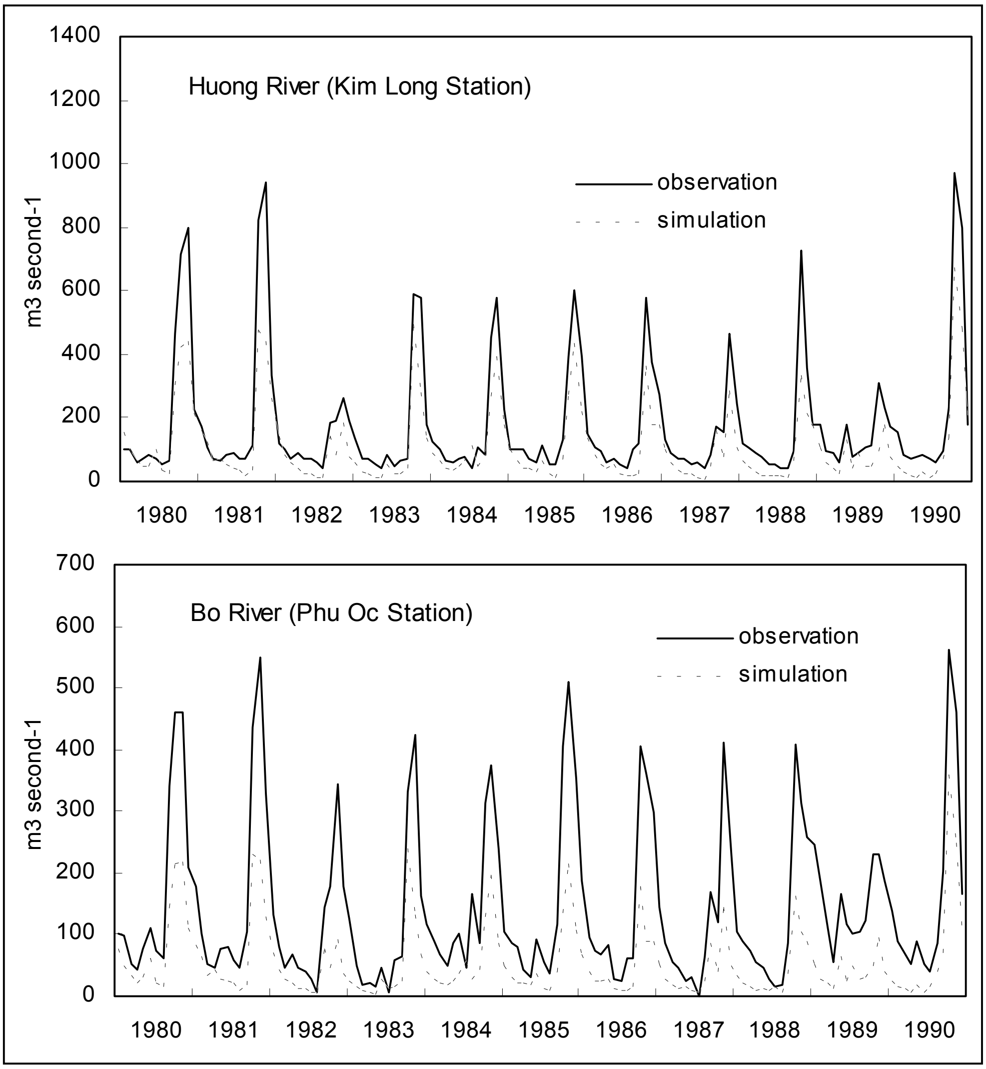

Figure 3.8. Calibration results for the stations of Kim Long and Phu Oc.

3.4 Validation results

The validation consists of comparing the simulated discharge amounts over the period 1991-2000 with the observed discharges for the stations Thuong Nhat, Duong Hoa and Binh Dien, and reconstructed discharges at the stations of Kim Long and Phu Oc. Additionally, the simulated amount of actual evapotranspiration and the simulated drainage pattern are compared to the observations in the Perfume River Basin area.

3.4.1 Discharges

To investigate whether the STREAM model accurately simulates the discharge amounts observed in the basins, the values at the station of Thuong Nhat (Ta Trach River) are compared in Table 3.3. Unfortunately, there is no discharge data available for the two other stations higher up in the catchment (Duong Hoa and Binh Dien) as well as there is no discharge data available for the downstream stations of Kim Long and Phu Oc.

The total yearly average discharge amount that is being simulated by the model for the station of Thuong Nhat very well matches the yearly average amount that is being observed (2856 versus 3007 mm). The total yearly average discharge is only slightly overestimated, by about 5.3% on average per year. From Figure 3.9 it becomes clear that most of this overestimation is occurring during the months in winter and spring.

