The University of New South Wales
WATER RESEARCH LABORATORY

Australian Water Resources Council Research Project 68/8
Extraction of Water from Unconsolidated Sediments

HYDRAULICS OF FLOW NEAR WELLS IN UNCONSOLIDATED SEDIMENTS

Volume 1: Theoretical and Experimental Studies

Volume 2: Field Studies

by

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Preface

This report covers work carried out over a three year period on Phases II, III and IV of the Australian Water Resources Council's Research Project 68/8, "Extraction of Water from Unconsolidated Sediments". The work involved theoretical and numerical studies including digital computer application, the design and construction of a large scale experimental tank for studying near-well hydraulics and its use for experimental verification of the numerical studies. Field experiments which are not yet completed will be the subject of a separate section of this report.

The studies were carried out by the authors at the Water Research Laboratory of the University of New South Wales with the assistance of the laboratory's staff. Almost all members of the staff were called on for assistance or advice at some stage and their help is gratefully acknowledged. Particular thanks are due to Mr. D.N. Foster who took over the duties of the project leader, Mr. C.R. Dudgeon, to organise the completion of the report during Mr. Dudgeon's absence overseas on study leave.

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31st March, 1972.

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Nomenclature

		Dimension
a	linear coefficient of hydraulic resistance	TL^{-1}
b	non-linear coefficient of hydraulic resistance	T^2L^{-2}
$\bar{d}$	characteristic grain diameter	L
$\vec{e}_i$	3 unit vectors along cartesian axes	
h	hydraulic head	L
$i = \lvert\frac{\partial h}{\partial l}\rvert$	absolute hydraulic gradient	
i, j	small letter subscripts	
m	saturated thickness of the aquifer	L
n	effective porosity	
n_i	components of unit outward normal vector	
p	hydrostatic pressure	$ML^{-1}T^{-2}$
$\bar{q}$	prescribed inflow flux	LT^{-1}
(r, z)	2-dimensional cylindrical coordinate system	
r_{cr}	critical radius	L
r_o	radius of influence	L
r_w	well radius	L
s	drawdown	L
s_o	total drawdown including well loss	L
s_w	drawdown in the well	L
Δs	drawdown increment	L
s_{wl}	well loss	L
t	time since pumping began	T
Δt	time increment	T
v_i	components of macroscopic velocity vector	LT^{-1}
$(x_1, x_2, x_3) = (x_i)$	right handed cartesian coordinate system	
A	non-linear parameter	
A_o	opening area of screen	L^2

Nomenclature (cont'd.)

		Dimension
A_r	effective open area ratio of well screen	
B	boundary of the flow system or empirical coefficient	
B_1	portion of boundary B where flux is prescribed	
B_2	portion of B where hydraulic head is prescribed	
C	empirical coefficient	
I, J	capital letter subscripts	
K	coefficient of hydraulic conductivity	LT^{-1}
K_{sc}	screen loss coefficient	
Q	prescribed total flow rate	L^3T^{-1}
Q/s_w	specific capacity	L^2T^{-1}
$\mathbb{R}$	Reynolds number	
$\mathbb{R}_{cr}$	critical Reynolds number	
$\bar{R}$	close region of the flow system	
R	interior of $\bar{R}$	
R^N, R^D	non-Darcy and Darcy subregions of the flow system	
$\bar{R}^e$	subregion of the finite element	
S_s	specific storage of the aquifer	L^{-1}
S	coefficient of storage of the aquifer	
$\vec{V}$	macroscopic velocity vector	LT^{-1}
$\|V\|$	absolute value of $\vec{V}$	LT^{-1}
V_n	entrance velocity	LT^{-1}
z	height of the free surface	L
α, β	Greek letter subscripts	
γ	specific weight of water	$ML^{-2}T^{-2}$
ρ	density of water	ML^{-3}
μ	coefficient of dynamic viscosity of water	$ML^{-1}T^{-1}$
ϵ	specific yield capacity of the unconfined aquifer	
ν	coefficient of hydraulic diffusivity of the aquifer medium or kinematic viscosity of water	L^2T^{-1}

Nomenclature (cont'd.)

