A REPORT ON THE HYDROLOGICAL IMPLICATIONS OF
FLOOD MITIGATION WORKS ON THE FLOODPLAIN
OF THE MACLEAY RIVER BELOW KEMPSEY

A study undertaken by the
Department of Geography
University of New England
Armidale N.S.W.

for the
Macleay River County Council

August 1967

RESEARCH SERIES IN APPLIED GEOGRAPHY - NO. 9.
A REPORT ON THE HYDROLOGICAL IMPLICATIONS
OF FLOOD MITIGATION WORKS ON THE FLOODPLAIN
OF THE MACLEAY RIVER BELOW KEMPSEY.

by

G. T. McDonald

Copyright (c) G. T. McDonald.
CONTENTS.

LIST OF TABLES (ii)
LIST OF FIGURES (iii)
PREFACE (v)
ACKNOWLEDGEMENTS (vii)
INTRODUCTION (viii)

SECTION I - PREMISES AND METHODS.
1. Introduction 1
2. Previous Assessments 8
3. A Method for Analysing the Hydrological Implications of Floods and Flood Mitigation Works. 15

SECTION II - HYDROLOGICAL CONDITIONS.
1. Drainage Areas 21
2. Flood Height 22
3. The Flood Regime of the Macleay River, Kempsey 29
4. The Conditions of Flooding in the Drainage Areas:-
   1. Glenrock-Tennessee 33
   2. Clybucca-Seven Oaks 38
   3. Pola Creek 44
   4. Redhill 48
   5. Austral Eden 51
   6. Belmore 54
   7. Gladstone-Kinchela 63
   8. Kinchela-Jerseyville 66
5. Overbank Flow 73

SECTION III - CONCLUSIONS.
1. Classification of the Floodplain by Probability of Flooding 87
2. Classification of the Floodplain by Drainage Status 90
3. The Usefulness of Hydrological Data for Economic Analysis 93.
(ii)

LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Areas of the Landscape Units of the Macleay Basin</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Probabilities of flooding in Selected Discharge Ranges</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>Discharge and Flood Height Observations:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glenrock-Tennessee</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>Clybucca</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>Pola Creek</td>
<td>44</td>
</tr>
<tr>
<td>6</td>
<td>Redhill</td>
<td>51</td>
</tr>
<tr>
<td>7</td>
<td>Austral Eden</td>
<td>54</td>
</tr>
<tr>
<td>8</td>
<td>Belmore</td>
<td>57</td>
</tr>
<tr>
<td>9</td>
<td>Belmore Floodway Operation</td>
<td>59</td>
</tr>
<tr>
<td>10</td>
<td>Gladstone-Kinchela</td>
<td>63</td>
</tr>
<tr>
<td>11</td>
<td>Kinchela-Jerseyville</td>
<td>66</td>
</tr>
<tr>
<td>12</td>
<td>Macleay River Length of O/B Flow Left Bank</td>
<td>80</td>
</tr>
<tr>
<td>13</td>
<td>Macleay River &quot; &quot; &quot; Right Bank</td>
<td>80</td>
</tr>
<tr>
<td>14</td>
<td>Belmore River Length of O/B Flow Left Bank</td>
<td>83</td>
</tr>
<tr>
<td>15</td>
<td>Belmore River &quot; &quot; &quot; Right Bank</td>
<td>83</td>
</tr>
<tr>
<td>16</td>
<td>Kinchela Creek Length of O/B Flow Left Bank</td>
<td>84</td>
</tr>
<tr>
<td>17</td>
<td>Kinchela Creek &quot; &quot; &quot; Right Bank</td>
<td>84</td>
</tr>
<tr>
<td>18</td>
<td>Macleay Floodplain Length of O/B Flow</td>
<td>85</td>
</tr>
<tr>
<td>19</td>
<td>Area Flooded by Floods of given Recurrence Interval</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Specified times</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Areas Taking Longer to Drain than the Specified times</td>
<td>92</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Landscape Units of the Macleay Basin</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Macleay Floodplain, Drainage and Flooding Areas</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Kuichling Graph</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>Macleay River Kempsey:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Annual Flood Frequency</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>Seasonal Flood Frequency</td>
<td>27</td>
</tr>
<tr>
<td>6</td>
<td>Unitgraph for the Macleay River, Kempsey</td>
<td>28</td>
</tr>
<tr>
<td>7</td>
<td>Graph of Flood to Peak Inundation</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>Glenrock-Tennessee: Contour Map</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>Flood Peak Discharge - Flood Height</td>
<td>34</td>
</tr>
<tr>
<td>10</td>
<td>Recession Curves</td>
<td>35</td>
</tr>
<tr>
<td>11</td>
<td>Clybucca: Contour Map</td>
<td>37</td>
</tr>
<tr>
<td>12</td>
<td>Flood Peak Discharge - Flood Height</td>
<td>39</td>
</tr>
<tr>
<td>13</td>
<td>Recession Curves</td>
<td>40</td>
</tr>
<tr>
<td>14</td>
<td>Pola Creek: Contour Map</td>
<td>42</td>
</tr>
<tr>
<td>15</td>
<td>Flood Peak Discharge - Flood Height</td>
<td>43</td>
</tr>
<tr>
<td>16</td>
<td>Recession Curves</td>
<td>45</td>
</tr>
<tr>
<td>17</td>
<td>Redhill: Contour Map</td>
<td>46</td>
</tr>
<tr>
<td>18</td>
<td>Flood Peak Discharge - Flood Height</td>
<td>47</td>
</tr>
<tr>
<td>19</td>
<td>Recession Curves</td>
<td>49</td>
</tr>
<tr>
<td>20</td>
<td>Austral Eden: Contour Map</td>
<td>50</td>
</tr>
<tr>
<td>21</td>
<td>Flood Peak Discharge - Flood Height</td>
<td>52</td>
</tr>
<tr>
<td>22</td>
<td>Recession Curves</td>
<td>53</td>
</tr>
<tr>
<td>23</td>
<td>Belmore: Contour Map</td>
<td>55</td>
</tr>
<tr>
<td>24</td>
<td>Flood Peak Discharge - Flood Height</td>
<td>56</td>
</tr>
<tr>
<td>25</td>
<td>Recession Curves</td>
<td>58</td>
</tr>
</tbody>
</table>
LIST OF FIGURES (cont.)

FIGURE 26 - Gladstone-Kinchela: Contour Map 60
" 27 - Flood Peak Discharge - Flood Height 61
" 28 - Recession Curves 62
" 29 - Kinchela-Jerseyville: Contour Map 64
" 30 - Flood Peak Discharge - Flood Height 65
" 31 - Recession Curves 67
" 32 - Area/Height Curves: Glenrock-Tennessee 69
" 33 - Clybucca 69
" 34 - Pola Creek 70
" 35 - Redhill 70
" 36 - Austral Eden 71
" 37 - Belmore 71
" 38 - Gladstone-Kinchela 72
" 39 - Kinchela-Jerseyville 72
" 40 - Incidence of Overbank Flow 74
" 41 - Comparison of Bank and River Profiles: Macleay River 77
" 42 - Belmore River 79
" 43 - Kinchela Creek 81
" 44 - Classification of the Floodplain by Probability of Flooding 88
" 45 - Classification of the Floodplain by Drainage Status 91
This report is the first in a series prepared by a team of research workers in the Department of Geography of the University of New England on behalf of the Macleay River County Council, and sustained by funds provided by the County Council.

The objectives of the research are:

1. to assess the hydrological and economic impact of flood mitigation measures in the lower Macleay area in which the County Council operates.
2. to examine the implication of flood mitigation work in the Macleay basin as a whole.
3. to examine the involvement in the Macleay basin of the Macleay River County Council and other public authorities in relation to the general question of better resource management and the particular question of better water control.
4. to recommend ways in which improved water control and resource management might be achieved through expansion of the scope of the operations of the Macleay County Council.

The present report is concerned with the hydrological implications of flood mitigation measures. It attempts to measure and analyse the manner in which inundation on the lower Macleay has been reduced by the flood mitigation measures carried out during the twelve years in which the County Council has conducted its operations.

This work has been carried out entirely by the author, Mr. G.T. McDonald B.A., who is a graduate of the University of New England and a research student in the Department of Geography. Mr. McDonald is also the principal author of the second report in the Macleay series, to be published shortly, concerning the economic implications of flood mitigation. Mr. McDonald has worked in close association with Mr. George Walker, the Engineer-in-charge of the Macleay County Council's operations, to whom the research team is heavily indebted for the valuable assistance he has rendered to it.

It is felt that Mr. McDonald's research work constitutes an original contribution of particular merit in the field of geographical studies. In
addition to the specific contribution he has made to the general body of knowledge on the subject of flood control, he has pioneered a methodology for the investigation of such phenomena which will prove invaluable to other research workers in the future. His work is regarded in the Department of Geography as an important step forward in the Department's research programme in the applied aspects of the discipline, for which a pressing need exists in Australia at the present time. In pursuing this programme the Department sincerely hopes that its work will assist our national progress in such matters as regional development and decentralisation, thereby furthering the general cause of the development of the Australian continent.

E.R. WOOLMINGTON. M.A., Ph.D.
Associate Professor of Geography.
ACKNOWLEDGEMENTS

The author would like to thank a number of people without whose help this report would not have been possible:

1. Mrs. P. Allen and Mr. L. Olive for cartographic work.

2. Miss L. Harvey and Mrs. B. Williams for typing.

3. Associate Professor E.R. Woolmington and Dr. L.I. Hodgson and other members of staff at the U.N.E. for guidance.

4. Especially Mr. George Walker and his staff at the M.R.C.C. who were very co-operative in providing the necessary basic information for this Report.
INTRODUCTION

The construction of flood mitigation measures on the Macleay River floodplain began in 1955 with the appointment of an engineer to implement a scheme devised by the Macleay Valley Flood Mitigation Committee. Events which lead to the adoption of this scheme will be discussed briefly in this report. After eleven years a large part of the work has been completed, and by 1969 the initial scheme will have been put into practice. It is logical that the inhabitants of the Valley should be trying to determine the next step to be taken in the development of a highly productive area.

In its approach to the University of New England to assist in this problem members of the Macleay River County Council provided a basis on which study could proceed. The outcome of discussion were terms of reference which stressed the importance of outlining further tasks which could be undertaken by the present Council or some type of body with extended powers.

It is a complex task to solve the problems of rural and urban areas in a short time or to point to the most profitable lines of development. A great deal of basic information is required. The aim of this study is modest: to outline the hydrological problems produced by flooding on the floodplain downstream from Kempsey and the extent to which flood mitigation works have altered this situation.

In an area such as this it is not possible to investigate everything in as much detail as would be desirable. It is necessary to compromise and aim to cover the most important factors only. It is hoped the material in this report can provide the basis for estimating the value of flood mitigation work established or projected. In the analysis which will be in another report, isolation of the most important problems facing development will be possible.
In satisfying the terms of reference of the research by the University of New England it is hoped in addition, that this report may enable a more accurate estimate of the risks facing users of the floodplain so that rational development can occur.
THE RESEARCH SERIES IN APPLIED GEOGRAPHY

The Research Series in Applied Geography, published by the Department of Geography in the University of New England, is designed as a series which enables the publication in sequence of the wide variety of research reports commissioned by various public authorities and private organisations.

Even though some volumes in the series, being commissioned works, have a restricted circulation, it is nevertheless felt that publication as a series will enable interested scholars and other persons to know of the work that has been done and to know where the results of that work may be obtained.

In addition to these volumes, some works published in the series have not been specifically commissioned, but fall clearly into the realm of applied geography. Volumes in this category may be purchased from the University of New England. Volumes in the "restricted" category may be obtained by permission of the appropriate authority.

L.R. Woolmington, 
Editor.
SECTION I. PREMISES AND METHODS

1. INTRODUCTION.

The Macleay River basin is an area of 4425 square miles which can be conveniently broken into three sections (see figure 1).

(a) The undulating Tablelands section of the catchment.
(b) The dissected ridge and gorge section which has restricted but important areas of river terrace between Lower Creek and Kempsey.
(c) The floodplain which is the product of erosion from the above catchment experiencing periodic inundation. It is bounded by ridges and sand dunes.

<table>
<thead>
<tr>
<th>Landscape Units of the Macleay Basin</th>
<th>Areas (sq.m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Tableland</td>
<td>2060</td>
</tr>
<tr>
<td>II Ridge and gorge</td>
<td>1856</td>
</tr>
<tr>
<td>III Terrace and foothill</td>
<td>252</td>
</tr>
<tr>
<td>IV Coastal ridge</td>
<td>66</td>
</tr>
<tr>
<td>V Sand dune etc.</td>
<td>35</td>
</tr>
<tr>
<td>VI Floodplain</td>
<td>156</td>
</tr>
</tbody>
</table>

This report is concerned with the 156 square miles of the floodplain.