Thuong Nhat

surface area (km2)		200		234
observed (average 1991-2000)			modelled average 1991-2000	
	total in m3	total in mm	total in m3	total in mm
Jan	12	150	20.5	227
Feb	7	91	14.7	163
Mar	5	62	9.5	105
Apr	5	63	10.0	111
Mar	9	117	10.2	113
Jun	9	116	9.1	101
Jul	7	89	5.6	62
Aug	8	105	6.6	73
Sep	19	244	19.5	216
Oct	55	709	60.2	667
Nov	51	660	61.9	686
Dec	35	450	43.7	484
		2856		3007

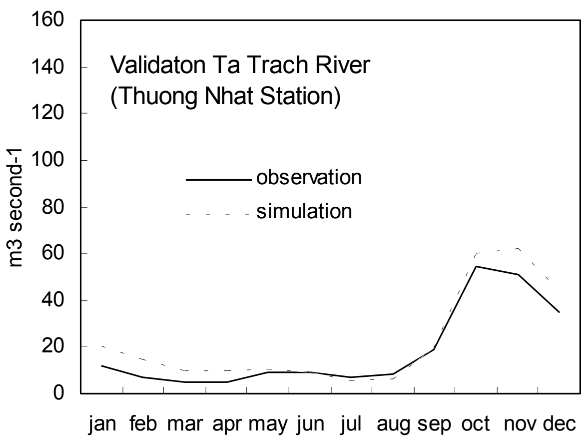

Table 3.3. Average monthly discharge amount in m^3 s^{-1} and mm comparison at Thuong Nhat Station 1991-2000. Surface area is the area upstream of the station.

Figure 3.9. Yearly distribution of discharge amounts simulated and observed 1991-2000.

The results show that the discharges at the station of Thuong Nhat (Taa Trach River) is matching quite well in particular during the drier seasons, although some monthly peak discharges are highly overestimated in particular during the years of 1996 and 1999. This discrepancy could be caused by the techniques that are being used to simulate the spatial rainfall distribution (described in Section 3.2.1). The results of this rather static approach could be that the actual rainfall distribution in a particular month is quite different, which has also consequences for the discharge simulations. The total yearly average discharge is only slightly overestimated at this station, like explained above.

In Figure 3.10, the average monthly deviation of the model compared to the observations for the stations downstream is shown. The model appears to be doing a much better job at reproducing the discharge amounts during the summer months over the validation period (1991-2000) than over the calibration period (1981-1990; see Figure 3.8).

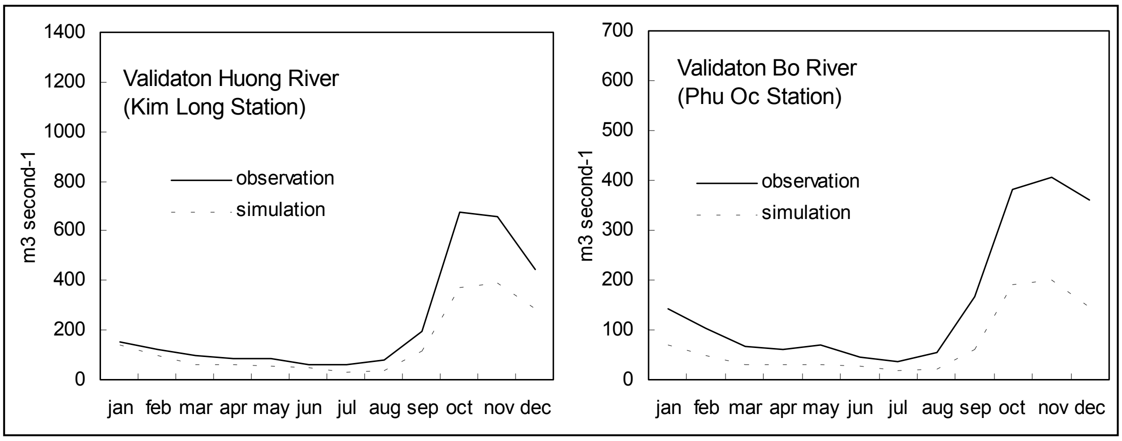

Figure 3.10. Yearly average validation results for the stations of Kim Long and Phu Oc.

Figure 3.11 illustrates the monthly validation results for the stations of Thuong Nhat, Kim Long and Phu Oc for the years 1991-2000. For the station of Thuong Nhat the discharges are simulated quite well, except for some peak discharges, notably in the years 1999 and 1996.

