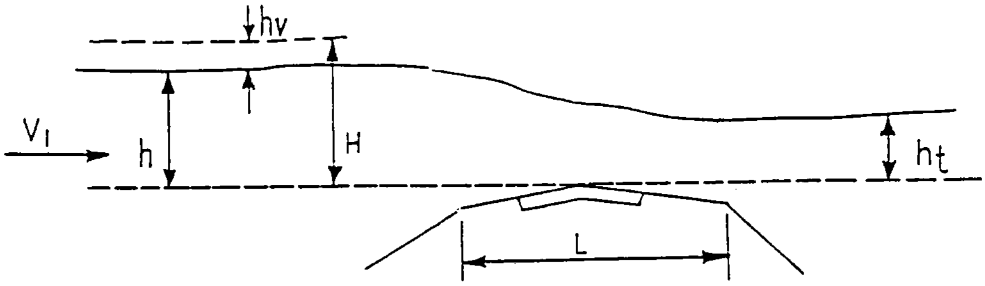
APPENDIX

1.0 BROAD CRESTED WEIR TYPE FLOW

A raised highway or a stopbank generally forms a weir type control section at which the discharge is related to the upstream water surface elevation.

The geometry and flow pattern for a highway embankment are illustrated below:



Under free flow conditions critical depths occur near the crown line. The head is referred to the elevation of the crown and length in the direction of flow is the distance between the top points on the upstream and downstream faces.

The equation for discharge over the roadway is:

$Q = C\,b\,H^{3/2}$ where

Q = discharge
C = coefficient of discharge
b = length of flow section along the road normal to the direction of flow
H = total head - $(h + V_1^2/2g)$

Extensive studies of flow over roadways (ref. 7) have indicated that the discharge coefficient for free flow is a function of h/L when $h/L > 0.15$.

Below this value the coefficient is a function of the head h and the roughness of the roadway.

For the range of depths and length L of roadways under consideration, the ratio of h/L will always remain less than 0.15.

The head H varies along the overflow length from zero at the ends to a maximum at the lowest point of the overflow section. The coefficient C has a range of values from C = 1.575 for H=0 to C=1.68 for H=1.0 m. The head corresponding to the discharges during July 1985 and Bola floods generally falls between 0 to 0.3 m.

A discharge coefficient of C=1.635 corresponding to a head of 0.15 m was used for calculation of discharges in metric units and the formula used is:

$Q = 1.635\,b\,H^{3/2}$ where

Q = discharge in m^3/sec

b = length of the flow section along the road normal to the direction of flow

H = is the static head ($V_1^2/2g$ assumed to be negligible)

As the flow over the road embankment increases, the downstream water level will rise above the road crest and the flow over the weir will become submerged. The discharge will also reduce as the degree of submergence (${}^{h_t}/H$ ref. diagram) increases.

Experiments have shown that the above discharge coefficient C = 1.635 is valid up to 80% submergence and the formula can be used up to 90% submergence for reliable estimation of discharge, with the coefficient reduced in the range from 80-90% submergence.

The crests of the roads where overflow occur are not truly horizontal and in certain long overflow sections, the water surface is also sloping. In calculating the discharges using the weir formula, the depths of flow from the water surface profile were obtained at approx. 50 m intervals using surveyed data. The discharge over the road for smaller lengths (approx. 50 m) was calculated and added for the total length of the road to obtain the total discharge.

The water level corresponding to the flood peak was determined by a trial and error basis using a spreadsheet.

2.0 WIDE CHANNEL FLOW

The flow of flood water over the gently sloping land in the flood-plain is complex and difficult to describe completely. However, simpler mathematical procedures can be adopted to represent the flow for the purpose of flood hazard mapping.

The momentum equation for gradually varying one dimensional flow can be written in the form:

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial x}(uq) + gA\left(\frac{\partial h}{\partial x} - S_o\right) + gAS_f = 0$$

after ignoring the lateral inflow, wind stresses and the contraction losses.

Q = discharge, U = velocity, A = flow area
h = depth of flow, S_o = bed slope
S_f = friction slope

The equation can be further simplified by ignoring the first two inertia terms representing the variation of velocity with time and variation of velocity of head in space.

The equation then takes the form:

$$S_f = S_o - \frac{\partial h}{\partial x}$$

When flow is uniform $S_f = S_o$

The flow over the flood-plain was assumed to be uniform as in a wide open channel and the friction slope was taken as the observed water surface slope during previous floods on the assumption that the slope of the energy line is parallel to the water surface.

There are several empirical formulae relating the discharge and the friction slope. The Maning's Equation in the form:

$$Q = \frac{A\,R^{2/3}\,S_f^{\,1/2}}{n}$$ was used to calculate

the depths and velocities.

Q = discharge in m^3/sec

R = hydraulic radius

A = area in m^2

S_f = friction slope - water surface slope

n = roughness coefficient

When the flood levels across an overland flow section are known, the product "Q x n" can be calculated using the known area of flow and the water surface slope. The discharge across the section for July 1985 or Bola is known at the control sections and using the relevant discharge "n" can be calculated. When the overland flow is modelled and calibrated as above, depths for the flood standard can be determined using water surface slopes (parallel to observed) and known or modified values of "n".

The roughness coefficient for a flood-plain may vary from 0.025 for a short grassed pasture land to as high as 0.200 for a densely planted bush area. A roughness coefficient of 0.500 was used for most areas.

The observed water surface slopes vary from near horizontal in ponding areas to 0.001 m/m in steep areas.

