COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS

RECORDS:

1965/105

MATERIAL PRESENTED AT GROUNDWATER SCHOOL, 1965

Part 2

(Drilling, Bore Construction, Chemistry of Groundwater, Utilization)

compiled by

D. A. WHITE

MATERIAL PRESENTED AT GROUNDWATER SCHOOL,

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INTRODUCTION

This Record is the second and final part of the material which was issued at the Groundwater School held in Adelaide from 29th March to 9th April, 1965. The School was organised by the Technical Committee on Underground Water of the Australian Water Resources Council.

Part 1 contains the Hydrogeology, Geophysics, Hydraulics and Pumping Tests; Part 2 contains the papers on Drilling, Bore Construction, Chemistry of Groundwater, and Utilization.

No attempt was made to edit the material which was written by the lecturer in most cases as lecture notes and not for publication.

ROLE OF EXPLORATORY DRILLING IN GROUNDWATER INVESTIGATIONS

by

E. P. O'DRISCOLL
Geological Survey of W.A.

The investigation of groundwater conditions in most fair-sized areas involves more than an examination of the surface geology. Usually our preliminary assessment, based on the visible geology and such groundwater information as can be obtained from a census, must be augmented by drilling.

This gives us information as to whether the groundwater is there as we expect; its salinity and pressure; the thickness and extent of the aquifers; location of the intakes; and of course the general stratigraphy. Very often little of the latter can be deduced from surface evidence, and geophysical work, though it has its uses especially in deep areas, also has its limitations.

Exploratory drilling is therefore one of, and probably the most important tool we command. However, it is expensive. One percussion plant probably costs something like £10,000 per annum to operate, plus the casing it uses. This is as much as several geologists, and lends point to something I said earlier, that groundwater census work is of basic importance, and time spent on it is never wasted because it will save on the drilling costs.

Drilling is also slow. Most of us have had experience of projects which have taken several years to complete, and in the case of town water supplies, for example, we may not be able to afford long delays.

Unanticipated construction difficulties may also arise, particularly in deep drilling.

Ex. Boyanup (basalt)
Mandurah (boulders)
Spence (blowing sand)

This is a hazard, because on an extended job we may be pushed into developing the water before the reserves are properly established. Ex. W.A. This could result in the water being 'mined'.

Planning.

In planning a test drilling programme we must consider:

(i) The economic value to the users of the water we find. Ex. Economic limit of 'lift', for irrigation.

(ii) The amount of money we are justified in spending on test drilling; and how much we should rely on our own predictions based on other criteria. This is probably one of our most difficult tasks. Discuss.

(iii) What results we hope to achieve; and what results we must regard as a worthwhile minimum in the way of drilling information. Discuss need for water analyses; strata samples; permeability determinations; geophysical logging; palaeo work; static water levels.

(iv) What plants are available, and whether the work is urgent. Discuss W.A. contract system.

(v) What supervision is needed, and how we can provide it. Ex. Extremes are use of drilling overseer, and full geological supervision.

(vi) Where the bores will be sited, and what limits of range will apply for depths and salinities.

Select sites that are accessible to plant.

Photo-interpretation and geophysical work may give help in site selection.

(vii) Decide whether the drilling will be done on a 'face', or if a skeleton grid is to be drilled first and the intervening points filled in later. To some extent this will depend on the type of country, and the access. In drilling river flats with nearby salt water, it is better to drill a central bore, then go wide out to pick up the salt water, and work back.

(viii) Are the bores to be used afterwards for

(a) observation bores
(b) conversion into production bores. Discuss.

(ix) What information should be gained from test pumping. How much pumping should be done.

(x) Notify the landholders well in advance.

The programme must be fluid enough to enable us to reconsider it as results come in. This may affect the total drilling done, and must be allowed for in the letting of contracts.

Discuss: Effects of outside pressure for resiting.
Purchase of bores by landholders.
Curtailing what we think is necessary work.

<u>Types of drilling plant.</u>

(i) Percussion. Gives the best and most comprehensive information, but is slow on deep work. Ideal for shallow alluvials.

Sludge samples should be collected every 5 or 10 feet and at each change of stratum; water samples every 10 feet and from the top and bottom (full analyses) of each aquifer.

Use of gamma-ray logging.

Cautions: Use of drilling mud; drilling water; 'washing' of samples during bailing; contamination of samples when being collected or dried.

(ii) Rotary. Fast. Ideal for production bores in a deep pressure-water aquifer at known depth. Not so well adapted to exploratory work, as sampling is not accurate and sometimes difficult. Coring. Water samples hard to collect, and may be contaminated by mud. S.W.L.'s hard to obtain. Use of electric logging for correlation.

(iii) Down-the-hole Hammer Drill.

Limitations of application. Use in shallow basement areas.
Pilot holes. <u>Ex.</u> Exmouth
Eucla
Kalamunda
Adelaide

(iv) Gemcodrill.

<u>Field supervision.</u>

Some geologists learn enough about drilling techniques to be able to discuss them intelligently with the drillers, and even make suggestions as to procedures. We should all try to attain this knowledge, though it may take a long time. However, unless you're an expert, keep out of things; you'll either lower your standing with the driller, or end up being a party to his doing something he shouldn't, perhaps with unfortunate results.

Supervision of drillers has pitfalls for both senior and junior men. Seniors may be inclined to assume that their subordinates know more about drilling than they actually do, and can 'talk turkey' to a driller with confidence. The junior man, on the other hand, may try to impress (a very human failing) and alienate the driller; or a lack of confidence may deter him from insisting that certain things be done.

A cunning driller can find all sorts of reasons for not running casing, for example; or not coring. Many Government drillers are well trained and thoroughly reliable tradesmen, but a lot of others are not, and need constant skilled supervision.

In cases where more or less continuous geological supervision is needed, and a senior man is not available, I think there should be a drilling overseer on the site. A junior geologist can tell him, with authority, what results are required, and supervise the sampling to see that it is thorough. Beyond that, if he wants anything done he should work through the overseer, not give personal instructions to the driller.

Test pumping.

Pumping from a well without observation bores merely tells us the capacity of that individual well, as constructed, to yield water.

Discuss. How reliable are readings in observation bores.
How many bores should be test pumped.

Records.

Sludges are best logged at the core shed, and the geologist must have the weekly return with the driller's log in front of him.
Reason: W.A.E. plans. Value of accurate description. Ex. Hd Peake.
Graphic logs. Long sections. Fence diagrams.
Preservation of samples.

ARTESIAN BORE CONSTRUCTION AND SPECIFICATIONS.

by

E. R. SMITH

Water Conservation and Irrigation Commission, N.S.W.

From the time of construction of the first Artesian bore at Kallara in New South Wales in 1887 until the middle 1940's Artesian bores were constructed in New South Wales without it being required that casings be cemented.

Cementing of casings of Artesian bores in Queensland was a requirement only a few years earlier, whilst up to the present time other States do not require that this important condition apply.

Poor construction techniques; inadequate casing provisions; slotting of casings at each aquifer horizon regardless of relevant pressure differentials; together with the fact that most bores were unsuitably located, (often adjacent to creeks and gullies, or in depressions) and flowed quite uncontrolled, has left a legacy of lost pressures and flows which can never be retrieved.

Quite ruthless exploitation of Artesian basins and in particular the Great Artesian Basin in Australia, was carried on for very many years, despite warnings by competent and foresighted engineers and geologists of the ultimate damage to be expected.

Squatters and graziers, to whom artesian waters were and are so valuable, were the chief architects of this thoughtless and quite ruthless exploitation and wastage, declining to exercise any form of control or conservation, and allowing of hundreds of million gallons of water to flow to waste daily.

Other countries have had similar experiences and are now paying the piper for their actions.

Effective control of the early high pressure artesian flows would have presented difficulties because of the comparatively poor bore construction techniques and limited equipment then available.

Nevertheless much more could have been done towards control of flows and prevention of excessive wastage.

Until 1912 or later in New South Wales and some years later in Queensland, any person could construct an artesian bore at any location he chose, and waste as much water as flowed from the bore.

Some Government Departments were little less guilty of wasteful exploitation of artesian water.

Unfortunately such wasteful exploitation can still be perpetrated in States other than New South Wales and Queensland.

Hydraulic engineers (as then called) endeavoured for many years in vain to induce Governments to introduce appropriate legislation to prevent exploitation and wastage, but the big landholders were too influential and politicians were little interested.

Even when legislation was enacted the drilling techniques were not adequate and most bores had outside casing leakages. When Departmental officers attempted pressure tests and flow measurements landholders often protested and re-acted quite violently.

Only two States, New South Wales and Queensland even yet have legislative powers under their respective Water Acts to ensure and exercise control and minimise wastage.

In these States artesian bores may be constructed only under License and to specifications which stipulate conditions as to maximum depths, casings to be used, cementing requirements and the use and control of flows from the completed bores.

Both States also possess powers by which wastage from old bores can be controlled and prevented, and owners may be called upon to effect such repairs or reconditioning of artesian bores as may be required to bring them under effective control.

This aspect of control and prevention of wastage has been implemented to a quite effective degree in New South Wales where all wasteful, leaking and uncontrolled bores have been reconditioned, most of them having been deep pressure cemented.

In Queensland a start has been made on a similar programme.

Licenses and specifications attaching to licenses for the construction of new artesian bores and for the reconditioning of existing bores must necessarily include provision for ensuring a long mechanical life for the bore itself, and for the control of flows at all times, prevention of wastage etc.

What are the factors requiring consideration and what are the ultimate aims in preparing specifications for the construction of new artesian bores?

Firstly - Site selection. It must be one from which the flow can be taken away at appropriate gradients, in the direction desired - this involves a survey - assuming open bore drain distribution is proposed and permissible.

The site must be one at which the desired flow plus a reserve for future pressure loss and flow diminution is available so that relative surface level becomes important.

A survey to select the most suitable site and to locate the distributory channels or bore drains is an essential preliminary.

In New South Wales and Queensland it is possible to predict with reasonable certainty the depths at which aquifers will be met with and the total flow anticipated at a proposed artesian bore site.

This is made possible because of the data available for examination, with due regard for the R.L. of the surface at a proposed site.

That such data is available is due to the fact that Authorities in both States have possessed at least some legislative powers to ensure the recording of bore logs and other data for some 40-50 years and this has improved as further legislative powers have been obtained and enforced.

Because of their importance to the grazing industry and the more spectacular nature of artesian flows, much more early attention was given to this resource of water supply than to the probably equally important, but less spectacular and shallower groundwater supplies.

Because of its characteristics - i.e. free flow under pressure of large volumes of more than one million gallons per day from many bores, artesian bores not only caught the imagination and attention but it became quickly demonstrated that artesian water was not in limitless supply but was subject to quite rapid pressure loss and flow diminution.

The only thought given for many years in relation to the construction of artesian bores was the most effective available way by which to drill to the required depths often up to 5,000 feet - 3,000 feet being common.

No thought was given to the need for the control of flows nor was any thought given to the relative pressures obtaining in the several aquifers penetrated in most artesian bores.

Casing diameters and lengths used were given consideration only as a means of constructing the bores with the least amount of difficulty in attaining the depth required, or thought to be necessary or probable.

No thought was given the need to exclude often met with salt supplies; the prevention of leakage outside of the casings, or the need to isolate dry sand or sandstone beds, or the lower pressure aquifers, from the deeper higher pressure aquifers.

Equipment and techniques were quite primitive by present day standards, but had an appreciation of the obvious facts been made at a much earlier date, far better construction could have been achieved even with the equipment available 50 or 60 years ago.

Controversy raged for many years regarding the effect of restricting flows, taking pressure tests or closing artesian flows off at bore heads.

Claims of causing flow cessation, bursting casings and the like were common.

Claims were made that closures caused flows to fail and new bores were drilled to replace them - invariably deeper to prove those claims, by tapping a larger flowing aquifer.

Originally dry sands or sandstones became water charged and even produced flowing supplies because of leakage into them from deeper beds due to poor construction and leaking casing seatings.

It has to be taken into account that most Artesian Basins (and this certainly applies to the Great Artesian Basin) possess more than one aquifer, in fact several aquifers separated at times by hundreds of feet, perhaps up to 1,000 feet or more.

Invariably the deeper aquifers contain the higher pressure larger flows. Furthermore, before reaching the top lower pressure aquifers most artesian bores penetrate one or more supplies of hightly saline waters and probably one or more non flowing aquifers.

If an effective efficient bore is to be constructed also one which will have a maximum effective life, it is essential that before construction is commenced all of these things be taken into account and Specifications be drawn up which will not only protect the bore itself as a structure but will make provision for the protection and best possible use of the water supplies to be passed through those to be utilised.

The prospective depth of the bore has to be considered and this will influence the lengths and diameters of casings to be used.

Salt or otherwise corrosive waters to be met with must be effectively shut off and the casings protected against them by cementing.

Low pressure sub-artesian or artesian aquifers must be excluded from access by the main higher pressure flow to be exploited, therefore casings and cementings must be designed to achieve this.

Losses from high pressure beds can be as high as 50,000 gallons per day and more into low pressure upper beds if flow is allowed to pass upwards outside of the casing and to have access to these low pressure beds.

This has been proved in almost every old bore reconditioned by deep pressure cementing.

The objective of an Artesian Bore Specification is to ensure construction in such a way that casings are so positioned and cemented that only the aquifer to be exploited has access to the inner casing by way of which it flows to the surface - and at the same time has no access whatsoever to any other aquifer and the best possible protection is afforded the bore casings against attack from corrosive waters or strata.

Two, three or four strings of different diameter casings may be used in constructing an artesian bore, depending upon depths and other factors.

Usually 8-inch and 6-inch casings are used to depths up to 2,500 - 3,000 feet - then generally the outer string of 8-inch casing may be required to be inserted to from 250' - 400' depending upon the existence or otherwise of salt supplies, drift sands or other formations likely to create difficulties in drilling for and inserting 6-inch casing to the full depth.

Beyond 3,000 feet perhaps to 4,000 feet or more it is not unusual to require the use of 10-inch casing to say 200 feet, 8-inch casing to 5 - 6 - 800 feet with 6-inch to the top of the main aquifer to be utilised.

6" x 3/16" casing generally should not be taken beyond 2,000 feet or at most 2,500 feet. Beyond that depth 6" x $\frac{1}{4}$" casing should be used.

The old system of casing to full depth and slotting the inner casing opposite aquifers is no longer employed.

These casing recommendations are for cable tool drilled holes and may be altered somewhat for rotary drilled holes.

In rotary drilling a few lengths of 8-inch or 10-inch may be inserted and cemented to 50 - 100 feet and the hole completed uncased to bottom until the main casing, say 6-inch is run and cemented from shoe to surface.

Specifications for Artesian bores can be enforced only if the State concerned possesses the necessary Licensing and Legislative powers to do so and it must have the organisation to supervise the work of contractors to ensure that Specifications are complied with.

Specifications and/or Licenses for Artesian Bores to be fully effective must include appropriate provisions for the fitting of control headworks, flow control devices (orifice plate is most effective, locks and chains can be broken) tappings for pressure gauges, outlet and distributory fittings and a gate valve.

Specifications or Licenses should include permissible use of flow by means of an approved distributory system, the maximum and minimum quantities of water which may be used etc.

Bore drains waste 90% and more of the flow from a bore and in New South Wales the policy now is not to issue licenses for new artesian bores from which the flows are distributed in open bore drain channels.

Pipe lines are insisted upon as a condition of License.

Open channel (bore drain) distribution almost invariably results in losses by evaporation and seepage to the extent of 90% and more.

This has been the accepted method of artesian water distribution because of its comparatively low cost and the fact that it provides a stock supply of water over the full length of channel.

Flow and pressure dimunition has reached the stage in New South Wales and Southern Queensland necessitating a more economical distribution method and artesian bore licenses in both States now require that pipe line (mainly polythene) distributory systems to storage tanks and troughing (float valve controlled) be employed.

The attached general specification attaching to Artesian Licenses is used in New South Wales; specific requirements as to depth, casings, control and distribution of water being included as required for each individual license requirement.

This specification provides (clause 5) for the use of bore drain distribution, but a new clause stipulating pipe line system now supersedes the clause.

WATER CONSERVATION AND IRRIGATION COMMISSION

STATE OF NEW SOUTH WALES, AUSTRALIA

STANDARD SPECIFICATION

for

CASING FOR BORES

C O N T R A C T N O.

1. SCOPE. This Specification applied to hot rolled weldless steel tubing for water bore casing having screwed inserted joints of the swelled not cressed type.

2. DEFINITIONS. Throughout this Specification the following definitions shall apply:-

   (a) Tube. Where the term "tube" is used without qualification, it shall be read as having referred to one length of casing covered by this Specification.

   (b) Size. The term "size" denotes the external diameter of the casing along the barrel.

   (c) Length. The "length" of a tube shall be taken as its "effective" length, which shall be the over-all length, less the length of thread engagement as shown in Plans Catg. No. 110/210 and No. 110/211 annexed.

3. MATERIAL. All tubes shall be made from steel and shall conform to the requirements as to chemical and physical properties given in this specification.

Chemical Analysis of Steel.

Phosphorous.	Not more than 0.04%
Sulphur.	" " " 0.06%

4. TEST SAMPLES FOR MECHANICAL TESTS. The tubes shall be presented for mechanical testing in accordance with Clauses 5, 6 and 7 of this Specification, and test samples shall not be subjected to any form of heat treatment other than that involved in the process of manufacture of the tubes from which they have been cut, except as specified for bend test in Clause 7. For tubes of size 6 inch and smaller, test samples shall be taken from one tube selected from each batch of 200 tubes, and for tubes of sizes larger than 6 inch, one tube from each batch of 100 tubes.

5. COMPRESSION TEST. The screwed ends of equal length of each tube selected for testing shall be cut off and screwed together for a length of thread 1/4 inch less than the full length of thread shown on Plan Catd. 110/211 so as to give a length of approximately 16 inches over ends. The ends shall then be machined so that the test specimen will sit true between the jaws of the testing machine. The test joint shall withstand without failure the compression load as shown in Table, Plan Catd. 110/210.

6. TENSILE TEST. The sample shall be cut longitudinally from the selected tube, and shall be machined to the appropriate form so that the central parallel gauge length section of the test piece, which is not to be flattened, shall be 8 inches long. The ends of the sample may be flattened for gripping in the testing machine. The test piece shall show without failure the following physical properties of the steel:-

   A Minimum tensile strength of 35 tons/sq. inch.
   A Minimum elongation in 8-inches of 15%.

7. BEND TEST. The sample shall be cut longitudinally from the selected tube, heated to a low cherry-red and cooled in water at 80 degrees Fahrenheit. When cold, the sample shall stand bending round a curve, the radius of which is not more than four times the thickness of the sample, without showing signs of injury or fracture. The edges of the test piece may be slightly rounded before testing.

8. RE-TESTS. Should any of the samples first selected fail to pass the compression, tensile, and bend tests, as specified in Clauses 5, 6 and 7 respectively, for each failure, two further test samples cut from of the same batch, but other than the tubes from which the first samples were cut, shall be selected for testing. Should either of the two additional samples fail to pass the mechanical tests, the whole of the batch of tubes represented by the test pieces shall be liable to rejection.

9. WORKMANSHIP. The finished tubes shall be reasonably straight, free from cracks, laminations and all other injurious defects.

10. DIMENSIONS AND WEIGHTS. The dimensions and weights of the tubes shall be as specified in Table, Plan Catg. No. 110/210, subject to the tolerances permitted in Clause II.

11. TOLERANCES. The manufacturing tolerances shall be as specified hereunder:-

Outside Diameter of Tube	± 1%
Wall thickness	± 10%
Weight of each tube without protectors	± 7½%

12. JOINTS. The joints shall be of the swelled not crossed screwed type. Both ends may be tapered before screwing to approximately the same taper as the screw. No other reduction in the internal diameter of the tube at the male end will be permitted, but Clause 15 of this Specification shall apply.

All threads shall be of the right-hand British Standard Whitworth form screwed at right angles to the axis of the casing, and cut on a taper, of 1/64th inch on diameter per inch of thread length. No threads shall be cut on the transition portion between the swelled end and the normal section of barrel of the tube. The screwing shall be such that by mechanical means, joints of tubes may be screwed hard up for the full effective length of thread given in Table Column "E", Plan Catg. No. 110/210 without damage to the threads or tubes. Screwing to be such that all tubes of like diameter may be interchangeable. The ends of the tubes shall be chambered, rounded and recessed as shown on Plan Catg. No. 110/211 to which all threads and dimensions of joints are to conform.

13. GAUGING OF THREADS. The threads shall be gauged with Standard screwed Ring and Plug gauges. The variation allowed from the standard (see column "J" Plan Catg. No. 110/210) shall be not more than 1/8th inch over or under when the gauge is screwed up hand tight and measured to the last effective thread.

14. ALIGNMENT TEST. The joints shall be tested for alignment by joining the two tubes together and rotating them in V blocks or on rollers. The maximum deviation from the straight shall not then be out of line by more than 3/4 inch in twenty (20) feet.

15. CLEAR BORE. After screwing, each tube shall be tested for bore at both ends, by inserting for a distance of twelve (12) inches, a cylindrical plug gauge of not less than nine (9) inches in length, and of 1/8 inch less diameter than the minimum internal diameter of the tube.

16. HYDROSTATIC TEST. Each tube, after swelling and before screwing shall be subjected to a hydrostatic test at the Manufacturer's works to a pressure of one thousand (1,000) lbs. per square inch.

17. PROTECTION.

(a) Tube. After testing and inspection and before despatch, each tube shall receive externally one coat of quick drying coating oil.

(b) Threads. The screws at each end of all tubes shall be well coated with a composition of white lead and tallow or other suitable non-drying rust preventative, and shall be protected for shipment with screwed rings and nipples. Nipple thread protectors on swelled ends of tubes shall be provided with a hole or a slot in the unscrewed section to facilitate removal without damage to threads.

18. MEASUREMENT. Payment shall be made on the effective lengths of a tube, which shall be the overall length, without protectors, less the effective length of thread shown in Table Column "H", Plan Catg. No. 110/210.

19. LENGTHS. Unless otherwise specified, the tubes shall be supplied in lengths of from 15 feet to 22 feet with 5 short lengths of from 5 feet to 10 feet in length included in every 100 tubes supplied, but these short lengths shall not be included in determining the standard average effective lengths.

20. BRANDING. After the casing has complied with all the test requirements, each tube shall be stamped with letters and figures not less than 1/4 inch in height. The branding shall be within 6 to 12 inches of the swelled end only and ringed in white paint.

The information to be branded shall consist of:-

(a) Government identification brand, viz.,

I C

(b) The number of the tube, prefixed by the letter "R" to indicate right hand threads, e.g. R.A22.

(c) The effective length of the tube, viz., 19' - 6"

The arrangement of the brands shall be as under:-

I C R.A22

19' - 6"

21. INSPECTION. The Manufacturer shall afford the Purchaser or his representative all reasonable facilities to satisfy himself that the tubes are being furnished in accordance with this specification. All tests and inspection shall be made at the place of manufacture unless otherwise agreed.

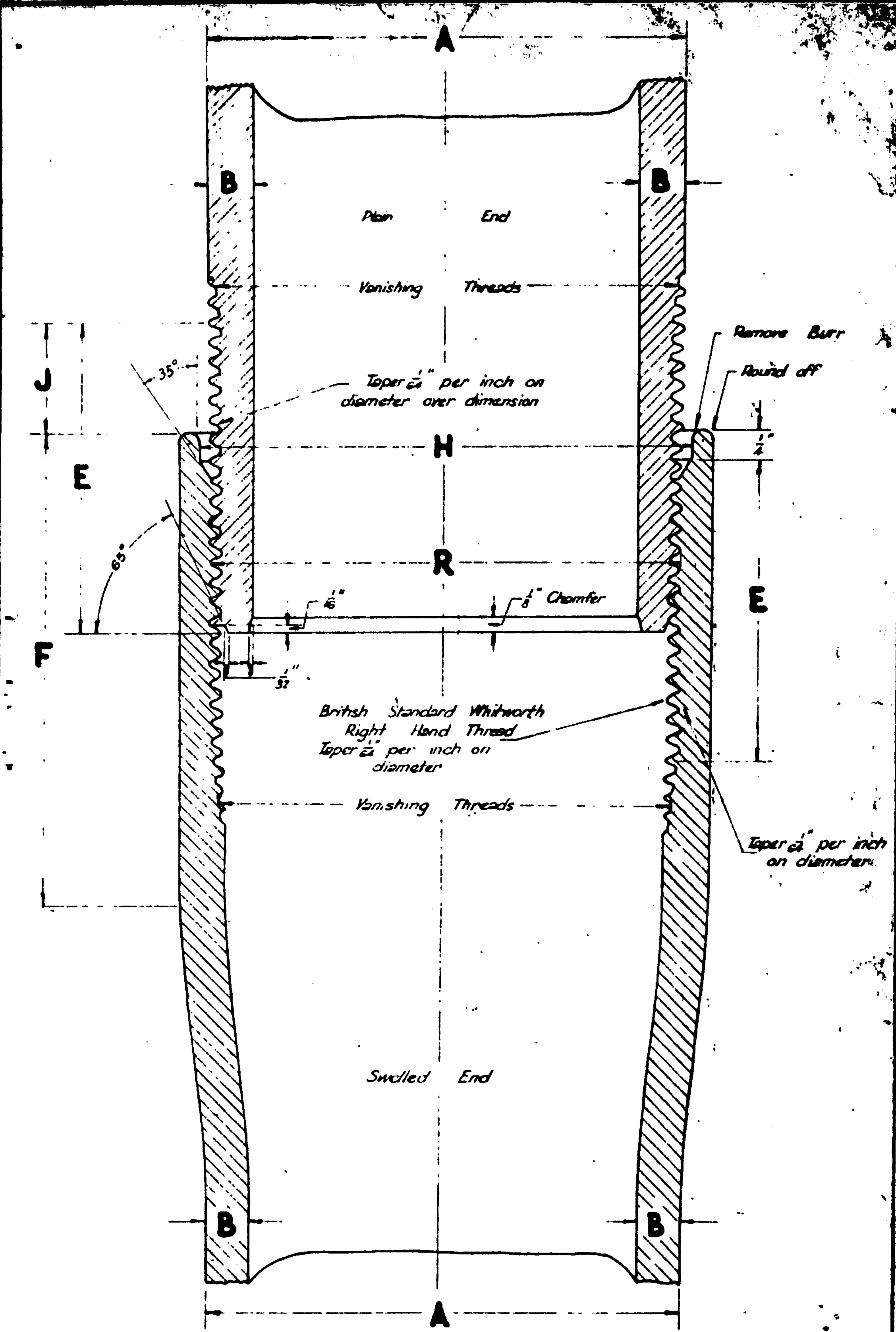
22. TESTING FACILITIES. The Manufacturer shall supply the material required for testing, free of charge, and shall at his own expense furnish and prepare the necessary test pieces and supply labour and appliances for such testing as may be carried out on his premises in accordance with this specification. All test pieces shall become the property of the Water Conservation and Irrigation Commission.