		Dimension
η	hydraulic efficiency of well	
(ξ, η)	local coordinate system for isoparametric elements	
$\dot{\Omega}$	total rate of dissipation of hydraulic energy	L^4T^{-1}
$[\Omega(h)]_R$	functional over the flow region R	
Ω^e	functional over the element subregion R^e	
$\dot{\phi}$	dissipation function	LT^{-1}
$\frac{\partial}{\partial x_i}$	differential operator	
$\int_B (\ )dB$	integral over the boundary surface	
$\int_R (\ )dR$	integral over the volume of the region	
δ	first variational operator	
$\vec{\nabla}$	gradient vector operator	
$\in$	belonging to	
U	union operator	
$[C^e]$, $[C^e]$, $[D^e]$, $[F^e]$	element matrices	
$[C]$, $[C]$, $[D]$, $[F]$	gross matrices	
$[K]$	hydraulic conductivity matrix	
$[N]$	shape function matrix	
$[S]$	slope matrix	

HYDRAULICS OF FLOW NEAR WELLS IN UNCONSOLIDATED SEDIMENTS
VOLUME 1: THEORETICAL AND EXPERIMENTAL STUDIES

Errata Sheet - Section A

Page	Location	Correct From	Correct To
	Section A Table of Contents Item 4	...., current stage of...	....current state of...
A1	Line 10 from top	...in Section 2,....	....in subsection 2,...
	Line 7 from bottom	...an appendix.	....Section D
A10	Paragraph 3 Line 4	...Section F to	....Section E to...

- Section B

Page	Location	Correct From	Correct To
B16	Following eq. (2.31)	$\frac{-\partial M/\partial t}{\rho \delta \forall}$	$\frac{\partial M/\partial t}{\rho \delta \forall}$
B18	RHS of eq. (2.45)	$S_s \frac{\partial h}{\partial t}$	$-S_s \frac{\partial h}{\partial t}$
B19	RHS of eq. (2.46)	$x_i \in \bar{R}$	$(x_i) \in \bar{R}$
B20	RHS of eq. (2.47)	$-\bar{q}(x_i, t)$	$\bar{q}(x_i, t)$
B22	LHS of eq. (2.52)	$v_i n_i$	$-v_i n_i$
B26	RHS of eq. (3.3)	$S_s \frac{\partial h}{\partial t}$	$-S_s \frac{\partial h}{\partial t}$
B26	LHS of second eq. following eq. (3.3)	$\frac{\partial G}{\partial(\frac{\partial h}{\partial x_i})}$	$-\frac{\partial G}{\partial(\frac{\partial h}{\partial x_i})}$
B29	Second line	$-\bar{q}$	$\bar{q}$
B29	Last expression	$-\int_{t}^{t+\Delta t}\int_{B_2}$	$\int_{t}^{t+\Delta t}\int_{B_2}$
B35	RHS of eq. (3.25)	$\frac{d}{d\lambda}\left[(h+\lambda\delta h)\right]_{\lambda=0}$	$\frac{d}{d\lambda}\left[\dot{\Omega}(h+\lambda\delta h)\right]_{\lambda=0}$

