SECTION 3

EMERGENCY MEASURES

GENERAL

3.1 In time of severe flood events, when disaster is imminent and flood control measures are unable to cope with extreme conditions, there are basically only two direct actions which can be taken to avoid or at least mitigate serious damage and loss of life. These are the evacuation of people and property, and the use of temporary devices to prevent structural failure and incursion of flood waters. For these actions to be efficient it is important that advanced and precise knowledge of a forthcoming event be available. If it is not, action may be implemented and subsequently found not to be necessary, or no action may be taken and consequences may be disastrous. Communities need to be made aware of the likely severity of flooding, the duration of flood stages, and their time of occurrence. They also need to be warned of the likely consequences if no action is taken.

In addition to the benefits that accurate forecasting produces, warning efficiency depends to a large extent on its timeliness. The more advanced in time a warning is given, the more valuable it will be to those involved in operating emergency measures. This can only be possible if firstly a supply of environmental data related to river flooding is readily available, secondly if these data can be translated into estimates of important flood parameters, such as peak levels, duration etc., and thirdly if these estimates can be transmitted immediately as warning material to flood control, flood fighting and evacuation authorities.

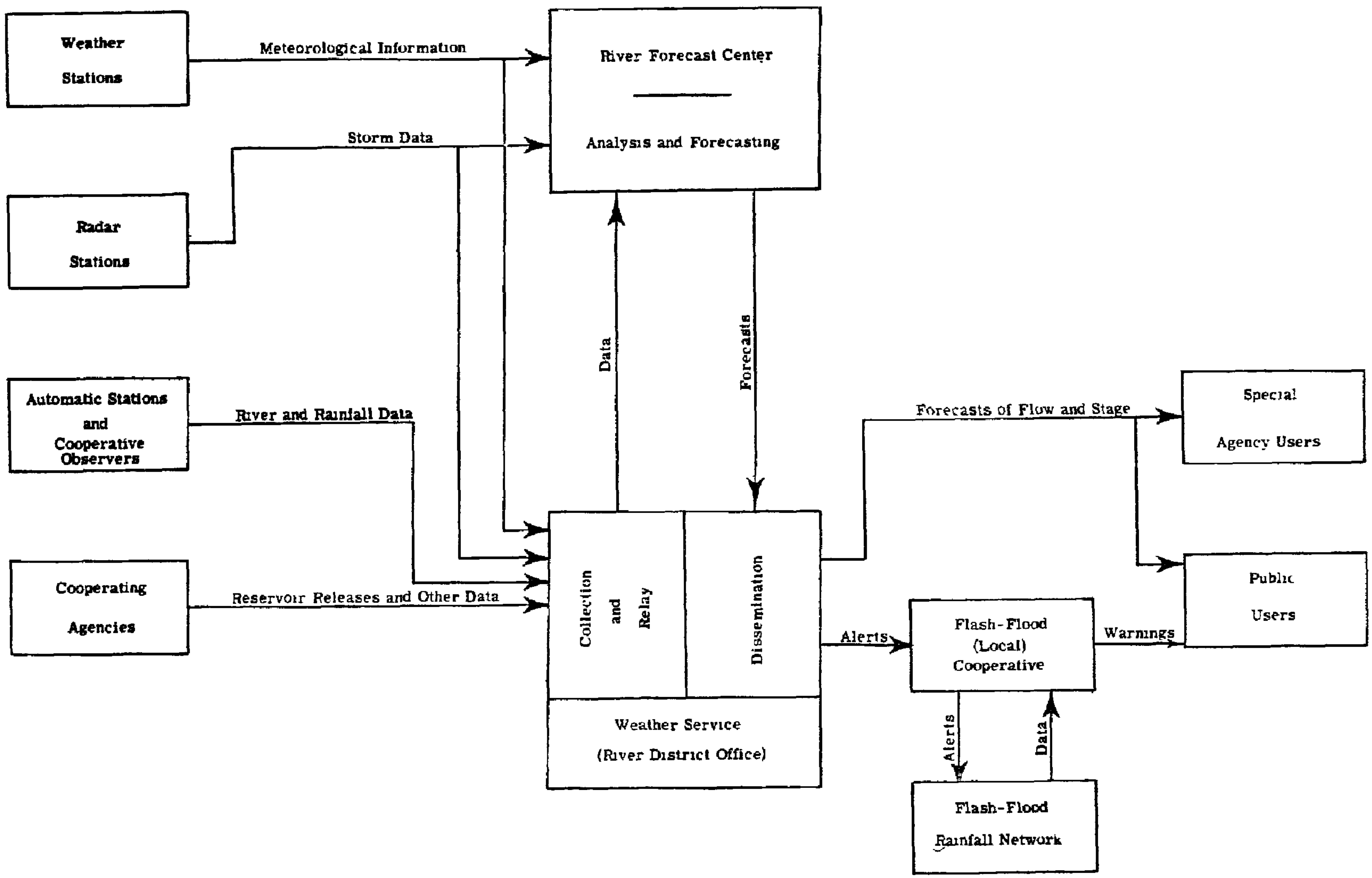
Disaster prevention using emergency measures depends on a clearly identifiable flow of information between various responsible centres. Organizational systems set up to effect this flow show marked similarity in over-all plan; they differ in detail very often due to non-technical reasons. An example of an operational system is shown in Figure 3.1 for the US Department of Commerce National Weather Service up to the point where emergency preparedness authorities become involved.

A description of flood emergency measures is basically a description of this and similar systems, and the direct action taken in flood control and by emergency preparedness authorities.

FLOOD FORECASTING METHODOLOGY

3.2 As in the case of flood hazard assessment and disaster prevention by land use and other control measures, a key aspect of emergency measures is the basic hydrological methodology employed in making forecasts. Accuracy is primarily related to this factor and a necessary characteristic is the ability to predict river flood hazard characteristics given a limited amount of monitored hydrometeorological data related to the flood event. It is important that prediction be possible with a tolerable accuracy commensurate with the time required for emergency measures to be taken.

Fig. 3.1 RIVER AND FLOOD FORECAST OPERATIONS CHART



Required accuracy and timeliness control the hydrological methods adopted to effect prediction. The two together often result in a programme of compromise in that very advanced but less accurate forecasts are made initially and are updated later and improved by one or more subsequent forecasts made nearer the time of the event.

In years gone by methods used were always simplistic to permit rapid hand computation of forecast. More elaborate hydrological techniques are now available but generally demand more monitored data and especially more computational aids such as analogue and digital computers and their peripheral equipment. It is interesting to note that some operational hydrologists still prefer to use the more simplistic technique. This could represent on the one hand a natural reluctance to accept a new and more complicated methodology. On the other hand, it probably represents in many cases a practical view that maintaining a simple approach is less liable to incur error and that many simple operational methods already giving satisfactory performance obviate the need for other techniques. There is place for both complicated and simple methodology. The former will be and of course should only be undertaken when the latter is not appropriate.

Flood forecasting methods for events embryonic in meteorological causes broadly classify under two headings:

(a) those methods which depend largely on river level or discharge data, and

(b) those methods which utilize established relationships or modelling technique of the rainfall-runoff or snowmelt-runoff process.

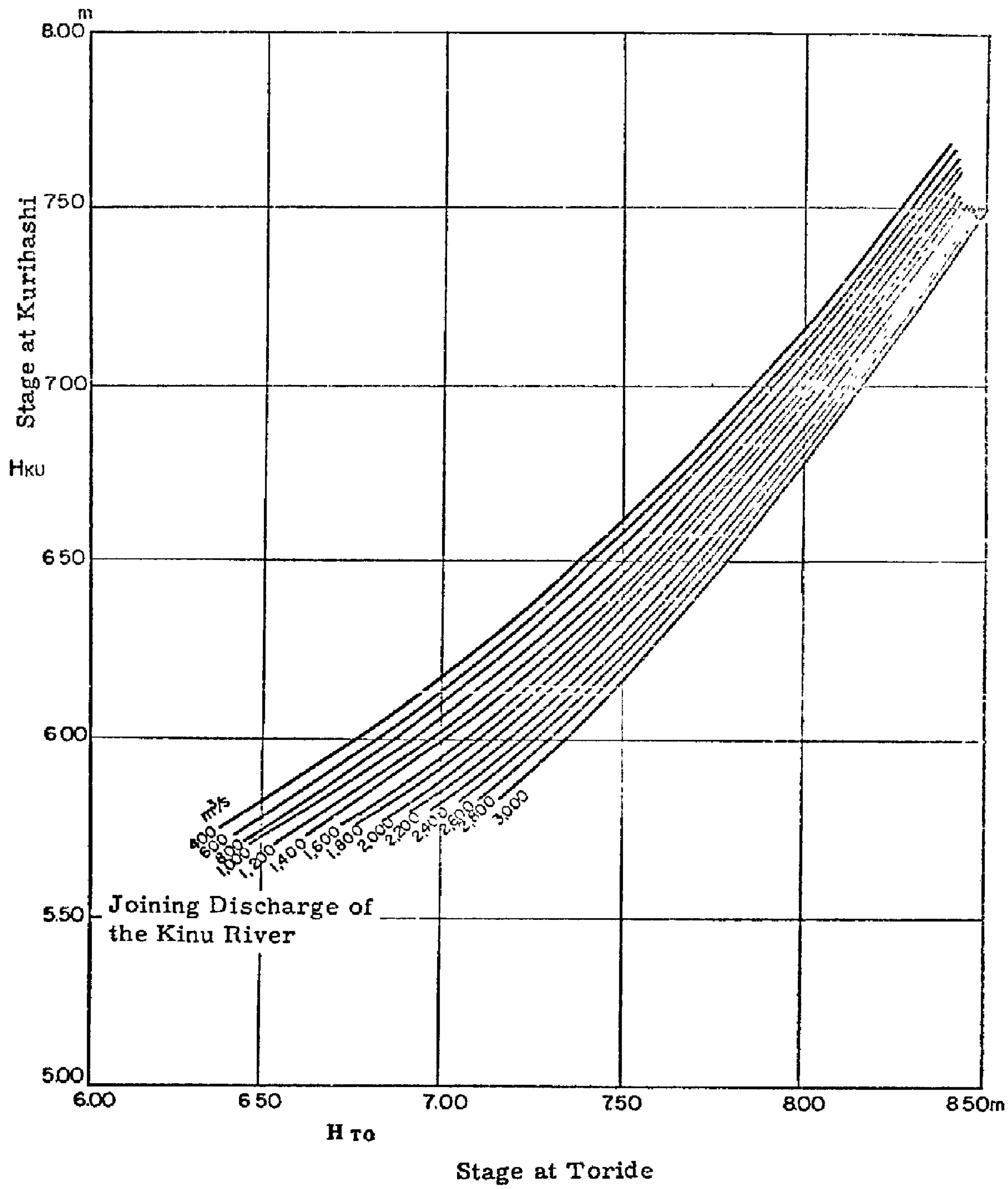
A degree of interplay between these two groupings exists.