23. MANUFACTURER'S CERTIFICATES. The Manufacturer shall supply signed certificates, in duplicate, giving the results of the tests.

E. R. SMITH
Principal Engineer
Water Supplies.

Water Conservation and Irrigation Commission,

SYDNEY. New South Wales.



Principal Engineer,
Water Supplies

Water Conservation & Irrigation Commission

WATER WELL CASING
STANDARD JOINTS
KEY TO DIMENSIONS

Tracing Catd 110/211A

Outside Diameter inches **A**	Thickness of Tube inches **B**	Weight per Foot of Plain Tube lbs.	Threads per inch	Length of Effective Thread inches **E**	Minimum Length of Swelled End inches **F**	Diameter of Recess inches **H**	Thread Exposure at Hand Engagement inches **J**	Dia. over Thread $\frac{3}{8}$" from Face of Pipe inches **R**	Compression Test Load tons.
4	8-9g.	6·25	12	$2\frac{1}{2}$	4	4·031	$\frac{7}{8}$	3·961	15
4	$\frac{5}{16}$	7·64	12	$2\frac{1}{2}$	4	4·031	$\frac{7}{8}$	3·961	19
4	$\frac{1}{4}$	10·01	12	$2\frac{1}{2}$	4	4·031	$\frac{7}{8}$	3·961	27
5	$\frac{5}{16}$	9·64	12	$2\frac{3}{4}$	$4\frac{1}{4}$	5·031	$\frac{7}{8}$	4·957	30
5	$\frac{1}{4}$	12·68	12	$2\frac{3}{4}$	$4\frac{1}{4}$	5·031	$\frac{7}{8}$ } $\pm\frac{1}{8}$	4·957	45
6	$\frac{5}{16}$	11·64	12	3	$4\frac{1}{2}$	6·031	$\frac{7}{8}$	5·953	40
6	$\frac{1}{4}$	15·35	12	3	$4\frac{1}{2}$	6·031	$\frac{7}{8}$	5·953	50
$6\frac{3}{8}$	$\frac{1}{4}$	16·36	12	3	$4\frac{1}{2}$	6·406	$\frac{7}{8}$	6·328	65
8	$\frac{9}{32}$	23·19	12	$3\frac{1}{4}$	$4\frac{3}{4}$	8·063	$\frac{7}{8}$	7·949	80

[signature] 7/2/57
Principal Engineer,
Water Supplies

Water Conservation & Irrigation Commission

WATER WELL CASING
STANDARD JOINTS
TABLE OF DIMENSIONS

Tracing Cat^d 110/210^A

WATER CONSERVATION AND IRRIGATION COMMISSION.

Specification Referred to in License No.
for the Construction of an Artesian Bore.

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1. GENERAL.

The work comprising the construction of the proposed bore as provided in License No. .... includes the supply by the Licensee of all casing, closing gear, fittings, labour, plant, tools and everything whatsoever necessary for the construction of the bore complete to the entire satisfaction of the Water Conservation and Irrigation Commission (hereinafter referred to as the Commission) or of the person (hereinafter referred to as the Superintending Officer) entrusted with the local superintending of the works on behalf of the Commission.

2. CASING

The casings shall be of the following external diameters and thicknesses:-

8" x 9/32"

6" x ¼" or 6" x 3/16".

5" x ¼" or 5" x 3/16".

in accordance with the Commission's Standard Specification for casing or other specification approved by the Commission. The whole of the casing in any one string shall comply with the same specification.

3. SINKING AND CASING OF BORE.

(a) The bore shall be carried to such depth below the surface as may be directed by the Superintending Officer and to such depth only, but in any event the depth of the bore shall not exceed feet unless and until the written consent of the Commission has first been obtained. The bore shall be cased for the full depth and shall be constructed to suit the several sizes of casing determined as provided in paragraph 3 (b) hereunder. The diameter of the hole, for each size of the casing as specified, shall be sufficient to ensure the casing being worked freely to the satisfaction of the Superintending Officer.

(b) It is anticipated that the respective lengths of the several sizes of casing, as required, will be as follows:-

inch casing ....

inch casing ....

inch casing ....

and the length of the 8 inch casing as provided above shall be the minimum length to be inserted.

(c) During construction the Commission at its discretion may, if such course be found necessary or desirable to protect the main supply of Artesian Water, or for any other reason, vary the lengths of the various sizes of casing.

(d) When in the opinion of the Superintending Officer the 8-inch casing has been satisfactorily inserted and conditions are suitable for cementing, the space between the walls of the drilled hole and the outside of the 8-inch casing shall be filled from the 8-inch casing shoe to the surface with liquid cement grout mixed in the proportions of 1 bag (94 lbs.) of cement to 5 gallons of fresh water in a manner directed by and to the satisfaction of the Superintending Officer, a period of not less than 24 hours being allowed to elapse to permit of the cement setting before drilling is re-commenced, and

(e) (i) The hole shall be continued for 6-inch casing, and the casing shall be inserted to the full depth of the bore from surface level until the principal water-bearing stratum has been penetrated, and shall then be withdrawn until the casing shoe is not less than 1 foot and not more than 4 feet above the top of the principal water-bearing stratum or at such level as may be determined by the Superintending Officer, thereby leaving the water-bearing strata below this level exposed in the open drilled hole below the inner casing shoe.

(ii) The open drilled hole below the inner casing shoe shall then be mudded off, bridged and/or backfilled to the level of the inner casing shoe with dry clay or other suitable material, to protect the water-bearing formation below this level during cementing operations.

(iii) When the operation in (ii) above has been completed to the satisfaction of the Superintending Officer the whole space outside the 6-inch casing shall be filled from the 6-inch casing shoe to surface level with liquid cement grout mixed in the proportions of 1 bag (94 lbs.) of cement to 5 gallons of fresh water, in a manner directed by and to the satisfaction of the Superintending Officer.

(f) After allowing a period of not less than 72 hours to elapse to permit of the cement setting, the backfilling below the inner casing shoe shall be drilled out, the water supply restored, and unless otherwise directed by the Superintending Officer, a perforated liner of 5-inch casing extending from the bottom of the bore to such height as may be directed by the Superintending Officer, but in any case not less than 10 feet above the 6-inch inner casing shoe shall be inserted and left in the bore. Perforations are to be not larger than 12 inches by $\frac{3}{8}$-inch and to be otherwise of such size and shape as may be directed.

(g) Notwithstanding anything contained in this clause the Superintending Officer may permit the whole of the cementing to be carried out in the one operation.

(h) If and when the Licensee considers the bore has penetrated to bedrock, he shall immediately notify the fact in writing to the Superintending Officer, and obtain a sample of the stratum in accordance with the instruction of and in a manner directed by the Superintending Officer and make such sample available to the Superintending Officer.

(i) The bore, on completion, shall be of the diameter as specified, shall have a true perpendicular alignment for its entire depth and shall be free of tools or other obstructions to the satisfaction of the Superintending Officer.

4. CLOSING GEAR.

The Licensee shall supply and fit closing gear complete with all fittings and accessories and generally conforming in principle with the closing gear shown on Plan .. .. The design of the Closing Gear and the fitting of same to the casing shall be to the satisfaction of the Superintending Officer, and an orifice plate shall be fitted within the headworks if the Commission so directs.

5. CONTROL AND DISTRIBUTION OF WATER.

(a) Upon completion of the bore and a flowing supply being obtained therefrom, the Licensee shall, if bore drains have not been constructed, control the supply from the bore at the borehead to not more than 5,000 gallons per day.

(b) The Licensee shall furnish to the Commission full information as to the surveyed levels and proposed gradients, together with a scale plan showing locations of all bore drains which it is intended shall be constructed and the drains shall not be constructed until the Commission's written approval of the design has been obtained.

Upon construction of the drains the flow must at all times be controlled to the minimum requirements of a well constructed and well maintained bore drain system and distribution of water in natural channels or depressions will not be permitted.

(c) Notwithstanding the provisions of paragraph (b) hereof, the flow from the bore shall at all times be controlled at the borehead to actual requirements, based on a maximum allowance of - - - - - gallons per day in respect of each mile of drain constructed and in any event the maximum flow shall be - - - - - gallons per day, and then only if not less than - - - - - miles of drains have been constructed.

6. WEEKLY RETURNS AND SAMPLES OF STRATA.

The Licensee shall notify the Commission's Boring - - - - - Superintendent at - - - - - - when drilling is to commence, and shall at his own expense furnish to the Boring Superintendent, each week after the commencement of drilling, returns in duplicate made on forms supplied by the Commission, setting out depths, diameters and other particulars of the bore and casing inserted, as well as the nature and thickness of the various strata encountered, and of the location, quantities and quality of all supplies of water met with and of the height each stands relative to the natural surface; and forward in suitable containers a sample of not less than two (2) quarts of water from each supply encountered, addressed to the

WATER CONSERVATION AND IRRIGATION COMMISSION,
Principal Engineer, Water Supplies, DARLING HARBOUR
(in the case of goods rail);

or

SYDNEY (in the case of passenger rail);

or

Cnr. Harrington and Essex Streets,
SYDNEY (in the case of parcels post),

for the purpose of analysis.

Water Conservation and Irrigation Commission,
Sydney.

SUMMARY OF THE USE OF CEMENT IN BORE CONSTRUCTION AND RECONDITIONING

by

E. R. SMITH
Water Conservation & Irrigation Commission.

Cementing of casings in oil and gas wells is an essential practice for both constructional and production purposes.

Discuss oil - well practice

1. Cementing surface casings - purpose and methods.
2. Cementing as a constructional (drilling) technique to fill cracks or crevices in rocks, via which mud or air circulation is or may be lost.
3. Cementing of production casings prior to gun perforating for oil or gas production.

   Pressure circulation method normally adopted - two plug (Perkins) method - describe and discuss.

   High pressure tubing methods - packer systems used.

Oil-well cementing practices developed and modified as an essential and important system in water bore construction.

First introduced in Queensland mainly for artesian bore construction and re-conditioning in mid 1930's, and some 10 years later in New South Wales.

Since 1946 all casings in new artesian bores have been pressure cemented - such provision having been made compulsory in terms of License conditions in New South Wales.

Cementing procedures have been and are an important and most effective means for re-conditioning and controlling flows from old artesian bores - normal practice for re-conditioning casing corroded sub-bores.

Numerous purposes are achieved and better construction attained by the appropriate use of cement in sub-artesian bores - shallower groundwater bores.

Included in the advantages of using cement in bore construction are:-

1. It is an effective means of providing a permanent seal between the walls of a drilled hole and the casing or casings inserted in the bore thus producing an impervious seal against water movement outside of casings.
2. It provides an effective seal between the casings and corrosive elements in the strata or saline water supplies cased off, thereby protecting the casings from outside corrosive attack.
3. It seals off unwanted or poor quality water thus permitting exploitation of and entry to the bore, of only the water desired to have access.

4. It prevents outside leakage of water from one aquifer to another and also leakage from high pressure aquifers to the surface.

5. It prevents ingress of contaminated materials from the surface around the casings and is thus an anti-pollutant medium.

6. It allows of full control of flowing bores - their complete shutting down if required without risk of damage or leakage.

Numerous additional advantages can be gained from the use of cement as a normal practice in bore construction.

Placing of a cement plug above a backfill in alluvium is a procedure often adopted in screened bore construction.

For re-conditioning old and/or leaky bores and as a means of making old artesian bores controllable cement is an indispensable aid.

Old bores can be made as good as new and control of flows is made possible by cementing of old bores, which if attempted without prior re-conditioning including cementing, would result in increased leakage or damage and even failure of flows.

Straight Portland Cement Grout is almost invariably used i.e. Portland Cement is mixed with water - 5 to 6 gallons of water per cubic foot of dry cement to produce a smooth grout or slurry which may be pumped to the position or positions required.

The addition of from 3 to 5% of Bentonite (by weight to cement) is quite useful in bore cementing - the Bentonite having the effect of producing a smoother grout and reducing shrinkage in the cement as it sets down the bore.

The most generally useful cement grout for bore cementing work is obtained by using 5½ gallons of water to each 94 bag of cement. Clean cool water should be used.

Both quick setting and slowing down agents are used under certain conditions as additives to cement for use in bore construction and re-conditioning.

Cementing methods and the many applications for the use of cement in bore construction and re-conditioning cannot possibly be dealt with in any detail in one lecture, therefore only broad principles may be dealt with at this time.

Each of you have received a copy of the Handbook on Cementing and although this also is necessarily couched in somewhat general terms considerably more detail is included than is possible in this discussion.

Perhaps those of you who have had or made the opportunity of reading the Handbook will have questions to ask on various aspects of this work - and I will later endeavour to answer questions and explain in some detail any aspect or procedures of special interest.

Cementing procedures are many, but the two common methods of placing cement grout in required positions are Pressure, and Gravity.

Pressure cementing i.e. the forcing of cement into the required position by pumping has the distinct advantage of generally being more positive and controllable. Indeed some cementing procedures can only be accomplished by the pressure method.

(1) Diagram and explain Sample Pressure Jet

(2) Diagram and explain Tubing Method

(3) Diagram and explain Gravity Method

Mixing of Cement -

Power Mixer

Jet Mixer

Hand Mixer

Need for Straining

Time of setting -

48 hours shallow work not subject to drilling out or vibration.

72 hours deep work - or where vibration of casing is likely to occur during completion work on bore.

Cementing of new bores is usually a straightforward operation because the details of casings are known, the condition of the hole is known, and the casings are not damaged or leaking.

Nevertheless it is essential that each job be properly planned and adequate equipment be on hand to ensure success.

Remember a few tons of cement set in the wrong place in a bore can present a lot of difficulty and can cause complete loss of a costly bore.

When it comes to the use of cement in re-conditioning old bores a completely new set of conditions and problems are presented - and seldom will it be found that any two jobs are alike.

The first essential is a thorough investigation of the bore, especially the casing or casings, before attempting any cementing.

It is essential that the inner casing condition be thoroughly explored and any holing determined and accurately located.

Provided the inner casing is sound, a satisfactory cementing job is almost always practicable, regardless of the conditions of outer casings.

Shallow holing of the inner casing is usually quite easily overcome by the use of a short liner and packer, but if holing of inner casings occurs at numerous levels extending to considerable depth it more often than not becomes necessary to use an inner casing liner throughout.

Dye tests are normally used to ascertain the condition of casings - and these are quite fully dealt with in the Handbook on Cementing.

Similarly the Au-Current meter is explained in some detail in the Handbook.

It cannot be overstressed that very thorough investigations and tests must be carried out before cementing of an old bore is attempted.

From these tests a plan must be formulated and the whole procedure planned in detail after considering all evidence and conditions as indicated.

Once a cementing procedure is commenced it is usually not practicable to "change horses in midstream" or to drastically alter the plan once under way.

Aquifer protection is a most important consideration in any bore cementing operation.

Placing cement in the wrong position or allowing cement to precipitate to the bottom of a bore opposite the aquifer are matters which must receive full consideration in any cementing programme. Total loss of a bore can result from a miscalculation or an oversight.

Some old bore re-conditioning and cementing jobs cannot be undertaken without the use of a boring plant - but in general, a boring plant is necessary only if there are obstructions in the bore or a new casing liner has to be inserted.

Provided appropriate equipment is available and adequate tests and investigations have been carried out, it can be said that no old artesian bore however decrepit the casings, unless total collapse has taken place, is beyond re-conditioning and deep pressure cementing.

Large flows, very hot water, no surface casings visible, craters around the bore hole full of hot water - all of these can be dealt with successfully if tackled in the correct manner and with appropriate equipment.

There are some cardinal rules to be observed by those undertaking deep pressure cementing of bores and included are those listed on pages 3 and 4 of the Handbook.

A quite commonly used method of cementing oil wells and deep water bores and not referred to in the Handbook is what is known as the "Tubing Method".

I have used this method very successfully but did not include it because it is applicable only under some conditions and in particular because it requires not only special equipment but some experience in handling if the tubing is not to be found firmly cemented inside the bore casing when it is proposed to recover it after the cement has set.

In the tubing method, a smaller diameter pipe say 2-inches diameter is inserted inside of the casing to the casing shoe level or thereabouts.

The top length of pipe 20 feet or more is fitted through a packing gland attached to the top of the casing and a by-pass or release pipe with gate valve is attached to the casing below the packing gland.

With the tubing at bottom the annuluses between the tubing and casing and between the casing and the hole are filled with mud or water - so is the inside of the tubing.

Cement is then pumped through the tubing until the annulus between the outside of the casing and the drilled hole is filled to the surface, control being by valve on the casing head.

Maintaining a constant pressure, mud is then pumped through the tubing to expel all cement and the tubing is raised through the packing gland to the first collar - i.e. the full length of the top length of tubing - which is left in that position with full pressure on until the cement outside of the casing has set.

The tubing is then recovered and the hole cleared of mud.

This method is very positive, and reduces the pumping time factor as well as reducing the quantity of displacing following mud to clear the tubing of cement as compared with the quantity required to fill say 8-inch casing.

The method is briefly described and depicted in The Johnson Drillers Journals of July - August and September - October, 1964.

Discussion.

THE USE OF CEMENT

IN

BORE CONSTRUCTION

AND

RECONDITIONING

(Hand Book)

BY - E. R. SMITH, Principal Engineer,
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THE USE OF CEMENT IN BORE CONSTRUCTION AND RECONDITIONING.

The successful "Shutting off" of undesirable water from bores by the use of cement is one of the most important and involved problems that the drilling engineer has to encounter, but the great importance of the practice to the petroleum production industry has resulted in the development of excellent equipment, and the attraction of highly skilled engineers and operators to the work.

Specially designed equipment is employed for the mixing and pumping the cement grout into the desired position in a bore, at times thousands of feet below the surface, in the shortest possible time. Such is the efficiency of these special cementing units that 1,000 cubic feet of cement can be mixed to the correct consistency and placed in position 10,000 feet down a well in 45 minutes from the time of commencement of mixing. Pumps capable of handling pressures up to 2,000 lbs. per square inch are often used, and iced water may be employed for mixing the cement to slow up the initial set, which is accelerated by the high temperatures obtaining at the lower levels in a deep bore. On the other hand quick setting agents are often added to the cement grout to induce more rapid setting and hardening of the cement after it has been placed in position behind the bore casing.

The high capacity powerful and expensive equipment necessary for oil well cementing is not required for the comparatively small jobs undertaken in the construction and reconditioning of artesian and sub-artesian bores in Australia, because the depths to which it is necessary to introduce cement do not approach the depths of many oil wells, and the quantities of cement required are correspondingly less.

By the introduction of cementing practice into new bore construction and old bore reconditioning, the effective life of bore casings can be considerably prolonged, outside corrosive attack from oxidised shales and corrosive waters can be practically eliminated, leakage outside and between casings can be prevented, and old bores in leaking condition can in most cases be repaired and controlled as required.

The use of cement for sealing the space between the walls of a drilled bore and the outside of the casing serves the dual purpose of--

(a) preventing leakage of the flow up behind the casing and its escape at the surface or laterally into low pressure, or dry "thief" beds, and

(b) protecting the casing from corrosive attack by the oxidised shales, saline waters etc. often met with in the upper strata.

In some districts (Coonamble, N.S.W., Tambo-Hughendon Queensland) the artesian waters are highly corrosive being charged with free CO_2 gas which is most destructive to steel casing, and the cementing of casings both outside and between the various sizes provides an effective resistance to this corrosive attack. The inner casing through which the water flows will be destroyed by the free CO_2, but the cement lining will maintain an effective resistance and prolong the life of the bore, permitting the maintained control of the flow.

This fact may appear contrary to the experience of many and the expectation that acid waters and CO_2 charged waters attack the free lime in cement and rapidly cause its breakdown. However experience has shown that such is not the case in respect of bores within the Great Artesian Basin, which have been deep cemented for many years and remain mechanically sound, there having been no attack on the cement introduced.

Investigations have not been made as to why this should be so, but it would appear that the carbonates and residual alkali present in the artesian waters form a protective "gell" on the surface of the cement, thereby preventing attack by the corrosive agents.

The time factor is of major importance when handling liquid cement in deep bore cementing and pumps of adequate capacity are essential to enable the placing of the cement in the required position within the time available before setting of the cement commences.

From a half to ten tons of dry cement, according to the particular bore, may be taken as approximately the minimum and maximum quantities required for artesian or sub-artesian bore cementing. A power driven pump capable of 500 lbs. working pressure, together with a displacement capacity of about 80-100 gallons per minute will meet all likely requirements, although the majority of cement jobs do not require the use of the full power or capacity of such a pump.

The pumps most adaptable are of the piston reciprocating double acting, or displacement types, fitted with renewable liners and piston heads. Readily accessible large size fullway spring loaded hard rubber faced valves should be incorporated in the design of a cement pump, as it is in the valves that trouble is most likely to be found when handling cement grout or heavy muds.

One of the principal difficulties connected with bore cementing is the fact that most of the work has to be carried out in isolated and inconvenient localities. Transport of plant and equipment is a considerable item, and the weight of pumps, power units, mixing equipment, tanks etc., must be kept to a minimum consistent with efficiency.

The neat cement grout is often mixed in low flat tanks a few lengths of collapsible cattle troughing, or collapsible steel frame canvas tanks, and the mixing is done by hand, with long handled rakes and hoes. Mechanical mixers are of course desirable and more efficient, and are indeed essential if much of this type of work has to be undertaken. Water Jet mixers are the most efficient, but quite satisfactory results can be obtained with the continuous type colloidal concrete mixing machines.

From 4½ to 6 gallons of water per cubic foot of dry cement may be used, the specific gravity of the grout varying according to conditions obtaining at any one particular bore, and the less water used for mixing the better. Five gallons of water per 94 lb. bag of dry cement is the most generally useful proportioned mix.

It is not proposed in this paper to deal with the more complicated cementing operations often required in deep oil wells, its purpose being to outline in somewhat general terms the most generally used and simpler methods of introducing cement during construction, and for the reconditioning of bores drilled for the production of water.

While there are general principles and practices applicable to the majority of cement jobs likely to be encountered, many varied conditions and circumstances are certain to occur, each calling for individual study and method of treatment. General knowledge of accepted practices, coupled with personal practical experience will be the best assets when making a decision as to the safest and best methods to be applied to any job.

It is the intention here to give details only of the methods used for jobs most likely to be met with, so that the reader may grasp the fundamental principles of cementing, then from his own experience and observations when carrying out different type jobs, exercise his initiative in meeting varying circumstances and difficulties which are certain to arise, especially in the reconditioning or repair of old bores.

Some important principles and details, enumerated hereunder, which are applicable to almost every cement job, and the adherence to these details will considerably assist the operator to carry out cementing work with a minimum of risk of failure and a considerable saving of time and ease of efficiency in handling the various stages of the works:-

1. Avoid undertaking a pressure cementing job with inadequate or makeshift equipment, and be certain that all plant, particularly the power unit and pump, is in good working order by having a trial run under as nearly working conditions as possible, before commencing to mix the cement grout. Mechanical breakdown during cementing operations could result in the loss of a costly bore.

2. Have everything necessary for the job completely in readiness, and a plan of procedure decided upon before commencing to mix the cement, as time is a limiting factor immediately mixing is begun.

3. Always be prepared for unexpected emergencies or contingencies and eliminate all risky procedures as far as possible.

4. Always use fresh cement, free from lumps. Old cement will take its initial set, particularly under pressure, more rapidly than will fresh cement.

5. When mixing by hand have in the mixing tank at least half of the water to be used for the mix before adding any cement. Have all of the water in the tank before adding the last of the cement. This will reduce lumpiness and speed up mixing.

6. Mix cement as quickly as possible, but be sure to mix thoroughly, and eliminate lumps. So far as is consistent with speed, the dry cement should be added gradually, and distribute each bag over the whole of the tank. Dumping a bag in one spot causes the cement to lump and adds to the time taken in mixing.

7. Always strain mixed cement through not larger than quarter-inch mesh sieve before allowing cement into the pump suction.

8. Five (5) gallons of water mixed with one bag of cement (94 lbs.) mixes 7½ gallons of cement grout of 1.92 specific gravity.

This mix is ideal for conditions to any depth provided that a suitable pump is available, but may be too heavy for a low pressure pump and confined spaces. Always use cool <u>fresh</u> water when mixing cement.

9. Five and a half to six gallons of water to each bag of cement have proved satisfactory for general use, the lighter mix being recommended for forcing into restricted spaces, such as between 6-inch and 5-inch casings, or when cementing through a bulkhead.

10. High temperatures are conductive to rapid set in cement, and this factor must be taken into consideration. 180°F will induce initial set to commence in about 8 minutes. Cooling of a bore by pumping in iced water is sometimes necessary, therefore, if cement is to be pumped to any depth, with small capacity pumps.

11. Care must be taken when measuring, or calculating quantities of water, following fluid, mud etc. Accuracy is essential as a few gallons may quite easily differentiate between success or failure when working to fine limits, whether it be in quantities or pressures.