Errata Sheet - Section B

Page	Location	Correct From	To
B36	Second integral term on RHS of eq. (3, 26)	$\frac{2}{3}\cdot\frac{3}{2}\sqrt{}$	$\frac{2}{3}\cdot\frac{3}{2}\frac{\sqrt{}}{\lvert\partial h/\partial l\rvert}$
B36	Second integral term on RHS of eq. (3, 27)	$\int_{B^D}\ldots\ldots dR$	$\int_{B^D}\ldots\ldots dB$
B36	LHS of eq. (3.28)	$\sqrt{}$	$\frac{\sqrt{}}{\lvert\partial h/\partial l\rvert}$
B42	Second integral on RHS of eq. (4.4)	$-\int_{t}^{t+\Delta t}\int_{B_2}$	$\int_{t}^{t+\Delta t}\int_{B_2}$
B46	Second expression following eq. (4.24)	$-\int_{t}^{t+\Delta t}\int_{B_1^e}$	$\int_{t}^{t+\Delta t}\int_{B_2^e}$
B46	Last integral on RHS of eq. (4.25)	$-\int_{t}^{t+\Delta t}\int_{B_2^e}$	$\int_{t}^{t+\Delta t}\int_{B_2^e}$
B52	LHS of eq. (4.43)	$\frac{2\pi\bar{r}}{4\Delta}$	$2\pi\bar{r}\Delta$
B54	LHS of eq. (4.52)	$-0.5(\xi+\xi^2)$	$0.5(\xi+\xi^2)$
B55	RHS of eq. (4.59)	$2\pi\int_{-1}^{1}[K][S]^T[S]$	$2\pi\int_{-1}^{1}[S]^T[K][S]$
B60	LHS of eq. (4.76)	$\frac{\Delta t}{2}(C_{JI}^{t}+C_{JI}^{t+\Delta t})$	$\frac{\Delta t}{4}(C_{JI}^{t}+C_{JI}^{t+\Delta t})$
B63	line 7	equation (4.79)	equation (4.78)
B63	equation (4.80)	t	Δt

Errata Sheet - Section D

Page	Location	Correct From	To
D21	Table 1 Test 16 r=0.75	1.086	1.586
D30	Line 10 from top	$\ldots \ln \frac{r_c}{r_w} + \ldots$	$\ldots \ln \frac{r_{cr}}{r_w} + \ldots$
D31	Line 15 from top	$b = \frac{4\pi^2 m^2}{\frac{1}{r_w} - \frac{1}{r_{cr}}}$	$b = \frac{4\pi^2 m^2 B}{\frac{1}{r_w} - \frac{1}{r_{cr}}}$
	Line 4 from bottom	$b = \frac{0.365 \times {}^2 \times 5^2 \times 4}{2.1}$	$b = \frac{0.365 \times \pi^2 \times 5^2 \times 4}{2.1}$
D32	Eq.5.6	$\mathbb{R}_{cr} = v_{cr} \bar{d}$	$\mathbb{R}_{cr} = \frac{v_{cr} \bar{d} \rho}{\mu}$
	Line 13 from top	$= 1.94\ldots.$	$\rho = 1.94\ldots.$
	Line 14 from top	$= 2.1 \times 10^{-5}\ldots$	$\mu = 2.1 \times 10^{-5}\ldots$
	Fig. 5.5	B = 0.52 C = 0.365	A = 0.52 B = 0.365

SECTION A

OBJECTIVES, PROCEDURES AND ACHIEVEMENTS

by

C.R. Dudgeon

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1. Introduction

An accelerated programme of investigation of groundwater resources in Australia and their exploitation for stock and domestic, irrigation, and town water supply led to the inclusion in the Australian Water Resources Council's research programme of a project aimed at improving the efficiency of groundwater extraction. The project, which is the subject of this report, had as its primary aim "the determination of the most efficient forms of construction in different classes of material"[1]. The proposed means of achieving this aim by theoretical, experimental and field studies are further elaborated in Section 2, 'Objectives'.

The project has been divided into four phases:-

I. A field study by the Queensland Irrigation and Water Supply Commission to examine the effect of the type of construction on well yield.

Phase I has been the subject of a separate report by the Commission.

II. A preliminary literature survey.

III. A preliminary design study for an experimental facility in which the hydraulics of flow in close proximity to wells could be studied and in which practical problems such as the effects of drilling and development techniques on well performance could be examined.

IV. A theoretical, experimental and field study aimed at improving the selection of the optimum type of construction for wells under various aquifer conditions.