River based data

3.2.1 Good and accurate relationships between river levels or discharges at two or more sections in a river system can be developed both for tidal and non-tidal reaches. Relationships are frequently represented in graphical form and are often given as a series of algebraic expressions of a purely empirical nature. They can be used to predict flood conditions, hours, days or sometimes even weeks in advance of the event. A variety of techniques exists and are collectively referred to as flood routing, which is commonly associated with the solution of unsteady open channel flow equations based on physical identity but which can in its broader sense include other techniques such as a simple stage to stage comparison.

An example of a simple effective stage to stage correlation used in Japan is shown in Figure 3.2, where peak levels at Toride on the river Tone are predicted knowing peak levels at Kurihashi, approximately 45 km upstream, and the intermediate inflows of the Kinu river. Fig. 3.3. A relationship of time between peaks is employed to forecast when flood levels at Toride will commence. A similar process of river level prediction is carried out for the river Danube in Hungary. The Hungarian National Water Authority obtains river level data from several sections along the river, including data transmitted from neighbouring countries. Forecasts of up to 6 days ahead of occurrence are possible, and accuracy of prediction is $\pm$ 10 to 50 cms. Seen in the light of 100 to 150 cm free-board of levee crest above design flood level this accuracy is satisfactory.

Fig. 3.2 Stage Correlation between Kurihashi and Toride Taking Account of the Kinu River.



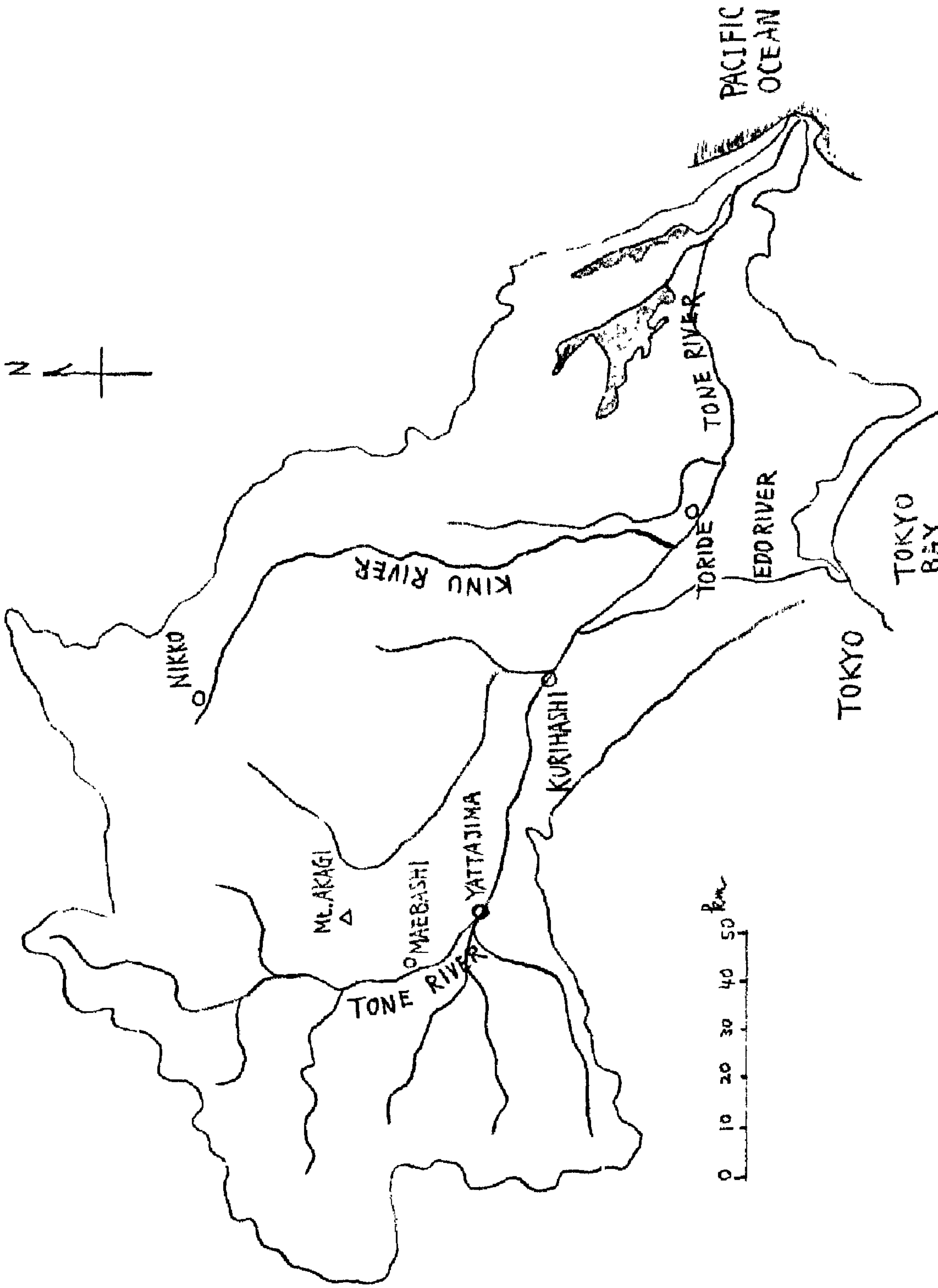


FIG. 3.3 - TONE RIVER BASIN

An effective but more physically based method is used in Holland for prediction of river Rhine levels at Lobith on the Dutch-German border. River levels at 25 main-river sections and 15 tributarial sections are converted into discharge through stage-discharge ratings at each section. These data are derived mainly from outside Holland, in West Germany, and many of them are obtained from German radio news bulletins at 09.00 hrs each day, generally given for all navigational users of the river. Additional information is obtained by telephone. Discharge volumes are added in an ordered way to forecast Lobith discharges and levels for periods up to 4 days in advance, Figures 3.4A and 3.4B. The annotated plan illustrates that discharges at certain points in the drainage network take a predetermined number of days (lags) before they effect discharges at Lobith, and the table is an example of prediction of Lobith discharges and levels making use of lags up to 4 days in advance. Extrapolation of tributary inflows some time ahead is necessary and uses an element of rainfall-runoff synthesis; empirically derived correction coefficients to allow for discrepancy in cumulative volumes forecast, and flood wave attenuation, are also employed. This method has been developed progressively over a period of several decades and works efficiently and accurately.

The simplicity of applying such techniques and the apparent accuracy they can given clearly makes them very suitable for flood forecasting in large rivers; time delay on large rivers between gauged sections is often in the order of days and the necessary interval of data acquisition is correspondingly not too frequent. Difficulties arise when not all tributary inflow is gauged. This demands estimation of unmeasured inflows using either correlation techniques or a rainfall-runoff procedure. Unfortunately when this is done, accuracy of prediction often suffers. A large-river example where this occurs is the river Mekong as it flows through its lower reaches in the Khmer Republic.

More rigorously analytical procedures to predict river flows involve the solution of physically based equations of unsteady flow in open channels. "Hydrological" technique involves an equation of continuity and an empirical expression between channel network storage and its outflows and inflows. These methods are well-known and widely documented and have the advantage very often of being capable of condensation into simple straightforward computational technique. 'Hydraulic' methods of flood routing are even more rigorous still, involving the solution of both storage and energy equations of unsteady flow. Use of hydraulic method is normally computer based because of its complexity but solutions are potentially the most accurate of all if ungauged inflow is not important. Application is advantageous whenever the channel system is complex and flood flows not dominated by hydrological considerations. Hydraulic routing and forecasting is therefore especially useful in tidal estuaries and delta regions, as exemplified in the Mekong delta, and in a river system which has a substantial degree of artificial control.

An illustration of the latter aspect is provided by the upper Rhine in the Federal Republic of Germany, Figure 3.5. Here river regulation works over a long period of time has involved river training by re-alignment,re-sectioning and flood levee construction, and construction of alternative channels and loops for navigation and hydro-electric power generation. This complex system of drainage and control constitutes an involved hydraulic problem, not capable of being solved easily by standard hydrological techniques. As a result the Bundesanstalt (Koblenz) für Gewässerkunde has developed a hydraulic routing model to forecast the effect of all controls, man-made or natural, on flood flows (and normal flows) and necessitating digital computer operation.