12. Make allowances for suction lines, pump and delivery line capacities when calculating cement quantities, or following displacement fluids.

13. A thorough cleaning of cement lines and pump is necessary immediately the cement has been placed in position in the bore.

The cementing job most frequently required is that of cementing an outer casing, as required in terms of artesian licenses granted for the construction of new bores.

The Pressure Circulation Method is recommended as being positive and easily handled. Generally, from 150' to 300' is the depth at which an outer casing is inserted and cemented, and a power driven pump capable of handling pressures up to 250 lbs. per square inch is adequate.

CEMENTING OUTSIDE CASING BY PRESSURE CIRCULATION METHOD.

With casing suspended free of bottom, establish circulation with power pump connected to the casing head by forcing water or light mud 1.2 to 1.4 specific gravity down inside of casing and up the outside between the casing and the walls of the hole until returns issue from the bore hole at the surface and the pump is operating without excessive pressure being required The water or mud flowing from the bore hole outside the casing, as it is forced up by the pump, should be run in a short drain, back to the pump suction via a settling tank or pit, and circulation continued until all cavings (if any) have been removed, and positive free circulation has been established.

If possible, it is of decided advantage to have the casing slowly lifted and lowered or turned in the hole while circulation is being established as it assists to free up any cavings around the hole outside the casing, and prevents bridging. Mud fluid is preferable to water circulation in most cases, and mud only should be used if there is any tendency for the hole to cave, as water tends to wash free any loose flakes of strata on the walls of the hole, thereby causing collapse or bridging, and the possible loss of circulation, while mud has the advantage of carrying with it any loose particles, besides plastering the walls of the hole and sealing off any loose sections.

Mud fluid must be used for establishing pre-cementing circulation if a loose sand strata has been penetrated in drilling.

With circulation positively established, mix cement grout of sufficient quantity to fill the calculated space between the walls of the hole and the outside of the casing. With a little trouble it is possible to measure this space between the wall of the hole and the outside of the casing with accuracy. Mix a small volume of the circulating fluid with fluorescein in Rho-damine dye, pump in the dye and then measure the further quantity of fluid following it until the dye reappears after circulating. Knowing the exact volume of fluid inside the casing, the volume outside is readily obtained. Where any marked cavitation of the walls is suspected, this method eliminates any doubt as to the quantity of cement required. Pump cement down inside of casing, and when cement has been pumped, follow it immediately with water or mud of measured quantity, sufficient to displace all but about 5 feet of the cement from inside the casing, thus forcing the cement grout up the outside of the casing to fill the space between the casing and walls of the hole to the surface.

Cementing equipment should include fullway quick-release casing cementing heads which permit of rapid removal and replacement of pump delivery connections to casing. If equipment provided permits it is most desirable that a separator or spacer plug be inserted in the casing between the column of cement pumped and the following displacement fluid. This separator may be a wood or heavy paper plug which prevents mixing of the following fluid with the top of the pre-pumped cement column. Unless this separator is used dilution of the upper few feet of the cement grout will occur and may result in a poor quality grout being placed at or about the casing shoe.

When the full quantity of following fluid has been pumped, close the valve at the casing head to prevent any movement of cement during the period of initial firm set, some six to eight hours at least, a period of at least 72 hours to elapse before any work is carried out on the bore or the valve opened.

It is essential to have a valve at the casing head between the top of the casing and the pump delivery, so that the pump may be cleaned of cement without disturbing the back pressure on the inside of the casing. A pressure gauge on the cement pump or casing head should be used as a check on the progress of the cement, and to ascertain if the pump is working satisfactorily and within its rated capacity.

All quantities of water, following fluid etc. to be calculated and checked into suitable, properly connected tanks, before any cement is mixed. Once mixing commences the whole operation should be completed with as little delay as possible.

"PERKINS" METHOD.

The two plug method of pressure cementing is known as the "Perkins System" after the inventor and patentee. After circulation is obtained, two wooden plugs about 18" long and having a clearance of ½-inch to the inside diameter of the casing, and fitted with leather, rubber, or fabric washers, fitting fairly closely inside the casing, are used. One plug is inserted in the casing first and the cement is pumped on top of it. As soon as all the cement is introduced the second plug is inserted and the pump turned on to water or mud fluid again. The result is that a column of cement is forced down inside the casing between the two plugs. The casing is suspended and rotated just off bottom so that the lower plug can pass out of the casing but the top plug cannot, and when this occurs the pump pressure immediately rises, indicating that all the cement has been forced out of the casing and the job is complete.

It is not always safe to rely on the pump pressure rise to indicate that all the cement has been pumped behind the casing, as a "flash" set of the cement, or some obstruction may give the same indication with the cement still inside the casing. Calculation and measurement of the displacement fluid should always be made, and the pressure rise used only as a check on the position of the cement.

NON PRESSURE CEMENTING.

Special conditions may be encountered in some areas where circulation outside of casing is not possible because of one or more, of four general reasons:-

1. Tight hole being drilled and casing driven.

2. Swelling shale, which when drilled and saturated with water closes in around the casing, leaving no clearance.

3. Drift sand conditions, where circulation with water only is not possible, because the water pumped down is absorbed by the drift. The use of mud fluid for circulation will overcome this in some cases, if the sand has not packed tightly. Drilling with mud continuously in the hole will often prevent caving of drifts.

4. Mud spring areas, where usually the heaving nature of the saturated strata necessitates driving of the casing. In mud spring country water will escape laterally as in drift sand.

Holes drilled by percussion methods in these strata are always much more difficult to handle than those drilled with rotary tools, because the latter method ensures positive mud circulation at all times, and the easy introduction of cement when required. Without circulation in percussion drilled holes, it is often only possible to cement around the outside bottom of the casing, but this can be done satisfactorily, and is sufficient to prevent leakage if properly carried out.

The various procedures for cementing casing in tight holes without circulation, in drift sand, or mud spring country are as follows:-

"A" INSIDE FLUID GRAVITY METHOD.

Lower, or if necessary drive casing firmly to bottom in order to prevent as much leakage into the casing around the shoe as possible. Bail all water from inside of the casing, then mix sufficient cement grout to fill up behind casing from shoe upwards, to where it is known that the hole is tight. Pour cement down inside of casing, then drop a paper plug on top of cement in bottom of casing. Fill casing to top with water, then lift casing from seat at bottom, when the weight of water inside of the casing will force cement around the shoe and up outside. Continue pouring water into casing as it follows down forcing the cement around the shoe, keeping a careful check on water added, and when the volume of water displaced after lifting the casing equals the volume of the cement poured down, re-seat the casing tightly on bottom. When casing is too tight in a hole to allow the weight of water alone to force the cement into position the use of pump pressure is necessary. It must be realised of course that it is useless to cement off before drilling and casing a bore below drift or mud springs, and that it is essential to have sufficient free hole below the strata to be cemented off, to allow for a good cement column between it and the casing shoe.

Having cement sealed the casing at the bottom as above, cement grout may be poured down outside the casing from the top, until the hole is filled to the surface level. Although the bottom cementing has made the "shut-off" to prevent outside leakage, there is much to be said in favour of then filling up from the top, as it firms up the casing, and where saline water is shut off behind the casing, cementing has a very definite advantage in neutralising the effect of the salt water on the outside of the casing, as it percolates down through the water and formation around the casing.

"B" DUMP BAILER METHOD.

Probably the earliest, and a still used method of forcing small quantities of cement outside of casing from the shoe up, when a non flowing bore is full of water, is the Dump Bailer Method. Cement is placed at the bottom of a bore, inside of the casing by means of a dump bailer, which is an ordinary sand pump having no bottom valve, but a glass or cast iron plate is fixed in a cage, to the bottom of the bailer, and a spring operated plunger breaks the glass, upon the weight of the bailer full of cement resting on it when the bailer reaches the bottom of the bore hole.

With the glass or cast retainer broken the cement is left at the bottom when the bailer is withdrawn for a fresh load of cement and a new retainer. Several runs with the bailer may be necessary to place the required amount of cement at the bottom of the bore, and it should be remembered that a comparatively thin mix is essential for the first few loads, otherwise the bailer will "float" on the cement already placed in the bore and fail to break the glass to release the load of cement.

Having placed the required quantity of cement on bottom, (the casing having previously been withdrawn to a height from bottom sufficient to leave open hole below the shoe which will accommodate the full quantity of cement and placed a separator plug on top of the cement, the casing is then filled to the top with water, a tighthead attached, and the casing lowered to bottom. The water column enclosed within the casing by the tighthead, will produce a solid ram-rod or piston effect as it is lowered down on top of the cement at the bottom of the hole, and force it around the shoe and up outside of the casing, as each length of casing is lowered into the bore hole.

It will be understood that the casing withdrawn prior to cementing will have to be replaced length by length, and as each length is screwed to top of the string, it will have to be filled with water and the tighthead attached before it is lowered. Generally two lengths are all that are withdrawn as this gives sufficient displacement to force a satisfactory amount of cement into position.

Speed in handling is essential, therefore the following procedure is recommended. Withdraw and unscrew one length Only; dump the cement on bottom, then pull the casing up to the height required i.e. just below the top of the cement. Fill the casing to the top with water, use a pump if available, fix the tighthead, then lower the casing back. Remove the tighthead and screw on the length of casing previously taken off, fill it with water, attach tighthead again and lower casing to bottom leaving tighthead in position until cement sets.

With the bottom cementing completed, cement can then be poured down from the top to fill up outside the casing. Where a particularly large hole has been drilled at the top, and it is desired to save some cement, clean sand may be mixed in equal parts with the cement and poured down.

When cementing at shallow depths by the Dump Bailer Method, an ordinary dart valve bailer may be used, by fixing a light line to the top of the valve inside the bailer, and passing the line up through the bailer to the surface. When the bailer reaches bottom with its load of cement the valve is released by lifting it from its seat by means of the attached line extending to the surface.

Another "Dump Bailer" method of cementing is as follows:-

After placing the cement at the bottom of the bore, the casing having first been withdrawn above the height to which the hole will be filled with cement, a casing plug with an inverted leather bucket fitted is lowered to the bottom of the casing shoe and fixed there. The casing is then lowered to bottom displacing the cement and forcing it up behind it. Plugs can be run in either on the bailer or tools tied thereto with soft rope; the plug is run below the shoe, and on being retracted fits tightly by the agency of the leather bucket, the soft the soft rope is broken and the plug left in position outside the shoe. This method is most positive and is time saving as compared with that of screwing lengths of casing on top and filling them with water.

Sometimes it is not possible to raise the water level inside the casing by pouring or pumping in more water, and if the casing is plugged or capped and then lowered with these conditions obtaining, the compressible air space between the water level and the cap or plug will permit of the cement coming up inside of the casing instead of being forced up behind it, and the cementing operation will fail.

This difficulty may be overcome by adopting the last described method or by the use of a water-tight plug to which washers or pump buckets are fitted being forced down by the weight of a string of drilling tools to the top of the water, and then filling above the plug with water to the top cap or plug.

"C" OUTSIDE GRAVITY METHOD.

In a few instances where no top water has been met with, no caving has taken place, and a good clean hole with ample clearance around casing has been drilled, it is satisfactory to cement the casing by pouring the cement down from the top, with the casing firmly seated on bottom, or plugged inside to prevent cement from running up inside of the casing. Fairly thin cement should be used for the first batch poured down, and no sand should be mixed with cement to be poured to any depth, because irrespective of how well mixed it may be, sand has a decided tendency to separate and "bridge" when part way down, thus preventing the cement from being placed where it is specially required, down to the casing shoe. It will be noted that almost ideal conditions have to obtain before this type of cementing job can be considered as one likely to prove satisfactory. Where a supply of water has been met with above the depth at which casing is seated, cement introduced from the surface cannot gravitate downwards more than a short distance below the level of the water bed, in which case it is necessary to ease the casing up from its seat to permit of the cement passing down to and around the shoe. Care must be exercised to ensure of the casing not being lifted too high or for more than a few seconds at a time, otherwise too much cement will probably precipitate around the shoe and up inside of the casing, where it is not required and only has to be drilled out again. The quantity of cement passing around the shoe can be checked by running in a sand pump after lifting and reseating the casing.

It will be appreciated that a quantity of cement cannot be introduced either by pumping or gravitation into a closed area, such as the water filled, or partly water filled, annular space between the walls of a bore hole and the outside of a string of casing of which the shoe is firmly seated on bottom, unless there is some way of escape for the impounded water and air. Such conditions would apply in a bore hole in which no water supply has been met with, and also to that portion of a bore hole between a water supply and the casing shoe, when the latter is firmly seated on bottom.

Having a much higher specific gravity, or weight per gallon than water, cement grout in comparatively less volume will, if gravitated or pumped in on top of a water column, force the water back into the aquifer from which it enters the bore. Therefore, provided sufficient space for cement is available above the static level of the water, and provided also the water is not so muddy as to clog the pores of the water beds, cement poured down from the surface can be successfully introduced to at least the level at which the water supply enters the bore hole, even with the casing shoe firmly seated.

While none of the gravity methods can be regarded as being as positive, nor generally so effective as the pressure (pump) circulation method of cementing from the shoe upwards to the surface, there are nevertheless many instances, particularly in the shallower non-flowing bores, where gravity methods can reasonably be employed, and there is in them the advantage of very little equipment being required, thereby saving in time and cost.

Gravity cementing, in addition to being useful for the treatment of outer casings, can, when conditions are favourable, be quite successful for deeper work where two or more strings of casing are involved.

In shallow sub-artesian bore construction, where salt, or otherwise corrosive or undesirable water(s) must be excluded, it is not sufficient to case off such water(s) without affording the casing the protection of an outside cement column from shoe to surface. Quite often the supply to be utilised is also of a corrosive nature and in addition to cementing off the upper supplies excluded by an outer string of casing, it is desirable to cement also between the inner and outer casing, and outside of the inner casing, extending to the top of the main water beds.

Cementing of the outer casing is best carried out immediately its seating depth has been reached, and before drilling is commenced for the insertion of an inner casing. The earlier cementing operations are carried out after a bore is drilled and casing inserted, the less likelihood there is of the occurrence of collapse or caving which may prevent effective cementing.

When the supply of water proposed to be used has been met with, the aquifer may be drilled into just sufficiently to establish its identity, or it may be drilled through and a sump of 20 feet or more drilled below it. Unless water bearing strata is of considerable thickness, it is good practice to always drill a sump below it. Where the water beds have merely been "tapped" it is necessary only to plug them off but, when drilled through, it is probably better to bridge the open hole immediately above the water beds, before cementing.

It is entirely a matter for the operator's discretion, having regard for time and other factors, whether a hole is plugged back, or bridged. With the water beds protected by a plug or a bridge, the inner casing is seated thereon, and cement is gravitated down between the two strings of casing from the surface and outside of the inner casing to the shoe. The casing should be lifted slightly from its seat and turned a few times while cement is being poured. This assists in the more even distribution of cement and permits of it reaching the shoe.

Similar procedure may be adopted for non-pressure cementing of new artesian bores, where the usual license conditions require that:-

(a) An outer casing (usually 8") be used to exclude upper salt supplies and drifts.

(b) A second string (usually 6") be used to prevent flow loss from the main artesian aquifer(s) to the lower pressure top artesian aquifer(s).

(c) An inner casing or liner, generally 5", be inserted from the bottom of the bore hole and extending to a short distance above the 6" casing shoe.

Two separate cementing operations are usually necessary in such cases. The first immediately after the 8" casing has been inserted to the required depth and before drilling is commenced for the 6" casing. Should caving or drift sand conditions obtain, and if pressure cementing equipment is not available, it may be desirable (provided the casing is sufficiently free) to cement outside of the 8" casing by both the dump bailer and outside gravity methods, with a view to obtaining a better distribution of cement and at least having a good top and bottom seal outside of the casing.

Where the top aquifer only of the artesian supplies is proposed to be used, the inner casing may be seated on a temporary bridge and cemented with the shoe placed immediately above the water beds, but if the usually higher pressure deeper aquifer(s) are to be tapped, and the top aquifer(s) therefore excluded, the inner casing should be carried down until the aquifer has been fully penetrated and a sump of some 20 to 30 feet drilled below.

After drilling has been completed to the required depth, the casing shoe set at the required level above the aquifer, and the necessary backfilling or bridging carried out to protect the aquifer and control the depth to which cementing will be carried out, cement may be introduced from the surface between the 8" and 6" casings until the whole of the annular space between the two casings, and outside of the 6" below the 8" shoe, is filled from the 6" shoe to surface level.

Whether or not the cement can be introduced initially by gravitation from the surface may depend upon the static level of the water obtained in the top aquifer. Should the water level be high, the available annular space between the casings may be too small to permit of a sufficient volume and weight of cement being introduced without pressure, to force the water back into the aquifer and so permit of the cement following down. It is then necessary to pump in the first hundred gallons or so of cement, until the water pressure becomes overwhelmed and the weight of cement sufficient to induce its own gravitation. A hand operated low-down force pump is usually suitable in such conditions, and when the quantity of cement required to be pumped is only relatively small. Immediately the water pressure is exceeded by the weight of cement introduced, gravitation takes over and the cement will begin to syphon through the pump.

Cement so introduced, if the casing is sealed at the shoe, will not extend far beyond the aquifer into which the water standing outside of the casing has been forced and it is essential that the casing shoe be slightly eased from its seat to allow the cement to pass down to that level. A few turns should be given the casing while the weight is off the shoe, in order to distribute the cement thoroughly around the hole and casing.

Construction of a temporary "bridge" in an open bore hole usually presents no difficulty in a low pressure low flow bore provided a little care is exercised, proper materials are used, and accurate measurements made. Obtaining an initial "stop" or obstruction upon which to build the "bridge" at the desired depth may be the most difficult part of the work, but a wad of material of a "springy" nature is generally successful. A bundle of small green tree branches with ends broken off the outside twigs, to "snag" in the walls, and inserted in the casing bramble ends downwards, then gently forced down the hole to the required level with a bailer or string of tools is usually effective. Strips of light bagging or hessian rolled into a loose cylindrical shape may then be forced down to the top of the tree twigs, after which about one cubic foot (kerosene tin full) of fine sand should be slowly poured down the bore hole to settle on top of the bagging. When allowed time to reach bottom the sand may be lightly tamped with a bailer (clack valve removed) or light tool. Should the bridge show a tendency to slip down the hole additional sand is usually stabilising. To finish off the bridge and make it reasonably water tight about a cuvic foot of good clay, preferably in small dry lumps, is poured down and tamped on top of the sand.

Both sand and clay may be wrapped in heavy paper or light, easily broken bagging torpedoes if necessary, which can be gently forced down the hole more quickly than it will gravitate through the water if poured in loosely from the top.

Pre-cast clay-cement plugs several feet in length and of about one inch less diameter than the inside of the casing are good bridging or plugging material and easily introduced. Dry clay wrapped in sisalkraft cylinders is often used also.

When larger flows and higher flow pressures have to be dealt with, bridging or plugging (backfilling) may not be possible unless the flow is first controlled.

If this is not done the bridging or plugging materials will be washed out before they can be placed in position and consolidated, and at best a great deal of time may be spent in finally placing a satisfactory bridge or plug.

One of two courses may be adopted in such cases, either being equally effective.

The flow may be simply and effectively controlled and stopped entirely by the introduction of a sufficient quantity of mud fluid into the inner casing by pumping through a cementing head or casing connection.

The quantity of mud fluid necessary to control the flow will depend in each case upon the flow and head pressure of the flow at the surface.

In most instances the comparatively low pressure flows now met with can be effectively controlled by the introduction of 100 - 200 gallons of sand free mud fluid weighing about 14 to 15 lbs. per gallon.

It is not satisfactory to introduce only sufficient mud fluid to just stop the flow or statically balance the flow pressure, because within a short period, as the mud fluid thins out and sinks through the column of water in the casing, the pressure will re-assert itself and the flow will recommence.

Sufficient mud fluid should be introduced to overwhelm the pressure and reduce the water column "head" in the casing to at least 50 feet below the surface.

When the flow has been controlled as above, bridging or backfilling may be carried out as earlier described, prior to intercasing cementing.

If the Pressure Circulation Method (or the Perkins Method) of cementing is to be adopted, flow control and aquifer protection are automatic with the introduction of mud fluid and the establishment of full circulation before introduction of the cement grout.

Full protection of the aquifer against cementing is afforded by the mud fluid which will fill the bore hole penetrating the aquifer before commencing to circulate upwards around the casing shoe and outside of the casing to the surface.

The mud will not penetrate a sandrock aquifer to any appreciable degree, and certainly not to such extent as would preclude re-establishment of the full flow following completion of cementing and removal of the mud fluid by bailing or swabbing.

Should full mud circulation be undesirable for any reason (suitable mud in sufficient quantity may be difficult of obtaining) a third method of flow control and aquifer protection may be adopted to permit of inter-casing being undertaken, and this is:-

Mix and pump into the inner casing (the show having been positioned at the top of and just above the main aquifer) sufficiently heavy mud (about 1.6 specific gravity) to fill the drilled hole through the aquifer below the casing shoe. Allowance must be made in calculating the quantity of mud for some losses by adhesion to the casing on its way to the bottom of the bore. Allow also for about 20 feet of mud to remain in the casing above the shoe for added margin of safety.

Force the mud column to bore bottom by pumping an accurately measured quantity of water sufficient to displace the mud fluid from the casing less the 20 feet margin abovementioned. Having placed the mud column within the aquifer and around the casing shoe for the purpose of protecting the aquifer against any cement penetration, cap the inner casing to prevent movement of the inner column of mud and water and fit a gate valve and pressure gauge to the inner casing head.

The bore is then ready for cementing between the inner and next outer casings, having provided an effective surface seal between them (usually a lead sealing ring) and fitted a cement pump connection to the outer casing.

Cement is then pumped through this connection to the annular space between the two casings and beyond to the space between the walls of the hole and the inner casing down to the shoe above the aquifer.

Slow release of water from the inner casing through the valve previously fitted will be necessary to permit of the outside column of cement passing down to the shoe if there is no aquifer above the shoe into which water can be forced by the cement column.

In any case a small quantity of water should be released from the inner casing to allow the cement to pass down to and just around the inner casing shoe, but care must be taken not to allow too much of the inner casing water to escape otherwise too much cement will pass around the shoe into the inner casing.

The pressure gauge on the inner casing will indicate progress of the cement and the interconnection between the outside and inside columns as cementing progresses.

The quantity of cement introduced should not exceed that calculated as required to fill the area proposed to be cemented outside of the inner casing.

If it is found that the intercasing space has not been filled to the surface when the pump is disconnected, the additional amount of cement necessary to do so should be poured (not pumped) in through the intercasing pump connection.

CONCRETE BLOCK OR BULKHEAD.

A practice often resorted to, and one to be avoided, in an artesian bore which has not been deep cemented is that of sinking a shallow shaft around the bore, filling it with concrete, and extending the concrete up around the outer casing, in an endeavour to prevent possible future sub-surface leakage, or stop an existing leak. Invariably where this has been carried out without deep cementing the leak has found its way around the concrete block, broken through to the surface and formed a crater, leaving the concrete block standing in the centre of a pool of water or mud, presenting an additional difficulty in its removal when reconditioning of the bore is undertaken by correct methods.

It is therefore not recommended, except perhaps in ideal and rarely occurring circumstances, when it is possible to sink a shaft around the casing of a very low pressure bore to a depth at which a good solid impervious strata is obtainable, and to which a good clean adhesion of the concrete is assured.

This is not to be confused with the useful practice very often employed on concreting around the above surface level casing, and headworks, as a measure of protection against outside corrosion. Too large a block of concrete should not be used for this, as a small reinforced cylindrical block will effectively serve the purpose for which it is intended, and is more easily removed if necessary.

CEMENTING AND RECONDITIONING OLD BORES.

The foregoing deals almost exclusively with conditions most likely to be met with in new bores, and where one string of casing only at a time has to be considered, thereby confining cementing methods to the simpler type, as compared with the problems presented by old and leaking bores, which may have been constructed with one, two, three or even four strings of casing of different diameters and lengths.

With many old bores having reached or approaching the stage where casing collapse may be not unexpected, particularly in corrosive areas; and the necessity for better control and conservation being more generally recognised, reconditioning by cementing methods has become more widely used and is standard practice in New South Wales.

A considerable number of old bores were constructed with one string of casing only, and when outside leakage develops under these conditions, it is generally found that control for reconditioning is more difficult and the job more costly than if two casings had been used.

Usually the source of outside leakage may be traced to one of the following causes:-

1. Seating Leakage in a bore constructed with only one casing, where part of the flow escapes around the outside of shoe, follows up outside of the casing to the surface, and flows away uncontrolled.

2. Outside leakage, in a bore constructed as above, when part of the flow escapes through a hole or holes in the casing caused by fracture, corrosion or erosion (sand blast.)

3. Seating leakage in a bore constructed with two or more casings, where part of the flow coming up outside of the inner casing also gets past the seating of the outer casing or casings, and passes to the surface up along the outside casing, or between the casings.

4. Outside leakage where two or three casings are used and where the outer string has corroded through allowing the intercasing water to escape and follow up to the surface.

Many factors contribute towards the development of leakages apart from the possibility of faulty construction and bad seating of outer casing. Similar surface conditions generally obtain, irrespective of the source or cause of leakages, and it is of considerable assistance, perhaps essential, to be able to determine their origin and location when reconditioning is projected. Varying pressures, temperatures, and local conditions generally, are of importance, and each bore must necessarily be considered according to its determined mechanical and hydraulic conditions.

PRELIMINARY INVESTIGATIONS.

A preliminary investigation is essential, and all possible information, history of the bore etc. should be obtained before any definite method of treatment is determined upon. The investigation should include ascertaining the following:- Depth of bore; Depths to which various casings have been inserted; Sizes and threads of casings and headworks fittings; Depth to various aquifers; Temperature of water; Whether acid or alkaline; Flow measurement; Leakage measurement, both under full flow and shut-down conditions; Pressure tests, and dye-circulation or au-current meter tests, or both, to determine the depth at which leakage occurs, and from which, knowing the casing depths and strata penetrated a reasonably accurate determination of the origin and cause of leakage can be formulated.