Phases II, III and IV were carried out at the University of New South Wales, Water Research Laboratory. All three phases are treated together in this report as Phases II and III covered preliminary work for Phase IV. Details of the design and construction of the experimental facility, commenced in Phase III and continued through into Phase IV, are presented in an appendix. The results of the literature survey appear in two parts. A review of the state of knowledge as revealed by the literature is included in the main body of the report. The references themselves appear in a separate volume. Since they are likely to be useful to a wider range of people than the main report they have been presented as a separate annotated bibliography which will be updated regularly in the future.

1. Original Project Formulation Proposal, November 1968.

2. Objectives of Phases II, III and IV

The objectives listed below are taken from the relevant project schedules.

Phase II: 'To carry out the literature survey and prepare a report on the extraction of water from unconsolidated sediments.'

Phase III: 'The overall objectives of the project are to develop a sound theoretical basis for determining the optimal geometry of bores and wells (singly or in groups) in unconsolidated sediments by laboratory studies and field performance testing with the long term aim of providing underground water engineers with an adequate theoretical basis and design criteria for the exploration, design and development of extraction facilities for a given aquifer and site.

The immediate objectives of this phase are as follows:-

To prepare a report for the project reference panel giving details of the design and estimated cost of a suitable test facility and setting out a recommended work plan and proposed research programme to meet the overall objectives of the project.'

Phase IV: 'The objectives are the overall objectives of Phase III.'

3. Scope of Investigation

After preliminary work had been carried out it became apparent that the ability to select the optimum well design for a given site in an aquifer depends mainly on three factors:-

(i) A knowledge of the physical and hydraulic characteristics of the aquifer material within a relatively small radius of the proposed well site.

(ii) The availability of adequate data on the discharge-drawdown-time relationship for a range of possible well geometries and types of construction and hydraulic characteristics of aquifer materials likely to be encountered.

(iii) The availability of reliable cost data for drilling, construction and development for the range of possible types of construction.

Before an optimum design can be selected on the basis of factors (i) and (ii) the requirements of the well in terms of discharge and cost must be fixed. In many cases the requirement is to produce as much water as possible from the well regardless of cost while in others minimizing the cost of the water is of primary concern. It is assumed in this report that information on costs applicable to various parts of Australia is available to the various underground water extraction bodies and that given the information on factors (i) and (ii) these bodies could make the necessary economic judgement in given cases.

The work on this project has therefore been concentrated on providing information on factors (i) and (ii).

This study has been concerned mainly with flow conditions in the zone in close proximity to the well site where high flow velocities may cause non-Darcy flow and high head losses and invalidate the assumptions made in more simple analyses. It is also within a limited portion of this zone that the natural aquifer properties may be modified by drilling and development methods. It was hoped that the theoretical, numerical and experimental work would also enable a better assessment to be made of the effect of these processes on the hydraulic characteristics of the affected aquifer materials.

4. General Review of Literature and Current State of Knowledge

This sub-section is not intended to serve as a detailed guide to current research or published literature. Its purpose is to define in the context of the current state of knowledge, the relevance of the investigation procedure adopted for the project to satisfying the needs of the groundwater extraction industry in Australia for improved methods of well design. Reference to specific literature or research will be found in appropriate places in the sections of the report which deal with particular aspects of the investigation.

The preceding sub-section listed the three factors which were considered most important in selecting an optimum well design at a given site. The current state of knowledge as revealed by published information and research which is known to be in progress relative to each of these factors is summarised below.

(i) A knowledge of the physical characteristics of unconsolidated aquifer materials is directly necessary for the selection of screen or gravel pack openings. Current sampling techniques and methods of interpretation appear to be adequate for this purpose and have not been pursued further, although improvements are clearly possible.