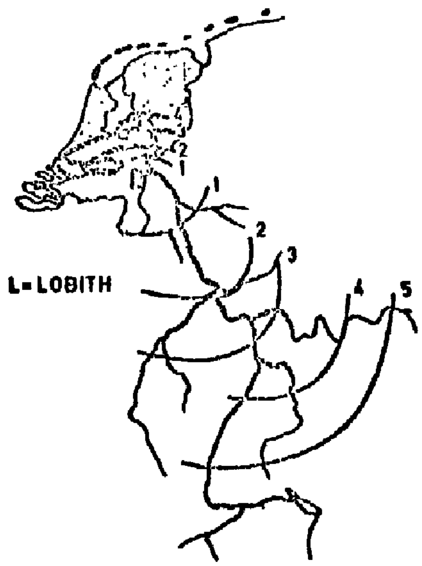


Fig. 3.4A - Travel time of floods in the Rhine catchment in days related to Lobith.

COLOR OF THE DAY	TRAVEL TIME UP TO LOBITH	WATERSTAGES CORRESPONDING WITH THE STAGE AT LOBITH: TODAY 27e	TOMORROW 1 DAY	2 DAYS	3 DAYS	4 DAYS	DISCHARGES	TODAY 27e	TOMORROW 1 DAY	2 DAYS	3 DAYS	4 DAYS
MAXAU	3 3/4 DAY					665					*2710	2750
							-33 % ΔQM					-50
GUNDELSHEIM	3 1/2 DAY					420					*620	630
							-33 % ΔQZ					-20
												-80
							ACCUMULATED CORR. 50 %					*-50
							CONTROL / CORR.				*3020	-50
WORMS	3 DAYS				495	535				*2700	2920	3240
							-33 % ΔQW				-70	-110
GRIESHEIM	2 3/4 DAY				645	620				*600	620	580
GROLSHEIM	2 1/2 DAY				310	270				*240	300	200
							-33 % ΔQZ				-30	+50
							ACCUMULATED CORR. 50 %				*+80	*+40
							CONTROL / CORR.			*3620	+100	+50
KAUB	2 1/4 DAY			x523	535	560			*3560	3310	3920	4030
							-33 % ΔQK			-80	-40	-40
KALKOFEN	1 1/2 DAY			430	400	380			*660	720	640	560
TRIER-175	2 3/4 DAY			x480	520	460			*1000	1190	1340	1100
							-33 % ΔQZ			-80	-30	+100
							ACCUMULATED CORR. 50 %			*+20	*+10	* -
							CONTROL / CORR.		*5150	+90	+40	+70
KEULEN	1 1/4 DAY		x592	613	638	*630		*4860	5330	5660	5550	5600
							-50 %		-220	-160	-110	+40
WETTER 50 %	1 1/6 DAY		x264	245	225	215		*360	470	430	390	370
							-50 %		-60	+20	+20	+10
									-420	-450	-470	-460
							ACCUMULATED CORR		*+20	*+10	*	*
							CONTR./CORR. 50 %	*4750	+40	+20	+10	
LOBITH		x1370	1336	1424	1436	1439		4820	5150	5550	5720	5760
DATA		27	28	29	30	31		27	28	29	30	31

• TO BE FILLED UP AT THE DAY BEFORE
X DERIVED FROM OBSERVED STAGE
| PREDICTED STAGE IN (COLOR OF THE DAY)

Fig. 3.4B - Forms for the forecasting of the discharge over 1, 2, 3 and 4 days.

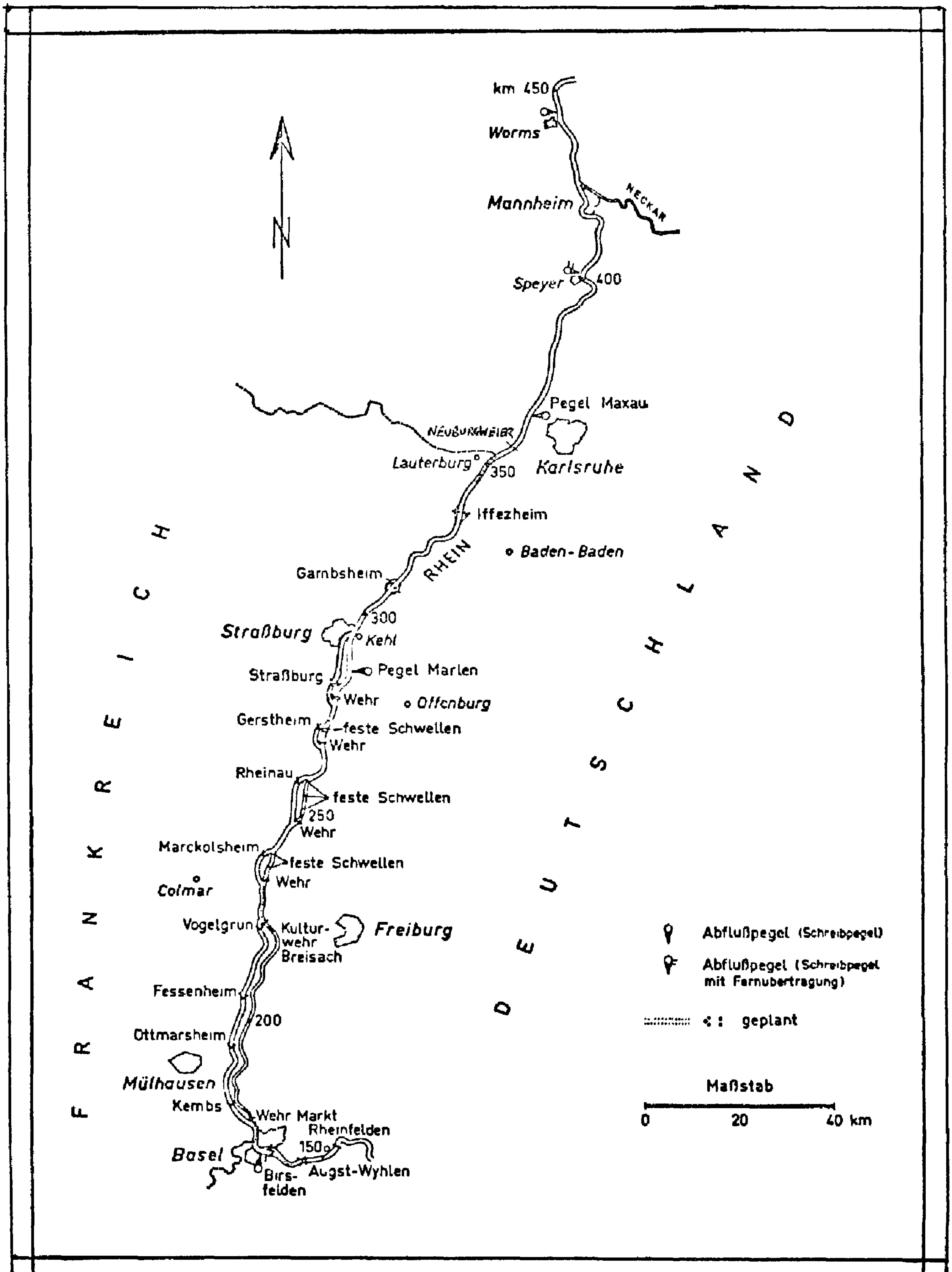


FIG. 3.5 - **River Regulation on the Rhine**

Two generally appropriate and important aspects of hydraulic routing emerge from the Rhine example. Firstly, despite complex boundary constraints and changes, it is capable of demonstrating with good accuracy the influence that control works and regime can have on flood flows (page 22). Secondly, hydraulic methods once developed can be applied easily to studying effects and improvements to be brought about by proposed river works. Control of flood flows in the Rhine for instance by the temporary storage of flood water during peak flows in local ground depressions remaining from past river realignment work is currently being investigated.

Another aspect demonstrated in this German example is the necessity on occasions to hybridize different methods of flood forecasting. The stretch of the river Rhine concerned requires forecasts of tributary inflows from France (especially the river Ill), and from Germany. It is also advantageous to have advanced forecast of mainstream inflow from Switzerland. These to some extent are being achieved by rainfall-runoff and snowmelt-runoff modelling but do not as yet reach an accuracy sufficient for final prediction of flood flows in the river Rhine.

River-based data methods of flood forecasting are generally more accurate than other methods.

Rainfall-Runoff Methods

3.2.2 Development of relationships between storm rainfall and flood discharge is important in flood forecasting for two major reasons. Firstly, it is not practical in many cases to gauge and monitor all important contributions to flood flows in a river channel. Secondly, and particularly appropriate to small and steep catchments when runoff is rapid and flash floods can occur, insufficient time may elapse between rainfall and flood flows to allow river-based data methods of forecasting to be used.

Before the advent of digital and analogue computers, techniques developed were limited to those capable of being handled by simple computational methods in the short time available. As in the case of river-based data methods many hydrologists still favour these simple techniques wherever they work with sufficient accuracy. Computers however have brought within the scope of forecasts more complex procedure for simulating or modelling the rainfall-runoff (and snowmelt-runoff) process, generally assumed to be more precise than previously used simplistic methods. A few of these models have found their way into operational forecasting.

Most rainfall-runoff forecasts involve two important features, a technique to determine how much of the rainfall will eventually form the river flood, and a technique to transform the effective rainfall volume into a hydrograph or flood wave ship and/or peak discharge. At a very simple level this may condense into one or more simple graphical or algebraic relationships between peak river discharge and measured storm rainfall. An example developed for the Chikugo river in Japan is a set of simple linear relationships between peak river levels (Y shakus)* and storm rainfalls (R mm) for different rainfall durations.

