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WAIRAU RIVER CATCHMENT FLOOD FORECASTING

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ABSTRACT

To improve real-time flood forecasts for the Wairau river catchment, an integrated method of forecasting from rainfall and river flows has been developed which increases the warning time by some five hours. The concept of a catchment storm concentration time is applied to calculate moving mean rainfall values from telemetered gauges, and the relationship to peak basin discharges is used to directly forecast flood levels. The initial discharge and identifiable variations in rainfall distribution from the model event are used to adjust calculated values. Simultaneous stage routing techniques are incorporated as tributaries rise. The procedure, using a conventional microcomputer, has proved successful in practical flood forecasting.

BACKGROUND

Early methods of forecasting floods in the Wairau River relied on river routing techniques relating water levels in the Waihopai river, and information from landowners in the Leatham and Northbank areas, to expected levels at Tuamarina township (Fig. 1). Between 1959 and 1964, river-level telemeters were installed on the Branch, Waihopai, and Wairau Rivers, transmitting coded information by telephone. These sites were later incorporated into a VHF communications system, and floods were forecast by relating water levels in the Branch and Waihopai Rivers to predicted flood levels in the Wairau at Tuamarina.

Following the installation of high technology communications, telemetry, and computing equipment in the 1980's, the opportunity existed for increasing the lead in time and accuracy of predictions using retrieval and analysis of real-time rainfall and river-level information, thus reducing the hazard to urban and rural communities on the Wairau floodplain. In 1987, the Marlborough Catchment Board proposed the following:

(1) To substantially increase the lead-in time for the issue of flood warnings to the public.

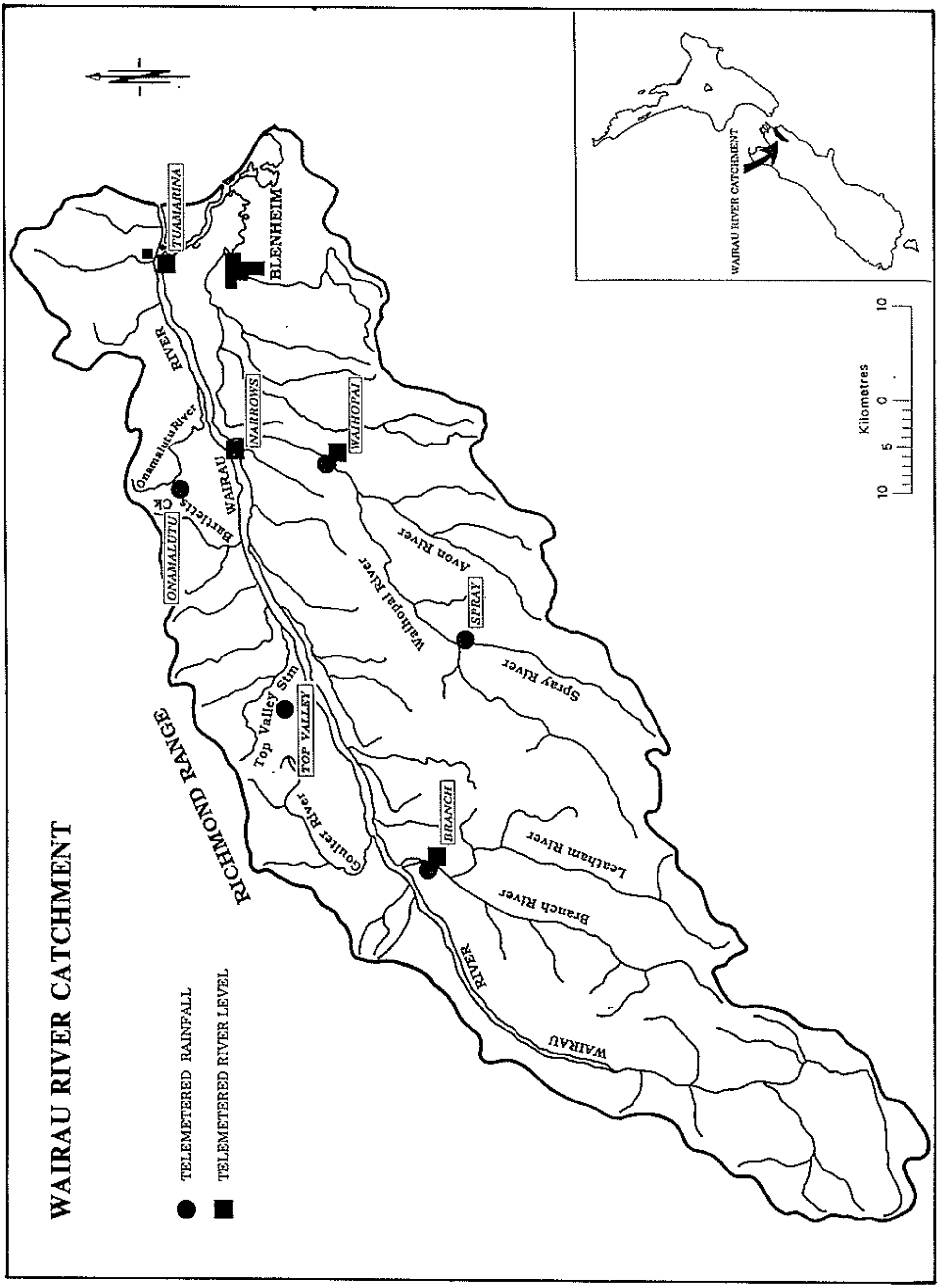

FIG. 1 — The Wairau River catchment.

(2) To apply computer modelling concepts only to floods, and not to attempt to simulate other parts of the hydrological cycle. Such techniques were to be structured on the simple criteria of volume, timing, and persistence.

(3) To establish an integrated rainfall and water-level network, to provide the necessary information for flood modelling.

The proposal was to be developed in three stages. The first stage included a review of historical data to assess the suitability of existing recording stations for flood forecasting. In particular, the objective of stage one was to identify clearly the meteorological influences and precipitation patterns associated with major storms, and to formulate techniques to forecast floods using both rainfall and river-flow information.