DYE-CIRCULATION TESTS.

Briefly, a dye-circulation test describes the following operation; the pumping of concentrated dyed water into the inner casing of a closed down bore or into the annulus between the various casings used in construction of the bore, and following the dye with clean water of measured quantity, until the dye reaches the point of leakage in the casing, and returns up outside of the casing to appear at the surface in the leak flow. Calculate from the quantity of fluid pumped into the casing, from commencement, until re-appearance of dye at the surface, the depth at which the dye escaped from the casing, taking into account the estimated velocity at which the dye travelled up with the leak to the surface. <u>Pumping should be by hand test pump and not at a fast rate.</u> The slower the rate of pumping the more accurate the results.

From the known depth of the leak, pressure of the bore, quantity of water escaping, both under free flow, and shut-down conditions, a fairly accurate diagnosis of the cause and nature of the leak may be obtained.

Where a bore has been constructed with two or more strings of casing, it will be necessary to have dye-circulation tests made between all existing casings, as well as inside of the inner casing, in order to determine more accurately the conditions obtaining. As an example, there may be leakage(s) in both the inner and outer casings, or in either one, and not the other, which conditions could only be accurately disclosed by pumping dye inside of the inner casing, and also by intercasing dye-circulation. Fluorescein or Rhodamine dyes are recommended as the most suitable for accurate detection in flows, as they do not disappear rapidly with dilution. Fluorescein is the better for general use although both may be used to check against each other when testing a bore. One ounce of dye powder to 4 gallons of clean water is a satisfactory concentration.

Where multiple strings of casings of different diameters have been inserted in a bore it is necessary that all annular areas between each casing be thoroughly dye tested.

AU-CURRENT METER.

This instrument is a current meter so designed that it may be lowered inside the casing of an artesian bore in order to measure the velocity of the rising water. Any marked variation in this velocity due to the escape of water through a leak in the inner casing, causes a variation in the speed of rotation of the blades and the presence of the leak can be established.

Revolutions of the blades are counted by a make-and-break device on a worm gear, giving a contact every five revolutions.

The meter operates on the principle that two different metals immersed in bore water and connected by a conductor constitute an effective wet voltaic cell. When an electrical circuit is established incorporating the make-and-break mechanism and a set of low resistance headphones, a click is audible in the earphones every five revolutions, and by this means, the latter may be counted.

The strength of the electric current depends on a number of factors but it has been found in practice that while an initial slight decrease occurs, an asymptote is rapidly approached and a practical current is obtained. Attempts to boost this by means of a dry cell may give good results for shallow tests, but the effect rapidly diminishes with depth.

Essentially the apparatus consists of three parts:-

(a) A long metal tube with a cage at its upper end to contain the meter. This tube ensures that the meter rides with its longitudinal axis parallel to the direction of flow, and also provides a smooth flow of water into the meter, free of eddies. Attached to the top of the tube is a yoke for suspension purposes.

(b) The meter itself, which is merely a set of blades and a make-and-break mechanism.

(c) A flexible galvanized wire cable with insulated core, capable of carrying the weight of the assembly at depth. An insulated lead is taken from the bore to the meter, and the galvanized wire itself is used for the return circuit, which is closed at the upper end by a set of headphones with two leads attached to bulldog clips.

The apparatus has been used with success to depths of 3,000 feet, and there is no reason to believe that this is the limit of its range. It has been found in practice, however, that small variations in the internal diameter of the casing can cause quite noticeable changes in the flow velocity, and for this reason, it would not be possible to detect with certainty the presence of small inner casing leaks causing a variation from the mean velocity of less than about 10%.

The use of the meter as a leak detector is of course confined to the inner casing, where it has advantages over dye-circulation methods in that it can be used on high pressure as well as low pressure bores, the time occupied in testing is only short, and the labour involved is small.

INTERCASING CEMENTING (EXAMPLE).

A bore has been constructed with an outer and inner casing, and not cemented. It is desired to introduce cement to prevent any possibility of leakage developing either around the seat of the outer casing, or through a break in the outer casing which may develop because of corrosive attack on the casing from outside, or in the case of corrosive water, from inside.

As the outer casing is probably firmly seated, there is little possibility of obtaining circulation outside of it, and this limites the method of treatment to the introduction of the cement between the two casings, and down past the shoe of the outer casing (this is quite effective if correctly carried out), but it will be understood that to obtain a satisfactory job it is not simply a matter of drilling a hole in the outer casing below the lead seal ring, fitting a connection, and pumping in sufficient cement to fill up the space between the casings and down past the outer casing shoe.

If more than a few bags of cement were required, and this procedure taken in a low pressure bore, the weight of the cement pumped in could overwhelm the water pressure and gravitate down until the static level of the cement column balanced by the water pressure was reached. This could be at a depth dangerous to the aquifer and flow of the bore. An excess quantity of cement pumped between casings or into the central casing of a low pressure bore would precipitate directly to the bottom of the bore with disastrous results, "killing" the flow and effectively sealing off the water beds, unless the water beds were "mudded off", a process which will be treated in further detail later.

The correct procedure is as follows:-

Having with an accurate pressure gauge ascertained the shut-down pressure of the bore, re-open the valve and drill a 1¼" or 2" hole in the outer casing below the lead seal-ring, then attach a circulating clamp or saddle flange over the hole, and obtain the increasing pressures with the bore closed down and open to full free flow then connect up the pump to the circulating clamps.

From the then known closed down intercasing pressure of the bore at the surface, and the known specific gravity of the liquid cement grout proposed to be used, calculate the number of gallons of cement necessary to be pumped into the annular space between the casings in order to overwhelm the water pressure and remain static at a desired level below the outer casing shoe, maintaining a predetermined back pressure on the bore by practically closing the main flow valve and retaining it at the same pressure throughout the procedure and for several hours after pumping has ceased, until the cement has taken its initial firm set. After about 12 hours the valve may be reopened if necessary. A valve must always be attached to the cement delivery line from the pump to the circulating clamps, and the valve must be closed immediately the cement has been introduced to its desired position, in order to prevent movement of the cement during the period of initial set.

By the above procedure a column of cement is placed between the casings, the bottom of the column being at a depth desired, while the height of the column will also be known, although it will vary according to the quantity of cement used, which in turn will be governed by the pressure of the individual bore and the depth at which the column has been placed.

Provided no leakage is occurring above the cement column a void is now established between the top of the column and the surface level, and when the lower column of cement has been allowed to set, sufficient cement is mixed to fill the increasing space to surface level. The second stage "pour" cannot be pumped into a closed area, without an air vent, so it is simpler therefore to pour the cement in through the opening made for the pump connection.

A pressure gauge should always be provided at the pump delivery and a gauge attached also to the inner casing. A careful check must be kept on pressures. Should a steep fall in pressure be noticed on the gauge attached to the inner casing during pumping, the pump should be immediately stopped and the borehead valve released, allowing the flow to escape more freely, but not to its full extent. A pressure drop on the gauge on the inner casing is a certain indication that the cement has travelled too far, and is shutting off the flow where it enters the inner casing, or has gained entry to the inner casing through a hole and is overwhelming the flow.

A quickly released valve in such circumstances may prevent a mishap, as the flow will carry the cement gradually with it and discharge it at the surface. The valve should not be opened to its full extent immediately, as the sudden release of back pressure on the cement column may allow it to rapidly enter the casing at the bottom or through the hole and probably overwhelm the flow, remain in the casing and waterbeds, possibly ruining the bore, or at least necessitating removal of the cement with a bailer. So long as cement is kept moving it will not readily set, and to bring cement out of a bore with the flow after having pumped it too far, the flow and back-pressure should be regulated to keep the cement steadily passing up with the flow, but not in sufficient quantity to "kill" the bore flow.

Bores with high pressures, or high temperatures may present difficulties and risks of scalding when drilling the outer casing for the attachment of circulating clamps, and it is recommended in the interests of safety, that the clamps be first fixed to the casing where desired, before the hole is drilled. First centre-punch the casing where the centre of the hole is required, then adjust the clamp so that the centre of the pipe connection on the clamps corresponds with the centre punch mark. Now drill the casing through the 2" collar connection on the clamp, shielding the operator with a light tin disc attached to the shank of the drill. With the casing thus drilled the escaping flow passes through the connection on the clamps, and it is quite a simple matter to screw an open valve to the clamps, when the flow may be controlled by closing the valve after attachment.

CIRCULATING CLAMPS.

Circulating clamps may be constructed from a pair of ordinary light clamps by drilling a 2" hole through the centre of one half of the clamps, and welding or brazing a 2" socket over the previously drilled hole. The inside of the half clamp to which the socket is welded should be so constructed as to have a clearance around the hole so that a ring of packing may be inserted, and the inside shoulders of the clamp are to have sufficient clearance to enable the centre of the clamp to be tightened firmly on to the packing.

An inexpensive and serviceable circulating clamp may be made from 6" x 5/8" flat mild steel shaped to fit the casing with the back half made from 3/4" round mild steel in the shape of a U bolt.

MUDDING OFF TO CONTROL FLOWS FOR RECONDITIONING.

Shutting off, and/or control of flows are very often essential to the successful cementing of an old bore, and the safest method is that of "killing" the flow with mud. No damage whatever can result from the shutting down of bore flows by the introduction of mud fluid either partially, or to the full depth of the bore. Care must be taken to ensure the elimination of all sand from mud before pumping it into a bore, and thorough mixing and straining is essential. Most muds have a decided tendency to thin out after being introduced into a bore and even when a hole is filled with mud from top to bottom there is always the possibility of the settlement of the heavier mud with the result that water beds higher up the hole may reassert themselves and commence to flow. It is, therefore, recommended that wherever possible constant gravity of the mud be maintained by periodical circulation in the bore.

Special clays and chemical compounds have been developed as artificial muds and these are often used to replace clay or shale muds because of their consistent qualities, greater weight per gallon, and less tendency to thinning out. These materials are packed in bags similar to cement, and therefore are easily transported, quickly mixed, and of greater all round efficiency than mud. Aquagel and baroid are the two better known artificial muds, Bentonite clay under the trade name Aquaseal is available in Sydney. When ordinary mud is being used and it is desired to increase its weight and prevent thinning out, a little cement may be added to the mud fluid after it has been mixed and strained. The method is as follows:-

Mix ordinary clay or shale mud to even consistency, and just priot to pumping it into the bore, add one bag of cement (previously mixed with about 6 gallons of water) to each 250 gallons of mud fluid. Mix thoroughly and pump as soon as mixed, before thickening of mud takes place. The cement thus added will coagulate the mud, forming a fairly stiff jell, but it will not set hard. Bentonite or Aquaseal may be substituted for cement.

Shales and clays make the best muds for general use. Mud pumped from a bore during the process of drilling through shales is usually ideal, provided it is kept in moist condition and free of sand, debris, etc. Mixing mud from dry shales and clays is usually a slow and unsatisfactory process, and if possible, it is more satisfactory to obtain mud from a lagoon, waterhole or dam rather than attempt to mix it from dry materials. High pressure jetting is the most satisfactory method of mixing mud from dry shales or clays.

LINER AND PACKER METHODS OF CEMENTING.

Where it is desired to cement off leakage in a bore which has been constructed with a single string of casing only, several methods may be adopted according to origin of leak, and depth at which leakage occurs. Before deciding upon a method, preliminary investigation and tests must be undertaken to determine the nature and depth of leakage, also pressure tests must be taken, so that the quantity of cement to be used will be of such volume as to successfully hold the bore pressure on the outside until a set has taken place. It will be understood that if a small quantity only were used the pressure of the leak would simply expel the cement from its position behind the casing.

A liner with tight fitting or expanding packer fitted to the bottom lower end is often useful when cementing a single "string" bore, as it affords a means of shutting off a leak through the casing and also allows for the introduction of cement between the casing and liner. With a seal fitted between the liner at the top, and the casing, and with the packer at the bottom preventing cement passing down the bore, cement can be forced between the casing and liner, and out through the perforation or fracture where the leak occurs, then up outside of the casing to the surface. Deliberate perforation of the casing is often helpful to ensure free circulation, and to permit of cementing to a depth desired.

Packers may be made from rubber, leather buckets, or oakum wrapped between two flanges welded to the liner. Oakum expands considerably when wet and if wrapped fairly tightly on a liner inside of casing will swell to form an excellent and tight shut off.

EXPANDING TYPE PACKERS.

The Hookwall expanding packer is superior in operation to all other types but has the disadvantage of being rather expensive. Several types of expanding packers have been designed, but the same general principles are incorporated in all types, i.e. the expansion of a rubber sleeve by compression, or by drawing through it a tapered mandrel attached to a shaft with a coarse thread screwed on it. The threaded shaft drawing the mandrel through the tubber sleeve is operated by turning the casing or piping from the packer up to the surface. The mandrel and screwed shaft are turned with the casing, and a nut taking the thread of the mandrel shaft is fitted inside of a short piece of pipe swivelled on the casing just below the packer. This short piece of pipe is fitted with four outside tension springs of the longitudinal type and the pressure exerted by these springs on the bore casing prevents the short swivelled section from turning, therefore when the casing with the attached mandrel is turned, the thread of the mandrel shaft turns into the nut in the lower fixed section, drawing the tapered mandrel down expanding the rubber sleeve hard against the casing making a shut off between the liner and the casing above the contact point of the packer.

An expanding packer of this or the Hook-Wall type is therefore valuable in controlling a leak which occurs near the surface, and where it is not possible to control the flow by pumping mud down the bore casing, because the leak allows the escape of mud to take place before a sufficient quantity to overwhelm the flow can be introduced.

EXAMPLE CASE FOR USE OF PACKER.

Take the case of a large leak of say 200,000 g.p.d. escaping from a high pressure bore, at a depth of twenty or thirty feet, or even 100 feet or more. Any mud pumped into the casing would simply pass out through the leak and return to the surface with the escaping water, before sufficient mud to overwhelm the flow could be forced down the bore. With a packer placed at the bottom of a short liner and set a few feet below the leak, all escape through the leak would be prevented and control of the bore would be simple, either by valve control on the liner or by pumping mud into the bore through the liner.

TUBING METHOD OF CONTROL OF FLOWS.

In such a bore as above, control may also be gained by introducing mud by the tubing method. This is accomplished by running piping or tubing down the bore to a depth at which a mud column will control the flow, and by rapidly pumping mud into the bore through the tubing until the flow is "killed", and the bore is filled either wholly or partially with mud, as desired. It must be remembered that the tubing has to be placed at sufficient depth to ensure the mud column between the bottom of the tubing and the top of the casing having sufficient weight to overwhelm the flow, so that as more mud is pumped in it will force the water down the hole and back into the water beds.

Rapid pumping is also essential in a tubing job, otherwise the flow if large will simply expel a small quantity of mud before it can achieve its purpose.

BULKHEAD CEMENTING.

Bore cementing may be carried out by what is termed the Bulkhead Method under some circumstances, and at times part of the cement is introduced through a bulkhead, while part is introduced by the intercasing, or liner method. It may be desired to prevent cement from sealing the inner casing to the outer casing of the bore, and yet carry out cementing to prevent leakage. It is in such cases that the bulkhead method is useful.

The object of bulkhead cementing is to introduce cement down outside of a string of casing from the top, without interference to the inner casings, and the procedure is as follows:-

A shaft is sunk around the outer casing of the bore, to a depth at which good solid impervious rock or hard clay is encountered, and to which it is safe to assume that cement will adhere and joint. With the shaft completed to a suitable strata, a pipe (generally 2") is placed as deep down as practicable alongside of casing at the position where most of the leak is issuing from the bottom of the shaft.

Control of any leakage and regulation of the water level in the shaft may be maintained with a de-watering pump, by sinking ahead with a small sump in one corner of the shaft, at a lower level than the remainder of the floor of the shaft, thus concentrating the leak to one section of the shaft, from where it can be more readily handled by the pump suction. Further details of bulkhead cementing are given in description of works carried out at Longreach No. 1 bore.

With the length of pipe firmly driven down beside the casing the space around the casing is then packed firmly with lead wool, greasy hemp, or bagging, forcing the outside leak to pass up through the pipe to the surface, where it can be carried or pumped away. Pressure relief to allow of better sealing around the bulkhead pipe can be obtained by attaching a reciprocating pump suction to the pipe thereby reducing water pressure at this point to the extent of the effective suction lift of the pump. The leak having been confined to the piping, concrete is then placed in the shaft around the casing and pipe, and carried up to the surface, or at least to a height sufficient to give strength and stability to the casing and pipe. A thorough cleaning of all surfaces of the shaft is necessary before placing the concrete, as a good knit of concrete and strata surrounding the packed off leak is essential, and must be sufficient to withstand pump pressure without undue leakage.

The concrete bulkhead having set, and circulation established through the pipe connecting the outside leak with the surface, cement grout of required quantity is pumped through the bulkhead pipe, and into the space outside of the casing through which the leak has been issuing. Control of back pressure, and a careful check on quantity of cement used is essential as in intercasing cementing, previously described.

As earlier discussed, the problems associated with deep cementing of new bores as a part of normal construction requirements are usually fewer and less complicated than those which may be met with in deep cementing and reconditioning old and/or leaking artesian bores.

One factor is that a drilling plant is usually set up and available for use as may be required in connection with cementing operations when a new bore is being dealt with.

New casings, fittings and valves are always used in new bore construction and accordingly there should be no problems associated with these such as corroded and holed casings, corroded and "stuck" valves and fittings so frequently found with old bores.

Furthermore, in a new bore an accurate log of strata penetrated, including water beds, is, or should be, available, and the various diameters, lengths and threads of casings and fittings are known. With an old bore, perhaps up to 50 years or more having elapsed since its construction, some, if not most of these important details may not be recorded or known.

These then have to be ascertained as far as possible, by inspection, tests and measurements before any plan of procedure and requirements may be formulated.

Many old bores have been neglected with maintenance nil for many years, casings are corroded and leaking both below and above ground surface, fittings and valves damaged or inoperative and the whole surrounded by mud, water, and weed growth.

Some bores stand in large deep pools of water (often hot) with the flow issuing from broken open casing, others have high outlets and long lines of pipe line or fluming attached to deliver the flow to higher ground. Not infrequently bores are found to have no casing visible, flows issuing through water pools feel higher than the outlets.

Suitable de-watering pumps are an essential part of the equipment necessary for the carrying out of repairs to such bore heads, and drainage is a pre-requisite in others less inaccessible.

A new bore, or one with sound casings above surface level usually presents no problems in the matter of making casing connections and attaching fittings to the several casings for the purposes of carrying out dye-circulation tests, pressure and flow tests, and for the introduction of cement grout as required.

Old and decrepit bores on the other hand must be repaired and at times virtually re-built in so far as top section of casings, valves and fittings, intercasing joints etc. are concerned before any attempt may be made to carry out tests or introduce cement grout.

Excepting in areas where the waters are corrosive, it is almost invariably found upon investigation, including excavation and de-watering as may be required, that casings are reasonably sound from a few feet below the surface, and that they are capable of repair or re-building with the assistance of a reinforced concrete block cast around the repaired sections from a few feet below surface to the lower flange of the main valve.

A well constructed reinforced concrete block (preferably cylindrical) having a thickness of about 6 inches around the casings and connections provides for stability and prevention of further leakage due to deterioration of the casings and fittings, in addition to the important factor of strength to withstand pressures during cementing operations.

Where casings are badly corroded or damaged to depth, reconditioning and deep cementing is practicable only if a liner is used, or re-casing is carried out.

This type of repair job necessitates the use of a drilling plant to handle the longer strings of casings, installations of a "bridge" or backfilling and the removal of either of these or mud, after cementing has been completed and the flow is to be regained.

There are so many variations in conditions which may be found in old bores that it would not be practicable to give details of the many different methods which may be adopted in the repair and reconditioning of artesian bore headworks preparatory to deep cementing.

Experience, experiment and an intelligent approach should indicate the best methods to adopt in each case when repairing headworks and providing the necessary casing connections preparatory to cementing.

Some form of temporary repair, frequently involving improvisation will, generally, be found practicable in fitting new headworks, connections for testing and cementing etc. on any bore, as a preliminary to casting a reinforced concrete "strengthener" block around the whole, usually from a few feet below the surface up to the lower flange of the main stop valve on the head works.

Account must be taken of the fact that the smallest water leakage under pressure (even very low pressure) will find its way through green concrete thus destroying one of the main purposes intended, i.e. the stoppage of all surface leakages from the headworks of a bore to be repaired and deep cemented.

Before pouring a concrete column around a bore head all leakages issuing from the area to be enclosed within the concrete must be eliminated or controlled.

Should it not be possible to stop off all leakage spots or leakage areas prior to casting the block these can usually be effectively dealt with by confining leaks to small areas and "bleeding them off" through small diameter pipes led outwards and downwards from the leak area through the concrete formwork. The leaks are thereby directed out through the pipe or pipes until the concrete has hardened, and the pipe(s) then plugged or capped.

Strips of lead and oil soaked canvas used as "bandage" wrapping is most useful for stopping small leaks and seepages. Plasticene is also useful for "setting" the pipes against the leak area in bore casings. Lead wool too is a useful item to have available for plugging and sealing.

Not infrequently repair and preparation of an old bore head is the most troublesome part of the work of reconditioning deep cementing.

However, throughout this stage the operator can at least see the problems he has to deal with. Once the shallow subsurface and above surface repairs are complete and prepared he can no longer visually appreciate his problems and conditions obtaining below the surface.

From this stage onwards results of his various tests, pressures and flow behaviour, dye and current meter tests etc. remain the operator's only guide, and from these he must interpret, visualise, sum-up and make a final appreciation of the situation, decide upon a plan, and proceed accordingly.

The majority of the older artesian bores were constructed with two or three strings of casing - 10", 8" and 6" being the more common, with the outer 10" extending from 100 to 300 feet; 8" casing from 300 to 800 feet and 6" casing to the full depth of the bore.

Leakages frequently occur between the 6" - 8" and 8" - 10" intercasing areas, also outside of the 10" casing. These leaks may arise from seating leakages around the shoe(s) of one or more of the casing(s) or they may come from holes in one or more of the casings, or from both sources.

A reasonable objective and one which would be effective for cementing a bore cased with say 200 feet of 10" casing, 550 feet of 8" and 3,500 feet of 6", assuming leakage between all casings and outside of the 10" would be the placing of cement between the 6" - 8", - 8" - 10" and outside of the 10".

The first objective in this case would be the placing of a column of cement grout outside of the 6" with the top of the cement column resting approximately 50 feet below the 8" shoe.

The quantity of cement grout to be used would be calculated according to surface pressure and pressure at the depth at which the bore of the desired column would rest.

When the first pour (column) of grout had firmly set - say in 12 hours after placing, a second pour would then be made by again pumping between the 6" - 8" casings and circulating cement sufficient to fill the annular spaces between the 8" - 10" and outside of the 10" to the surface.

"Topping up" if necessary can be done after the several columns of cement have taken an initial set.

The first placed column of cement outside of the 6" casing and below the 8" shoe effectively prevents the cement introduced at the second stage passing beyond the top of that pre-set column and permits of the second stage grout being forced upwards into the desired areas between and outside of the casings where it is required for effective cementing of the bore.

An alternative procedure for cementing a similar bore would be the introduction of the first stage grout column between the 8" - 10" casings so that the top of the column would rest about 50 feet below the 10" shoe.

Second stage cementing would then be the introduction of cement grout again between the 8" - 10" casings in sufficient quantity to fill between the 8" - 10" casings and outside of the 10" to the surface.

By adopting the second method (the 8" casing must be sound to do so) the inner 6" casing is not cemented, an often desirable feature should there be any likelihood of the bore requiring to be equipped with a large diameter pump at any future time.

Each of the above described procedures pre-supposes the 6" casing to be sound and free of any holes or leakage of consequence from the surface to a depth at least somewhat beyond the depth at which the bottom of the first column of grout would rest.

Before adopting either procedure cognisance would need to be taken of the occurrence or otherwise of shallow supplies of water which may have been met with as the bore was originally drilled.

Should shallow water exist, modifications of procedure, particularly as regards length and depth of first pour columns would necessarily have to be made in order to prevent their having any adverse effect upon the placing and efficacy of the cement grout first introduced, and before it had set.

Although the above hypothetical cases are not uncommonly met with, there can be almost any number of variations found in different bores and each must be assessed and dealt with according to the individual bore conditions as found.

Leakages in inner casings or leakages in all casings necessitate variations in methods to be adopted, inner casing leakage in particular presenting problems.

It can be assumed at once that where appreciable inner casing leakages occur deep cementing is practicable and safe only when a liner and packer is used. Alternatively renewal of the inner casing may prove to be necessary or perhaps a complete liner placed inside of the old casing.

Where only shallow leakages occur in the inner casing the use of a temporary short liner and packer may achieve the objective of preventing ingress of cement grout to the main flow whilst deep cementing.

By mudding between the inner casing and liner above the packer before pumping cement outside of the inner casing, cement may be introduced in the same manner as though the inner casing were not holed.

Upon completion of cementing and if desired the short liner and packer may be removed to retain the full diameter of the inner casing for flow, thereby eliminating the restriction of the liner, which must be of a lesser diameter than the inner casing.

Theoretically one would expect that there could be appreciable dilution of the lower section of a cement grout column introduced under pressure into a water filled casing or intercasing area, due to interface instability for a cement grout resting upon a pressure column of water.

It has been postulated that interface instability in a cement grout column above water or light mud within or between casings would be so high as to allow the cement grout column to virtually dissolve and disintegrate, and precipitate through the lighter fluid to the bottom of a bore.

On this basis claims have been made that it is not practicable to "float" a column of cement grout of pre-calculated weight to a pre-determined depth in a bore, and hold the column at a desired level until it sets.

