Institute of Hydrology

Natural Environment Research Council

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TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL

STRATEGY STUDY - PHASE II

(TELADFLOCOSS 2)

WORKING PAPER NO. 13

PROGRESS WITH REAL-TIME FLOOD FORECASTING

FOR THE INDUS BASIN

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1. INTRODUCTION

1.1 This third Working Paper on real-time flood forecasting, RTFF, provides a brief summary of the work carried out to date and on planned work for the pilot RTFF system for the River Indus Basin. Because the development of the pilot system is currently underway, this paper cannot attempt to provide a final detailed description of the system, which is still evolving. However, the intention is to inform the various agencies of Government of progress to date and to present current development plans for implementation of the pilot RTFF system.

1.2 Installation of the software for implementation of the pilot RTFF system is currently planned for the end of May to coincide with the availability of data from the new data acquisition system, DAS. The software will be installed on one of the SunSparc workstations and will be connected to the RO database system, AWRS II or III, using a dedicated line. The pilot RTFF system will be operated by the consultants during the remainder of the wet season, recalibrated as data from the DAS become available, and the system performance will be reported on in the final report of the study.

2. PILOT RTFF SYSTEM OUTLINE

2.1 The pilot RTFF system being developed has been described in earlier working papers and in responses to comments on those reports. However, for completeness, a brief summary of the system is given below.

2.2 The pilot RTFF system will run on a SunSparc workstation which will be permanently connected to the RO database of telemetry data and will receive a selected set of data sent routinely every 5 minutes by RO using their AWRS software. The data transmission will be controlled by RO with the SunSparc workstation acting as an intelligent terminal during data transmission. Thus some simple error checking on transmission will be possible using a checksum as agreed with the RO, and if the SunSparc detects an inconsistency in the checksum, the RO computer will be asked to re-transmit the data. There will be no facility for the SunSparc to request data from the RO and it has been agreed that the control of data transmission will be carried out by the RO computer.

2.3 Having received the data from the RO computer every 5 minutes, the pilot RTFF system will automatically make a forecast of flows and levels for the Indus basin and will store the results. The forecast will use observed rainfall data only and will use currently available river level and flows to correct automatically the rainfall-runoff model and hydrodynamic model components. Similarly, the system will automatically compute any necessary tidal storm surge correction and apply it within the modelling. This automatically initiated model run will be called a routine forecast, and will be tagged with the time and date of the forecast. Users will be able to inspect the forecast made at any particular time by simply selecting the required results from a list of recent routine forecasts. The user will also be able to initiate special runs to examine a range of "what-if ?" scenarios. This point is discussed later.

2.4 The received telemetry data will be stored on the SunSparc using the Oracle database software, a commercial relational database with a structured query language access facility, SQL. However, users of the pilot RTFF system will not require to know anything about either the Oracle database or its associated SQL; data storage and retrieval will be achieved through a simple menu system, or GUI, written using the Windows system on the SunSparc. This window-based GUI will be the means by which the user operates the pilot RTFF system using a combination of the mouse and keyboard and will avoid users having to learn the UNIX operating system language used by the workstation.

2.5 The modelling software to be used will be based on the RFFS hydrological kernel developed by the Institute of Hydrology. This software can accommodate a range of algorithms for rainfall preprocessing, rainfall-runoff modelling, hydrological channel flow routing and hydraulic modelling of a tidal river. A fairly general model, called the PDM will be used for rainfall-runoff modelling. It is specifically tailored for real-time application and is based on the probability-distributed storage capacity concept. It is described in detail in Appendix B of Working Paper No. 9, Real Time Flood Forecasting For The Indus Basin.

2.6 The RFFS software kernel includes a simple 1-D hydrodynamic model which will be applied to the lower reaches of the catchment, and which will be configured to include the Lower Shenzhen river down to Deep Bay. This model will be configured to mirror that used for the BMP studies, and the results of the BMP modelling will provide the initial model calibration for the pilot RTFF system. The intention is to use the same cross-sectional data, topographic information and fitted roughness values as used for the BMP studies to provide the RTFF model with the best available hydraulic information. We are confident that the hydrodynamic model contained within the RFFS software can be configured to closely reproduce the results obtained in the BMP studies using MIKE-11.

2.7 The flows from the upland tributaries will be input to the hydrodynamic model. The information control algorithm, ICA, within RFFS controls the order of execution of the component models involved. This point is discussed in Chapter 4.

2.8 The user will be able to examine the forecast levels at a predetermined number of sensitive sites, which are discussed in Chapter 3. The forecasts, together with observed and forecast levels and flows for each telemetry site can be examined either graphically or as a tabulation of levels against time. It will be possible to look at the forecasts on the SunSparc screen and also to print or plot these forecast results on either a printer or plotter.

2.9 In general, forecasts will be stored on the SunSparc for a period of days or weeks, but will then be deleted automatically, or purged, from the system in order to conserve disk space. There is a parameter within the pilot RTFF system to indicate the length of time for which results should be stored before being purged. The pilot RTFF system manager will be able to change the setting of this parameter, an optimal value of which will be determined during the pilot study. Because routine forecasts will be generated and stored automatically by the system every 5 minutes, even during periods when flooding is unlikely or impossible, the system must be designed to purge unwanted and old forecast results or else the hard disks will simply fill up. However, there may be periods of time for which the forecasts are of sufficient interest to warrant longer storage, for example the recent floods following Typhoons Warren and Brenda, and the RTFF system will have a facility to flag forecast results to prevent them being purged. This will be achieved by setting a start date and time flag to indicate that from that time results should not be purged. Users must however ensure that this flag is subsequently switched off at the end of the event of interest in order to prevent the hard disk becoming filled. Should the hard disk become full, the pilot RTFF system will print a warning message to the user suggesting that the purge limits flag be checked and suggesting that some results be archived onto magnetic tape.

2.10 As explained above, the pilot RTFF system will operate automatically and will generate a routine forecast of levels every 5 minutes using all telemetry data received up to the time of the model run. However, during a major flood event it may be apparent to the user that further rain is likely and it may be more prudent to run the model using some estimate of this future rain to examine the implications of various "what-if ?" scenarios. This point has been discussed in earlier working papers, and whilst it is clear that reliable quantitative forecasts of rainfall cannot be produced, it is essential that the user has the facility to examine the possible impact of further rain in the short term on the developing flood situation in the lower Indus Basin. This point is discussed further in Chapter 3.

2.11 The following section discusses a number of technical points in rather more detail before progress on software development is described in Chapter 4.

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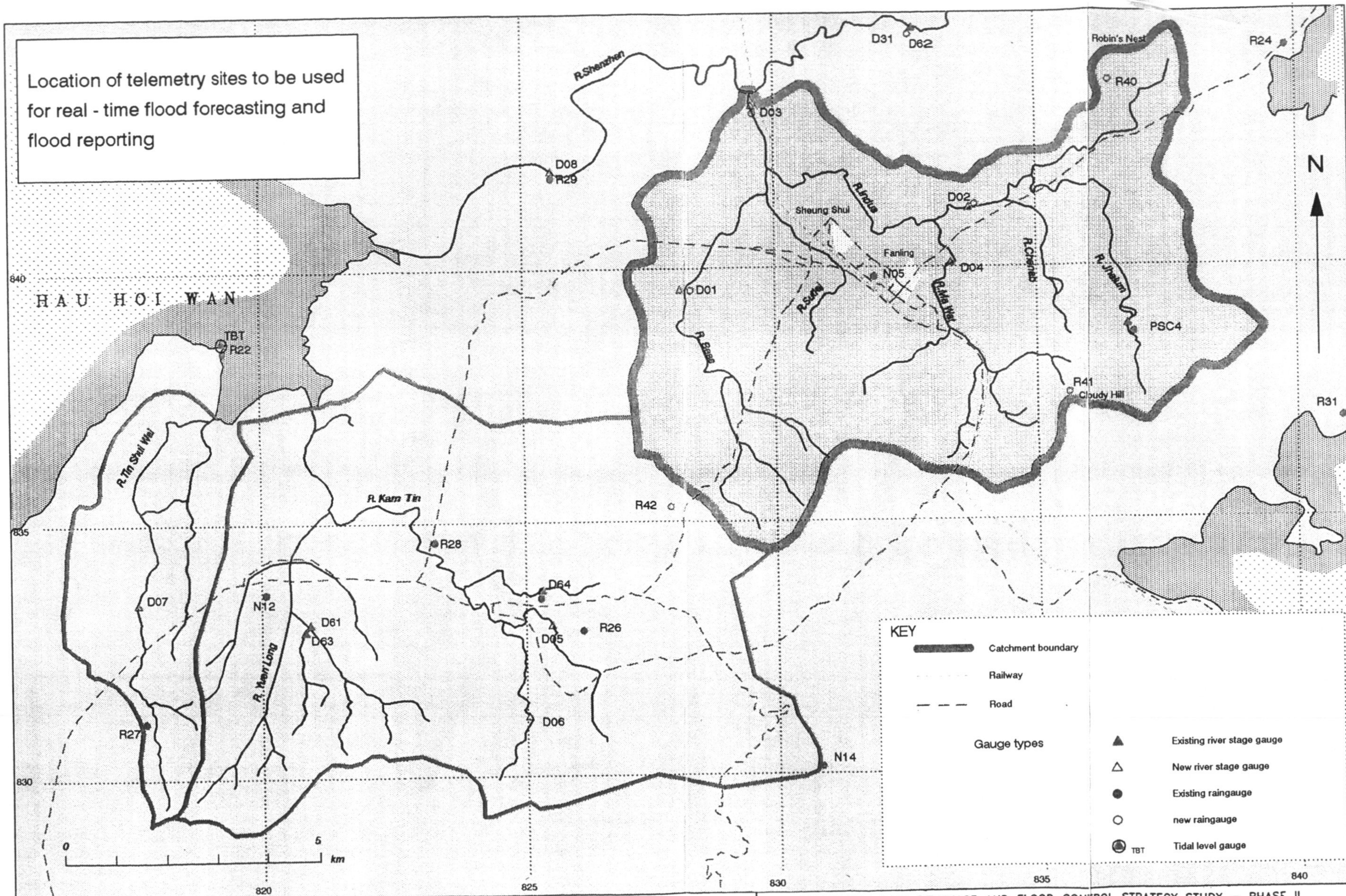
APRIL 1992



TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY – PHASE II

LOCATION OF TELEMETRY SITES TO BE USED FOR REAL-TIME FLOOD FORECASTING AND FLOOD REPORTING	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date JULY 92	Scale NTS
	BINNIE MAUNSELL CONSULTANTS	Initial FAKF	Figure No. 3

3. TECHNICAL ISSUES

Forecast Sites

3.1 During operation of a real-time flood forecasting system it is important not to swamp the user with information or to offer too many choices. The hydrodynamic model will be computing levels and flows at a very large number of cross-sections, but we do not believe that the user would either wish to, or be able to, examine results at all of these during any event. The BMP studies will help to identify the critical sites throughout the lower Indus Basin where flooding is likely, and it is suggested that the user be given a limited list of these critical sites where forecast levels and flows may be examined during an event. This list of sites will be displayed on the screen and the user will be able to select from the list using the mouse.

3.2 The BMP studies have not yet reached the stage on the Indus Basin where these critical sites can be identified, and for the time being an initial selection has been made based on local knowledge of the Indus Basin. This preliminary list, which is given in Table 3.1, will be modified in the light of experience and as the results of the BMP become available. It is believed that a list of this size is likely to be adequate to indicate imminent flooding in the sensitive areas of the Lower Indus, and that the user will be able to judge when and where flooding is likely in any event without being overwhelmed by model results.