3.0 PONDING IN BASINS

The flood water reaching large depressions in the flood-plain has to fill them before flowing out to other areas. The maximum ponding levels in such areas (and the outflow hydrographs) have to be determined for mapping purposes.

For a hydrologic system, Input I (t), Output Q (t) and Storage S(t) are related by the continuity equation:

$$\frac{ds}{dt} = I(t) - Q(t)$$

If the inflow hydrograph and the storage function, i.e. the relationship between S and Q are known, then the equation can be solved to determine the maximum storage that will be reached.

The inflow hydrograph for a basin was determined by using the hourly outputs from the Waipaoa River as generated by the "LATIS" mathematical model.

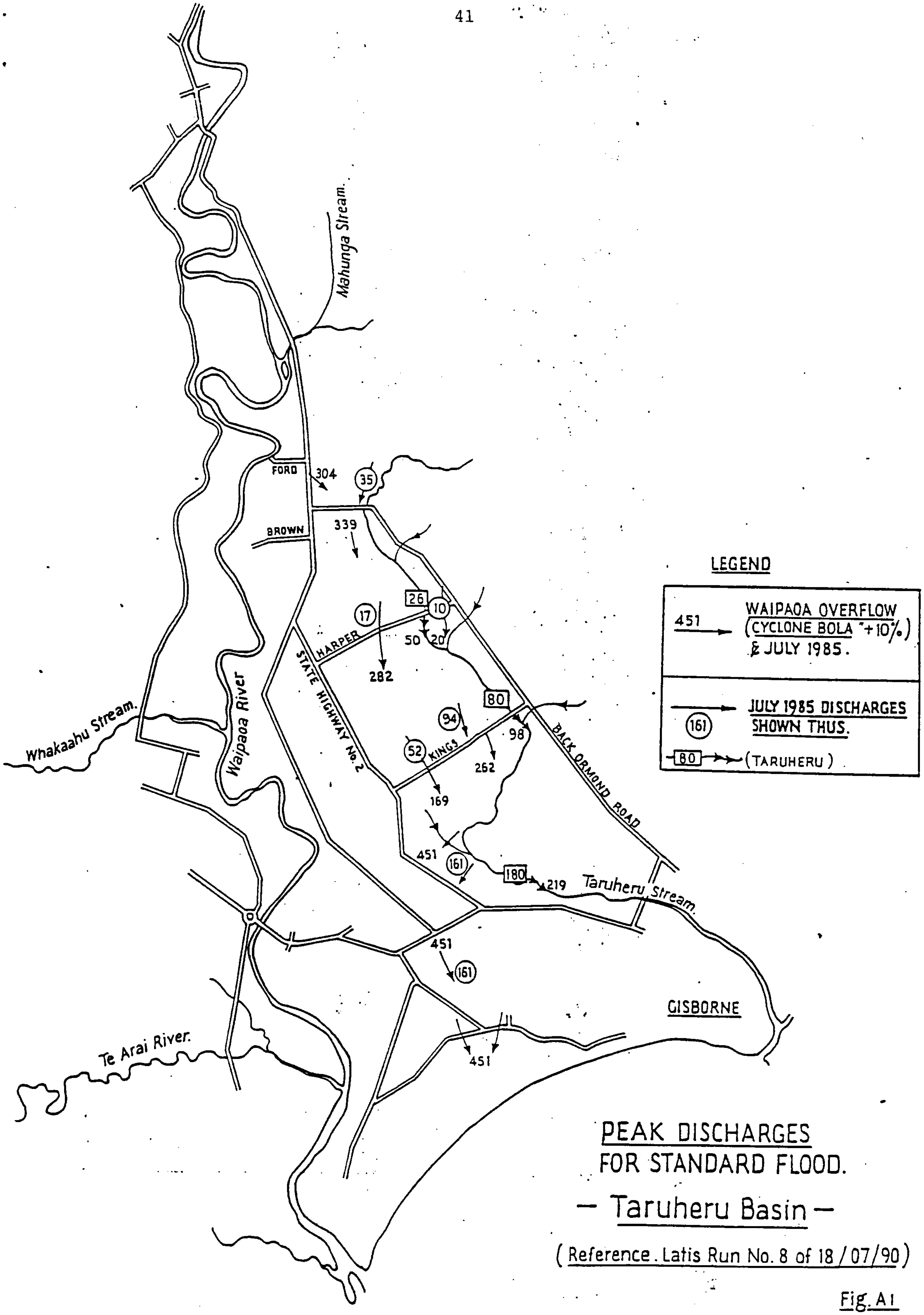
When a large basin has a horizontal water surface its storage is a function of its water surface elevation or depth in the pool. Capacity curves representing the elevation vs volume were prepared for the basins, planimetering the area under each contour on available maps.

The outflow discharge is also a function of the water surface elevation and for the basins under consideration, generally represented by weir flow or natural channel spillway flow or a combination of both. Discharge curves representing elevation vs outflow were also prepared for the basins.

Level pool routing procedure was adopted to determine the peak flood levels and the outflow flood hydrographs. A time interval of one hour was used in the calculations.

The flood peak also gets reduced as it travels through the flood-plain due to storage along the flow path. The reduction in peak and delay can be estimated using hydrologic routing methods. Such calculations were not carried out under this study but the following factors were used for the reduction of the peak.

For large open areas where flood wave inundates additional areas	0.85
Areas already flooded by Taruheru (where the flood wave inundates comparatively less additional areas)	0.90-0.95



PEAK DISCHARGES
FOR STANDARD FLOOD.

– Taruheru Basin –

(Reference. Latis Run No. 8 of 18/07/90)

Fig. A1