Such theories can be discounted for practical purposes - some dilution of the lower part of a cement grout column undoubtedly does occur but grout of proper consistency maintains a quite homogeneous form for an adequate period of time for initial setting to commence and stability to ensue.

Over many years a large number of deep cementing jobs have been successfully carried out under variable and adverse conditions, in the majority of cases almost exactly as planned and calculated as regards depths and quantities.

Furthermore in no instance in a properly controlled job has there been any indication of cement having travelled downwards beyond limits of safety to the water beds, or the bore as a whole.

In some instances pre-calculated quantities have been found not to "work out" as anticipated due to unknown and indeterminable sub-surface conditions in an old bore, but provided the operator is sufficiently experienced and alive to these situations it will almost invariably be found that a successful and satisfactory "adaptation " plan to meet the circumstances and achieve the main objectives can be implemented.

THE USE OF MUD IN INTERCASING CEMENTING.

It is always a wise precaution to have the water beds protected by mudding off when introducing cement between casings if it is proposed to pump the cement to any depth, especially if approaching a depth greater than is considered safe for the back-pressure only, to hold the cement at the desired level.

Waters entering from behind the casing or through leaks in the outer casing from upper water beds also have to be considered when intercasing cementing is projected, as they may not allow the work to be carried out in two stages, as they may well prevent the second stage of the process (pouring cement down to fill the space from the top of the set cement column to the surface) from being carried out, due to the space being filled with water and it is not practicable to place the cement where required unless by high pump pressure, forcing the water back into the water beds ahead of the second batch of cement. This is not very satisfactory, as the water beds are likely to become clogged with silt or cement particles, thus preventing further pumping and an uncemented space is left between the top and bottom columns of cement.

Under such condition it is preferable to complete the whole of the cementing in one operation, and this can only be done by "mudding off" the water beds below the level desired to cement, generally the level below the inner casing shoe.

With the hole below the casing mudded off, control of the cement is maintained by the valve attached to the inner casing, and this must be closed as soon as the required quantity of cement has been pumped, thereby preventing the cement pumped outside of the inner casing from following down around the shoe of the casing and forcing its way up inside.

By mudding off in this manner the depth of the hole is, to all intents and purposes, temporarily reduced to the bottom of the inner casing, as all circulation, whether with mud or cement, is controlled to the required depth by the non-compressible column of mud below the casing shoe.

CIRCULATION CEMENTING WITH MUD PROTECTED WATER BEDS.

Should it be desired to cement say 1500 feet of casing suspended in a 2,000 feet bore, with water beds exposed below the casing, the work could be carried out by the ordinary circulation method with the water beds protected completely with a column of mud fluid.

The first procedure would be to completely fill the bore with mud fluid, then continue pumping mud into the casing until circulation is established around the shoe at 1,500 feet and up behind the casing, leaving a stationary column of mud below 1,500 feet to the bottom of the bore.

Cement is then pumped down inside the casing as in the usual circulation method of cementing, and forced up behind the casing where it is allowed to set with the bore head valve closed.

After the cement has been allowed time to set, any cement inside the casing is drilled out, the mud is bailed from the bore and the flow re-established. Some few inches of cement may be met with just below the shoe of the casing when a bore is cemented by this method, but in no instances have more than 3 feet of cement been found to have remained in the hole below the casing shoe, provided that a good column of mud has been established before pumping cement. This cement is always easily drilled out, and in most instances can be removed with a good heavy bailer, or chop pump.

It has been endeavoured in the foregoing to include sufficient detailed information on the principles involved in General Bore Cementing Practice, to enable intending operators to acquire sufficient knowledge to successfully carry out any projected cementing or mudding job.

General boring knowledge will of course be essentially helpful to cementing operators, but it may be taken for granted that bore cementing will be of concern and interest principally to those directly engaged in well boring operations.

Comparatively simple as most cementing operations may appear to the casual reader or observer, experience will reveal that in actual practice many difficulties will be encountered and some surprisingly unforeseen or unaccountable reactions observed when mud or cement is being used, the more especially in old bores, where unknown mechanical breakdowns have occurred below the surface, and where hydraulic conditions are indeterminable, have been disregarded, or taken for granted.

Being possessed of a knowledge of the general principles, practical experience and observations should enable operators to successfully conclude most bore cementing work.

Remember:- It may be taken that if cement has not firmly set in a bore within 24 hours, it will never set. Good cement should be set sufficiently hard in 3 days to permit of careful drilling out and testing of a bore.

GENERAL NOTES.

Commercial cement is required to set reasonably quickly, so that the forms etc. can be taken off and used on other portions of the work, but a cement to be used in bores may have the set delayed for several hours, so that there shall be sufficient time to get it into place before this occurs, as, if cement is in motion whilst setting is taking place, it is rendered almost useless.

There are two recognised stages in the setting of cement known as the "initial" and "final" sets. The initial set may take place as soon as the water is mixed with it, being then known as a "flash" set, but generally a percentage of gypsum is mixed with the cement by the manufacturer to slow the set.

There are several factors which may influence the setting time of a cement, they are as follows:-

(1) Temperature - the higher the temperature the quicker the set.

(2) The proportion of water - the greater the proportion of water the slower the set.

(3) The amount of Plaster of Paris or gypsum in the cement - these materials in small quantities - up to 3 per cent - tend to delay the setting time.

(4) The age of the cement, or the period it has been in store - cements often become quick-setting with age, although the reverse has been noted.

(5) The chemical composition of the water used in the mix - this may contain lime, salt or other minerals.

(6) The fineness of grinding - the more finely ground cements generally set more rapidly than those that are coarser, the high-alumina and low-lime types being most affected in this respect.

The following tables show the effects of temperature:-

Dry Atmosphere.				Under Water.	
Cement.	Temperature F°.	Initial.	Final.	Initial.	Final
A	50	155	410	210	480
	60	150	270	150	410
	70	105	225	100	350
	85	50	95	60	300
	100	30	55	45	180
B	50	385	660	480	750
	60	215	365	420	600
	70	130	295	300	410
	85	95	170	210	360
	100	85	115	60	195

Time in minutes -

A is a medium-setting cement from a rotary kiln. -

B is a slow-setting cement from an intermittent kiln.

The quantity of water used in gauging was in each case 22 per cent.

		Sample Number.						
Temperature F°.	1.		2.		3.		4.	
	H.	M.	H.	M.	H.	M.	H.	M.
35 Initial Set	3	0	5	0	2	0	2	10
Final Set	8	0	10	0	6	0	6	0
45 Initial Set	1	5	3	0	1	15	1	5
Final Set	3	15	7	30	3	30	3	15
60 Initial Set	0	30	2	30	0	15	0	3
Final Set	1	10	6	0	1	0	0	10
80 Initial Set	0	4	2	0	0	2	—	
Final Set	0	10	5	30	0	5		
100 Initial Set	—		0	45	—		—	
Final Set	—		3	10	—		—	

As the temperature of deep bores generally exceeds 100°F., it will be noted that all the cements tested above would prove unsatisfactory if a greater time than 1½ hours was consumed in getting them into position.

The amount of water used in mixing cement for introduction into an oil-well is generally from 40 to 50 per cent, so the ordinary tables of comparison, wherein it does not exceed 24 per cent are of little use to us; however, this large proportion slows the sets greatly.

The influence of age is shown in this table:-

	Sample Number. 1		2		3		4		5		6	
	H.	M.	H.	M.	H.	M.	H.	M.	H.	M.	H.	M.
Fresh Initial Set	2	50	3	10	4	10	2	40	0	2	0	10
Final Set	6	0	6	40	8	0	6	15	0	15	0	25
1 week old Initial Set	1	30	0	10	2	15	0	3	0	2	0	5
Final Set	4	10	0	25	6	0	0	8	0	10	0	15
2 weeks old Initial Set	0	3	0	5	1	25	0	3	0	15	0	30
Final Set	0	7	0	11	3	40	0	8	0	35	1	5
3 weeks old Initial Set	0	3	0	5	0	30	0	5	0	30	1	50
Final Set	0	7	0	15	1	50	0	11	4	10	4	45
3 months old Initial Set	0	30	0	4	0	10	0	3	1	35	2	0
Final Set	1	15	0	15	0	30	0	8	4	0	6	10
6 months old Initial Set	0	25	0	20	——	——	0	3	2	10	3	0
Final Set	1	15	1	10	——	——	0	8	6	0	6	10
1 year old Initial set	0	25	0	55	2	20	0	4	2	0	1	40
Final Set	1	10	2	30	5	45	0	10	5	30	5	5

Many oil companies use a reagent in order to accelerate the setting of the cement in the well. These are mostly patented mixtures, and are called by fanciful names, such as "Kenset", "Cal" etc. The Santa Cruz Portland Cement Co. says:-

"Calcium chloride ($CaCl_2$) appears to meet all requirements as an accelerator and the best results were obtained by using 3-3¼% of the weight of the cement used. With our oil-well cements the following results were obtained:-

In a 40% slurry.

In a period of	24 hours	- 97.5	increase of hardness
"	3 days	45.8	" "
"	7 "	16.3	" "
"	14 "	10.0	" "
"	28 "	3.7	" "

In a 50% slurry.

In a period of	24 hours	- 143.5	per cent increase of hardness
"	3 days	37.0	" " "
"	7 "	32.2	" " "
"	14 "	0.9	" decrease "
"	28 "	21.4	" " "

In the presence of an excess of water equal to 50% the increase in the degree of hardening is confined to the 24-hour, 3 and 7-day periods.

It has been found that a 40% slurry containing calcium chloride equal to 3¼% of the weight of the original cement gave compressive and tensile strengths in 24 hours equal to the same cement without $CaCl_2$ in three days.

SPECIAL METHODS FOR CEMENTING IN CABLE TOOL DRILLED BORES.

By reason of the differences between Rotary and Cable Tool Drilling, bores constructed by the latter method frequently present problems and require special technique in cementing as against the more generally orthodox procedures adopted in rotary drilled bores, because the establishment of circulation is seldom a problem when a bore is drilled with rotary tools employing mud circulation throughout the whole process of drilling.

On the other hand it is not infrequently found that full free circulation cannot be reasonably established between the casing and walls of a cable tool drilled hole, at least for full depth of the hole. By using very high pressure pumps and working the casing for a sufficiently long period it is probable that complete circulation could be established in most cable tool drilled bores, but in many instances such a lengthy and costly procedure is not warranted and it is sufficient to pressure cement only the upper section of the hole provided the principal objectives of cementing are thereby achieved. These generally include the sealing off of upper salt and corrosive supplies of water passed through; protection of the casings from corrosive attack by these waters; prevention of intercasing leakages to flowing bores, and the prevention of loss of flow from the deeper and higher pressure supplies by leakage into the upper lower pressure water bearing strata or dry sand beds.

Usually the more important requirement is to cement to a depth sufficient to seal off and protect the casings against the upper salt supplies and as these are usually at comparatively shallow depths of a few hundred feet maximum, it is in most cases practicable to establish circulation, and cement to depths necessary to achieve that objective, even if it is not practicable to carry out the more desirable full cementing operation of cementing the casings from shoe to surface. Two comparatively simple but quite effective methods of partial outside or intercasing and outside cementing have been successfully adopted and either one may be used according to conditions existing in the particular bore being dealt with.

These may conveniently be termed (1) The Fixed Plug and Slotting Method, and (2) The Outside Packer Method.

(1) Fixed Plug and Slotting Method.

This method is usually adopted when the inner casing is too tight to pull, or for one of several possible reasons it is not desirable to pull the casing any distance from the bottom of the bore, e.g. the presence of a drift sand or badly caving stratum.

Procedure is to drive a round (machined) dry softwood plug, two to three feet in length down inside of the casing to a predetermined level, say 50 feet beyond the last salt supply met with, slot the casing, utilising two or three short slots just above the plug, then cement outside of the casing by circulating cement from the inside through the slots and up outside, tothe surface.

It is important that the plug be accurately made to a close easy driving fit inside of the casing and it be dry so that when in position it will absorb water and swell to a tight fit which will not allow of its displacement when pump pressure is applied in cementing. About 24 hours is required to ensure that the plug has tightened against the inside of the casing before pressure cementing is attempted. On completion of cementing and when the cement has set, the plug is quite easily drilled out, or forced to the bottom and drilled up.

If the casing can safely be withdrawn and re-inserted to the required depth at which it is intended to cement, the plug may be placed in the casing at a joint and the slots then put in above the plug also, but whichever procedure is adopted will be governed by the condition peculiar to the bore being dealt with. However, this method is more usually employed in cases where the casing cannot be withdrawn, and the Outside Packer Method is employed when it can be safely withdrawn.

(2) Outside Packer Method.

Procedure for the second or Outside Packer Method is along the following lines:-

Withdraw the casing until the length to which depth it is proposed to cement is at the surface, then fit a packer around the outside, the packer to be of the maximum diameter calculated to pass back through the outer casing (if there is an outer casing in the bore) or the drilled hole with as little clearance as possible. When all casing has been re-inserted and the packer thus placed at the desired level (below the last salt supply of water) one or two cubic feet of fine sand is then slowly poured outside of the casing to form a bridge and seal above the packer. A small batch of liquid cement (1 or 2 bags) may be pumped down to form a good seal and assist the packer to withstand the weight of the full cement column to be finally placed.

This method may be as effectively employed on a bore in which full free circulation is available, but in which it may be desired to restrict the depth of cementing.

Packers may be made by welding two rings 15 to 18 inches apart on the outside of the length of casing and closely wrapping between the rings with strips of canvas, rope or strong bagging. The packing must be sufficiently strong to withstand friction against the walls of the hole when the casing is being re-inserted.

Cementing by this method may be by either pressure pump or gravitation as circumstances may dictate, but it must be remembered that the introduction of cement is dependent upon the annular space between the casing and hole above the packer being void of water or there must exist one or more aquifers into which water within the annular space be displaced as the cement is introduced.

EXAMPLE OF CEMENTING JOB.

LONGREACH NO. 1 BORE.

RECONDITIONING AND CEMENTING.

The above bore was reconditioned and cemented in August, 1937. Preliminary investigations, and dye-circulation tests were carried out prior to the work being undertaken, and hereunder are details of the tests, also actual cementing work carried out:-

PRELIMINARY INVESTIGATION.

HISTORY -

This bore was completed on 10/12/1897 to a depth of 3,590 feet with a flow of 204,700 gallons and a static head of 225 feet.

In June 1914 as it was reported that a considerable quantity of water escaped from outside the casing and it was stated by residents in the town that water issued from the ground on the opposite side of the street, a large concrete block placed around the bore eventually confined the leak to around the casing.

PRESENT POSITION:

No measure of the volume of leak could conveniently be obtained since it was confined within concrete sumps and led away through pipes into a cooling pond used for filling the town baths, but it was estimated at about 20,000 g.p.d. under normal town pressure of 11 lbs. to about 40,000 gallons per day under closure of 20 lbs. Thirteen and a half (13½) gallons of dyed water were pumped into the 6" casing at about 2'6" from ground level when the dye appeared in the outside leak giving the depth of the leak below the surface at about 10 feet. Owing to the absence of any outer string of casing there existed the possibility of further leaks at shallow depth or within the limits of the oxidised zone, say to 50 feet, but which could not separately detected with dye-circulation. No current meter was available. The presence of green sand in the outside leak also suggested a deep seated leak since the sand was typical sub-artesian sand and unlikely to occur within the limits of the oxidised zone. The water is non-corrosive and it was therefore unlikely that the leak would be issuing through the casing at any point below the oxidised zone. It would therefore appear that the leak is coming from the bottom up outside the casing and carrying with it particles of sand from a sub-artesian bed.

RECOMMENDATION:

The absence of an outer string of casing renders a 5-inch liner say 200 feet long and cemented necessary to carry out a successful repair job. The introduction of this in view of the comparatively small flow of the bore estimated at, say 100,000 g.p.d. should not place any appreciable restriction on the flow, and with the further introduction of cement in view of the non-corrosive nature of the water should guard against future perforation of the 6" casing by external corrosion.

Whilst this procedure would shut off the upper leaks within the limits of the oxidised zone any further leak of a deep seated nature would still remain uncontrolled by reason of the comparatively shallow depth at which any perforations in the oxidised zone other than that located at 10 feet occur, and the consequent inability of so short a column of cement introduced above the deep seated leak when circulating between the five and six inch casings and through the upper perforations to overwhelm the pressure of the deep seated leak of say 100 feet.

To overcome this outside leak should it be present deliberate perforation of the 6" casing just above the bottom of the 5" liner was recommended to enable positive circulation to be established and allow of the introduction of cement outside the 6" casing.

PROPOSED PROCEDURE:

It will be necessary to erect a light plant over the bore to handle the 5" liner and for perforating the 6" casing.

The 200 feet liner should be inserted and the entire flow mudded off. Should an outside leak still persist it will evidently be a deep seated one, in which case one length of the liner should be withdrawn and the 6" casing perforated at about 195 feet. The flow should then be regained and an estimate of the volume of the space outside the 6" casing obtained by dye-circulation; from this can be determined the amount of cement required to fill the outside space and balance the static pressure. The calculated quantity of cement should then be introduced inside the 5" liner and following by a quantity of water equal to the internal 5" casing volume above the perforation. The borehead should be opened up by a shaft to at least 12 feet from the surface and collar of cement placed around the casing extending to the surface.

AS CARRIED OUT:

1. 12" slots were cut in the 6" casing at 175', 193' and 195' from the surface, after having swedged the casing to ensure the packer being placed in position without damage.

2. A 5" diameter liner was inserted to 200 feet with a special packer consisting of 5½" diameter leather pump buckets fitted to a short length of casing, especially turned for adjustment of the buckets.

3. 600 gallons of mud with cement grout mixed in proportion of 1:100 was pumped in and established a balance at 110 feet below the surface, gradually rising to 90 feet.

4. Excavation of shaft was commenced to expose the shallow leak. Concrete extending to 9 feet below the surface was shot away. An outside leak commenced to show up when the shaft had been excavated to 5 feet, and gradually increased as the shaft was deepened, finally forcing sinking operations to be suspended at 11 feet where a solid band of rock was struck. This leak definitely indicated that the volume of mud forced outside of the 6" to 200 feet was insufficient to maintain control of the outside leak, and that to avoid this the liner should have been taken to about 250 feet.

5. An attempt to pump more mud through the liner failed due to bridging of the mud, caused by the cement action, and the pump backpressure was therefore excessive.

6. The mud was then bailed out, the flow partially regained, and a further 600 gallons of mud pumped in at a backpressure of 100 lbs. "killing" both flow and outside leak, but both returned while the bore was standing overnight. The reason for the 100 lbs. backpressure while pumping this last batch of mud was no doubt due to the fact that the flow had not been allowed to fully regain itself, and consequently clear all mud from the bore, therefore the settled particles of mud having reached the waterbeds, these became partly "clogged" immediately the pump was started up, and restricted the re-entry of the water below the mud, into the water beds.

7. After allowing the flow to clear itself, a further 600 gallons of mud with 6 bags of cement were pumped in, killing the main flow but having no effect on the outside leak. It was evident from this that the slots in the 6" or the packer had become clogged with mud, preventing any further introduction of mud outside of the 6", by pumping down the 5", up past the packer to the slots and outside the 6" to the leak channel. The design of the packer was such as to allow reverse circulation.

8. With all possibility of controlling the outside leak without withdrawing the liner now gone, the shaft was completed by dewatering, and a 2 feet diameter cylinder was fitted around the casing at the bottom of the shaft to confine the leak and concentrate it for better pump suction.

9. The shaft completed to the leak in the 6" casing at 10 feet the hole was clamped, and the leak forced up between the 5" and 6" and out through a hole in the 6" at the surface. After 12 hours the leak re-appeared outside of the 6", and this was controlled by connecting the pump suction direct to the hole in the 6" casing, thus lowering the water level between the casings and outside the 6" to the maximum suction lift of the pump. This was sufficient to allow the concrete bulkhead to be placed in the bottom of the shaft, with a 2" circulating pipe driven down alongside of the casing, and extending up to the surface level. Pumping was continued for eight hours to allow the bulkhead to set firmly, when a 2 feet diameter concrete collar was cast around the casing and 2" pipe, and extended up to the surface. Eighty gallons of dyed water were then pumped between the 5" and 6" casings, when dye appeared in the 2" bulkhead circulating pipe, and also on the footpath on the street about 40 feet distant. A very small flow from the top of the 5" liner increased during the circulation of the dyed water.

Twenty-six bags of cement were mixed to a volume of about 180 gallons and pumped between the 5" and 6". No cement appeared in the 2" bulkhead pipe or in the leaks on the footpath, but the flow from both ceased shortly after pumping of cement was completed.

After allowing 15 hours for set in the cement, a further 5 bags were mixed to a volume of 40 gallons and pumped through the 2" bulkhead circulating pipe, to fill up the space below the bulkhead, outside of the 6".

This cement was allowed to set, the mud and cement bailed from the bore, and the flow regained. After connecting the bore up to the mains the pressure was 107 feet as against 60 feet before reconditioning. No leakages have occurred since cementing.

Considerable time and additional work was incurred on this job because of the inability to completely mud off the bore from top to bottom. This would have precluded all possibility of the recurrence of the flow, and consequent re-mudding, but the plant available for bailing out the mud on the completion of the job was capable of a depth of 1,000 feet only, and had the bore been thoroughly "killed" by mudding to bottom, the plant would not have been capable of removing the mud to sufficient depth to regain the flow.

The result of having only a small plant available was that only a limited quantity of mud could be introduced, and this was barely sufficient to control the bore for the required period.

EXAMPLE - TAMBO NO. 2 BORE - RECONDITIONING AND CEMENTING.

Tambo No. 2 bore was completed in 1926 and cased with 312 feet of 10-inch, 483 feet of 8-inch and 2,444 feet of 6-inch casings, the latter seated on bottom and slotted opposite the principal aquifers.

The lower waters in the district being extremely corrosive due to the presence of free CO_2 had very extensively corroded all three casings and the resultant leaks had rendered control of the flow impossible and the bore useless as a town water supply direct coupled to the reticulation system.

The following is a brief summary of the work carried out:-

The 6-inch casing was slotted at 1,200 feet, 1,020 feet, 900 feet and 800 feet; cut off at 400 feet and withdrawn from that depth.

The 8-inch casing was slotted at 390 feet, 300 feet, then cut and withdrawn from 140 feet. Five-inch casing was then inserted to 1,300 feet, but as circulation was not possible at that depth it was withdrawn to 800 feet where good circulation was established and the hole mudded off from top to bottom.

After depressing the top mud level to 300 feet outside of the 5-inch by bailing from the inside, 5½ tons of cement were mixed to 1.8 gravity, aggregating 1,100 gallons, and poured down outside of the 5-inch casing; control of the cement being maintained by means of a head and valve attached to the 5-inch casing.

When 72 hours had been allowed to elapse, the mud fluid was bailed from the bore, the flow recovered, headworks attached, and the bore-reconnected to the town mains. The total flow after reconditioning was 366,157 g.p.d. and the pressure at the bore head 27 lbs. with the gauge 28 inches above surface level. Prior to reconditioning, the pressure at the bore head was 9 lbs. on the mains and the leak approximately 200,000 g.p.d.

DETAILS OF WORK:

After cutting the 8-inch casing at 140 feet it was found to be studded and leaded to the 10-inch casing, below the surface, and when the 8-inch was pulled the 10-inch also parted 20 feet from the surface, allowing a large quantity of cavings to fall into the hole, kill the flow, and bridge at several places down the hole, particularly at the top of the cut off 8-inch and 6-inch casings, at 140 feet and 400 feet respectively.

The hole was cleared of cavings, and the 20 feet of 10-inch casing replaced in position. Five-inch casing was then inserted to 1,300 feet but very little circulation could be obtained outside of the 5-inch, indicating that scale from inside of the old corroded 6-inch and probably other debris had practically sealed the space between the 5-inch and 6-inch; also that the lower slots placed in the 6-inch were of no value, as there was no circulation outside of the 6-inch at this depth.

The 5-inch casing was then withdrawn to 1,260 feet where a little improvement in circulation was obtained and 3,000 gallons of mud and cement of 1.4 gravity were pumped into the bore. No returns of mud were obtained, indicating that a porous strata at some lower level was "taking mud". A further 2,000 gallons of mud and cement were mixed and pumped, and when pumping the last 500 gallons the pump pressure rose to 200 lbs. indicating insufficient circulation space between the 5-inch and 6-inch.

The 5-inch was again lifted, but satisfactory circulation could not be established until it was withdrawn to 800 feet. A further 2,500 gallons of mud were pumped without any returns to the surface, so 2,500 gallons more mud was mixed, and when 2,000 gallons had been pumped free circulation to the surface was obtained.

Although 9,500 gallons of mud had been pumped before circulation was established, and as the calculated capacity of the bore, allowing for all intercasing spaces, was less than 3,000 gallons, at least 6,500 gallons of mud had disappeared into a permeable formation, probably a caving shale strata, through which connection with No.1 bore, 8 chains distant, had been established previously, No. 1 bore being an old collapsed bore still flowing about 100,000 g.p.d. and probably somewhat the cause of outside corrosion of the lower casings at No.2 bore.

No.1 bore was being used as a temporary town supply during the reconditioning of No.2, a centrifugal pump having been connected directly to the mains, and a distinct taste and odour of the mud used at No.2 was noticeable in the water being pumped from No.1 bore.

With free circulation definitely established around the 5-inch liner at No. 2 bore, the mud fluid level was then lowered to 300 feet outside of the 5-inch, by bailing from the inside, and a head and valve were fitted to the top of the 5-inch.

Five and a half tons of cement were then mixed to aggregate 1,100 gallons and gravitated down between the 10-inch and 5-inch casings, the 5-inch being worked up and down the hole during the pouring of the cement, to assist circulation of the cement between the 5-inch and 6-inch and to prevent channelling of the cement in the large hole above 400 feet.

