THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

REPORT No. 51

Research in Soil and Water Conservation Engineering

Progress Report No. 1, 1957–1960

by

John R. Burton

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The University of New South Wales
WATER RESEARCH LABORATORY

Report No.51.

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING - PROGRESS REPORT NO.1. 1957-1960

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January 1962

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PREFACE

Within the School of Civil Engineering of the University of New South Wales several research projects, which together come under the heading of Conservation Engineering Research, have been in progress since 1957.

These projects are financed by the Water Research Foundation of Australia Limited, the Rural Credits Development Fund of the Commonwealth Bank, and the University of New South Wales.

This Report discusses the conservation research programme and outlines progress for the period January 1957 to June 1960. Detailed progress reports for the major topics of the programme are appended. This material was first issued as an internal report in June 1960.

Since 1959 conservation research activities have been centred at the Water Research Laboratory, Manly Vale, N.S.W. The research programme is under the direction of Mr. J.R.Burton of the Laboratory Research staff.

H.R. Vallentine
Assoc. Professor of Civil Engineering,
Officer in Charge of the Water Research Laboratory.

3rd January 1962

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING - PROGRESS REPORT NO.1. 1957-1960

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1. INTRODUCTION

Since 1957 the School of Civil Engineering of the University of New South Wales has fostered research into many problems of agricultural water management. This research, which embraces aspects of hydrology, hydraulics and soil mechanics, is classified, following American practice, under the general heading of conservation engineering.

Research activities in this field began in 1956, when Mr. J.Burton undertook an investigation of the engineering features of the "Water Harvesting" and "Keyline" systems of water management. Although this work was not financed by the Water Research Foundation, the results were published by that Foundation in 1957 as Research Bulletin No.1. In November 1956 the Foundation made two financial grants to the University, under the topics of "Improved Methods for the Design and Construction of Farm Dams" and "The Use of Plastic Membranes for Sealing Farm Ponds". These topics, for which the grants have been renewed annually, have formed the basis of the present research programme. A subsequent grant from the Rural Credits Development Fund of the Commonwealth Bank has permitted an extension of the seepage control investigation beyond the field of plastic membranes. It should be noted, however, that whilst these grants have more or less defined the research programme, the University, through the provision of staff and equipment, is the major financial contributor to the conservation research activities of the Civil School.

The research programme covers the following broad topics:

a. Hydrological and economic design of small storage reservoirs.

b. Structural design and construction of low earth dams.

c. Seepage control in farm dams.

d. Miscellaneous projects concerned with specialised local water problems.

This report discusses the research programme and outlines its financial background. Detailed progress reports for the major topics are included as appendices.

2. THE CONSERVATION RESEARCH PROGRAMME

The conservation research programme is concerned primarily with the economic design of small storage reservoirs and the design and construction of small earth dams.

The need for research under these topics has become increasingly apparent as Australian landholders have begun to make extensive use of stored water for supplemental irrigation. By contrast with the almost 1,000 cubic yard stock tank of ten to fifteen years ago, farm dams of all sizes up to and exceeding 100 million gallons are now being built in large numbers.

Engineering science has developed to a stage where earth dams can be designed and built with safety to almost any height. For farm dams, however, detailed individual design is not justified; for example, the cost of a simple hydrologic and structural design for a 10 million gallon dams costing about £900 to construct, would be of the order of £100. In consequence the great majority of farm dams are built without any attempt at engineering design; and in further consequence a considerable proportion of those built are failures, either directly, as a result of collapse or destruction of the embankment, or indirectly as a result of inadequate capacity, unsuitable catchment or excessive seepage and evaporation losses. Whilst it is not feasible to undertake a detailed individual design for each dam built, the aggregate value of these farm storages to the rural economy is such that an overall investigation, aimed at developing generalised design data which may be applied to individual dams at low cost, can well be justified. It might be noted that a parallel state of affairs exists in the United States, where Universities and the Soil Conservation Service are actively engaged in the preparation of such design data. The purpose of this conservation research programme is to provide similar information for Australian conditions, which in many respects differ from those experienced in the U.S.A.

The following topics are currently under investigation.

2.1 Hydrologic and Economic Design of Small Reservoirs

A detailed progress report for topics under this heading is included with this paper as Appendix E. These topics are as follows:

a. Yield of Small Rural Catchments.

Very few runoff data are available from small rural catchments. Procedures for the estimation of catchment yield from past rainfall records are therefore under investigation. Runoff records from three experimental catchments in N.S.W. have been analysed and data from Soil Conservation Service catchments and plots have been studied. Arrangements are being made for the analysis of records from other experimental catchments in Australia, of which only 3 or 4 appear to be suitable. Summarised records from many experimental catchments in the United States are available.

A detailed study has been made for a proposed runoff estimation method which involves water balance computations based on available rainfall and climatic records. In particular, detailed water budgets have been prepared for Badgery's Creek and Hunt's Creek in N.S.W. It appears that this method may be suitable for yield estimation on larger watersheds with permanent watercourses. Present indications are, however, that the method is inaccurate for the typical ephemeral farm dam catchment.

A new approach, based upon a rainfall-runoff relationship recently developed by the United States Soil Conservation Service, is now under investigation.

b. Data Collection

To overcome the serious lack of hydrological data from small rural areas a scheme has been put in operation whereby Junior Farmers throughout N.S.W. are collecting approximate information about rainfall, runoff and reservoir losses. This information is being supplemented by a network of small experimental catchments which provide precise runoff data. The scheme is known as HYDRA (Hydrological Data from Rural Areas). Detailed information about this scheme is included with this paper as Appendix F.

The present network of HYDRA stations (May 1960) comprises 6 Class I stations (Junior Farmer operated, approximate information) 3 Class II stations (dams equipped with water level recorders) and 7 class III stations (experimental catchments).

c. Determination of Storage Capacity

Some data relating to water use and evapo-seepage losses have been accumulated and methods for determining the irrigation needs of crops have been studied. Procedures for estimating storage capacity have been investigated and long term mass curve and storage behaviour studies have been made for Badgery's Creek and Hunt's Creek in New South Wales. It is hoped that it may be possible to prepare generalised maps of New South Wales showing required storage capacities for different purposes.

d. Economic Design of Storages

Various aspects of the economic design of small storages are under investigation by J.R.Burton in connection with a Master of Engineering Thesis. This includes considerations of the value of stored water, relationships between shape, depth, storage excavation ratio etc., and a linear programming technique for the optimum design of multi-storage systems of the Water Harvesting type.

e. Devices for Measuring Runoff

During 1959 Theo. ten Brummelaar, in preparation for an undergraduate thesis in the School of Civil Engineering, investigated methods of measuring runoff and developed a model of an improved measuring weir. Prototype studies of the weir are to be made.

2.2 Structural Design and Construction of Low Earth Dams.

A detailed progress report for topics under this heading is included with this paper as Appendix G. These topics are as follows.

a. Current Practices

A body of information has been accumulated regarding current practices in farm dam design and construction. This includes details relating to state legislation controlling small dam construction; practices of various Government licensing and construction authorities; and methods employed by earthmoving contractors and farmer-builders.

It is proposed to conduct a questionnaire survey of landholders in order to collect further information about sizes and types of dams, methods of construction, costs of construction and operation, and performance of dams. A draft questionnaire is included with Appendix G.

b. Design and Construction Procedures

The investigation of current practices has revealed that whereas adequate design procedures for small earth dams are available, it is generally neither economical nor feasible to carry out the detailed soil testing and construction control testing necessary to the success of these procedures. A similar state of affairs exists in the United States. In this regard Dr. Terzaghi has written (Trans.Am.Soc.C.E. Vol.CT.1953)

"Thorough compaction is generally considered necessary for earth dams of any height.... However, the enforcement of rigorous water-content controlon small projects in remote districts may be impracticable. If economic or other considerations preclude rigorous water content control, the designer is compelled to rely on semi-empirical rules. Such rules can be established only on the basis of the performance record of earth dams which were made of soils with a water-content far above or far below the optimum and by correlating the findings with the index properties of the construction materials."

This part of the conservation research programme is therefore concerned with the determination of the index properties of soils used in farm dam construction, with the measurement of compaction, settlement and shear strength during and after construction, and with observations of embankment performance. This is a long term project which may continue for some years.

To date the following work has been carried out -

i. A study of the index properties of New South Wales soils is in progress. 230 individual tests have so far been conducted on 90 representative samples.

ii. Failures of small earth dams have been investigated whereever possible; 10 failures have been studied to date.

iii. A co-operative construction study with the Soil Conservation Service of N.S.W. has commenced. 10 small dams are to be constructed at Bulga in the Hunter Valley, using a variety of construction methods, and their performance closely observed. 4 dams were constructed and detailed testing carried out. These dams were all destroyed shortly after completion, and the project has been postponed until the spring of 1960.

Tentative arrangements have been made with certain earth-moving equipment distributors and contractors for the carrying-out of experimental embankment construction in various parts of N.S.W. These experiments have not been commenced because of lack of staff.

c. Solodic Soil Investigation.

In conjunction with the Soil Conservation Service, a study is being made of the engineering properties of a group of soils which causes considerable trouble in the Hunter Valley and the Central West of N.S.W. These soils are highly dispersive, and dams constructed from them frequently fail by tunnelling. To date, index and compaction tests have been carried out on 40 samples provided by the Service.

d. Farm Dam Manual

The study of current practices referred to in item a. above has indicated that a great deal can be done to improve dam construction techniques by simply educating dam-builders in the basic principles of soil mechanics and dam building. The author has been appalled at the extraordinary misconceptions held quite generally by farmers and earthmoving contractors in regard to elementary hydrology, hydraulics and soil mechanics.

At the present time there is no publication dealing with these matters with the exception of the Britstand handbook "Tanksinking", which, whilst in gives excellent information on earthmoving practices, is totally inadequate in regard to design principles. It is therefore proposed to write a manual of farm dam building and design at some time in the future.

3. Sealing Farm Dams with Plastic Membranes

A progress report under this heading is included with this paper as Appendix H.

The greater part of the research undertaken in this field has been concerned with the application of polythene film, which in 1957 appeared to be the only film available in Australia which possessed properties suitable for dam sealing. An improved vinyl has recently been developed and some tests have been conducted on this material.

The mechanical and weathering properties of polythene have been studied. Methods of testing have been investigated and some equipment manufactured. Tension, tear strenth and bursting strength tests have been conducted on both fresh and weathered samples, limited samples having a history of up to two years outdoor exposure being available.

A device has been built to determine the resistance of films to mechanical damage resulting from theplacing of cover material. Tests have been conducted on various grades of polythene and outdoor vinyl.

Specimens of welded and adhesive-sealed joints have been obtained and tested. Permeability tests have been conducted on unsealed specimens.

Field liner installations in Victoria have been observed and the performance of a liner in New South Wales was closely studied. Movie film records of lining operations have been made.

The problems of wind damage and its prevention have been considered. Some preliminary research has been conducted to develop methods of wind damage control.

2.4 Sealing Farm Dams - Other Methods

A progress report for topics under this heading is included with this paper as Appendix J. These topics are as follows.

a. Bentonite

Laboratory studies have been undertaken to determine the properties of bentonite and the suitability of various soil types for sealing with this material. A field experiment has been conducted at Alstonville in New South Wales, where a dam was effectively sealed with a mixed bentonite blanket. Soil tests have been carried out in conjunction with a number of other proposed field experiments.

b. Sodium Tri-polyphosphate.

Laboratory studies have been undertaken. A field experiment has been undertaken at Nashdale, New South Wales, where a small tank has been sealed. Soil tests have been carried out in connection with other proposed field trials.

c. Bitumens.

Some consideration has been given to the use of bitumens and samples have been obtained for laboratory experiments.

d. Explosives

The use of explosives in conjunction with bentonites or other fine materials is under consideration. Discussions have been held with explosive manufacturers and two sites for field tests have been selected.

2.5 Miscellaneous Projects

Several miscellaneous projects, each concerned with a particular local storage problem, have been undertaken. These projects each embrace some aspect of the overall research programme, and in most cases they have been undertaken in order to explore this aspect and to provide field experience for members of the conservation team.

The principle ones are as follows:

Futter Park, Harden. (The King's School), design of a complex of small storages for irrigation purposes.

Bogan Gate: (Mr. W. Davies), Design and construction of a large ring tank.

Shooter's Hill: (Mr. R.Cotton), Piping through dam foundations.

Wiseman's Ferry: (Mr. P.Hoskins), Construction of off-stream storage in swamp area.

Bribbaree: (Mr. W. Macullum), Tunnelling failures.

Baulkham Hills: (Baulkham Hills Shire): Damage to roads from farm dam seepage.

Forestry Commission of New South Wales: Sepage in fire-fighting storages.

2.6 Future Development of Conservation Research Programme.

Most of the projects currently under investigation are essentially long term in nature. The research programme must therefore continue along the lines already established, and extension into other major topics cannot be expected within the next two years.

Some expansion can, however, be anticipated in the dam sealing field. During 1960 it is proposed to carry out a detailed investigation of polyvinyl chloride film, and to study the possible applications of bitumens, explosives and trace stabilising chemicals other than sodium tri-polyphosphate.

There are many other topics within the conservation field which need to be investigated, most urgent of them include:

a. Hydrological design of farm dam spillway

b. Hydraulic design and construction of spillways and catch drains.

c. Treatment of small catchments to increase runoff.

d. Effects of stabilising trace chemicals on compaction characteristics of soils for small dam building.

It is hoped that when funds and research staff become available it will be possible to extend the research programme to cover these topics, in the other of priority listed above.

3. ADVISORY SERVICE

Apart from straight out research activities, the Conservation group has received many requests for advice from persons faced with problems similar to those encountered in the research programme. These enquiries come either direct to the Civil Engineering School or through the office of the Executive Director of the Water Research Foundation. They are made by private individuals, commercial undertakings, schools, institutions and Government departments. It has been the practice to provide assistance whenever possible, on the grounds that many of the problems presented shed light on current research problems and that this form of service is good public relations for the University and the Water Research Foundation.

The standard of assistance provided ranges from a brief letter, as in the case of many private individuals, to field visits, design or soil testing, as in the case of certain schools and Government departments. In those cases where detailed technical assistance has been provided reciprocal advantages, such as exchanges of data, have been obtained, several of these enquiries have grown into special research projects.

During the period 1957 - 1960 approximately 80 requests for assistance have been dealt with. Details of this service are given in the attached Appendix C.

4. PUBLIC RELATIONS

Since 1957 Mr. Burton has been requested on a number of occasions to give talks, radio interviews etc., in connection with his research activities. In every such case the opportunity has been taken to publicise the work of the University and of the Water Research Foundation in the Conservative Engineering field.

A total of 22 addresses, radio talks and television interviews has been given since 1957. Details of these public relations activities are given in Appendix B of this report.

5. CO-OPERATION WITH OUTSIDE ORGANISATIONS

During the period under review many useful contacts have been made with outside research organisations and Government departments. These organisations have included many Divisions of C.S.I.R.O., Universities, Departments of Agriculture, Soil Conservations authorities, etc. In all cases exchanges of data and other research information have been made to a mutual advantage. In several instances the liaison has developed to the stage where co-operative research projects are being carried out. Notable in this regard is the Soil Conservation Service of New South Wales, with which the University is now co-operating in three joint research projects. Extremely valuable co-operation is also maintained with the Farm Water Supplies Branch of the Water Conservation and Irrigation Commission of New South Wales, which has supplied hydrologic data, survey information and technical assistance, and whose officers are always ready to discuss farm dam research from the practical viewpoint. Special mention should also be made of the assistance provided by the

New South Wales Department of Agriculture, the New South Wales Forestry Commission, the Veterinary Science School of the University of Sydney, and the Agricultural Engineering School of the University of Melbourne.

Details of these co-operative inter-departmental activities are given in Appendix D of this report.

Several commercial enterprises have also co-operated willingly in the conservation research programmes. Notable amongst these are I.C.I.A.N.Z. Ltd., Albright and Wilson Ltd., and the Standard Chemical Company, who have freely provided materials, technical data and the assistance of technical and research staff. Details of these firms are also given in Appendix D.

It should be pointed out that apart from the direct research benefits to be gained from these contacts, a considerable fund of goodwill for the University and the Water Research Foundation has been built up amongst scientists, engineers and commercial people who are in a position to influence a large section of the population.

STAFF

The conservation research programme is under the immediate direction of Mr. J. Burton, who is a lecturer in Civil Engineering at the University of New South Wales.

From December 1956 to November 1959 all conservation research activities were undertaken by Mr. Burton, on a part-time basis, with occasional field and laboratory assistance provided, over the latter half of this period by Mr. J. Clark, laboratory attendant. In the summer of 1959-60 three engineering students were employed on a temporary basis, and in February 1960 a Research Fellow, Mr. T. Fietz, was appointed. At the present time he is the only full-time employee engaged on conservation research, and the conditions of his employment are such that he can only be used on Water Research Foundation topics. The present staff is not adequate to cope with the current research programme.

Except for a period of about nine months in 1957, when his salary was met from Water Research Foundation grants, Mr. Burton has been paid by the University. Since 1957 he has carried a reduced lecturing load; this has varied between 3 and 14 hours per week and is currently 13 hours per week. He is responsible for undergraduate courses in irrigation engineering and construction methods and the graduate course "Irrigation and Drainage", which is the only graduate course in this field offered in Australia. He also takes portions of the graduate courses in hydrology and hydraulic design. Other activities outside the conservation research programme have included responsibility for the purchase and maintenance of hydrologic instruments and the operation of all experimental catchments run by the University. During 1958-59 he filmed, edited and produced the 16mm. motion film "Saving A City from Flood", which in itself was a major undertaking. He has also arranged various displays for fund raising purposes for the Water Research Foundation at the Sheep Show etc. For these reasons the amount of time he has been able to devote to conservation research has been limited.

On 2nd February 1960, Mr. T.R.Fietz was appointed as Research Fellow to work in the conservation field. He is concerned with research in the use of plastic membranes and the construction of small earth dams, his salary being met from the Water Research Foundation grants which cover these topics.

Mr. J.Clark, laboratory attendant, serves principally as field assistant. During the past two years he has worked tirelessly and enthusiastically, and the progress achieved has been in no small way due to his efforts. His salary is paid by the University, and at present he is nominally allocated to the conservation group for half his time.

In April 1960 Mr. G.Leach, Laboratory Assistant, was temporarily allocated to the conservation group on a half time basis. His salary is met by the University.

Between November 1959 and February 1960 three engineering students were temporarily appointed to assist in field and laboratory. The salaries of these students were met from Research Grants.

Of the four persons currently engaged in this research programme only one, Mr. Fietz, is a full-time appointment. The staff allocated at present is inadequate and a serious bottleneck exists in the laboratory where routine testing would alleviate this situation.

Details of salary commitments are given in Appendix A.

7. FINANCE

The conservation research programme is financed partly by the University, principally through the payment of salaries of research workers, and partly by grants from the Water Research Foundation of Australia and the Rural Credits Development Fund of the Commonwealth Bank.

There are three annual grants, as follows:

i. Water Research Foundation: "Improved Methods for the Design and Construction of Small Dams": annual grant of £1,000 total received to date £3,000.

ii. Water Research Foundation: "Use of Plastic Membranes for Sealing Farm Dams": annual grant of £1,000 total received to date £3,000.

iii. Rural Credits Fund: "Seepage Control in Farm Dams": annual grant of £1,000 total received to date £2,000.

These grants have been used for the purchase of equipment, for travelling expenses and for the payment of salaries. Detailed statements of expenditure are included in Appendix A to this report.

It is estimated that the University meets approximately 55 per cent of the total cost of the research described in this report, the Water Research Foundation 30 per cent, and the Rural Credits Fund 15 per cent. Further details are included in Appendix A.

8. PUBLICATIONS

The following publications have been initiated within the Conservation Engineering group.

A. Research Bulletin:

1. Burton, J.R. "Engineering Aspects of Water Harvesting and the Keyline Plan;" Research Bulletin No.1. Water Research Foundation of Australia, June 1957

2. Above reprinted with some amendments as Civil Engineering Publication No.7. University of New South Wales, October 1958.

B. Semi-Technical Articles

1. Burton, J.R. "Turkey's Nest Tanks" - The Living Earth, V.2 No.4. 1957

2. Above reprinted as Civil Engineering Publication No.6. University of New South Wales, Sept. 1957.

3. Burton, J.R. "The Australian Heartland - A Garden?". The Living Earth, V.2.No.4.1957

4. Burton, J.R. "Sealing Farm Dams with Bentonite:" Power Farming V.69 No.1 Jan. 1960.

5. Burton, J.R. "Sealing Farm Dams with Polyphosphate" - Power Farming V.69 No.2. Feb. 1960.

6. Burton, J.R. "Sealing Farm Dams with Polythene Film:" Power Farming V.69 No.3. March 1960.

7. Burton, J.R. "The Water Research Foundation of Australia": Wool Technology and Sheep Breeding, Vol.5 No.1.1958

8. Burton, J.R. "Water for the Inland - A review of the Bradfield Plan": Accepted for publication as Report No.2. by the Water Research Foundation of Australia.