Stage two involved the placement or redeployment of monitoring equipment to implement and calibrate new techniques over a sufficient length of time to evaluate the system's performance during storms.

A third stage is for further analysis of collected data and a final refinement of the flood forecasting model.

Work on the "Wairau Catchment Flood Forecasting System" proposal commenced early in 1988, with the objectives of both stage one and stage two substantially achieved.

METEOROLOGICAL SITUATIONS ASSOCIATED WITH HEAVY RAINFALL

Analysis of historical meteorological and rainfall information associated with floods in the Wairau valley indicates that the major exposure of the valley is to heavy rainfalls from two directions.

Southeasterly storms can severely affect coastal catchments to the south of Blenheim with flooding of the Taylor and Omaka rivers. Under these conditions, much of the Wairau catchment is unaffected, being largely sheltered by the catchments of the Clarence and Awatere rivers. Heavy southeasterly rainfall is common during the passage of depressions through the Cook Strait region, or from the north, down the east coast of the North Island. In typical storms, associated frontal systems feed moist tropical air around the depression and into Marlborough, with precipitation on the eastern coastal catchments. Less common, though of greater concern are tropical cyclones or deep depressions originating in the northern Tasman, which move southward before crossing New Zealand.

The heaviest rainfall in the Wairau valley and the origin of nearly all significant Wairau floods, comes from the northwest and in particular from around 330 degrees. Under such conditions, coastal catchments are least affected, and most heavy rainfall occurs in the northern catchment in the region of the Richmond Range, with diminishing rainfall southward across the valley. The rainfall distribution (Fig. 2) and the associated weather map (Fig. 3) show typical conditions producing many floods. The orographic influence of the Richmond Range is clearly evident, with a centre of rainfall mass in the region of Top Valley. There is little protection from the North Island or the Richmond Range from this direction.

In northwesterly to westerly winds however, greater protection is afforded by the Tasman Mountains and the Arthur Range. In such conditions, heavier rainfalls and flooding can occur in the Nelson or West Coast regions, with the

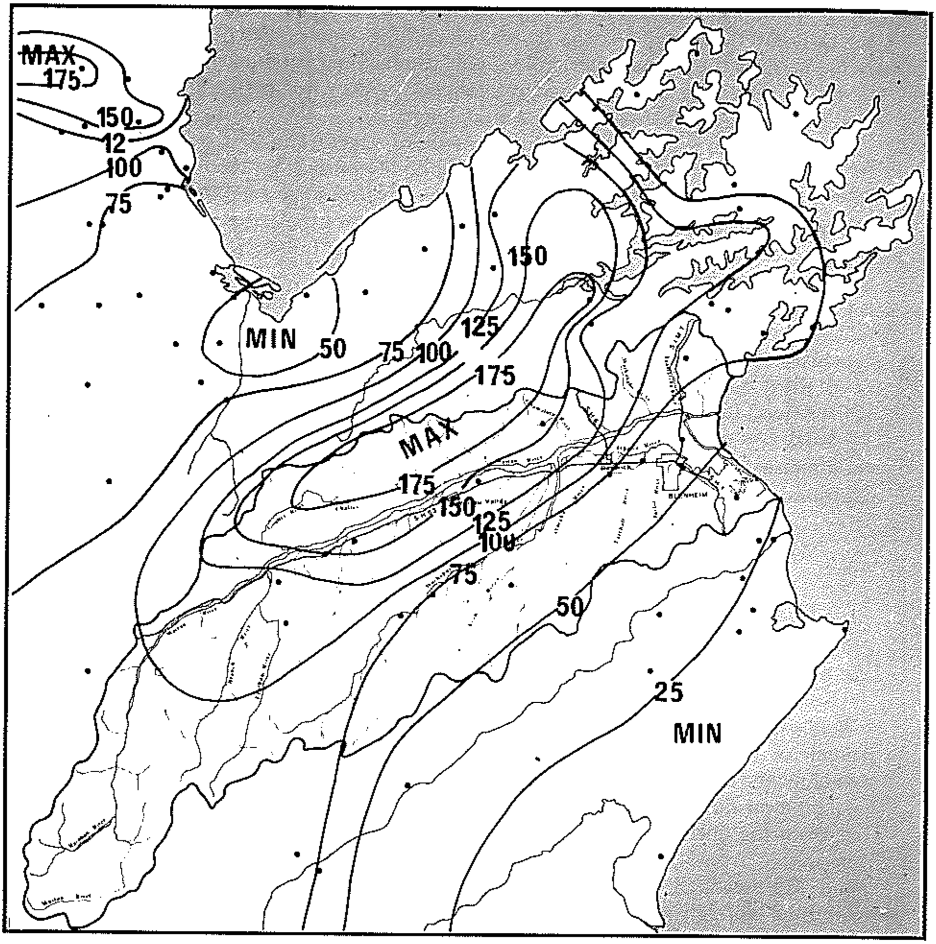

FIG. 2—Isohyets of 24-hour rainfall, 0900 1st to 0900 2nd April 1975.

Wairau rainfall mass centred further to the west, commonly extending into the Upper Wairau catchment above the Branch River. Conversely, during rainfall from a more northerly direction, the region of heaviest rainfall lies towards the northeastern regions of the catchment.

Frontal systems with a strong westerly flow may produce heavy rainfall in the upper catchment in the initial stages, followed by a change of direction to the northwest and north as the front proceeds from west to east. The shape of the frontal system and its direction of movement are critical, as flood waters generated in the upper catchment may arrive coincidentally with runoff entering the river system from the north, producing higher than anticipated levels of flooding. Fortunately such events are infrequent and may be identified at an early stage.