Discharges for the stations of Kim Long (Hue) and Phu Oc were calculated using a regression equation between water levels and long-term average discharges, explained under the calibration section. Any deviations for these two stations (in particular peak discharges) can be attributed to the uncertainty in the regression analysis. For the station of Kim Long (Huong River) the observed discharges during the year are matching the observed amounts quite well, except that the peak flows during the months of October, November and December are too low.

The same holds true for the station of Phu Oc, except that the peak flow amounts are estimated about 2 times lower than the observed ones. The same could be observed during the calibration phase (see Figure 3.8). It must be noted, however, that the model was calibrated using data for stations located along the Huong River and not the Bo River. This indicates that a separate calibration and validation exercise for the Bo River should be conducted.

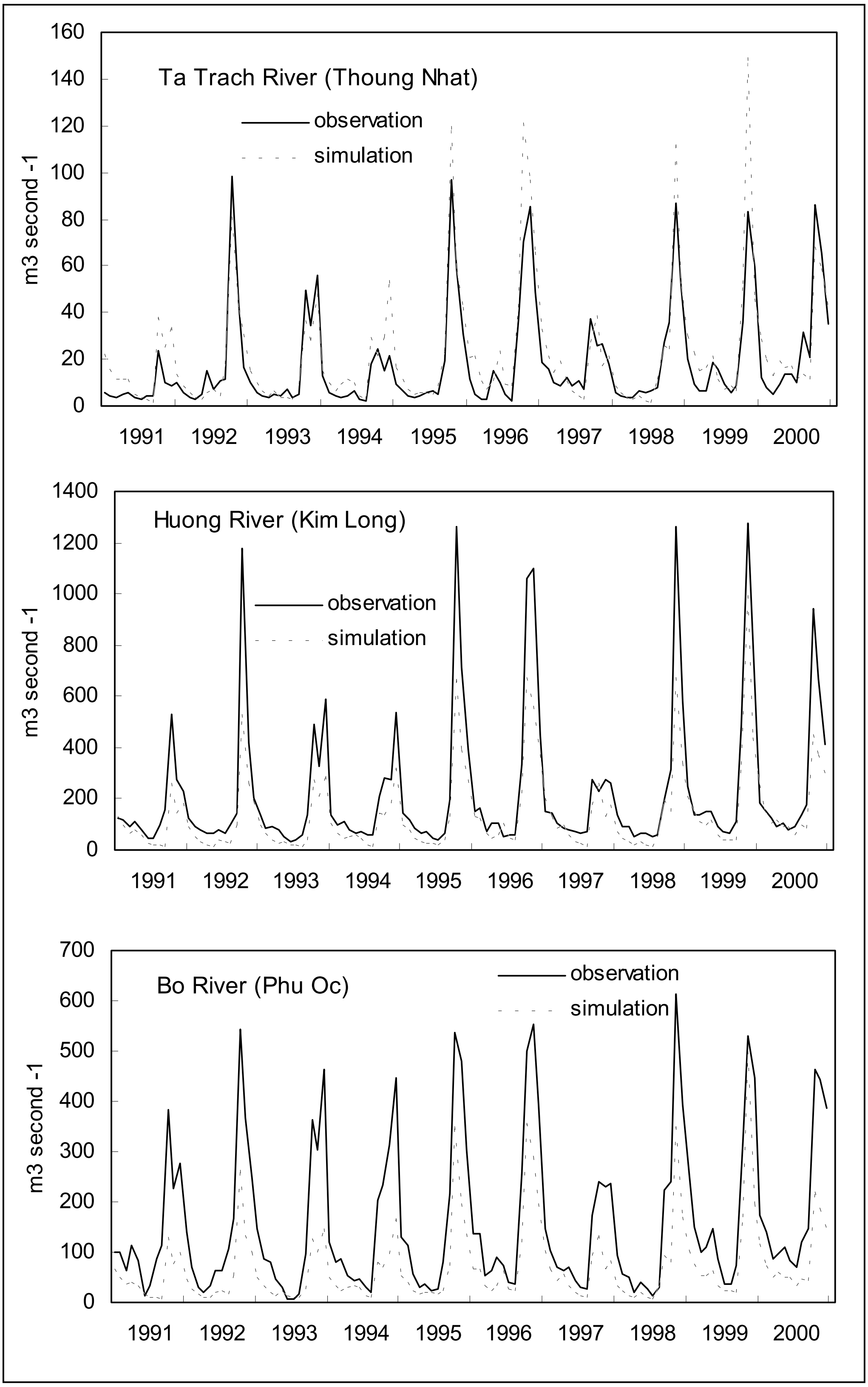

Figure 3.11. Validation results for the stations of Thuong Nhat, Kim Long and Phu Oc for the period 1991-2000.