C. Undergraduate Theses.

1. Quah, C.H. - "Hydrologic Design of Farm Ponds" (Literature Survey) School of Civil Engineering, University of New South Wales, 1957.

2. Ten Brummelaar, Theo. - "A Study of Devices for Measuring Runoff from Small Rural Areas". School of Civil Engineering, University of New South Wales, 1960

D. Newspaper Articles

1. "Water Research and Australia's Future" - Muster 20 May 1958

2. "Big Water Problem" - Daily Mirror Supplement, 30 Jan. 1959.

9. CONCLUSION

Since 1957 the School of Civil Engineering of the University of New South Wales has engaged in research in Conservation Engineering. At the present time the annual expenditure on this research is of the order of £6,000.

The research programme covers three major topics; the hydrologic and economic design of small storage reservoirs, the structural design and construction of small earth dams, and the control of seepage from farm dams. Much of this work is of a long-term nature, involving the collection of hydrologic data or field observations of the performance of dams and storages. Much useful information has already been obtained, however, notably in the field of dam seepage control.

A feature of the research programme has been the liaison which has been established between the University and other research bodies from all parts of Australia, many of whom are now co-operating in joint research projects.

A valuable by-product has been the publicity afforded the

University and the Water Research Foundation in the course of this research. Through radio talks and addresses, publications, an advisory service and by personal contact with scientists, engineers, farmers, graziers, business men and private citizens from all over Australia, the conservation group has done a great deal to foster an interest in water research and to enlist financial support for the Water Research Foundation of Australia.

It is anticipated that the research programme will develop along the broad lines already established, most of the existing projects being essentially of a long-term nature. Expansion may be expected in the dam sealing field, where it is proposed to investigate techniques for seepage control using bitumens, explosives and stablising chemicals during the coming year. If and when funds and staff become available it is hoped that the research programme will extend into the field of hydrologic design of small spillways, hydraulic design of spillways and catch drains, catchment treatment, and the use of trace chemicals for improving the mechanical properties of dam building soils.

Comprehensive research publications in the fields currently under investigation cannot be expected during 1960. Research reports dealing with the uses of polythene film, bentonite clays and sodium tripolyphosphate for seepage control should be available in 1961.

J.R. Burton,
June 1960.

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING -

PROGRESS REPORT NO.1. 1957-1960

APPENDIX A - FINANCE

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING
PROGRESS REPORT NO.1.

1957 - 1960

APPENDIX A - FINANCE

A. GENERAL

The conservation research programme is financed from three sources:-

(a) General University Funds
(b) Water Research Foundation of Australia benefactions
(c) Rural Credits Development Fund benefaction.

Details of these sources are as follows:-

1. Water Research Foundation

(i) Water Research Foundation - Commonwealth Bank Grant: topic, "Improved Methods of Design and Construction of Small Dams Under Australian Conditions": annual grant of £1,000; first grant dated December 1956: total grant to date £3,000.

The money from this grant is used for purchase of equipment, for travelling expenses, and for salary payments. Salaries paid from this grant have been for temporary laboratory assistance and part of stipend of Research Fellow T.R. Fietz.

(ii) Water Research Foundation - I.C.I.A.N.Z. Grant; topic, "The Use of Polythene and Polyvinyl Chloride Membranes in the Construction of Waterproof Dams"; annual grant of £1,000 first granted dated December 1956; total grant to date £3,000.

The money from this grant has been used for purchase of equipment, for travelling expenses, and for salary payments, including temporary laboratory assistance and part of stipend of Research Fellow T.R.Fietz.

2. Rural Credits Development Fund.

Topic, "Seepage Control in Farm Dams"; annual grant of £1,000; first granted date November 1958, total grant to date £2,000.

The money from this grant has been used for the purchase of equipment, for travelling expenses and for salaries of temporary laboratory assistants.

3. University of New South Wales.

It is difficult to assess the extent to which the University financially supports the conservation research programme. The following points should be noted:-

The University pays the salaries of J. Burton, lecturer, J. Clark, laboratory attendant and G. Leach laboratory assistant; a total of about £5,000 per annum, of which half is chargeable to conservation research.

The University has provided a vehicle for a mobile laboratory. The cost to the University of repairing and fitting out this vehicle was about £500; maintenance costs are met by the University.

Certain hydrologic instruments on experimental catchments, and survey instruments used for research purposes, are the property of the University.

Other University staff assist in hydrologic data collection; in repair and maintenance of instruments; in survey, photography, soil testing, workshop etc.

It is estimated that the University financially supports the conservation research programme to the extent of about 55 per cent of total cost; and the Rural Credits Fund, about 15 per cent.

B. FINANCIAL STATUS OF RESEARCH GRANTS AS AT 31st JANUARY 1960

1. C.806 Water Research Foundation Grant; "Improved Methods for Design of Farm Dams"

Balance as at 31.1.60		£1,158.10. 7
Less Commitments:		
Salary - S.Mahalingham) T.R.Fietz)	£787	
Orders placed	70	857. 0. 0
Uncommitted 31.1.60		£ 301.10. 7.

2. C.807 Water Research Foundation Grant "Plastic Membranes"

Balance as at 31.1.60		£1,681.17.11.
Less Commitments		
Salary - French) Hall) Fietz)	£749	
Orders Placed	314	1,063. 0. 0
Uncommitted 31.1.60		£ 618.17.11

3. C.809 Rural Credits Grant; "Dam Sealing"

Balance as at 11.1.60		£1,278.14. 8
Less Commitments		
Salary - French) Hall)	£ 50	
Orders placed	70	120. 0. 0
Uncommitted 31.1.60		£1,158.14. 8

N.B. £1,000 grant received November 1959, to be used for equipment, as follows:-

Instruments for measuring depths of water	£500
Rainfall Measuring Equipment	200
Laboratory and Field permeability measurements	300
	£1000

Note: Mahalingham, French and Hall were temporary student appointments over 1959-60 long vacation period.

3. WATER RESEARCH FOUNDATION OF AUSTRALIA - COMMONWEALTH BANK GRANT.

IMPROVED METHODS OF DESIGN AND CONSTRUCTION OF SMALL DAMS UNDER AUSTRALIAN CONDITIONS.

AGGREGATE STATEMENT - 26TH DECEMBER 1956 to 31ST DECEMBER 1959

(PROJECT C.806)

1. RECEIPTS

Grants:	December 1956	£1,000. 0. 0	
	July 1958	1,000. 0. 0	
	November 1959	1,000. 0. 0	£3,000. 0. 0

2. PAYMENTS

Salaries etc.	£ 928. 7. 2	
Travelling Expenses	176.10. 4	
Materials	654. 5. 7	1,759. 3. 1

BALANCE: unexpended 31st December 1959. £1,240.16.11.

WATER RESEARCH FOUNDATION OF AUSTRALIA - I.C.I.A.N.Z. GRANT

THE USE OF POLYTHENE AND POLYVINYL CHLORIDE MEMBRANES IN THE CONSTRUCTION OF WATERPROOF DAMS

PROJECT C.807

1. RECEIPTS

Grants:	December 1956	£1,000. 0. 0	
	July 1958	1,000. 0. 0	
	November 1959	1,000. 0. 0	£3,000. 0. 0

2. PAYMENTS

Salaries etc.	989. 9. 7.	
Travelling Expenses	92. 8. 3	
Materials and Equipment	170.11. 3	1,252. 9. 1
BALANCE unexpended 31st December 1959		£1,747.10.11

RURAL CREDITS DEVELOPMENT FUND - ANNUAL GRANT

SEEPAGE CONTROL IN FARM DAMS.

AGGREGATE STATEMENT 11TH NOVEMBER to 31ST DECEMBER 1959

PROJECT C.809

1. RECEIPTS

Grants:	November 1958	£1,000. 0. 0	
	December 1959	1,000. 0. 0	£2,000. 0. 0

2. PAYMENTS

Salaries	112.13. 1	
Travelling Expenses	119. 0. 7	
Materials and Equipment	409.11. 9	641. 5. 5
BALANCE unexpended at 31st December 1959 -		£1,358.14. 7

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING -

PROGRESS REPORT NO.1. 1957-1960

APPENDIX B - PUBLIC RELATIONS

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING -

PROGRESS REPORT NO.1. 1957-1960

APPENDIX B - PUBLIC RELATIONS

Since 1957 many talks, broadcasts etc. have been made in connection with the conservation research programme and the activities of the Water Research Foundation.

This has resulted in the establishment of many useful contacts amongst the rural community and has constituted valuable publicity for the University and the Foundation. The Executive Director of the Foundation has stated that many applications for membership have followed these public relations activities. Most of the requests for assistance listed in Appendix C were initiated in this way.

Several important research projects have developed from contacts made with broadcast listeners. Amongst them should be mentioned the Junior Farmers co-operation in the HYDRA scheme, the polyphosphate sealing experiment at Nashdale and most of the tunnelling and seepage studies listed in Appendix C.

A total of 26 addresses, radio talks or television interviews has been given by Mr. Burton, and two radio interviews by Mr. Fietz. In addition, newspaper articles and press releases have been issued and many statements made for city and country press. Details of these are as follows:-

1. J.R. Burton.

A. Radio Talks

1. 17.5.57. - two recordings for Caterpillar Tractors programme "Farming to-day"; topics were "Water Harvesting" and "The Keyline Plan". Subsequently broadcast over 18 commercial stations in N.S.W.

2. 21.3.58 - two recordings for A.B.C. rural programmes; topics, "Water Harvesting" and"Farm Dam Research"; subsequently broadcast over 2CR.

3. 25.11.59 - three recordings for A.B.C. rural programmes: topics "Polyphosphate Sealing", "Farm Dam Failures" and "Mobile Laboratory of Water Research Foundation". Subsequently broadcast over 2CR and some excerpts on national programmes.

4. 3.2.60 - recording for "Farming To-day"; topic "Dam Sealing Research" to be broadcast over 18 stations in N.S.W.

5. 12.3.60 - recording in Queensland for A.B.C. rural programme; discussed experimental catchment at Barcaldine - to be broadcast over Queensland Country Hour, May 1960.

6. 27.4.60 - recording for A.B.C. school broadcast "Behind the News" re water conservation problems; broadcast over 2FC on 28th April 1960

7. 19.5.60 - recording for F.S.A. programme "Farmset News" - re farm dam building; broadcast over eight country stations in N.S.W.

8. 19.5.60 - recording for Wool Bureau re farm dam building

B. <u>Television</u>

1. 3.2.58 - ABN 2 programme "Focus"; discussing groundwater research and Foundation activities

2. 12.10.58 - ATN 7 programme "The Burning Question" with Mr. Beale and Mr. Wiesner; topic "Can Australia Get Enough Water."

3. 23.5.59 - Telerecording of ceremony of handing over of £5,000 cheque by Premier: ABN 2 and ATN 7 ; demonstrated research equipment.

4. 22.10.59 - ABN 2 telecast from Manly Laboratory; discussed mobile laboratory.

C. Addresses

1. 28.8.57 - At Gloucester; Dairy Farmers' Co-op. - topic "Sealing Dams with Polythene".

2. 3.9.57 - At Narrabri; Graziers group; topic "Water Research Foundation".

3. 23.10.57 - in Sydney; Technical Education Dept. Luncheon Club: topic "Water Harvesting and Keyline".

4. 21.3.58 - at Parkes; F.S.A. Western Zone Convention: topic "Future of Water Harvesting".

5. 16.5.58 - University of New South Wales, Sheep and Wool School: paper "The Water Research Foundation of Australia".

6. 29.11.58 - at Lismore: North Cost and Tablelands Chambers of Commerce: topic "Supplemental Irrigation from Farm Dams".

7. 4.2.60 - at Lowther: Jubilee Convention, Agricultural Bureau: topic "Farm Dam Research".

8. 7.3.60 - In Sydney: Agricultural Engineering Society: topic "Dam Sealing Methods".

9. 30.3.60 - at Bathurst: Bathurst District Agricultural Education Society: topic "Farm Dam Research".

10. 19.5.60 - University of New South Wales: Sheep and Wool School: paper "Designing and Building a Farm Dam"

D. Newspaper Articles etc.

1. "The Water Research Foundation of Australia"; Wool Technology and Sheepbreeding, Vol.5.No.1.1958

2. "Water Research and Australia's Future", Muster, 20th May 1958.

3. "Big Water Problem" Daily Mirror Supplement, 30th January 1959.

In addition, statements and press releases have been made for city and country press from time to time.

2. T.R.Fietz

(a) 1st May 1960 - 2WM Deniliquin - broadcast re HYDRA scheme.

(b) 3rd May 1960 - 2 WG Wagga - broadcast re HYDRA scheme

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING -

PROGRESS REPORT NO.1. 1957-1960

APPENDIX C - ADVISORY SERVICE

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING-PROGRESS REPORT No.1. 1957-1960

APPENDIX C: ADVISORY SERVICE

INTRODUCTION

From time to time requests for advice are received from individuals, schools, Government departments etc, who have encountered problems in the conservation engineering field.

These enquiries come either direct to the University or through the office of the Executive Director of the Water Research Foundation of Australia. In the majority of cases they have been forwarded as a direct result of one of our radio talks, addresses etc. listed in Appendix B of this report.

Since 1957 a total of approx. 80 enquiries has been answered. In 16 cases the initial enquiry has resulted in a research project undertaking.

Brief detals of the individual enquiries and of research project developments are given below.

DETAILS OF ENQUIRIES.

(Note: Where a name is underlined it means that the enquiry has developed into a research project. Further details of these projects are given at the end of this Appendix).

1. General Enquiries: New South Wales.

F. Hall, Condobolin	Re dam sealing
T. Bridgland, Tahmoor	" pump location, irrigation
Cobar United Services Club	" plastic dam lining
J. Hoskins, Orange	" dam sealing
D. Wilson, Warialda	" dam sealing
J. Swinton, Kulnura	" dam sealing
R. Littlejohn, Harden	" hydrologic data
J. Jackson, Inverell	" hydrologic data

Riverina Spraying Service	Re catchment sealing
P. Cassin, Little Hartley	" dam construction
V. Potts, Merriwa	" water testing
K. Crawford, Holbrook	" plastic dam lining
S. Mills, Tottenham	" dam sealing
J. Richmond, Goodooga	" dam sealing
H. Truelove, Lidster	" dam sealing
K. Reed, Young	" hydrologic data
Fransciscan Nunnery, Mittagong	" dam sealing
J. Nash, Cudal	" dam sealing
D. Vann, Canberra	" dam sealing
S. Plowman, Orange	" dam sealing
J. Hearne, Tuena	" off-stream storage
J. Reynolds, Cumnock	" dam sealing
K. Neals, Carcoar	" dam construction
E. Hunt, Wagga	" hydrologic data
J. Prosser, Brocklesby	" dam failures
W. Fay, Cowra	" dam construction
L. Hill, Moree	" dam failure
J. Mackay, Warren	" dam failures
H. Goodacre, Woodstock	" water harvesting
St. Michael's College, Inveralochy	" dam sealing
A.C.I. Ltd., Coff's Harbour	" dam sealing
D. McIntosh, Blackheath	" plastic membranes
Gardner-Denver Aust.Ltd. Sydney	" plastic lining
D. Winston Smith, Inverell	" plastic dam lining
B. Wilson, Burrumbuttock	" dam sealing
J. Whitmill, Gloucester	" dam sealing
C. Brown, Dubbo	" hydrologic data
M. Coles, Boggabri,	" dam construction
Sub-Normal Children's Welfare Assoc. Penrose	" dam design
J. N. Barret, Narrabri	" turkey's nest construction
Theloma Nursery, Yanco	" dam sealing
King's School, Harden	" dam design
King's School, Bowral	" dam construction
W. Davies, Parkes	" turkey's nest tank constr.
B. Williams, Nashdale	" dam sealing

P. Hoskins, Wisemans Ferry	Re dam construction
M. Cotton, Shooter's Hill	" piping failure
W. McCullum, Bribbaree	" tunnelling failure
W. Vile, Branxton	" dam failures
Baulkham Hills Shire Council	" seepage problems

2. General Enquiries, Interstate

K. Stewart, Sea Lake, Victoria	Re dam sealing
H. Lloyd-Jones, Port Augusta S.A.	" water drilling
G. Brown, Rosewood, Q.	" water harvesting
Welch-Perrin, Melbourne	" dam construction
G. Bremner, Maryborough, Q.	" dam construction
B.H.P. Whyalla, S.A.	" polythene lining
G. Bourne, Barcaldine, Q.	" hydrologic data collection

3. General Enquiries, Overseas

C. Hobson, Virginia, U.S.A.	Re plastic membranes
G. Broomell, California, U.S.A.	" " "
Gering Products, New Jersey, U.S.A.	" " "
Palco Plastics, California, U.S.A.	" " "
J. Wardell, Lake Pakaki, N.Z.	" " "
R. Kerr, Vila, New Hebrides	" " "

4. Government Departments etc.

Water Conservation and Irrigation Commission, N.S.W.	Frequent enquiries re dam problems. General co-operation in field studies.
Soil Conservation Service, N.S.W.	Enquiries re dam sealing, tunnelling soils, general co-operation. Two co-operative research projects.
Forestry Commission, N.S.W.	Several enquiries re dam sealing.
Agriculture Department. N.S.W.	Re dam sealing

Agriculture Department, Vic.	Re dam sealing
Agriculture Department, S.A.	" dam sealing
Agriculture Department, W.A.	" dam sealing
C.S.I.R.O. Divn. Industrial Chemistry, Melbourne	" dam sealing
C.S.I.R.O. Divn. Soil Physics, Adelaide	" dam sealing
C.S.I.R.O. Divn. Land Research, Canberra	" dam sealing
State Rivers and Water Supply, Victoria.	" dam and channel sealing
University of Melbourne	" dam sealing
University of Sydney	" dam sealing

RESEARCH PROJECTS.

The underlined enquiries have developed into research projects. Details are as follows:-

(a) Swinton, Kulnura: Proposed dam sealing experiment - Bentonite

(b) Sub-normal Children: Dam design completed, project discontinued.

(c) King's School: Design of irrigation system: instruments installed, survey carried out.

(d) Davies, Parkes: Turkey's Nest dam: soil survey, contour survey, preliminary design completed.

(e) Williams, Nashdale: Dam sealing experiment carried out: see Appendix J.

(f) Hoskins, Wiseman's Ferry: Dam construction in swamp: contour survey and soils survey carried out.

(g) Cotton, Shooter's Hill: Piping failure: some soil testing.

(h) McCallum, Bribbaree: tunnelling failure study: soil tests etc. carried out: see Appendix G.

(j) Vile, Branxton: Tunnelling failures: see Appendix G

(k) Baulkham Hills Shire: seepage problems: proposed explosives sealing experiment.

(l) Bourne, Barcaldine: Experimental catchment installed; see Appendix E.

(m) Soil Conservation Service: co-operative research project in tunnelling soil problem; also dam construction studies: see Appendix G.

(n) Forestry Commission: Two dam sealing experiments; see Appendix J.

(o) Agriculture Department, N.S.W.: dam sealing experiment completed (Alstonville, N.S.W.) see Appendix J.

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING -

PROGRESS REPORT NO.1. 1957-1960

APPENDIX D - CO-OPERATION WITH OUTSIDE ORGANISATIONS

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING - PROGRESS REPORT NO.2. 1960-1961

APPENDIX D - CO-OPERATION WITH OUTSIDE ORGANISATIONS.

During the period under review many contacts have been established with research organisations and Government departments. In all cases useful exchanges of research information have been made and a number of co-operative research projects has been undertaken.

Details of these co-operative activities are as follows:-

A. C.S.I.R.O.

1. Division of Soils; exchange of data re dam construction.
2. Division of Industrial Chemistry; exchange of data re plastic membrane testing; supply of seepage measurement figures from Guyon tank.
3. Division of Soil Physics, Waite Institute; exchange of data re dam sealing.
4. Division of Land Research and Regional Survey; exchange of data re dam sealing.
5. Irrigation Research Station, Griffith; exchange of data re seepage control; Station has offered to conduct plastic weathering tests.
6. Irrigation Research Station, Merbein; exchange of data re seepage control, seepage measurements.

B. Universities

1. Melbourne University, Agriculture Engineering Dept.: exchange of data re hydrology, dam sealing, dam construction; general co-operation.