Disastrous floods in 1949 and 1950 led to reaction by the residents of the floodplain that something should be done to combat the flood problems. The result was a submission to the Minister of the N.S.W. Department of Conservation. This led to the formation of the Macleay Valley Flood Mitigation Committee whose task, because of the backward state of knowledge on the flood problem, was to prepare the basis for developmental work. The Report*, commonly known as the Jaoa Report, comprises sections written by specialists from the following organizations:-

* "Report of the Macleay Valley Flood Mitigation Committee". N.S.W. Gov't Printer Sydney 1953.
(i) N.S.W. Department of Public Works whose task involved investigating the area of the valley within tidal influence. The basic problems were drainage, channel regulation and improvement and erosion control.

(ii) N.S.W. Water Conservation and Irrigation Commission who were responsible for the streams outside of tidal influence from the point of view of channel improvement and the possibility of flood control dams.

(iii) N.S.W. Forestry Commission and the Soil Conservation Service investigated the problems of vegetative cover and erosion against which remedial measures may have been necessary to reduce the magnitude of floods and their load.

(iv) N.S.W. Department of Agriculture submitted a special report dealing with specific problems confronting farmers in flooded areas to give reality to planning proposals.

(v) New England University College investigated the problems of flood damage and flood incidence. The flood damage assessment was for the floods of 1949 and 1950.

The investigations which made up the Jacka Report have provided the basis for planning flood mitigation work. Rather than outline all the conclusions reached in the Jacka Report, the following appear to be the most significant for the purposes of this study:

1. Although the Committee did not have the information to assess flood control, it was obvious from the high cost of works and the fact that only a partial solution would result, that flood mitigation was the only practicable proposition.

2. The Department of Public Works drew up a plan of works for the Lower Valley which involved an estimated expenditure of £1,090,000 and offered a solution to some of the most serious problems of flooding.

3. There appeared to be very little in the way of forestry work which could have any significant effect of the flood control situation.

4. Soil conservation practices were strongly advised for the cleared section of the basin, virtually the whole of which was suffering from sheet erosion, much from gully erosion and along the Macleay
downstream from Bellbrook, river bank was severe.

From the point of view of the floodplain the Jacka Report efficiently proved that flood mitigation was the only economic project. Because of the relatively high discharge carried by the river in flood, costs of control can not be justified and the residents of the floodplain have to accept the inevitability of flooding against which a number of less expensive but effective mitigation measures could be taken. These are the subject of the following work.

Flood mitigation in the Macleay Basin is administered by the Macleay River County Council whose area of influence is from the boundary of the Macleay Shire at Comara to the mouth. The bases of these works are essentially:-

(a) The Floodplain

(i) By a system of levees which needed uplifting along parts of the river and headworks across creeks and drains, to completely contain within the river channel and part of the channels of distributaries, floods with a peak discharge of 60,000 cusecs or less.*

(ii) By the use of floodways, principally the Belmore floodway, but also two small ones in the Kinchela area, to confine floods with peak discharges between 60-88,000 cusecs within the river channels and the floodway storage areas.

(iii) By a number of drains in all drainage areas to remove floodwater more quickly once it has inundated.

(iv) By a flood outlet to the sea through Korogoro Creek to assist in more rapid drainage.

(v) With the aid of various protective measures to reduce the erosion of river banks and in some cases to improve the capacity of the channel.

* Unless otherwise stated, all river discharges refer to the river at the Kempsey Traffic Bridge.
(b) The Basin from Comara to Kempsey

(i) The clearing of the channel of the main stream and some of its tributaries to enhance the flow of water and reduce unnecessary erosion particularly during lower stages of the rivers.

(ii) By a variety of mechanical methods reduce the erosion of valuable river flats.

(c) The Basin above Comara

This section of the basin has no part at this stage in the amelioration of floods. On the Tablelands it would appear that increased activity in soil and water conservation plus greatly extended areas of more productive and water retentive pasture could have some long term effect on the volume of flood waters entering the basin below Comara.

In order to evaluate flood mitigation and to outline possible further developments it is convenient to divide the problems into several categories. The aim of this report will be to provide the basic hydrological data.

The aim of this section of the report will be to outline the hydrological changes which will result from the various flood mitigation projects specifically applied to the floodplain, the area where inundation causes the largest amount of damage and interference to settlement and land use.

The Macleay River floodplain is typical of many floodplains throughout the world. The river reaches tidal influence just above Kempsey from which point it meanders through a system of high natural levees to the sea some 26 miles downstream, (see figure 2). The floodplain grades back from these levees and those of the three major distributary streams, Belmore River, Clybucca and Kinchela Creeks, to large semi-permanent swamps with heavy clay soils. These depressions along with a number of minor depressions caused by former stream action are isolated below the height of the stream levees and become naturally land locked areas of poor drainage.
The width of the plain varies, reaching its widest section of 12 miles, midway between Kempsey and the coast. At the estuary quite a large area of swamp and dune has been created by the migration of the mouth between South West Rocks and Stuarts Point. The littoral between Crescent Head and Stuarts Point is composed of two steep headlands, Korogoro Point and Smoky Cape, which are linked by a set of contemporary and relic dunes.

The climate of the floodplain is humid warm temperate with mean annual rainfall of 45-50" of which 60% falls during the summer and autumn. At West Kempsey the mean maximum and minimum temperatures are 85.9°F and 63.0°F for January and 67.5°F and 41.6°F for July.

The area is climatically suited to intensive pastoral and agricultural activities which are concentrated particularly on the better drained areas of the floodplain itself where soils and topography are excellent.* Man has elected to utilize and settle in an area of first class agricultural qualities, but an area which is subjected to periodic inundation from floodwater.

In the past floods were endured and little action was taken to ameliorate or mitigate the effects. Co-operative Drainage Unions were created in many parts of the floodplain but through lack of capital and maintenance little real improvement resulted. There is no doubt that the major and medium floods of the Macleay River cannot be economically prevented, but it is certain that steps can be taken to reduce the effect of these and to keep the small nuisance floods from causing almost constant interference.

The basic objective of any developmental plan is to provide the most economic use or combination of uses of water and related land resources, in terms of foreseeable short and long term requirements. Basic information necessary to achieve this aim is an accurate assessment of costs and benefits to be expected from projected developmental schemes. Engineers and economists have been striving to construct concepts and methods in project evaluation and have produced useful theoretical material. As yet no common method has been adopted, general principles have been outlined (IARB)* and individual projects have been assessed in a number of ways. The most commonly sought statistic is the cost-benefit ratio which if reliable contains the necessary economic evaluation.

Design engineers can readily estimate the quantities of land, labour, capital and materials required for specific projects. Induced costs resulting from uncompensated adverse effects of the project, and costs associated with the utilization of the new conditions must also be taken into account. All cost-benefit estimates must take cognisance of possible price level changes, and discount the costs on a common time basis with benefits, by a standard interest rate.

There is controversy over the constitution benefits to flood mitigation works. It would appear the following categories are most important:

(i) Prevention of loss of property and income through damage to land, building, stock, utilities.
(ii) Reduction in indirect losses to wages, goodwill, taxes etc.
(iii) Increase in the usefulness of urban, rural, transport and recreation resources.
(iv) Intangible benefits - human health, morale.

* See: Federal Inter-Agency River Basin Committee: "Proposed Practices for the Economic Analysis of River Basin Projects". U.S. Gov't Printer Wash, D.C. 1950, which appears to be the most accepted of a large number of theoretical papers.
The most common method by which flood control benefits can be estimated is by a form of urban and industrial survey. The intensity of such a survey may vary considerably and the reliability of the results likewise. The problems with such a method is

(i) That it relies heavily on the memory of the individuals questioned. These errors can be quite severe when added for a large number of farms. (Laut Personal Communication in his investigations of the Macleay Valley rural industry found that in 1966 farmers could not accurately remember either the conditions or the damage done by a flood in 1963. Similarly officers of the M.R.C.C. have found individual's knowledge and memory of flood conditions a very poor source of information.)

(ii) It is very time consuming

(iii) It is only able to assess likely damages from one flood.

In being very realistic such a study is also very limited in application. For such a method to be useful for long term or specific studies it must be repeated for a number of floods; a necessity which is not usually possible in a short space of time.

A second method which is much less time consuming is the estimation of losses from authoritative local sources such as dairy processing works and agronomists as to the quantity of fencing, crop, pasture, milk production lost. The problem is again basic - only one flood is being measured.

The assessment of secondary benefits; the improvement in the productivity or value of intensified land use as a result of ameliorated flood conditions can usually be made quite readily by an economist knowing the previous returns, possible returns and associated costs.

There have been a number of attempts made to assess the damages caused by flooding on the floodplain of the Macleay River. Little attempt has been made to make the assessments in a rigorous form of cost-benefit type. For comparative and information purposes the assessments which have been conducted are included below. In addition, with most projects, approval for which came from the N.S.W. Department of Public Works, a rough economic justification was provided.
Details of these will not be given here.

(a) Department of Agriculture (1953)

"The only assessment of loss attributable to nuisance floods is by the Department of Agriculture, relating to dairy production only, and which, therefore, represents the absolute minimum. In the 1953 report it is stated that, in an overall assessment, protection from nuisance floods can be expected to give rise to an average increase of 25 per cent. in dairy production alone, which, based on values at that time, would be equivalent to £750,000 per annum from 350 dairy farms. It is further stated that this increase would be gained through the medium of more constant level of production per cow, rather than an increase in cow numbers, together with more intensive use of pastures, fodder conservation and a better integrated drainage system." (Civil Engineers Report 1962)

(b) University of New England (1953)

"Based on the Interim Report of 1953 of the New England University, the following will give an approximate indication of the magnitude of the total losses as a result of the major floods of 1949 and 1950 combined. Quantities are from the University report, whilst amounts have been assessed in respect of costs of buildings and values of stock. Sources of any information other than above are noted.

Stock losses as given by the Macleay Cattle Replacement Committee.

<table>
<thead>
<tr>
<th>Category</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cows &amp; Heifers</td>
<td>5664</td>
<td>£20</td>
<td>£113,280</td>
</tr>
<tr>
<td>Calves</td>
<td>2316</td>
<td>£28</td>
<td>£63,904</td>
</tr>
<tr>
<td>Horses</td>
<td>218</td>
<td>£20</td>
<td>£4,360</td>
</tr>
<tr>
<td>Pigs</td>
<td>1236</td>
<td>£9</td>
<td>£11,124</td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>806</td>
<td>£35</td>
<td>£28,210</td>
</tr>
</tbody>
</table>

£175,502
Loss to dairy production as assessed by Department of Agriculture from 350 farms, average area 157 acres, total nett income £600,000 per annum based on 1947-48.

<table>
<thead>
<tr>
<th>Year</th>
<th>Loss %</th>
<th>Net Income (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1948-49</td>
<td>3.9%</td>
<td>£23,400</td>
</tr>
<tr>
<td>1949-50</td>
<td>7.0%</td>
<td>£42,000</td>
</tr>
<tr>
<td>1950-51</td>
<td>27.0%</td>
<td>£162,000</td>
</tr>
<tr>
<td>1951-52</td>
<td>32.1%</td>
<td>£192,600</td>
</tr>
<tr>
<td>1952-53</td>
<td>12.2%</td>
<td>£123,200 £493,200</td>
</tr>
</tbody>
</table>

Dwellings destroyed
- 26 @ £2,000 = £52,000

Dwellings damaged
- 1,236 @ £200 = £247,000

Business premises destroyed and damaged and stock losses, (1949 flood only) as assessed by Kempsey Chamber of Commerce = £750,000

Other buildings destroyed
- 1 Church = £5,000

Other buildings damaged
- 1 Church, 4 factories = £5,000

Farm buildings, not recorded, say, = £5,000

Loss and damage to contents of dwellings,
- 1,246 @ £375 (Av. by N.E. Uni.) = £467,250

Loss and damage to contents of other buildings
- 6 @ £500 = £3,000

Railways
- Restoration = £87,000
- Extra operating costs = £113,000 £200,000

P.M.G.'s Department
- Restoration of lines etc. = £15,000

Macleay River County Council
- Restoration of lines, etc. = £15,000

P.W.D.
- Restoration of roads and bridges = £109,000
Municipal Council,

Roads, pavements, water and sewerage ........................................ £90,900

TOTAL ................................................................. £2,573,052

(Civil Engineers Report 1962)

(c) Macleay River County Council (1964)

The floods which occurred on the Macleay Valley during 1963 were assessed in very broad terms by the Macleay River County Council. In addition to assessing direct and indirect losses, an attempt was made to indicate the possible nature of secondary benefits.