The simulation results for the stations of Duong Hoa (Ta Trach River) and Binh Dien (Huu Trach River) are included in Figure 3.12 for completeness. However, no observational data were available to enable the actual validation of these results.

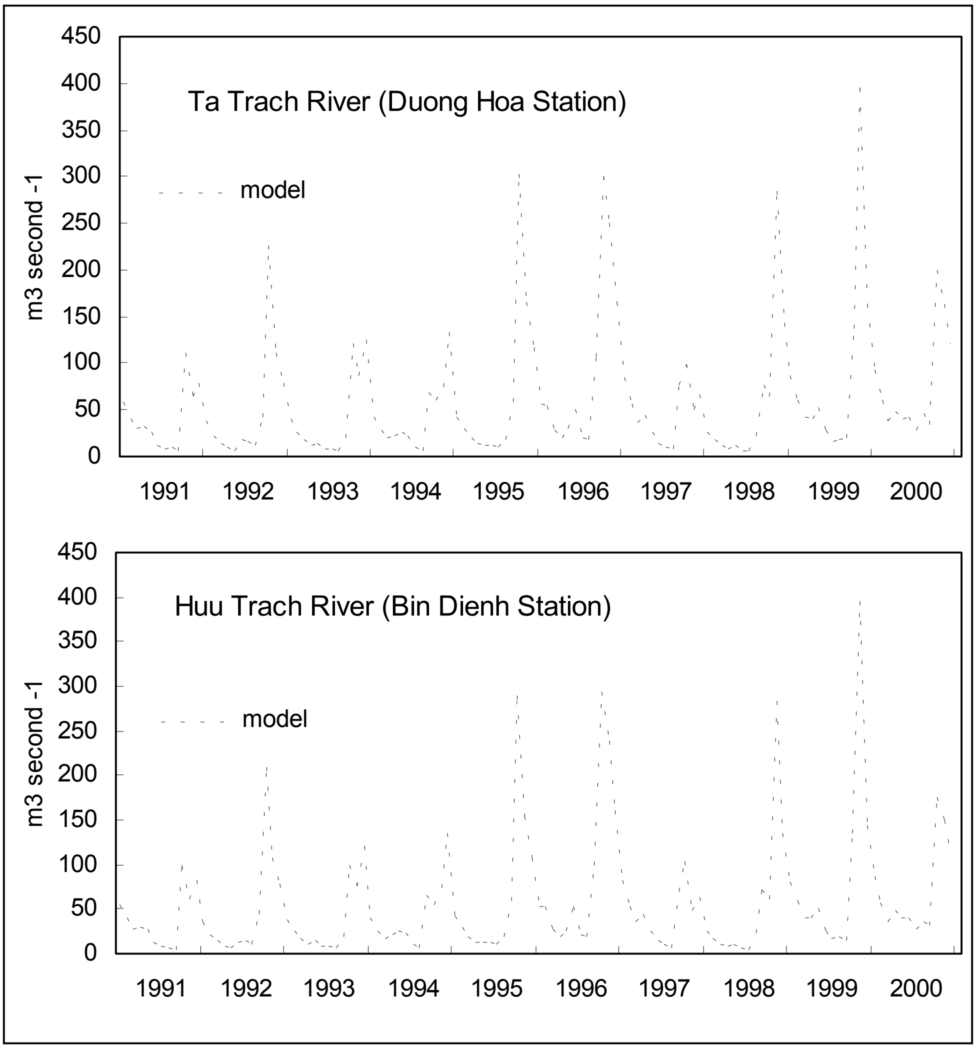

Figure 3.12. Simulated discharges for the stations of Duong Hoa and Binh Dien over the period 1991-2000.

3.4.2 Evapotranspiration

The simulated total yearly actual evapotranspiration – between 989.3 and 1006.2 mm per year for the period 1981-1990 and 1991-2000 respectively – very well matches the observed total yearly actual evapotranspiration. The reported yearly amount in the Vietnam VA study of 1995 is about 1000 mm per year.

Figure 3.13 shows the monthly distribution of the simulated evapotranspirarion. However, no monthly data was available yet to compare this seasonal pattern with observations.