(eg. $Y = 6.01 + 0.0436\ R$ for 15 hrs of rainfall duration.)

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* A shaku is a linear measure approximately equal to 1 foot.

A very popular technique is one which firstly determines the volume of effective storm runoff through a relationship between this volume and various relevant parameters, including total rainfall, rainfall duration, initial wetness of catchment, time of year and so on. This relationship can be represented in algebraic form or in the very popular form of coaxical graphical correlation. Distribution in terms of the estimated runoff volume (the flood hydrograph) is effected by one of several methods, the techniques of unit hydrograph and area-time being two in general use.

Many varieties of this basic approach exist. An example is the method developed for forecasting floods in the river Conway valley of North Wales. In this valley serious flooding develops mostly as a result of heavy rain falling in the Snowdonian mountain range, remote from the point of flooding. As a consequence flood stages are typically delayed in reaching the lower valley but are flashy when they do. Fig. 3.6A.

Forecasting is carried out in three parts;

1. Time of flood wave translation To and rise T2 are predicted using well defined relationships with the estimated duration of rainfall and initial discharge Qo. (Figs. 3.6 B and 3.6 C);

2. Peak discharge Qp is predicted using graphical correlation between base discharge Qo and rainfall duration D. (Fig. 3.6 D);

3. A Hydrograph is chosen from a selection of derived typical hydrographs, having a time of rise T2 equal to the value of T2 predicted in '1'. Ordinates of this chosen hydrograph are multiplied by the ratio of predicted peak discharge to chosen hydrographic peak discharge. This enables the prediction of duration of critical discharges (discharges above these cause serious flooding). (Fig. 3.6. E).

This process has reasonable success in predicting peak discharges for an area of catchment of 344 km^2, which is perhaps surprising in view of the fact that in its proving stage rainfall data were derived from only one telemetering raingauge. More telemetering raingauges refine and improve prediction and weather radar in an adjacent valley may add considerably to rainfall information. The method was designed originally for hand computation.

Accuracy of prediction using simplistic hand operated methods depends to a large extent on a hydrologists individual ability, foresight and local knowledge. On occasion flood forecasting may be improved considerably by using more comprehensive methods to simulate the rainfall runoff or snowmelt runoff process, but to do so requires the computational aid of a digital, or analogue computer. Comprehensive simulation, most often referred to as catchment modelling, is a relative term since models vary enormously in complexity. They endeavour to represent as much as possible the general influence of the various physical processes involved such as interception, surface detention, infiltration, evapotranspiration, overland flow, interflow, groundwater seepage, channel flow and so on. Development of a catchment model normally begins with the construction of a flow diagram representing conceptual interconnexion between the physical

Fig. 3.6 B- RELATIONSHIP BETWEEN START OF RAIN AT CWM DYLI AND MOMENT OF RESPONSE OF RIVER CONWAY AT CWM LANNERCH (LOG LOG SCALE)

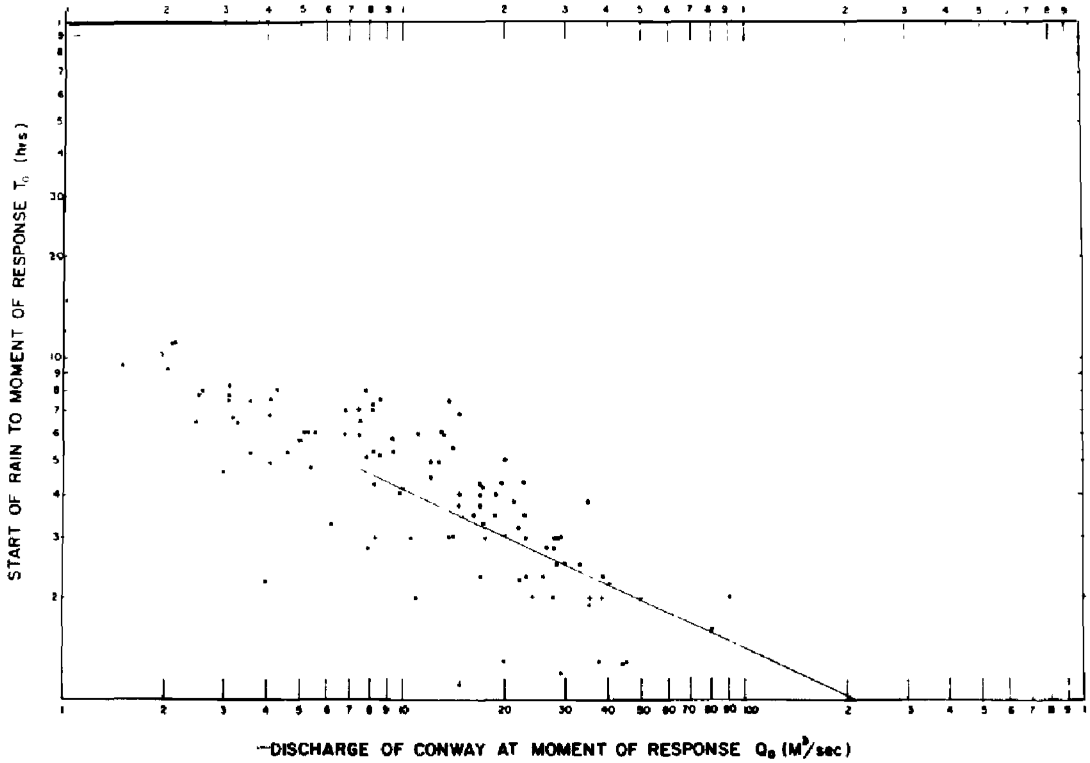
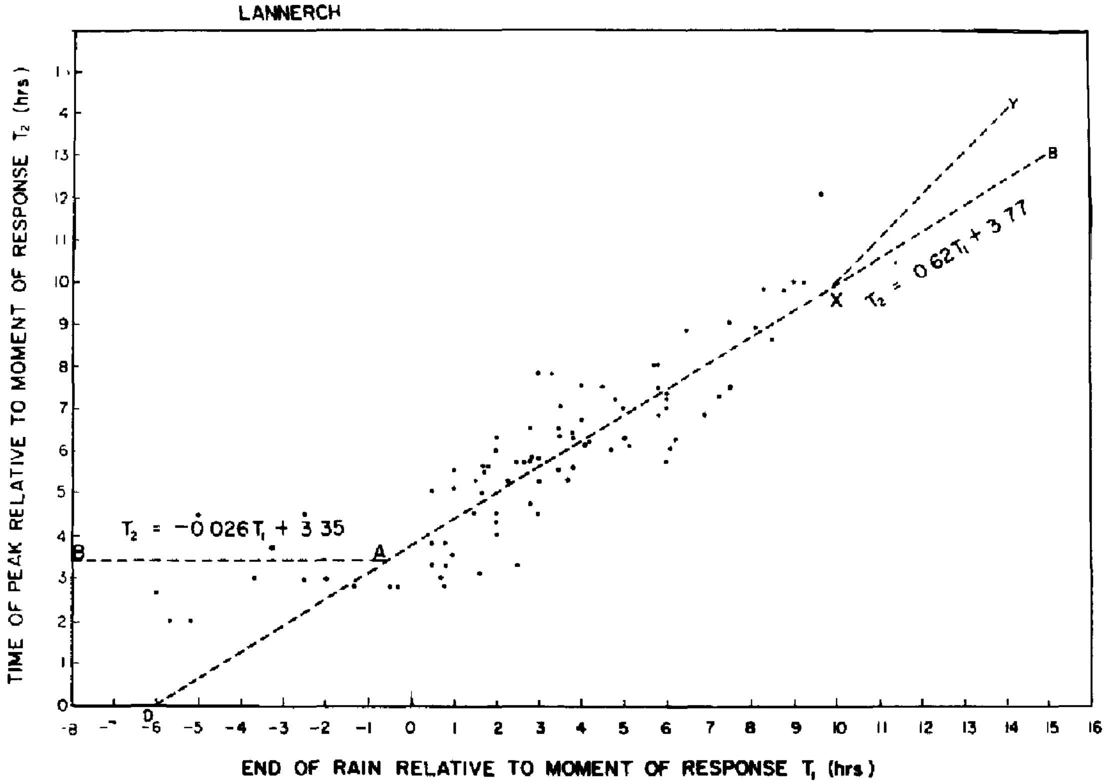


Fig. 3.6 C -RELATIONSHIP BETWEEN END OF RAIN AT CWM DYLI RELATIVE TO MOMENT OF RESPONSE OF RIVER CONWAY AND TIME OF PEAK AT RIVER CONWAY AT CWM LANNERCH