"Some of the losses which occurred during 1962, a year in which only nuisance and minor floods occurred are as under:-

Dairy Products .................................................. £105,000
Beef Cattle ...................................................... £100,000
Maize ............................................................... £45,000
Potatoes ............................................................. £25,000

TOTAL ................................................................. £275,000

"With the exception of potatoes (maize is used principally for fodder for dairy products) the losses mentioned are almost wholly upon goods produced for export and as such are of national importance.

"It should be noted however that the losses itemized only relate to production, to be added to them are the losses of wages to factory staff, of carriers income and of retail trade".

Estimated losses incurred on the Macleay as a result of the nuisance floods early in 1963 and the major flood in May, 1963, are as follows:-

Nuisance flooding prior to May .. .. .. £225,000
Loss in production May flood .. .. .. £350,000
Loss of crops .. .. .. .. .. .. £65,000
Loss of pastures .. .. .. .. .. .. £35,000
Loss in factory wages .. .. .. .. .. .. £60,000
Loss of factory profits .. .. .. .. .. .. £85,000
Loss of fencing on Lower Macleay .. .. £30,000
Loss of Carriers income .. .. .. .. .. £15,000
Cost of fodders .. .. .. .. .. .. £150,000

TOTAL .. .. .. .. .. .. .. .. .. .. £1,015,000

"The amount of £1,015,000 pertains to the estimated loss to the dairy industry above and to this must be added the losses of beef production, maize and potatoes, the loss of household effects, damage to roads, bridges and public utilities, and the loss in retail trade."

"In considering the losses referred to and the possible increase in production upon the completion of the mitigation scheme, the effect upon the local community must be borne in mind. This Council is also concerned with the distribution of electricity and has ample evidence of the reduced prosperity throughout the community following even the smallest of floods."

"Treatment of secondary benefits was made using a map showing the four categories of land on the flood plain, pointing out the changes that might take place, and evaluating these at a considered conservative extra income capacity of £10 per acre".
"Besides obviating losses such as those set out in Section 6 and amount to £275,000 the works proposed in the overall report will result in the improvement of 62,000 acres with an anticipated increased production of not less than £10 per acre per annum.

"The estimated potential annual production on the completion of the works would be therefore to the order of £2,895,000 an increase of nearly 50 per cent. However, it must be emphasised that this figure is very conservative and the potential is likely to be greater rather than less."

Finally the benefits were summed up:-

1. Elimination of nuisance floods (those to a height of 16 feet on the Kempsey gauge)
2. More rapid draining of floodwater when banks are overtopped resulting in greatly reduced loss of pastures and crops.
3. Improvement to land consequent on improved drainage and suitability for establishment of improved pastures, resulting in an estimated increase in production, based on existing land use, of £10 per acre per annum on 62,000 acres.
4. Damage to roads and highways will be reduced and less interruption will occur to communications and transport of goods.

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>EXISTING USE</th>
<th>POSSIBLE FUTURE USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark Green</td>
<td>Crops and pastures</td>
<td>This land justifies extensive planting of high quality crops and improved pastures</td>
</tr>
<tr>
<td>(The natural levees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Green</td>
<td>Generally grass land</td>
<td>Crops and improved pastures</td>
</tr>
<tr>
<td>(Intermediate land)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>Poorer quality grasses</td>
<td>Better quality grasses and improved pastures.</td>
</tr>
<tr>
<td>(Swamp to levee toe)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>Semi-permanent swamp</td>
<td>About 30% could be used for better quality grass and with reclamation by silt</td>
</tr>
<tr>
<td>(Back swamp)</td>
<td></td>
<td>this figure could well be increased in the future.</td>
</tr>
</tbody>
</table>
5. Continuity of production on farms and dairy factories would benefit all sections of the community.

6. The drift of population from farms would be halted and eventually reversed.

7. The carrying capacity of the river would be increased."

As can be seen from the previous attempts to assess the extent of flood damage on the Macleay Flood plain, very little accurate information is available for planning. Information and implicit cost benefit analysis in the minds of planning officers and the County Council itself have been dominating the trend of work to date. These estimates may be approximately correct but there is no doubt more rigorous economic information is required for evaluation of works constructed or planned, and for indicating valuable further developments.


From the foregoing section the damages resulting from a number of flood events can be seen and a rough order of magnitude of damages and flood size determined. This is useful to provide an indication of the large amount of damage done by floodwater in the area and to isolate the prime causes of this damage. For the purposes of evaluating specific constructions it is almost useless.

Flood damage is a function of the height of water, its duration, silt and debris content and turbulence. These particular factors vary with the volume of water in any flood event and with conditions which are from past experience unique to that event. An example of this unique nature of flood events, and flood damage, is the 1949 flood which flowed through a sawmill in Kempsey washing logs downstream to cause serious damage to buildings. At lower levels of flooding however water movement is much less violent and much less scope exists for unusual events such as this. It is proposed for the purpose of this study to systematically analyse the conditions of flooding in the
Valley and to provide the basis for evaluating the changes in these by way of general parameters of damage which can not take into account unique events.

Although it would be valuable to indicate the damage done by any given flood this would involve more work than is necessary to demonstrate the value of a given set of works. The nature of the works themselves then determine to an extent the best approach to the problem. The significant features of the present work on the Lower Macleay Valley are:

(a) Containment of floods of discharge less than 60,000 cusecs and confinement of those 60-80,000 cusecs
(b) Assistance in the drainage of floodwater of floods larger than this.

The conditions of flooding both before and after the establishment of flood mitigation works are basic, the important variables being extent of overbank flow, height of water and time of inundation. The height of floodwater reached in an area of the floodplain can be closely related to the discharge of floodwater in the river by the use of flood records held by the Macleay River County Council. The frequency that water reaches a certain height in a particular area is then seen by reference to the probability curve for flood discharges in the river. If the capacity of the river is increased by levees and is halted from premature intrusion by a system of headworks across drains and creeks, the new conditions of flooding are a reduced frequency of flooding below a given height, as indicated by the probability of flooding, in the range of discharge levels which are newly contained.

Changes in the period of inundation of floodwater are simple to determine if recession curves are available both before and after the instalment of increased drainage capacity. This information is available for the lower Macleay floodplain on records held by the M.R.C.C.

Analysis of the conditions of flooding outlined above and with the nature of flood mitigation works in mind, the following factors are basic:
(a) Flooding resultant from river discharges below 88,000 cusecs only affects the lower landscape components. Although this amounts to flooding a large area of the floodplain (some 71,000 acres, excluding Yerrahappinni), the land flooded is predominantly rural. There is a negligible amount of building in this area, nor is water of sufficient depth to seriously harm communication lines. Any residential or commercial building in the area flooded would have sufficient clearance to be out of flood range. The maximum height of floodwater in the area flooded by a nuisance flood on the floodplain is 4-5' which would be over the swamp areas. The general depth of water above the toe of the levees in the floodplain when flooded by a nuisance flood is at the most 3'. There are no doubt exceptions to this generalization but for practical purposes it will be assumed that nuisance flooding of 88,000 cusecs river discharge, only affects rural production in damaging pastures and crops. It would only be necessary in assessing the likely benefits of containing these floods to assess the annual damage to crops and pastures by floodwater of this level. It is also significant that these floods leave exposed large enough areas of rural land to provide stock refuges enabling stock to be saved.

(b) As can be seen clearly from the pre-flood mitigation and post-flood mitigation curves of floodwater recession (see part 4), the contribution of drainage work is valuable at the lower levels. Recession from higher levee areas was always quick due to the general overland flow which will not be significantly changed. The land use components which stand to benefit most from drainage work are those located below the level of rapid drainage, i.e. the levee toe and swampy areas.

Damage to the building occupying the higher land then is not being altered for all practical purposes. Reduction in the period of flooding in the higher areas is in all cases very slight and this together with the fact that to a large extent damage to building is not likely to be altered by a minor reduction in the period of inundation, leads to a further conclusion that the components of the landscape benefitting also from drainage, are crops and pastures.
The contribution of flood mitigation works in the Lower Macleay floodplain is largely in reducing damage to pastures and crops which may encourage extension of the more intensive use of land as a secondary benefit. This is a simplified account of the flood problem to be assessed and it omits the damage resulting from the following causes against which the works will provide some positive ameliorative effect.

(i) Damage from flooding other than that resulting from the Macleay River. This includes occasional flooding of parts of the right bank of the floodplain from the Maria River and low level flooding as a result of intense rain on the floodplain itself or its immediate catchment.

(ii) Damage caused by silt deposition.

The economic damage resulting from these causes would be very difficult to assess - the contribution of the flood mitigation to a reduction in the damages even more difficult to assess.
RELATION BETWEEN FLOOD DISCHARGE AND DRAINAGE AREA

KUICHLING'S:

Curve a \( q = M^{1.70} + 20 \) for occasional floods

Curve b \( q = M^{1.70} + 7.4 \) for rare floods

Based on observations on American, European, and Australian rivers showing the outstanding position of the Macleay River at Kempsey.

(Reproduced from "Public Water Supply," by Turneour and Russell, page 73.)
For the purposes of assessing the flood mitigation works of the Macleay River County Council it is necessary to determine what effect the works will have on the conditions of flooding. Damage by flood water can be derived from a number of different factors:

(i) The height of water  
(ii) The period of inundation  
(iii) Overbank flow  
(iv) Turbulence  
(v) Silt and debris in flow and deposition,

In this study the first three factors above will be analysed. With the latter two which are quite important it is very difficult to determine what is the extent of any changes that will take place as a result of flood mitigation in a flood of given size. There is no doubt that damage caused by turbulence will be reduced in some areas by floodway construction and ameliorated in others by bank protection. Silt and debris on the other hand are carried by all floods, the damage resulting from the movement and deposition varying from flood to flood. Part of the reason for the severity of the 1949 flood was the flow of logs from a sawmill in Kempsey which struck buildings and exacerbated other flood damage. Sensible floodplain management has reduced this hazard.

For the purposes of economic analysis it appears that the important hydrological factors to be analysed are:

(i) The effect of containing and confining floods in the 60-88,000 group and less.  
(ii) The results of installing drains to remove confined water in the flood storage areas and of waters of floods higher than 88,000 cusecs in other sections of the floodplain.  
(iii) The extent of reduction in the area experiencing overbank flow.

The majority of the necessary discharge, frequency, swamp height, natural and modified drainage, elevations and areas, overbank flow routes and areas can be best examined by a series of graphs in conjunction with detailed base maps.
1. **Drainage Areas.**

As was mentioned in the introduction to this report, the floodplain is a complex of minor relief features which have a profound affect on drainage and flood frequency. These areas are distinct in the lower stages of drainage and height of flood water, particularly in smaller floods, that they must be isolated for study. (The floodplain referred to is from Kempsey to the sea, omitting minor areas in the Frenchman's Creek, Eureka and Maria River areas (see Fig. 2)). Important factors in forming distinct drainage and flooding areas are

(i) The natural levee system of the river and its distributaries.

(ii) More prominent ridges as at Red Hill and Frederickton.

(iii) The height above mean sea level of the levees and swamps. This tends to decrease from Kempsey downstream, but the decrease is by no means a uniform one.

The drainage areas delimited by the above factors are (in order from Kempsey to the coast)

1. **Left Bank**
   (i) Glenrock-Tennessee
   (ii) Clybucca-Seven Oaks-Cocroombongatti
   (iii) Yarrahappinni

2. **Right Bank**
   (i) Pola Creek
   (ii) Redhill
   (iii) Austral Eden
   (iv) Belmore
   (v) Gladstone-Kinchela
   (vi) Kinchela-Jerseyville

For the purposes of this investigation detailed information relating to flood height, recession and topographic conditions were required. Maps and flood recordings held by the Engineering Department, Flood Mitigation Branch of the Macleay River County Council were
sufficient to enable study of all but one of the areas above. The Yarramalpinni area is at this stage relatively under-developed, topographic and hydrological information is not adequate and consequently was deleted from the study as it would provide very little indication of flood mitigation value. Study in other areas of the floodplain should provide valuable information for planning work in areas such as this which have not been so far included.

2. Flood Height.

Flood heights in each of these areas above have been recorded since 1956 and in some cases isolated readings before this are available. In addition more reliable sources of information such as civil engineers and agronomists, can remember flood peaks of larger floods. These points can be evaluated from topographic maps. It is useful to compare the flood peak heights recorded in each area with the peak discharge of the river at Kempsey for each available flood.