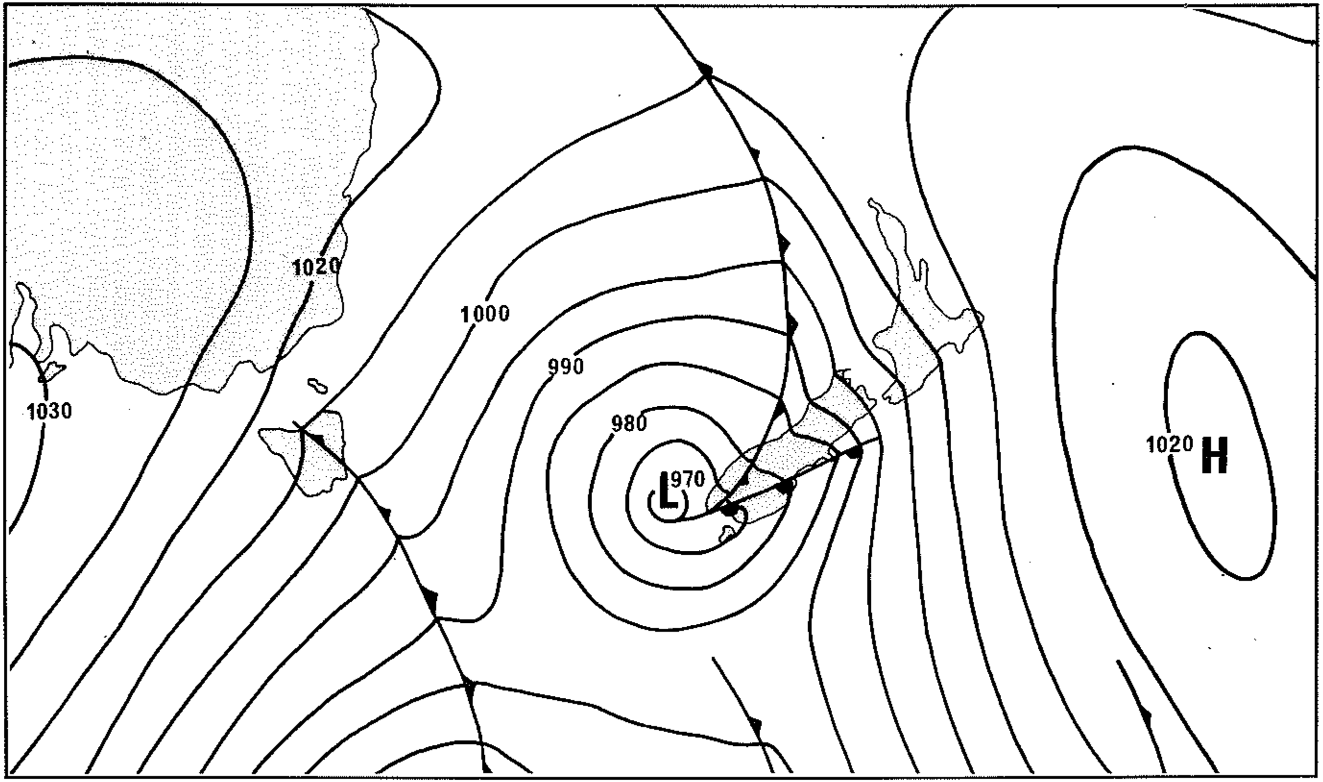

FIG. 3—Synoptic weather map of 1st April 1975.

An infinite range of variations can exist between the basic meteorological patterns. The critical consideration however, is an understanding of their interaction with the Wairau landmass.

An analysis of historical events with strong north to northwesterly wind reveals a well-defined pattern of rainfall distribution. Pascoe (1982) confirms that during the 1975 flood, the direction of flow was critical, with the catchment being afforded little protection by the North Island or the Nelson Ranges. A close similarity to the floods of June 1954 and September 1970 was also noted; both developed from similar situations, and with strong winds over Marlborough from close to 330 degrees. Again, the two major floods of 1983 resulted from the same wind patterns, which exposed the catchment to high-intensity, flood-producing rainfalls.

Dominant meteorological patterns are identifiable in other forms of rainfall analysis, and the map of rainfall normals — calculated from rainfall records between 1951 and 1980 — clearly shows their influence. These are also indicated in the frequency analysis isolines of high-intensity rainfall calculated by Tomlinson (1980). Both forms of analysis also show a discontinuity in the upper Wairau catchment, which is largely governed by the different meteorological influences referred to previously.

The strength of surface winds is also a critical factor in the distribution of rainfall intensities across the Wairau valley, particularly into the catchment of the Waihopai River. In the larger events studied, again there is a similarity to the patterns of rainfall distribution to the south, and with strong winds southern catchments can contribute significantly to flooding in the lower Wairau. In strong westerly conditions, however, when rainfall gradients may extend well eastward from the upper Wairau, the Waihopai catchment can again contribute a significant percentage of Wairau flow. Such floods are generally smaller and less frequent than the typical event, which originates from strong north to northwesterly flows.

RAIN GAUGE NETWORK

To sequentially forecast flood events from rainfall and river-flow information, it was first necessary to identify the minimum telemetered rain gauge information needed to represent dominant rainfall patterns.

The Branch River rain gauge had the only long-term record of rainfall intensities suitable for this purpose, and it had been incorporated into the new telemetry system at an earlier date. A telemetered site at an altitude of some 1100 m above Top Valley established in September of 1985 has a short, though useful record of rainfall intensities.

The Wairau river catchment has an area of some 3800 square kilometres. A lack of sufficient historical rainfall intensity data creates difficulties in developing flood forecasting methods directly from rainfall. To describe rainfall adequately for runoff routing or catchment modelling techniques could involve prohibitive capital costs, and an extended period of data collection for calibration.

Due to the nature of tributary inputs, particularly from the north, it is not possible to extend warning time to any significant degree using conventional river routing techniques. The understanding of storm patterns and rainfall distributions were thus critical in the development of a new flood forecasting system which might be implemented immediately, and which would indicate flood magnitude using real-time rainfall, with continuing calibration as further events occurred.

It was decided that at least two additional telemetered gauges would be required to describe the areal extent of rainfall, and in January of 1988 equipment was installed on the boundary of the Onamalutu and Bartletts Creek catchments, and at the junction of the Spray and Waihopai rivers. The purpose of the former was to assist in identifying the centre of rainfall mass across the northern boundary of the catchment, and of the latter to clarify the rainfall gradients into the southern catchments.

TIME OF CONCENTRATION

The well known Rational formula has proved satisfactory in engineering design work for small urban areas, gutters and paved areas, but is inadequate when applied to larger drainage basins (Chow 1964).