Table 3.1 Initial List of Sites on the Lower Indus at Which Level Forecasts May Be Displayed

Ref. No	River	Location	River	Chainage
1	Beas	Hang Tau Tai Po	Beas	43.990
2	Beas	Kwu Tung	Beas	45.720
3	Beas	Ho Sheung Heung	Beas	46.910
4	Sutlej	Tai Tau Leng	Sutlej	31.140
5	Indus	Lo Wu	Indus	112.570
6	Indus	Indus Pump'ing Station	Indus	110.930
7	Indus	Man Kam To Road	Indus	109.340
8	Indus	Indus/Ma Wat Confluence	Indus	105.490
9	Indus	Kwan Tei (use Gullipoli Lines	Indus	103.780
10	Indus	Ting Ping Shan	Indus	107.260

Estimation of Runoff from the Shenzhen Basin Draining from the People's Republic of China

3.3 The rainfall runoff model for that part of the Shenzhen River catchment draining from the People's Republic of China (PRC) cannot be calibrated because there is insufficient historic data. The limited data that are available are generally several years old and the extensive development of Shenzhen during recent years further reduces the usefulness of the data. The daily rainfall data for station 493 (Bao On), obtained by the RO under the international information exchange, is not currently made available in time to be of practical use for the pilot RTFF system.

3.4 In view of the limited data available from the PRC portion of the Shenzhen basin, estimation of flows will initially be based on scaling flows from the Indus catchment. This option is the best available at present. The scaling factors will be based on data in three reports (Shenzhen Natural Resources and Economic Developments, 1986, Flood Prevention Proposals for the Shenzhen River, 1985 and Shenzhen River data, 1991). The scaling factors will be established on the basis of a comparison of annual and seasonal rainfall, soils and geology and land use for the Shenzhen and Indus basins. The aim will be to establish how much runoff the Shenzhen basin might generate in any storm relative to that from the Indus. It may be useful to include an option within the model to adjust this scaling factor during any event, partly at least to allow for marked differences in observed and forecast levels at Lo Wu and Lok Ma Chau. This adjustment might also act as a "what-if?" scenario to allow users to assess the impact of possible releases from the Shenzhen Reservoir by the Chinese authorities. It would be possible to provide a separate, explicit facility to assess the impact of reservoir releases, but there is a great danger of confusing the user with too many options and results. Operating experience with RTFF systems has shown that it is important that the user is not overwhelmed with information and forced to make too many choices during an event. The software should as far as possible provide the user automatically with the best estimates of short-term developments, and with this in mind, offering too many "what-if?" scenarios for Shenzhen flows may be counter-productive. However, should better data be obtained from the Shenzhen basin in future, the additional data could easily be built into the RTFF system at any time through its flexible configurable structure.

Rainfall Forecast Scenarios

3.5 The pilot RTFF system will have a facility for users to enter future rainfall scenarios to study in real time how a flood may develop. In view of the fact that firm deterministic rainfall forecasts cannot be produced, a series of probabilistic rainfall forecasts are proposed. These will offer the user a range of possible short-term future rainfalls which will be appropriate for the time of year and which will have in-built time distributions for any desired duration. These rainfall scenarios will be derived from the currently available information on rainfall depth-duration-frequency produced by the RO for the northern New Territories, combined with analysis of past storm profiles. It is proposed that rainfall scenarios based upon the following range of storms be made available to the user:

- twice a year storm
- mean annual storm
- 1 in 5 year storm

The "what-if?" scenario will take account of recorded rainfall which has fallen up to 'timenow' and will continue the recorded storm to make up the rainfall to the return periods indicated. Thus the rainfall scenarios offered will not be say a 1 in 5 year storm in addition to the rainfall that has already been observed, but must bring the observed rainfall up to the required event, building upon the rain that has already fallen. This is not an easy task to accomplish realistically, particularly once much of the likely storm has apparently been observed already, and work is continuing on this topic. A range of times will also be suggested to the user during which additional rainfall is anticipated, which we propose should be 1, 2, 4 and 6 hours. During the pilot studies these various probability scenarios will be tested and refined in order to produce the most likely and useful set of alternatives for users, and results presented in the final report.

3.6 Once the RTFF system has been proved during the pilot studies, and assuming that a decision is made to use the system routinely during flood events, it is anticipated that users will use the future rainfall scenarios to determine how likely flooding may be on the Indus and may perhaps issue standby warnings to Government agencies and possibly public utilities, based on the results of the scenarios. However, it is not suggested that flood warnings would ever be issued to the public using these rainfall scenarios. There is sufficient lag between rainfall on the catchment and flood runoff in the lower reaches of the Indus to enable the RTFF system user to wait until recorded, telemetered rainfall indicates that flooding is likely before warnings to the public need to be issued. The rainfall scenarios would be used to issue standby warnings and possibly to initiate flood alerts, whereby the public are warned that some flooding may occur, but that no details of when and where such flooding will occur can be given yet. Firm flood warnings would not be issued on the basis of rainfall forecast scenarios. The dissemination process and reliability of the forecasts based on the future rainfall scenarios will be one of the key areas to be investigated during testing of the pilot scheme.

3.7 Since the SunSparc running under the Unix operating system allows multiple jobs to run on the computer concurrently, it should be possible for the user to run a number of "what-if ?" runs at the same time as the system is generating its automatic routine ("normal") forecasts. Thus, even when the user is examining a range of possible future scenarios, the RTFF system will continue to make routine forecasts and will always provide the user with information on how the catchment is expected to behave using the most up-to-date observed information. It is not yet possible to state how many "what-if?" runs could be examined concurrently before the system response time became unacceptably slow. This is one of the things that will have to be examined during testing of the pilot scheme.

Storm Surge Forecasting

3.8 In Working Paper No. 9 on RTFF it was stated that a short-term (up to 4 or 6 hours ahead) forecast of storm surge would be computed automatically within the RTFF software. This forecast would be derived from real-time comparison of the actual observed tide levels at Tsim Bei Tsui in Deep Bay with the astronomical tide prediction. A clear persistence has been observed in this storm surge residual during past events, and this pattern of residuals is currently being analysed in order to enable short-term forecasts to be made during a flood event.

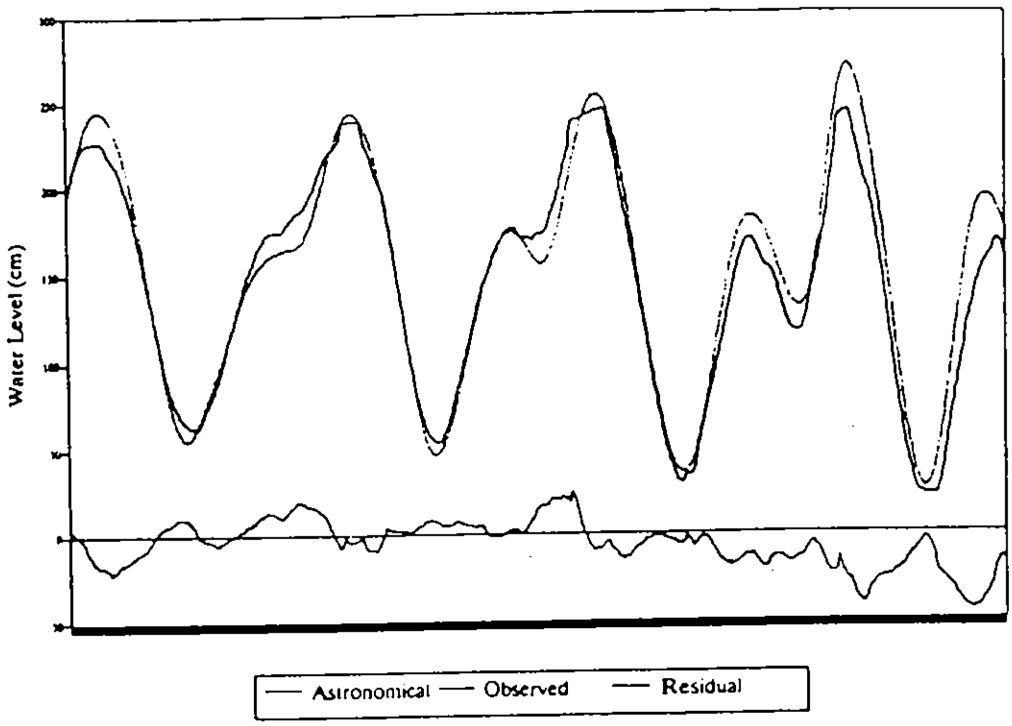
3.9 Figure 3.1 shows two typical examples of observed surge residuals from relatively small events, and the short-term persistence of these over a period of hours is apparent. This persistence may consequently be used to provide short-term forecasts of storm surges in real-time.

3.10 We propose to develop an autoregressive moving average (ARMA) model to make short-term forecasts of storm surges. A time series program written by the Institute of Hydrology is currently being used to establish the degree of serial correlation in the tidal residuals and to measure the cross-correlation between residuals and the predicted astronomical tide. It is clear from Figure 3.1 that there is generally a regular cyclic pattern to the tidal residuals which appears to be related to the tidal cycle. This cyclic pattern and the short-term observed persistence in surge residuals will be combined to produce the forecasting algorithm. The model structure and parameter order is still being established but model development and calibration will be completed shortly.

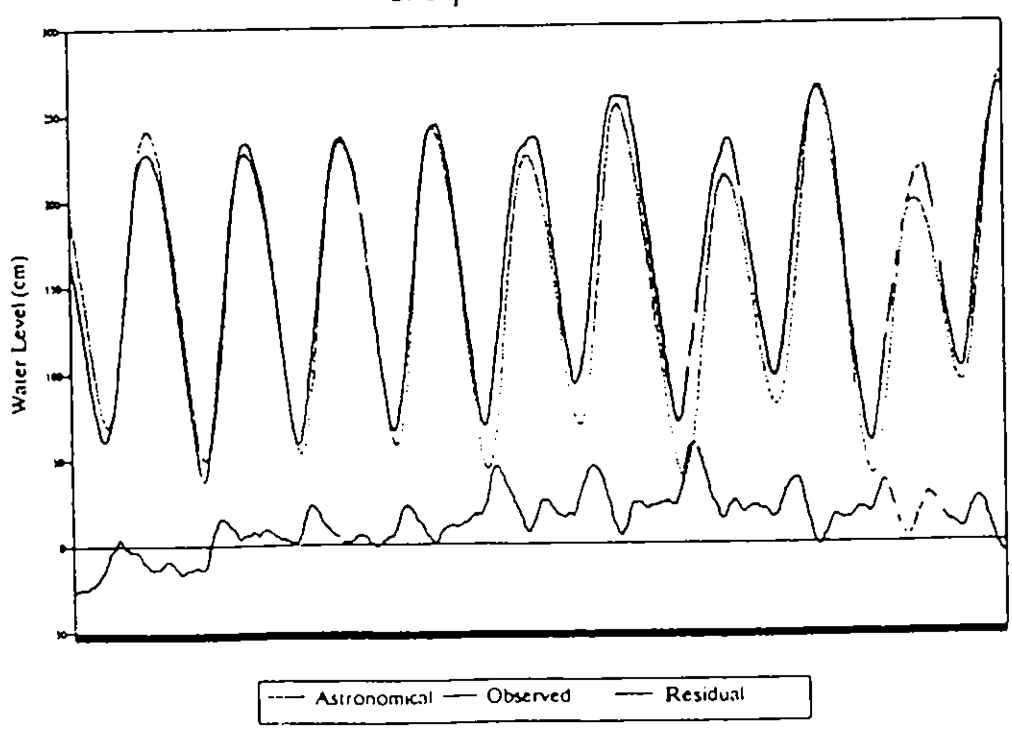
4. SOFTWARE DEVELOPMENT

4.1 As described earlier, much of the software to be used for the pilot RTFF system exists already, but it has not previously been combined in exactly the form required for use on the Indus Basin. The main innovations being applied to the Indus system are the use of Oracle as the database and the use of Windows as the primary tool for the graphical user interface, GUI. The work on development of a GUI under Windows is described below.