2. Sydney University, Soil Physics Dept: exchange of data re seepage control.

3. Sydney University, Vet. Science School: exchange of data; co-operative hydrologic data collection.

4. University of W.A.: exchange of data.

5. University of New Zealand: exchange of data re dam sealing.

C. Government Departments

1. Water Conservation and Irrigation Commission, N.S.W.:- general co-operation in all research activities. Commission has provided data, survey information, hydrologic equipment.

2. Soil Conservation Service of N.S.W. - general co-operation, exchange of data re soil testing, hydrology. Co-operative hydrologic data collection; co-operative study of solodic soils; co-operative study of construction techniques.

3. Department of Agriculture, N.S.W. - co-operative seepage control experiment at Alstonville.

4. Forestry Commission, N.S.W. - exchange of data; co-operative seepage control experiments at Orange, Tumut, Blue Mountains.

5. Education Department, N.S.W. : - HYDRA scheme, all Junior Farmer activities in relation to HYDRA organised by Department.

6. Department of Public Works, N.S.W.: - exchange of data re soil testing, dam construction; use of equipment.

7. Soil Conservation Authority, Victoria: exchange of data re hydrology, dam construction. Authority has supplied runoff data.

8. State Rivers and Water Supply Commission, Victoria:- general co-operation; exchange of data re dam sealing.

9. Department of Agriculture, Victoria; exchange of data re dam sealing; co-operation in sealing equipment at Silvan.

10. Department of Agriculture, S.A. - exchange of data re dam sealing; supply of hydrologic data.

11. Department of Agriculture, W.A.: - exchange of data re dam sealing.

12. Department of Agriculture, Tasmania: - exchange of data.

13. Rivers and Water Supply Commission, Tasmania: - exchange of data.

14. Soil Conservation Service, Queensland: - exchange of data, proposed co-operative experimental catchments.

D. <u>Commercial Enterprises</u>

The following firms have provided materials or equipment and made available the services of research staff.

1. Standard Chemical Co. - Re bentonite sealing
2. Albright and Wilson - Re polyphosphate sealing
3. Shell Co. - Re bitumen sealing
4. Nobel's Explosives - Re explosive sealing
5. I.C.I.A.N.Z. Ltd., - Re plastic membrane sealing
6. Moulded Products Ltd. - Re plastic membrane sealing.
7. Freydis Ltd., - Re plastic membrane sealing.
8. William Adams Tractors and Caterpillar Tractors - re dam construction.

9. Britstand Ltd., - Re dam construction
10. Le Tourneau Ltd., - Re dam construction
11. Whealtraction Ltd., - Re dam construction
12. P.A. Yeomans Pty Ltd. - Re dam construction

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING

PROGRESS REPORT NO.1, 1957-1960.

APPENDIX E

HYDROLOGIC AND ECONOMIC DESIGN OF SMALL STORAGES.

TABLE OF CONTENTS

1. Introduction.
2. The Problem.
3. Existing Hydrologic Data for Farm Reservoir Design.
4. Extension of Existing Data Collection Facilities -- the Hydra Scheme.
5. The estimation of catchment yield.
6. The estimation of reservoir capacity.
7. Economics of Water Storage.
8. Multi-Storage Projects.
9. Conclusion.

. . . .

1. INTRODUCTION

The hydrologic design of a small storage reservoir intended for farm water conservation purposes involves the consideration of three factors; the volume of storage needed to meet the required demand conditions, the area of catchment needed to fill this storage and the spillway capacity required to protect it. Economic design relates these factors to capital and operating costs and likely returns from the water used, and involves some consideration of allowable failure frequencies, storage-excavation ratios, watershed area: irrigated area ratios, reservoir losses and operating procedures.

A farm reservoir has obviously failed when it empties because of breaching of the embankment. Less obvious, but far more numerous, are the partial failures resulting from inadequate capacity, unsatisfactory catchment, poor siting or excessive seepage and evaporation losses. A reservoir can be classed as an economic failure when it does not yield a maximum utilisation of water for a given expenditure. An unduly high proportion of farm dams in Australia to-day are economic failures in some degree.

The immediate blame for this high failure rate can be laid at the door of the designer or dambuilder, who is more concerned with building an embankment than forming a reservoir and considers a favourable storage-excavation ratio or a high catchment yield as something in the nature of an act of God. The fault is not entirely his, however, for he is handicapped by a lack of design data and a complete absence of established design procedures. It is the purpose of this research programme to provide such information.

2. THE PROBLEM

Hydrologic design of a small reservoir involves two distince problems; the estimation of spillway capacity and the determination of storage volume.

Research conducted overseas (1,2,3) and more recently in Australia (4) has shown that more failures of low earth embankments are caused by overtopping due to inadequate spillway capacity than by any other factor. At the same time, however, reasonably adequate design procedures are available for the determination of spillway flood flows (5,6), these procedures being handicapped chiefly by a paucity of data relating to loss rates and times of concentration. The use of conservative values for these doubtful data results in a design which is safe, if not altogether economical, and this problem has therefore been considered as secondary to the largely neglected question of storage design.

A study made by Quah (7) in 1956 revealed that most of the literature relating to the hydrologic design of farm ponds or reservoirs is concerned with the estimation of spillway capacity, and that little consideration has been given to the questions of catchment yield and reservoir capacity. Some American engineers, notably with the Soil Conservation Service, have developed storage design data (8,9,10) but these in general apply to specific districts of the United States and are not directly applicable to Australian conditions. Current research in the U.S.A. (11) is concerned with the collection of runoff data from small rural catchments and with methods for the estimation of catchment yield, but the major emphasis continues to be placed on the design flood problem.

In 1957 the writer suggested procedures for the design and operation of supplemental irrigation storages in the first Research Bulletin of the Water

Research Foundation (12). These procedures, like the American ones on which they were partly founded, depended upon data relating to catchment yield and water use which were then, as now, not readily available. They have formed the basis of the present research programme which has been principally concerned wit data collection and with techniques for the estimation of runoff volumes.

The current research programme has involved a consideration of the following topics:-

1. An evaluation of hydrologic records already available from small experimental catchments in Australia.

2. The establishment of a network of experimental catchments to supplement the very scanty runoff data already available.

3. The instrumentation of a network of farm dams to collect data relating to water use, evapo-seepage losses and reservoir operation.

4. The development of methods for estimating catchment yield in the absence of long-term runoff records.

5. Further development of the storage design procedures put forward by the writer in Bulletin No.1 of the Water Research Foundation.

6. A study of the economics of farm water storage in relation to reservoir design and operation.

7. Extension of the storage design procedures to cover special problems associated with the design and operation of multi-storage projects of the Water Harvesting type.

The remainder of this report deals with progress under the above headings.

At this juncture it should be emphasised that, whilst work of a somewhat similar nature is being undertaken in the United States, this does not render the University of New South Wales programme redundant. In the first place, the collection of hydrologic data from specific areas, to be used for the design of small dams within those areas, is essential no matter what design techniques are employed, and the bulk of the American research is concerned primarily with this phase of the problem. In the second place, the best techniques for estimating yield from small ephemeral catchments would appear to depend upon a simi empirical approach, requiring the development of coefficients for particular districts and climatic conditions. In the third place, American work on storage design procedures appears to be very restricted and not so generally applicable as that being conducted within the University of New South Wales. There is, therefore, ample justification for an extensive Australian research programme in this field.

3. EXISTING HYDROLOGIC DATA FOR FARM RESERVOIR DESIGN.

To determine the volume of storage required in a small reservoir it is necessary to have data about the volume of runoff to be expected from time to time from the catchment area. For preference these data should be in the form of tabulated monthly runoff volumes over a period of 20 years or more; at the very least, the average annual runoff and the minimum annual runoff to be expected with a given frequency should be known.

It is desirable that design runoff data be obtained from a small gauged catchment which is hydrologically similar to the catchment on which the proposed dam is to be sited. Where such data are not available runoff figures must be synthesised from rainfall records.

The first stage of this research programme has therefore been to evaluate the hydrologic data already available from small rural catchments in Australia, having regard to their suitability for the design of small storage reservoirs.

Farm reservoirs are located on rural catchments which range in area from less than 10 acres to several hundred acres. These are generally ephemeral catchments which yield runoff only as surface flow from storm rainfall, and periods of up to two years and longer may elapse without appreciable inflow to the reservoir. Hydrographs of runoff from such catchments differ in nature from the hydrographs of small streams, where groundwater flow may make appreciable contributions to annual runoff. Streamflow records are therefore not entirely suitable for the design of farm reservoirs, strictly valid runoff data coming only from experimental catchment areas similar in size and nature to the farm reservoir catchment.

It is considered desirable that a catchment area providing data for farm dam design should have the following general characteristics:-

(a) The catchment should be representative of a considerable surrounding agricultural area.

(b) The area of the catchment should be less than one square mile.

(c) Any watercourse on the catchment should be non-perennial.

(d) At least 10 years of reliable runoff data should be available.

The investigation has revealed that there are no catchment areas in Australia which meet all these requirements; it may, in fact, be categorically stated that there are no catchment yield data available in this country which might be directly applied to the hydrologic design of small storage reservoirs.

There is, however, a small number of catchment areas which have provided data which might be suitable for research purposes, e.g., checking techniques for estimating runoff from rainfall. The investigation therefore continued by looking at these catchments and selecting suitable ones for catchment yield research.

It was considered that all gauged rural catchments having total areas of less than 10 square miles would merit investigation.

These catchments fall into three main groups. These are, firstly, small-area runoff plots on soil conservation research stations, having in general an area of about one thirtieth acre; secondly, small experimental catchments, set up specifically for research into runoff rates, rainfall-runoff relationships etc. which generally range in area from a few acres to about 2,000 acres; and thirdly, streamflow stations on small streams, ranging in area up to 10 square miles, which have been established by streamgauging authorities to collect data for the design of hydraulic structures and flood control works.

A survey of all Australian catchments falling within these groups has been made and the results of this survey are presented in Tables 1,2 and 3. This survey was based on information available in Sydney, supplemented by visits to other states and correspondence with recording authorities, and is considered to be comprehensive. It is however, to be supplemented by a written survey now being circulated to all streamgauging authorities in Australia.

TABLE I - GAUGED RUNOFF-PLOTS IN AUSTRALIA.

STATE	OPERATING AUTHORITY	LOCATION	DETAILS
N.S.W.	Soil Conservation Service	Wagga Wagga Cowra Wellington Gunnedah Inverell	1/30th acre plots: runoff and soil loss measured generally under various phases of wheat rotation or permanent pasture. 12 yrs. of record available from most stations.
Vic	Soil Soil Conversation Authority	Parwan	Understood some plots operating: details not known. Period of record less than 5 years.
Q'land	Dept. of Agriculture-Soil Conservation Branch	Darling Downs	Plots proposed: none yet installed.
S.A.	Nil	-	Some plots proposed.
Tas. N.T. W.A.	Nil	-	-

Table I shows brief details of runoff plots in Australia. Records of useful length are available only from the plots of the Soil Conservation Services of N.S.W., which are located in the wheat belt of that State. Although the small size of these plots raises doubt of their suitability for dam design purposes, the fact that they measure surface runoff only makes them particularly useful for research purposes. Periods of record of up to 12 years are available and comprehensive records of cover conditions, soil moisture etc. have been kept, as well as daily rainfalls, daily runoff totals and evaporation data. Some preliminary analyses have been made by officers of the Service (13, 14, 15) and a detailed study of the records from Wellington station has recently been made by Logan (16). All records have been made available to the University and a study of yield coefficients and other factors is now being undertaken for the Wagga plots. The remaining stations will be treated in the same way. (See Section 5, "The Estimation of Catchment Yield").

Table 2 shows details of all rural experimental catchments in Australia, an experimental catchment being defined as a small area equipped with a continuous runoff recording device and pluviometer and intended to collect data for research purposes.

Of the 40 catchments listed in this Table, only 2, the adjacent 20 acre catchments at Wagga, have records for a period as long as 8 years; the group of 7 at Parwan, Victoria, has records for 5 years, and none of the others has records any longer than three years.

None of these catchments provides data suitable for design purposes. The Wagga and Parwan groups have records of sufficient duration to be of value for research purposes, particularly in checking yield estimation procedures against measured runoff. Hydrographs and hyetographs from Wagga for the period 1952 to 1959 have been made available to the University and methods of yield estimation are now being studied with these records (see Section 5). The Parwan records have been analysed by the Victorian authority and some water balance studies have been undertaken (17).

Of the remaining catchments there are six on which the University of N.S.W. operates instruments, and hence has ready access to records, which have been in operation for up to three years. These comprise the catchments at Badgery's Creek, Mt. Vernon, Buttai and Scone. Whilst not suitable for checking yield estimations based on monthly rainfall records, they may provide useful data for a "storm runoff" approach. Data analyses have therefore been undertaken by the University and a stucy of empirical rainfall-runoff relationships is in hand.

TABLE 2: EXPERIMENTAL CATCHMENT AREAS IN AUSTRALIA

State	Operating Authority	Location of Catchment	Area	Details of Catchment	Instrumentation	Period of Record Available	Suitability for Research Programme
N.S.W.	Univ. N.S.W.	Badgery's Creek	15 ac.	Clay Soil: mod. slope: native grass cover Av.P 28 inches	Parshall flume with L.S. Recorder. Mort pluviometer. Daily gauge. DSIR intensity recorder. Aust. and U.S. evaporimeters. Infiltrometer studies available.	3 yrs.	Useful - under investigation, records analysed by University.
"	"	Mt. Vernon	173 ac.	Steep: native grasses and light timber: clay and shale: Av.P 28 inches	Bristol recorder in water course. Casella Pluviometer, daily gauge.	2 yrs.	Useful - under investigation, records analysed by University.
"	"	Futter Park	½ sq.mile	Steep granite country: light timber, heavy native grass cover. Av. P 25 inches.	Bristol recorder in watercourse - not yet gauged. Mort pluviometer, daily gauges.	2 yrs.	Of no use until fully gauged. Set up for dam design purposes.
"	"	Futter Pk. Harden	1½ " "	do. do.	do. do.	2 yrs.	do. do.
"	"	Parramatta	1300 ac. 1300 ac.	Mod. slopes, timber and grasses, some buildings, some run-off. Sandstone country. Av. P 34 ins.	Bristol recorder in watercourse - not yet gauged. Mort pluviometer.	Installed 1960	No records yet available: set up for dam design purposes.
S.A.	Hunter Valley Res.Foundation (Nel.Univ. Coll.)	Buttai (Hunter Valley)	210 ac.	Mod. slopes, pasture and some bush cover. Clay soil. Av. P. 25 ins.	V-notch weir - L.S. Float recorder; duplex with pluviometer included. Also Mort pluviometer, D.S.I.R. intensity recorder, daily gauge. Evaporimeter and lysimeter. Soil moisture readings.	3 yrs.	Reliability of records doubtful.

TABLE 2 (cont'd.) EXPERIMENTAL CATCHMENTS IN AUSTRALIA

State	Operating Authority	Location of Catchment	Area	Details of Catchment	Instrumentation	Period of Record Available	Suitability for Research Programme
N.S.W.	Soil Cons. Service	Wagga	18 ac.	Med. slopes: skeletal and red brown soils: natural pasture. Av. P = 21 ins.	H Flume: electric L.S. float recorder, pomerine wheel soil sampling box. Pluviometer distant 1/3 ml.	8 yrs.	appear suitable records available, some analysis completed.
		Wagga	18½ ac.	Med. slope: skeletal and red brown soils: improved pasture, pasture furrowed Av. P = 21 ins.	H. Flume: S.C.S. pattern float recorder. Pluviometer on catchment, also met. station.	Not known	Records very doubtful, serious silting of weir.
		Scone	600 ac.	Steep to med. slope: pasture cover: conservation works on catchment. Av.P = 24 ins.	Rectangular weir: S.C.S. pattern float recorder: Mort pluviometer on catchment, Negretti Zambra tipping bucket near weir. Met. station nearby.	18 months	Suitable, but period very short. Records analysed by University which owns Mort pluviometers.
		Scone	400 ac.	Steep: granite soil: native pasture cover: Av. P = 24 ins.	H flume: S.C.S. pattern float recorder: remote pluviometer: Mort on catchment.	18 months	
		Scone	40 ac.	as above - adjacent catchment	as above, catchment Mort serves both areas	18 months	
		Inverell	200 ac.	Runoff from research station: various forms of treatment Av. P = 29 ins.	Rect. weir, S.C.S. pattern float recorder: pluviometer and met. station.	Installed 1959	No useful records
		Cowra	200 ac.	do. Av. P. = 22 ins.	do.	Installed 1959	No useful records

TABLE 2 (cont'd.) EXPERIMENTAL CATCHMENTS IN AUSTRALIA

State	Operating Authority	Location of Catchment	Area	Details of Catchment	Instrumentation	Period of Record Available	Suitability for Research Programme
N.S.W.	S.M.H.E.A.	Snowy Mountains	8 catchments ranging from 50 ac. to 1 sq. mile: all above 5,000 ft. - all snow-covered part of year		All equipped with V weirs and type F Leupold Stevens Stage recorders	4 yrs.	Not suitable due to snow, soil and cover conditions
Q'land	University of N.S.W.	Barcaldine	100 ac.	Black soil, downs-type topography, Mitchell grass cover. Av.P=20 ins.	V-notch weir, Ingram float recorder, Mort pluviometer	Installed 1960	No records yet available.
Vic.	Soil Cons. Authority	Parwan (near Bacchus Marsh) Marsh).	200 ac. 6 catchments of 4 acres	(Solod soils: varying grass cover: (moderate slopes. (6 small catchments (located within the (large one and subjected to various (forms of treatment.	Each catchment has H flume with Ingram float recorder: no details of 200 ac. outflow measurement: one Negretti Zambra pluviometer in centre of area. Soil moisture measurement and met. instruments.	5 yrs.	Only useful catchments in Victoria: Some analysis and research conducted by Authority.
		Stewart's Creek	10-65 ac.	5 small catchments in undulating to hilly timbered country, with clay loam soils. Av. P= 40 ins.	All catchments have H.flumes with A 35 L and S recorders. Mort pluviometer. Soil moisture and met. instruments.	6 months	Length of record as yet too short.

TABLE 2 (cont'd) EXPERIMENTAL CATCHMENTS IN AUSTRALIA

State	Operating Authority	Location of Catchment	Area	Details of Catchment	Instrumentation	Period of Record Available	Suitability for Research Programme
S.A.	Dept. of Agriculture (Soil Cons. Section)	Barossa Valley	2 adjacent catchments having area about 25 acres each	Not known	H flumes - Ingram stage recorders, one pluviometer	2 yrs.	Period of record too short.
W.A.	Public Works Dept.	Bolganup Creek	1100 ac.	Not known	Pluviometer and gauging stn.	not known	doubtful suitable only specialised cases.
		Warrogin	50 "	Road catchment	Pluviometer, runoff measurement	" "	
		Bear Drain	1000 "	Not known - may be urban drainage	Pluviometer and gauging stn.	" "	Doubtful
Tas.	Nil						

TABLE 3 - SMALL GAUGED CATCHMENTS IN AUSTRALIA (LESS THAN 10 SQ. MILES)

State	Authority	Total No. of Catchments less than 10 sq.ml.	Catchments Considered Suitable for Research Use.			
			Location	Area (sq.mil)	Period of record (yrs.)	Remarks.
N.S.W.	W.C.I.C.	15	Barrington R.	8.0	15	Monthly run-off volumes available. Early records from staff gaugings only.
			Big Creek	3.5	23	
			Deer Park	4.0	34	
			Jock's Water	3.6	35	
			Major's Creek	4.6	35	
			Rocky Creek	7.2	37	
N.S.W.	S.M.H.E.A.	45	None of these considered suitable because of short period of record, elevation and snow cover.			
Vic.	S.R.W.S.	Not known	Arthur's Creek	7.0	19	Published data available.
			Crystal Creek	4.0	15	
			Diamond Creek	3.5	19	
			East Barwon R.	7.5	32	
			Kootong Ck.	8.0	23	
Vic.	S.E.C.	5	Not suitable because of elevation and snow cover.			
Vic.	M.M.B.W.	1	Not suitable - steep forrest catchment.			
Q.	I.W.S.C.	Not known	None available with period of record longer than 10 years.			
S.A.	None known					
W.A.	P.W.D.	1	Conditions not known			
Tas.	H.E.C.	1	May be suitable, but elevated.			
N.T.	Dept. of Territories N.T.A. Water Resources Branch.	5	Maximum period of record 5 years; mainly installed in connection with rice growing studies.			

There are many gauged catchments in Australia, particularly in the eastern states, having an area of less than 10 square miles. Since the available periods of record on catchments less than 1 square mile in area are so limited, the investigation was extended to cover larger catchments having long-term records, even though these catchments might not be typical of farmed areas and they might experience considerable groundwater inflow. A brief summary of such catchments is shown in Table 3.