In the rational formula the time of concentration is usually the time required for surface runoff from the remotest part of the drainage basin to reach the point considered. With uniform rainfall intensity, this is the time of equilibrium, when runoff equals the rate of rainfall supply. However, in the Wairau catchment this time is longer than the lag time from rainfall to peak flow, with runoff from the most remote portions arriving too late to contribute to the peak flow. A more useful measure is the catchment *storm concentration time,* which is the time required for maximum runoff to reach the outlet of the contributing catchments which dominate the *peak* discharge at the basin's outlet.

Analysis of rainfall records in conjunction with flood hydrographs, indicates that the characteristic Wairau storm concentration time is about nine to nine and a half hours, which agrees with Thomson's (1986) assessment that peak times at Tuamarina tend to occur 10 hours after those at the Branch recorder. The lag time and the storm concentration time are close because the Tuamarina recorder is only a short distance downstream from the outlet of contributing catchments which dominate the peak discharge.

SPATIAL PATTERN OF RAINFALL

In the Wairau river catchment, the typical or dominant event is generated by flows from around 330 degrees, in a rainfall pattern which is clearly centred about the Richmond ranges (as shown in figure 2), and which grades uniformly into other areas of the catchment. If all storms had similar characteristics, and rainfall varied only in magnitude, mean storm concentration time rainfalls could be related to peak discharges using a single representative raingauge located near the centre of rainfall mass.

Having identified a range of events however, it is possible to identify variations from the model event, and calibrate such variations in order to correct standard forecast calculations.

To accommodate temporal east-west variations in the northern rainfall gradients, data from three raingauges at Onamalutu, Top Valley and the Branch (in the centre, and at the extremities of atypical distributions) was used to calculate simultaneous means of the peak mean values for the storm concentration time. These values were then used to derive an initial relationship with the corresponding peak discharges observed at Tuamarina.

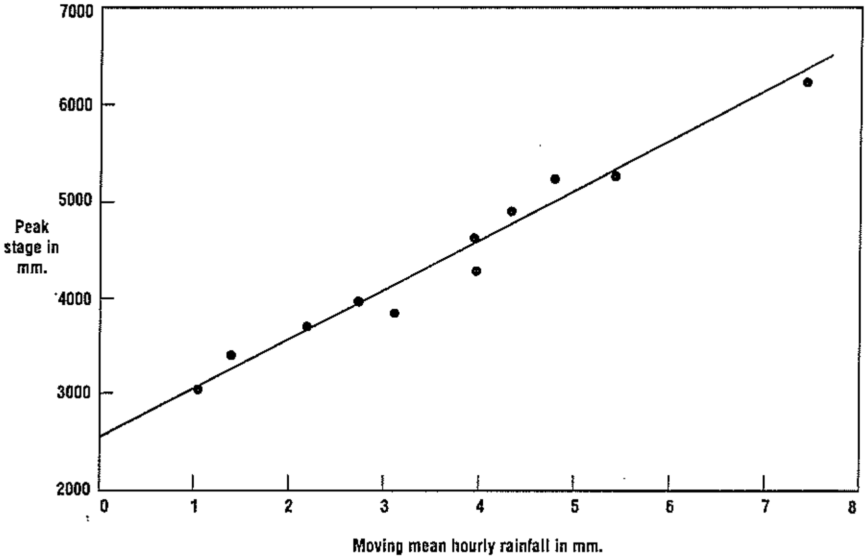

FIG. 4—Regression of the mean hourly rainfall rate (derived from the combined nine hour moving means of the Branch, Top Valley and Onamalutu raingauges) and peak stage values observed at Tuamarina.

In determining this relationship multiple regression techniques were less successful than a simple rainfall regression, which has a Y intercept approximating an average base flow preceding floods. Initial flood warning levels, and the shape and stability of the high stage rating curve for the Wairau at Tuamarina are such that, to simplify calculations — which are concerned more with river heights than discharges, a linear regression was calculated directly from peak nine-hour means to river stage height. Eleven pairs were available for the initial regression calculation, covering a range of events up to 6.3 m. The Y intercept was at about 2.4 m (39 m^3/s) with an adequate correlation coefficient (r^2) for forecasting of about 0.8. Further refinement from subsequent data of *characteristic* storms improves the correlation coefficient to 0.96 (refer figure 4) but the equation remains effectively the same.

The current equation is:

$$S = 2550 + 513R \qquad (1)$$

where S is the forecast peak stage height in mm, and R is the mean hourly rainfall rate in mm, derived from the combined nine-hour moving mean of the three raingauges.

An example of this equation's application is shown in Figure 5, where the progressive hourly calculation of forecast levels closely approximates the frontal limb of the recorded stage hydrograph. In this particular case the calculation has been moved forward in time by some nine hours as a forecast approximation. Although the initial base level is a little higher than the intercept, it has little