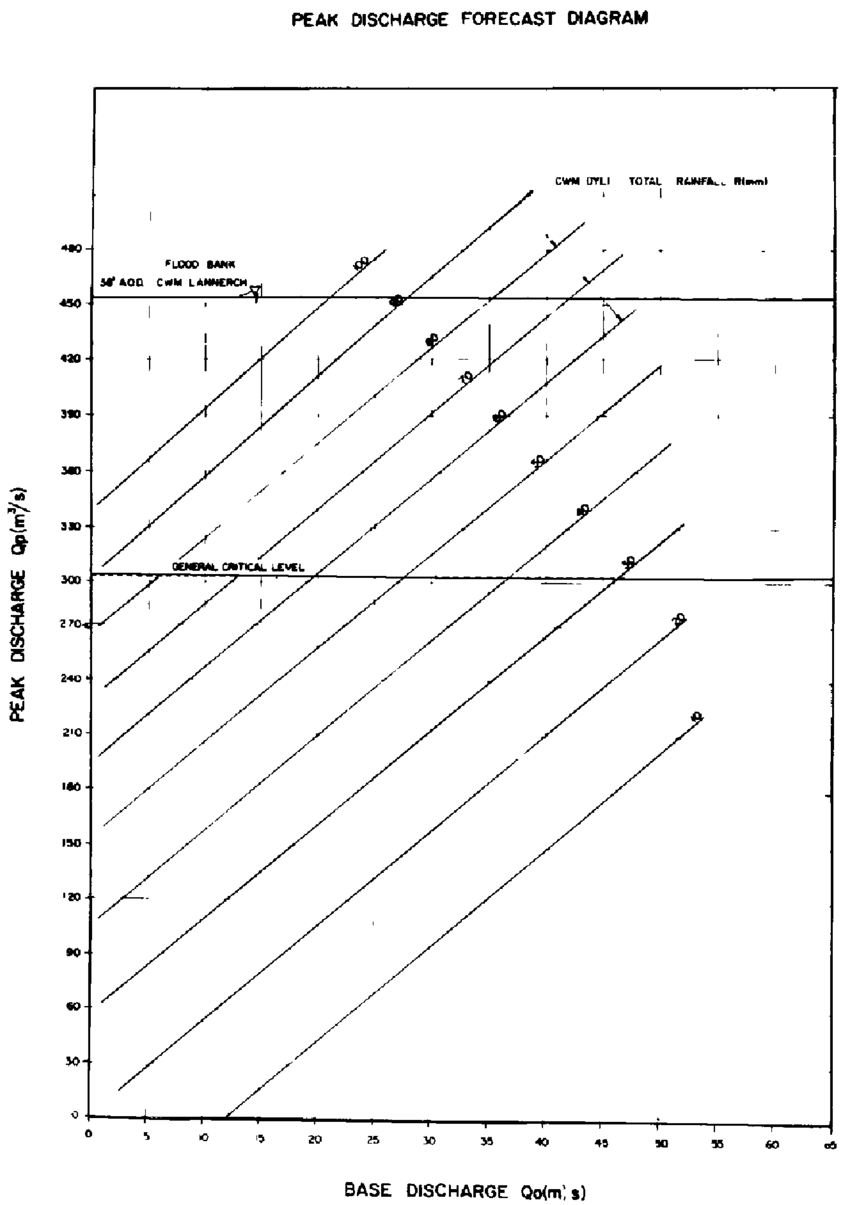


FIG. 3.6 D

Peak discharge forecast diagram

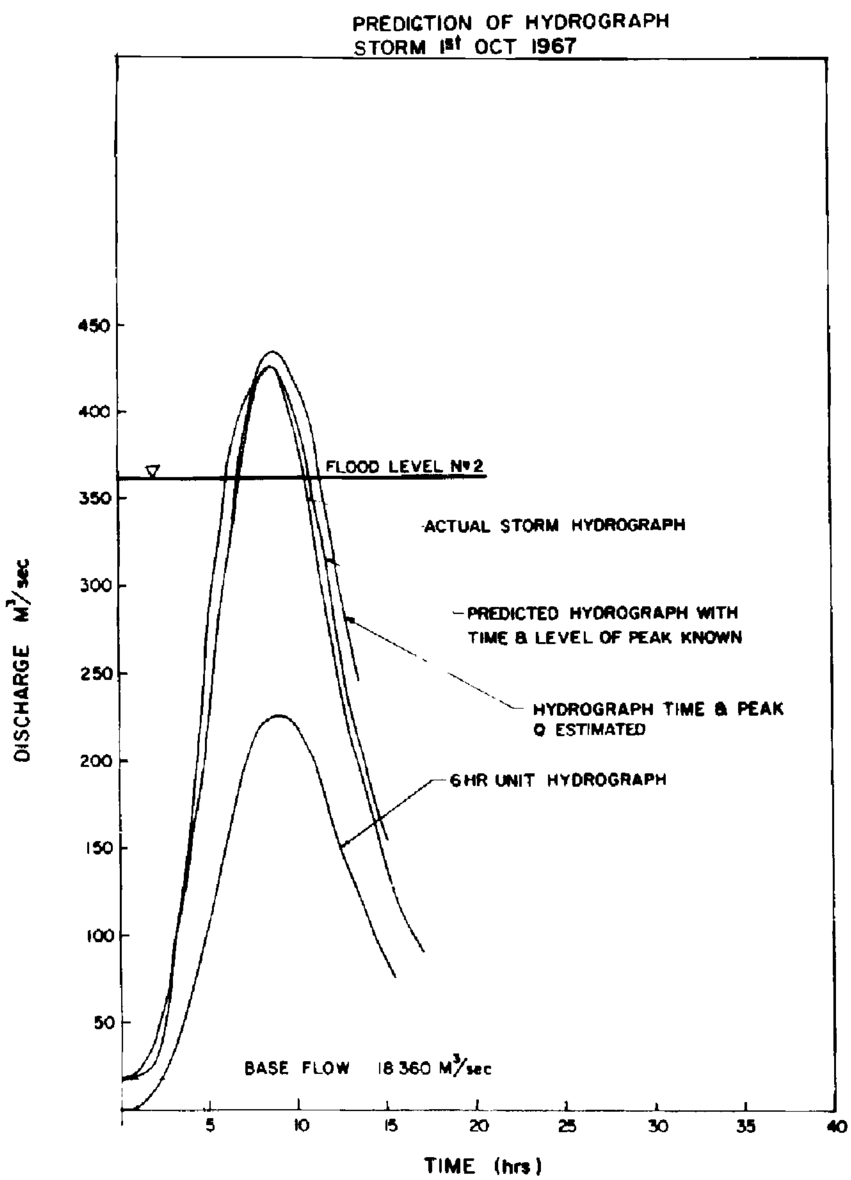

PREDICTION OF HYDROGRAPH
STORM 1st OCT 1967
FLOOD LEVEL No 2
ACTUAL STORM HYDROGRAPH
PREDICTED HYDROGRAPH WITH
TIME & LEVEL OF PEAK KNOWN
HYDROGRAPH TIME & PEAK
Q ESTIMATED
6 HR UNIT HYDROGRAPH
BASE FLOW 18 360 M³/sec
DISCHARGE M³/sec
TIME (hrs)
450
400
350
300
250
200
150
100
50
5
10
15
20
25
30
35
40

FIG. 3.6 E

elements. A well known example is shown in Fig. 3.7. It is a fairly easy step to transcribe the flow diagram into a digital computer programme, the most popular form of operating a model to simulate streamflow. The physical elements in this case are represented by parametric function.

The simplicity of structure that modelling can achieve is exemplified in Fig. 3.8. This represents the basic structure of the tank model which is currently operational in Japan. It consists of one or more conceptual tanks, each tank having a number of apertures in its side and one in its base. When more than one tank is employed, outflow from the base of an upper tank becomes inflow to the tank immediately below. Inflow to the top tank represents rainfall. Total side outflow from all tanks represents streamflow. This structure has been formed to simulate natural catchment response to storm rainfall and does so very well. It also has the advantage that its conceptual behaviour can be programmed quite easily for digital computer simulation or a much cheaper physical representation can be constructed to allow simulation by direct analogue.

A number of catchment models have become operational in flood forecasting schemes. The tank model and the previously illustrated Stanford Watershed Model are two such examples. Another example is the SSARR model which has been applied in a semi-operational mode for the river Mekong since 1970, and its modified version, the LSSARR model, which simulates flow, in the complex channel network of the Mekong delta.

Significant problems exist in making models simulate flood flows and adjustments are necessary in parametric values to improve accuracy of prediction. Many of the problems encountered have origins in the general inadequacy of input data. This inadequacy is often brought to light during model development and application and leads to improved design of the hydrometric network acquiring the necessary data. Models in general are only as good as input data will allow and for this reason may not give improvement of prediction over simple models that their sophistication might lead one to expect.

Considering these and other related problems led the WMO to carry out an international programme of intercomparison of operational models. Eleven models have been investigated including the three to which reference has just been made. Results obtained give general guidance as to the goodness of prediction that can be expected by using each model and the environmental conditions in which each is acceptable for application.

Snowmelt

3.2.3 Snowmelt in concept constitutes an alternative input to a model of the rainfall-runoff process and can thus be modelled quite simply by employing a special and separate sub-routine. This sub-routine attaches readily to the land and channel phases of a model to permit the prediction of snowmelt flooding.