Of approximately 80 catchments covered by this Table there are 5 having periods of record of more than 30 years and 6 more having periods longer than 15 years. Whilst those catchments might not be suitable for design purposes, because of special topography or climate, they may be most useful for checking procedures for the estimation of catchment yield, where differences from normal agricultural conditions can be alled for. An investigation of the quality of the long-term records from N.S.W. catchments listed in Table 3 is now in progress as a preliminary to yield studies.

The results of the catchment investigation may be summarised as follows:-

Of the 120 odd experimental or gauged rural catchments in Australia having an area of less than 10 square miles, there is none which provides runoff data which can be directly applied to the design of farm reservoirs. Two groups of catchments, at Wagga in N.S.W. and Parwan in Victoria, provide detailed short-term records which are being used for research into methods for estimating catchment yield. 5 gauged catchments having records extending for more than 30 years are being investigated as regards their suitability for checking water-balance yield estimates.

Of the 40 experimental catchments in the Commonwealth, the majority have not been properly calibrated or synchronised and few data have been fully analysed. There is a serious need for these stations, in particular, to be put in proper working order, for the network of experimental catchments to be extended to cover normal rural conditions, since most of the existing ones are of a specialised type, e.g., Snowy, Soil Conservation, etc., and it is essential that a central body be appointed to co-ordinate and control extension, maintenance and data collection and analysis. The body most fitted for this task is the established hydrographic authority for each state, i.e., Water Conservation and Irrigation Commission, State Rivers and Water Supply Commission, and so on.

4. EXTENSION OF EXISTING DATA COLLECTION FACILITIES - THE "HYDRA" SCHEME.

Of the 40 experimental catchments listed in Table 2 only 6, namely those directly under the control of the University of New South Wales, have been set up specifically to measure rates and amounts of runoff for the design of small hydraulic structures such as farm dams, culverts etc.; the majority have been set up either to measure the effects of various forms of soil conservation treatment or to provide data for the design of high-altitude hydroelectric projects. None of these 6 catchments has been in operation for more than three years.

The widespread and rapidly increasing farm dam building activities in all States of the Commonwealth justify the setting-up of a great many more experimental or gauged catchments to collect data for the design of future dams. These catchments should embrace the major climatic, topographic and soil types encountered in primary production. Since there exist at present no usable runoff data from typical agricultural areas, and having in mind the small size and relative cheapness of farm reservoirs, there is a need for the widespread collection of relatively approximate data at low cost, rather than for the setting up of a few expensive and precisely instrumented experimental catchments.

At the outset of the research programme described herein, it was apparent that an extension of the existing data collection sources was essential. In 1957, the writer first proposed the HYDRA scheme, which aimed to collect approximate catchment yield data as cheaply as possible by simply measuring inflow into selected farm dams. The scheme is now in operation with records being collected from a total of 17 stations, and it will be extended to cover approximately 50 stations within the next two years if sufficient funds become available.

An explanation of the HYDRA scheme is given in Appendi F of this report. Briefly, the scheme aims to collect not only runoff figures but other hydrologic data required in the design of farm dams, such as evaporation, seepage rates and water use. The basis of the scheme is the Class I station, which comprises a farm dam equipped with graduated posts for measuring changes in water level, a daily-read raingauge and a simple evaporimeter. More precise information about reservoir behaviour is obtained from the Class II station, where the Class I instruments are supplemented by a continuous water-level recorder in the dam and a weir for the measurement of outflow. As funds permit a network of fully instrumented experimental catchments of Class III stations is being set-up to complement the approximate data obtained from the Class I and Class II stations. Details of all stations now in operation are given in Table 4.

In 1958, following publicity given to HYDRA on press and radio, Mr. John Wildman, Junior Farmer Supervisor for the South-West region, approached the writer with the proposal that the Junior Farmer movement might take part in the Scheme. With the active support of the State Supervisor of Junior Farmers, Mr. W. Tearle, Class I Stations will in future be operated by Junior Farmers under the surveillance of their District Supervisors. This will maintain interest in the scheme and ensure a high standard of record keeping. It is proposed by the Education Department that this record keeping be undertaken as a Junior Farmer "Project", and a Project Booklet for this purpose has been drafted by the writer. It is hoped that the Water Research Foundation will provide an annual prize for competition amongst young people taking part in this Project. At the present time there are 5 Junior Farmer observers in the Riverina District, and approximately 30 other Junior Farmers are awaiting the installation of instruments and the completion of storage surveys.

TABLE 4 - DETAILS OF HYDRA STATIONS, APRIL 1960

Station Class	Station Number	Location	Operated By	Date Installed	Average Annual Rainfall	Instrumentation
	HI-1	Dubbo	C.Brown	1958	21	Gauge plates; rain gauge
	HI-2	Harden	King's School	1958	25	do. do.
	HI-3	Urana	R.Duncan	1958	17	do. do.
	HI-4	Mathoura	J.Berryman	1958	15	do. do.
	HI-5	Temora	B.Reinhold	1958	2	do. do.
	HI-6	Wagga	F.Bussen-chutt	1958	21	do. do.
	HI-7	Humula	N.Linsell	1958	35	do. do.
	HI-8	Parkes	W.Davies	1959	21	do. do.
	HII-1	North Richmond N.S.W.	University N.S.W.	1958	31	Bristol recorder, evaporimeter; raingauge, gauge plates.
	HII-2	Pearce's Creek N.S.W.	Dept. of Agriculture	1959	60	Bristol recorder; evaporimeter; raingauge; gauge plates.
	HII-3	Nashdale, N.S.W.	B.Williams	1959	30	Bristol recorder; evaporimeter; raingauge; gauge plates; inflow meter.

TABLE 4 (cont'd) DETAILS OF HYDRA STATIONS
APRIL, 1960.

Station Class	Station Number	Location	Operated By	Date Installed	Average Annual Rainfall	Instrumentation
	HIII-1	Badgery's Creek N.S.W.	Univ.N.S.W.	1956	28	For details of catchments and instrumentation see Table 2.
	HIII-2	Mt. Vernon, N.S.W.	Univ.N.S.W.	1957	28	
	HIII-3	Futter Pk. N.S.W.	King's School	1958	25	
	HIII-4	Futter Pk. N.S.W.	King's School	1958	25	
	HIII-5	Scone, N.S.W.	Soil Cons. Service	1958	24	Note: HYDRA participation in Scone projects commenced 1960.
	HIII-6	Scone, N.S.W.	Soil Cons. Service	1958	24	University supplies pluviographs and undertaken data analysis.
	HIII-7	Scone, N.S.W.	Soil Cons. Service	1958	24	
	HIII-8	Barcaldine, Qld.	C.H.Wilson	1960	20	
	HIII-9	Nth.P'matta N.S.W.	King's School	1960	34	
	HIII-10	Quilpie, Qld.	C.H.Wilson	To be installed late 1960.		

5. THE ESTIMATION OF CATCHMENT YIELD

The major problem in hydrologic design of a small storage reservoir for agricultural purposes is the determination of catchment yield. As has been explained above there are no suitable runoff data for this purpose and recourse must be had to some method of estimating catchment yield from rainfall figures, reasonably long-term rainfall records being available in most parts of Australia.

The limited American literature on farm pond design (7) offers little assistance in this regard, the generally recommended approaches being either to use measured runoff data or to adopt tabulated values of catchment area - storage volume ratios, which latter have themselves been prepared from runoff records. Hamilton and Jepson (18) have published a generalised map of the United States showing average and minimum volumes of annual runoff for small catchments, and it is an ultimate aim of this investigation to produce maps of this type for Australian conditions. The maps prepared by Hamilton and Jepson have, however, been based on published runoff data, whereas local maps must be based on synthetic runoff figures.

In the first Bulletin of the Water Research Foundation the writer proposed a method in which daily rainfall records were analysed and the volume of flood runoff from each storm estimated. This is now considered to be the best method where suitable rainfall data are available and an attempt has been made to establish suitable yield coefficients and to compare estimated values of runoff with measured values on selected catchments.

The degree of accuracy required in the catchment yield estimation depends upon the storage design procedure adopted. In the design of a large irrigation reservoir by storage-behaviour analysis it is desirable to have available monthly runoff totals over a period of at least 20 years; for small stock tanks, on the other hand, annual totals may suffice. A number of approaches has therefore been investigated, each involving varying degrees of approximation.

The methods so far studied fall into the following groups:-

(a) Water budget computations.
(b) Empirical rainfall-runoff relationships.
(c) Estimation of runoff from individual storms.

(a) Water budget computations.

The water budget approach assumes that runoff is the residual of rainfall after allowing for evapor-transpiration, soil moisture accretion and other losses. Runoff may be computed on a monthly or annual basis.

Attempts have been made to compute water balances and compare them with measured runoff for catchments at Wagga, Badgery's Creek and Hunt's Creek. Results have not been successful. This was to be expected, since on ephemeral catchments where the water table is well below watercourse bed level all losses cannot be accounted for. It has been concluded that this method is not suitable for estimating catchment yield on ephemeral catchments, although it shows promise for larger catchments were groundwater discharge contributes to streamflow.

Computations carried out so far indicate, however, that this method may give a reasonable approximation to the minimum annual yield and that whilst the volume of runoff in any year might be considerably in error, the length of periods without any runoff is indicated with reasonable accuracy. This method is therefore useful in storage design to indicate the length of periods of no inflow, and is considered suitable for the design of stock tanks where storage-behaviour analyses are not necessary.

(b) Empirical rainfall-runoff relationships.

Attempts have been made to prepare empirical rainfall-runoff relatioships for selected experimental catchments on both annual and monthly bases. It was hoped that such relationships might be extended to cover large areas of N.S.W.

The investigation has been handicapped by a lack of data and by short-comings of available data. Attempts have been made to establish relationships for catchments at Badgery's Creek, Scone and Wagga and for runoff plots at Wagga. In all cases the scatter of points has been too great to yield any satisfactory correlation and this approach has been abandoned.

(c) Estimation of runoff from individual storms.

On the basis of the foregoing investigations it was concluded that for Australian conditions the only satisfactory approach to the yield problem is in fact to consider it as a flood problem and to estimate the volume of runoff from each individual storm of the rainfall record. This is the approach used by the writer for Badgery's Creek in the first Bulletin of the Water Research Foundation, and advocated in a general way by some American authorities, notably Wisler and Brater (19) and the Soil Conservation Service of the United States Department of Agriculture (20).

Attempts to establish rainfall-runoff curves for individual storms and daily rainfalls indicated that suitable correlations might be established on those bases. At this stage the writer's attention was directed to a method of Soil Conservation Service (20) but not published in the literature. This method uses standardised rainfall-runoff curves with modifying parameters depending on soil type, cover, antecedent moisture etc. Use of this method for catchments at Wagga has indicated good correlation with measured runoff. The S.C.S. method has been somewhat modified, notably in regard to the effect of antecedent moisture conditions, and checks for other catchments are in hand. The modified method is now tentatively recommended as the best method of yield estimation available in Australia for small ephemeral catchments.

6. The Determination of Reservoir Capacity.

American procedures for determining the storage capacity of farm ponds (7) are based either upon a modified storage-behaviour analysis or upon the use of arbitrary storage values determined for various districts. Each technique requires the availability of runoff data, and neither can be directly applied to Australian conditions. It might be pointed out that most American research in the hydrologic design of farm ponds has been concerned with storages located in the humid eastern states, where there are definite seasonal periods of use and replenishment. This considerably simplifies the problem of determining storage capacity and catchment area as compared with Australian conditions, where year-round use is normal and inflow is erratic, non-seasonal and unpredictable.

In the first Bulletin of the Water Research Foundation the writer proposed four methods for determining storage capacity depending upon the type and size of the storage and the quality of the design data available. The current research programme is based upon these methods.

The determination of storage volume depends upon a number of factors, the most important of which are :-

(a) Volume and temporal distribution of runoff.
(b) Volume and temporal distribution of demand.
(c) Operating procedures.
(d) Economic considerations; storage-excavation ratios, WSI ratios etc.

Investigation of these factors has been as follows:-

(a) Volume and temporal distribution of runoff.

The determination of catchment yield, particularly with regard to its distribution throughout the year, has already been dealt with in the previous section.

To complement the records available from experimental catchments, data relating to frequency of replenishment and length of periods without inflow are being collected from landholders operating farm dams throughout N.S.W. by means of a Farm Dam Questionnaire, which is now being circulated in a preliminary survey to 50 landholders in various parts of the State. It is anticipated that at least 1000 landholders will be questioned in this way by the end of 1960.

This Questionnaire is dealt with in more detail in Appendix G of this report, and a copy of the Questionnaire Form is included with that Appendix.

(b) Volume and temporal distribution of demand.

It has been outside the scope of this investigation to measure the use of water by crops or stock and this part of the research programme has been principally concerned with the collection of data published by other authorities and with some attempt at its evaluation. In this regard considerable assistance has been rendered by Mr. C.J. Wiesner, Senior Lecturer in Civil Engineering and Hon. Secretary of the Water Research Foundation, who has concurrently conducted research into methods for the determination of irrigation need.

These already-published data are being supplemented both by the HYDRA Scheme and by the Farm Dam Questionnaire. The HYDRA Scheme has as one of its principal aims the measurement of water use from small reservoirs and it is anticipated that in some years time this will shed important light on the design figures now available. The Farm Dam Questionnaire also includes certain questions relating to the use of water by stock and irrigation.

The Penman method (21) has been adopted for the determination of irrigation need. Frequency studies of irrigation need for the County of Cumberland have been made in connection with this research programme, and a frequency curve of irrigation need for this area is shown in Figure 1. It is proposed to prepare generalised irrigation need data for N.S.W. on an isopleth map.

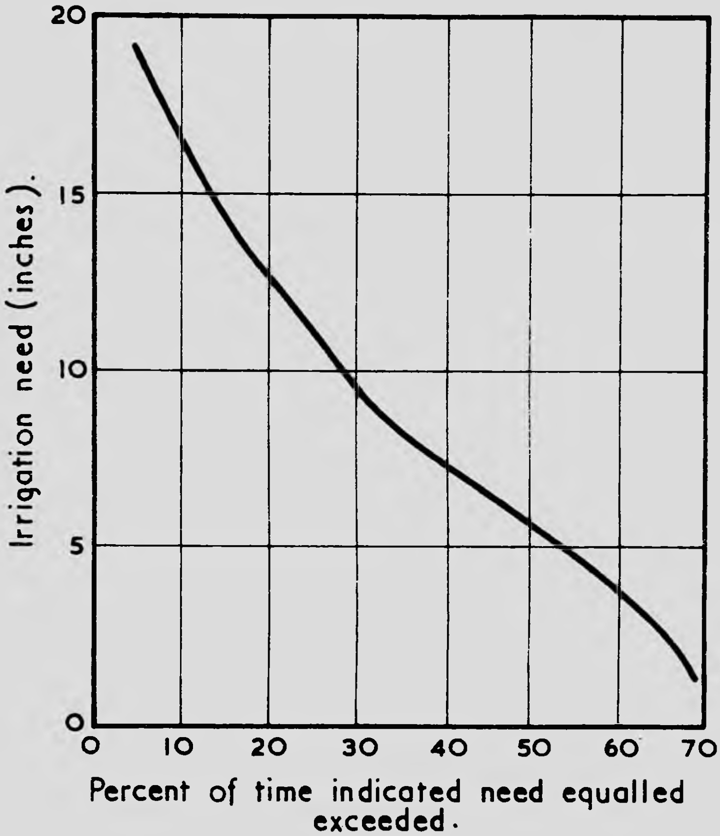

FIG. 1.—IRRIGATION NEED. COUNTY OF CUMBERLAND.

TABLE 5 : COMPARISON OF RESERVOIR DESIGN METHODS.

Irrigated Area (acres)	Degree of Reliability	Frequency Analysis Method		Storage Behaviour Analysis	
		Required capacity.		Required capacity.	
		ac. ft.	a.f. / ac.	ac. ft.	a.f. / ac.
200	90	312	1·56	330	1·65
150	90	212	1·41	220	1·46
135	90	178	1·32	180	1·33

(c) Operating Procedures

In Bulletin No.1 of the Water Research Foundation the writer considered the operation of supplemental irrigation storages at some length and concluded that the most economical procedure for the watering of pastures was to use as low a degree of regulation as possible. Some further studies have proceeded on the basis of computed storage behaviour analyses for Hunt's Creek. The Farm Dam Questionnaire and HYDRA are also aimed at giving information about existing operation procedures.

(d) Economic considerations

Some preliminary investigations have been carried out in relation to best values of storage-excavation ration and the optimal ratios between watershed area and irrigated area, in so far as these may determine storage capacity.

The Farm Dam Questionnaire asks specific questions in regard to costs of construction, repair and maintenance of farm dams which are expected to shed light on this problem.

Three basic storage design procedures are proposed:-

(i) Storage behaviour analysis.
(ii) Design on basis of expected minimum runoff and maximum demand.
(iii) Use of arbitrary storage coefficients.

A storage behaviour study is desirable for a large irrigation storage or for a water-harvesting scheme. Such an analysis is straightforward once design figures for inflow and demand have been established. Typical analyses have been made over a 20 year and 30 year period for various reservoirs at Badgery's Creek and Hunt's Creek respectively.

Design on the basis of frequency studies of runoff and demand appears to be suitable for small storages. A comparison of this method with a detailed storage behaviour analysis on a monthly basis has been carried out for parts of the County of Cumberland, and results of the comparison are given in Table 5. Generalised demand and inflow maps for N.S.W. are proposed eventually for design use.

Arbitrary storage provision is suitable for stock tanks and small irrigation storages where the consequences of failure are not important. Arising out of the storage behaviour and demand frequency investigations mentioned above, it is proposed to prepare arbitrary data showing the volume of storage required to irrigate one acre and to water 100 sheep for various zones in N.S.W. A typical preliminary map is shown in Figure 2.

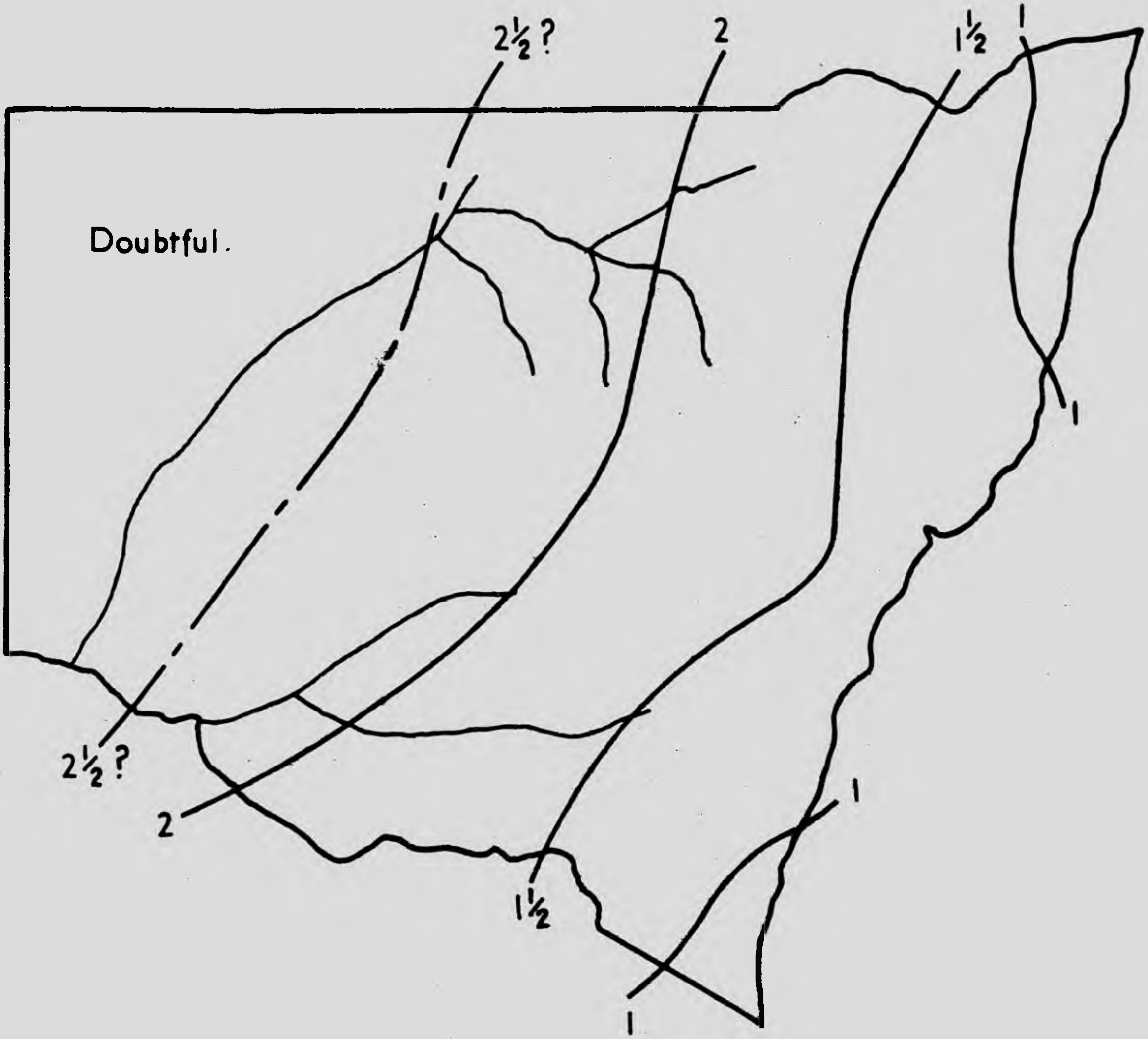

FIG. 2.-VOLUME OF STORAGE IN ACRE FEET REQUIRED TO IRRIGATE ONE ACRE OF PASTURE.