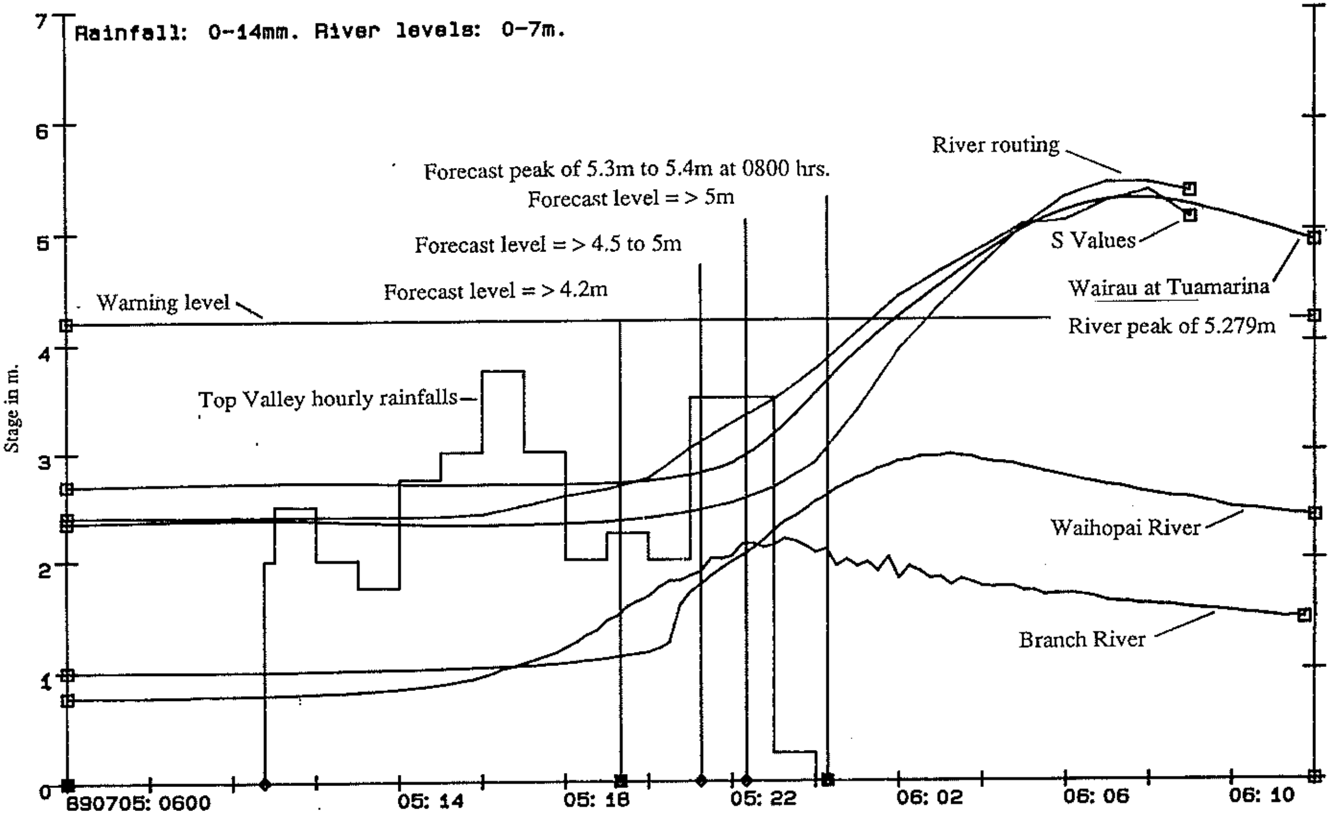

FIG. 5—A characteristic Wairau river flood where 'S' values closely approximate the hydrograph's rising limb.

or no effect on the value of S at higher stages. This event is an example of a characteristic rainfall pattern in the Wairau catchment, with a centre of rainfall mass in the Top Valley region. The forecast levels shown are those issued at the time, as rainfall occured, with a peak predicted after rainfall had ceased and as the major southbank tributaries were responding. These river responses are used to confirm earlier forecasts from rainfall. A computer stage-routing forecast is also shown (calculated from levels at the Waihopai and Narrows recorders), which has been moved forward by its lead-in time of four and a half hours.

The value of S is representative of the *characteristic distribution;* where significant spatial and temporal variations occur, greater or lesser flows must be identified from changes in the rainfall pattern. The forecasting procedure then depends on a summation of identifiable variations about the model event.

VARIATIONS OF RAINFALL PATTERN FROM THE MODEL EVENT

Different meteorological patterns have known relationships to rainfall distributions in the Wairau catchment. Identification of meteorological cause and effect therefore becomes important in anticipating rainfall patterns and the nature of floods before rainfall commences.

In any event which has a reasonably stable rainfall pattern any significant displacement of the centre of rainfall mass in an easterly or westerly direction about the central Richmond Ranges, will affect the level forecast for Tuamarina. The location of rainfall mass in the eastern or lower catchment indicates a forecast level lower than the value of S, and in the western or upper catchment, a higher value. The reasons for this relate largely to topographical influences and drainage characteristics which vary over the basin's length.

To quantify the degree of east-west displacement, a simple method of dimensionless moments is used, based on values for mean storm concentration time rainfall values from the three stations at Onamalutu, Top Valley, and the Branch. Moments are calculated about the Top Valley region with negative values indicating a displacement to the west, and positive values displacement to the east. Displacements are continually calibrated as further storm data becomes available. This relationship has been applied during real-time forecasting with significant success and modification of the S value has proved to be well within acceptable forecasting error limits for small floods, and during larger events the value of S becomes less sensitive to correction, with a higher degree of forecasting accuracy.

The distribution of rainfall across the catchment from north to south in most cases, has less influence on predicted values than an east-west displacement. Relative north-south gradients are similar for most events of any magnitude. In smaller events, major variations rarely occur. When they do, the confinement of rainfall to the northern boundary can reduce predicted levels. When rainfall is well distributed southward into the Waihopai catchment, predicted levels are less affected, and more closely approximate those of a typical event.

To identify this north-south gradient in broad terms, the raingauges at Top Valley and the Spray are used to calculate dimensionless moments about a midway point, in a manner similar to that of the east-west displacement, from rainfall moving means. Here, positive values indicate a shift toward the northern boundary, and negative values a shift of the gradient southward across the valley.

These values have been used successfully to refine predicted levels at Tuamarina during smaller events, which may be confined to the northern boundary of the Richmond Ranges.

LOSSES

An important factor in the calculation of storm runoff from rainfall is infiltration, and the reduction of rainfall by an amount which depends on the antecedent condition of the catchment. The degree of catchment saturation, however, is not known during real-time flood forecasting. The discharge of the catchment can be used as an indicator of its saturation immediately preceding an event and is readily available from telemetered river gauges. Sargent (1983) has observed that the relationship between the ratio of flood runoff volume to rainfall volume and initial discharge is continuous, and can be applied for any state of the catchment, the relationship becoming less sensitive at high flows. This method has been used by Sargent with success in the Haddington flood warning system. A relationship is observable for the Wairau at Tuamarina which would appear to be adequate for general forecasting, even though the recorder is not truly representative of storm concentration catchments. Calibration of this relationship is currently incomplete, owing to a lack of historical rainfall intensity data, and requires the collection of further information. A generalised correction procedure, however, has been applied to smaller events with reasonable success. In larger and more widespread events, the relationship has less effect on forecast levels.