Tsim Bei Tsui Tides
20 to 23 Sep 1988



Tsim Bei Tsui Tides
29 Sep to 03 Oct 1989



TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II

	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. 3.1

4.2 For previous RTFF applications, the Institute of Hydrology has used a variety of databases, ranging from a relational database similar to Oracle on the DEC Vax series of computers to a database written in-house. The use of Oracle on the SunSparc workstation has necessitated modification of existing data storage and retrieval subroutines, but such work is now complete, and final testing is underway at present.

4.3 The various software components required for an effective, operational RTFF system for the River Indus Basin may be summarised as;

- Graphical User Interface (GUI)
- An Information Control Algorithm (ICA) to control information flow
- Subroutine to receive telemetry data from RO and store on Oracle
- Data retrieval subroutines from Oracle
- The RFFS (river flow forecasting system) software which contains;

  software to infill missing data
  rainfall-runoff model (PDM)
  hydrodynamic model
  forecast updating algorithms using telemetry

- Subroutine to compute catchment areal rainfalls
- Rainfall forecast scenario subroutine
- Storm surge forecasting subroutine
- Subroutine to initiate "What-if ?" special runs
- Subroutine to present forecast results
- Subroutines to purge old unwanted forecasts

4.4 A summary of the work undertaken on these various software components is given in Table 4.1, which shows how much progress has been made on each topic to date. A fuller discussion on particular topics follows:

Table 4.1 Progress on RTFF Software Development

Task Percentage Completed	20	40	60	80	100
Graphical User Interface (GUI)	***	***			
An Information Control Algorithm (ICA) to control information flow	***	***	***	***	
Subroutine to receive telemetry data from RO and store on Oracle	***	***	***	***	***
Data retrieval subroutines from Oracle	***	***	***	***	***
The RFFS (river flow forecasting system) software which contains; software to infill missing data; rainfall-runoff model (PDM); hydrodynamic model; forecast updating algorithms	***	***	***	***	***
Subroutine to compute catchment areal rainfalls	***	***	***	***	
Rainfall forecast scenario subroutine	***				
Storm surge forecasting subroutine	***	***	***		
Subroutine to present forecast results	***	***			
Subroutines to purge old unwanted forecasts	***	***	***	***	

Graphical user interface, GUI

4.5 The user will operate the pilot RTFF system using a graphical user interface based on the Sun Open Windows system. Our experience is that users find a GUI to be the easiest way to operate complex software such as the pilot RTFF system. The system operation is controlled primarily through the mouse, although the keyboard is also used, either to enter alpha-numeric information, or as an alternative to the mouse. Work on this task is still underway but should be ready by mid-May.

4.6 It is intended that the primary window should be a map of the Indus Basin showing all key points of interest. The user will be able to select a site of interest from this map using the mouse, and for example, display the recorded rainfall for say Cloudy Hill, or the forecast levels for Lo Wu.

4.7 A digitised image has been produced from the 1:50,000 scale map, using the IH software package WIS. Some new software is being written to allow the graphics to operate under the Windows environment. The preliminary version shown on Figure 4.1 requires some modification of colours, line thickness and so on before it is finalised.

4.8 Work is continuing on this task.

The Information Control Algorithm, ICA

4.9 The ICA controls the flow of information within the pilot RTFF system. Thus it specifies to the system what telemetry data are required for a particular modelling task, it determines what order the various sub-catchment modelling tasks are run in and ensures that the output from each rainfall-runoff model for any particular sub-catchment is input to the correct reach of the hydrodynamic model. It also controls storage of forecast results, ensuring that these are appropriately named and stored within the Oracle database to allow subsequent retrieval.

4.10 The ICA software exists already, and is at the core of the RFFS software being used for the modelling. Configuration of the ICA for the Indus Basin has been completed. Some additional software has had to be written in order to interface the ICA with the Oracle database, as on previous applications of the ICA other databases have been used. This additional software has been written and is currently being tested.

Telemetry Interface Software

4.11 A program has been written to interface with the RO computer in order to receive telemetry data every 5 minutes. The data to be transmitted by the RO and their format was agreed during the last visit to Hong Kong by staff of IH. This program has been written and preliminary tests completed. The model will be tested further using an emulation program written to run on a PC computer which will send data of the required type and format to the SunSparc every 5 minutes. This emulation exercise will provide a check to ensure that the software will operate as intended when installed in Hong Kong.

Rainfall-Runoff Model Calibration Software

4.12 The rainfall-runoff model calibration software exists already within the RFFS. The software is currently being used for calibration on a MicroVAX computer at IH, exploiting availability of a relational database. Some additional work is required to permit the calibration software to retrieve data from an Oracle database and this work has almost been completed.

4.13 Calibration of the rainfall-runoff model for the Hok Tau and Kam Tin gauging stations is described in Chapter 5, with results being given in Appendix A. The model is being calibrated on data for the Kam Tin gauge in order to use this catchment as an analogue for the Beas River, which has no flow data.

5. PDM CALIBRATION

5.1 Calibration of the PDM rainfall-runoff model has been carried out on the Kam Tin and Hok Tau catchments using available 15 minute data from storm events between 1985 and 1989, including Typhoon Warren and Typhoon Brenda. River level measurements were converted to flow using rating equations derived from the rating tables provided by the Water Services Department (WSD). Rainfall data were obtained from the Royal Observatory (RO) and Geotechnical Engineering Office (GEO) reporting raingauges. Between events the model states were maintained using the daily rainfall and evaporation data obtained from the RO autographic raingauge at Tai Lung Farm and potential evaporation data from turfed plots at Kings Park.

5.2 Figures 1 to 14 in Appendix A show the best calibration obtained for the Kam Tin and Hok Tau catchments to date. The calibration at Kam Tin is tolerably good considering the data available, and short-comings in the calibration are discussed below. The calibration for Hok Tau however has been derived using the existing reporting raingauge network, which does not adequately represent rainfall over the catchment. For both Kam Tin and Hok Tau, the need for the additional raingauges to be installed during the data acquisition programme is clearly demonstrated. The rainfall-runoff models will be re-calibrated during the pilot studies as more representative data become available.

5.3 The model calibrations have shown that the fit is reasonable on some occasions but is very poor on others. This arises primarily as a consequence of two factors which are discussed below:

i) poor representation of the areal catchment rainfall during some events, and

ii) poor water accounting between events.

5.4 Although both the Kam Tin and Hok Tau catchments are very small (11.72 km^2 and 5.02 km^2, respectively) the major difficulty in PDM calibration is determining a representative areal precipitation over each of the catchments from the existing raingauge network. Throughout Hong Kong rainfall is very often highly localized both in time and space. In the Kam Tin catchment there is a single RO reporting raingauge at the Shek Kong airfield (R26), with an elevation of 10 mPD. However, some 4.75 km^2 (41%) of the catchment is at an altitude of more than 100 mPD and the highest point in the catchment is more than 550 mPD. There are no reporting raingauges at all in the small Hok Tau catchment all of which is at more than 200 mPD. There is a non-reporting raingauge at the Hok Tau gauging hut but the two nearest reporting gauges are the RO gauge (R23) at Tai Po and one of the GCO gauges (N05) in Fanling. Both are approximately 4.5 km from the centre of the catchment and R23 is at an elevation of 25 mPD, while N05 is situated on a tower block at 112 mPD.

5.5 Figure 5.1 shows the correlation of the 30 year mean annual rainfall (1953-1982) with elevation for those RO raingauges with the longest records (data from Kwan & Lee, 1984). Although there is a great deal of scatter about the regression line drawn, it is clear that in general rainfall increases with altitude. However, the amount of scatter indicates that altitude is not the only factor that causes variation in rainfall and it is probable that aspect is also significant. The prevailing wind direction in Hong Kong is easterly throughout the year (Bell & Chin,1968).

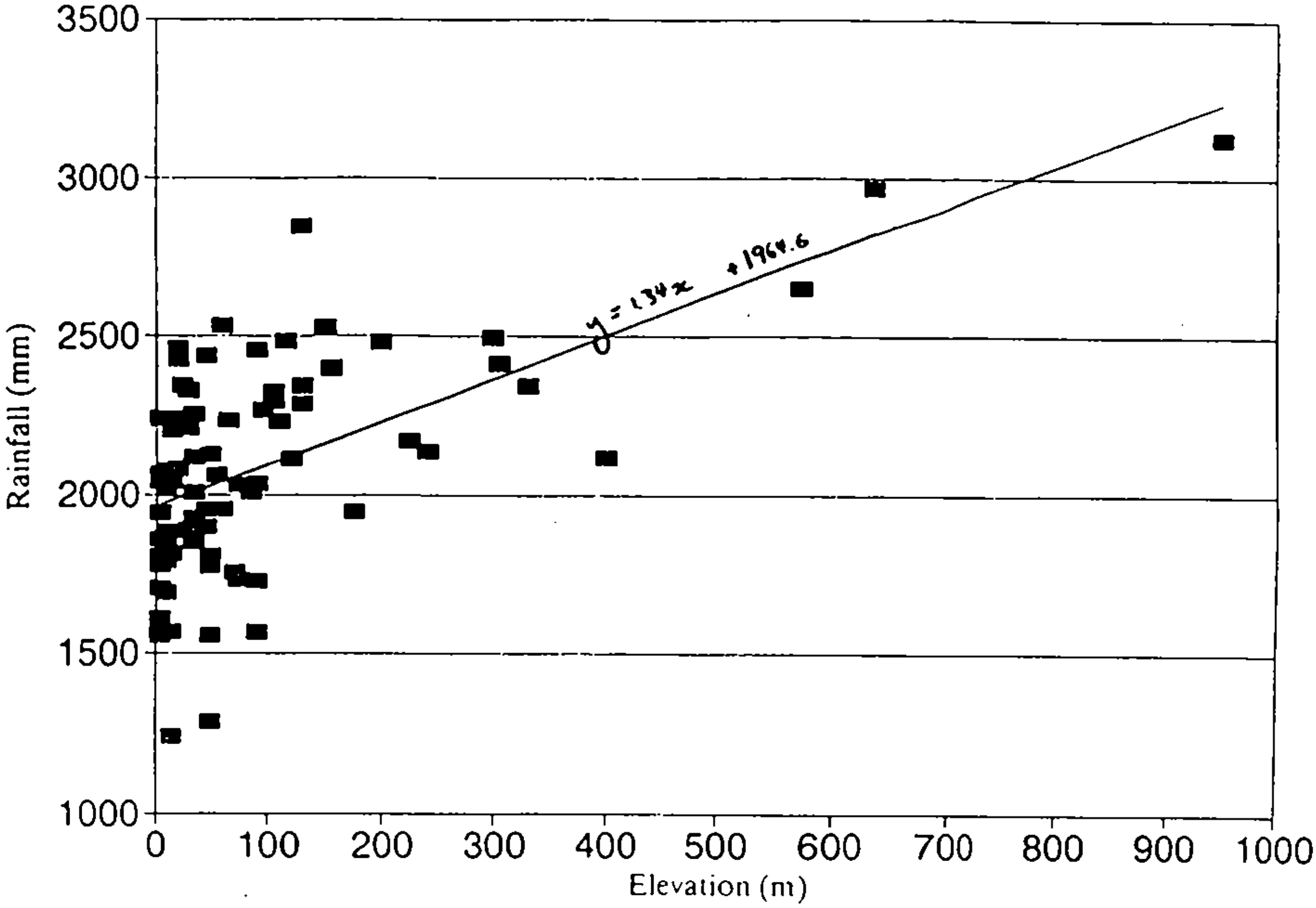
5.6 Daily rainfall shows marked temporal and spatial variation from one location to another. Often rainfall is recorded in one raingauge while there is none at all in another. As would be expected this variation becomes even more pronounced for shorter durations.