Control of the cement was regulated and maintained throughout by means of the valve on the 5-inch head. The hole being filled with mud below the 300 feet level, when the cement was introduced outside of the 5-inch, the weight of fluid outside of the 5-inch being in excess of the weight of the mud fluid on the inside, circulation around the 5-inch shoe from the outside was set up, and the mud column below the 300 feet level and outside of the 5-inch was forced up inside of the 5-inch, and allowed to flow away through the valve at the head, until the whole of the cement had been poured. The valve was then closed and movement of the cement stopped. The greater quantity and weight of the cement column outside of the liner, in excess of the quantity and weight of mud on the inside, created a pressure of 284 lbs. at the 5-inch casing head. The stationary non-compressable column of mud fluid standing in the hole below the 5-inch shoe prevented the cement passing down below that level. The cement was mixed and placed in position in 55 minutes.

Seventy two hours were allowed for the cement to set before bailing was commenced to remove the mud and regain the flows. Approximately 5 bags of cement were found to have passed up inside of the 5-inch casing, and this had to be drilled out with light tools. When 1,500 feet of mud had been bailed out, the flow asserted sufficient pressure to clear the hole.

<u>WATER FACTORS.</u>

1 Imp. Gal.	=	10 lbs.
1 " "	=	277.46 c. ins.
1 " "	=	0.16 c. ft.
1 " "	=	1.2 American Galls.
1 cu. ft. of water	=	62.425 lbs.
1 " " "	=	6.24 Imp. Galls.
1 cu. yard of water	=	168.5 Imp. Galls.

1 cwt. of water	=	11.2 Imp. Galls.
1 " " "	=	1.8 c. ft.
1 ton " "	=	224 Imp. Galls.
1 " " "	=	35.9 c. ft.

1. Clean fresh water at 60°F. has a specific gravity of 1.0.
2. Feet head x .434 x specific gravity = pounds pressure per square inch.
3. Pounds pressure x 2.31 ÷ specific gravity = feet head.
4. Doubling the diameter of a pipe increases its capacity four times.
5. To find the capacity of a pipe or cylinder in gallons, multiply the square of the diameter in inches, by the length in inches and by .00282.
6. The weight of water in any length of pipe is obtained by multiplying the length in feet by the square of the diameter in inches and by .282.
7. 1 inch depth of water over one acre = 22,700 Imp. Galls.
8. One acre foot of water = 272,400 galls.
9. Friction of water in pipes increases as the square of the velocity.
10. Friction in each 100 feet of pipe may generally be taken to equal about one foot in vertical height.
11. A column of water 1 foot high exerts a pressure of .434 lbs per square inch.
12. A column of water 27.7 inches high exerts a pressure of 1 lb. per square inch.
13. To convert feet head to lbs. pressure, multiply by . 434.
14. To convert lbs. pressure to feet head multiply by 2.3.
15. One inch of vacuum = 1.13 feet to convert inches vacuum to feet suction multiply by 1.13. Mean sea level pressure = 14.7 lbs. per square inch. With a perfect vacuum at sea level this pressure will sustain a column of water 33.9 feet high and a column of mercury 29.9 inches high.

TABLE OF BORE CASING CAPACITIES, VOLUMES ETC.

Size of Casing.	4" x 3/16"	5" x 3/16"	6" x 3/16"	6" x 1/4	6⅜" x 1/4"	8" x 9/32"	10" x 11/32"
External Diameter	4"	5"	6"	6"	6⅜"	8"	10"
Internal Diameter	3⅝"	4⅝"	5⅝"	5½"	5⅞"	77/16"	95/16"
External Area Sq. Inch	12.566	19.635	28.30	28.30	31.919	50.3	78.5
Internal Area Sq. Inch	10.135	16.800	24.85	23.71	27.109	43.50	68.114
External Volume Gals. per ft.	.541	.848	1.221	1.221	1.380	2.171	3.393
Internal Volume Gals. per ft.	.409	.727	1.071	1.026	1.173	1.885	2.945

INTERCASING VOLUMES.

Casing Sizes	4"-5"	5"-6"	5"-8"	6"-8"	$6\frac{3}{8}$"-8"	6"- 0"	8"-10"
Annular Area sq. ins.	3.79	4.015	23.9	15.2	11.58	40.1	17.8
Volume Gals. per ft.	.159	.178	1.037	.664	.505	1.724	.774

ESTIMATED VOLUMES BETWEEN OUTSIDE CASINGS AND HOLE.

Casing diam. Hole diam.	4"-5"	5"-6"	5"-7"	6"-7"	6"-8"	8"-9"	8"-10"	10"-12"
Annular Area	7.07	8.7	18.9	10.2	22.0	13.4	28.3	34.6
Volume Gallons per ft.	.307	.377	.82	.444	.955	.58	1.23	1.50

USEFUL TABLES FOR CALCULATION.

Contents of Cylinder in Gallons = $(DIAM)^2$ x HEIGHT x .00282

ALL MEASUREMENTS IN INCHES.

Area of Circle = $(DIAM)^2$ x 11/14 = $(DIAM)^2$ x .7854
Circumference of Circle = DIAM. x 3.1416
Diameter of Circle = Circ. x .31831
1 cubic foot of water = 6.232 IMP. Galls.
1 Imp. Gall. of water = 277.274 cub. ins.
1 Imp. Gall. of water = .16 cubc. ft.

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1 paper bag of dry cement = 94 lbs. or 1 cub. foot.

1 cubic foot dry cement mixed with .80 cub. ft. or 5 gallons water. = 7.5 gallons or 1.20 cub. ft. grout having a specific gravity of 1.92.

1 bag of cement mixed with 6 Imp. Galls. of water = 8.5 gallons at 1.81 gravity.

1 bag of cement mixed with 7 Imp. Galls. of water = 9.5 gallons at 1.72 gravity.

Principal Engineer,
Water Supplies.

C E M E N T I N G .

from

"Handbook of the Petroleum Industry"
by
David T. Day.

In known regions where wells of large capacity or high pressure are anticipated or where the exclusion of water is difficult it is customary to cement the "water" string of casing in the most suitable formation between the oil sand and the last water-bearing stratum encountered above it. The objective sought in cementing is to construct a water-tight barrier between the exterior of the lower portion of the casing and the wall of the well in order to exclude from the drill-hole all water previously encountered.

For reasons apparent, the plastic cement must be lowered to bottom within the casing, after which the column of casing is raised a few feet and by mechanical means the cement is then forced upward into the annular space between the casing and the surrounding wall and there allowed to solidify. Several distinct methods have been devised to accomplish this. In earlier practice a dump bailer was successfully used to lower the cement into shallow wells in which the water did not rise to a high level. The casing was then raised slightly and a wooden plug was quickly driven to bottom by the weight of a string of tools, drill pipe, or tubing. This forced the cement into the desired position as above indicated. By another method the cement was pumped through tubing to the bottom of the hole and forced upward behind the casing by a plug propelled by a column of water, a packer preventing the return of the cement between the tubing and the casing. Although the rapid "setting" of the cement renders these methods dangerous and they are not generally approved; extreme necessity may occasionally justify recourse to them.

Another method (the two-plug method) commonly employed in many parts of the United States during the past ten years, has been widely discussed in several publications and will be briefly described here. Any good grade of quick-setting (one to two hours) cement will serve. The crystallizing action of cement in the process of hardening is irrelevant to this work, but a uniform mixture should be obtained with the least amount of fresh water possible to effect complete emulsification. With this method the mixing of the cement is usually done by hand but everything (cement, tools, vat and water) should be so arranged that the mixing operation may be completed in briefest possible time. Cement of the proper grade for this work begins to solidify in from one to two hours after being mixed with water and for this reason the entire cementing operation should not consume more than about one and one-half hours. Cold water retards and hot water hastens the process of solidification. From 75 to 80 pounds of cement should be used for each cubic foot of space to be filled. The total amount required depends upon the diameter of the hole and the nature of the formation, and varies from 5 to 35 tons. The cement should be screened to eliminate all lumps.

Two wooden plugs are prepared, slightly smaller in diameter than the interior of the casing through which they are to pass and a circular piece of heavy belting to fit the casing is nailed to the bottom of each. The combined length of the two plugs should be about 5 feet and the casing should be raised about 4 feet to permit the egress of the cement. If the casing shoe is inadvertently raised too high it may lodge on the top plug in being lowered again after the cement has been forced out.

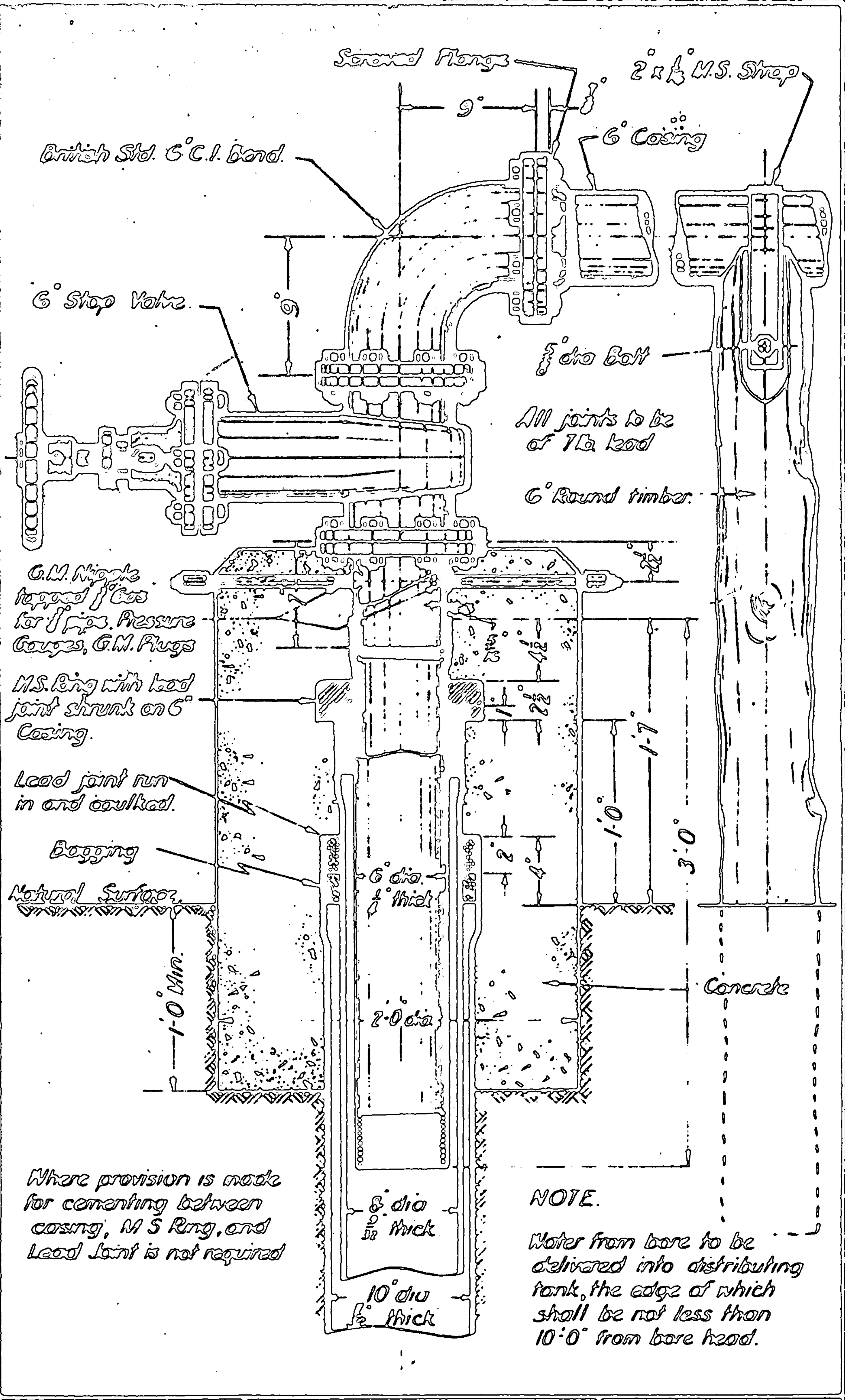
If the well is full of mud-laden fluid (still prescribed in some fields) this method will prevent contamination of the cement, a factor largely ignored by modern practice, although it must be possible to renew circulation immediately when the cement is mixed and ready to run. At this juncture the bottom plug is inserted in the casing followed by the cement and the top plug. Some operators then throw some empty sacks or a piece of burlap and some clay on the top plug. The slush pump is then connected with the casing and the cement and plugs are rapidly forced to the bottom of the hole by the fluid from the pump. When the lower plug reaches bottom the cement will pass upward between the casing and the wall and when the plugs come together the action of the pump will so indicate. The casing should then be rotated a few turns, (to distribute the cement now outside of the casing) and lowered to the bottom. The cement will permanently solidify in from twelve to fifteen days, after which the wells may be drilled in and completed in the regular way. Before inserting the plugs, however, a casing swedge or other tool should be run to ascertain that the casing is clear and free from dents or "blisters". Otherwise the plugs might lodge and a serious situation result from the premature setting of the cement at some point in the casing.

The two-plug method is still commonly used except in California, and, while it clearly illustrates the principle of cementing, it is based largely on erroneous assumptions. It was formerly believed that the mixed cement would become diluted or contaminated if exposed to contact with liquid in the hole and that the mud-laden fluid must be retained in the well to prevent caving of the walls - two contentions that modern practice in California has disproved, as both are disregarded in the Perkins and the Scott patented methods.

In California it is now customary to wash the hole thoroughly with clear water before cementing. But during the washing process the innermost string of casing must be slightly raised and lowered constantly to prevent freezing. When the mud has been washed out some operators pump in about a ton of slaked lime to purify the water and aid the cement in setting. The cement (10 to 30 tons) is then pumped in and followed by a special plug (the Perkins One-plug Method). A few operators prefer to leave 10 or 15 feet of cement within the bottom of the casing, and to accomplish this a piece of timber about 4 inches by 4 inches by 10 feet is capped with a circular piece of heavy belting to fit the casing, and dropped in between the cement and the plug. This stops the plug at the desired distance from the bottom.

The Scott Method, simple and very successful, is similar except that the cement is mixed with a mounted mixer (instead of by hand) and no plugs are used. After the cement is run, pure water accurately measured is pumped into the well in sufficient quantity to fill the casing and force the cement outside, after which the casing is lowered to bottom, the cementing operation being complete. Two pumps, generally moved about on a truck, are used. The larger is similar to a regular rotary slush pump and the smaller one is a higher-pressure pump, as great power is often necessary to force the 20 or 30 tons of cement upward between the casing and the wall of the hole.

Upon completing any cementing operation, sufficient time must be allowed for the cement to solidify, after which the plugs or the portion of cement remaining within the casing may be drilled out and the well completed in the regular way.



15/7/43

ENGINEER FOR BORING

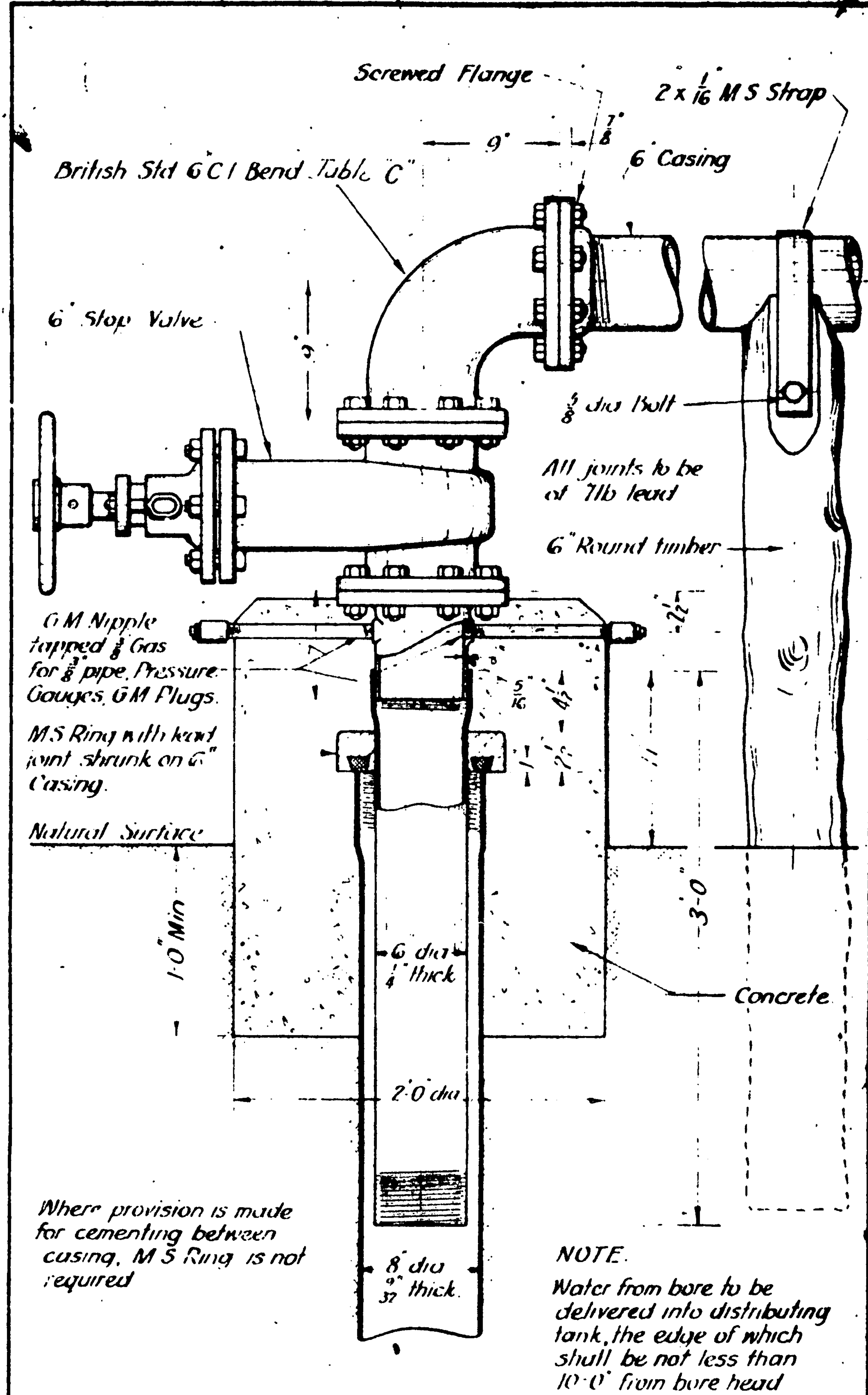
PRINCIPAL ASST. ENGINEER

WATER CONSERVATION & IRRIGATION COMMISSION

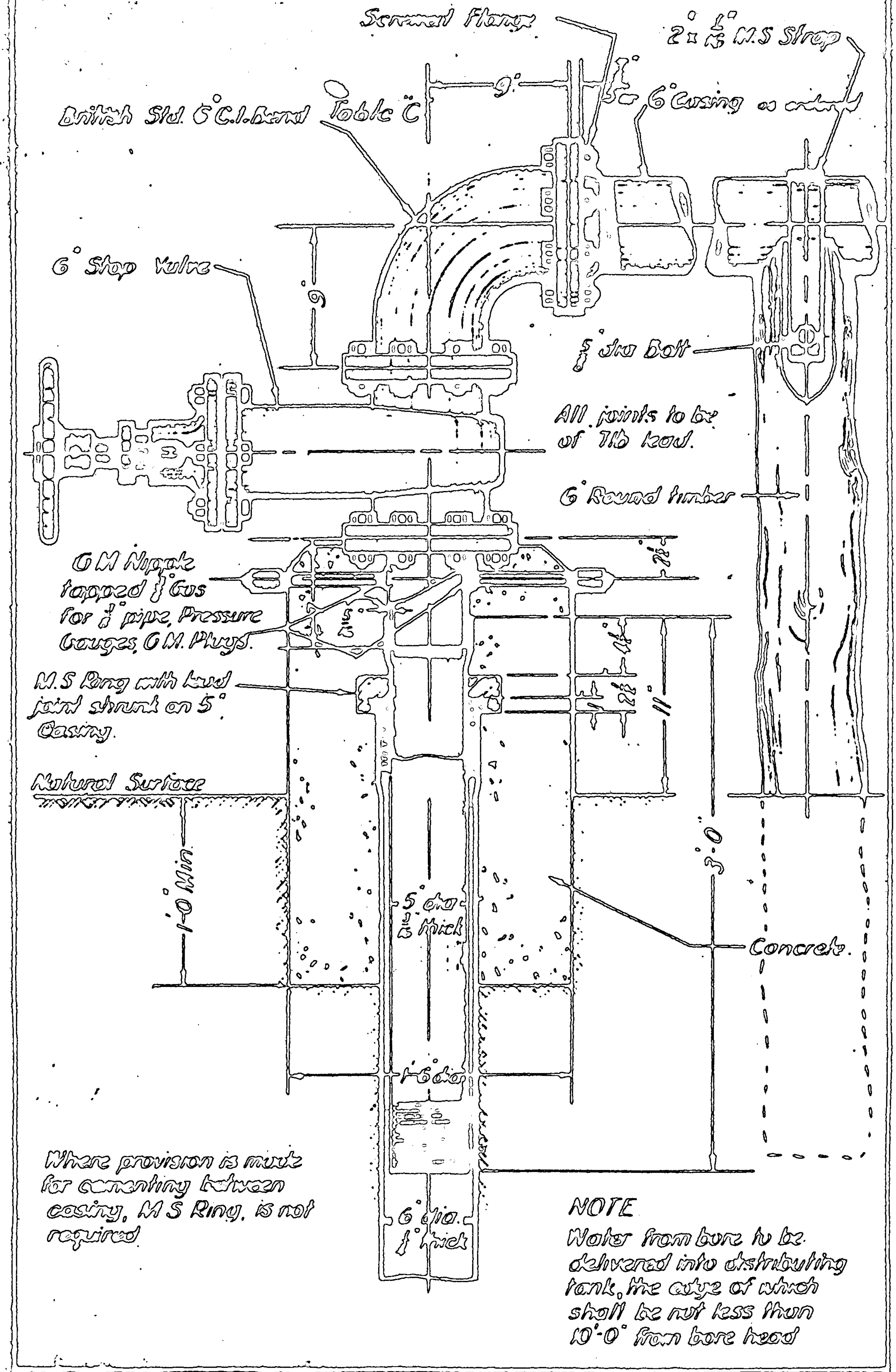
ARTESIAN BORES.
STANDARD CLOSING GEAR
FOR 10", 8" & 6" CASING.
TYPE A.

Scale :- 1½" = 1 FOOT.

TRAC. CAT^LO 105/292



ENGINEER FOR BORING	WATER CONSERVATION & IRRIGATION COMMISSION ARTESIAN BORES. **STANDARD CLOSING GEAR FOR 8" & 6" CASING.** TYPE B.	Scale :- 1½ = 1 FOOT.
PRINCIPAL DES^N ENGINEER		TRAC. CAT^LD 106/293



ENGINEER FOR BORING

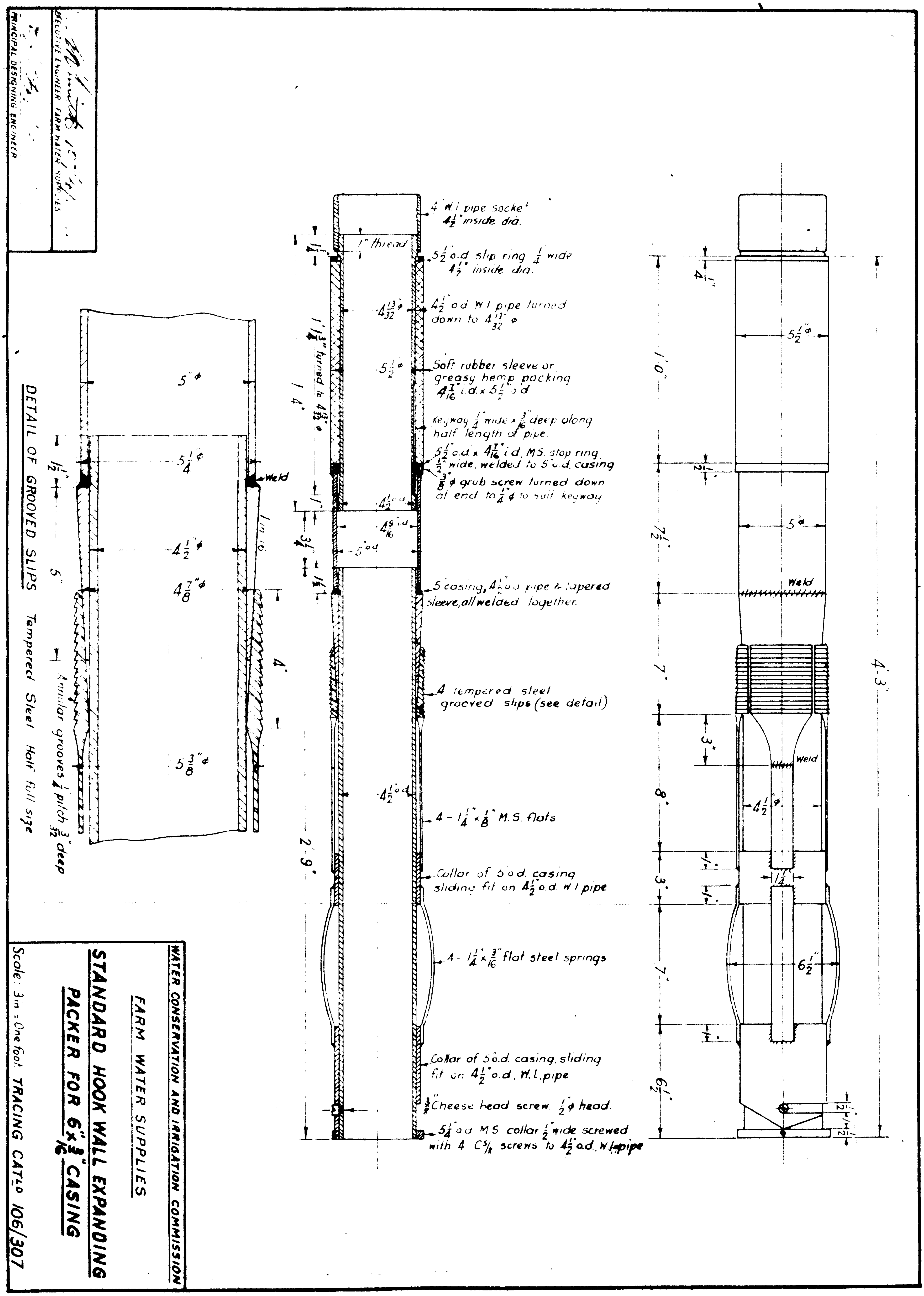
PRINCIPAL ASST ENGINEER

WATER CONSERVATION & IRRIGATION COMMISSION

ARTESIAN BORES.
STANDARD CLOSING GEAR
FOR 6" & 5" CASING.
TYPE C.