The physical characteristics may also be used in the determination of the hydraulic characteristics which need to be known for the prediction of hydraulic losses near the well. Over the last decade the knowledge of the type of relationship which exists between hydraulic gradient and flow rate through aquifer materials over the range of velocities likely to be encountered has reached the stage where it is of sufficient accuracy for all practical predictions of flows near wells, whether they be linear (Darcy) or non-linear. A number of papers reporting experiments over a wide range of flow conditions differ only in the types of equation fitted to results and the interpretation of the phenomena observed. In all cases a single hydraulic constant (permeability) has been required to define the flow rate - hydraulic gradient relationship in the linear regime while two constants have been found necessary for a non-linear regime. Unfortunately, however, there has been little progress in relating the constants in the flow equation to measurable physical characteristics of granular media. What appears to be necessary is a comprehensive experimental programme to define geometrically similar families of granular media, determine their hydraulic characteristics and express the results in the form of a series of dimensionless friction factor - Reynolds number charts. The authors have not discovered reference to any such programme of research. It was decided that a comprehensive general programme of this type lay outside the scope of this project and would require much greater resources than were available. As a result, physical characteristics determined by tests on aquifer samples have been used only to indicate the likely range of corresponding hydraulic characteristics.

The alternative method of determining the hydraulic constants of aquifer material in close proximity to a proposed well site is to carry out in-situ tests via an exploratory borehole. This method has been used to determine the permeability of soils at relatively shallow depths and might possibly be extended to aquifers at greater depth and to non-linear flows. A limited amount of information on such techniques was discovered in the literature. Although it was considered that the present project would allow only preliminary work on this topic, a follow-up project should allow the technique to be developed into a useful tool. If this were pursued in conjunction with attempts to improve techniques of sampling from exploratory holes and improvement of the accuracy of predicting hydraulic constants from these samples, an outstanding gap in current knowledge, as evidenced by the paucity of recent literature on the subject, might be closed a little.

(ii) Reference to the literature reveals that even if the hydraulic characteristics of the aquifer material close to a well site were known, most designers would lack the means of predicting the effects of the geometrical and hydraulic parameters on the drawdown-discharge-time relationship for the range of possible well geometries and types of construction. This is particularly true for cases where non-linear flow would occur near the well. For instance the published data which are available for assessing the effect of well diameter on yield for a given drawdown is incorrect when non-linear flow occurs near the well.

A number of recent papers have described numerical or model methods which allow complex flows near wells to be determined. However, none of these appear to have been taken to the stage of producing design charts for use in selecting an appropriate design for given hydraulic constants of the adjacent aquifer material. The lack of such information led to the decision to make the development of numerical methods suitable for producing the necessary data and the preparation of charts for selected values of the geometrical and hydraulic parameters a major part of the project.

(iii) Data on costs of well drilling and construction seem to be entirely lacking in the Australian and overseas technical literature. No satisfactory comparison of techniques used in different countries can be made without adequate information on costs of the various operations involved. Nor can the optimum design of well for a given location be selected without applying economic criteria, the use of which demands data on costs of construction, operation and maintenance of the various possible designs.

Application of the information on the relationship between discharge and drawdown for various aquifer properties and well geometries which this project set out to provide can be made only in the light of local cost information. A useful task at some later date would be the compilation of costs in the various parts of Australia. This, together with corresponding information from overseas sources, would allow valid differences in technique between different regions to be understood and irrelevant techniques to be eliminated and replaced by those more economical in the local scene. Many cases of inappropriate copying of methods from one region to another are evident in the literature although in some cases attempts have been made to modify methods to suit local conditions. An instance of a major difference which occurs throughout Australia between local and American practice is the extent to which reverse circulation drilling is used. This has been found almost entirely absent in Australia, despite similar conditions. Appropriate data on costs, not only of drilling but also of subsequent development operations, associated with the use of reverse circulation instead of mud for drilling water wells would indicate whether, and under what conditions, introduction of reverse circulation drilling would reduce the cost or improve the efficiency of wells.