(Tentative only)

7. Economics of Water Storage

In conjunction with the studies of hydrologic design and operation of small storages mentioned in previous pages, detailed consideration is being given to the economic factors associated with the use of farm dams for supplemental irrigation. This work is being undertaken by the writer for a Master of Engineering thesis under the title of "Economic Design of Small Storage Reservoirs". The object of this thesis is to establish a simple basis for the economic design of small dams and farm water storage systems of the Water Harvesting type. In particular, attention is being given to the use of linear programming techniques for determining the optimum economic design under a given set of circumstances.

Data relating to construction costs, storage-excavation ratios, WSI ratios, operation costs are likely returns from irrigated crops and pastures have been collected from a variety of sources, including the Water Conservation and Irrigation Commission and the Bank of N.S.W. The Farm Dam Questionnaire referred to previously is designed to collect information about certain of these factors.

A simple graphical method of linear programming for optimising the design of small reservoirs is under study. Detailed linear programming studies for the Water Harvesting Scheme at Badgery's Creek and the Keyline properties at North Richmond are also being undertaken.

8. Multi-Storage Projects.

Following on the publication of Bulletin No.1 of the Water Research Foundation, which dealt with the engineering aspects of Water Harvesting and Keyline schemes, further developments in these schemes have been studied. In particular the development of the Keyline water storage systems at North Richmond has been closely followed, with the co-operation of Mr. P.A. Yeomans, and some proposals for further research on these properties are now under consideration.

9. Conclusion

Research in the field of Hydrologic and economic design of small storages for farm water conservation has developed in two main phases; firstly, an attempt to provide design data for immediate use and secondly, the collection of suitable long-term data for future design use.

The second phase must continue for many years through the expansion of the HYDRA Scheme. Additional funds for instrumentation of HYDRA stations will be required for at least two years. Further limited funds will be required over at least the next 10 years for maintenance of the scheme.

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APPENDIX F - THE HYDRA SCHEME

HYDRA

A Scheme for Hydrological Data Collection.

1. The Need for Hydra.

The hydrologic design of a farm dam or tank involves the determination of such things as the storage capacity needed to meet stock or irrigation requirements, the area of catchment needed to fill the dam, and the size of the spillway or bywash needed to ensure its safety. To provide answers to these questions with any degree of accuracy, hydrologic data about water use, runoff, evaporation and seepage losses must be available.

In Australia there are sufficient records of streamflow and rainfall to enable the design of large dams to be made with reasonable accuracy. For farm dams, however, which are fed by intermittent surface runoff, very few data are available, and the hydrologic design of such dams must be based largely on guesswork. In consequence a large proportion of them are failures; either directly as the result of overtopping of the embankment, because the bywash is too small, or indirectly, but just as seriously, because the dam is too small, or the catchment is not large enough, or seepage losses are too high.

Twenty years ago this might not have been very serious, and it could have been argued that it was cheaper to build another dam than to worry about data collection and scientific design. During these twenty years, however, there has been a considerable change in the pattern of agricultural water use in Australia. High farm incomes, improvements in earthmoving equipment, the decline in the rural labour force and a growing realisation of the importance of stored water to the landholder, spectacularly demonstrated by experiments like water harvesting and the Keyline Plan, have conspired to bring about something of a revolution. Farm dams are being built in ever-increasing numbers and, more importantly, in ever-increasing sizes, so that reservoirs storing 100 million gallons have become almost commonplace. In the aggregate these dams represent a considerable investment and they play an important part in the rural economy. A research programme aimed at the development of generalised data which can be applied cheaply and simply to the design of individual farm dams can therefore be well justified.

Such a programme is now being undertaken by the School of Civil Engineering of the University of New South Wales, in conjunction with the Water Research Foundation of Australia.

To develop these design data, information about runoff, water use and reservoir losses must be available. Since such hydrologic data are not available in Australia, the first stage in the research programme must be to begin collecting the necessary basic information.

The collection of accurate hydrologic data from small catchments and farm dams involves, however, a considerable expenditure, and a lengthy time period must elapse before the accumulated information becomes useful for research purposes. For example, the instruments needed to measure rainfall and runoff on a 100 acre experimental catchment would cost between £500 and £1000, and the records obtained with these instruments would be of little use until a period of perhaps five years had passed. To give an accurate picture of runoff conditions from small catchments in N.S.W. alone about twenty such catchments would be needed, and costs of installation and maintenance would probably exceed £30,000 over a five year period.

To instrument an experimental catchment of this type involves the building of a measuring flume or weir, which must be fitted with an automatic water-level recorder, and the installation of one or more pluviographs or recording raingauges. A great deal of useful information can be obtained cheaply, however, by simple and less precise means.

The most important information required for the hydrologic design of a farm dam relates to the volume of runoff coming from time to time from the catchment area. Under favourable circumstances this can be measured simply by collecting the runoff in a large receptacle, such as the farm dam itself. Cheap instruments, read periodically by local observers, can be used to record the volume of runoff, as well as rainfall, evaporation and seepage losses. Twenty stations of this type can be set up for the cost of just one fully instrumented experimental catchment. Because of the very large number of farm dams being constructed today, and the almost total lack of data on which to base their design, it is considered preferable to sacrifice quality for quantity and simplicity in the early stages of the data collection programme.

The accuracy of the results obtained with these cheap methods is appreciably lower than can be expected from an experimental catchment. Two factors should, however, be borne in mind. Firstly, the HYDRA scheme has as its immediate object the preparation of generalised design data, for which catchment yield figures accurate only to the nearest inch per annum are needed; and secondly, relatively inaccurate data are preferable to no data at all. In farm dam design, moreover, it is essential to know the periods of time over which no runoff can be expected, and this can be determined with considerable exactitude by the method suggested above.

Precise information relating to peak rates of runoff is needed, of course, in the design of spillways and for the design of other structures such as bridges, culverts and causeways which may be located on rural areas. This sort of information can only be obtained from properly instrumented experimental catchments; a scheme such as the one outlined above must therefore be supplemented by a related network of experimental catchments to give a complete picture of the hydrology of a rural area.

All this is now being attempted by the University of New South Wales through a scheme known as HYDRA, or Hydrologic Data from Rural Areas. The scheme was devised to overcome the considerable expenditure and long time delay involved in the conventional catchment instrumentation, by setting up a network of simple measuring stations designed to give approximate information about catchment yield and reservoir behaviour byusing farm dams as measuring devices. The scheme is being extended, as funds become available, by a related network of precisely instrumented experimental catchments. It is anticipated that the complete project will yield a body of research and design data which will be of value, not only to farm dam designers, but to all concerned with the hydrologic design of hydraulic structures - bridges, culverts, causeways, soil conservation works and so on - located on rural areas.

2. Collecting Hydrologic Data in Farm Dams.

The basis of the HYDRA programme is to collect hydrologic data by using farm dams and tanks as measuring devices. This is accomplished by measuring changes in storage level in selected dams and relating these changes to rainfall and other climatic factors. In this way data are accumulated with regard to catchment yield, evaporation and seepage losses and water use.

A farm dam provides a suitable device for measuring runoff for the following reasons:-

1. The dam is a convenient receptacle in which changes in volume can readily be measured using staff gauges or water-level recorders.

2. The catchment is generally small, homogeneous and easily surveyed, so that flow into the dam can readily be related to runoff from the catchment.

3. A great many dams can be instrumented at low cost and records can be collected by landholders.

The hydologic factors governing the water level in a small dam are related by a "Water Balance" equation, which may be simply stated as follows:-

Volume of water going into the dam	=	Volume of water going out of the dam
	plus	
		change in volume of water stored in the dam,

when considered over a given period of time.

This may be expanded to include the separate factors as follows:-

(Runoff from the catchment area (and rain falling on dam surface	=	Spillway overflow) +evaporation loss) +seepage loss) +water used by stock or irrigation) +increase in the volume of water stored in the dam)

If all but one of the above factors can be measured, the value of the unknown factor can be determined from the equation. The total annual inflow from the catchment area is known as the yield of the catchment, and the primary purpose of the HYDRA scheme is to accumulate a body of data about annual yield which can be analysed to indicate average yield and the likely minimum yield to be expected in a given year at a given location. This information provides a basis for determining the required storage capacity of a dam and the area of catchment needed to fill it.

All the items in the water balance equation, with the exception of the inflow from the catchment, can be measured by simple means. The most important of those items is the change in storage volume, which is determined by recording the change in water level in the dam as indicated on a graduated post or depth gauge. The change in the depth is related to the change in volume by Storage-Elevation Curve, which is a graph showing the volume held in the dam for a given depth of water. This graph is prepared by surveying the dam when it is empty or by taking soundings when it is full. A mobile laboratory, equipped with up-to-date surveying instruments, a boat and compressed air diving apparatus is used by the University for this purpose.

The remaining items may be measured with varying degrees of accuracy. Runoff into farm dams occurs only infrequently and for short periods. During these periods evapo-seepage losses are negligible, and the volume change may therefore be taken as due to inflow alone. On the other hand, during the bulk of the year when no runoff is entering the dam the change in storage level is due entirely to evaporation and seepage, plus farm use and minus rain falling on the dam. These last two items can be measured, leaving the balance as evapo-seepage losses. A simple form of evaporimeter is installed to indicate what proportion of the total evapo-seepage loss can be attributed to evaporation. Where water from the dam is taken for irrigation purposes, the volume used can be determined by checking the storage level immediately before and after each irrigation. Water use by stock is estimated from the recorded number of animals using the dam, or, for preference, by metering the supply from a windmill into stock troughs.

The remaining item to be measured is the volume of water lost through the bywash. This can be determined with sufficient accuracy by reading the depth of water in the dam at six hourly intervals during the infrequent periods that overflow occurs, and noting the times at which overflow commences and ceases. A simple maximum water level recorder is attached to the gauge post and records the peak rate of discharge.

The accuracy of the measurements obtained by the methods outlined above will vary according to the size and shape of the dam, proportion of losses due to seepage, frequency of spillway discharge and so on. It is considered that a maximum allowable error of half an inch in the annual runoff figure is permissible. On a 100 acre catchment this represents just over one million gallons of water, so that a very much higher accuracy than the allowable maximum should be obtained in most cases.

3. Extensions of the Farm Dam Scheme.

For the design of larger farm storages used for large scale supplemental irrigation, as well as for determining the peak rates of discharge through spillways, bridges and culverts, it is necessary to have more precise information than can be obtained from the farm dam scheme outlined above. The scheme is therefore being extended with a related network of more extensively instrumented dams, together with a series of experimental catchments.

In a number of representative areas the basic farm dam recording station is being supplemented by the addition of a water level recorder, placed in the dam, together with a weir sill in the bywash. These additional instruments give a much more accurate picture of reservoir behaviour, shed further light on evapo-seepage losses and water use, and provide hydrographs of rate of flow through small dam spillways. It should be pointed out that there are no gauged spillways on farm dams in N.S.W., and design capacities are currently based on peak rates of runoff from the catchment, taking no account of the regulating effect of the reservoir. It is anticipated that the data obtained from these more precisely instrumented dams will therefore lead to some reduction in spillway sizes and consequently in costs of construction. An improved evaporimeter pan is installed on these stations to give more precise information about evaporation rates. The cost of instrumentation for a station of this type is approximately five times the cost of that for the basic HYDRA station.

As funds become available a further class of station is being installed in representative climatic areas. These are fully instrumented experimental catchments, which wherever possible are being set up on farm dam catchments in conjunction with the storage behaviour instruments described above. They are intended primarily as research catchments, as distinct from the basic stations whose immediate purpose is to provide approximate data for design purposes. The experimental catchments involve the construction of a measuring flume which measures the volume and rate of flow of runoff into the dam, this flume incorporating an automatic water-level recorder. A pluviograph is also necessary, giving a continuous record of amount and rate of rain falling on the catchment. Records from these experimental catchments will be used for a variety of hydrologic research apart from the farm dam problem, and most of those so far instrumented have been installed in conjunction with other University research projects.

4. The HYDRA Project

The complete HYDRA scheme involves three types of measuring station. The backbone of the scheme is the simple gauged farm dam, the records from which are kept by landholders. This basic station is called a Class I station, and it comprises the following instruments.

Class I Station

Gauge posts in dam	(graduated in feet and inches)
Daily-read rain gauge	(standard 8 inch pattern)
Evaporimeter drum	(non-standard 2 ft. dia.)
Peak water level indicator	

The cost of these instruments is about £25.

The second class of station includes a water level recorder for more detailed information about reservoir behaviour and spillway outflow. It comprises the following instruments.

Class II Station

Gauge posts and raingauge as for Class I
Water-level recorder, Bristol or Gurley type
Weir sill in bywash
Evaporimeter pan (American Class A land pan)

The third group of stations comprises the experimental catchments. Instrumentation on these catchments varies, but includes the following:-

Class III Station

Daily read raingauge and pluviograph (Normally Mort type pluviograph is used).
Measuring flume or weir with automatic recorder.

Wherever possible the Class III station is being set up in conjunction with a farm dam having Class II instrumentation.

At the time of writing (June 1960) the University operates 17 stations in the HYDRA scheme, of which 8 are Class I stations, 3 are Class II stations and 6 are Class III Stations. In addition records are obtained from another 3 Class III Stations on which the University has provided pluviographs only. A map showing the location of these catchments is shown in Figure 1. Figures 2, 3 and 4 show photographs of typical Class I, Class II and Class III Stations respectively.

A number of further stations has already been selected, these being in the main of Class I type. It is anticipated that by the end of 1960 a total of 50 HYDRA stations will be in operation.

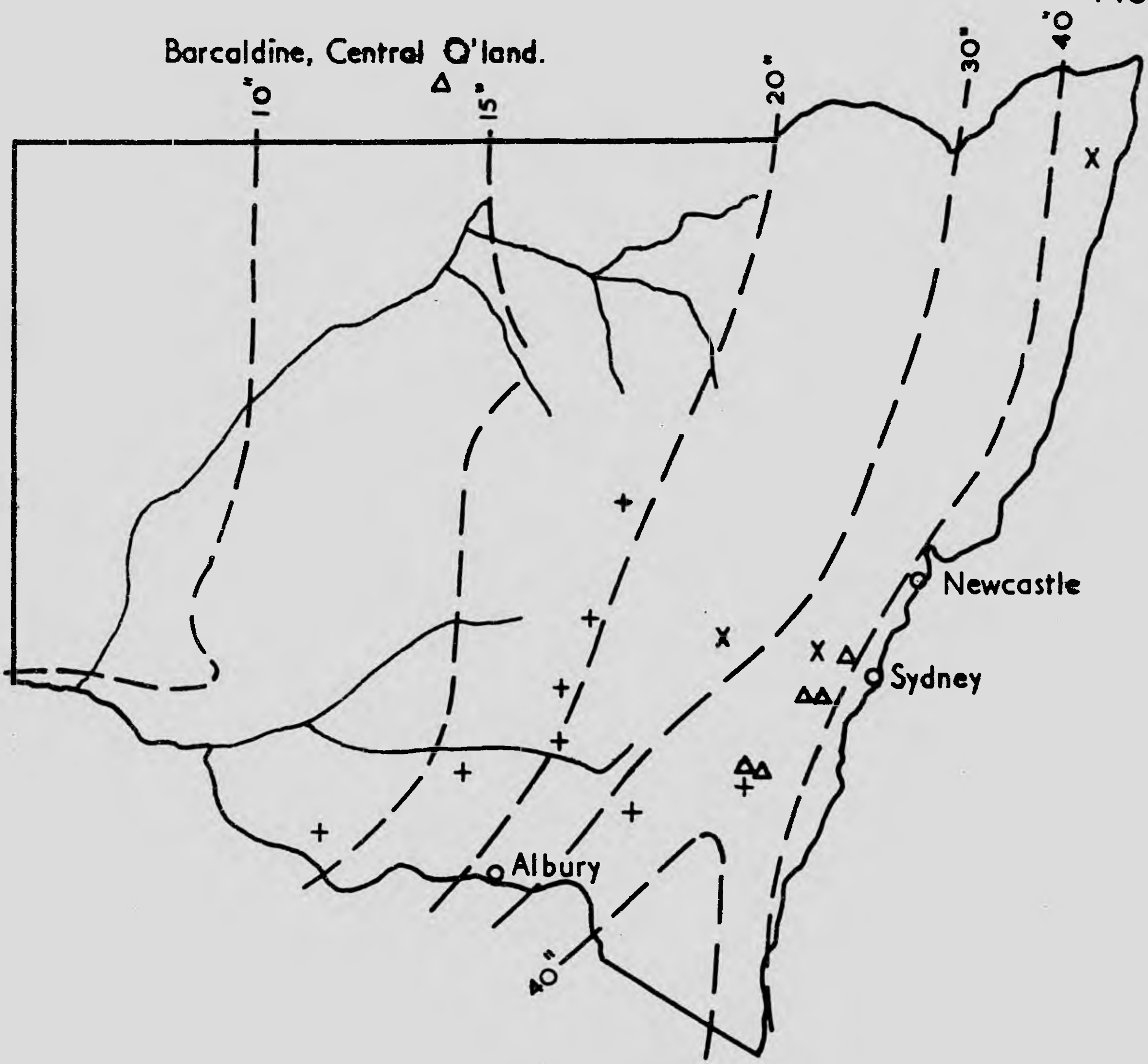
5. Administration of the HYDRA Scheme

The HYDRA Scheme is operated and administered by the School of Civil Engineering of the University of New South Wales. The University owns all instruments, and installation and maintenance of these instruments, together with catchment and storage-elevation surveys, are carried out by the Conservation Engineering team of the Civil Engineering School. All records and instrument charts are forwarded periodically to the University, where they are analysed and stored within the Hydrology Section of the School.

Most of the cost of purchasing and installing instruments has been met from grants made to the University by the Water Research Foundation of Australia and the Rural Credits Development Fund of the Commonwealth Bank. In most cases people taking part in the Scheme have also assisted with the provision of labour and materials. In this regard particular mention should be made of the co-operative effort involved in the installation of the Class III Station at Barcaldine in Central western Queensland, which is the only experimental catchment in that state.

In this case instruments only, to the value of about £250 were provided and installed by the University, whilst the cost of constructing a weir and float well, also amounting to about £250 was met by the Western Queensland Local Authorities Association. This sum was raised by contributions from local government bodies throughout Western Queensland, who will derive particular benefit from the records obtained on the Station. This fine example of co-operation and self-help could well be emulated in other districts, to the benefit of the rural community at large.

The majority of the Station operators are private individuals. Of particular interest, however, is the assistance provided by the Junior Farmer Movement in N.S.W. Following the suggestion of Mr. John Wildman, Regional Supervisor of Junior Farmers for the Southwest of N.S.W., and with the active support of the State Supervisor, Mr. W. Tearle, it is now proposed that wherever possible Class I Stations will be operated by Junior Farmers, under the general surveillance of their District Supervisors. This co-operative effort by the Junior Farmer Movement has done a great deal to place the HYDRA Scheme on a sound footing, and has ensured a continuing interest in the Scheme and a high standard of record keeping. There are now 5 Junior Farmer observers in the Southwest District, and a further 30 young people are awaiting the delivery of instruments.



HYDRA STATIONS

Class I +

Wagga (JF)
Temora (JF)
Urana (JF)
Mathoura (JF)
Humula (JF)
Parkes
Dubbo
Futter Park

Class II X

Alstonville
Nashdale
North Richmond

Class III Δ

Badgery's Creek (Uni. N.S.W.)
Mt. Vernon
Futter Park (2 catchments)
Barcaldine, Queensland
Parramatta

Average annual rainfall shown by dotted lines.