The height of floodplain flooding follows the basic hydro-geomorphological principles:

i) At the lower levels of river discharge flow can be contained within the banks. The maximum river discharge which is contained within the channel before the works of the H.R.C.C. varied from 40-60,000 cusecs. The constructed capacity now has been indicated and the minimum necessary discharge in most areas is 88,000 cusecs.

ii) Once inundation is produced by higher discharge the height of floodwater increases slowly at first because of the large storage area available at the swamp level.

Once swamp storage (largely below R.L. 105' over all parts of the floodplain) has been filled, rapid height increase results, the storage available having a much reduced areal component.

After flooding has reached the elevation of the levees the rate of increase in height is reduced markedly because of a general overland flow.
It would be extremely useful if this relationship could be expressed in graphical form. The reduction of flooding in a certain discharge range could then be shown by reference to this and the storage curve.

The Macleay River County Council has swamp levels for floods in the range 70,000 cusecs or greater. From statistical analysis by log-log regression it appears that floods above 70,000 cusecs produce swamp levels which can be represented by a straight line on log-log paper.

However there have been very few records for floods less than 60,000 cusecs which precludes the use of statistics alone in the determination of the height of flooding produced by various flood peak discharges. Some facts are known however:-

i) In each area the necessary minimum discharge to produce inundation is known. This applies to conditions as they were before any construction work, and as they will be with all works in operation.

ii) The statistical treatment of recordings of available floods indicate that at approximately 70,000 cusecs the flood discharge-height relationship is linear on a log-log scale.

iii) Between the necessary minimum discharge for flooding in each area and the operation of the calculated section it is necessary to interpolate. The basic factors that affect this have been outlined, some of the individual circumstances modifying them would be:-

(a) The length of the flood peak
(b) The volume of storage occupied by local flooding and rainwater.

It would be very difficult to calculate the impact of all these factors on the height of inundation and the two points

(a) the beginning of flooding
(b) the lower end of the calculated line will be joined by a straight line.
There is obviously some lack of realism in this but the error involved could only be slight owing to the narrow discharge range concerned and the fact that some of the factors would be cancelling.

Through the increase in the discharge contained within the river channels, a greater volume of water in any flood will pass through the river without contributing directly to floodplain inundation. It is extremely difficult to assess what this reduction will have on the level of water in each of the drainage areas. The Belmore area is an exception as the volume of water passing through the floodway under optimum management can be calculated and the storage levels determined (fig.24). For the other areas this is not possible. From discussions with Flood Mitigation engineers of the M.R.C.C., however, and from indications shown by calculated figures for the Belmore area, it seems likely that this initial reduction in the volume of water would be largely offset once the peak flood discharge reached approximately 160,000 cusecs. This would result from the sheer volume of water involved and the fact that inundation could continue whilst the river was in its falling stages which may not have been possible under earlier conditions of full storages.

In terms of the discharge-height relationships this means the new conditions will have the points 88,000 cusecs and zero flooding for all areas except the Belmore, and 160,000 cusecs and the previously experienced level of flooding for all areas.

There is little doubt that the removal of roughly 40,000 cusecs off the flood peak by containment and confinement measures will have some effect at discharges higher than 160,000. What this effect is would depend on an extremely complex range of factors which cannot be simply explained. Other possible patterns could be:

1) The removal of 40,000 cusecs off the base of the peak could be transferred through the known relationship by lowering the rating curve by this equivalent.

2) It could be expected that at high discharge the relationship between river profile, rate of flood build up in the storage areas and hence the flood height would be of the same pattern. The slope of the rating curve could not be expected to alter.
PROBABILITY CURVE FOR THE MACLEAY RIVER
AT THE KEMPSEY TRAFFIC BRIDGE

RECURRENT INTERVAL (Years)

PEAK DISCHARGE (1000 cusecs)

Plot: %P = 100 \left( \frac{m}{n+1} \right)
substantially. The increase in height over the sections of the rating curve would be very similar for the pre and past mitigation conditions. The breaking point could be isolated for the past flood mitigation conditions by reference to the pre flood mitigation situation.

iii) It appears the only truly reliable method, taking into account the changes in flood profiles by containment measures, is by observation in future floods. Model testing could produce an approximate answer.

For the purposes of this study these solutions are not available and the continuation of conditions above 160,000 cusec peak floods as before will be adopted for simplicity and apparent equal validity to other alternatives. Its use is valuable in facilitating further analysis but preliminary in the sense that when the relationship can be determined more accurately the curves used here should be replaced.

In addition to flooding from the Macleay River, other low level flooding occurs:

i) Local flooding occurs in Seven Oaks, Pola Creek and Tennessee areas from the immediate catchment of the floodplain itself.

ii) Further flooding at low levels has occasionally been experienced by water flowing in from the Maria River in the South when the Macleay itself was not flowing in flood proportions. This affects only the right or southern floodplain of the Macleay, especially in a belt between the top of Belmore River through Swanpool to Jerseyville.

iii) Marine intrusion occurs intermittently at the lower end of the floodplain in Yarahappinni and Jerseyville areas.

iv) Heavy rainfall causes waterlogging in the lower levels of all drainage areas on the floodplain. Such flooding is produced only by abnormally heavy and consistent rainfall but is sufficient to reduce the use of low areas until dry again and to inhibit pasture use in the same areas.
INCIDENCE OF FLOODS 1921-1967. MACLEAY RIVER, KEMPSEY TRAFFIC BRIDGE.

(Note: No height recorded shown --- )
UNIT GRAPH for MACLEAY RIVER at KEMPSEY TRAFFIC BRIDGE.
(after Met. Bureau)
These other flooding causes mentioned are very minor in comparison with the Macleay river flooding and will not be specifically treated in the remainder of this report. It is necessary to take account of these in arriving at a complete picture of flooding.

3. Flood Regime of the Macleay River, Kempsey Traffic Bridge.

The problem of ameliorating the effects of flooding is not an easy one, especially on the Macleay River which carries floods of considerable magnitude and velocity as a result of very intense rainfall in a steep catchment area. Reference to the Kuichling graph (fig 3) of the relationship between drainage area and flood discharge clearly shows the extreme flood prone nature of the Macleay River and its floodplain.

Reasonably reliable stage-height records have been collected for the Macleay River at the Kempsey Traffic Bridge since 1921. Prior to this records of at least some value are available as far back as 1863. For statistical purposes however only those collected since 1921 are reliable.

The important features of floods are:-
(i) The recurrence period of various size floods.
(ii) The seasonal distribution of floods.
(iii) The normal hydrograph of flood flow.

From the accompanying graph a probability analysis was applied to provide as accurate an indication as possible of the frequency of flooding (fig. 4). The method used to derive this curve was that based on mean probability. This method in which

\[ P(x) = \frac{n}{n+1} \]

where \( m \) = flood rank
\( n \) = number of years of record

is that used by the United States Geological Survey. It has the advantage of simplicity and appears to produce results equally as useful as any of the more complex. (see: T. Dalrymple: "Flood Frequency Analyses". U.S.G.S. Water Supply Paper 1543-A 1960)
The probability of a flood being equalled or exceeded in any given year can be determined by reference to the lower abscissa values. The probability that a flood will occur within any given range can be calculated simply by subtraction i.e.

$$P(A \geq B) = P_A - P_B$$

The values of this for floods in the relevant ranges can be seen from table below and hence the reduction of flooding as a result of less frequent inundation at lower levels determined. These flood ranges roughly correspond to the categories of nuisance, minor, medium and major floods. It can immediately be seen that confinement and containment of flood discharges in the range 60-88,000 cusecs will prevent 13 floods every 100 years from inundating as previously in all areas except the flood storages.

**TABLE 2.**

<table>
<thead>
<tr>
<th>Flood Range (cusecs)</th>
<th>Probability of Occurrence in any one year</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 - 88,000</td>
<td>.13</td>
</tr>
<tr>
<td>88 - 130,000</td>
<td>.18</td>
</tr>
<tr>
<td>130 - 250,000</td>
<td>.19</td>
</tr>
<tr>
<td>250 - 500,000</td>
<td>.09</td>
</tr>
</tbody>
</table>

The seasonal distribution of floods at the Kempsey Traffic Bridge shows a marked concentration in the months of January, February and March and to a lesser extent June, July and August. Little relationship exists between flood size and season. The major producers of flood rainfall are cyclonic depressions which form over tropical seas and migrate in a southerly direction in any season but most commonly in summer (fig. 5).

**The Normal Flood Hydrograph.** The Commonwealth Bureau of Meteorology in its "Report on Development of a Flood Forecasting System for the Lower Macleay Valley N.S.W." produced a very important study of the characteristic flood hydrograph for the Kempsey Traffic Bridge. For flood forecasting techniques the "unitgraph" has especial value; for the
33.

purposes of illustrating flood flow, this curve (fig. 6) shows the mean time for rise, peak, recession. The floods for which this unit graph occurred were between 1949 and 1959. The rapid attainment of peak flow is obvious from this graph, the period 30 hours. This period is even less when it is taken into account that flooding of the plain does not occur until the river passes 40-50,000 cusecs in most areas. The flood to peak stage for these areas would be more of the order of 6 hours. From Meteorological Bureau study and analysis of the hydrographs of floods the best approximation of the flood (40-50,000 cusecs) to peak is an interval of 12-18 hours and a maintenance at peak of 6 hours. The June flood of 1967 however maintained a peak flow for 26 hours. Such anomalies will always occur as a result of temporal and spatial differences in rainfall patterns.

Such periods although small must be incorporated in deriving the total period any land is inundated. For all areas studied these relationships are held to be constant. To determine the period of time involved in flood to peak flooding a graphical formulation as in figure 7 is useful.

4. THE CONDITIONS OF FLOODING IN THE DRAINAGE AREAS.

1. Glenrock-Tennessee

The Glenrock-Tennessee area extends on the left bank of the river from the heart of Kempsey to a ridge on which Frederickton is situated. The area stretches from the river under the railway to the hills which are the catchment for Christmas Creek and its tributaries.

(a) The levee system in this area is overtopped when the river exceeds a discharge of 120,000 cusecs, previously this occurred when the river reached 100,000 cusecs. Prior to levee overtopping the floodwater used to enter the area through Christmas Creek at a discharge of 45,000 cusecs. This has been halted.

The relationship between peak river discharge and flood
GLENROCK - TENNESSEE
FLOOD PEAK DISCHARGE - HEIGHT

A Before flood mitigation
B After flood mitigation

\[ Yc = 57.61X^{-0.600} \]
for the observed section

FIG. 9
RECESSION GLENROCK–TENNESSEE

- Before Flood Mitigation Works
- After Flood Mitigation Works
height can be seen from figure 8. The correlation for the section of the graph which was produced from observations is .93. The observed readings are in Table 3.

### TABLE 3.

**Flood Peak Discharge and Peak Inundation Height Observations**

**Glenrock-Tennessee.**

<table>
<thead>
<tr>
<th>Date</th>
<th>Peak Q Kempsey (000 cusecs)</th>
<th>Height Gl.Ten. M.S.L. + 100</th>
<th>Computed Height</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/1/63</td>
<td>76</td>
<td>113.2</td>
<td>113.1</td>
<td>0.1</td>
</tr>
<tr>
<td>14/1/62</td>
<td>77</td>
<td>113.9</td>
<td>113.2</td>
<td>0.7</td>
</tr>
<tr>
<td>25/2/56</td>
<td>80</td>
<td>112.1</td>
<td>113.4</td>
<td>-1.3</td>
</tr>
<tr>
<td>23/1/59</td>
<td>124</td>
<td>116.0</td>
<td>116.3</td>
<td>-0.3</td>
</tr>
<tr>
<td>11/7/62</td>
<td>126</td>
<td>117.0</td>
<td>116.5</td>
<td>0.5</td>
</tr>
<tr>
<td>20/2/56</td>
<td>128</td>
<td>114.8</td>
<td>116.6</td>
<td>-1.8</td>
</tr>
<tr>
<td>12/11/59</td>
<td>142</td>
<td>118.6</td>
<td>117.4</td>
<td>1.2</td>
</tr>
<tr>
<td>11/4/62</td>
<td>145</td>
<td>119.0</td>
<td>117.6</td>
<td>1.4</td>
</tr>
<tr>
<td>10/5/63</td>
<td>300</td>
<td>123.4</td>
<td>122.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Model</td>
<td>400</td>
<td>124.0</td>
<td>124.9</td>
<td>-0.9</td>
</tr>
</tbody>
</table>

$Y_0 = 57.61 \times 0.06$ for observations


(b) Once floodwater has inundated it recedes at varying rates. At higher levels the water re-enters the river by overbank flow but once the level of water is below bank level must drain through Christmas Creek and Verges drain. The capacity of these outlets prior to work by M.R.C.C. was restricted and drainage slow. Recession prior to mitigation work can be closely approximated by averaging the periods recorded in the area since 1956. The mean of recession time at 1' intervals was computed to construct the curve in Fig.10.