When the catchment is completely saturated, such as during a double event before base-flow inflection, the situation is less complex. Flows immediately preceding the event may be then dealt with directly as a simple addition to the equivalent discharge indicated by a calculated forecast level. Altered channel storage has some effect when the second event is small and the preceding flow is large. In such a case the value of S slightly underestimates the observed flood level. When the second event is large and the initial flow is relatively lower, the effect is minimal and may be disregarded. Channel storage is accommodated in small events included in the regression of storm concentration time rainfall against peak flood values. The shorter duration of the rising limb, and therefore the peak value of small events, in relation to runoff producing rainfalls, is more affected by channel storage than in larger events.

TEMPORAL RAINFALL PATTERNS

While a range of rainfall patterns can occur as an event develops, the dominant flood producing patterns can be readily identified and appropriate forecasting adjustments applied. For example, an early shift of the rainfall mass into the lower Wairau may be followed by a movement into the central region as flood-producing rainfalls develop. In such cases, the dominant contribution during the peak storm concentration time will have the greatest influence on predicted levels. On the other hand, where a frontal system initially generates heavy rainfall in the upper Wairau, (with a change in wind direction from west to north as the front moves across the basin), the subsequent movement of rainfall into the Richmond Range can produce runoff which either raises the peak value, or produces a double-humped hydrograph, depending on relative intensities and the shape and speed of the front. In most cases this additional flow is absorbed

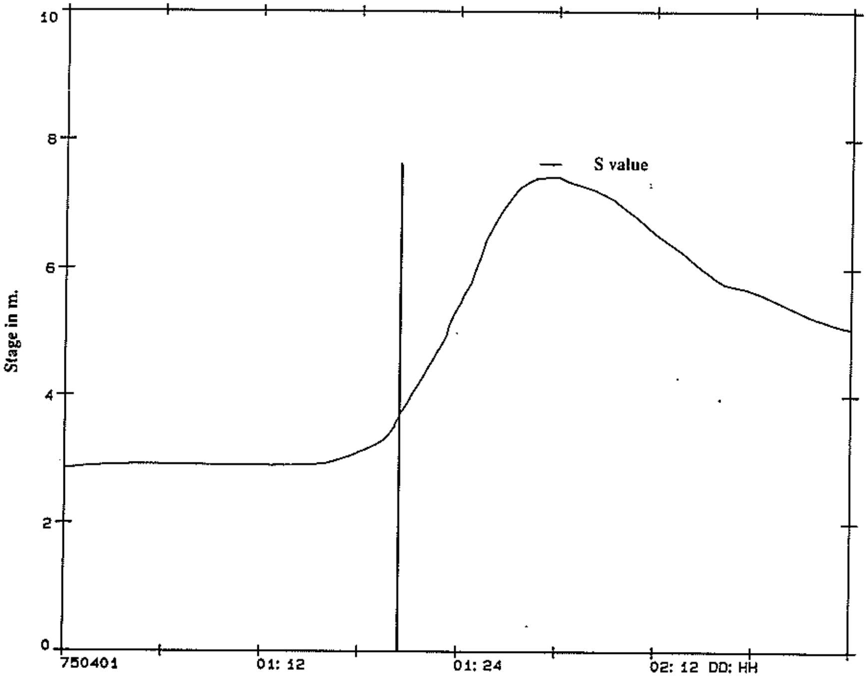

FIG. 6—The recorded flood hydrograph of April 1975, showing the potential peak lead-in time and the calculated value of 'S'.

in the falling limb of the hydrograph, but when it is significant, it may be anticipated from meteorological information, or detected from intensity measurements at the Branch and Charlies Rest raingauges. Additional rainfall information from the upper Wairau would be advantageous in such cases.

In smaller events changes in rainfall distribution with time can be more significant, and their potential influence must be carefully assessed. In larger events, distributions are generally more stable, and any changes are readily identifiable.

Temporal changes in gradient across the valley are also observed closely during small events. Again however, these vary less during more intense and widespread rainfalls.

An extreme situation could occur if the entire basin were subject to simultaneous heavy intensities for a period approaching the natural time of concentration. Such an event could not be accommodated in the method previously described. The probability of this occurring in the Wairau catchment is remote, and it is not known to have occurred over the past fifty years of flood records. To generate such rainfall would require a storm of even greater magnitude than that which produced the largest known flood of July 1983.

The peak nine-hour return period in the centre of rainfall mass, closely approximates the calculated peak return period of Wairau River flood flows for both the 1975 and July 1983 floods, which had return periods of 35 and

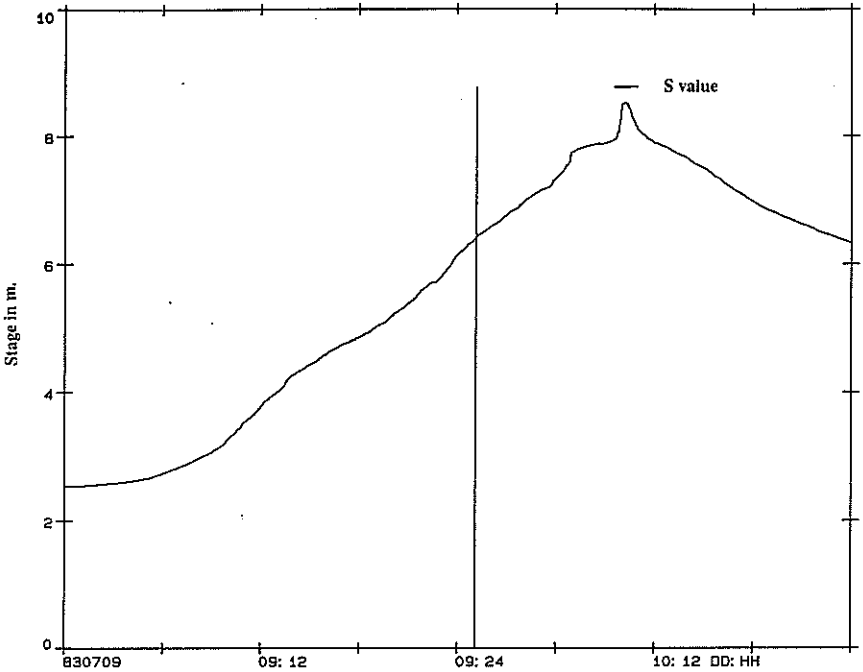

FIG. 7—The recorded flood hydrograph of July 1983, showing the potential peak forecast lead-in time and the calculated value of 'S'.