Model sub-routines have in the past formed the basis of simple methods of flood forecasting. Flooding is predicted generally using one of two approaches, the one employed depending mainly on whether or not the snowpack disappears completely during a melt season. If the pack disappears methodology is based mostly on temperature-index technique. This has the concept that runoff is

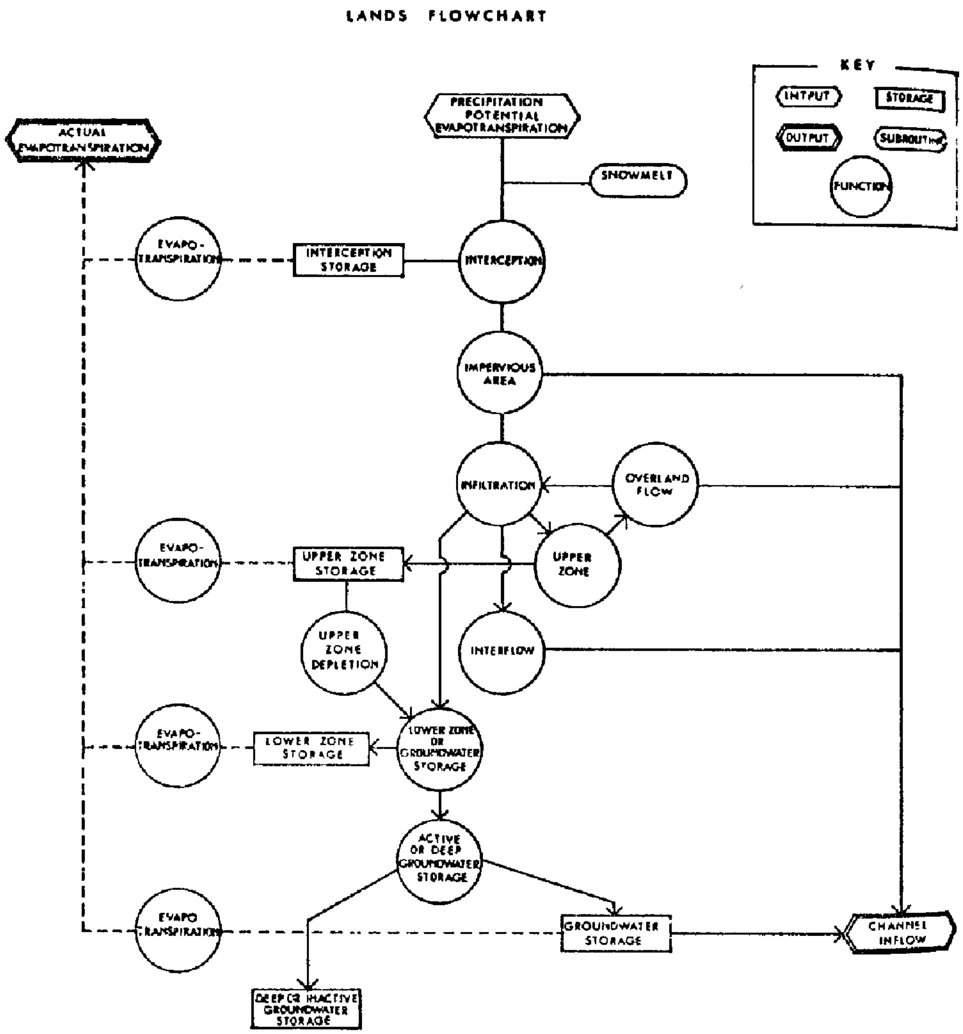


Figure 3.7 THE STANFORD WATERSHED MODEL

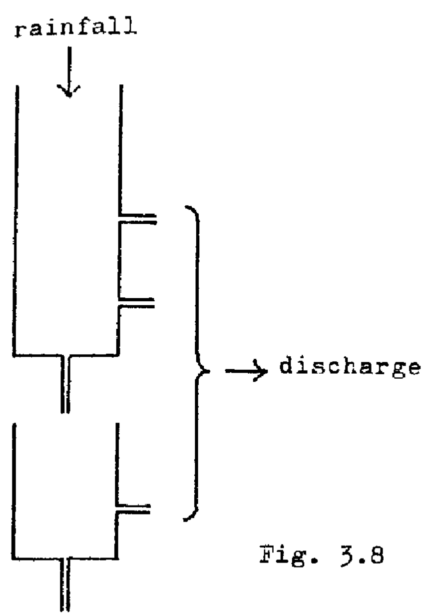


Fig. 3.8 THE TANK MODEL

directly related to air temperature above freezing point averaged over some suitable interval of time (1 hr, 3 hrs, 1 day, etc.). More refined and physically direct techniques use indexes of total energy input to the snowpack but during the occurrence of a major snowmelt flood, this technique is often not found to give a marked improvement of prediction over the simple temperature-index methods. Energy-index methods are also used in regions where snowpack does not disappear altogether from the whole catchment. In such regions the so-called Percentage-Index method developed primarily for the Rockies and Sierras of the U.S.A. can be employed. This is a purely empirical method. It is based on the concept that flood volume during a melt season is dependent on the amount of water present in the snowpack. If water equivalent at a few index points (snow survey points) is larger than a 'Norm', snow-melt runoff will be greater during the melt season and consequently so will the peak discharge. Correlation of relative index water equivalent with both recorded peak discharges and volumes of runoff help in both flood forecasting and in planning potential irrigation development for the growing season. Corrections are made to allow for rainfall and varying snowmelt volumes which occur during the developing melt season.

Other problems

3.2.4 Methodology so far outlined has referred mainly to what might be termed standard hydrological technique of flood prediction. A number of the problems exist which on occasion deserve much greater attention than these. They include flooding due to ice jams, floods induced by storm surge, special provision for flash floods, aspects of flood control and the possibility of advancing forecasts further by attempting to forecast precipitation in quantifiable terms (QPF).

Quantified Precipitation Forecasts

3.2.4.1 In many respects QPF and flash flood forecasting are strongly associated because of the significance of time of forecast in advance of flooding. QPF is still a major problem and although refined and physically based models have been developed forecasts are largely of an experimental nature. Valuable progress has however been reported in the U.S.A., Japan and China. Rainfall subsequent to the forecast has an overriding influence on the success of crest-stage forecasts released during the early portion of a rise. A QPF is a useful guide for adjusting or qualifying such forecasts and is mostly achieved by empirical and statistical estimation rather than a simulation model. They are usually not sufficiently accurate to justify inclusion with observed data in the computation, and the adjustment is handled by a condensed procedure. The forecast can then be issued in bracketed form, with the upper value determined by the QPF. If heavy continuing rain is a certainty and time permits, a wide spectrum of crest forecasts can be issued for guidance, based on various assumed values of prospective rainfall. (More detail is provided in the volume dealing with meteorological aspects of disasters and their prevention.)

There are regions in the world where satisfactory flood forecasts cannot be issued without the assistance of QPF. River Conway flood prediction is one example (page 39). Other cases occur in small islands in the western Pacific which are frequently visited by typhoons producing heavy rains that may last several days. Many of the streams head up in the mountains and are very steep, and generally crest before the end of rain. QPF is an absolute necessity for effective flood forecasts, and numerical relationships have been developed for predicting total storm rainfall at representative stations from meteorological parameters associated with the typhoon, and its probable track and point of landfall.

To minimize demands on the meteorologist, the QPF is limited to a specification of storm types and predictions of total storm rainfall at an index station and total duration of rain. To utilize these predictions it is necessary for a hydrologist to convert station rainfall into corresponding watershed depths, and distribute these depths with time. In such highly mountainous areas, point to a real conversion is accomplished by a standard procedure. Time distribution is accomplished through the use of the non-dimensional mass rainfall curves (Figure 3.9.). Both the abscissae and ordinates of the graph are plotted in per cent of total. This enables determination of the probable series of rain increments for any selected time unit given the storm type, total rainfall, and storm duration. The basis for this graph is the similarity in shape of mass rainfall curves within storm types, as evidenced by a study of 15 years of records of rainfall accompanying typhoons striking or passing close to the area.

Flash floods

3.2.4.2 An important responsibility of a river forecast centre is to furnish guidance material for local issuances of flash flood forecasts. The river Conway method previously outlined (page 39) is one such example. In many cases there is too little time to collect and analyse rainfall and river stage data as the basis for forecasting flash floods, and automatic systems may be necessary to act both as data sensing and alarm systems without intermediate data processing and analysis (page 69). General preparatory data may however be given as headwater advisories or flash flood guidance material.

Headwater advisories, in conjunction with previously furnished tables, within U.S.A. enable a district office or local flood warning distributor to prepare flood forecasts or warnings for specific points identified from past experience as points subject to flash flood threat. The table, developed from the forecast procedure for the basin and illustrated in the teletype printout of Figure 3.10, relates forecast crest stage to the headwater advisory index and the 3-hour average depth of rainfall over the basin. The headwater advisory index, transmitted twice-weekly, is defined as the amount of 3-hour rainfall required to produce bankfull stage. Once heavy rain is reported a stage forecast can be prepared from the headwater advisory table and issued as such, or worded qualitatively, as "minor", "moderate", or "severe flooding", depending on the position of the exit value of the table.