(c) Work by the M.R.C.C. has or will involve:

(i) Headworks across Christmas Creek and associated with this

(ii) Levee banks along Christmas Creek
(iii) Increase the capacity of Christmas Creek
(iv) Increase the capacity of Verges Drain.
(v) Construct a new drain of approximately 1400 yards between Christmas Creek and Verges drain.

The improvement in drainage of this area will be as in the new recession curve on Fig. 10.

The total period of inundation as with all other areas must be derived from the flood to peak information presented on Fig. 7.

2. Clybucca - Seven Oaks

This area extends from the ridge at Frederickton to the S.W. Rocks road near Jerseyville. It is bounded on the north by hill country which provides a catchment area of approximately 64000 acres and contributes to local flooding on the floodplain in periods of intense rainfall.

(a) Macleay River floods enter the area by general overbank flow when a discharge of 88,000 cusecs is reached at Kempsey. Prior to this encroachment through levees occurred particularly up Clybucca Creek and the main channel at Seven Oaks bend from a discharge of 45,000 cusecs.

The height which water reaches at various discharges at Kempsey can be seen in Fig. 12. The correlation for the observed section of the relationship is .84. In only one case was the height computed from the regression greater than 1' different from that observed.
CLYBUCCA—SEVEN OAKS
FLOOD PEAK DISCHARGE—HEIGHT

FIG. 12
RECESSION CLYBUCCA—SEVEN OAKS

Before Flood Mitigation Works

After Flood Mitigation Works

Time Days

Exceedance M.S.L. (000')

100

106

112

118

124

130
TABLE 4.

<table>
<thead>
<tr>
<th>Date</th>
<th>Kempsey (000 cusecs)</th>
<th>Height Clybucca</th>
<th>Computed height</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>26/6/56</td>
<td>70</td>
<td>106.5</td>
<td>107.4</td>
<td>-0.9</td>
</tr>
<tr>
<td>5/1/63</td>
<td>76</td>
<td>108.1</td>
<td>107.6</td>
<td>+0.5</td>
</tr>
<tr>
<td>14/1/62</td>
<td>77</td>
<td>108.2</td>
<td>107.7</td>
<td>+0.5</td>
</tr>
<tr>
<td>10/3/64</td>
<td>94</td>
<td>109.2</td>
<td>108.4</td>
<td>+0.8</td>
</tr>
<tr>
<td>2/3/56</td>
<td>108</td>
<td>107.7</td>
<td>108.9</td>
<td>-1.2</td>
</tr>
<tr>
<td>23/1/59</td>
<td>124</td>
<td>108.7</td>
<td>109.4</td>
<td>-0.7</td>
</tr>
<tr>
<td>11/2/56</td>
<td>127</td>
<td>110.1</td>
<td>109.5</td>
<td>+0.6</td>
</tr>
<tr>
<td>20/2/56</td>
<td>128</td>
<td>109.4</td>
<td>109.5</td>
<td>+0.1</td>
</tr>
<tr>
<td>12/11/59</td>
<td>142</td>
<td>109.9</td>
<td>109.9</td>
<td>0.0</td>
</tr>
<tr>
<td>11/4/62</td>
<td>145</td>
<td>109.8</td>
<td>110.0</td>
<td>-0.2</td>
</tr>
<tr>
<td>10/5/63</td>
<td>300</td>
<td>112.8</td>
<td>112.6</td>
<td>+0.2</td>
</tr>
</tbody>
</table>

(b) Once the water exceeds a level of 109.0 it recedes by overland flow in a north-easterly direction along Clybucca Creek. The area west of the Pacific Highway continues to drain by Clybucca Creek once the water falls below this level, but the area south of the Highway and west of Croads lane drains through McCabes drain below this level; the area between Croads and Plummer's lane via Collins drain; the area north of Plummer's land draining direct to lower Clybucca Creek and Andersons inlet. The rate of drainage becomes very slow and in some low areas there is no drainage. The rate of recession can be seen from fig. 13.

(c) The main work constructed or planned by the M.R.C.C. involves drainage works via:

(i) Extensive work to improve the capacity of Clybucca Creek.

(ii) A new drain (Clancy's) from the Macleay River to Cooroobongatti Swamp.

(iii) Enlarge McCabes drain
POLA CREEK
FLOOD PEAK DISCHARGE - HEIGHT

A Before flood mitigation
B After flood mitigation

\[ Y_c = 57.61X^{-0.600} \]
for the observed section

FIG. 15
(iv) Enlarge Collins Drain.

The new recession periods can be seen from the modified curve on fig. 13.

3. Pola Creek.

This area is on the right bank of the flood plain from East Kempsey downstream to a high alluvial terrace. The area extends back from the river in a form of basin (see fig. 14) with the swamp at a level of R.L. 105.

(a) Apart from local flooding from the catchment of Pola Creek itself, the Macleay River backs up the Pola Creek and old Pola Creek channels commencing when the Kempsey discharge reached 40,000 cusecs. Direct overbank flooding is experienced when the river reaches a discharge of 125,000 cusecs.

The observed and interpolated relationship between peak height at Kempsey and level of flooding in the Pola Creek area can be seen from fig. 15, the correlation being .95, for the observed section.

(b) Once water has inundated this area recession is slow due to the inadequate capacity of Pola Creek, the only outlet in this area. The recession periods can be seen on fig. 16.

TABLE 5.

<table>
<thead>
<tr>
<th>Date</th>
<th>Kempsey (000 cusecs)</th>
<th>Height in Pola Creek</th>
<th>Computed height</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>14/1/62</td>
<td>77</td>
<td>110.2</td>
<td>110.1</td>
<td>+0.1</td>
</tr>
<tr>
<td>25/2/56</td>
<td>80</td>
<td>109.8</td>
<td>110.5</td>
<td>-0.7</td>
</tr>
<tr>
<td>23/1/59</td>
<td>124</td>
<td>113.9</td>
<td>113.9</td>
<td>0.0</td>
</tr>
<tr>
<td>11/4/62</td>
<td>145</td>
<td>116.2</td>
<td>115.3</td>
<td>+0.9</td>
</tr>
<tr>
<td>10/5/63</td>
<td>300</td>
<td>123.9</td>
<td>121.4</td>
<td>+2.3</td>
</tr>
</tbody>
</table>
RECESSION POLA CREEK

FIG. 16

Before Flood Mitigation Works
After Flood Mitigation Works

Time Days

Elevation M.S.L. -100'

120
118
116
114
112
110
108
106
104

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
A Before flood mitigation
B After flood mitigation

\[ Y_c = 57.61X^{-0.600} \]
for the observed section

FIG. 18
(c) The work of the M.R.C.C. has involved:

(i) Construction of a headworks and associated levee along the mouth of the Pola Creek to prevent premature flooding.

(ii) Enlarge the capacity of Pola Creek.

The impact of the works on drainage can be seen from the modified recession curve - fig. 16.

4. Redhill

This area extends from the Macleay River to the S.W. Rocks road at Austral Eden as far as the Old Station Road. It is bounded in the south-west by a high alluvial terrace.

(a) Flooding commenced in the lower areas when the river reaches a discharge of 40,000 through flow back up Belmore River into Frogmore-Darkwater Swamp which extends into the Redhill area. When the flow exceeds 100,000 cusecs at Kempsey general overbank flow from Redhill and Austral Eden levees, a continuance of Belmore effluent flow and at very high levels flow from the higher level swamp of Pola Creek is experienced.

The observed and interpolated relationship between height of peak at Kempsey and depth of flooding can be seen in fig.18, the correlation co-efficient the observed section being .94.

Frogmore Swamp in this area which has a connection with the Belmore floodway storage will be used as part of the system and will be affected as indicated in figure 18 and described in the Belmore area.

(b) Once the water has inundated it recedes by way of Belmore River and Old Pola Creek, becoming slow to negligible at lower levels. The rate of recession can be seen from the curve in fig. 19.
Land below this takes a further 40 days to evaporate to 101 below which may take 1-2 years to dry completely.
TABLE 6

<table>
<thead>
<tr>
<th>Date</th>
<th>Kempsey (000 cusecs)</th>
<th>Height in Redhill</th>
<th>Computed Height</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>25/2/56</td>
<td>80</td>
<td>108.8</td>
<td>107.6</td>
<td>+1.2</td>
</tr>
<tr>
<td>2/3/56</td>
<td>108</td>
<td>109.5</td>
<td>109.2</td>
<td>+0.3</td>
</tr>
<tr>
<td>23/1/59</td>
<td>124</td>
<td>109.3</td>
<td>110.0</td>
<td>-0.7</td>
</tr>
<tr>
<td>11/2/56</td>
<td>127</td>
<td>109.6</td>
<td>110.3</td>
<td>-0.7</td>
</tr>
<tr>
<td>20/2/56</td>
<td>128</td>
<td>110.3</td>
<td>110.3</td>
<td>0.0</td>
</tr>
<tr>
<td>12/11/59</td>
<td>142</td>
<td>110.0</td>
<td>110.9</td>
<td>-0.9</td>
</tr>
<tr>
<td>10/5/63</td>
<td>300</td>
<td>116.7</td>
<td>115.3</td>
<td>+1.4</td>
</tr>
<tr>
<td>25/8/49</td>
<td>500</td>
<td>118.0</td>
<td>118.4</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

(c) Improvements constructed or planned by the H.R.C.C. are:

(i) Construction of headworks and levees along Belmore River.

(ii) Improve the capacity of Lancaster's, Frogmore, Darkwater and Barnett's drains.

The result such will have on recession can be seen from figure 19.

5. Austral Eden.

Austral Eden is situated in a large meander of the River between Belmore River in the east and a swale of low lying land which runs parallel with the S.W. Rocks Road. The area enclosed is a natural swamp basin of approximately 2,500 acres.

(a) This area used to be flooded initially by river flow backing up the Belmore river until the river reached 100,000 cusecs at Kempsey when general levee overtopping occurs. The observed and interpolated relationship between peak discharge at Kempsey and flood height in Austral Eden can be seen from figure 21, the correlation coefficient being .97 for the observed section.
Austral Eden
Flood Peak Discharge - Height

A Before flood mitigation
B After flood mitigation

\[ Y_c = 57.61 \times 10^{0.60} \]
for the observed section

FIG. 21
Before Flood Mitigation Works

After Flood Mitigation Works

Dry except for lagoons in approximately 4-6 weeks
TABLE 7.

$$Y_c = 86.56X^{0.0231}$$

<table>
<thead>
<tr>
<th>Date</th>
<th>Kempsey (000 cusecs)</th>
<th>Height in Austral Eden</th>
<th>Computed Height</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/1/63</td>
<td>76</td>
<td>111.7</td>
<td>112.2</td>
<td>-0.5</td>
</tr>
<tr>
<td>14/1/62</td>
<td>77</td>
<td>111.8</td>
<td>112.3</td>
<td>-0.5</td>
</tr>
<tr>
<td>23/1/59</td>
<td>124</td>
<td>113.7</td>
<td>113.4</td>
<td>-0.3</td>
</tr>
<tr>
<td>20/2/56</td>
<td>128</td>
<td>114.3</td>
<td>113.6</td>
<td>+0.7</td>
</tr>
<tr>
<td>11/4/62</td>
<td>145</td>
<td>114.3</td>
<td>114.0</td>
<td>+0.3</td>
</tr>
<tr>
<td>10/5/63</td>
<td>300</td>
<td>115.5</td>
<td>115.8</td>
<td>-0.3</td>
</tr>
<tr>
<td>25/8/49</td>
<td>500</td>
<td>116.9</td>
<td>117.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

(b) In the past floodwater in the centre of the Austral Eden area could not be drained adequately and recession below R.L. 116 when overbank flow ceased was very slow (fig. 22)

(c) Work in the Austral Eden area has been completed and involved reconstruction of two drains, Austral Eden and Whalen's, and headworks with levees to keep floods below 88,000 cusecs out.

6. Belmore Area

This area extends from the S.W. Rocks road and Old Station road on the north between hill country and the left bank of Belmore River. It extends through to Killick Creek at Crescent Head and the line of sand dunes which parallel the coastline to Koregoro Point. At the top of Belmore River a low but significant saddle separates the area from the Gladstone Kinchela area.