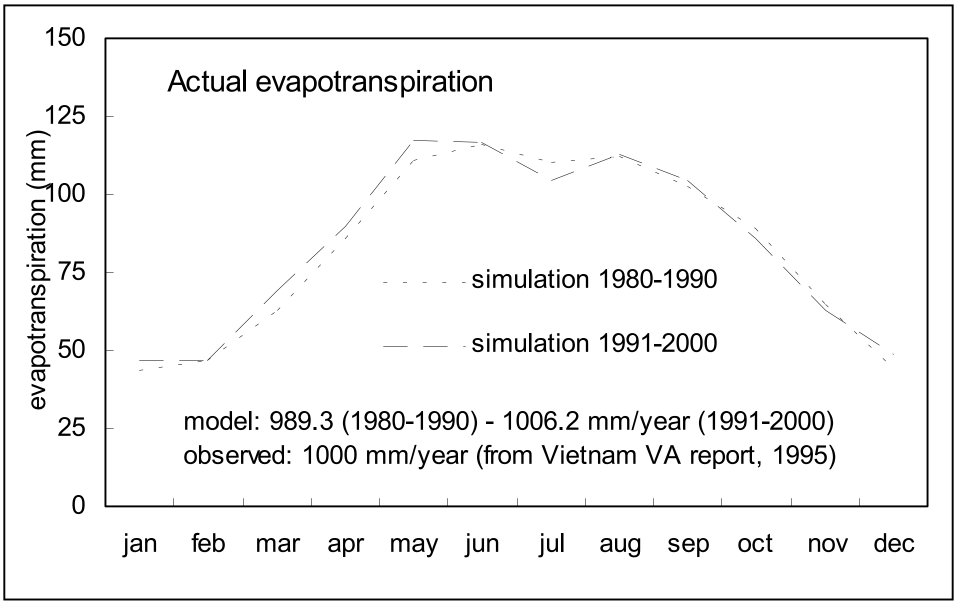

Figure 3.13. Simulated actual evapotranspiration for the periods 1980-1990 and 1991-2000.

3.4.3 Drainage patterns

The drainage patterns that are simulated by the STREAM model appear to resemble the observed patterns in the upstream areas quite well (see and below). The patterns in the coastal area – in particular the location of the downstream end of the Bo River close to the lagoon – is not very well approached. The 1 square km sized digital elevation model for the area is the likely cause here, as this DEM tends to even out small differences smaller than 1 km2 that tend to determine the course of the river.

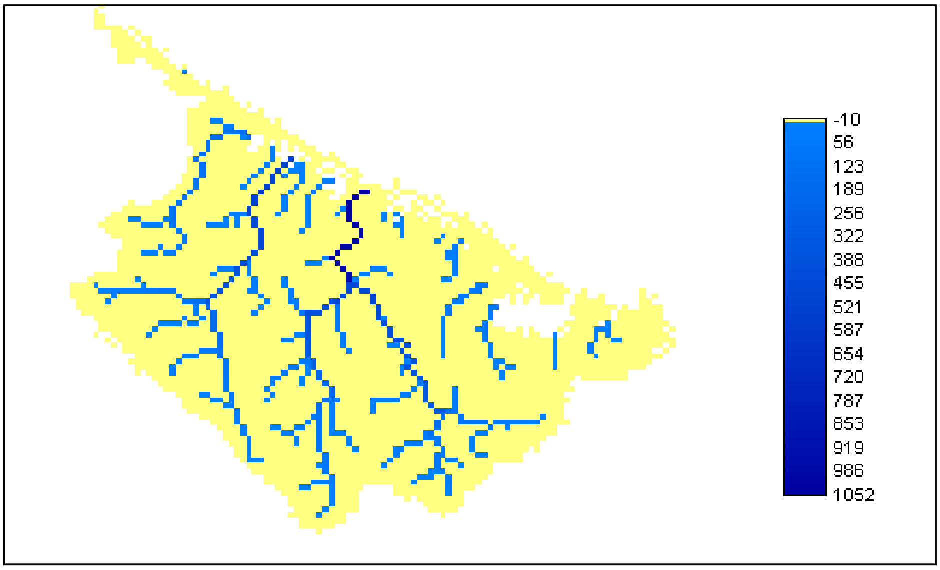

Figure 3.14. Simulated drainage pattern; discharges in m^3 per second (November 1999).

Figure 3.15. Observed drainage pattern, and locations of the hydro-meteorological stations.

3.5 Conclusions and remarks

The results show that the model very well predicts discharges in the upper reaches of the river basin, but discharges closer to the coastline are not very well represented. This is probably due to the fact that set of observed discharges from the low-lying stations were derived from water levels in a regression analysis. The discharge data in the regression analysis was rather limited, since only the monthly average discharge data provided by Anonymous (1973) was available. This means that the model at the downstream stations still may be right, and that this can be verified by improving the observational set of data. The regression analysis would certainly improve when more discharge data would be available for these low-lying stations.