Many streams subject to flash flooding are not equipped with a stream gauge that would permit a formal procedure for forecasting. Some area-wide warning service can be provided in this situation by the use of a flash flood guidance. In the eastern half of the U.S.A. guidance material consists of a map transmitted twice-weekly, showing amounts of 3-hour rainfall that would produce flooding of small streams anywhere in the area. This map, illustrated in the facsimile reproduction of Figure 3.11, is based on the fact that there is considerable regional homogeneity in headwater advisory indices thus justifying their generalized use. The map, transmitted on schedule on the national teletype, enables

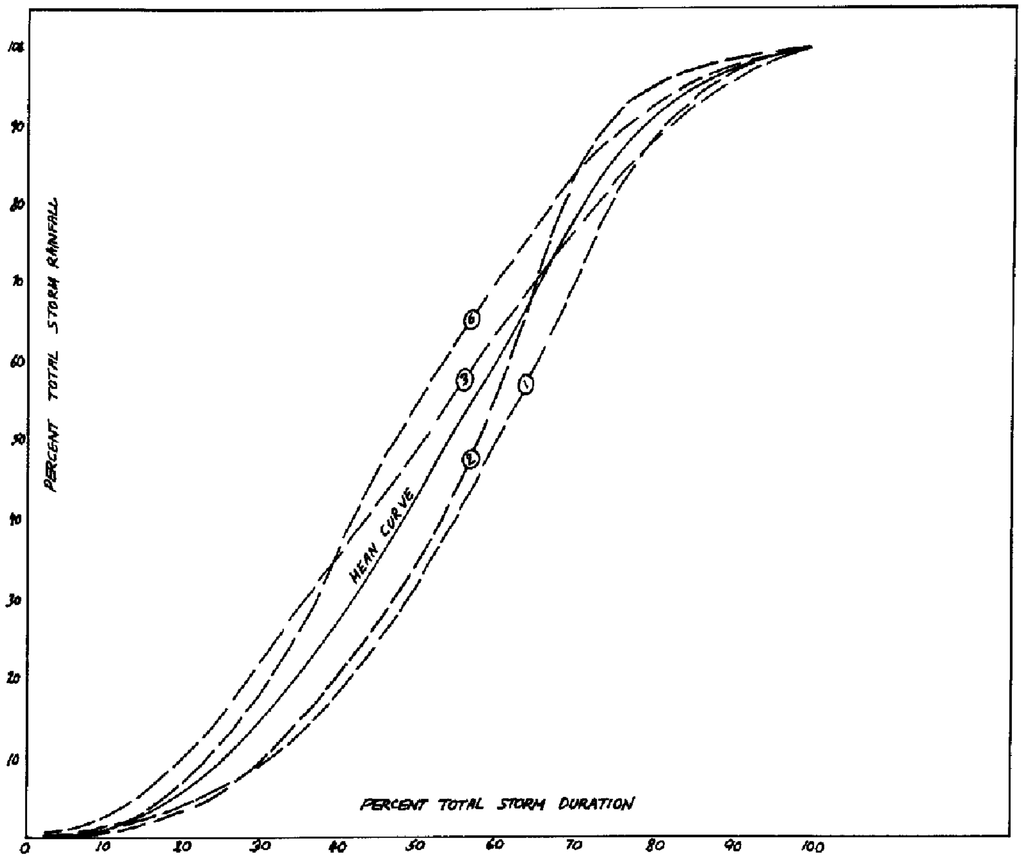


Figure 3.9 Non-dimensional mass rainfall curves
Storm types I, II, III & IV

FLOOD ADVISORY TABLE

BLUE RIVER - BANNISTER ROAD KANSAS CITY, MO.

FLOOD STAGE IS 21.0 FEET

LAG FROM MIDDLE OF TIME PERIOD OF THE HEAVIEST RAIN TO CREST IS ABOUT 9 HOURS

	STAGE FEET	DISCH. CFS	3 HOUR RAINFALL AMOUNTS (INCHES)										
	14.0	3322	.6	1.0	1.4	1.9	2.3	2.7	3.2	3.6	4.1	4.5	5.0
	15.0	3561	.6	1.0	1.4	1.9	2.3	2.8	3.3	3.7	4.2	4.6	5.1
	16.0	3800	.7	1.1	1.5	2.0	2.4	2.8	3.3	3.7	4.3	4.7	5.2
	17.0	4360	.7	1.2	1.6	2.1	2.5	3.0	3.5	3.9	4.4	4.8	5.4
	18.0	4920	.8	1.3	1.7	2.2	2.7	3.1	3.6	4.1	4.6	5.0	5.5
	19.0	5480	.9	1.3	1.8	2.3	2.8	3.2	3.8	4.2	4.7	5.2	5.7
	20.0	6040	1.0	1.4	1.9	2.4	2.9	3.3	3.9	4.3	4.9	5.3	5.8
FS	21.0	6600	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	22.0	7280	1.1	1.6	4.1	2.7	3.1	3.6	4.2	4.6	5.2	5.6	6.2
	23.0	7960	1.2	1.7	2.2	2.8	3.2	3.7	4.3	4.7	5.3	5.8	6.3
	24.0	8640	1.3	1.8	2.3	2.9	3.4	3.8	4.4	4.9	5.5	5.9	6.5
	25.0	9320	1.4	1.9	2.4	3.0	3.5	4.0	4.6	5.0	5.6	6.1	6.6
	26.0	10000	1.5	2.0	2.5	3.1	3.6	4.1	4.7	5.1	5.7	6.2	6.8
	27.0	11180	1.6	2.1	2.6	3.3	3.8	4.3	4.9	5.3	6.0	6.4	7.0
	28.0	12360	1.7	2.3	2.8	3.4	3.9	4.5	5.1	5.5	6.2	6.6	7.2
	29.0	13540	1.9	2.4	3.0	3.6	4.1	4.6	5.3	5.8	6.4	6.9	7.4
	30.0	14720	2.0	2.5	3.1	3.8	4.3	4.8	5.5	5.9	6.6	7.1	7.7
	31.0	15900	2.2	2.7	3.3	4.0	4.5	5.0	5.6	6.1	6.8	7.3	7.9
	32.0	16975	2.3	2.9	3.4	4.1	4.6	5.2	5.8	6.3	6.9	7.4	8.0
	33.0	18050	2.4	3.0	3.6	4.2	4.8	5.3	6.0	6.5	7.1	7.6	8.2
	34.0	19125	2.6	3.1	3.7	4.4	4.9	5.5	6.1	6.6	7.3	7.8	8.4
	35.0	20200	2.7	3.3	3.8	4.5	5.1	5.6	6.3	6.8	7.4	7.9	8.5
	36.0	21300	2.8	3.4	4.0	4.7	5.2	5.8	6.4	6.9	7.6	8.1	8.7
	37.0	22700	3.0	3.6	4.2	4.9	5.4	6.0	6.6	7.1	7.8	8.3	8.9
	38.0	24233	3.2	3.8	4.4	5.1	5.6	6.2	6.8	7.3	8.0	8.5	9.1
	39.0	25975	3.4	4.0	4.6	5.3	5.8	6.4	7.1	7.6	8.2	8.8	9.4
	40.0	27925	3.7	4.2	4.8	5.5	6.1	6.6	7.3	7.8	8.5	9.0	9.7
	41.0	30100	3.9	4.5	5.1	5.8	6.4	6.9	7.6	8.1	8.8	9.3	10.0
	42.0	32500	4.2	4.8	5.4	6.1	6.7	7.2	7.9	8.5	9.1	9.7	10.3
	43.0	35300	4.6	5.2	5.7	6.5	7.0	7.6	8.3	8.8	9.5	10.0	10.7
	44.0	38467	4.9	5.5	6.1	6.9	7.4	8.0	8.7	9.2	9.9	10.5	11.1
	45.0	42000	5.2	6.0	6.6	7.3	7.9	8.5	9.1	9.7	10.4	10.9	11.6

PEAK UNITGRAPH ORDINATE = 8300 CFS   FLOOD STAGE R.O. = .88 IN.

INSTRUCTIONS

USE ALL AVAILABLE RAINFALL REPORTS ABOVE BANNISTER ROAD AND AVERAGE.

EXAMPLE...THE RFC ISSUES AN ADVISORY THAT 3.5 INCHES IS THE AMOUNT OF RAINFALL THAT WILL PRODUCE A FLOOD STAGE AT BANNISTER ROAD. THAT NIGHT AN AVERAGE OF 5.0 INCHES FALLS OVER THE BASIN ABOVE BANNISTER ROAD. ENTER THE TABLE ABOVE WITH A VALUE OF 3.5 AT FLOOD STAGE, 21.0 FEET. FOLLOW DOWN TO 5.0 AND READ OFF 31 FEET. THE LAG TIME SHOWN AT THE HEAD OF THE TABLE IS 9 HOURS, SO THE PREDICTION IS FOR A 31 FOOT FLOOD CREST 9 HOURS FROM THE MIDDLE OF THE TIME PERIOD OF THE HEAVIEST RAIN.

TO DETERMINE CREST BELOW FLOOD STAGE, REVERSE PROCEDURE.