(a) Flooding occurred by water backing up Belmore River from the Macleay at discharges greater than 40,000 until the discharge at Kempsey reaches 100,000 cusecs when general overbank flow from Austral Eden and Redhill areas occurs. In times of high flow in the Maria River to the south of Crescent
FIG. 23
BELMORE
FLOOD PEAK DISCHARGE - HEIGHT

A Before flood mitigation
B After flood mitigation

$Y_c = 57.61X^{0.66}$
for the observed section

FIG. 24
Head, flooding has been experienced in the Belmore area from this source alone. The height water reaches at various levels of flooding can be seen on figure 24, the correlation being .94, for the observed section of the graph.

The Belmore River floodway will benefit all other areas of the floodplain. Its operation aims at withdrawing water from the River once its discharge has exceeded 60,000 cusecs. The storage area for this water is the whole of the swamps in the Belmore and Redhill areas. Regulation of flow into this storage should lead to the minimum amount of water being let in, to avoid filling the storage unnecessarily if the River does not exceed 88,000 cusecs.

To determine the effect of storage of such optimum management, the unitgraph (fig.6) was used as the typical hydrograph. The surplus water above the channel containment capacity, 60,000 cusecs could be calculated. If this surplus was channeled into an empty storage, the results are as in Table 9. Once the river exceeds a discharge of 88,000 cusecs overbank flow will occur in places and the volume entering storage can no longer be accurately determined.

<table>
<thead>
<tr>
<th>Date</th>
<th>Kempsey (000 cusecs)</th>
<th>Height Belmore</th>
<th>Computed Height</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>26/6/56</td>
<td>71</td>
<td>107.0</td>
<td>106.4</td>
<td>+0.6</td>
</tr>
<tr>
<td>5/1/63</td>
<td>76</td>
<td>106.5</td>
<td>106.4</td>
<td>+0.1</td>
</tr>
<tr>
<td>14/1/62</td>
<td>77</td>
<td>106.6</td>
<td>106.5</td>
<td>+0.1</td>
</tr>
<tr>
<td>25/2/56</td>
<td>80</td>
<td>108.0</td>
<td>106.8</td>
<td>+1.2</td>
</tr>
<tr>
<td>10/3/64</td>
<td>94</td>
<td>107.3</td>
<td>107.5</td>
<td>-0.2</td>
</tr>
<tr>
<td>27/3/61</td>
<td>110</td>
<td>108.9</td>
<td>108.3</td>
<td>+0.6</td>
</tr>
<tr>
<td>23/1/59</td>
<td>124</td>
<td>109.0</td>
<td>108.8</td>
<td>+0.2</td>
</tr>
<tr>
<td>11/2/56</td>
<td>127</td>
<td>109.0</td>
<td>109.0</td>
<td>0.0</td>
</tr>
<tr>
<td>10/2/56</td>
<td>128</td>
<td>109.5</td>
<td>109.1</td>
<td>+0.4</td>
</tr>
<tr>
<td>12/1/59</td>
<td>142</td>
<td>109.8</td>
<td>109.6</td>
<td>+0.2</td>
</tr>
<tr>
<td>11/4/62</td>
<td>145</td>
<td>109.2</td>
<td>109.7</td>
<td>-0.5</td>
</tr>
<tr>
<td>10/5/63</td>
<td>300</td>
<td>113.5</td>
<td>113.6</td>
<td>-0.1</td>
</tr>
<tr>
<td>25/8/49</td>
<td>500</td>
<td>116.0</td>
<td>116.3</td>
<td>-0.3</td>
</tr>
</tbody>
</table>
Below which is dry after 1-2 years, evaporates to 101 in approximately 8-10 weeks below which is dry after 1-2 years.

FIG. 25
(b) Drainage of overland flow is to Belmore River, across to Gladstone into Killick Creek around the top of Belmore River. After overbank flow has ceased the water used to recede very slowly as in figure 25 by a number of grossly inadequate drains.

(c) The proposed or constructed work of the M.R.C.C. has involved:

(i) Substantial improvement of Frogmore and Darkwater drains.

(ii) Construction of a large headgates mid-way along Belmore River to prevent flood intrusion to a level of discharge 88,000 cusecs at Kempsey, whence it will be directed through the Belmore floodway by a collapsible dam.

The effect of the work on drainage can be seen by the modified recession curve on Fig. 25.
FIG. 26

GLADSTONE - KINCHELA

- Road
- Drain
- Permanent Water

Contour Interval: 2 feet
GLADSTONE – KINCHELA

FLOOD PEAK DISCHARGE – HEIGHT

![Graph showing flood peak discharge and height comparison before and after flood mitigation. The equation Yc = 57.61X^0.600 is also provided for the observed section.](FIG. 27)
Before Flood Mitigation Works

After Flood Mitigation Works

Approximately 3
years reclamation.

FIG. 29
7. **Gladstone - Kinchela**

This area extends back from the Macleay River to the coastal sand dunes, bounded in the west by Belmore River and in the east Hat Head Road. The centre of this area is occupied by Gladstone swamp, one of the most permanent swamp areas on the floodplain.

(a) Once a discharge of 40,000 cusecs or greater at Kempsey is reached, water backs up Kinchela Creek and Belmore River and at higher levels overbank flow from the main river itself occurs. Heavy rainfall aggravates flooding or may cause local flooding in the area. The relationship between Macleay River discharge and level of flooding in this area can be seen from Fig. 27, the correlation coefficient being .99 for the observed section.

TABLE 10

<table>
<thead>
<tr>
<th>Date</th>
<th>Kempsey (000 cusecs)</th>
<th>Height Gladstone-Kinchela</th>
<th>Computed Height</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/1/63</td>
<td>76</td>
<td>107.0</td>
<td>106.9</td>
<td>+0.1</td>
</tr>
<tr>
<td>27/3/61</td>
<td>110</td>
<td>108.6</td>
<td>108.9</td>
<td>-0.3</td>
</tr>
<tr>
<td>12/11/59</td>
<td>142</td>
<td>110.2</td>
<td>110.3</td>
<td>-0.1</td>
</tr>
<tr>
<td>10/5/63</td>
<td>300</td>
<td>115.0</td>
<td>114.2</td>
<td>+0.8</td>
</tr>
<tr>
<td>25/8/49</td>
<td>500</td>
<td>116.5</td>
<td>117.0</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

(b) Once floodwater has inundated this area it recedes by flow into Kinchela Creek and at high levels across Hat Head Road into Saltwater Inlet. Drainage by these natural courses was relatively slow as can be seen from Fig. 28; land below 102 having little or no means of outflow.

Gladstone Swamp has only dried up twice since the beginning of the 20th century. (Personal communication with A. Anderson).
Road

Drain

Permanent Water

Contour Interval 2 feet

KINCHELA - JERSEYVILLE

FIG. 2.9
KINCHELA JERSEYVILLE
FLOOD PEAK DISCHARGE - HEIGHT

FIG. 30

A Before flood mitigation
B After flood mitigation

\[ Y_c = 57.61X^{0.600} \]
for the observed section
(c) Work by the M.R.C.C. involves:

(i) Improve the Swanpool-Saltwater Inlet channel by a large drain.

(ii) Construction of two new headgated drains, to the Macleay River. The effect of these works can be seen on the modified recession curves - Fig. 28.

8. Kinchela-Jerseyville

This area extends from Hat Head road to the hill country near Jerseyville, bounded on one side by the Macleay River, on the other by the line of sand dunes.

(a) Flooding in this area results initially from flow across Hat Head road but once the river exceeds a discharge of 100,000 cusecs at Kempsey, general overbank flooding occurs. In addition tidal intrusion up Saltwater Inlet causes low level flooding in that area. The relationship between discharge at Kempsey and flood height in this area is shown on Fig 30, the correlation coefficient for the observed section of which is .95.

<table>
<thead>
<tr>
<th>Date</th>
<th>Kempsey (000 cusecs)</th>
<th>Height Kinchela</th>
<th>Computed Height</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>26/6/56</td>
<td>71</td>
<td>105.2</td>
<td>105.2</td>
<td>0.0</td>
</tr>
<tr>
<td>25/2/56</td>
<td>80</td>
<td>107.0</td>
<td>106.2</td>
<td>+0.8</td>
</tr>
<tr>
<td>2/3/56</td>
<td>108</td>
<td>108.2</td>
<td>107.4</td>
<td>+0.8</td>
</tr>
<tr>
<td>12/2/56</td>
<td>127</td>
<td>107.5</td>
<td>108.2</td>
<td>-0.8</td>
</tr>
<tr>
<td>12/11/59</td>
<td>142</td>
<td>107.8</td>
<td>108.8</td>
<td>-1.0</td>
</tr>
<tr>
<td>11/4/62</td>
<td>145</td>
<td>108.2</td>
<td>108.9</td>
<td>-0.7</td>
</tr>
<tr>
<td>10/5/63</td>
<td>300</td>
<td>113.2</td>
<td>112.8</td>
<td>+0.4</td>
</tr>
<tr>
<td>25/8/49</td>
<td>500</td>
<td>114.7</td>
<td>115.6</td>
<td>-0.9</td>
</tr>
</tbody>
</table>
RECESSION KINCHELA-JERSEYVILLE

FIG. 31

Time Days

Elevation M.S.L. +100'

Before Flood Mitigation Works

After Flood Mitigation Works

Land below this seldom dry
FIG. 34

ELEVATION—AREA POLA CREEK

FIG. 35

ELEVATION—AREA REDHILL
ELEVATION - AREA AUSTRAL EDEN

FIG. 36

ELEVATION - AREA BELMORE

FIG. 37
(b) Once floodwater has inundated this area it recedes directly to Saltwater Inlet at higher levels and below this via Marriots and Rafferty's and Ball's and Back Creeks. The rate of drainage is reasonably fast under natural conditions, there being only limited areas where drainage is not available.

(c) Work constructed or planned by the M.R.C.C. involves:

(i) Improve the capacity of Marriots Drain and Back Creek.

(ii) Extend Ball's Creek to a new headgated outlet downstream of the present one.

(iii) Construct a tidegate across Saltwater Inlet.

The impact of these works on water recession can be seen from figure 30.
MACLEAY RIVER

INCIDENCE OF OVERBANK FLOW
AT THREE DISCHARGES

0 1 2 3
Miles

FIG 40
5. Overbank Flow.

i) Introduction

In the previous parts of this section little attention has been given to the processes by which the floodplain is actually inundated. A large part of the damage caused by floods and their significance to land use can be assessed by examining the behaviour of floodwater in the storage areas, the majority of the floodplain. For fuller explanation of flooding however, it is important to describe and attempt to evaluate the movement of water from the surcharged channel. Measurements of flood height and recession already used are much more suitable for systematic treatment than is overbank flow, the data for which is much less easily gathered and used.

The basis of overbank flow is the inability of the river channel to contain a given flow of water. The obvious facts necessary to determine where this will occur are:

(i) The longitudinal profile of the river at various discharges.

(ii) The longitudinal profile of river banks.

The belt of land which suffers from damaging overbank flow is in most parts of the floodplain narrow. After a short distance (100-400 yards) the larger part of the water's velocity has been dissipated and more gentle flow into the available storage area continues.

Before the advent of flood mitigation works, the river could flow through levee breaches at low discharges (40-60,000 cusecs). At higher discharges flow through these breaches was consequently deeper and more ravaging. It is a natural phenomenon for rivers, especially in their floodplain reaches by a process of resorting to shift their meanders downstream. It is especially evident during major floods that sections of banks are eroded and that gaps in the levees are created by turbulent overflow. Additional breaches are produced by small streams such as Christmas Creek, and through farmers more primitive efforts to drain land without sufficient gating.
River Profile Miles from Mouth

26  25  24  23  22  21  20  19  18  17  16  15  14  13  12  11  10  9  8  7  6

Raised levees

MACLEAY RIVER RIGHT BANK
"CONFINED FLOOD"
(88,000 cusecs)
Raised levees
LI-MACLEAY RIVER LEFT BANK - RIVER & BANK PROFILES at 88,000 CUSECS.

MACLEAY RIVER LEFT BANK RIVER & BANK PROFILES at 88,000 CUSECS.
MACLEAY RIVER LEFT BANK
RIVER & BANK PROFILES at 150,000 CUSECS.

Raised levees
River Profile miles from mouth

26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6

RIVER

FIG 41

MACLEAY RIVER LEFT BANK
RIVER & BANK PROFILES at 200,000 CUSECS.