5. Procedure Adopted

5.1 Three Avenues of Investigation

A three sided approach was adopted to provide the necessary theoretical and empirical information required in optimising well design:

Task (i): To develop theoretical and numerical methods which would allow the discharge-drawdown relationship for wells of various geometries to be predicted for aquifer materials of given hydraulic characteristics for both steady and unsteady flow conditions.

Task (ii): To provide data on the hydraulic characteristics of various types of aquifer material so that the information determined in (i) could be put to practical use. This would involve a broad classification of unconsolidated aquifer materials into groups based on existing experimental data on grain size and porosity. Approximate hydraulic constants taken from this classification would allow entry into the graphs and tables produced in (i) so that the effect of the variation of well diameter, degree of penetration, screen length, gravel pack properties etc. could be studied in particular cases.

It was not expected that this approach would yield very accurate results but would allow a range of possible designs to be considered and a selection made within broad limits.

Task (iii): To develop methods which could be used in the field to determine the in-situ hydraulic characteristics of the aquifer material local to a trial hole so that more accurate entry to the relationships determined in (i) would be made possible than by using the broad correlations proposed in (ii).

It was envisaged that both Tasks (i) and (iii) would require the development of fast digital computer programs which would allow the flow in close proximity to wells to be analysed taking into account the possibility of a non-linear velocity-hydraulic gradient relationship near the well (non-Darcy flow) and local effects caused by screens, gravel packs and clogging at the well boundary.

5.2 Application of Digital Computer

Although there is still argument about the fundamental form of the flow-rate-hydraulic gradient relationship for high rate flow through granular media, the relationships are sufficiently well established to allow numerical analysis of flow patterns near wells for practical well boundary configuration. Predictions of flow patterns, discharges and drawdowns are possible with an order of accuracy at least comparable with that applicable to the hydraulic constants of the aquifer material ascertained by drilling and sampling at a given site. Some reservations must be held when high degrees of streamline convergence, curvature and anisotropy exist (e.g. in free surface flow through coarse anisotropic gravels) but at present, in most cases, the uncertainties associated with determining the hydraulic constants for the material near the well are likely to overshadow such effects.

It was decided that the analysis of complex flow near a well would best, at this time be carried out using numerical methods and a digital computer to solve the equations derived from the continuity and flow rate - hydraulic gradient relationships.

The alternative of using non-linear analogue models was not selected because the techniques required have not yet been fully developed. In contrast, the numerical processes required for digital computer solutions have been well established in recent years. The possibility of using analogue models will be investigated further in future work by the authors on groundwater extraction.

Tasks (i) and (iii) required the development of similar digital computer programs for both steady and unsteady flow. Priority was given to confined flow cases as these form the bulk of the cases met in practice. The programs were intended for use in the preparation of graphs showing the relationship between the well flow and drawdown and design variables for a range of typical cases. They would also be available for the solution of individual problems where necessary but it was considered that the graphs would find greater use as not all well designers would have immediate access to a digital computer or the wish to use one. In the more complex cases the computer time and cost involved for individual solutions would almost certainly be a deterrent. The programs would also be required for the analysis of field tests to determine the hydraulic constants of aquifer materials close to trial drill holes.

5.3 Experimental Verification

It was planned to seek experimental verification of theoretical and numerical procedures both in the experimental tank and in the field.

The design and construction of a suitable laboratory test facility was undertaken and plans made to drill trial holes which would later be enlarged and completed as production holes of various types to confirm predictions of optimum design made on the basis of the criteria defined in the execution of Tasks (i), (ii) and (iii) described in 5. 1.

6. Achievements

6.1 Literature Survey and Annotated Bibliography

The literature survey revealed that the tasks inherent in providing data for improved well design procedures had not been completed elsewhere and, in fact, did not appear to be under attack in many quarters. This conclusion was reinforced by reference to lists of current research projects in the hydraulic research centres throughout the world and contacts with other research workers. Despite recent advances in the application of numerical and experimental techniques to the solution of complex well flow problems, most reported investigations have stopped short of using the methods developed to prepare solutions over the range of parameters relevant to well design.