FIG. I.— HYDRA SCHEME — STATIONS IN OPERATION, MARCH, 1960.

APPENDIX F.

Fig. 2

CLASS I STATION

Fig. 3

CLASS II STATION

Fig. 4

CLASS III STATION

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APPENDIX G - STRUCTURAL ASPECTS OF DESIGN AND CONSTRUCTION OF LOW EARTH DAMS - PROGRESS REPORT 1957-1960

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1. Introduction
2. Research Equipment
3. Current Practices in Design and Construction
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5. Tunnelling Failures
6. Conclusion.

1. INTRODUCTION

The need for research into improved methods for the design and construction of small earth dams for farm water storage is not immediately apparent. The average farmer, accustomed to handling soil with a variety of farm implements, thinks of the construction of a small embankment as a simple matter of pushing up a heap of soil to "hold back the weight of water", and has no appreciation of the problems in soil mechanics he thus creates. On the other hand, the average civil engineer considers such small structures as unworthy of detailed attention, and simply applies the principles of large dam construction with results which, if generally (but not always) are safe, are rarely economical.

Research in the United States (1) has shown that the greatest proportion of failures occurs amongst small earth dams, and it has been stated (2) that the two failures causing greatest loss of life and damage to property were of structures less than 50 feet in height. Whilst the failure of a farm dam is unlikely to cause loss of life, it may result in considerable property damage, loss of capital and reduction in income. After some years of studying the construction of farm dams the writer has concluded that the proportion of farm dams which fail for structural reasons is excessively high; this is due in part to poor design and more particularly to poor construction methods. Statistical data to support these conclusions are now being collected (See Section 2 and Addendum 1)

The reasons for this research project and the basis of the current research programme are contained in the following quotations from well known engineers:-

G.D.Aitchison of the C.S.I.R.O. Division of Soils, in the introduction to a paper describing an investigation of construction methods for a turkey's nest dam at Brenda in N.S.W., has written (3) "... These circumstances, which may be considered as typical of many such dam sites in similar areas of Australia, are dominated by two factors - firstly that the only construction material available is a heavy clay, and secondly that the type of construction equipment available to form and compact the embankment is limited to light-weight general purpose machinery".

"There is thus a sharp contrast between the requirements of such small dams and the engineering problems of larger embankments. Generally, the construction of a large earthen dam involves the use of a central clay core for water retention, with coarser material in the outer body of the dam to provide the necessary stability. Normally there is careful selection of materials followed by a study of construction procedures and of construction equipment to suit each class of material."

"Obviously such refinements are impractical in the case of a small dam as proposed at Brenda. Nevertheless it is possible that many such dams will be constructed in the course of time and so an investigation conducted along normal engineering lines may ultimately prove to be economically justifiable. From the point of view of academic interest it is worthy of note that an efficient design of a small dam is probably more difficult to achieve than a comparable design for a major dam. It is however, comparatively easy to produce a conservative (or inefficient) design for a small dam but virtually impossible to produce a grossly inefficient design for a major dam of maximum height."

The problem of construction control on small dams has been outlined by Dr. Terzaghi as follows (4):-

"Thorough compaction is generally considered necessary for earth dams of any height... However the enforcement of rigorous water content control on small projects in remote districts may be impracticable. If economic or other considerations preclude rigorous water content control, the designer is compelled to rely on semi-empirical rules. Such rules can be established only on the basis of the performance record of earth dams which were made of soils with a water content far above or far below the optimum and by correlating the findings with the index properties of the construction materials."

The great majority of farm dams constructed today are built by landholders or small earthmoving contractors who have little or no knowledge of the stability requirements of earth dams: in consequence, a very large proportion of these dams are failures. Words written by Joel B. Justin (5) many years ago are pertinent:-

"Unfortunately there is a feeling among many people that the design and construction of earth dams are matters so simple that that anyone can handle them. Men who employ experts to audit their books will sometimes entrust the design and construction of an earth dam, on the safety of which, perchance, their very lives and fortunes may depend, to anyone at all without inquiring into his competency".

By contrast with this statement, two articles appeared some time ago in "Country" magazine, a rural journal circulating in the eastern states of Australia (6), which purported to teach how farm dams could be built simply and cheaply by anyone at all. One of these articles, written by an earth-moving contractor, described the system of dams built on his own property - a system which has since failed because of the collapse of most of the embankments. The other article, which stated that "you don't need an engineer" and claimed that most of the accepted engineering practices are unwarranted, was written by the manager of an earthmoving firm which has subsequently gone into liquidation following an exceptionally high proportion of failures amongst the embankments it constructed.

It is therefore apparent that the methods of farm dam construction now in vogue amongst landholders and contractors are not satisfactory; that accepted engineering techniques for the design and construction of major earth dams cannot economically be applied to small structures; and that in consequence there is a need for research, generally among semi-empirical lines which involve field studies and long term observations of the performance of typical embankments. This provides the general basis for the current research programme, the progress of which is reported upon in the following pages.

2. RESEARCH EQUIPMENT

This research programme revolves around field studies in soil mechanics, and it has been necessary to establish a mobile soils and general purpose laboratory for the efficient carrying-out of these field studies. The comprehensive facilities of the Soils Laboratory of the School of Civil Engineering are available for detailed testing of soil samples. Since the headquarters of the Conservation Engineering team is located at the Water Research Laboratory at Manly Vale, some 10 miles distant from the Soils Laboratory, a small laboratory has also been established at Manly for routine testing work.

The mobile laboratory has been set up in a Fargo panel van provided and maintained by the University. It has been fitted with sink, cupboards, roof rack etc., and equipped with water and gas supply and fluorescent lighting. A tent is available to provide additional laboratory space when carrying out extensive testing on a fixed site.

Details of the equipment associated with the Mobile Laboratory are given in Table 1. Since this vehicle was taken over for conservation research purposes in July 1958 it has travelled a total of 16,000 miles in connection with this research .

TABLE I

MOBILE LABORATORY -- EQUIPMENT AVAILABLE OR ON ORDER

Purpose of Equipment	Details
1. General	Water supply: S.S. sink and D acting pump Propane gas cylinder and gas burners 45v. battery operated fluorescent lighting Dual-wave radio receiver. 9' x 9' autotent (temporary laboratory) Cupboards, shelves, roof carrying rack
2. Soil Testing	250 gm. Chaindial balance 2 Kgm triple beam balance 100 lb. platform scales Standard sieve set 8" dia. Portable sieve shaker Hydrometers and other apparatus for grain size determination Apparatus for determining Atterberg Limits Field Density apparatus Pocket penetrometer Harvard compaction apparatus Proctor compaction apparatus Portable permeameter Neutron-scatter soil moisture meter

TABLE I (Cont'd)

Purpose of Equipment	Details
3. Soil Survey	8 HP. petrol driven drilling rig for soil boring and undisturbed sampling 2 HP. jetting pump Hand auger and sampling tubes
4. Survey	Theodolite, microptic type Tilting level with horizontal circle Aluminium staff Binoculars, 8 x 50 Tapes, bands, arrows, pegs, ranging poles etc. Prismatic compass Abney level Aneroid "Bunyip" level
5. Hydrographic	8' plywood dinghy Sounding lines Life belts Self-contained underwater breathing apparatus with cold-water suit.
6. Water testing	pH meter Resistivity meter
7. Meteorologic	8 day clock, barometer, max and min. thermometer, standard raingauge, anemometer.
8. Miscellaneous	Motor tools and spares Chains and sand mats Shovel, axe, crowbar, ropes etc. Fire extinguishers, foam and CTC First-aid kit Kerosene pressure lantern Primus stoves.

3. CURRENT PRACTICES IN DESIGN AND CONSTRUCTION

(a) General investigation

A body of information has been collected about current practices in farm dam design and construction. This has been obtained from the following sources:-

(i) Details about legislation, administration, design procedures etc., have been obtained from State Authorities responsible for or concerned with farm dam building in all states except Western Australia.

(ii) Recommendations made by earthmoving equipment manufacturers have been obtained and studied.

(iii) Dambuilding methods employed by contractors and farmers-builders have been studied in the field. Some field measurements of compaction, settlement etc. have been made (See Section 3)

From this general study it has been concluded that the Design figures recommended by authorities such as the Farm Water Supplies Branch of the Water Conservation and Irrigation Commission of N.S.W. are safe, if in many cases over-conservative, and that the principal causes of structural failure can be related to poor construction. This is due not so much to the general construction procedure adopted (that of pushing soil into position with a bull-dozer with little or no compaction,) which, whilst not in accordance with the ideas of civil engineers trained in major dam construction, appears if intelligently carried out to result in safe embankments; but to the poor practices employed within this general procedure on individual projects. It might generally be stated that the immediate need in the farm dam construction field is not for research but for the education of farmer-builders and small earthmoving contractors in the basic principles of the soil mechanics of low earth dams. Were these principles generally understood the average farm dam builder would not continue to use slipshod construction methods, so frequently employed not to save money but simply because the builder does not appreciate the reasons for proper compaction, stripping of the foundation, proper forming of the back batter and so on.

In May 1960 the writer presented a paper on this topic to a School for graziers conducted by the Institute of Rural Technology of the University of New South Wales. It is intended that this paper should form the basis for a manual of farm dam building and it is hoped that the Water Research Foundation might give some consideration to the publication of this manual.

(b) Farm Dam Survey

In order to collect more specific data about the design, construction and performance of farm dams than has been possible from the general enquiries mentioned above, a detailed questionnaire has been prepared for circulation to selected landholders.

The questionnaire is now being circulated to 50 selected graziers in order to check its suitability. On completion of this trial survey a total of 1000 forms will be circulated, in two groups, firstly, to landholders selected by random sampling from the Australian "Pastoral Directory" in order to collect statistical data about the pattern of use of farm dams in N.S.W. and secondly, to farmers and graziers known to have some experience with farm dams in order to collect information about methods of construction, hydrologic factors, and reasons for failures. The survey may be expanded during 1961 to cover other states of the Commonwealth.

4. EXPERIMENTAL INVESTIGATIONS IN DAM CONSTRUCTION

Farm dams are generally constructed from in situ soils at natural water content and using general-purpose equipment, such as medium and light bull-dozers or rubber tyred farm tractors and scoops. No control testing of any sort is carried out to determine the properties of the soil or the degree of compaction obtained or desirable.

Major earth dams, on the other hand, are constructed using selected soils placed at carefully controlled water contents and compacted under controlled conditions with specialised equipment.

It is apparent from the investigations mentioned in the preceding section that a considerable reduction in the number of failures of farm dams would result from the introduction of control techniques. It is rarely economical or feasible to go to the trouble involved in the construction of a major embankment; it is, however, desirable that semi-empirical methods which can be applied generally to farm dams should be developed. The quotations from Aitchison and Terzaghi given in the Introduction to this report are relevant to this point.

Research with this aim has commenced. It has so far been conducted along the followinglines:-

(a) Determining the index properties of typical dam building soils.

(b) Studying failures of dams built by conventional methods.

(c) Measuring soil properties and performance of dams built both by conventional and experimental methods, in an attempt to develop some form of control technique. This may take the form of recommending specific batters for specific soils and construction methods: and/or recommending construction techniques, particularly in regard to methods of compaction: and/or devising simple tests for moisture and compaction control.

This research may continue for several years, particularly in regard to observations of the performance of dams constructed by experimental procedures. It is considered, however, that the major part of the work will be completed within two years. Progress under the above headings has been as follows:-

(a) <u>Index properties of typical soils</u>

Samples taken from a number of actual or proposed damsites have been tested to determine their index properties. To date some 230 individual tests have been carried out on over 90 separate samples.

An attempt is being made to interpret these engineering tests in relation to the terms used by soil scientists, in order to bridge the gaps between the nomenclatures and classification systems used by engineers and agricultural soil scientists.

(b) Failures of small earth dams.

Wherever possible dam failures have been studied in order to establish the reasons for failure and to relate them to the methods used in designing and building the dam. Despite appeals to the public on press and radio, information about failures has been difficult to obtain. The farm Dam Survey asks specific questions about failures which are expected to be of considerable assistance in locating failures for further study.

To date a total of 14 failures has been investigated. Details of these are as follows:-

1. Pye's Dam, Liverpool. Failure of 25 ft embankment following heavy rain. Cause of failure was slide of downstream face due to very poor compaction of soil.

2. McCallum's Dam, Bribbaree - repeated failure of 20 ft. embankment by tunnelling - detailed soil testing carried out, and methods for overcoming problem still under consideration.

3. Vile's Orchard, Branxton. Failure of 5 embankments following heavy thunderstorm, after dams empty for two years - one failure from tunnelling(solodic soil) and others from cracking.

4. Soil Conservation Service, Bulga - failure of 4 dams by overtopping: detailed compaction and survey information before failure had already been undertaken by the University.

5. Cotton's Dam, Shooter's Hill - piping failure.

6. New Brighton Golf Club, Liverpool - overtopping following excessive settlement.

7. Yeoman's Dam, Orange - tunnelling failure of 30' embankment - reconstruction studies in hand.

Figure 1 shows a typical failure from poor compaction. Figure 2 shows a tunnelling failure resulting from the presence in the wall of a dispersive soil.

Fig. 1: Dam failure at Liverpool, N.S.W.
Cause of failure – inadequate compaction at extremely low moisture content.

Fig. 2: Dam failure at Bribbaree, N.S.W.
Cause of failure – presence of solodic soil in embankment.

(c) Experimental Dams

The major objective of this research project is to construct experimental embankments and to observe their performance. Limited work only in this direction has been possible, the emphasis so far having been concentrated on setting up the mobile laboratory and developing suitable test procedures. A number of landholders, contractors and manufacturers of earthmoving equipment has been approached to make available land and equipment for field studies. In particular, Caterpillar Tractors Ltd., Wheel Traction Ltd., Camden Constructions Ltd., and the Soil Conservation Service of N.S.W., have agreed to make plant available for field trials with crawler tractors and rubber tyred plant, and preliminary surveys and soil testing have been undertaken for an experimental ring dam at Parkes and an off-stream swamp storage at Wiseman's Ferry. Land has been promised by a number of people, and a property at Wallacia in particular has been selected for the building of trial dams. Partial studies on two dams built on this property have been made.

Full field studies of dam construction have been made in two places: at Bulga, in co-operation with the Soil Conservation Service, and at North Richmond, in co-operation with Mr. P.A. Yeomans.

Bulga Studies

At Bulga, near Singleton, the Soil Conservation Service of N.S.W. in 1959 commenced the construction of 10 small experimental dams as part of an investigation into tunnelling failures. These dams were to be constructed by a variety of methods, and the University team was given permission to make field tests and performance observations on these structures.

Four dams were built in November 1959, and detailed surveys and measurements of soil moisture and field compaction were made. These dams failed shortly after completion from overtopping, and some measurements of density and settlement subsequent to failure have been made. It is anticipated that the whole programme will re-commence in the spring of 1960.

Keyline Study

The general survey of current practices mentioned in Section 3 has indicated that the construction and earthmoving methods advocated by Mr. P.A.Yeomans(7,8) as part of the Keyline Plan merit detailed investigation. In the autumn of 1960 arrangements were made with Mr. Yeomans for a detailed study to be made of the construction of a large dam on his property "Yobarnie" at North Richmond. Construction soil tests, including moisture and compaction studies, were carried out on this embankment, and cost figures have been made available. Settlement plugs have been placed in the completed embankment and the performance of the structure will be observed from time to time.

5. TUNNELLING FAILURES

The problem of dam failures from tennelling, when dispersive soils are used in the embankment, was first drawn to the writer's attention in 1958, when a large dam at Bribbaree, near Young, in N.S.W., failed in this way. A photograph of this failure is shown in Figure 2.

During investigations in connection with this failure it became apparent that the dispersive soil problem was far more extensive that had been appreciated. At about the same time the Soil Conservation Service of N.S.W became increasingly aware of the problem and commenced a detailed investigation. Since mid 1959 the Service and the Conservation Engineering team have worked more or less in conjunction on this investigation.

Tunnelling failures occur when highly dispersive soils are used in a farm dam embankment. When the dam fills, water works its way through the wall from the upstream face, forming tunnels which gradually enlarge from the upstream end. When these tunnels reach the downstream face the dam empties. In extreme cases the tunnels become so large that the roof collapses and the dam fails by breaking. The failure shown in Figure 2 occurred in this way.

The reasons for this dispersive property of the soil are not properly understood. It has recently become apparent, however, that the problem is widespread in N.S.W. and Victoria, as more and more dams are being built in areas where previously only small stock tanks had been considered necessary. The problem is serious in the Hunter Valley and on a large part of the Burrendong Dam catchment, particularly in the Hill End area: it would seem that the recent financial collapse of Agriplan, a large contracting company, was due to the building of a number of dams in the tunnelling area of the Burrendong catchment without any appreciation of the dangers involved. Tunnelling can also occur on many parts of the slopes and tablelands on N.S.W., in ephemeral watercourses where fluctuating water tables may produce salting of the surface soils and develop a solodic condition.

It has therefore become apparent that this problem is a serious one, which will grow in importance as more and more landholders wish to build dams on the ephemeral watercourses of the slopes and tablelands. A considerable expenditure on tunnelling investigations would seem justified, and it is planned to seek funds for this purpose in the coming year.

Apart from the Bribbaree studies, which have been inconclusive, the following investigations have been undertaken:-

(a) Co-operative soil testing of samples of tunnelling soils has been undertaken with the Soil Conservation Service, in an attempt to establish identification tests for the dispersive soils and to define areas within which tunnelling is likely to occur. The University team has carried out standard mechanical tests whilst the Soil Conservation Service has undertaken various chemical and dispersion tests. Over 40 samples have now been tested.

(b) In conjunction with the construction studies carried out at Bulga, the University team is co-operating generally in the tunnelling investigation. This work will be recommenced when the Bulga Project starts again in the spring of 1960.

(c) A large dam constructed by Mr. P.A. Yeomans at his property "Kencarley" at Orange has failed by tunnelling. This dam is located in a classic deposit of solodic material. Soil samples have been tested and a detailed study of proposed reconstruction measures is to be undertaken.

A considerable expansion of work in this field is proposed within the coming year. In conjunction with the Soil Conservation Service, a number of trial dams are to be constructed on parts of the Burrendong catchment. Approximate soil and topographic surveys have been made available, a number of sites has been selected and funds and plant have been promised. In conjunction with these field studies a programme of laboratory testing, aimed at establishing the causes of tunnelling and investigating measures for its prevention, is planned to be undertaken at the Water Research Laboratory.

6. CONCLUSION

Research into the design and construction of farm dams has so far involved preliminary studies of existing methods and the establishment of a mobile laboratory. Some field studies have been made, notably the investigation of some 14 small dam failures and construction studies on 5 embankments. Some investigations of the index properties of typical N.S.W. soils and the causes of tunnelling failures have also been commenced.

Work in this field is, by its nature, slow, time-consuming and subject to delay because of weather conditions. In the case of the Bulga Project, for example, trips to Bulga on four successive weeks had to be cut short because of inclement weather and on the following week heavy rains caused the whole project to be abandoned.

The principal reason for slow progress in this field, has, however, been a shortage of personnel who can stay in the field for long periods and, more particularly, of a suitable laboratory assistant who can undertake the great volume of routine soil testing necessary. An application for funds to meet the salary of a laboratory technician for this work has recently been made to the Water Research Foundation. Appointment of such a person will result in a considerably accelerated progress in this field.

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RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING–

PROGRESS REPORT NO.1, 1957-1960

APPENDIX H – SEALING FARM DAMS WITH PLASTIC MEMBRANES: PROGRESS REPORT 1957-1960

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING - PROGRESS REPORT NO.1, 1957 - 1960

APPENDIX H: SEALING FARM DAMS WITH PLASTIC MEMBRANES

1. INTRODUCTION

The obvious way to prevent leakage from a farm dam is to line it with a watertight membrane, and a variety of materials have been used for this purpose. These have ranged from reinforced concrete and bitumen paving decks, which are high in cost to tarred hessians and rubberised canvas, which have poor durability. For reasons either of cost, low durability or inadequate seepage reduction none of them has been able to compete with the stabilisation techniques described in the earlier articles of this series.

When plastic films became commercially available in large quantities during the early 1950's it appeared that some of them, notably polyethylene and polyvinyl chloride, possessed desirable properties for dam sealing. The first experimental tanks were lined by C.W.Lauritzen at Utah Agricultural Experiment Station, U.S.A. in 1954. Since that time dams have been lined with plastic film in many parts of the world, notably the U.S.A., Canada and Australia.

The first dam to be lined in Australia was the municipal reservoir at Charlton, in the Victorian Mallee, which was sealed with polythene film in 1955. It was at that time the largest plastic lined dam in the world. The total number of plastic treated dams in this country now exceeds 20.