Raised levees.
The policy of the N.R.C.C. with respect to levee construction has been outlined earlier in this report and in the Engineers Report (1964). The location of works has been described for each drainage area. Due to the extreme flood prone nature of this floodplain it has been decided as uneconomic to attempt to protect by levees from floods larger than 88,000 cusecs. (Figures 41-43 show the vast amount of build up required to contain a flood of 200,000.) If levees are built up too high there is the likelihood that compensating changes in the stream bed will largely negate such work. Even if not when these levees were overtopped damage would be exacerbated by the increased gradient from the river. By installing headworks across small creeks and all drains, and by the construction of protected levees of necessary elevation, it appears that the N.R.C.C. have undertaken moderate but realistic steps to combat overbank flow. The changes in the nature of overbank flow is a reduction in depth and hence turbulence at higher discharges together with prevention at discharges of 88,000 cusecs and below.

Evaluation of these changes from economic and hydrological viewpoints is difficult. The impact of these changes will depend on velocity, length of period of flow and channel morphology both in the river and through the bank.

ii) Analysis of Available Data.

(a) River Profiles

The declining elevation of a river at a given discharge in its flow to the sea can be either measured by flood recording or simulated using an hydrological model. Both of these are available for the Macleay River below Kempsey and its two distributaries, Belmore River and Kinchela Creek.

River profiles depend on a complex of channel factors. Once a flood flow has passed through Kempsey it continues declining reaching close to sea level upstream of the mouth. Its actual height will depend on the capacity of the channel and the reduction in actual volume if overbank flow occurs. Raising levees to prevent overbank flow therefore
increases the volume of water which must be accommodated downstream, normally resulting in a raising of the profile.

A model study by E.J. Lesleighter* was specifically designed to determine the effects of levee and headwork construction in the vicinity of Kempsey on the longitudinal profile downstream. The results showed a negligible change, however when all works between Kempsey and Jerseyville have been installed some change must be expected. Engineers of the H.R.C.C. are confident that compensating changes in the river bed may occur as a result of scour. In addition the Belmore floodway will have a similarly compensating effect.

The Macleay River

There are three reliable longitudinal profiles available for the main river at 88,000, 150,000 and 200,000 cusecs. The profile for 88,000 cusecs assumes the Belmore floodway to be in operation to reduce the actual discharge downstream of its confluence with the Macleay which may have been affected by changes in channel capacity. These ad hoc assumptions mean that the profiles for this order flood and above will remain unaltered. This has been tested as correct in parts (see Reports on the Operation of the Belmore Floodway, M.R.C.C. Kempsey) and appear reasonable for the remainder.

The Belmore River

For this river, profiles for the same discharges as the Macleay itself are available. The modification here being that the Belmore floodway in having a capacity of up to 25,000 cusecs will have a profound affect on the gradient of this river. To estimate the reduction in the amount of overbank flow it is necessary to have the profiles for 88,000 cusecs with and without the floodway operating.

The construction of headworks immediately upstream of the floodway means that no overbank flow at all will be experienced upstream of this. The flow will enter the storage through an especially designed floodway channel and only at high discharges will any overbank flow occur at all along the Belmore.

* E.J. Lesleighter (1963) op cit.
BELMORE RIVER RIGHT BANK
RIVER & BANK PROFILE at 80,000 CUSECS.

BELMORE RIVER LEFT BANK
RIVER & BANK PROFILES at 88,000 CUSECS.
BELMORE RIVER RIGHT BANK
RIVER & BANK PROFILES at 150,000 CUSECS.

BELMORE RIVER LEFT BANK
RIVER & BANK PROFILES at 150,000 CUSECS.

(c)

(d) FIG 43
BELMORE RIVER RIGHT BANK
RIVER & BANK PROFILES at 200,000 CUSECS.

BELMORE RIVER LEFT BANK
RIVER & BANK PROFILE at 200,000 CUSECS.
**Kinchela Creek**

This is a similar case to the Belmore in that the river profiles will be affected by the operation of floodways, only minor ones, and headworks. The effect of these floodways on the longitudinal profile has not been estimated and for this report will be ignored. The headworks however will prevent overbank flow further upstream than 4.2 miles from the conjunction of Kinchela Creek with the Macleay River.

(b) **Bank Profiles**

The longitudinal profiles of the river banks demand little description. For each bank of the three streams, the elevation of the bank is known along the relevant sections. Where the levee banks have been raised a new profile is created as can be seen from the accompanying graphs (figs. 41-43)

(iii) **Extent of Overbank Flow from Comparison of River and Bank Profiles.**

Simple measurement of the relationship between the longitudinal bank and river profiles allows some evaluation of the extent of overbank flow and changes that have occurred. The location of the various lengths of overbank flow can be seen from fig. 40. The severity of the flow can be gauged approximately by the depth of flow.

Although only three discharges are available for comparison it is possible to appreciate the overall position. For constructing figures 41-43 the river profiles have been prepared horizontally to provide a clearer picture of the incidence of overbank flow. However once the discharge exceeds 150,000-200,000 cusecs little of the increased flow is represented by an increase in the height. This can be seen clearly at Kempsey by reference to the rating curve which is extremely flat in its upper stages. As is general in most streams at higher discharges the velocity and width of the flow increase much faster than the height; in the case of Kempsey by the river using an additional channel through the town. Such activity will continue further downstream. There will be increased overbank flow at discharges
KINCHELA CREEK RIGHT BANK
CONFINED FLOOD & 88,000 CUSECS.

River Profile Miles from Mouth
6 5 4 3 2 1

RIVER

HEADWORKS

Raised levees

(a)

KINCHELA CREEK LEFT BANK
CONFINED FLOOD & 88,000 CUSECS.

River Profile Miles from Mouth
6 5 4 3 2 1

RIVER

HEADWORKS

Raised levees

(b) FIG 42
KINCHELA CREEK RIGHT BANK
RIVER & BANK PROFILES at 150,000 CUSECS.

River Profile Miles from Mouth

6 5 4 3 2 1

RIVER

HEADWORKS

Raised levees

KINCHELA CREEK LEFT BANK
RIVER & BANK PROFILES at 150,000 CUSECS.

River Profile Miles from Mouth

6 5 4 3 2 1

RIVER

HEADWORKS

Raised levees

FIG 42
KINCHELA CREEK RIGHT BANK
RIVER & BANK PROFILES at 200,000 CUSECS.

River Profile Miles from Mouth
6 5 4 3 2 1

RIVER

HEADWORKS

Raised levees

KINCHELA CREEK LEFT BANK
RIVER & BANK PROFILES at 200,000 CUSECS

River Profile Miles from Mouth
6 5 4 3 2 1

RIVER

HEADWORKS

Raised levees

FIG 42
exceeding 200,000 cusecs but not increasing at the same rate as the length up to this stage. The conditions represented by the map and Tables here are more significant than they might appear at first.

**TABLE 12.**

Macleay River Left Bank Length of Overbank Flow (miles)

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>80,000 cusecs</th>
<th>150,000 cusecs</th>
<th>200,000 cusecs</th>
<th>Pre MRCC</th>
<th>Post MRCC</th>
<th>Pre MRCC</th>
<th>Post MRCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>3.40</td>
<td>3.85</td>
<td>5.12</td>
<td>4.10</td>
<td>4.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>-.50</td>
<td>2.99</td>
<td>2.62</td>
<td>3.08</td>
<td>4.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-3</td>
<td>-.13</td>
<td>-.96</td>
<td>2.50</td>
<td>2.49</td>
<td>1.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>-.77</td>
<td>1.10</td>
<td>-</td>
<td>0.78</td>
<td>0.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-5</td>
<td>-.29</td>
<td>-.45</td>
<td>-</td>
<td>0.72</td>
<td>1.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-6</td>
<td>-.11</td>
<td>-.42</td>
<td>-</td>
<td>0.57</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-7</td>
<td>-</td>
<td>0.58</td>
<td>-</td>
<td>0.93</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>5.20</strong></td>
<td><strong>10.35</strong></td>
<td><strong>10.24</strong></td>
<td><strong>12.67</strong></td>
<td><strong>12.67</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: All overbank flow prevented at 88,000 cusecs.

**TABLE 13.**

Macleay River Right Bank Length of Overbank Flow (miles)

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>80,000 cusecs</th>
<th>150,000 cusecs</th>
<th>200,000 cusecs</th>
<th>Pre MRCC</th>
<th>Pre MRCC</th>
<th>Post MRCC</th>
<th>Post MRCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>1.15</td>
<td>2.65</td>
<td>5.62</td>
<td>4.65</td>
<td>3.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>1.00</td>
<td>2.95</td>
<td>1.73</td>
<td>-.52</td>
<td>2.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-3</td>
<td>-.37</td>
<td>1.45</td>
<td>-.85</td>
<td>2.20</td>
<td>2.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>-.38</td>
<td>-.53</td>
<td>-.10</td>
<td>1.97</td>
<td>1.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-5</td>
<td>-.</td>
<td>-.25</td>
<td>-.</td>
<td>-.52</td>
<td>-.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-6</td>
<td>-.</td>
<td>-.43</td>
<td>-.</td>
<td>-.09</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-7</td>
<td>-.</td>
<td>-.04</td>
<td>-.</td>
<td>-.17</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>2.90</strong></td>
<td><strong>8.30</strong></td>
<td><strong>8.30</strong></td>
<td><strong>10.12</strong></td>
<td><strong>10.12</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FLOOD PROBABILITY CLASSIFICATION OF THE MACLEY RIVER
(Omitting areas of overbank flow)

Before flood mitigation
--- After flood mitigation

Number indicates the recurrence interval (years)

FIG 44
(a) **The Macleay River.** (see Tables 12, 13 and Fig. 41)

The accompanying Tables show the situation clearly. At 88,000 cusecs, some 8.1 miles of overbank flow will be prevented. Similarly at discharges lower than this 100% of overbank flow will be prevented.

At higher discharges the overall reduction in the length of overbank flow has been negligible. As has been mentioned, none of the constructed levees has been very high. The gaps that were filled however were areas where flow was deep and damaging. This however precludes the alteration in the length of flow but on the other hand at these discharges the length of bank affected by deep flow has been reduced significantly. No flow over 5' in depth will occur at 200,000 cusecs or over 4' at 150,000 cusecs.

(b) **Belmore River.** (see Tables 14, 15 and Fig. 42)

The installation of the headworks across Belmore River will have a dramatic effect on the amount of overbank flow at all flood discharges along the Belmore. The most vulnerable section of this stream was in the upper reaches where the banks were very low. Downstream of the headworks little overbank flow occurred in the past and with a minimum of levee construction only a mile of flow will occur along both banks combined at a discharge of 200,000 cusecs.

Overbank flow along the Belmore was never very deep, not exceeding 3' at 200,000 cusecs. All future flow over the banks at a discharge of this or lower will be less than 1' deep.
### TABLE 14

**BELMORE RIVER LEFT BANK LENGTH OF OVERBANK FLOW (miles)**

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>88,000 cusecs Pre MRCC</th>
<th>150,000 cusecs Pre MRCC</th>
<th>200,000 cusecs Pre MRCC</th>
<th>200,000 cusecs Post MRCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>1.49</td>
<td>2.91</td>
<td>-.40</td>
<td>2.92</td>
</tr>
<tr>
<td>1-2</td>
<td>-.82</td>
<td>-.57</td>
<td>-.</td>
<td>-.74</td>
</tr>
<tr>
<td>2-3</td>
<td>-.15</td>
<td>-.92</td>
<td>-.</td>
<td>-.92</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2.46</td>
<td>4.40</td>
<td>-.40</td>
<td>4.58</td>
</tr>
</tbody>
</table>

### TABLE 15

**BELMORE RIVER RIGHT BANK LENGTH OF OVERBANK FLOW (miles)**

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>88,000 cusecs Pre MRCC</th>
<th>150,000 cusecs Pre MRCC</th>
<th>200,000 cusecs Pre MRCC</th>
<th>200,000 cusecs Post MRCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>1.89</td>
<td>1.92</td>
<td>-.</td>
<td>3.28</td>
</tr>
<tr>
<td>1-2</td>
<td>1.21</td>
<td>-.20</td>
<td>-.</td>
<td>-.67</td>
</tr>
<tr>
<td>2-3</td>
<td>-.</td>
<td>1.05</td>
<td>-.</td>
<td>1.05</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3.10</td>
<td>3.17</td>
<td>-.</td>
<td>5.0</td>
</tr>
</tbody>
</table>
TABLE 16
KINCHELA CREEK LEFT BANK LENGTH OF OVERBANK FLOW (miles)

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>88,000 cusecs</th>
<th>150,000 cusecs</th>
<th>200,000 cusecs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre MRCC</td>
<td>Pre MRCC</td>
<td>Pre MRCC</td>
</tr>
<tr>
<td>0-1</td>
<td>2.12</td>
<td>3.76</td>
<td>3.44</td>
</tr>
<tr>
<td>1-2</td>
<td>-.07</td>
<td>-.43</td>
<td>-.1-</td>
</tr>
<tr>
<td>2-3</td>
<td>-.04</td>
<td>-.05</td>
<td>-.1-</td>
</tr>
<tr>
<td>3+</td>
<td>-.07</td>
<td>-.10</td>
<td>-.1-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2.30</td>
<td>4.29</td>
<td>3.44</td>
</tr>
</tbody>
</table>

TABLE 17
KINCHELA CREEK RIGHT BANK LENGTH OF OVERBANK FLOW (miles)

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>88,000 cusecs</th>
<th>150,000 cusecs</th>
<th>200,000 cusecs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre MRCC</td>
<td>Pre MRCC</td>
<td>Pre MRCC</td>
</tr>
<tr>
<td>0-1</td>
<td>-.60</td>
<td>1.23</td>
<td>-.36</td>
</tr>
<tr>
<td>1-2</td>
<td>-.10</td>
<td>-.15</td>
<td>-.18</td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.70</td>
<td>1.38</td>
<td>-.36</td>
</tr>
</tbody>
</table>

Kinchela Creek. (see Tables 16, 17 and Fig 43)

The situation along Kinchela Creek is similar to the Belmore in that the headworks will restrict all overbank flow from 4.2 miles upstream of its confluence with the Macleay. However the banks of the Kinchela are much more flood prone, especially the left bank, than those of the Belmore. Although the reduction in overbank flow at discharges higher than 88,000 cusecs has not been as spectacular, no flow of greater than 1' will occur up to a discharge of 200,000 cusecs.
The aggregate for the three streams is presented in Table 18. The total reduction in overbank flow is 16.2 miles. When it is remembered that the river profile rises steeply through to 150,000 cusecs, the large reduction at 88,000 cusecs, is in itself a partial justification of the selection of this as the maximum "containable" flood, i.e. if a larger flood was selected, a vastly increased amount of levee construction would have been necessary.