Apart from its direct use in the course of this project, the annotated bibliography will be useful to other research workers and practising groundwater engineers and scientists both in Australia and overseas. The framework used to present the bibliography and the computer programme used to store, index and print the references will be used in future to extend the bibliography and keep workers in the field informed of recent publications from a wide spectrum of literature if adequate resources are made available.

6.2 Theoretical and Numerical Work

The theoretical and numerical work detailed in Section B provided the means of preparing the tables and charts used in comparing the hydraulic performance of wells of various types in a number of types of aquifer material. It is only a matter of additional computer time to extend the work to a wider range of the parameters involved. Alternatively, the computer programmes developed can be used to prepare solutions for particular cases of aquifers and types of construction. A great deal of work remains to be done to verify the computed results over a wider range than there has been time to do in this project, and to determine the significance of the results in the context of uncertainties in the estimation of the properties of an aquifer at the point at which a production well is to be constructed. The results allow the effect of variations in geometry of wells at a given point in an aquifer to be assessed if the characteristics of the aquifer material at that point are known within reasonable limits. Future work to improve the accuracy of estimating the hydraulic constants of aquifer material by in-situ testing or sampling and laboratory tests should make the selection of optimum well design for a given site more definite.

6.3 Determination of the Hydraulic Characteristics of Aquifer Materials

As mentioned in the preceding paragraph, methods of determining the hydraulic characteristics of aquifer material within a small radius of a proposed well site must be improved before accurate use can be made of the computer programmes described in Section B or more than a broad selection of optimum well geometry can be made from graphs such as those given in Section C.

Preliminary studies have been made of suitable short-duration tests to be applied to a trial borehole on the site of a proposed production hole to determine these properties of the aquifer material. In addition, development of the computer programmes to analyse unsteady flow in close proximity to wells referred to in Section B was aimed partly at providing a basis for analysis of the tests envisaged. The work will be continued in the project which follows this project.

It has not been found possible to allocate effort to producing correlations between such factors as aquifer material grain size, shape, grading and porosity and the hydraulic constants required to describe non-linear flow. These constants were determined for the materials used in the laboratory experiments but typical values for other materials were taken from published data. A computer programme was developed to allow the constants to be derived from the data presented. It is proposed to extend this work into the next project.

6.4 Design, Construction and Use of Experimental Facilities

Experimental work undertaken in the laboratory during the course of the project included permeameter studies of typical aquifer material and experiments on a large scale in a well simulation tank.

The permeameter used was a previously made piece of apparatus modified for the current work.

The well simulation tank was designed and constructed specifically for use in studying the hydraulics of flow into wells and practical aspects associated with well drilling and development. At the conclusion of the current project the tank has been completed, measuring equipment calibrated and a number of experiments carried out to verify the results of numerical analysis of flow to wells. It will be used in the succeeding project to study the effects of drilling and development techniques on the hydraulic characteristics of the aquifer material close to a well. Details of the design, construction and operation of the tank are given in Section D.

6.5 Field Studies

Phase I of Project 68/8 consisted of field trials by the Queensland Irrigation and Water Supply Commission to gain experience on constructing wells of various diameters at a given site and to assess the effect of diameter on the yield which could be obtained from the well. The results have been reported separately by the Commission.

Funds were allocated in Phase IV to allow the results of the theoretical and numerical studies and laboratory experiments to be tested under field conditions. This work is still in progress and will be the subject of a separate Section F to be added to this report.

Two sites have been chosen. One is in an area where problems have been encountered in extracting water because of the variability of the aquifer material and small available drawdown. The other is at a site where high yields are possible from deeper aquifers. In the former case comparisons between samples from mud rotary and percussion drilling, prediction of hydraulic constants and verification of the computed relationship between well diameter and yield are planned. In the latter case, instrumentation will be installed to allow head losses close to a high yielding well to be compared with computed values.