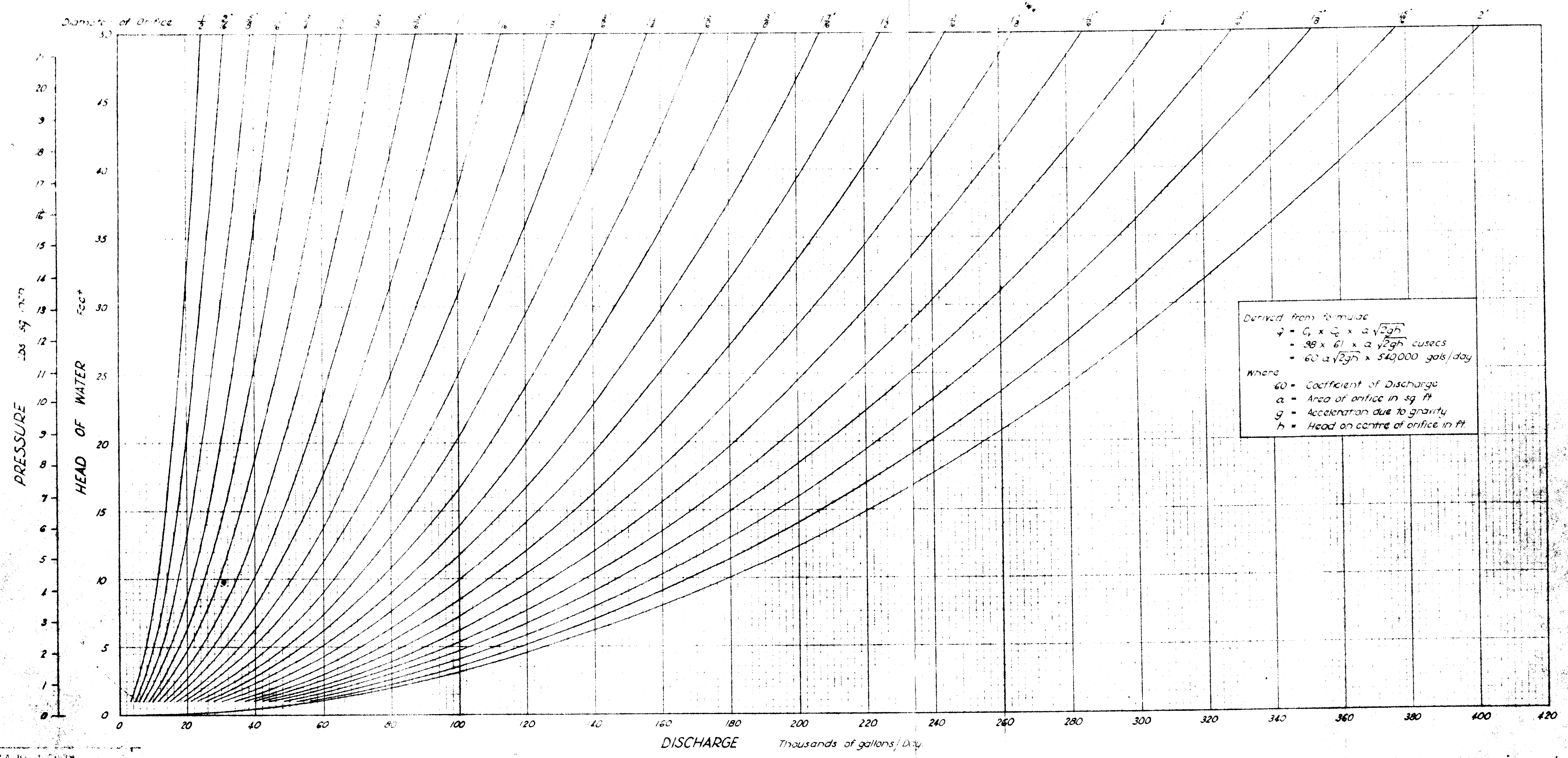
Scale :- 1 1/2 = 1 FOOT.

TRAC. CAT. No. 10C/234


EXECUTIVE ENGINEER FARM WATER SUPPLIES
PRINCIPAL DESIGNING ENGINEER
DETAIL OF GROOVED SLIPS Tempered Steel. Half full size
Annular grooves 1/4 pitch 3/32" deep
Weld
1 in 10
4" W.I. pipe socket 4 1/2" inside dia.
1" thread
5 1/2" o.d. slip ring 1/4" wide 4 1/2" inside dia.
4 1/2" o.d. W.I. pipe turned down to 4 13/32" ϕ
1' 1 3/4" turned to 4 13/32" ϕ
Soft rubber sleeve or greasy hemp packing 4 7/16" i.d. x 5 1/2" o.d.
Keyway 1/4" wide x 3/16" deep along half length of pipe.
5 1/2" o.d. x 4 7/16" i.d. M.S. stop ring 1/2" wide, welded to 5" o.d. casing
3/8" ϕ grub screw turned down at end to 1/4" ϕ to suit keyway
5" casing, 4 1/2" o.d. pipe & tapered sleeve, all welded together.
4 tempered steel grooved slips (see detail)
4 - 1 1/4" x 1/8" M.S. flats
Collar of 5" o.d. casing sliding fit on 4 1/2" o.d. W.I. pipe
4 - 1 1/4" x 3/16" flat steel springs
Collar of 5" o.d. casing, sliding fit on 4 1/2" o.d. W.I. pipe
3/8" Cheese head screw. 1/2" ϕ head.
5 1/4" o.d. M.S. collar 1/2" wide screwed with 4 C5/16 screws to 4 1/2" o.d. W.I. pipe
Weld
4' 3"
WATER CONSERVATION AND IRRIGATION COMMISSION
FARM WATER SUPPLIES
STANDARD HOOK WALL EXPANDING PACKER FOR 6" x 3/16" CASING
Scale: 3 in = One foot. TRACING CATLO 106/307

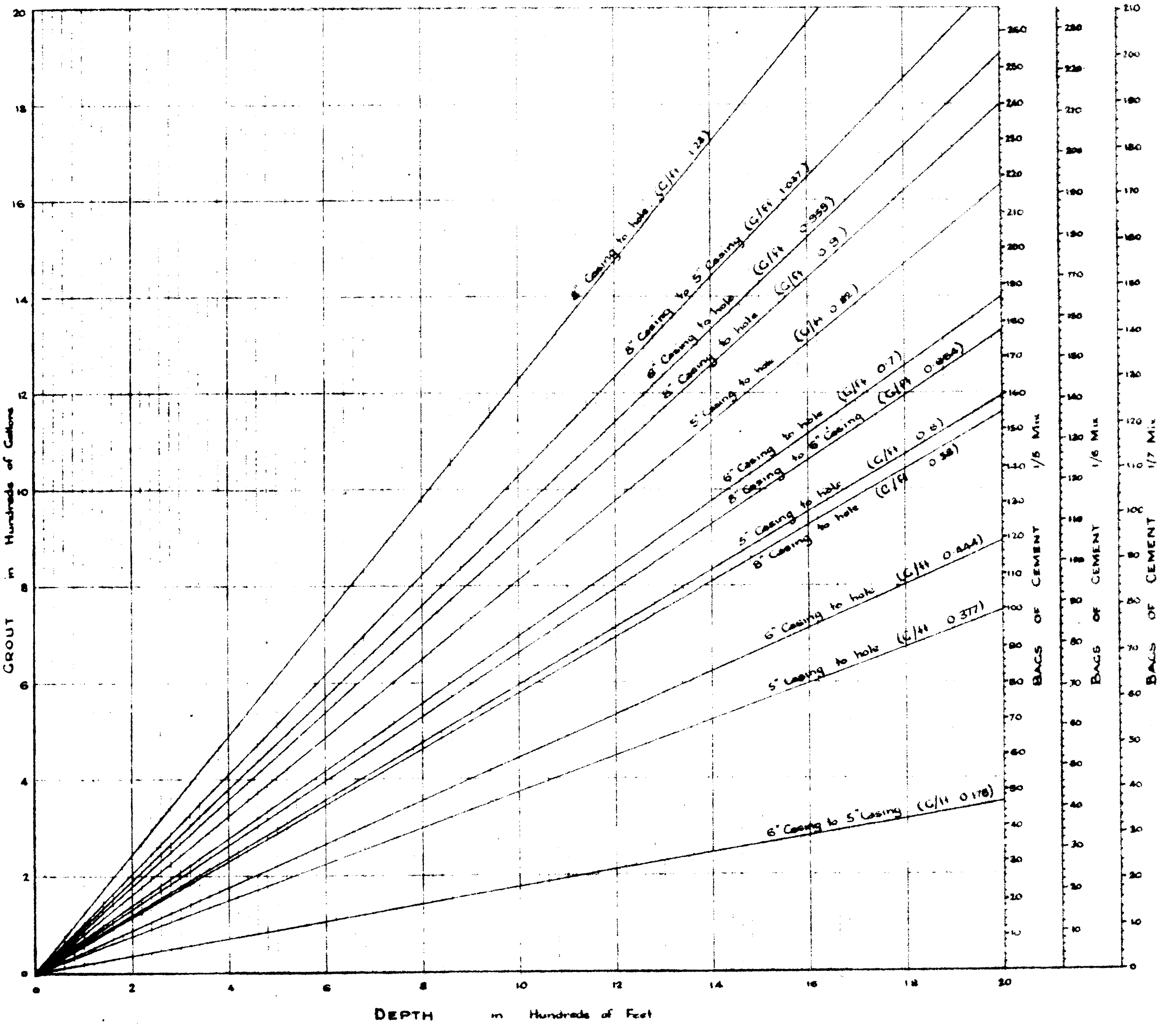
GRAPH SHOWING

DISCHARGES THROUGH ORIFICES



This tracing replaces original tracing which has been lost.

Tracing Cat. 270/71



GRAPH SHOWING

QUANTITIES OF CEMENT REQUIRED FOR CEMENTING BORES

W.R.H. 11/8/50

Tracing Cat. 270/65

SCREENED BORE CONSTRUCTION

by

E. R. SMITH

Principal Engineer, Water Supplies,
Water Conservation and Irrigation Commission,
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SCREENED BORE CONSTRUCTION

Foreword

This paper, prepared for presentation at the Symposium on Water Boring Techniques held in conjunction with the Second Annual Meeting of the Underground Water Conference of Australia at Adelaide 9th - 11th May, 1962, is not in any way a technical one.

Each of the several phases of screened bore construction as distinct from the mechanical operations of drilling, is a subject on which a technical paper exceeding the length of this paper could be written. A detailed treatise on the mechanical aspects of drilling including the almost infinite number of variables which might be dealt with, would require a very lengthy volume in itself.

The intention of this paper is to present in simple terms some of the more important aspects of screened bore construction techniques which might be appreciated and understood by those working in this field, including field supervisors and plant operators who may not be technically trained.

Readers will note the incidence of repetition in several parts of the paper. This has been deliberate in some instances for the purpose of emphasising certain important features. In others it has been the result of lack of available time for editing and I apologise for these.

It is hoped that the paper will be of some value to those already engaged in, or proposing to engage in the important and interesting work of screened bore construction for the improved development and utilisation of groundwater resources.

E. R. SMITH,

May, 1962.

SCREENED BORE CONSTRUCTION

INTRODUCTION.

Modern living standards demand continuously increasing quantities of water - that essential mineral which must be available from a reliable source.

Farmers must have water for the irrigation of their crops and the requirements of their livestock. Much of that water is available only from Natures "larder" of stored supplies beneath the surface of the earth.

The occurrence of groundwater in uncompacted sands and gravels as distinct from consolidated rock formations, has been a challenge for centuries past. The challenge has been to discover the most suitable methods of extracting the water contained in the interstices of subsurface sand and sand-gravel strata, without induction of the finer materials.

From time immemorial man has dug and drilled wells or boreholes in order to tap hidden supplies of water so that he may survive and prosper.

Many of his efforts have been crude by present day standards, and in the light of knowledge now available, but it is a regrettable fact that quite obsolete methods continue to be employed in bore and well construction.

Despite the fact that the dug well, whether it be lined with timber, steel, or concrete, or any other of the several forms of wall stabilisation, constitutes one of the oldest means of gaining access to the shallower groundwaters, there has not been a very marked improvement either in construction methods, efficiency, or reliability of such wells.

The shallow dug well still retains its place in the scheme of things. By more costly mechanical means, high yielding, stable deep wells <u>can</u> be constructed, but only the more costly structures compare favourably with the modern screened and developed bore, in efficiency, or reliability.

TERMINOLOGY.

Some confusion exists in respect of the terms "bore" and "well". In the U.S.A. the term bore is rarely used and the term "well" is applied to include the smaller diameter steel lined or cased drilled hole or bore hole as well as the larger diameter timbered or otherwise lined, well.

Several Asian countries utilise the term "tube-well" when referring to a drilled and cased bore hole. In Australia the term "bore" means a drilled hole lined with mild steel bore casing, and the term "well" describes a larger diameter hole dug, usually by hand methods, to either a round, square or rectangular shape and lined with timber, concrete or brick.

A "screened bore" in Australia and for the purposes of this discussion is synonymous with the terms "Tubewell" or "Screened Well" as generally adopted in Asia and the U.S.A. respectively.

The term "Screened Bore" will therefore be adopted as describing a drilled and cased "bore" in which a sand screen or screens are used.

WHY AND WHEN DO BORES REQUIRE TO BE SCREENED?

Sound construction of bores where aquifers consist of unconsolidated materials, necessitates that screens be used for maximum yields of sand-free water, stability of the aquifers and a long effective life of the bores.

If this is accepted for stock water supply bores, it is infinitely more significant for the high capacity bore essential for irrigation, industrial, or municipal water supply requirements.

There can be no comparison as regards yield, stability, reliability and effective life between a properly constructed screened and developed bore in which is used a well designed screen made from suitable material and a bore constructed with perforated or slotted casing, where the aquifer consists of sand, or sand gravel mixtures.

A screen should not be regarded simply as a "strainer" to keep most or all of the sand out of a bore and at the same time let some of the water in. It is a specially designed type of "stabiliser" which may be described as a device for supporting the bore hole within or through a loose water bearing formation and at the same time providing the medium for the "development" of a permeable filter of coarse grained material surrounding the screen. This will then produce the greatest possible number of open spaces (or interstices) for the water to flow into the bore hole.

"Development" of a screened bore means the removal of the finer particles of sand or gravel from a mixed type aquifer in which the screen is placed so as to produce a naturally coarser, more uniform and more permeable area of material around the screen, thereby, amongst other things, greatly reducing the head loss as water flows towards the bore, and correspondingly increasing the yield of the bore.

In effect, "development" of an aquifer per medium of a correctly designed screen enables use to be made of only the larger sized grains of sand or gravel contained in an aquifer in such a way that the material is more evenly graded, is stabilised, and capable of transmitting far greater quantities of water through the screen for pumping from the bore. At the same time the previously "mixed" aquifer is graded and stabilised against the otherwise inherent dangers of movement, bridging, or even collapse, under high rates of pumping.

THE PROCESS OF DEVELOPMENT.

All "development" of an aquifer is carried out through the sandscreen, hence it becomes the real "control centre" of the screened and developed bore.

The process of "development", in simple terms, means the rapid forcing of water both inwards and outwards through a screen thereby creating turbulence within the aquifer and drawing into the screen for removal of those finer sand and/or gravel particles which will pass through the slot openings of the screen. Thus, on completion of development only the desired coarser materials are left outside of and surrounding the screen.

Development is usually carried out by means of a "surge plunger" which may be described as a plunger or piston attached to a heavy cable tool sinker bar and operated in the water inside of the bore casing above the screen, or within the screen.

The importance of adequate strength in a screen, in addition to the essential requirements of conformity and accuracy of slot widths together with a correctly shaped slot can be visualised.

The above briefly described process of development known as "natural development" is practicable only in unconsolidated sands and gravels consisting of a mixture of grain or pebble sizes. In such formations the screen slot width is designed to allow a predetermined percentage of the finer materials to pass through into the bore for removal by means of a sand pump.

Many areas contain water bearing sands of a quite uniform grain size which are not suitable for "natural development" there being little or no coarser material for separation and retention outside of the screen. A screen having a slot opening sufficiently small to exclude all of the sand does not permit the maximum yield to be obtained. Entry of water is restricted and the screen becomes in effect a "strainer" and cannot perform its true function or fulfil its real purpose. Modern practice is to utilise a screen having a slot opening several times greater than the effective grain size of the natural aquifer and to adopt special methods of treatment.

In such cases the bore may require to be gravel packed, or provided with an artificial gravel "envelope" of selected graded material around the screen for the purposes of increasing stability, improving the yield of water from the bore, and preventing the movement and ingress of the finer sands through the screen into the bore hole.

The various processes of development and gravel packing are discussed later.

THE NEED FOR TEST DRILLING.

Excepting in some areas where very uniform strata and water bearing formations obtain and where the sub-surface hydrologic conditions are reliably known, the construction of screened bores must be preceded by the drilling of a test bore or bores. Their purpose is to ascertain the nature and thicknesses of all strata penetrated and in particular to obtain accurate "in situ" samples of the water bearing sands and gravels. In other words a complete bore "log" is established, and representative samples of the aquifer(s) are obtained for sieve analyses, by which will be determined the length and slot openings of the screen to be selected.

The bore log, considered in conjunction with the sieve analyses of the water bearing strata also provides the basis for determining if natural development is possible, if artificial gravel packing will be necessary, or if a gravel envelope is most suited.

Test bore drilling differs entirely from the normal practice of drilling bores with cable tools in consolidated strata. Accurate information is being sought as to the disposition and characteristics of the strata penetrated, particularly the water bearing strata and that immediately overlaying it. Sampling of the water bearing strata and the extraction of these samples as nearly as possible in "in situ" condition is of primary importance.

The normal drill bit should be used only to penetrate the harder formation above and/or between non-consolidated aquifers - all other drilling must be carried out by means of a drive pump (often termed a "chop pump") which allows the extraction of each stratum as it is penetrated and permits of an accurate log being compiled.

Immediately unconsolidated water-bearing materials are met with, the bore casing must be taken to bottom and driven into them. By this means a "core" of the formation through which the casing shoe is driven is collected inside of the casing for extraction, drying, bagging and labelling preparatory to sieve analysis.

Extraction of the "core" can be carried out by means of an ordinary sand pump, a plunger type vacuum pump, or a chop pump, but the latter is the most effective tool, especially if coarser gravels are included.

When penetrating a sand or sand-gravel aquifer in test boring, it is essential that the casing shoe be kept driven well ahead, and the sampling by bailer or chop pump extraction does not approach closer than 2 feet from the casing shoe unless and until the casing has fully penetrated the aquifer and entered a firm formation below. In such circumstances the whole of the "core" can be extracted as one continuous operation.

Sample extraction should be in one or two feet sections; i.e. if the casing is driven 6 feet ahead into the aquifer (after having cleared out all surplus sludge, clays etc., which may have accumulated inside of the casing during earlier drilling) take out the "core" in 1 foot or 2 feet sections with each run of the pump.

Each extracted sample must be retained in a suitable container until any clays or fines suspended in the water brought out with the sample have settled. Slowly decant surplus water and place the sample in a marked tray to dry, making sure that losses of any contained fines are kept to a minimum.

It is not good practice to attempt to obtain too much "core" of sand or sand-gravel in the test hole casing at one driving. The tendency is for a long "core" to compact within the casing thereby causing it to "seize" so that, as the casing is driven further, it is not collecting a "core" but is driving the formation below the shoe ahead of and away from the shoe. Therefore do not drive the casing too hard or too far ahead.

If a water bearing bed is, say, 6 feet in thickness the casing may in all probability be quite readily driven that distance at one driving. In such a case the whole of the 6-ft. core is extracted in 1-ft. or 2-ft. sections and drilling continued through non-water bearing formations until the next aquifer is met with should deeper exploration be desired. Casing should be driven ahead only so far as it will go freely and in this regard the driller's judgment and experience alone can tell him when to stop.

By retaining a reasonable amount of "core" in the casing the risks of "blowing" are minimised, but in any case it is always a wise precaution to maintain a high water level inside of the casing by pouring clean water into the bore hole. This is the best insurance against differential pressure causing sands and gravels to "blow" up inside the casing, thereby upsetting the accuracy of sampling and measurements.

In test drilling and sampling for screened bore work it is of the utmost importance that all measurements of casing, tools, drill cable, sand pump and sandline be accurate to one inch, and that at all times the driller knows exactly from a surface reference mark the depth at which he is operating with his tools in relation to the casing shoe. All measurements and other data or observations must be recorded for future reference.

SELECTION OF SAMPLES FOR SIEVE ANALYSIS.

Each sample, representing 1 ft. or 2 ft. - as the case may be - of the aquifer, as extracted and when completely dry, must be thoroughly mixed and any clayey materials contained therein crushed before placing in the sieves. Samples, representing 1 ft. from a 6 inch test bore may weigh from 4 to 6 lbs. There is no necessity to use the whole sample for analysis, provided the sample has been completely mixed to truly represent the whole; and 3 lbs. weight is a satisfactory size of sample to sieve.

Record analysis according to the footage represented by each sample. It is not satisfactory to mix a series of samples representing the whole thickness of the aquifer. Wide variations almost invariably occur in each aquifer, and it is important to have sectionalised analysis.

Observe samples and allow a percentage for any clays, silts, or other fines which may have run off with the water when setting aside the samples for drying.

Otherwise "good looking" gravels or sand-gravels are often poor water yielders when the percentage of incorporated clay or fine silts present is relatively high. A certain amount of washing is unavoidable during extraction and, frequently, samples as extracted appear cleaner than they are in situ.

Samples which, when dry, form hard "cakes" which have to be forcibly broken up for sieve analysis rarely represent a good-yielding aquifer - the clay content is usually too high.

The opposite can also occur, in that the shearing effect of driven casing can, and frequently does carry with and ahead of it clays and silts from upper formations into the water bearing materials, thus distorting and disturbing them.

It is important to remember that lensing and "piping" occur within many unconsolidated aquifers, and these conditions are not likely to be observed during test drilling and sampling. However they must be considered as probabilities when assessing the potential of an aquifer and in determining the length of screen to be used.

From an aquifer say 10 ft. in thickness it is not at all improbable that a large proportion of the available water supply will be derived from one, two, or perhaps several quite thin sections of the whole aquifer due to piping, or the occurrence of lenses of free yielding material within the aquifer.

The need to use a sufficient length of screen to take advantage of such conditions is quite apparent and unexpectedly high yields from unattractive looking aquifers can result.

SELECTION OF APPROPRIATE SCREENS.

Selection of the appropriate slot width of screen to be used in a screened bore is important and can only be done after close examination of the sieve analyses of the aquifer proposed to be developed.

The log of a bore, especially the nature and thickness of the stratum immediately overlying the aquifer must be considered in relation to the screen length and slot width openings of the screen.

Quite frequently several varying slot width screen sections are necessary for best results in variable thicker aquifers where gravel packing is not proposed or is unnecessary.

It is preferable in most cases where gravel packing or a gravel envelope is required, to utilise a screen having the same slot width throughout its length.

Slot width selection may be varied to allow of from 40% to 60% to pass the screen depending upon the type and thickness of the aquifer as well as the total length of screen to be used in relation to the total thickness of the aquifer. It does not pay, however, to skimp on length of screens.

In thinner aquifers not permitting the retention of a sufficient thickness of aquifer above the top of the screen, it is generally wise to be conservative in selecting the slot opening and to attempt to "develop out" a lesser percentage of the aquifer.

Gravel packing or gravel stabilisation is frequently adopted as the best means of ensuring stability and obtaining the highest yield in such conditions.

SIEVE ANALYSIS.

Samples are sieved through standard sieves and the weights retained on each sieve and the tray recorded. Tyler sieves are usually used, the range generally found suitable being Nos. 8, 14, 20, 28, 35, 48, 65, 80, 100 and tray. If the sample is of coarse material 5/16", 1/4" Nos.4 and 6 mesh Tyler may be included. Random large pebbles or stones of 3/4" and upwards are generally disregarded and not included in a sample to be sieved.

The material retained on each sieve number is weighed to the nearest $\frac{1}{4}$ oz. and results are recorded on tabulated sieve analysis sheets for reduction to "percentages retained" on each sieve number or its equivalent in thousandths of an inch and the "cumulative percentages retained" in the next column.

The complete sieve analysis of a stratum should be plotted on graph paper to produce a curve which shows the grain size distribution of the aquifer, the cumulative percentage by weight retained on each sieve number or its equivalent in thousandths of an inch being plotted against sieve number.

Sieve analysis curves are used primarily to determine the screen slot width best suited for a naturally developed bore, the method of which is dealt with hereunder. They are also used to determine the selection of gravels for artificial gravel pack, gravel stabilisation and gravel envelope treatment as and when required.

SELECTION OF SCREEN AND SCREEN SLOT WIDTH.

Only a screen of proven design, materials and construction should be used for best results and maximum life.

Selection of screen length and slot width for naturally developed bores is based upon consideration of the shape of the sieve analysis curve, the nature, thickness, and type of sand and gravel aquifer, together with the relative positions within the bore hole of the various strata.