5.7 For the purposes of PDM calibration, areal rainfall was determined for the Kam Tin and Hok Tau catchments using two reporting raingauges in each case. The Kam Tin areal rainfall was determined using RO reporting raingauge R26 and GEO reporting raingauge N14. N14 is located some 6 km from the centre of the Kam Tin catchment, but at an elevation of 950 mPD is the nearest raingauge (and one of the very few in Hong Kong) located above 500 mPD. The Hok Tau areal rainfall was determined using RO reporting raingauge R23 and GCO reporting raingauge N05.

5.8 The Hong Kong mean annual isohyetal map (Kwan & Lee, 1984) was used to determine an average mean annual rainfall for each catchment. Throughout an event the recorded 15 minute rainfall values were determined as a percentage of the thirty year mean annual rainfall at each gauge. An overall catchment percentage was determined by weighting each gauge percentage by the distance of the gauge from the centre of the catchment. The catchment percentage thus obtained was used to calculate the 15 minute catchment rainfall from the catchment mean annual rainfall. By using the isohyetal maps and mean annual rainfall at each gauge, differences in elevation and aspect will have been incorporated to a limited extent into the calculation of areal rainfall.

5.9 The calibration results indicate clearly that determining catchment areal rainfall in this manner is only successful on a limited number of occasions. Particularly poor results are obtained for the Hok Tau catchment in which presently there are no reporting raingauges.

5.10 Poor water accounting between events also arises as a consequence of the fact that the data used are not representative of the catchments. The Tai Lung Farm autographic raingauge is a single gauge at low lying elevation. It will often fail to represent rainfall that occurs on the steeper higher altitude regions of both the Kam Tin and Hok Tau catchments. Consequently catchment soil moisture storage will in general be underestimated at the start of events.



TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II

CORRELATION OF MEAN ANNUAL RAINFALL WITH ELEVATION	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale N.T.S.
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. 5.1

5.11 Figures 3 and 4 in Appendix A, show a plateau in observed flows at the Kam Tin gauge during typhoons Warren and Brenda. Examination of the station for the draft BMP for Basin No. 9 suggests that this arises as a consequence of bypassing of the station at high flows. The stage-discharge relationship for this station appears to break-down at flows above about 58 m^3/sec. To date no attempt has been made to simulate this truncation in flow at the Kam Tin site, within the PDM, but it would be a very simple process to do so. However, it must be noted that total flows, that is flow at the station plus that bypassing it, will need to be modelled, particularly if water re-enters the main channel further downstream. Thus it will be necessary to predict the volume of water by-passing the station.

5.12 It is to be expected that better calibration will be obtained when the new raingauges, details of which are in Working Paper No. 5 - Hydrological Data Acquisition, are installed. These will be located at sites designed to give a good areal spread throughout the Indus Basin and to monitor over a wider range of elevations than at present. We believe that these gauges will provide much improved estimates of areal catchment rainfall. Furthermore the same gauges will be used continuously, so that between events water accounting will also be maintained in a more realistic manner than is presently possible.

5.13 Improvement in model fit will also arise from real-time updating of model states during events. Work has started on calibrating the state updating parameters. Consideration is currently being given to model sensitivity to the use of 15 minute data for calibration and the 5 minute data to be used operationally.

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APPENDIX A

PDM CALIBRATION RESULTS

APPENDIX A - PDM CALIBRATION RESULTS

Calibration Events:

Kam Tin

Event	Dates
1	22nd-28th June 1985
2	10th-14th July 1986
3	18th-21st July 1988
4	19th-22nd May 1989
5	17th-19th July 1989
6	20th-24th August 1989

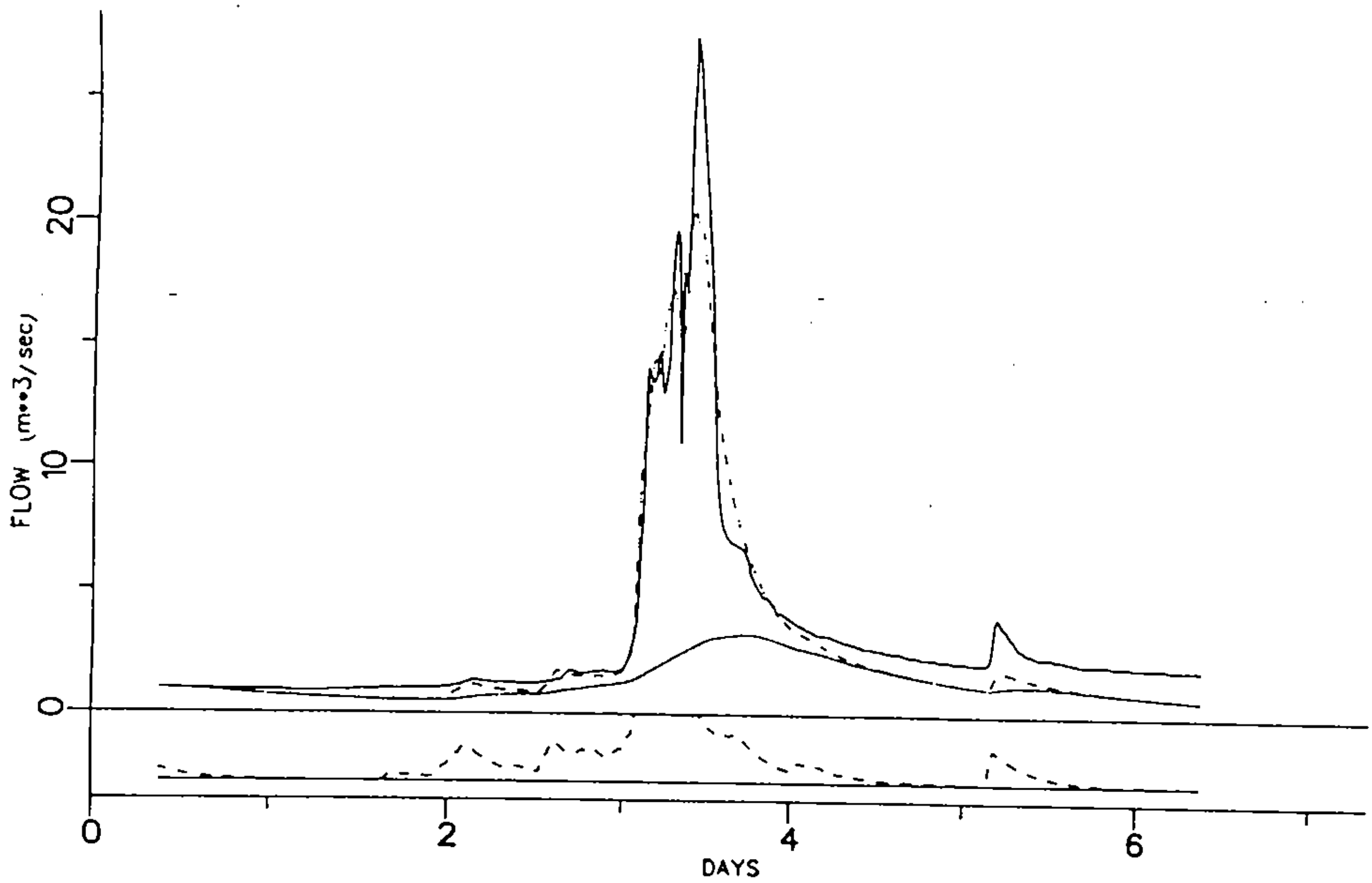
Hok Tau

Event	Dates
1	8th-15th April 1985
2	22nd-28th June 1985
3	2nd-9th September 1985
4	10th-14th July 1986
5	18th-21st July 1988
6	19th-22nd May 1989
7	17th-19th July 1989
8	20th-24th August 1989

Key for all graphs:

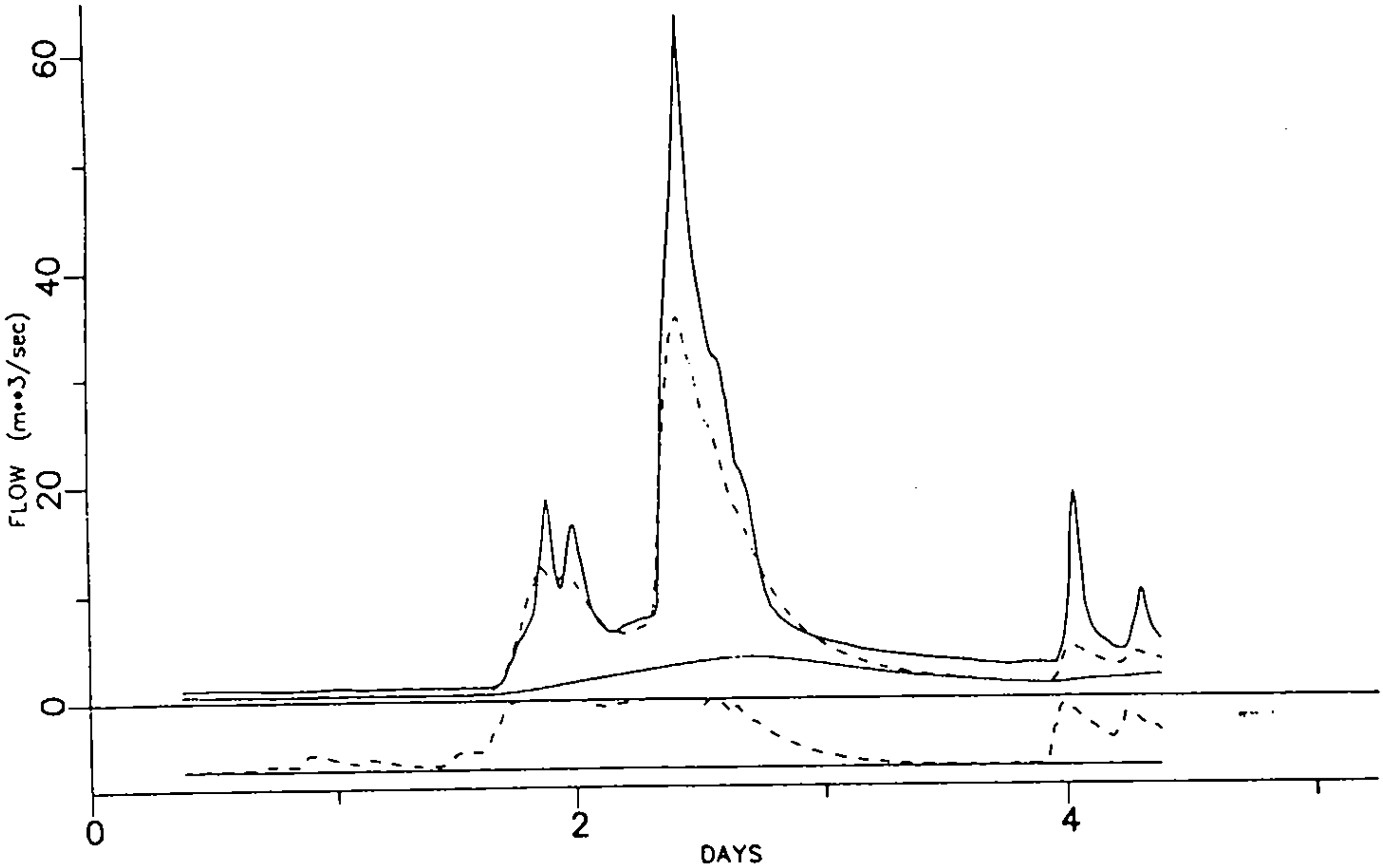
Upper continuous line : observed flow
Upper dashed line : total forecast flow
Lower continuous line : baseflow forecast
Lower dashed line : soil moisture deficit

[report\tb0809]