In 1957 the Water Research Foundation of Australia, through the generosity of ICIANZ Ltd., financed a research project at the School of Civil Engineering of the University of New South Wales, to investigate the use of plastic membranes for sealing dams and irrigation channels. The field and laboratory studies undertaken in the course of this investigation have shown that whilst polythene film, in particular, can be used to achieve a high degree of seepage control, its high cost in Australia makes this technique uneconomical by comparison with stabilisation methods using bentonites or polyphosphates.

There are, however, special applications for which the plastic liner is particularly suited, and it is anticipated that within a few years reduced manufacturing costs and improved sealing methods may permit the plastic liner to compete economically with bentonite in normal applications.

2. FILM MATERIALS FOR DAM SEALING

Of the many plastic film materials now available, only two are considered suitable for dam lining in Australia. These materials, both manufactured in this country, are polyethlyene, more generally known as polythene, and polyvinyl chloride, more generally known as vinyl or PVC.

Polythene, a tough durable waterproof and chemically inert plastic, is used for a multitude of commercial applications. These include food packing, silage covers and wall sarking; the manufacture of piping, liquid and chemical containers, household ware and toys; it also has extensive use in electronics as an insulating medium.

Vinyl is best known as the material used to make the familiar plastic raincoat. It is also used for protective clothing, weather covers, furnishing fabrics, toys and many other purposes.

At the commencement of the Foundation's research project in 1957 it was decided to concentrate initially on the applications of polythene film, which at that time had certain important advantages over vinyl and was being used far more extensively for dam lining.

Polythene is 100 per cent water-tight; it has high tensile strength and good resistance to tearing and puncturing; whilst its resistance to deterioration in sunlight and its ability to withstand all forms of chemical attack make it ideal for outdoor applications. At the same time however, its characteristic chemical inertness constitutes a major problem in dam lining, since this makes it extremely difficult to join strips of the film together into a continuous membrane. Whilst this problem has to some extent been overcome by heat welding, it remains the major factor contributing to the relatively high cost of polythene liners.

In 1957 the vinyl films available in Australia were not suitable for prolonged outdoor use. An improved all-weather vinyl is now manufactured, and this has the advantages of greater flexibility and better resistance to puncturing than polythene. Its greatest merit lies in its ability to be joined simply and cheaply with commercial adhesives. The research programme has now been extended to look into the suitability of this material

3. <u>USE OF POLYTHENE FILM AS A DAM LINER</u>

Polythene film is available in Australia in thicknesses of $1\frac{1}{2}$ thousandths of an inch and upwards and in widths of from 6 ft to 10 ft. The main problems involved in the sealing of a dam with this material are to join the strips of film together to form a continuous membrane; to lay the membrane in position on the floor of the dam; and to protect it from damage by wind, sunlight, stock or other agencies.

Polythene is naturally a waxy, translucent material which breaks down when exposed to sunlight due to the oxidative action of ultra-violet rays. This can be overcome to a considerable extent by the incorporation of carbon black, and the resulting black polythene is invariably used for dam liners.

The best thickness of film for dam sealing depends upon an economic balance between cost and resistance to damage - both factors being directly proportional to film thickness. Most of the early liners used in America and all so far used in Australia have been fabricated from film 4 thousandths of an inch in thickness. Experience has shown that this is not adequate and most membrane fabricators in Australia and the U.S.A. now recommend thickness of 6 thousandths of an inch.

Readers will be familiar with the technique used for placing the membrane in position in the dam, through the wide publicity given to the lining of dams at Red Hill and Ouyen in Victoria and North Richmond in N.S.W. during 1957 and 1958. This technique has been used almost without variation in nearly all the dams so far lined in this country. Briefly, it involves the following steps:-

(1) Prefabrication of the liner, generally using heat welding; screening sand over the floor of the dam to form a smooth base for the liner.

(2) Spreading the liner over this base.

(3) Anchoring the edges of the liner in a shallow trench.

In all cases, except for the original dam at Charlton, the liner has been left exposed; that is, no cover material has been placed over it to afford protection against wind, sunlight or stock. Experience has shown, however, that liners installed in this way do not stand up to service conditions, particularly in hot windy locations.

Each of the three dams mentioned has suffered damage in more or less degree - in one of them the liner was completely destroyed after a life of less than four months. Public reaction to these failures has, not unnaturally, led to a general "writing off" of polythene lining amongst the farming community.

It is clear, however, that these failures have resulted from an incorrect application of the plastic material, rather than from inherent shortcomings of the polythene itself. The writer's research programme is now directed towards the development of techniques by which polythene liners can be used with a life expectancy of many years. If this can be coupled with a reduction in raw material and fabrication costs, polythene membranes have a useful part to play in farm seepage control.

4. PROBLEMS WITH POLYTHENE DAM LINERS

1. Fabrication of the Membrane

The first problem arising in the use of polythene membranes is that of joining the strips of film into a continuous liner. This may be achieved using either liquid adhesives, adhesive coated plastic tapes, or by heat welding.

Because of the chemical inertness of polythene no really effective adhesive material has yet been devised, the direct adhesives and tapes now available having the disadvantage that they are pressure sensitive; that is, seams made with them may peel apart under tension.

Heat welding, on the other hand, produces an effective water-tight seal, but has the disadvantage that the heat and pressure developed during the welding operation may alter the properties of the film and produce zones of weakness adjacent to the weld. Furthermore, heat welding is a specialist task which cannot be undertaken in the field by unskilled personnel.

At the present time as much as half the total cost of a polythene membrane is involved in the fabrication process. It is apparent that the development of a satisfactory adhesive which can be used in the field by unskilled operators will do much to reduce the cost of polythene lining. Plastics manufacturers are promoting research in this direction.

It might be noted that an ability to be sealed readily and cheaply forms one of the principal advantages of vinyl film.

The membrane may be put together either by joining the strips in situ in the dam or by prefabricating the complete liner. Each method has its advantages.

With in situ fabrication the strips of film are rolled out on the floor of the dam and joined with adhesives, tapes or portable electric welding irons. The method is time consuming and dependent upon vagaries of the weather in that it is difficult to achieve a good seal under windy or dusty conditions. On the other hand, with suitable adhesives, it can be carried out with unskilled labour at little cost. The only tank in Australia to be sealed in this way was the original project at Charlton.

In Canada and the U.S.A., however, this method is very widely used; the use of prefabricated heat-sealed membranes is apparently discouraged in the western United States due to the weakening effect of the welding process.

The alternative is to prefabricate the entire liner off the site, using either adhesives or welding. Large-scale factory welding of polythene film was pioneered in Australia by Plastalon Ltd., of Melbourne, who have manufactured most of the dam liners used in this country. This technique greatly simplifies the installation of the liner, which can be completed by a few men in one ortwo hours. It is, however, expensive - a prefabricated heat-sealed liner costing approximately twice the cost of the polythene used.

The effect of the weld upon the membrane strength needs further investigation; wind damage failures examined by the writer have generally taken place along zones of weakness adjacent to welded seams.

4.2. Mechanical Damage

Apart from high initial cost, the principal disadvantage of the polythene liner as used in Australia has been its poor durability.

When the Water Research Foundation investigation commenced it was thought that the principal danger with polythene film would come from deterioration due to exposure to the ultra-violet rays in sunlight. Early research was therefore directed towards methods for checking the life of the film when exposed to these rays, and accelerated weathering devices were investigated.

It might be pointed out that nowhere in the world have long-term measurements been made of the effects of ultra-violet oxidation on the mechanical properties of black polythene film.

Field experiments with weathering samples and dam liners in many parts of Australia have now shown that the effects of ultra-violet oxidation are negligible compared with mechanical damage caused by wind. This is the principal factor determining the useful life of a dam liner, and unless active measures are taken to control wind damage polythene liners cannot be expected to function satisfactorily.

Severe wind damage occurs on exposed black polythene liners for several reasons. In the first place, such liners may develop extremely high temperatures when exposed to the sun. Experiments conducted by the writer have shown that black polythene film may reach a temperature some 40 to 50 degrees higher than the shade temperature. Temperatures of up to 150 degrees have been measured in Sydney, and high readings could be expected in summer in western districts.

Such higher temperatures are potentially dangerous to a dam liner. The strength of polythene decreases with temperature; at 150 degrees its tensile strength is less than half that at normal temperatures.

Furthermore the material ceases to behave elastically at temperatures of this order, a small tension producing excessive and permanent stretching.

At about 160 degrees a distinct change takes place in the chemical nature of polythene, so that it loses most of its strength and suddenly becomes susceptible to attack by many organic chemicals. It is therefore of vital importance that the temperature of the film be kept well below this critical level.

In the second place, a loose polythene membrane is so light that it will flap or vibrate even when quite gentle winds are blowing. This motion results in puncturing due to beating of the film against sharp particles, whilst rapid vibration in strong winds may produce early fatigue failure in stressed portions of the liner.

Of greater importance, a strong wind blowing during hot weather when the film develops high temperatures may lead to stretching and billowing, which in turn places excessive loads on the weakened film and may produce extensive tearing along the lines of weakness.

The obvious technique for controlling this form of damage is to place a cover layer of sand or soil over the membrane. This serves the multiple purpose of preventing wind flap, reducing temperature and providing protection against ultra-violet oxidation.

At first sight it would appear that this is not a practicable proposition, due to the difficulty of placing the cover on the membrane without puncturing it and the problem of keeping it in place against wave action. Methods of achieving these objectives are currently under investigation, and it appears that the process may in fact be relatively simple.

In most cases cover need only be placed on the batters of the dam, particularly on the upper levels where wind damage is most severe. In small dams this area can be covered by hand from the top of the bank; on larger slopes sand may be spread using light tractors fitted with a grader blade. Slopes must, of course, be flat enough for plant to operate without sliding and for this reason, as well as to prevent washing of the cover down the batter, a slope of 3 to 1 is desirable. Where wave action is excessive the sand may need to be protected with a gravel layer.

A simple method for placing the cover layer by sluicing sand and water from chutes moving along the crest of the batter is now under investigation.

Where slopes are too steep for cover layers, as in many existing dams, wind action may be controlled to some extent by using heavier gauge polythene on the upper batters and by anchoring the liner at intervals with long sausages of polythene filled with sand. These measures cannot be wholly effective in hot, windy locations, and in such places it is advisable to resort to some alternative method of sealing such as bentonite blanket.

4.3 COST OF POLYTHENE LINERS

As discussed in the earlier articles in this series, polyphosphate lining can be carried out for about 2d per square foot of treated area and bentonite for about 4d. These techniques can achieve about 95 per cent reduction in seepage on the average. Each method is only suitable on a specific range of soil.

The recommended thickness for polythene dam liners is 6 thousandths of an inch. The retail price of this material in the roll is 4.3/4d per square foot. The cost of prefabricated membranes varies, according to the sealing method used, from 5,1/4d to 9d per square foot. If installation costs are included, the minimum cost of sealing a dam with a 6thous. polythene liner is about 6d per square foot. For an in situ joined liner the unit cost will also be of this order.

The cost of polythene membranes could be reduced in two ways; by reducing the price of the raw material, and by producing the film in wider sheets so reducing the amount of jointing required.

In 1957, when the first heat-sealed prefabricated liners were produced in Australia, polythene was available in 6 feet widths. It is now available in 10 feet widths, and this, coupled with a slight reduction in the price of the polythene stock, has reduced the cost of a prefabricated liner by about one-fifth since 1957.

In the U.S.A. polythene film is available in 40 feet widths and the price of the film is appreciably lower than in Australia; polythene lining can therefore compete economically with stabilisation techniques.

It can be anticipated that as the demand for polythene in Australia increases the film will be manufactured in wider sheets and at a lower unit cost. It might therefore be predicted that in the forseeable future polythene lining may compete economically with bentonite sealing, providing problems of poor durability can be overcome. It is not likely to supersede polyphosphate on economic grounds.

5. FUTURE OF POLYTHENE FOR DAM LINING

At the present time polythene lining suffers the disadvantages of high cost and poor field performance. In run-of-the-mill sealing operations, it cannot therefore be recommended, either bentonite or polyphosphate being preferable according to soil type.

It is considered that polythene membranes will give satisfactory performance if they are covered with a protective layer of sand or soil. If manufacturers and fabricators can reduce initial costs they may therefore have a much wider application, than at present, particularly where a high degree of seepage control is desired.

Polythene lining has the advantages of high seepage reduction(in the case of the Ouyen tank, measured seepage was negligible) and, where a prefabricated liner is used, ease and rapidity of installation. In addition the technique can be used on any soil type. At the present time, therefore, it has value for special applications where these advantages outweigh its high cost. These include the provision of temporary water storage for stock or fire fighting, and portable irrigation channel linings which can be rolled up and stored after use.

It is unlikely that plastic dam liners will ever supplant stabilisation techniques to any large extent unless drastic reductions in cost come about. Polythene has, however, a large potential field of use as a structural medium in water conservation. Such applications might include the lining of water storage tanks and small town water supply reservoirs; anti-seepage blankets and cores in earth dams; erosion control blankets, etc. As an instance of such an application the writer is now planning a dam built from polythene stretched on a timber frame for use in a swamp area where the natural soil is quite unsuitable for normal dam construction.

(Note: This report appeared in the March 1960 issue of "Power Farming" under the title of "Sealing Farm Dams with Plastic Film")

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING - PROGRESS REPORT NO.1. 1957-1960

APPENDIX J: SEALING FARM DAMS, OTHER METHODS: PROGRESS REPORT, 1957-1960

RESEARCH IN SOIL AND WATER CONSERVATION ENGINEERING - PROGRESS REPORT NO.1. 1957-1960

APPENDIX J : SEALING FARM DAMS; OTHER METHODS; PROGRESS REPORT 1957-1960

1. INTRODUCTION

Seepage control research at the University of New South Wales has been conducted under two grants; the Water Research Foundation grant for plastic membrane study and the Commonwealth Bank grant for an investigation of other sealing methods. A report on work conducted on behalf of the Water Research Foundation is presented in Appendix H.

The principal research effort under the Commonwealth Bank grant has been directed towards the evaluation of two important sealing materials; bentonite clays and soil dispersants. The following report discusses progress with these materials.

2. SEALING FARM DAMS WITH BENTONITE CLAY

2.1. Introduction

It has become clearly apparent that there is no universal solution to the seepage problem. Each of the techniques so far investigated has proven successful for a specific range of soil types and has been shown to be unsuitable for soils outside this range.

Apart from soil type, the availability of plant and labour, the size and shape of the dam, climatic conditions and the degree of urgency of the problem may determine the appropriate sealing technique in a particular location.

Failure to consider each of the above factors may lead to disappointment and economic loss, and landholders are advised against accepting the claims of a particular salesman or agency without first considering the possible alternatives.

2.2. The Sealing Properties of Bentonite Clays

Over the past 20 years, American farmers and irrigators have made extensive use of bentonite, a natural clay, for sealing dams and irrigation channels. One of the tasks of the Water Research Foundation has been to evaluate this material for use under Australian conditions.

Bentonite is a highly colloidal natural clay which contains a high proportion of montmorillonite, a mineral noted for its swelling properties. It has been formed from the deposition of volcanic ash in salt water, and is to be found in many parts of the world, including Australia.

The properties of individual bentonite deposits vary widely and the material is used for a variety of purposes according to these properties. It is used, for example, as a filtering medium, in foundry moulding sands, in oil drilling muds, and in the preparation of medicines and cosmetics.

For dam sealing a high swelling sodium bentonite is essential, and the best swelling bentonites are mined in Wyoming and South Dakota in the U.S.A.

Wyoming bentonites are marketed in Australia and local deposits appear to be much inferior to the imported material for dam sealing purposes.

A good quality swelling bentonite can absorb up to five times its weight of water and at full saturation it will occupy a volume of 12 to 15 times its dry bulk. It is this unique characteristic which imparts its sealing properties to bentonite, since when mixed with a porous soil and wetted, the material swells and seals the interstices in the soil through which seepage takes place.

The swelling process is reversible, a good bentonite being capable of drying and re-swelling an indefinite number of times. The sealing properties of bentonite can therefore be expected to last for a very long time.

Imported American bentonites are marketed in Australia under several trade names. The material is ground to a fineness of the same order as cement and distributed in multi-wall paper bags of 100 lbs weight.

A coarse granular form is also available. The current price ranges from £30 to £33 per ton f.o.r. Sydney.

2.3. The Application of Bentonite

There are three techniques by which bentonite may be used for dam sealing. The most generally applicable method is known as the "mixed blanket" technique. In this method, the powdered bentonite is mixed thoroughly with the top four to six inches of soil in the floor and sides of the dam and compacted by rolling with flat rollers or rubber-tyred plant. A reduction in seepage of about 90 per cent or better can be achieved this way.

For the mixed blanket technique to be successful the soil must be a light sandy or loamy textured material which will mix readily with the powdered bentonite. It cannot be used with heavy soils. Clays can, however, be sealed with the "pure blanket" technique, which is also suitable on light soils.

In this method, the area to be sealed is levelled and lightly rolled and a continuous layer of pure bentonite spread over it to a depth of about an inch. This blanket is then covered with six inches of topsoil, sand or gravel and the whole area again rolled.

Seepage reductions of 95 per cent and better have been claimed for this technique by American engineers, but the method has not been fully tested in Australia. Due to the difficulty of placing the bentonite membrane and its covering layer and the somewhat higher application rate necessary to give a continuous blanket, the cost of this technique will be appreciably higher than the cost of the "mixed blanket" method.

The "pure blanket" technique shows promise however, as a solution to the cracking associated with heavy clays like the black soils of N.S.W.

The third technique is most useful in the sealing of old dams and concrete tanks which leak through well-defined cracks or seams. In this method the bentonite is dispersed over the surface of the tank and allowed to settle to the bottom, where it is drawn into the cracks and so seals them. A granular form of bentonite is most suitable for this purpose, and a number of tanks and swimming pools have been successfully sealed in Australia using this technique.

2.4. The Pearce's Creek demonstration

Laboratory tests and field trials conducted by the writer have shown that bentonites, provided they are used on suitable soil types, can give efficient and economical sealing. Of particular practical interest is the full-scale field demonstration undertaken this year at Pearce's Creek, near Lismore, on the north coast of N.S.W.

The red soils of the "Big Scrub" area around Lismore are so porous that farm dams are rarely constructed. Climatic conditions are such, however, that stored water would assist materially to stabilise production during the dry spring months. In order to demonstrate the economic potential of conserved water to dairy farmers in the district, the N.S.W. Department of Agriculture decided in 1958 to construct a dam and seal it against seepage losses.

A site was chosen on the property of Mr. Harold Gibson at Pearce's Creek, in an area known to be extremely porous. Soil tests conducted for the Department by the University of New South Wales, indicated that bentonite would be the most suitable material for the purpose, and construction of the dam was completed late in 1958. It is a typical gully dam on a steep red soil catchment, with a total capacity of about half a million gallons.

After allowing the dam to fill so that seepage measurements could be made in the unlined soil, the sealing operation was carried out in March 1959.

The sealing material used was Volclay, a high grade Wyoming bentonite distributed by the Standard Chemical Company, and the work was supervised by Mr. Claude Brelaz of this Company.

The soil was suitable for a mixed blanket seal, and the Volclay was applied by loosening the top four inches in the floor and sides of the dam, spreading the Volclay at the rate of one pound per square foot, mixing thoroughly with a rotary tiller and rolling with a farm tractor and flat roller.

The dam has since been fenced and provided with a circumferential catch drain and paved inlet to prevent damage from the scouring effects of inflowing water.

Extremely heavy rains fell before the rolling of the blanket had been completed, and continuing wet weather has made it impossible to repair the scouring which resulted. Despite this, however, the results have been extremely satisfactory.

Seepage measurements made before the dam was sealed showed a drop in water level due to leakage of 32 inches per week. After sealing was completed the University installed instruments for accurate measurement of seepage and evaporation losses from the dam and these instruments show that the seepage rate has been reduced to somewhat less than 2 inches per week

This represents a reduction in seepage of approximately 95 per cent., and provides a most convincing demonstration of the effectiveness of Volclay as a sealing agent.

It is anticipated that remedial measures soon to be undertaken will reduce the seepage loss to negligible proportions.

2.5. The Practical Application of Bentonite

Research carried out by the writer has shown that the mixed blanket technique can be successfully applied under Australian conditions and the following practical points are set down for the guidance of those wishing to seal dams with this method.

The mixed blanket bentonite seal is suitable in soils of a loose and friable nature, ranging from pure sands to silty loams.

Suitable soils can be identified by their appearance and feel and by observation of their behaviour under tilth. A lump of dry soil which is suitable for bentonite sealing will crumble readily when crushed between the fingers, and these soils will work up to form a fine surface.