100 years. Despite the difficulties in relating known nine-hour intensity information to daily storage gauges used at the time, such events would appear to be predictable from rainfall, with acceptable accuracy, using the techniques previously described (Figs. 6 and 7).

RIVER ROUTING

A basic objective of forecasting has been to provide an early warning of event magnitude from rainfall analysis, before rainfall enters the river channels, and to subsequently forecast flood levels using integrated techniques of river routing.

A simple and reliable three-way relationship of peak river levels was calculated in the early 1960's, between the Branch, Waihopai and Wairau at Tuamarina recorders. Despite a noticeable scatter in the data, this relationship had been used successfully for many years, by extrapolation to the Waihopai peak following a peak level at the Branch. The relationship was again updated in the 1980's, incorporating a better understanding of the influence of rainfall gradients, and it has become a valuable tool in confirming rainfall analysis, as tributary levels rise. The reasons for the data scatter are now better understood in terms of different flood-producing patterns.

New regressions have also been calculated with the Waihopai and Narrows recorders, to predict levels at Tuamarina some four and a half hours before the peak. These regressions can provide a more accurate forecast of river level during the later stages of an event.

The basic relationships established are;

$$T = 0.97N + 0.38W + 0.61 \qquad (2a)$$
$$T = 1.22N + 0.70 \qquad (2b)$$
$$T = 1.34W + 1.29 \qquad (2c)$$

where T is the forecast peak river level at Tuamarina in metres, and N and W the observed peak levels in metres at the Narrows and Waihopai recorders. The correlation coefficients (r^2) for these equations are 0.97, 0.96 and 0.82 respectively. The second and third equations are less accurate than a multiple regression, and are used only in the event of a telemeter failure at either recorder.

Simultaneous stage values were used in arriving at equation one, and in most events, the Waihopai River peaks approximately one hour before the Wairau at the Narrows recorder. The equation relies on this common time difference between the two peak values for its high degree of forecasting accuracy. Potential error due to peak timing is of little concern, however, as the relationship never underestimates forecast levels at Tuamarina, and any major or unusual time difference merely requires a slight adjustment to the forecast level.

The Waihopai has a particularly stable relationship with Tuamarina at high stages. The Narrows, on the other hand, is subject to periodic changes which can necessitate the selection of a suitable equation from a range of predetermined calculations. The river bed at the Narrows is less stable and sensitivite to river works and changes in channel configuration. The equation shown is that currently in use, and is important in timing the peak level when considering closure of public roading below Tuamarina.

OPERATIONAL FORECASTING

The basic methods of forecasting previously described, are integrated into forecasting procedures which refine predicted values and timing as river levels rise during the more advanced stages of an event.

In the early stages, meteorological advice and satellite photographs provide early warning of flood-producing rainfalls. The relationship in use now therefore links approximate river responses from expected rainfall intensities in a manner not previously possible using river routing techniques alone.

As rainfall develops, it may be monitored directly be telemetry, using either a centrally-located microcomputer, or from the forecasters home, with simplified retrieval equipment. In the latter case, graphical relationships are generally adequate to determine the initial nature and magnitude of an event. The positive forecasting of a flood however requires more detailed information and computational ability.

Telemeter alarms for rainfall are set on a basis of intensity and duration. For example, the three northern raingauges at the Branch, Top Valley and Onamalutu, are set to alarm when they register a minimum value, over a nine-hour period, which relates to the initial warning level for the Wairau at Tuamarina. Other rainfall alarms are also set based on an understanding of rainfall gradients, and river level alarms to values indicated by routing relationships, or immediately preceding flood warning levels. In effect, the use of alarms has now become

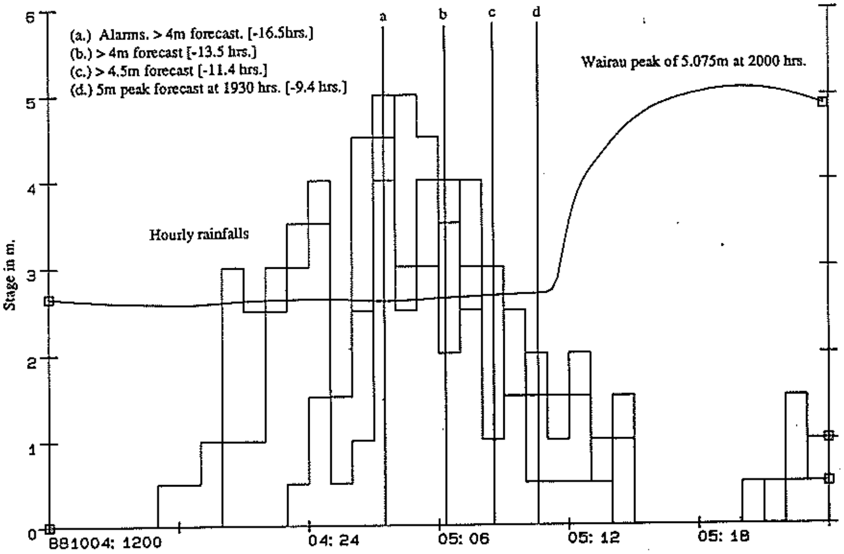

FIG. 8—Wairau river flood of October 1988, showing lead-in times and Northbank rainfall.

a method of confirming observations, or alerting the forecaster of unexpected occurrences and equipment malfunctions. After office hours, alarms are automatically routed by telephone to the forecaster's residence.

Most of the forecasting methods described have been incorporated into software routines on a small microcomputer, which also controls the telemetry system. The necessary calculations have been written into simple simulation programmes, which generate coloured graphics displays of the various forms of analysis, including hourly rainfalls, rainfall moving means, tributary levels, dimensionless displacements, and projected levels.