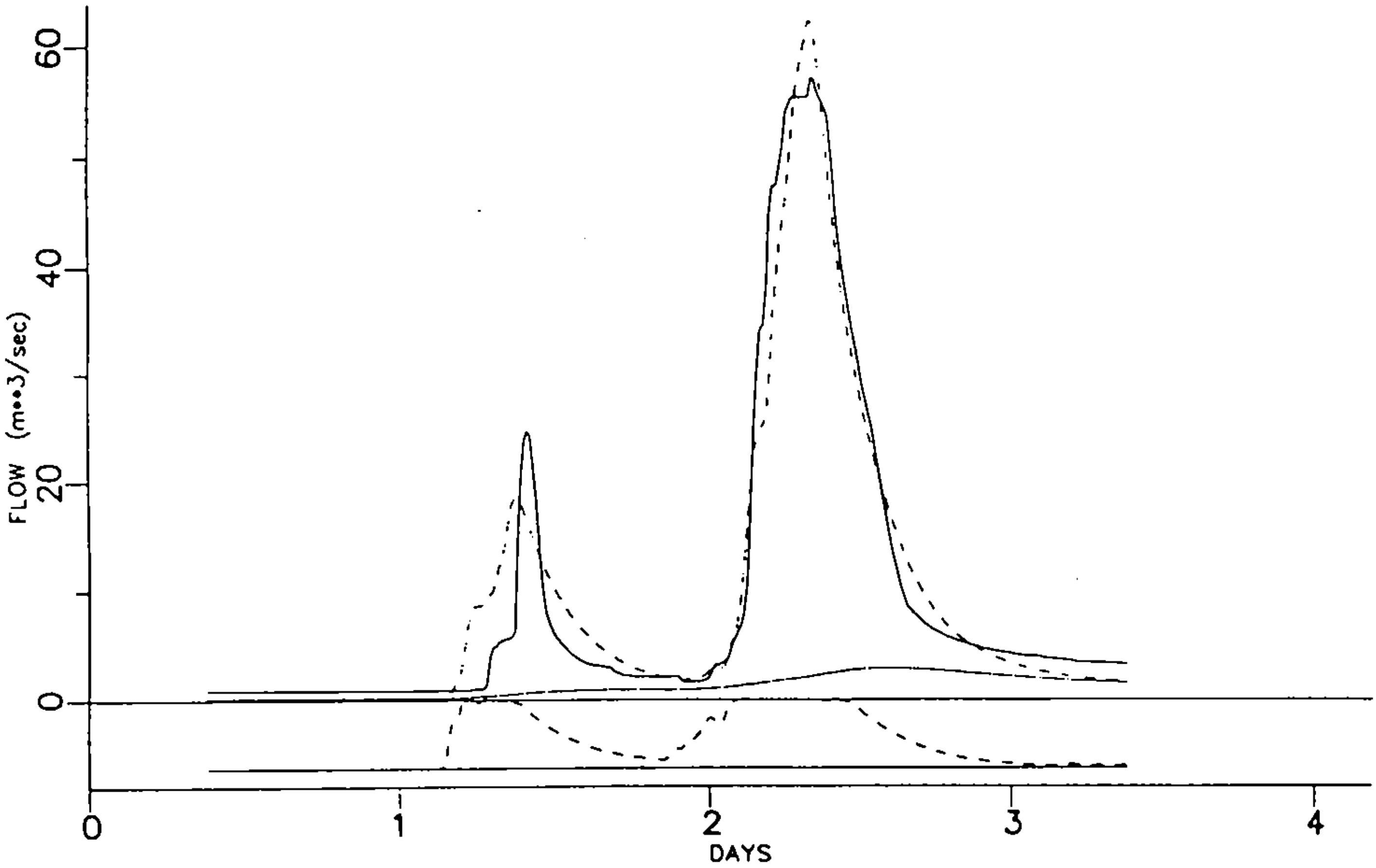
LEGEND :
Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II			
KAM TIN EVENT 1: SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.1



LEGEND:
Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II			
KAM TIN EVENT 2: SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A2

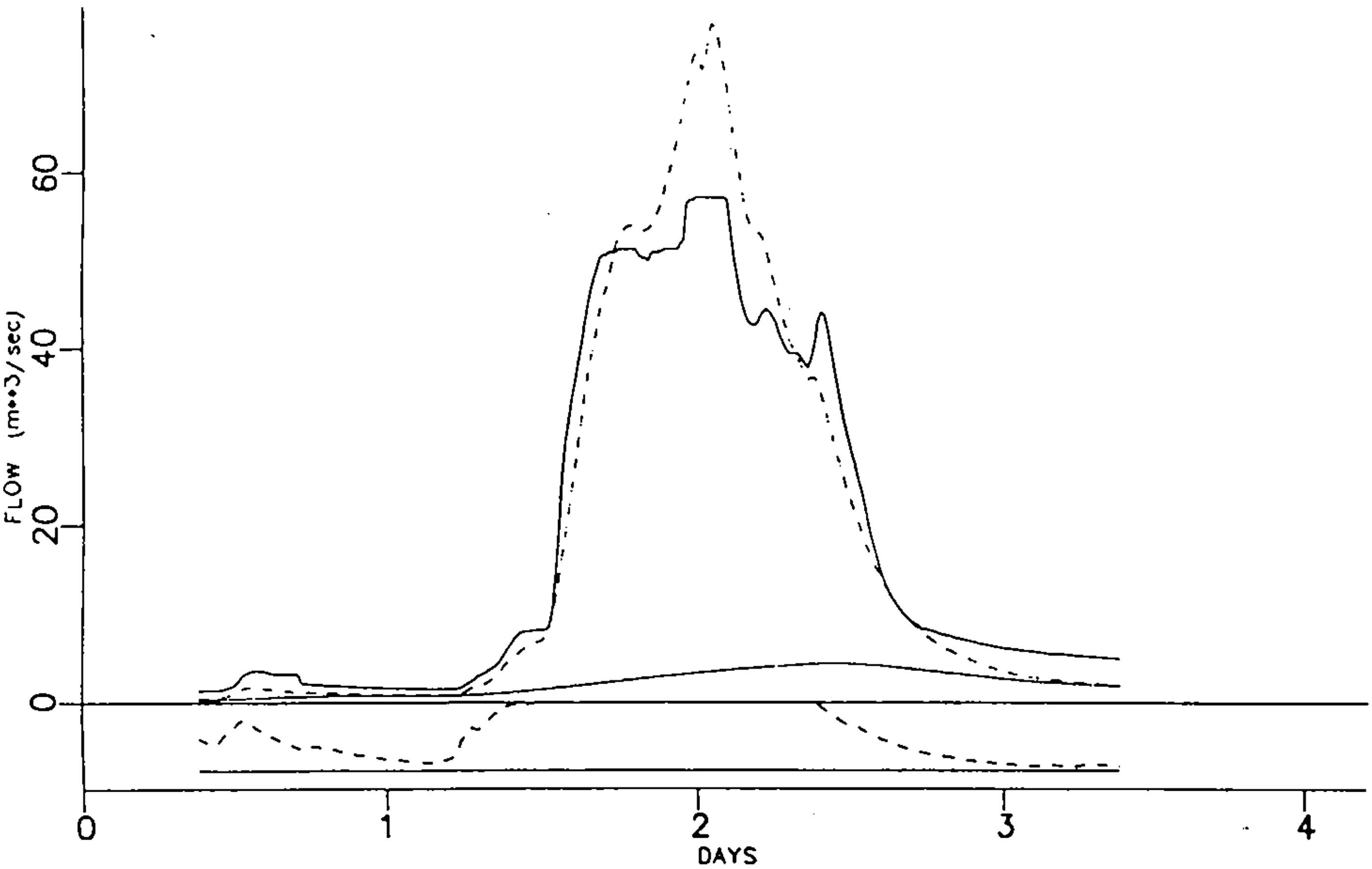


LEGEND:

Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY – PHASE II

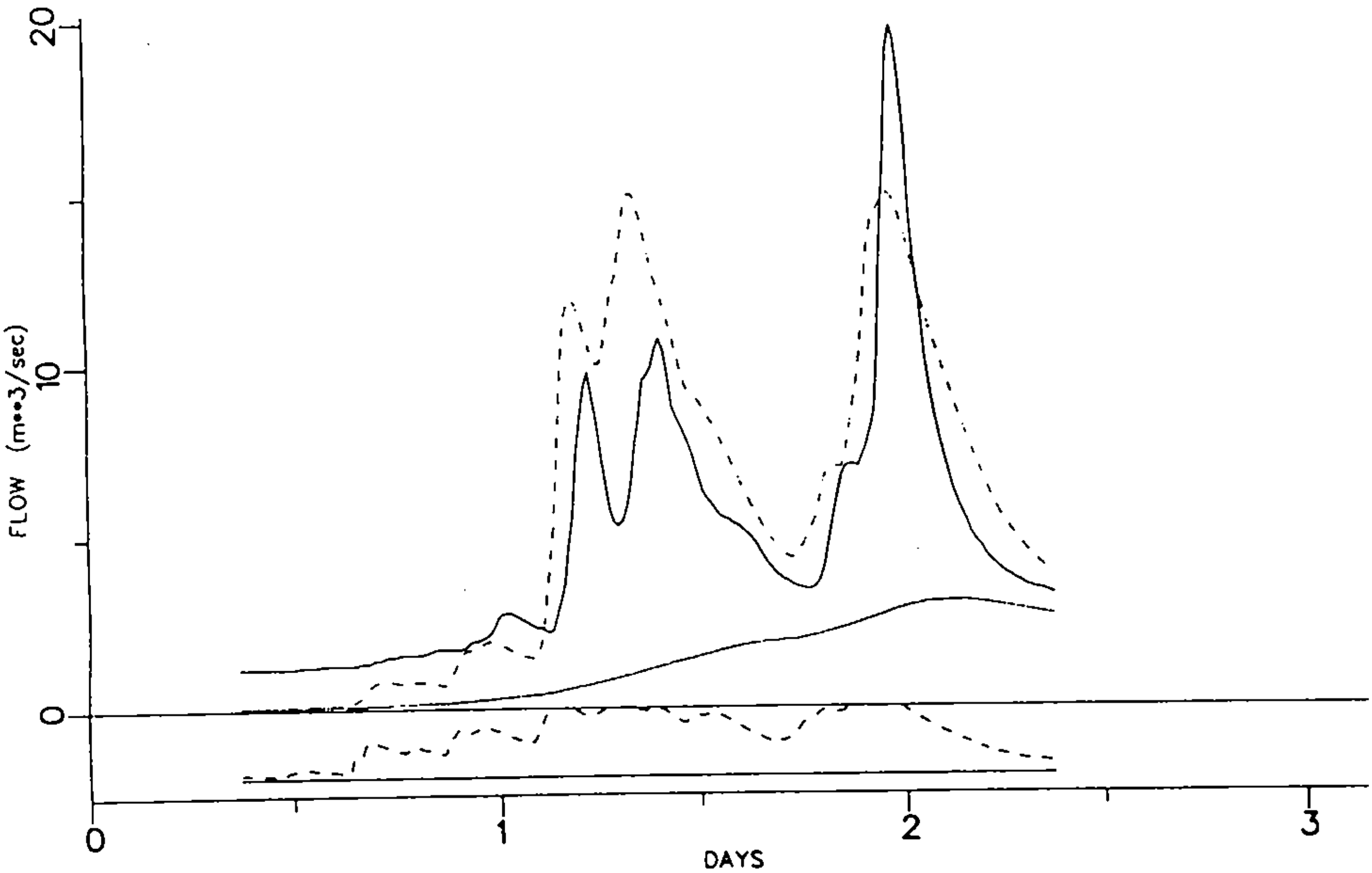
KAM TIN EVENT 3 : SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.3



LEGEND:

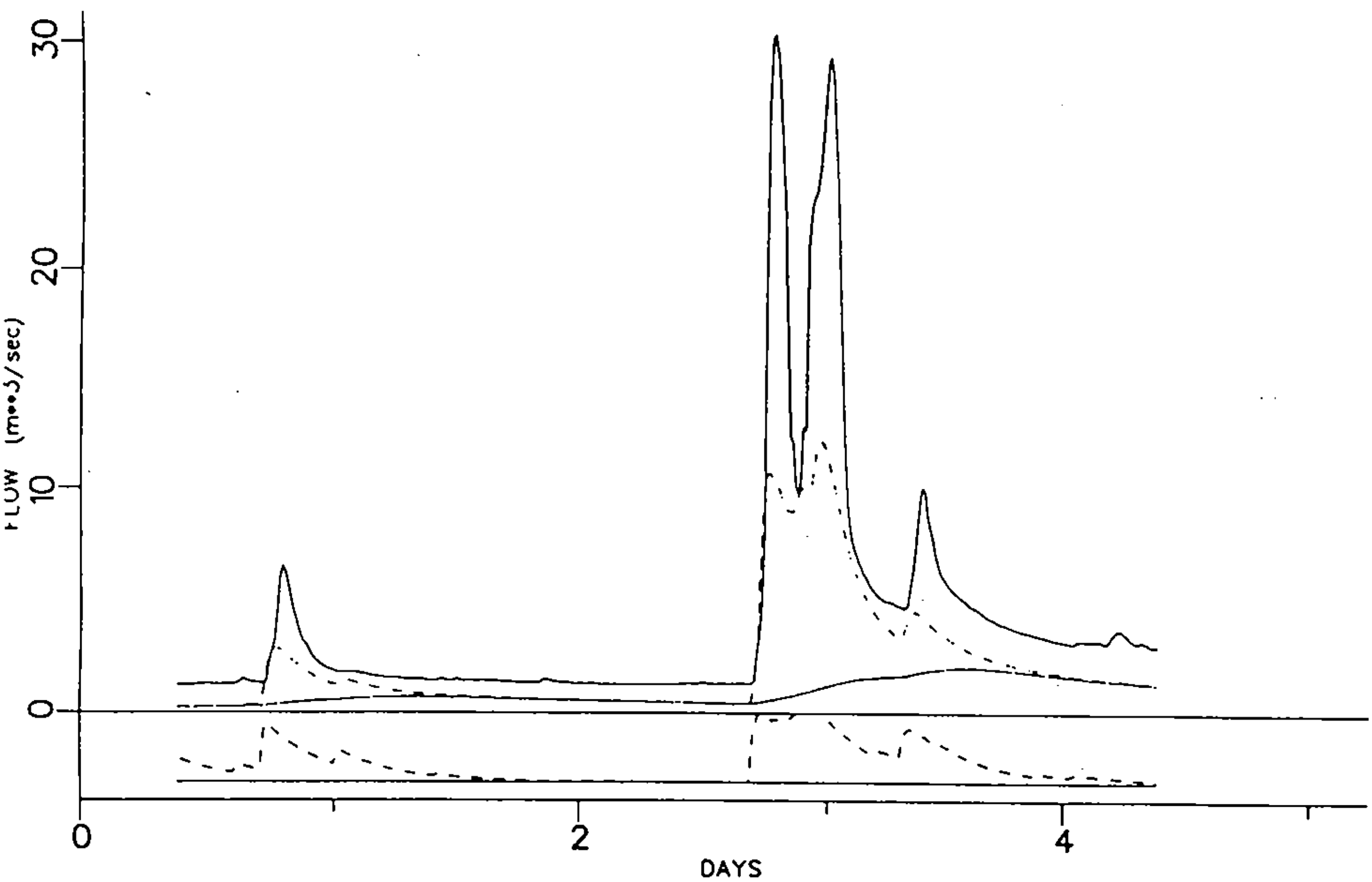
Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II			
KAM TIN EVENT 4 : SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A. 4



LEGEND :
Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II			
KAM TIN EVENT 5 : SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.5

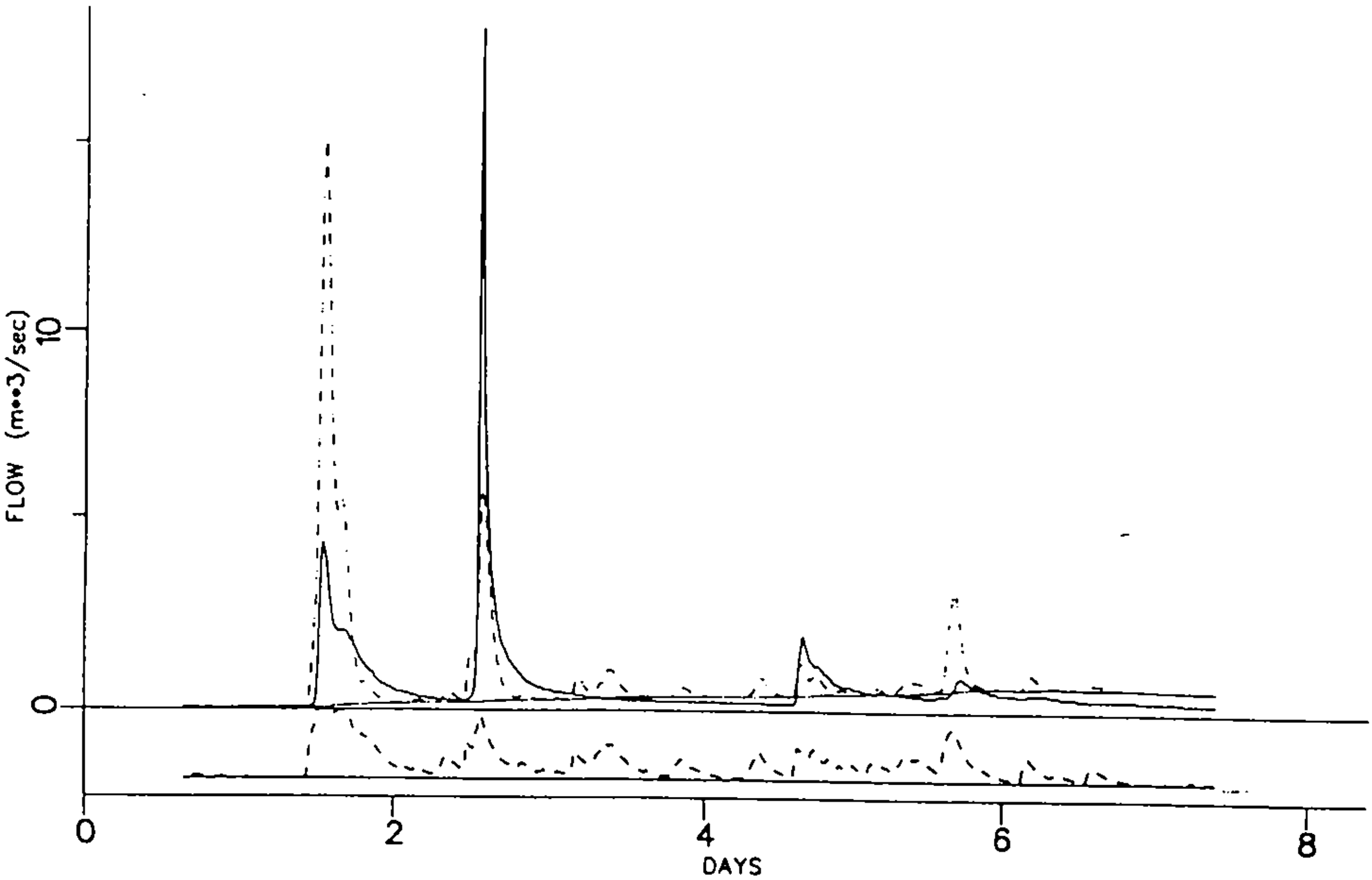


LEGEND :

Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY – PHASE II

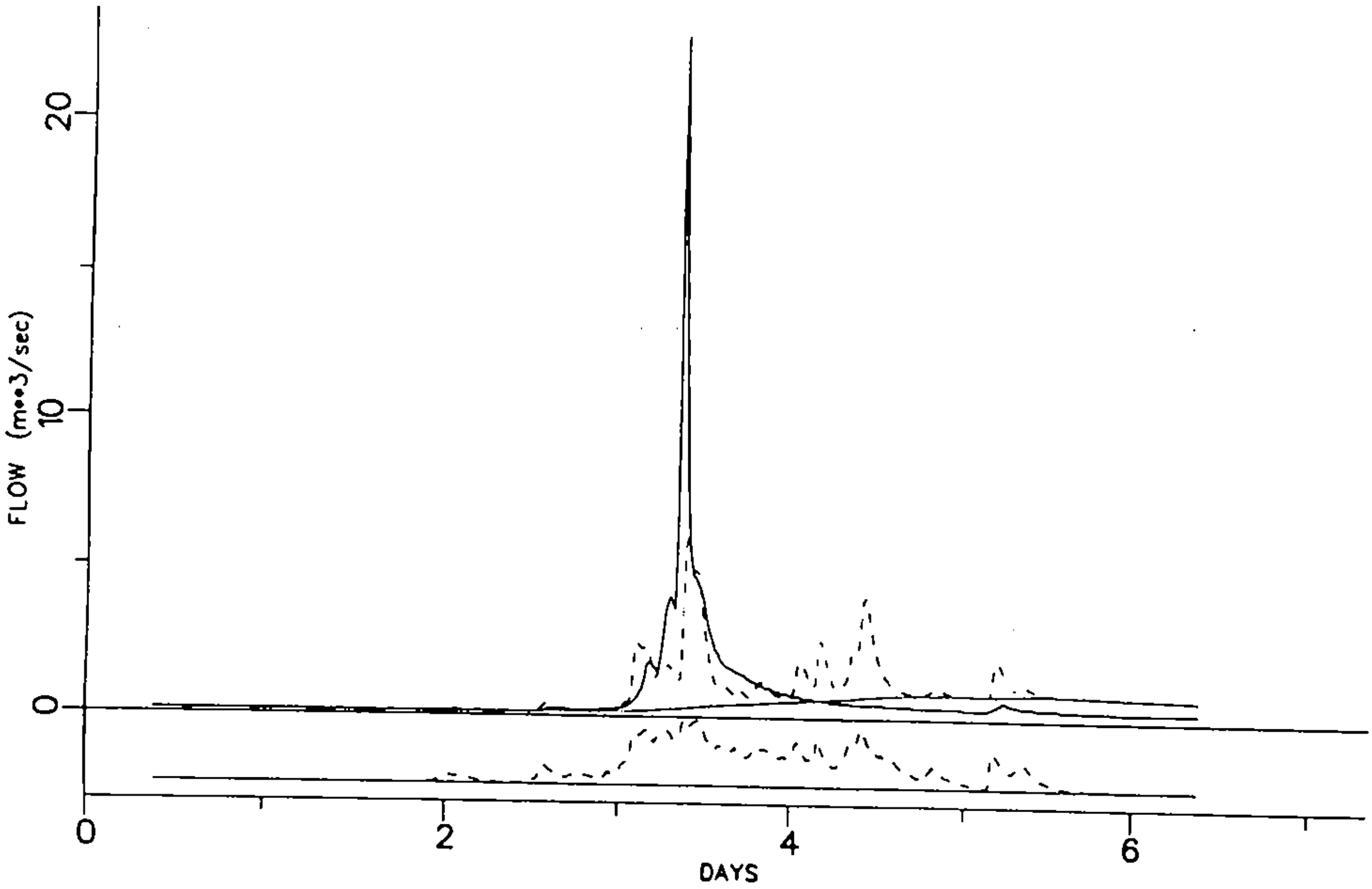
KAM TIN EVENT 6 : SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.6



LEGEND:

Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

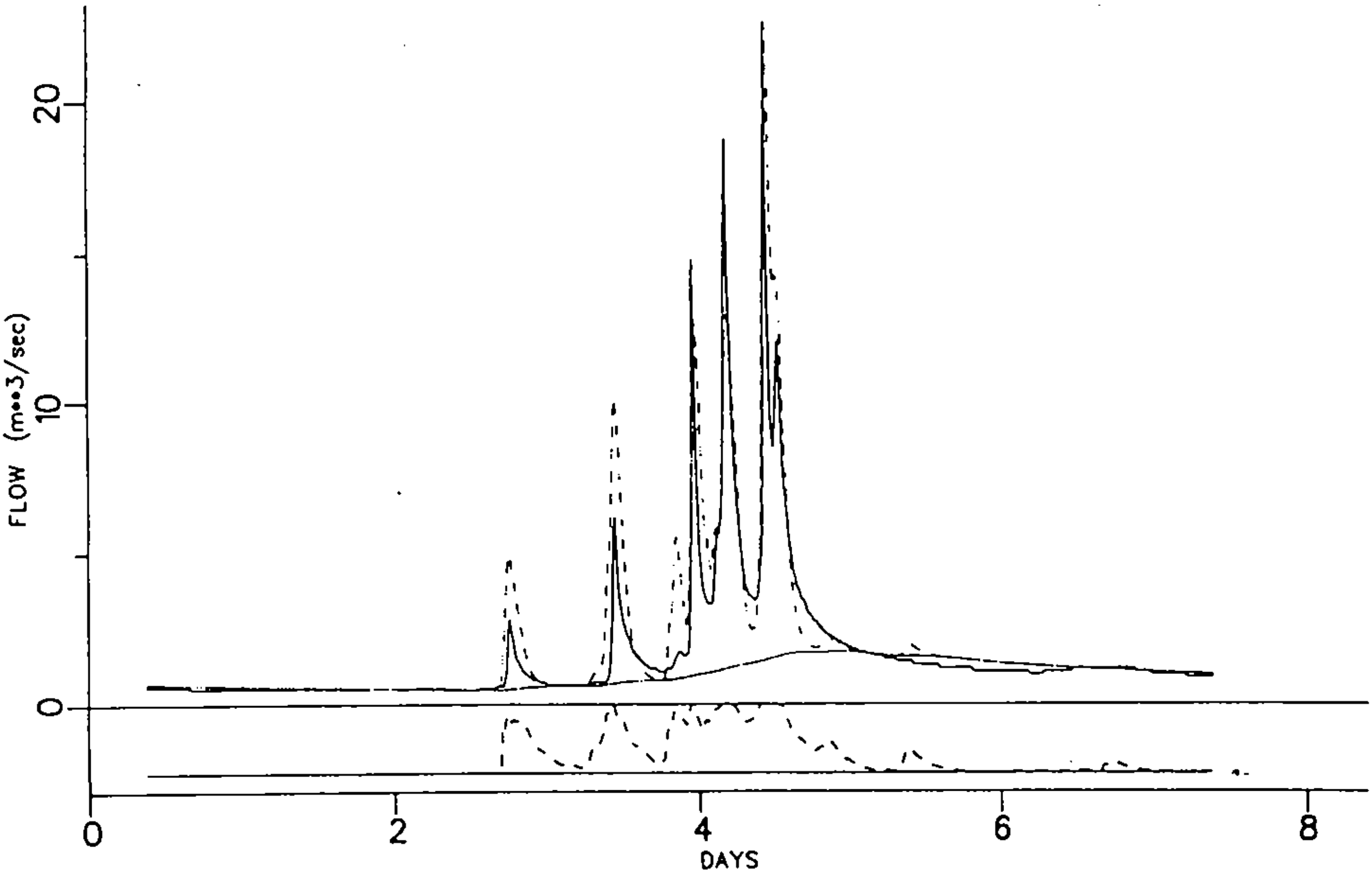
TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II			
HOK TAU EVENT 1: SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.7



LEGEND :

Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

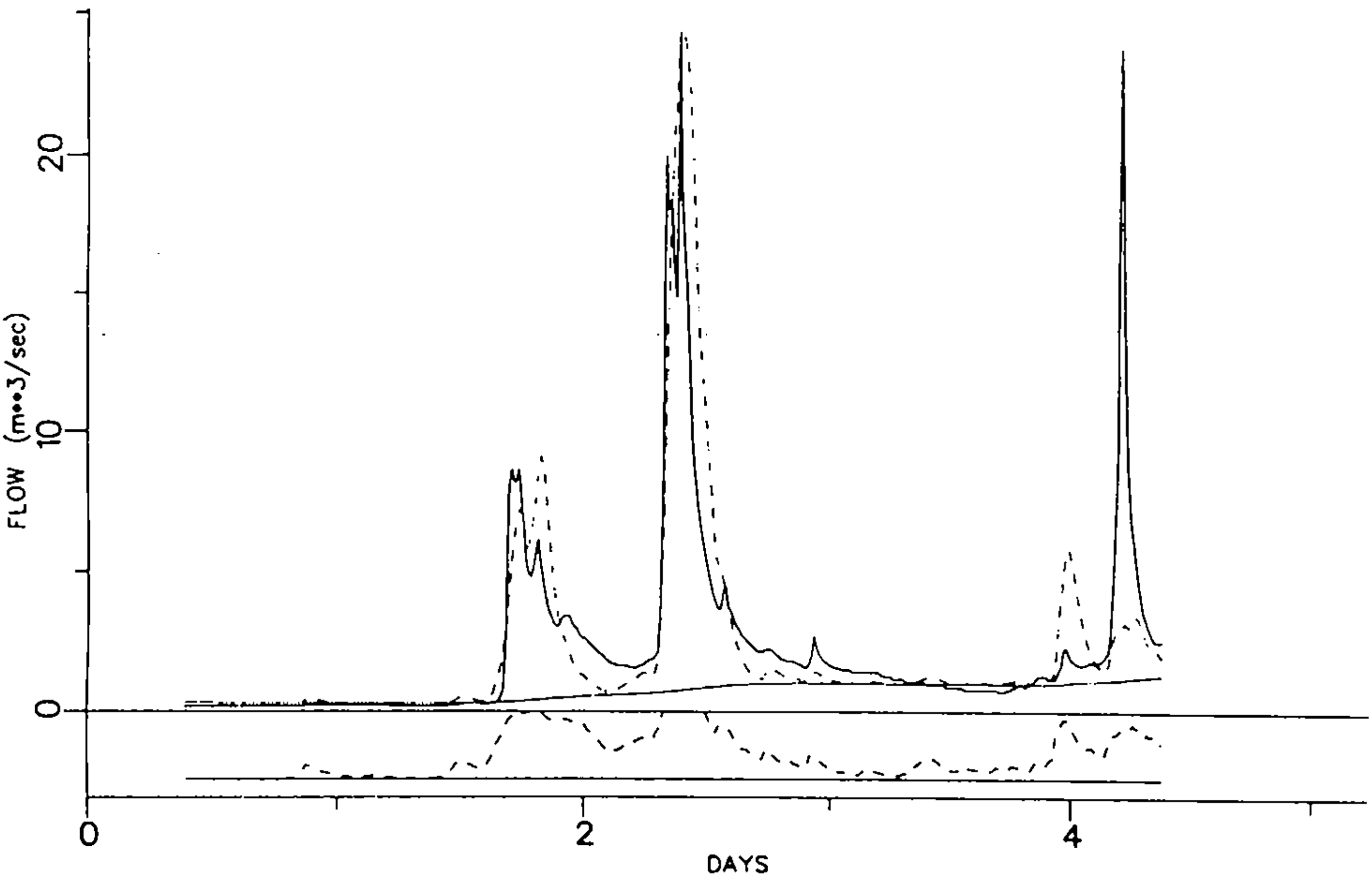
TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II			
HOK TAU EVENT 2: SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.8



LEGEND :

Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY – PHASE II			
HOK TAU EVENT 3: SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.9

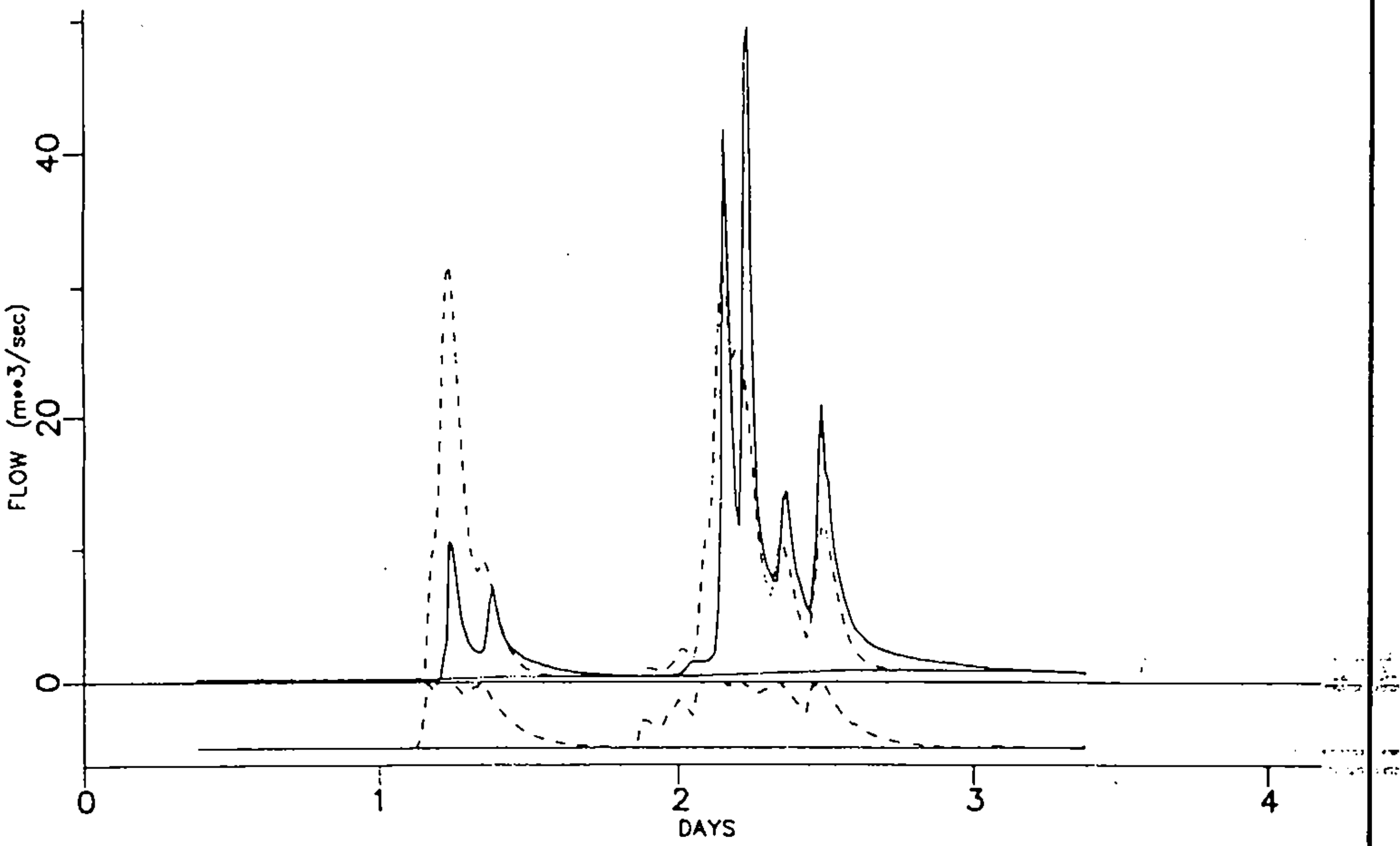


LEGEND :

Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY – PHASE II

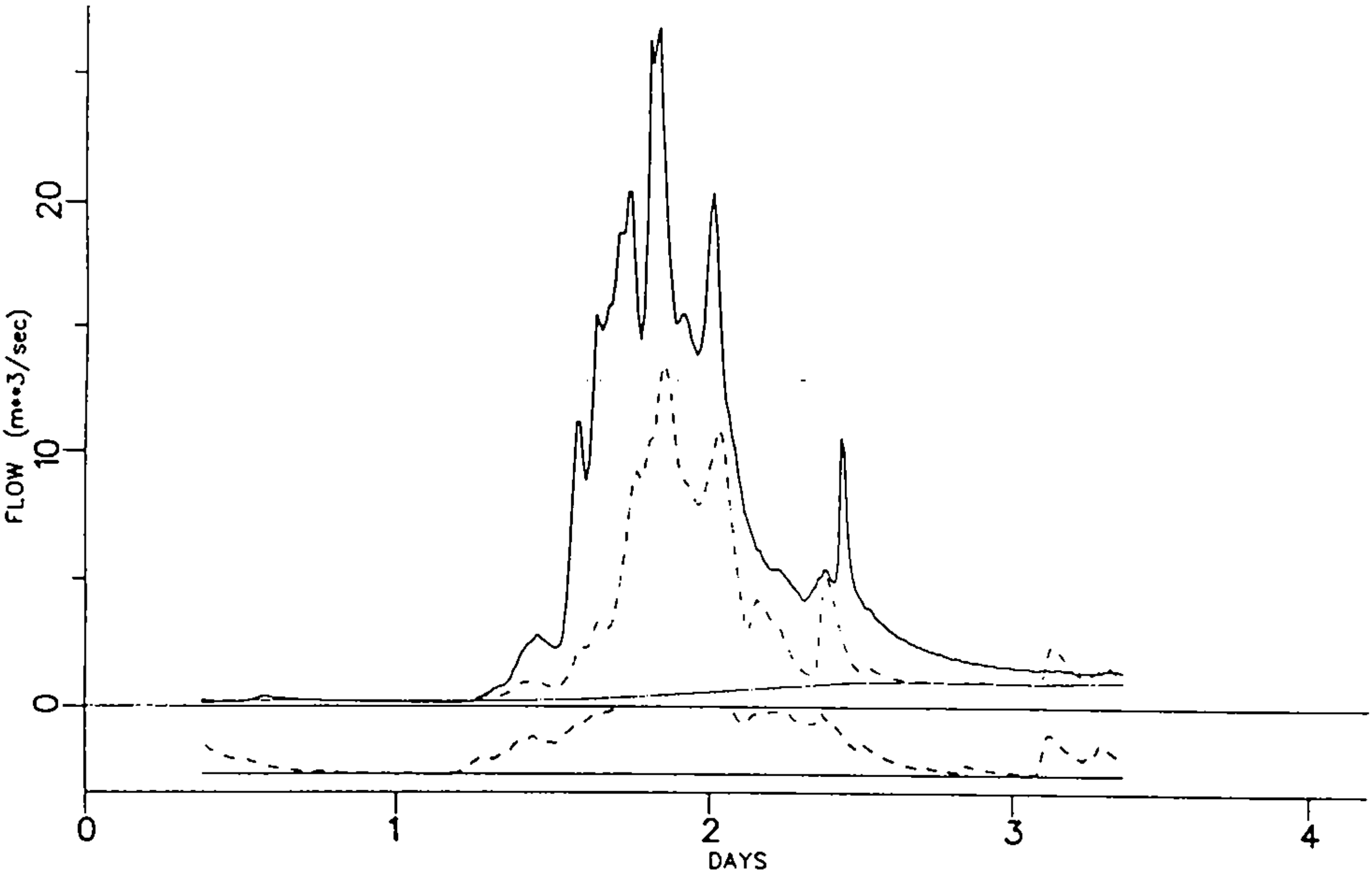
HOK TAU EVENT 4 : SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.10



LEGEND :

Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY – PHASE II			
HOK TAU EVENT 5: SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.11

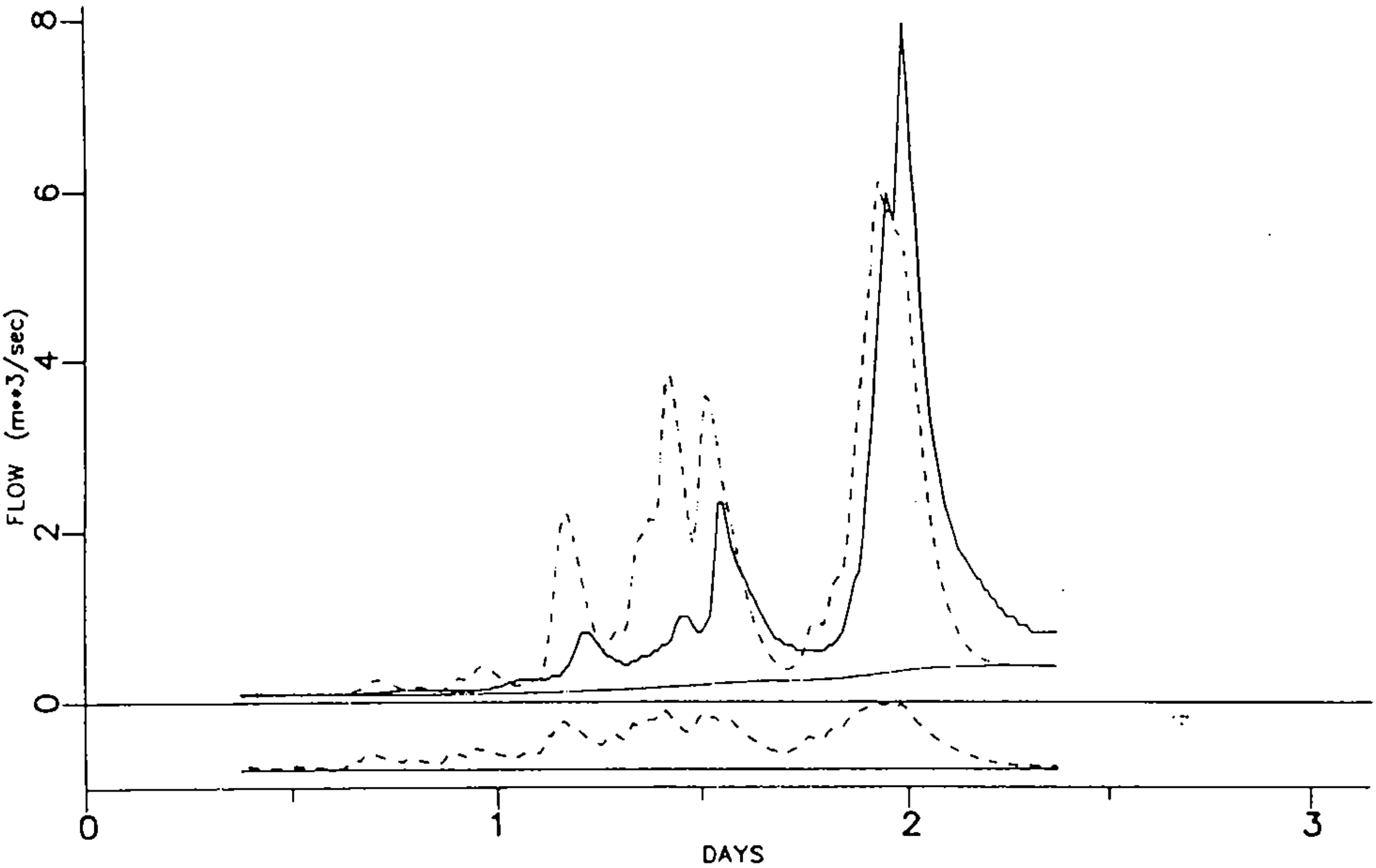


LEGEND :

Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

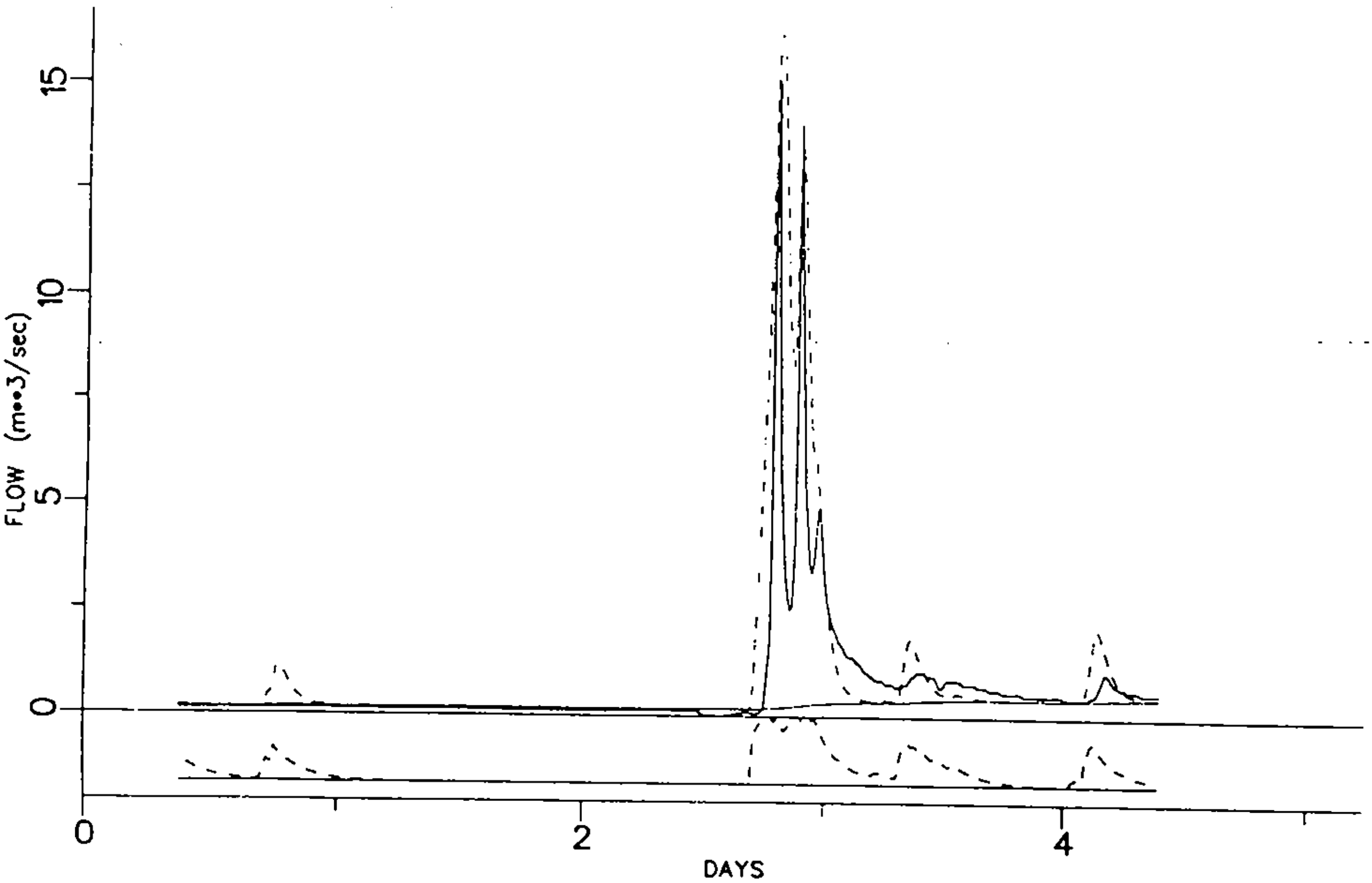
TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II

HOK TAU EVENT 6 : SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.12



LEGEND:
Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II			
HOK TAU EVENT 7: SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.13



LEGEND:

Upper continuous line: observed flow
Upper dashed line: total forecast flow
Lower continuous line: baseflow forecast
Lower dashed line: soil moisture deficit

TERRITORIAL LAND DRAINAGE AND FLOOD CONTROL STRATEGY STUDY - PHASE II

HOK TAU EVENT 8: SIMULATION MODE	HONG KONG GOVERNMENT DRAINAGE SERVICES DEPARTMENT	Date APR. 92	Scale NIL
	BINNIE MAUNSELL CONSULTANTS	Initial	Figure No. A.14