This brief treatment of overbank flow has omitted a small amount of flow over the banks of the lower reaches of Christmas Creek. By the construction of headworks however this will be prevented.
SUGGESTIONS FOR ECONOMIC EVALUATION

The damage caused by turbulent flow crossing the levees will depend on the velocity of the water, its silt load, depth and duration of flow. The area of land which will suffer from the severe effects of overbank flow is not great but due to its intensive utilization has the highest damage potential. To determine the area where velocity should be taken into account, as additional to the depth and time factors, reference should be made to the contour maps of the relevant areas. To determine the area of land not affected by any other form of flooding except non-turbulent overbank flow it would be possible to trace the flow of water into the storage and calculate the area along this flow line above the known maximum water level of the particular flood.

It is important that some attempt be made to measure the damage caused by overbank flow so that future floodway plans (e.g. the Frederickton floodway) may be economically justified or otherwise. This will be attempted in Report 2.
SECTION III.

CONCLUSIONS.

1. CLASSIFICATION OF THE FLOODPLAIN ACCORDING TO FLOOD FREQUENCY.

In the previous Section material was presented that enables the construction of a map showing the probability of flooding of any area of the floodplain. The relevant data is:

(i) The frequency curve for flood discharges at Kempsey.
(ii) The relationship between flood peak discharge and flood height in each of the drainage areas.
(iii) The contour maps.

In addition to determine the area affected, the area-height curves will be used.

The fact that floodwater finds a relatively horizontal level even if overland is occurring and the peaks may be reached at different times, allows a height determined from the discharge-height curves to be transferred to a map location. By use of contour maps the location becomes a continuous contour line. The discharge which correlates with a given recurrence interval can be read from the probability curve.

Although there would not be a great deal of labour involved in abstracting this information manually, for purposes of future use it was decided to use the University's IBM 1620 computer. For this task the relevant curves and equations were read in together with the arbitrary recurrence intervals used. By processes of solving equations, interpolation and reverse interpolation, the required height and area information could be obtained automatically. The situation existing before flood mitigation and that which will exist with the works in place could be both analysed.
The map (figure 44) was prepared from the resultant height figures. Interpolation between the contours was necessary in most cases and a minor source of error was produced by the treatment of drainage areas as discreet units when in fact the floodplain for flood height purposes is a dynamic whole. The border discrepancies were very slight;

(a) because the lower values were distinct for each area
(b) at the higher levels the gradients at a 2' contour interval are relatively steep and the minor height differences at this boundary point produced negligible planimetric differences.

The relatively high gradient of the floodplain along its rim and across the levees made it impossible to plot all the computed categories which are presented in Table 19. The outstanding feature of the map and the Table is the very large proportion of the floodplain included within the most frequent flood classes. For example 76,000 acres were flooded by a flood of recurrence interval 3 years. At a recurrence interval of 20 years the area is increased to only 89,000 acres.

Due to the considerations that lead to the construction of the discharge-height curves, the frequency of flooding by floods of discharge greater than 160,000 cusecs will remain unaltered. This corresponds to a flood of recurrence interval 4.1 years.

TABLE 19

<table>
<thead>
<tr>
<th>R.I.</th>
<th>Before MRCC</th>
<th>After MRCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>89355</td>
<td>NC (no change)</td>
</tr>
<tr>
<td>10</td>
<td>87419</td>
<td>NC</td>
</tr>
<tr>
<td>5</td>
<td>83515</td>
<td>NC</td>
</tr>
<tr>
<td>4</td>
<td>81608</td>
<td>78609</td>
</tr>
<tr>
<td>3</td>
<td>76879</td>
<td>65369</td>
</tr>
<tr>
<td>2</td>
<td>66695</td>
<td>11865</td>
</tr>
</tbody>
</table>
DRAINAGE CLASSIFICATION OF THE MACLEAY RIVER FLOODPLAIN

Number indicates the drainage time in days from a flood of 500,000 cusecs

Before flood mitigation
--- After flood mitigation

FIG. 45
It is very significant however that by preventing floods of lower order large changes are made in the flood status of large areas of the floodplain. For example, the change of a recurrence interval of 2 to 3 years amounts to a saving of 17 floods in 100 years, a 30% reduction in the number of floods affecting some 54,000 acres of the floodplain.

The operation of the Delmore floodway produces a reduced benefit in this area which must act as a flood storage for low order floods for the remainder of the floodplain.

The method used in this classification will be used in Report 2. In conjunction with the overbank flow analysis in Section II it could provide the necessary basis for rational expansion of agriculture on the floodplain. Using the "games theory" approach farmers could readily determine the practicable limits to the growth of crops of particular damage potential and productivity.

2. CLASSIFICATION OF THE FLOODPLAIN ACCORDING TO DRAINAGE STATUS.

In part 1 of this Section an attempt was made to classify the floodplain by the probability of flooding. A similar method can be used to classify the floodplain according to rates of drainage, before and after flood mitigation works. In this analysis the relevant data used from Section II was:-

i) The height-discharge curves
ii) The recession curves
iii) The contour map
iv) The area-height curves.

For this classification the aim will be to show the areas of the floodplain which drain in certain periods (see Fig. 45) In the graphical-map "model" above it is necessary to begin calculations with
92.

a flood event. It would seem most useful to select a large flood so that all parts of the floodplain susceptible to flooding will be "flooded". In this case a flood of 500,000 cusecs was used in the calculations. The times taken for the lower areas to drain therefore are approaching a maximum and at lower peaks the times of inundation at all levels will be reduced by the extra time involved in the removal of water at high levels. This time is relatively short.

The material produced in Figure 45 was produced by reading in the peak discharge, the height-discharge curves, the recession and area-height curves; by solving the initial height equation and by interpolation, automatically calculating the appropriate areas for the conditions of drainage before and after flood mitigation (Table 20).

**TABLE 20**

<table>
<thead>
<tr>
<th>Areas Taking Longer to Drain Than the Specified Times.</th>
<th>Pre</th>
<th>Post</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>65999</td>
<td>50597</td>
<td>15402</td>
</tr>
<tr>
<td>10</td>
<td>47237</td>
<td>14432</td>
<td>32805</td>
</tr>
<tr>
<td>15</td>
<td>31145</td>
<td>9622</td>
<td>21523</td>
</tr>
<tr>
<td>20</td>
<td>25889</td>
<td>9163</td>
<td>16726</td>
</tr>
<tr>
<td>25</td>
<td>24146</td>
<td>8705</td>
<td>15441</td>
</tr>
<tr>
<td>30</td>
<td>22580</td>
<td>8246</td>
<td>14334</td>
</tr>
<tr>
<td>35</td>
<td>21592</td>
<td>7739</td>
<td>13853</td>
</tr>
<tr>
<td>40</td>
<td>20578</td>
<td>7280</td>
<td>13298</td>
</tr>
<tr>
<td>45</td>
<td>19773</td>
<td>6819</td>
<td>12954</td>
</tr>
<tr>
<td>50</td>
<td>18891</td>
<td>6390</td>
<td>12501</td>
</tr>
</tbody>
</table>

The Table and map of the altered drainage conditions show a much more marked alteration than was the result of the probability study. Drains were initially installed to remove the bulk of floodwater within 6-10 days, this being the critical period for pasture survival. The Table shows that after 10 days following a maximum flood water will remain on only 14,000 acres of the floodplain.
Much of this area previously took up to 50 days to drain or evaporate in the past. At the lower levels in each basin the efficiency of the drains is impeded by the low gradients operating. In the future when the farmers have their own smaller drains in an integrated network, the areas inundated for longer than 15-20 days could be drained. This appears to be a highly necessary step if reclamation of the lower swamp areas is to be complete.

Combined with part 1 of this Section and the analysis of areas affected by overbank flow, a reasonably accurate evaluation of the flood status of the floodplain is possible. It appears certain that the benefit of drainage is going to have a profound effect on the utilization of previously under-developed land. Other factors such as deposition of debris and overland flow would make a more complete understanding possible. However the time it would take to analyse these does not appear justified in the light of the vast amount of more basic analysis of the above material which is of prime importance.

3. THE USEFULNESS OF THE HYDROLOGICAL DATA FOR ECONOMIC ANALYSIS.

In Section II an attempt was made to systematically analyse the conditions of flooding on the floodplain and the changes in these conditions as a result of flood mitigation work by the M.R.C.C. Apart from the treatment of overbank flow which must be viewed separately, this information can be very readily synthesized in the form of a "model". This model was given a preliminary application to the problems in the first two parts of this Section.

For the purposes of assessing the benefits of flood mitigation the two categories which are most important are:

i) The damage reduction
ii) The secondary benefits which may come from ameliorated flood conditions.
The model has applications to both of these problems.

(a) **Flood Damage.**

In Section I an assumption was made that flood mitigation works are unlikely to benefit aspects other than production and transport in rural areas. This is significant enough but it simplifies the analysis to that of studying pastures, crops, livestock activities and transport. The amount of loss sustained by farmers on the floodplain depends largely on the components of the area affected, the duration of inundation and the height of water in any given location. To produce a dollars and cents evaluation then some of the following information should be included with the model:

i) The tolerance period of various pasture types
ii) The costs of shifting, hand-feeding or agisting stock
iii) The possible loss of lactation or sale price of stock
iv) The tolerance range of maize at various stages of growth
v) The reduced harvest from maize as a result of various levels of inundation.

These can be associated with the known distributions of activities, probabilities of flooding and the remainder of the hydrological model to produce results of the losses incurred and hence the reduction in losses as a result of flood mitigation works.

The capacity of the computer to repeat arduous mechanical tasks over a short space of time should allow the construction of stage-damage curves and hence the annual average benefit.

(b) **Secondary Benefits.**

These benefits should be most significant in justifying expensive flood mitigation measures. The boundaries of land use zones on the floodplain are known and due to the close correlation between these boundaries and elevation, they can be tested with respect to
conditions of flooding. A long period adjustment has produced these zones and if the conditions of flooding at a boundary can be shown now to exist at a lower elevation then some indication of the likely economic changes in land use could be determined. If these were supported by knowledge of changes which have already occurred and the increased return associated, some measure of the likely secondary benefits could be produced.
<table>
<thead>
<tr>
<th>No.</th>
<th>Authors</th>
<th>Title</th>
<th>Organization</th>
<th>Publication Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Houghton D.S.</td>
<td>The ability of country towns to sustain service industries for the N.S.W. Department of Decentralisation.</td>
<td>December 1966.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Fielding G.</td>
<td>Present levels of industrial development in country towns for the N.S.W. Department of Decentralisation.</td>
<td>January 1967.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Rodgers B.</td>
<td>Student origins and university catchments in N.S.W. (in print).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Davies T., Lee K., McDonald G. &amp; Thorpe E.</td>
<td>Reports on various economic aspects of the Macleay Floodplain for the Macleay River County Council (in print).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>