As telemetry operates on a radio channel which is also used for voice communications, groups of data are retrieved only once an hour, and at five minutes past the hour to compensate for any slight timing inaccuracies in the field equipment. This is adequate for forecasting and any more frequent analysis would be completely unwarranted in view of the natural responses of the catchment. All telemetry transactions and forecast levels are recorded on a small computer log printer.

Most events are forecast from rainfall to within plus and minus 0.35 m at Tuamarina, and frequently with greater accuracy in medium and larger events. Greater forecasting precision can be achieved using newly developed river routing techniques. Figure 8 shows a typical sequence of forecasts during a small event, and the improved warning time possible. Hourly rainfalls of the Branch, Top Valley and Onamalutu raingauges illustrate the general pattern of rainfall development. In this instance, with rainfall still occuring, a *peak* level (d) was forecast only after consultation with a meteorological forecaster and after an assessment of tributary responses. Figure 9 shows forecast events recorded since

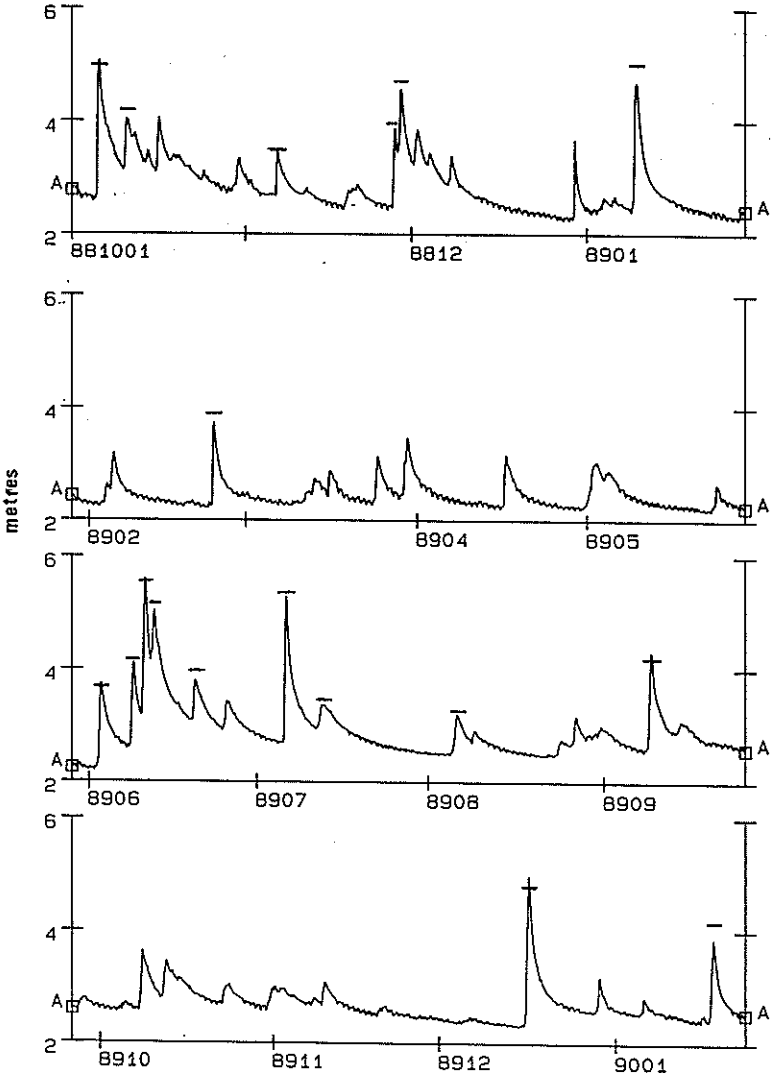

FIG. 9—Wairau river-stage records since October 1988, with forecasted levels shown thus —.

these procedures became operational, and illustrates the acceptable levels of forecasting accuracy from a combination of the techniques described.

A certain confusion exists on the definition of a Wairau river flood. With stable river containment, public inconvenience first occurs when the river reaches a level of 5.6 m at Tuamarina, and the road at Morrins Hollow floods. At this level, the discharge at Tuamarina is in the order of 1750 m^3/s, which has a probability of occurring in any year of about 56%. The average annual flood has a probability of about 43%, with a level of 5.8 m at Tuamarina, corresponding to a discharge of some 2000 m^3/s. Initial flood warnings, however, are issued to sections of the rural community and others when the Branch is forecast to exceed 1.6 m, or the Wairau at Tuamarina is expected to equal and exceed 4.2 m. At these levels, berm flow is occurring in some sections of the river, and livestock can be at risk.

The 4.2 m level requires detailed assessment of antecedent conditions and rainfall distributions. In addition, all events must be monitored well before any level is forecast, as rainfall intensities can suddenly and unexpectedly increase at any time. Many storms from the northwest change rapidly within a few hours, producing significant flood levels. For example, the flood of July 1983 was caused by an extreme (though not unusual) rainfall distribution pattern. The initial twenty-four hour period of rainfall indicated a flood level of about 4.5 m at Tuamarina. Within six to seven hours the situation changed rapidly, with rainfall intensities of over 16 mm per hour developing, producing a flood peak beyond the capacity of the river system. The careful monitoring of events in the early stages allows forecasters to make informed calculations during larger events.

The Meteorological Office acknowledges the difficulty of accurately forecasting rainfall intensities from meteorological analysis alone, and it is not uncommon to experience flood-producing rainfall without first receiving a meteorological alert or warning. Conversely, heavy rainfall does not always eventuate following receipt of a Meteorological Office warning. Forecasters should therefore be continually aware of the potential for rapid change in every meteorological situation, at any time of year.

SUMMARY AND CONCLUSIONS

The concepts of rainfall variations about the distribution of a model event, and the relationship between mean storm concentration time rainfall and peak flood levels, have provided a practical method of flood forecasting in the Wairau river catchment. The warning time for peak levels has been substantially increased by some five hours, with a greater level of accuracy than had been originally envisaged. The integration of recently developed river routing relationships with rainfall techniques has proved to be remarkably accurate in forecasting levels as tributaries rise.

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