The annual discharges simulated by STREAM are matching very well both calibration and validation numbers. When examining, however, the peaks and base flow of the simulations, it appears that base flow is underestimated in summer. This is caused either by an overestimation evapotranspiration and the lack of incorporating routing and irrigation use and storage in the model.

Discharge patterns of the River Bo are not very well simulated, but again it should be noted that a) the model was calibrated towards discharges of the upper reaches of the river Huong (Taa Trach and Huu Trach), and b) the amount of evapotranspiration very well matches the observed annual amounts.

From the discussion above we can conclude the following:

- There is a need to better understand downstream discharges at the stations of Kim Long (Huong River) and Phu Oc (Bo River).
- The relationship between cross-section measurements and the observed water-levels at the stations is not clear. A better understanding can improve the observational dataset of the discharges at the downstream stations and therefore also the calibration and validation of the STREAM model.
- The impact of land-use change over the past few decades could be investigated on the basis of some analyses already preformed on aerial photographs and satellite imagery.
- The development of a separate model for the Bo River seems warranted, since the calibration and validation exercise shows that the behaviour of this river is quite different from the Huong River.
- The interpolation of the rainfall measured at the different stations seems to be overly simplified, and may cause some of the discrepancies observed in the calibration and validation exercises. A better and more dynamic way of interpolation may yield better results. For this there is some model development work to be done.
- The drainage pattern of the rivers is not very clear; i.e. is the map depicted in Figure 14 really accurate?

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Annex I. Soil erosion estimate

A preliminary, rough estimation of soil erosion in the TT Hue province

by
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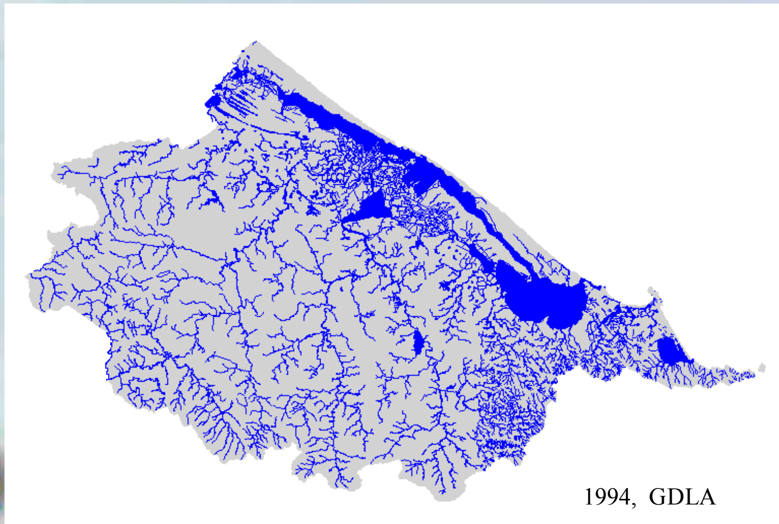
Hanoi, CCP/VN-ICZM Workshop, September 16, 2002 Hanoi

An estimation of soil erosion in the Perfume River basin using GIS



Universal soil loss equation

(USDA, 1978)

$$A = R * K * LS * C * P$$

where
A = tons soil loss per hectare per year,
R = rainfall erosivity factor,
K = soil erodibility factor,
LS = slope factor,
C = vegetation cover factor,
P = conservation practice factor

Rainfall erosivity factor (R)

$$R = \Sigma_{(i = 1\text{-}365)} 3.24 + 1.79 \ln (x_i)$$

where x_i is rainfall amount on day i

We assume R ≈ 600
(number taken from north east Thailand)

Soil erodibility factor (K)

The soil map is reclassed to represent the erodibility factor values from the table:

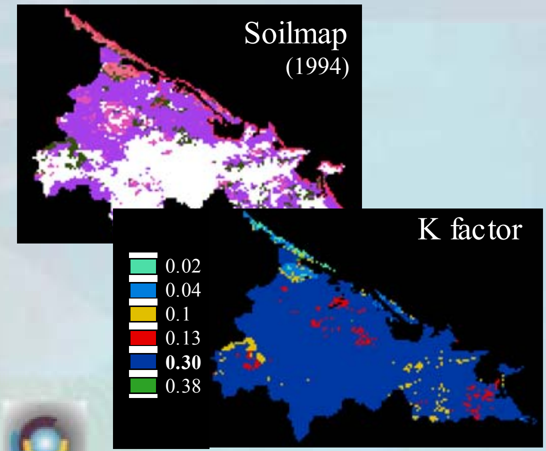
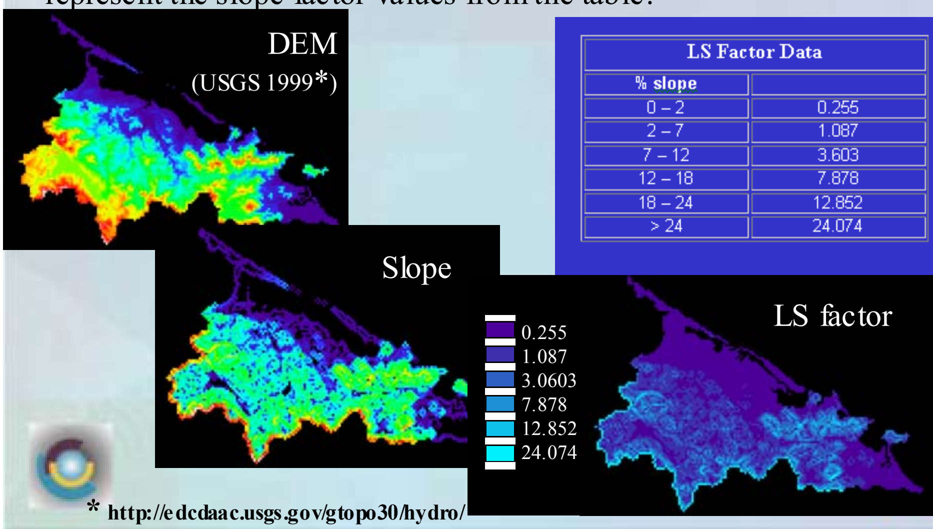


Table 2: K Factor Data	
Textural Class	**Average**
Clay	0.22
Clay Loam	0.30
Coarse Sandy Loam	0.07
Fine Sand	0.08
Fine Sandy Loam	0.18
Heavy Clay	0.17
Loam	0.30
Loamy Fine Sand	0.11
Loamy Sand	0.04
Loamy Very Fine Sand	0.39
Sand	0.02
Sandy Clay Loam	0.20
Sandy Loam	0.13
Silt Loam	0.38
Silty Clay	0.26
Silty Clay Loam	0.32
Very Fine Sand	0.43
Very Fine Sandy Loam	0.35

Slope factor (LS)

Slopes are calculated from the digital elevation map (DEM) to represent the slope factor values from the table:

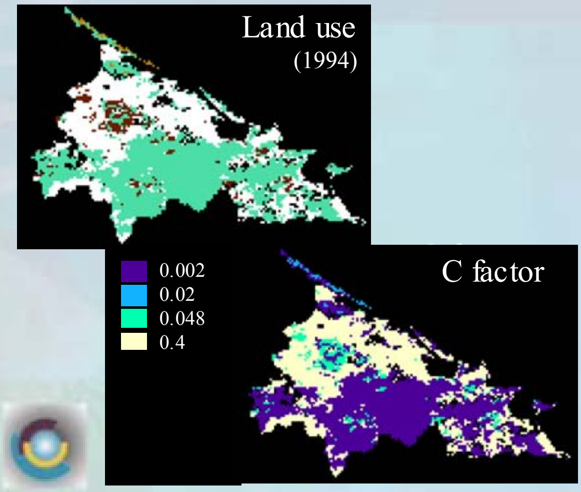
LS Factor Data	
% slope	
0 – 2	0.255
2 – 7	1.087
7 – 12	3.603
12 – 18	7.878
18 – 24	12.852
> 24	24.074



* http://edcdaac.usgs.gov/gtopo30/hydro/

Vegetation cover factor (C)

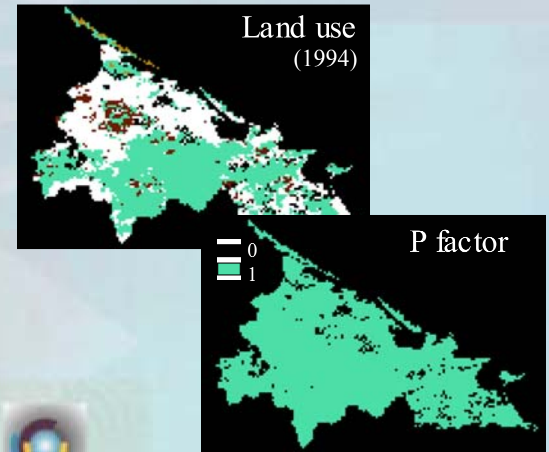
The land use map is reclassed to represent the vegetative cover factor values from the table:



C Factor Data	
Land use	
Rice	0.28
Cassava	0.60
Sugar cane	0.45
Pasture	0.02
Fruit tree	0.0048
Deciduous forest	0.0088
Planted forest	0
Village	0
Water	0