MAXIMUM STAGE OF RECORD 44.5 9/13/61

MKC RFC   OCT. 1973 MKC RDO   BIG BLUE RIVER   BANNISTER ROAD.   KANSAS CITY, MO

FIG. 3.10

Flood advisory table

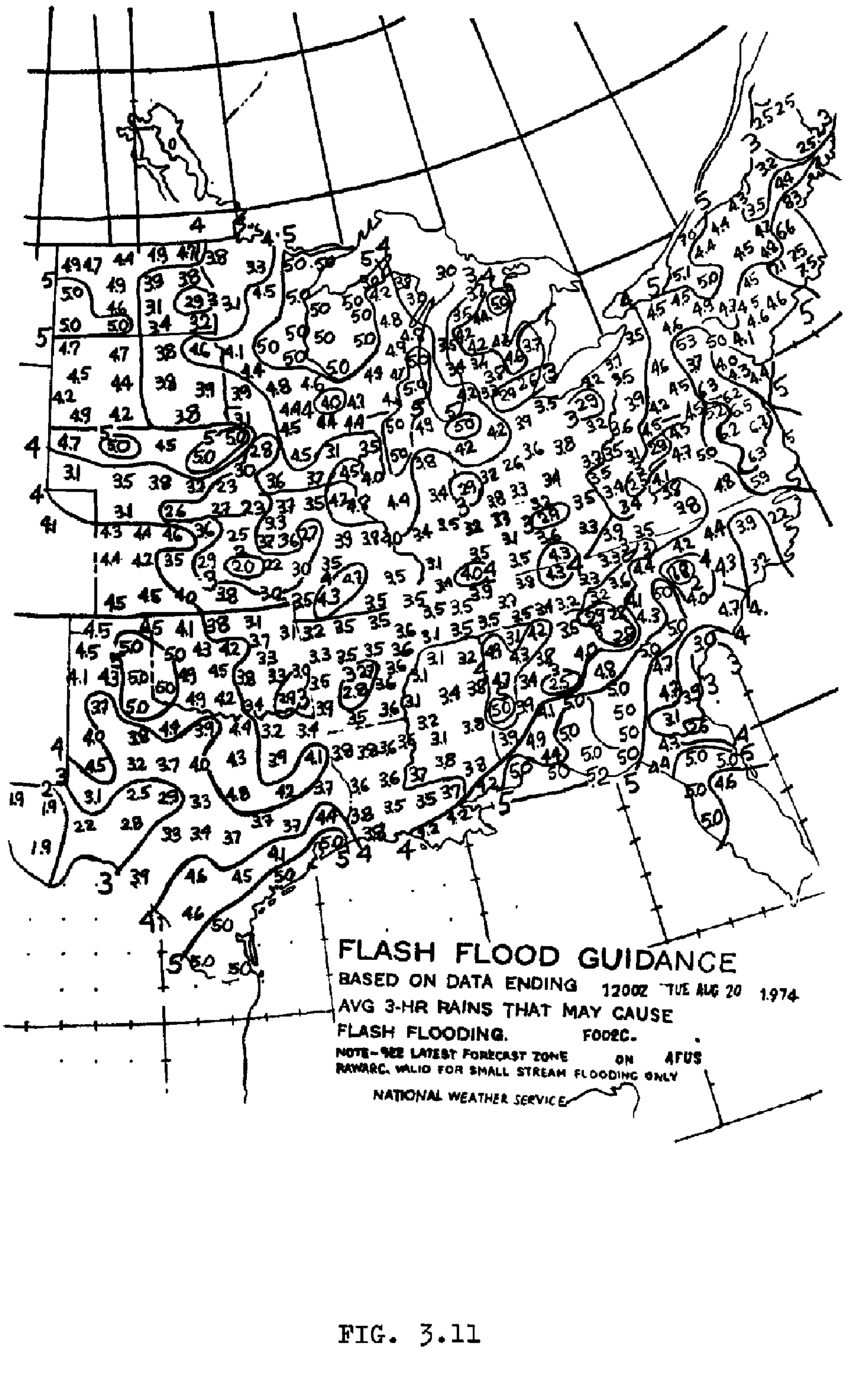

FLASH FLOOD GUIDANCE
BASED ON DATA ENDING 1200Z TUE AUG 20 1974
AVG 3-HR RAINS THAT MAY CAUSE
FLASH FLOODING. FOO2C.
NOTE-SEE LATEST FORECAST ZONE ON AFUS
RAWARC. VALID FOR SMALL STREAM FLOODING ONLY
NATIONAL WEATHER SERVICE

FIG. 3.11

all weather offices having access to current rainfall and radar reports to issue area-wide warnings of local flood danger. These warnings are issued to alert campers and motorists to the threat, especially during night-time, of sudden rises of small streams and flooding of secondary roads.

Ice jams

3.2.4.3 The prediction of river flooding caused by ice jams (or by storm surges in tidal estuaries) is not just a hydrological problem. Both are induced by meteorological phenomena which eventually result in a hydraulic surcharge being created in river levels.

Ice-jams occur generally when ice flows from up-stream meet with other ice flows or sheet ice in a river reach. Larger interlocking masses of ice develop and cause an afflux in up-stream water levels. The eventual and sudden breaking of an ice-jam can cause flood surges downstream of it.

The appearance, growth and eventual break-up of ice is forecastable in the short term using synoptic weather forecasts. But the probable occurrence of an ice-jam is so far forecastable only in statistical terms. For instance, the occurrence of ice-jams in some rivers in Canada and northern regions of the U.S.S.R. is predictable because it is an annual event and not because the physics of the jamming are determinate.

The appearance of a jam is subject to a number of random factors which explains why only the jam itself might be anticipated. Its quantitative influence on river levels is difficult to forecast in advance of the jam. Once a jam has become established however, hydraulic surcharge is determinate and forecasts of flood levels may be made. Ground ice is another possible cause of ice-jams.

Storm surges

3.2.4.4 Storm surge is caused by high winds and is particularly severe during tropical cyclones and deep depressions. Scientific modelling of induced wind set up has been achieved with reasonable success. Prediction of water levels is made up of two components, an accurately estimated value of astronomical tidal level on top of which is superimposed a not so accurately estimated value of wind set up. This latter estimate is normally extrapolated in time based on currently observed levels in excess of astronomical tidal level together with projected estimates of wind strength obtained from meteorological services. When the two factors combine to give estimates showing critical flooding conditions forecasts are issued as warnings (Fig. 3.12). In Holland, these are issued at least 15 hours ahead of expected high water levels. (A more detailed explanation of storm surges with respect to coastal flooding is given in volume III).

Structural control operation

3.2.4.5 Reference has already been made to the interaction between the design of flood control structures and the characteristics of flood hydrographs (page 27). The design and operation of flood control structures depends very much on the operational aspects of flood warning systems and the ability to forecast floods

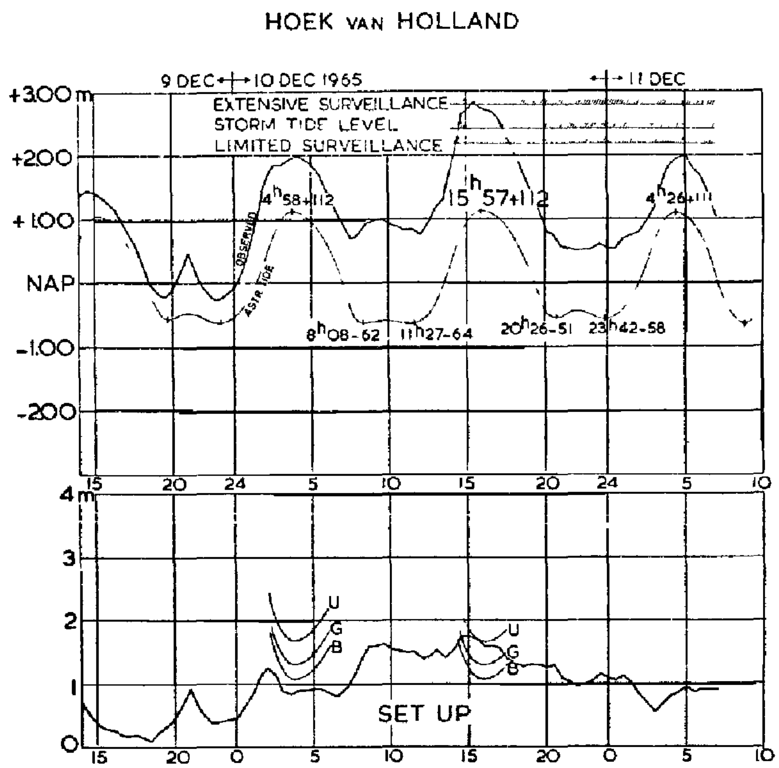


Fig. 3.12 – Time history of the normal astronomical tide, the wind set up curve and the resulting observed sea level.

Tidal surge forecast in Holland

and their hydrographs with accuracy. Rules of control operation are set out to suit predetermined conditions of flood inflow to a reservoir or river reach and have sufficient slack in them to take up the probable errors of forecast and to allow for intervention by experienced personnel. These rules will generally affect only river reaches downstream but they can also relate to the maintenance of safe water levels upstream of control as for instance occurs in the control of Lake Burley Griffin which is an artificial lake located in the heart of Canberra. Control of outflow from this lake provides an interesting exercise in combined problems of hydrological forecasting of inflow, the hydraulic implications of surges in lakes, and the accentuation of peak flows released from the reservoir in the downstream river.

DATA MONITORING

Ability to forecast river flood discharges with sufficient accuracy depends primarily on there being a supply of readily available and suitable hydrometric data. The type of data required is governed by the method of forecasting used. River-based data methods need information mainly on river levels and river discharges. Rainfall-runoff techniques need both river-based and hydrometeorological information, the river data in these cases being required principally for developing the forecasting procedure. Forecasting rainfall in a quantitative manner to advance river forecasts further in time is as yet mostly experimental and insufficiently precise; this constitutes a major missing link between weather forecasting and hydrological forecasting (page 46). When it becomes feasible on a sufficiently general scale, forecasting rainfall induced river flood events will require a still greater variety of information. In general, but depending also upon catchment size and its response to hydrometeorological phenomena, the more remote in time a prediction of river flooding is required before the event occurs, the more numerous and complex are data requirements. Snowmelt, wind set-up, and other causes of river floods demand their own particular type of data if forecasting is to be carried out.

In developing a fully integrated flood warning service hydrologists seek to use the simplest method possible without reducing the accuracy of prediction to any marked extent. Simplicity of method and accuracy of method however are not always directly related. Accuracy depends largely on the temporal and spatial distribution of hydrometeorological phenomena and their methods of measurement.

Data Sensing and Measurement

3.3.1 Many hydrometric techniques have been developed to measure the various hydrological and meteorological phenomena involved in river flooding.

Water level

3.3.1.1 Standard gauges for measuring relative elevations of water surface include calibrated staff gauges, float gauges, bubble gauges and ultrasonic gauges. Special gauges are made to sense flood conditions such as the Telemark gauge which registers peak levels and differentially coloured staff gauges developed in Japan for unmistakeable identification of level during bad conditions (Fig. 3.13). This illustration also shows reed-switch gauges which are simply vertical hollow tubes