If a lump of soil requires considerable strength to crush between the fingers when dry or when moistened, can be rolled out to form a fine pencil, it contains too much clay for use with bentonite.

Where doubt exists as to the suitability of a soil for bentonite sealing a representative sample should be laboratory tested. It is understood that the Standard Chemical Company has facilities for conducting such tests, for which a nominal fee is charged.

Heavy, clayey soils can probably be sealed by the pure blanket method if sufficient cover material is available, but the use of another sealing chemical such as polyphosphate (to be described in a following article) may prove more economical in such cases. The writer would be pleased to hear from landholders having seepage problems in such soils.

A bentonite blanket is most conveniently applied as the final stage in the construction of a new dam. The need for such sealing may be apparent from the behaviour of other dams in the district.

A simple test may be conducted by digging a number of post-holes in the floor of the dam and filling these with water. After allowing some two or three days for saturation of the soil surrounding the hole, the rate at which the water level falls should be measured. A rapid rate of loss will indicate the need for sealing.

Dams which have been constructed for some time must first be drained and allowed to dry out to a stage where a disc cultivator can be worked without clogging. Good compaction of the blanket can not be achieved if the soil is too dry.

The first stage in the placing of the blanket is to level any irregularities in the area to be sealed and remove weeds, rocks and stumps. The surface soil should then be loosened to a depth of four inches, using a disc cultivator, rotary hoe or similar implement, and working the soil up to a reasonably fine condition.

The area to be treated should next be pegged out in 10 ft by 10 ft squares and a bag of bentonite placed in each square. The contents of each bag should be spread evenly over its square by hand raking. Application rate of one pound of bentonite per square foot of surface

Mixing can then proceed. On small tanks this may be carried out by hand, but a small two-stroke garden tiller will greatly facilitate this work. Disc cultivators or rotary hoes are desirable on larger areas.

The soil should be mixed until the bentonite is thoroughly dispersed through the loosened layer. This condition is reached when the soil takes on a uniform grey colour. Finally the blanket must be rolled to bring the soil back to its original density.

In small dams and tanks, excellent compaction can be achieved using a heavy, rubber tyred farm tractor, particularly if dual rear wheels are fitted. On larger dams a heavy flat roller or, a sheepsfoot roller hauled by a crawler tractor will be suitable.

It is desirable that the soil be slightly moist for ease of rolling, and very dry soils will require careful attention if the rolling is to be satisfactory.

A further point to be considered is the batter on which the implements must work. In old dams this will determine the type of equipment which can be used.

New dams should be constructed with batters flat enough to permit the working of discs or rotary hoes without danger of overturning.

The sealing operation should be completed by fencing the dam and constructing an inflow drain. Whilst a bentonite blanket is to some extent self-sealing, possible damage by stock can best be avoided by fencing the area.

On steep batters the bentonite blanket may be scoured by heavy rainfall or inflowing run-off. To avoid this a catch drain should be constructed around the perimeter of the dam to lead all inflowing run-off into a paved inflow section, which should be protected with bitumen, stone pitching or polythene strips.

It might be pointed out that this is a desirable practice in all dams, whether bentonite sealed or not.

Finally, a word about costs. The normal application rate for bentonite is one pound per square foot, or 20 tons to the acre. The cost of a mixed blanket, including labour, should be of the order of 3d to 4d per square foot, or, say, £600 - £700 per acre. This compares favourably with polythene film, for example, which will cost between £1,000 and £1,500 per acre.

3. SEALING FARM DAMS WITH POLYPHOSPHATE

3.1. Introduction

The methods used for sealing farm dams can be classified into two main groups. The most direct approach- and in practice, the most expensive- is to line the floor and sides of the leaking tank with a watertight barrier. Such devices as plastic membranes and reinforced concrete toppings are examples of this approach.

The alternative to an artificial barrier is to alter the natural characteristics of the soil forming the floor and sides of the tank so that the soil itself becomes impervious. This may be achieved by mechanical means, such as rolling or puddling, by the incorporation of additives such as bentonites or bitumens, or by the use of chemicals which change the behaviour of the soil.

Any such process for improving the natural properties of a soil is known as stabilisation. A parallel example is to be found in the cement stabilisation of road and aerodrome surfaces to improve strength and wearing qualities.

During the past six or seven years soil engineers in the United States have made remarkable strides in the science of soil stabilisation. Of particular interest to the man on the land has been the discovery that certain chemicals, when mixed in minute quantities with suitable soils, can produce substantial improvements in the mechanical properties of these soils.

These chemicals may cost from ten to 100 times as much per ton as conventional stabilising additives such as cements or bitumens, yet they can be effective in such small quantities that the overall cost of soil treatment with them may be considerably less than if an additive were used.

This technique, which is known as trace stabilisation, is still in the developmental phases. Sufficient practical applications have been made however, to show that trace stabilisation has a wide field of application in the economical control of seepage from dams and reservoirs.

3.2. Stabilising with Polyphosphate

The group of trace-stabilising chemicals which has been the most widely investigated overseas is the soil dispersants. These comprise a number of compounds of sodium and phosphorous known as sodium polyphosphates.

The soil dispersants are particularly effective in reducing the permeability of a treated soil. One of them, sodium tri-polyphosphate, is now manufactured in Australia, and part of the University's programme of research into dam sealing methods has been directed towards an evaluation of this chemical as a sealing agent.

Tri-polyphosphate is a detergent and is used in large quantities in the manufacture of commercial washing detergents. Its action when mixed with soil is to disperse the soil particles and permit them to pack closely together, thus reducing permeability. Its effect is directly opposite to that of the so-called "soil conditioners" which are used to produce a fluffy, well-aerated soil.

Most fine grained soils exist naturally in a state of partial aggregation- the very fine particles being held together in clumps or aggregates by electro-chemical attractive forces. Within these aggregates the particles are arranged in a haphazard fashion, much like jumbled logs in a heap of firewood.

When sodium tripolyphosphate acts on such a soil it replaces the attractive forces by repulsive forces which permit the particles to reorient themselves, particularly if they are subjected to mechanical working or rolling, so that they come to resemble logs neatly stacked side by side. This rearrangement and closer packing of the soil particles must obviously bring about a considerable reduction in the permeability of the soil, since it reduces the void spaces through which the seepage water passes.

At the same time it has important effects on the compaction, settlement and strength of the soil, which of themselves may be of considerable future importance in farm dam construction.

Since the stabilising properties of polyphosphate result from electro-chemical effects on very fine soil particles, it follows that this technique will be of value only in soils which contain a large proportion of these fine particles - in other words, clays and silts. It cannot be expected to work with sandy or gravelly soils, which are best sealed with an additive stabiliser such as bentonite.

Furthermore, the effectiveness of a particular soil dispersant depends upon the chemical nature of the soil to be treated. For example, sodium polyphosphates are of little value with soils high in calcium, even though such soils contain an adequate percentage of very fine particles.

There is a very considerable field for further research into the effects of the trace stabilising chemicals, and many new applications can be predicted as knowledge of their behaviour increases.

Sodium tri-polyphosphate is manufactured in Australia by Albright and Wilson of Melbourne. It is marketed as a fine white powder in multi-wall paper bags of 70 lb weight. It costs about £160 per ton, or approximately £5 per bag. Despite this high unit price the cost of soil treatment with polyphosphate is much lower than any of the other techniques investigated by the University.

The application rate recommended by the manufacturers is 10 lb per hundred square feet for a stabilising depth of 12 inches. On this basis the cost of polyphosphate sealing should be in the order of 2d to 3d per square foot, depending upon the methods used for spreading and mixing.

3.3. Seepage Control with Polyphosphate

Polyphosphate sealing is a very recent technique. The first water storage in the world to be sealed in this way was the 22 million gallon lagoon of the International Paper Co. in Maine U.S.A. which was convincingly sealed in 1954. Since that time an indefinite number of small dams have been treated in the U.S.A.

So far as the writer is aware, only one dam has so far been sealed in Australia, this being a small experimental tank which is still under investigation.

Laboratory investigations carried out by the C.S.I.R.O. in South Australia, and the University of Sydney, and the University of New South Wales, have shown, however, that there is a very promising field for the application of the technique in this country, and several dams and a length of irrigation channel will shortly be treated in N.S.W.

Polyphosphate can be added to the soil in powder or solution form, depending on the conditions of the job in hand. The manufacturers recommend that the powdered chemical be spread, mixed and rolled in the same way as a mixed bentonite blanket is formed.

The electro-chemical effects of polyphosphate depend upon the presence of a reasonable amount of moisture in the soil, and under Australian summer conditions soils are normally too dry for effective powder mixing. It thus becomes essential that the soil be watered. In such a case the polyphosphate may be very conveniently applied by dissolving it in the water.

The chemical has also been applied by spraying directly onto the soil surface, without mixing, and by direct injection into the soil mass.

Laboratory tests conducted by the writer indicate that under certain conditions sealing can be achieved by simply mixing the chemical with the water in the dam. These, however, are specified conditions, and anyone planning to use polyphosphate is advised to adopt the conventional mixing and rolling methods

3.4. The Nashdale Demonstration

As already mentioned, the writer is aware of only one polyphosphate treated tank in Australia, although plans for sealing a number of others are in hand. This is an excavated tank at Nashdale, near Orange, in N.S.W. which was treated in November 1959.

The tank has been constructed on the property of Mr. Bruce Williams, the well-known orchadist. This property lies on the western slop of Mount Canoblas, and the soil in the area is a red volcanic materoal, very fine grained, which might best be described as a lean clay. The natural soil is extremely porous, and seepage losses from dams and tanks present a considerable problem to orchardists in the Nashdale district.

In 1958 Mr. Williams offered the writer full facilities for the construction and sealing of an experimental tank. After the experimental work has been completed the water it holds will be used for fruit spraying and emergency fire fighting.

Following detailed laboratory tests of the soil from the tank site the decision was made to use poly-phosphate. The tank was excavated late in 1958, and a record of all costs has been kept. It is 50 feet square at the top and holds about 8 ft of water, the total capacity being about 45,000 gallons. There is no surface inflow, the tank being filled by pumping from a spring some distance away. It is therefore possible to measure the exact amount of water put into it at any time, and a water meter has been installed on the pipeline for this purpose.

In addition to this meter, other instruments have been installed to measure seepage losses. These comprise an automatic water level recorder, rain gauge and evaporation tank.

Soon after the tank was excavated an attempt was made to fill it, in order to measure seepage losses in the natural soil. These losses were so high that the tank could not be filled to a depth greater than three feet, and the measured rate of loss was in excess of 5,000 gallons per day. Nine months later, immediately before the application of the polyphosphate, losses of this magnitude were again measured.

It has been planned to seal the tank in two stages. The first step, now completed was to stabilise the sides and floor using the dry misture and rolling procedure, with half the quantity of polyphosphate recommended by the manufacturer. After allowing some time for seepage measurements it is planned to add a similar quantity of the chemical by dissolving it in the water in the tank.

The first stage was carried out in essentially the same way as the mixed bentonite blanket described in the first article of this series. The soil in the floor and sides of the tank was loosened to a depth of about 4 inches with a set of spring tynes, and showery weather on the previous day brought the moisture content of the soil to a reasonable level.

Polyphosphate was spread at the rate of 5 lb per 100 sq. feet, using 10 ft by 10 ft pegged squares to ensure even spreading. The soil on the floor of the tank was mixed with a rotary hoe and the batters were mixed with a set of discs, for purposes of comparison. Better overall mixing was obtained with the discs.

Finally the soil was rolled hard with a Ferguson tractor fitted with dual rear wheels, and filling commenced immediately the rolling was completed.

Initial results were disappointing until it was discovered that leakage was taking place through the valves in the outlet pipeline. After blanking off this line the seepage rate dropped to about 500 gallons per day, representing a reduction in seepage loss of about 90 per cent. It is anticipated that the second stage treatment, shortly to be undertaken, will reduce this figure appreciably.

The cost records of this project are extremely interesting. Construction of the tank cost about £50. The polyphosphate used was donated by Albright and Wilson, who have given every co-operation in the project; its actual value was less than £10. The sealing operation involved about seven hours work; two experienced men could seal a tank of similar size in less than four hours. Allowing for the second stage sealing, the total cost of the sealed tank should be well under £100.

By comparison, a prefabricated polythene liner for the tank would cost approximately £180 not including installation costs or the cost of sinking the tank.

3.5 The Practical Application of Polyphosphate

On the basis of limited experience in Australia some suggestions for the economical use of polyphosphate can be made. It should be emphasised that the technique is still experimental, and landholders contemplating the use of the chemical would be advised to seek technical advice as to the suitability of their soils.

On the other hand, it is desirable that as many people as possible attempt polyphosphate sealing, so that its field behaviour can be properly evaluated. The writer would therefore be pleased to assist any persons interested in the use of this chemical.

The first step in any sealing problem is to determine the soil type. As explained previously, polyphosphate is only suitable with silty or clayey soils. It is desirable that the material have at least 15 per cent clay particles. As a rough field test, it should be possible to roll a moist lump of the soil between the palms to form a fine pencil. A dry lump should be reasonably difficult to crush between the fingers.

Generally speaking a fine-grained soil which does not pass the field test for bentonite, described in the previous article, should be suitable for polyphosphate.

Two further tests can be used if a small quantity of polyphosphate is obtainable. In the first, a moist pat of soil is taken and kneaded into a ball. A pinch or two of polyphosphate is then added to the soil and the whole again kneaded well to form a ball. If the material is suitable the second ball will feel wetter and distinctly more plastic than the first.

The second test involves thoroughly shaking a handful of soil in a jam-jar to which a pinch of polyphosphate has been added. If the soil is suitable the water will remain muddy for several weeks.

Even if a soil is suitable from the point of view of clay content its chemical composition may preclude the use of polyphosphate. Clay soils with a high lime content may require considerably more polyphosphate than normal soils, and if such a condition is suspected soil tests should be arranged. In addition the solodic soils of the Hunter Valley and parts of the central west of N.S.W. which frequently cause failure by tunnelling are not likely to benefit from polyphosphate treatment.

The best technique for applying the chemical to the soil depends upon the type of soil, climatic conditions and the area to be treated. The manufacturers, on the basis of experience with the International Paper Co. lagoon, recommend that the material be incorporated as a dry powder, mixed into the top 12 inches of soil and thoroughly rolled. It is suggested that this be done by first removing and stockpiling the first six inches of soil; next, ripping a further six inches, spreading polyphosphate, mixing and rolling; finally, replacing the stock-piled soil and repeating the process. This gives a stabilised blanket 12 inches in thickness, the application rate being 5 lbs of polyphosphate per square for each of the two layers.

In small tanks with conventional farming plant it should be sufficient to treat only six inches of soil in one pass, using 10 lbs of polyphosphate per square. On such projects the chemical is best spread by hand in the manner recommended for bentonite.

On large areas considerable labour may be saved by utilising some form of lime or super-phosphate spreader, and large disc cultivators or even stabilising machines might be employed with advantage.

As had already been pointed out, it is essential that adequate moisture be present in the soil to ensure the electro-chemical action of the poly-phosphate. Under normal Australian conditions soils are too dry in any case, and it would appear to be an excellent technique to first rip the soil to the desired depth, water with a solution of polyphosphate in a concentration sufficient to give uniform coverage of 10 lbs per square, then disc and roll. The soil should be brought to a moisture content such that it is almost too wet for the rollers to operate.

In dry hot weather it would be desirable to work in small areas to avoid drying out of the soil before rolling is complete. This technique has not yet been tried in practice.

It may be found after filling a dam sealed with polyphos-phate that the water becomes discoloured and will not settle. This is not harmful, but if the water is to be used for irrigation it might be desirable to settle the fine particles with an electrolyte such as alum. If, however, the water is used for fruit or pest spraying, some difficulty may be experienced in dissolving or emulsifying the spray chemicals. The advice of the manufacturers should therefore be sought if this water use is contemplated.

4. FURTHER RESEARCH

It is proposed to extend the seepage control research to evaluate other possible sealing materials. Preliminary studies have already been made concerning other trace chemicals, such as Calgon; proprietary sealing agents, such as SS13 and AM9; bitumen emulsions; and underwater explosions.

Figure 1 shows the location of the field experiments currently in operation or under investigation.

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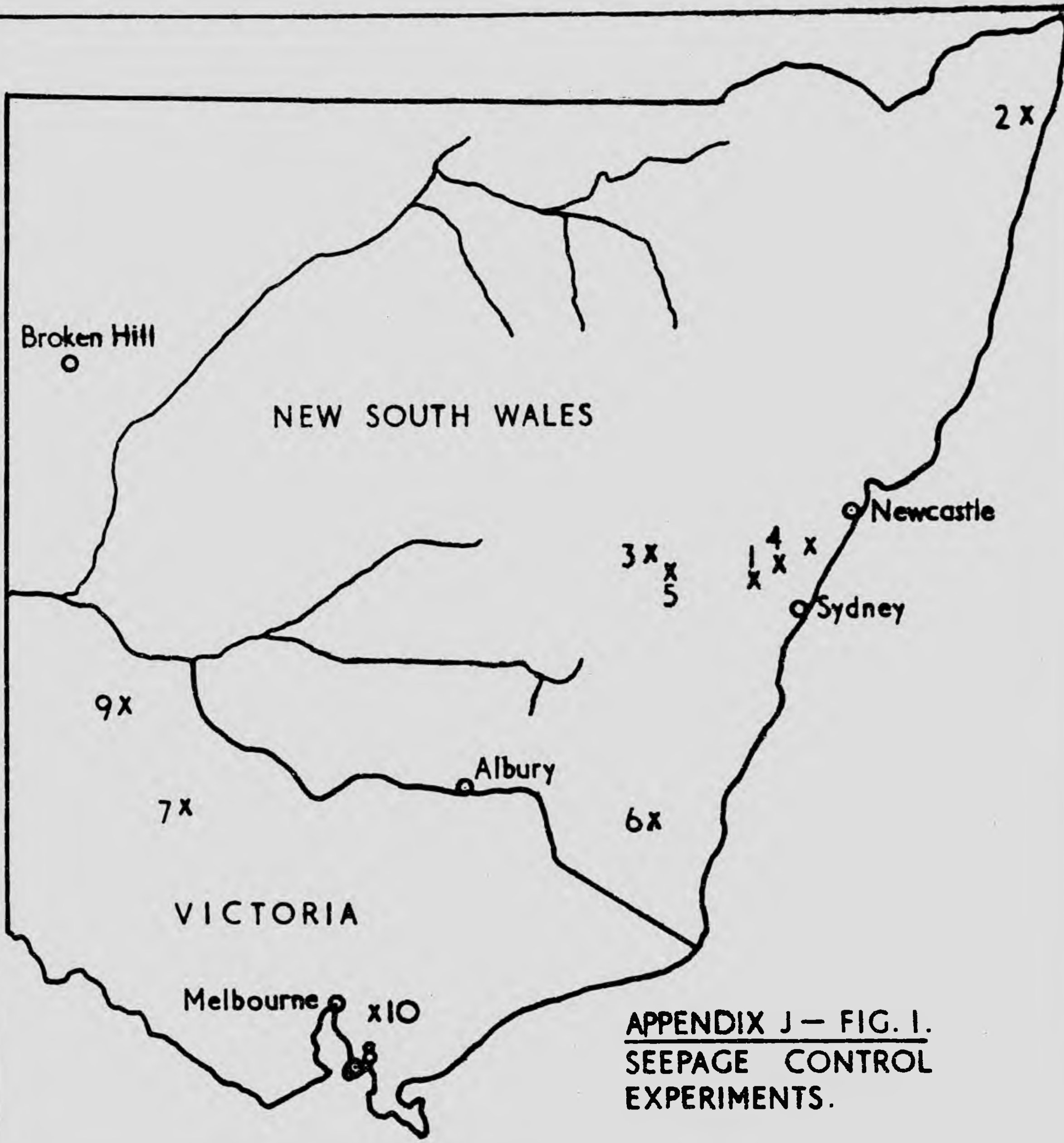
(Note: This report appeared in modified form in the January and February 1960 issues of "Power Farming".)



APPENDIX J — FIG. I.
SEEPAGE CONTROL EXPERIMENTS.

Location of Seepage Control Experiments.

1. North Richmond : polythene liner : tests complete.
2. Alstonville : bentonites : final observations in progress.
3. Nashdale : polyphosphate : second stage sealing in progress.
4. Kulnura : survey, soil tests completed : bentonite proposed.
5. Orange (Forestry) : soil tests completed : polyphosphate proposed.
6. Tumut (Forestry) : soil tests completed : method not decided.
7. Charlton : polythene liner under observation.
8. Red Hill : polythene liner under observation.
9. Ouyen : polythene liner under observation.
10. Silvan : soil tests completed : pilot tanks for polyphosphate to be constructed, 1961.