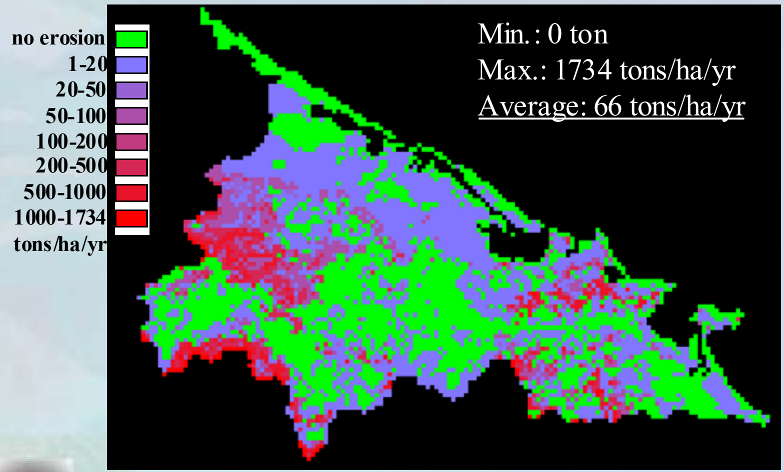
Conservation practice factor (P)

The land use map is reclassed to represent the conservation practice factors from the table:



P Factor Data	
Land use	
Rice	0.0027
Cassava	1
Sugar cane	1
Pasture	1
Fruit tree	1
Deciduous forest	1
Planted forest	0
Village	0
Water	0

Calculation results:
(R*K*LS*C*P)



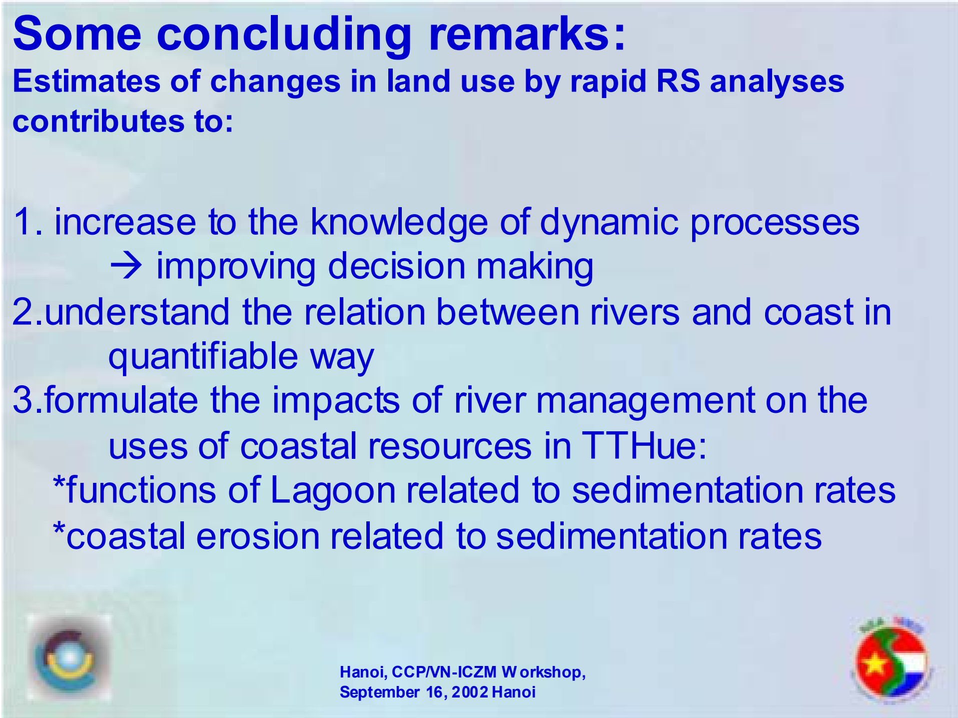
→Estimated loss for entire TT Hue area (6226 km^2)
→≈ 40 million tons/year

The eroded soil material is transported by the rivers to:

1. Laos
2. the TT Hue Lagoon
3. The sea.

Proposed next steps for improvements:

1. Verify the coefficients of the soil loss equation
2. Make first estimates of sediment balances
3. Make field checks.


Some concluding remarks:
Estimates of changes in land use by rapid RS analyses contributes to:
1. increase to the knowledge of dynamic processes
→ improving decision making
2.understand the relation between rivers and coast in quantifiable way
3.formulate the impacts of river management on the uses of coastal resources in TTHue:
*functions of Lagoon related to sedimentation rates
*coastal erosion related to sedimentation rates
Hanoi, CCP/VN-ICZM Workshop, September 16, 2002 Hanoi