Slot openings are usually selected so as to exclude from 40% to 70% of the coarser part of the aquifer, thereby allowing for from 40% to 60% of the finer materials to pass the slot openings for induction into the screen during development and their removal from the screen in the process of that development.

ARTIFICIAL GRAVEL PACKING, GRAVEL STABILISATION AND GRAVEL ENVELOPE.

For aquifers comprised of sands of a fairly high uniformity of grain size it may not be practical to extract such large percentages of fines. The screen slot width then requires to be selected to exclude a higher percentage of material.

Where a very high uniformity of grain size occurs, and especially where the grain size is small, natural development to any degree is not practicable. Development can then be accomplished by either of two methods, the gravel envelope, or by gravel packing. In either case, both the screen slot widths and the size of gravel to be introduced require to be selected on the basis of the sieve analysis results (See Appendix A).

The gravel pack must be selected so that the interstices will not become "clogged" with the finer sands of the aquifer during development or under pumping conditions, and the grain size of the gravel introduced must be of a diameter that will not pass through the screen slots.

It is preferable that gravel selected for either a gravel pack or gravel envelope be smaller rather than larger if the ideal cannot be obtained or there is doubt as to the correct size. The use of too large gravel (a common error) can neither effect stability of the aquifer nor allow the production of maximum quantities of water.

The gravel pack method when employed either to stabilise and improve permeability in an aquifer or to counter the encroachment of fines from a stratum above a screen (e.g. when collapse has occurred through washing up behind the casing during surging), generally contemplates the developing out of a proportion of the fines contained in the aquifer.

When the gravel envelope is utilised in the more uniform and finer types of aquifers, little or no development for the extraction of fines is usually practicable, although this method may be used within limits for developmental work. Broadly, the gravel envelope, by whatever method it is introduced, increases the effective diameter of the bore hole around the screen and permits the use of a larger screen slot opening. The cumulative nett effect is to increase permeability, reduce entry losses and improve the yield, and, at the same time, establish stability of the aquifer surrounding the screen.

CONSTRUCTION METHODS.

Where there are reasonable prospects of obtaining a production bore, and a 6 inch diameter bore will not meet requirements, a considerable saving in cost may be accomplished by using 8 inch casing for the test bore.

This procedure eliminates the cost of first constructing a smaller diameter test bore and its later conversion to a larger diameter cased bore. Excepting for the higher cost of casing, the actual cost of constructing an 8 inch bore as compared with a 6 inch bore is relatively small, so that the time saved in not having to convert to a larger diameter casing is often worth consideration.

The diameter of casing to be used in a production bore must be considered in relationship to the desired pumping rate and the anticipated yield of the bore; also with due regard for the respective diameters of available borehole pumps capable of delivering the required quantity of water from the completed bore at an acceptable efficiency rating. Obviously a small diameter casing restricts the size of the pump which may be installed, and although a 6 inch diameter bore may be capable of producing a high yield it may not be possible to obtain a pump to take advantage of the available water supply.

The generally adopted procedure in screened bore construction including insertion of screen and the process of development is along following lines, assuming that test drilling, sampling, sieve analysis have been concluded and selection of screen slot width, location and length of screen have been decided upon:-

The production casing is inserted to the desired depth with the shoe at the bottom of the aquifer to be screened, or at the level at which it is proposed that the bottom of the screen be placed, in the latter case adequately compacted backfilling to this level is essential. The screen is then assembled with bottom cap and lead packer fitted.

Screens available in sections of the required slot widths permit a screen of any suitable length being made up to suit any variations within the aquifer being dealt with, an important factor in many aquifers.

The screen to suit the aquifer having been assembled on the ground is then raised with the drilling rig, or by hand if it is only a short screen, lowered into the hole and held at the top of the bore casing by clamps under the lead packer adaptor or by means of a manilla rope.

An offset bar-and-link self-releasing screen lowering tool attached to the drilling cable or sand line cable is then fitted inside of the screen and within the lead packer adaptor collar. Weight of the screen is then taken by the drill cable or sandline and the screen slowly lowered to the bottom of the bore.

Accurate measurement of the assembled screen must be taken and recorded before it is lowered down the bore.

Having lowered the screen into position the lowering tool is released by simply "letting off" the weight of the screen so that the longer and heavier end of the lift bar drops to a vertical position and the tool is withdrawn.

In shallower bores and where the water level is close to the surface screens may be simply dropped into the water and allowed to sink to bottom, water resistance to the bottom cap being sufficient to prevent rapid descent and damage to the screen. Make certain by measurement check with bailer or tools that the screen is at the correct position on bottom.

When the screen is located correctly on bottom, the casing is lifted by jacking if necessary to a height where the bottom of the casing shoe is just above the top slotted section of the screen and the lead packer is inside of the casing above the casing shoe.

Accurate measurement of both the casing and screen being known and previously recorded for reference, the above procedure presents no problem, but care must be taken to ensure that the screen is not lifted with the casing. This can be checked by resting the drill tools or a bailer on the bottom cap of the screen with rope taut. If the rope slackens the screen must be lifting and appropriate action taken.

With the casing and screen correctly positioned and the casing firmly clamped at the surface, the lead packer at the top of the screen is swedged out to seal off the annular space between it and the casing.

The swedging tool, usually made of mild steel or hardwood, is shaped and tapered to fit the inside bevel of the lead packer. It is rested in the lead packer and bumped downwards by means of a sliding dolly attached to the sandline, the dolly being attached to a rod on which it slides and which is fixed to the centre of the swedging block. Three to five strokes of a 30-35 lb. dolly having a free fall of 24 to 30 inches on the guide rod are usually sufficient to fully expand a lead packer and firmly fix it to the inside of a bore casing.

Alternatively, a lead packer may be expanded by fixing the swedging tool to a set of drilling jars which are lowered until the swedge is sitting within the lead packer and the jars are in the "closed" position. Hand operation of the top half of the jars by lifting the drilling cable and allowing the jars to drop closed several times is a commonly adopted and satisfactory practice.

Examination of marks on the swedge tool indicate whether or not it has adequately expanded the lead packer.

With the screen and casing in these final positions and the screen packer swedged to the casing the process of developing and testing may begin.

A preliminary bailer test is the first requirement after accurately measuring and recording the static water level in the bore hole. About 20 minutes bailing at the fastest practicable rate is recommended, measuring the quantity of water extracted and recording draw down level as accurately as possible.

This bailer test serves several important purposes. Firstly, it provides the operator with some indication of the probable yield he may expect from the bore on completion of development and, at the same time, gives him a "reference point" as regards draw down in relation to yield, from which he can gauge the progress being achieved as development proceeds.

Secondly, it brings into the screen, for removal with a sand pump, or vacuum pump, the initial quantity of fines immediately surrounding the screen - thus beginning the development process.

Thirdly, it "cleans up" any residual drilling mud, silt or clays which may have been introduced around the screen and into the aquifer during the process of drilling, sampling and screen insertion.

Clean water is thereby drawn into the bore for the commencement of surging - a desirable feature - as much better progress is possible by maintaining the bore in a clean condition so that clays and silts are not continually being surged through the screen.

DEVELOPMENT BY SURGING.

Despite the fact that surging inside the screen is not advocated, nor is it usually practised in some other countries, it is strongly advocated that surging operations be commenced by surging <u>within</u> the screen with a solid surge block, commencing from the bottom of the screen and working upwards to the top of the screen in sections according to the length of the stroke of the drilling plant being used. In practice this process has been proven most successful.

Each step commencing from the bottom of the screen at short five minute intervals enables the full length of the screen to be "worked over".

The actual time for surging in each section of screen may have to be varied; in a freely developing formation the initial intake of fines over a five minute period may be greater than the capacity of that section of the screen and the surge block must be raised accordingly.

Never allow the surge block to "strike bottom" and compact the sand inside the screen.

Surging inside of a screen should be commenced at a slow rate say 20-25 strokes per minute and it may be continued on a pattern, working from the bottom of the screen upwards at each run with the rate of strokes per minute gradually increasing up to say 35-40 until the quantity of incoming fines is markedly lessened.

When the above stage has been achieved surging inside the casing above the screen may be commenced, using a loose fitting solid or valve type surging tool submerged at least 10 feet.

Commence again at a slow rate for short intervals between removal of the fines from the screen until it becomes known at what rate fines are being induced.

Strokes per minute may be gradually increased and closer fitting surge tool may be used as development proceeds, and when the quantity of incoming fines shows a marked decrease, revert to a few series of "runs" inside of the screen.

Alternate surging within and above the screen should be continued until little or no fines can be induced.

Periodic bailer tests must be run for the purpose of "clearing up" the water within the bore and around the screen and at the same time gauging the progress of development by comparison with draw down and pumping rate of the initial bailer test.

It is desirable that bailing rates be maintained as nearly equal as possible at each test so that the draw-down improvement may be better assessed. They should be carried out at least twice daily during the process of development. Initial surging inside of screens has the desirable effect of improving permeability throughout the full depth of aquifer exposed to the screen, thus reducing any tendency towards channeling within the naturally more permeable sections of an aquifer. It also reduces the risk of forcing water upwards outside the casing and possibly causing collapse during the next stage of development.

In practice it has been found that alternate surging inside and above screens produces far more effective and rapid results than operation only above the screen. However where aquifer conditions are known to be unstable; where there is good reason to believe that collapse within or above the aquifer may be induced, or when conditions are such that there is no margin for "freeboard" above the screen, the whole of the surging process for development may be carried out within the screen.

The resultant development will be somewhat less both in penetration and efficiency than if alternate surging within and above the screen were carried out, but in some cases a quite satisfactory result together with adequate aquifer stability can be attained by "in-screen" surging alone.

All development work and particularly surging operations must be carried out with a defined purpose and in a planned manner. Close observation of work throughout is essential, watch for a "fall" of upper strata which indicates "washing up" behind the casing. Colour and texture of materials removed through the screen as compared with strata penetrated in drilling and logged, are guides to the operator. Accurate measurements and their recording for reference, in respect of depth and quantities together with an intelligent appreciation of "what is happening" at all stages of screened bore construction make it both interesting and challenging.

Within alluvial deposits there are to be found an almost infinite variety of sub-surface and aquifer conditions. It is not therefore possible to lay down a set of rules which may be followed in all cases. General principles only may be specified and variations in procedure must be adopted to suit conditions as found in order to obtain the most satisfactory results.

Some operators prefer to use a valve surging tool to a greater extent than the solid surging tool. Both have their specific advantages and it will generally be found that more effective and rapid development of an aquifer can be achieved by judiciously utilising all three methods of surging - solid surger within the screen, alternating with both the solid and valve type surging tools in the casing above the screen.

A solid surging tool has the effect of forcing water inwards and outwards through a screen at approximately the same rates and velocities.

A valve surging tool, because of its design, allows a considerable proportion of water to pass through it on the downstroke thereby reducing the quantity of water forced into the aquifer. On the up-stroke the valve flap automatically closes so that water is drawn through the screen at a high velocity. By reason of this the valve surger is less likely to cause collapse through "back washing" up behind the casing above the screen and is generally a safer tool in that respect.

On the other hand, by using a valve surger only, there is a tendency towards bridging of sand-gravel particles outside and around the screen. Use of a solid surger by reason of its higher outwards displacement effect breaks up any bridging. Its alternate use with the valve surger is therefore desirable.

Where the water table is within about 12-15 feet of the surface a well fitting valve surger may be used towards the end of the developmental process for the purposes of "pumping" the bore.

Long rapid strokes with a good valve surging tool will bring water "over the top" at perhaps several thousand gallons per hour, and is a good method of cleaning up a bore and displacing all fines, silt etc. from within the casing and screen. It also reduces the bailing time prior to final test pumping.

However this process produces quite violent turbulence and should be attempted only where aquifers are of adequate thickness, are very stable and the risks of collapse are negligible.

<u>Gravel Packing and Gravel Stabilising</u> as distinct from the gravel envelope method of constructing screened bores may have to be utilised in many types of aquifers and under varying conditions, such as:-

(a) Where an aquifer is comparatively thin, i.e. only of a few feet thickness, and the stratum immediately overlying it is of an unstable, fine sandy, or silty nature, gravel stabilisation should be considered and provided for from the outset.

(b) Not infrequently it will be found that gravel packing and stabilisation will become necessary after development has commenced.

An unexpected collapse may occur, a cavity may have developed above an aquifer during the process of drilling the bore, or backwashing upwards around the casing whilst surging may have caused channeling and the induction of materials from a stratum above the screen.

In the case of (a), where the test bore will have provided information as to the type of aquifer and its relationship with overlying strata, one of two methods of gravel stabilisation may be adopted.

A large diameter bore cased with say 15 inch, 12 inch or 10 inch casing may be constructed, the casing shoe penetrating to the bottom of the aquifer to be screened. The screen is then inserted attached to a smaller diameter casing e.g. 8 inch, centralisers being fixed around the screen and the 8 inch casing for at least 10 feet above the screen.

With the screen fixed to the 8 inch casing and lowered to its position inside of the larger diameter casing, the annular space allows introduction of graded gravel between the two casings.

Immediately prior to commencing withdrawal of the outer casing a small quantity of suitably graded gravel is introduced at the surface between the casings to surround the screen. Allow ample time for it to travel to the desired position, at the bottom of the screen.

Sufficient gravel to fill the annular space between the screen and the outer casing to a depth of only about two feet should be introduced at a time.

The outer casing is then raised about a foot - more gravel to fill another foot of the annular space outside of the screen is then introduced and the outer casing again raised. This process if repeated until the shoe of the outer casing is level with the exposed top of the screen and the outer casing clamped in that position Sufficient graded gravel is then introduced between the casings to fill a further 4-5 feet above the screen and between the two casings. Development may then be commenced by initial bailer test and alternate surging procedures as for ordinary or natural development earlier described.

As development proceeds additional graded gravel is fed into the annular space between the two casings, maintaining from 3 to 5 feet of gravel above the screen. A weighted line should be used to measure the level of the gravel above the screen between the two casings and at the same time permit frequent checks being made as to the rate of feed of the gravel down around the screen. Occasional raising or lowering the outer casing a few inches may be necessary to prevent bridging and maintain adequate downward movement of the gravel feed.

When development is nearing completion the outer casing may be raised above a foot at a time with gravel feed continuing to ensure of a good envelope of gravel being placed around the top and above the screen.

On completion of development and final test pumping, not less than 20 feet of gravel should be introduced above the screen, as the outer casing is withdrawn.

For conditions as described in (b) above, "Pilot" or gravel feed bores are generally adopted for the purpose of introducing gravel as a stabiliser.

These also can be quite satisfactorily used for conditions as described in (a), if large diameter casing is not available or if its use is not desired for any reason.

Usually not less than two "pilot" or gravel feed bores are necessary for effective gravel packing or gravel stabilising; sometimes three are used. On the other hand, under some circumstances one bore may be found adequate - depending upon local conditions, and the type and extent of any collapse which may have occurred.

Where the screened production bore has already been constructed and gravel stabilisation becomes a need, pilot holes cased with 6 inch, 5 inch or 4 inch casing and spaced from 12 inches to 18 inches from the production bore should be drilled to penetrate to a depth level with or a few inches above the top of the screen.

Where it is evident that gravel packing or gravel stabilisation is an essential or desirable part of the procedure of construction of a production screened bore, it is preferable that pilot holes be drilled and cased to the required levels prior to inserting the screen in the production bore. This procedure eliminates any possible damage to a previously installed screen should a pilot hole deviate towards the production bore.

GRAVEL ENVELOPE TREATMENT.

Gravel envelope treatment, as distinct from natural development, gravel packing or gravel stabilisation treatment, is generally more applicable where the aquifer is comprised of finer uniform sands.

When the gravel envelope method is used, development work is usually restricted to pumping and possibly some light back-washing with a pump, with very little, if any surging. This is because, other than for the purposes of cleaning out any muck or silt which may have been carried down into the aquifer during the process of drilling and placing the screen, no improvement in the permeability of the aquifer can be effected by surging. On the other hand over-surging can well result in clogging of the gravel envelope surrounding the screen, due to the induction of fines from the aquifer, thus reducing yield and defeating the objective.

Selection of screen slot width and the size of gravel to be used are of primary importance in gravel envelope treatment of a screened bore. As in all screened bore work, these are based upon the sieve analysis of the aquifer.

Screen slot widths are selected to exclude the gravel used for the envelope, and gravel introduced must be of a size that will not, under pumping conditions, allow the movement of the natural sands of the aquifer to clog the interstices of the gravel introduced as the envelope.

The gravel envelope surrounding a screen in a uniform grain sized aquifer should not be of too great a thickness. It is generally accepted that the thickness of a gravel envelope surrounding a screen should be between three and five inches. Nine inches can be taken as a maximum.

Of the several methods which may be adopted for the construction of "gravel envelope" type screened bores, two are suggested as being the most practicable, simple and effective.

For both methods a large diameter casing is sunk to the required depth, the casing being of a diameter adequate to provide for the required thickness of gravel to be introduced between the outer casing and the outer diameter of the screen to be used.

Having inserted the large diameter outer casing a smaller diameter production casing with screen attached is then inserted so that the screen rests at the desired level usually coincident with the outer casing shoe.

Centraliser lugs are brazed or otherwise fixed on the screen, usually these are fixed to the bottom cap and lead packer adaptor collar, in order that the screen is positioned centrally in the outer casing.

Preselected graded gravel (or coarse sand as the case may be) is then introduced between the two casings, and the outer casing is progressively withdrawn as the gravel envelope is placed around the screen. No surging or pumping is carried out and the gravel envelope must be placed continuously as the outer casing is withdrawn until it extends above the top of the screen for at least several feet.

The height to which the gravel may be brought above the top of the screen may depend upon the type of formation overlying the aquifer. If the aquifer is continuous, gravel can be introduced for the full depth. Should a silty material overlie the aquifer, backfilling with fine sandy material is necessary above the gravel envelope.

In all cases backfilling with suitable material should continue to the surface as withdrawal of the outer casing proceeds. On no account leave an open hole space outside the production casing left in the bore.

A second method of placing a gravel envelope may be utilised in lieu of the method above described.

A cylinder of gauze such as brass or galvanised fly-wire or similar material, is made up to a diameter suitable for insertion inside the outer casing used in construction of the bore.

The cylinder should be at least three feet longer than the screen to be used, and the gauze cylinder is placed over the screen, open end upwards.

Graded gravel of the required size is then placed in the gauze cylinder and outside of the screen to form an evenly distributed "envelope" around and extending above the screen.

The top of the gauze cylinder is then closed off and tied to the casing to which the screen is attached and thewhole then lowered to the bottom of the bore.

The outer casing is then withdrawn, backfilling between the outer and inner casings with suitable materials proceeding above the envelope until all of the outer casing is withdrawn.

Several other methods requiring different and more involved procedures may be employed for gravel envelope treatment, but the end re-ult objective is the same.

With the gravel envelope placed and the bore completed, "cleaning up" and testing the supply are the next requirements.

Pumping is the first requisite and this should be carried out initially at a relatively low rate, and be gradually increased as the bore clears itself and the aquifer "settles down".

Stopping and re-starting of the test pump, produces a backwashing effect which can help considerably in increasing yield and stabilising the aquifer as a final treatment before test pumping.

It will be appreciated that screened bore construction methods differ markedly from the generally accepted practices and procedures adopted for the construction of stock-supply bores.

Drillers and others concerned with the drilling industry must be prepared to learn, adapt themselves to, and apply completely different techniques and, for practical purposes, to ignore most of the old procedures if they are to successfully apply themselves to screened bore construction and development work.

Patience, intelligent observation, accuracy in measurement and the proper tools used with judgment and intelligence are essential to the effective accomplishment of screening and developing bores.

Cost of the best available screen constitutes quite a small percentage of the total cost and value of a screened bore. Therefore there is no valid reason for using an improvised or cheap screen which will more than likely fail to produce the best results as regards yield, but will in all probability have a shorter effective life by reason of its inability to resist corrosion and erosion. Most "cheap" screens actually induce electrolitic corrosion because of the different types of metal used in their make up.

No contractor, driller, or landholder would consider using a cheap grade of oil in his motor vehicle, tractor or engine, because he knows full well that by so doing he would shorten the life of his engine which would cost him many times what he saved on oil.

Similarly the use of random slotted casing or a cheap screen which is generally fabricated from unsuitable materials and includes several different kinds of metals is false economy in screened bore construction. Not only is it impossible to obtain maximum development of the aquifer and maximum water yield when poor screens or slotted casings are used, but far worse still, the reliability of the bore is always suspect because the screen is so liable to fail due to chemical corrosion or electrolytic action.

Such screen failures not only cause the bore to fail or even cease to exist as a functioning unit, but they usually occur at a most inopportune time for the owner when water is urgently required. In addition they frequently result in damage, through sand pumping, to an expensive pump.

Replacement of a collapsed screen is not always a simple matter, sometimes it is not practicable, even if an experienced operator is available to carry out the work at short notice.

Sometimes a completely new bore is the only solution to a failure due to sand pumping or through collapse of a screen.

Irrespective of whether a screened bore is developed by the more orthodox natural process, by gravel packing; gravel stabilisation, or by the gravel envelope method, a well designed screen made of suitable material and having slots specially suited to the particular aquifer materials to be dealt with, must be used for maximum efficiency and effective long life.

Screened bore construction is not costly when all relevant factors are taken into account. By comparison with an ordinary low yield stock bore the cost may appear high, but the only basis for evaluation of the cost of any structure is the end result, what it gives and for how long, in relation to money expended. It is not valid to compare the cost per foot of a screened and developed bore with the cost per foot of a stock supply bore.

The careful work which is essential in the construction of a screened bore, which may require surging for several days for complete development and stabilisation must make it considerably more costly than a normal stock bore, even excluding the cost of a good screen.

There cannot be any comparison, however, as regards results - the screened bore in suitable formation, and properly screened and developed, is capable of yielding as many thousands of gallons of water per hour as a stock bore may yield in a month, and will continue to yield continuously regardless of seasons.

Initial cost values are hardly comparable, but by comparison with a surface storage work, for the conservation of water for irrigation or any other purpose, a screened and developed bore will not only prove more favourable in capital cost, but is usually a more dependable source of water supply.

The fact that screened bore work is entirely different in character and techniques employed to those well known to drillers and contractors, who have for many years drilled smaller yielding stock supply bores, should not deter the enterprising and progressive driller or contractor from entering this field of drilling activity.

There is no mystery about screened bore construction. An appreciation of the principles and an understanding of the reasons for the various procedures to be adopted are the essentials, and any intelligent driller prepared to study the problems and equip himself with adequate plant and tools can adapt himself to successfully undertake this type of work.

AQUIFER CHARACTERISTICS.

Sand, sand-gravel, and gravel formations carrying water can yield their water into a screened bore only at rates determined by the natural characteristics of the formation as a whole, irrespective of how well the screened bore may be designed, constructed and developed.

This is not to infer that design, length and type of screen are not of major importance, nor that good development of the formation immediately surrounding the screen cannot markedly increase the yield from a bore, but in the final analysis it is the ability of an aquifer to yield water that determines the capacity of a bore.

Uniformly graded sands and gravels provide the higher yielding aquifers because they possess a higher porosity than do sands and gravels consisting of a wide range of grain sizes. In the latter types the finer materials occupy the spaces between the larger pebbles and grains, thereby reducing the size of the interstices and restricting the flow of water through the waterbearing formation.

Screening and developing in effect, increases the diameter of the bore, thus presenting a much larger and freer area for the water to pass through between the natural formation and the bore.

Few sand or sand gravel aquifers are uniform throughout their depth, more often than not they are comprised of layers of varying thickness of coarse and fine materials, silty layers, clayey layers and so on.

Stratification therefore affects the flow of water within an aquifer as well as to a bore from an aquifer and is one of the natural characteristics which cannot be changed excepting within the zone of development around the screen.

It may be accepted that, other factors being equal the thicker an aquifer the more water it is likely to yield. Accordingly, a thick aquifer, even though its natural characteristics make it a comparatively low yielder per foot of thickness it can be a high yielder.

The specific capacity, or yield per foot of draw down is related to permeability of the aquifer. Correspondingly the yield of a bore is related to the length of screen used, provided development is properly carried out over the full length of the screen.

PUMP TESTING. (See also Appendix D).

The importance of carrying out an accurate and thorough pump test of a screened and developed bore on completion cannot be overstressed. No bore is complete unless and until a satisfactory pump test is made.

A partial test is almost valueless as is any so called test which is of insufficient duration and does not include accurate information in respect of rates of pumping in relation to drawdown time.

Two principal types of pump tests are acceptable - (1) a stepped draw down test or (2) a constant rate test, each having its own particular virtues depending upon the scope of information sought.

The former describes a test where pumping is carried out at several different rates, at least three, each over a sufficient period to provide appropriate information on the drawdown - time relationship at each rate.

A constant rate pumping test is one in which a pre-determined rate of pumping is maintained throughout the full test period and draw down measurements are made at regular intervals throughout the test. The rate of pumping should be one ap roaching the maximum capacity of the bore but not at such a rate that draw down will reach the pump suction inlet, at least not until the test has progressed for at least eight (8) hours.

The pump suction inlet during a pumping test or for permanent pump installation should not be below the lead packer of a screen. It is not good practice in any circumstances to place a pump suction inlet within the slotted section of a screen.

Only from a correctly conducted pumping test is it practicable to determine the maximum rate for continuous pumping, and also the permanent pumping unit most suited to the demands on the bore.

Pumping rates during tests must be measured accurately by means of suitable equipment, such as a flow meter, orifice meter, or measuring weir.

Similarly static water level and draw down levels must be accurately measured with suitable equipment, preferably an electrical probe. Measurements should be to the nearest quarter inch or less if practicable, and the times of starting the test, and measuring flow rates and draw down levels, must be recorded.

SUMMARY.

(a) Screened bore construction must be preceded by drilling a "test" bore, or bores, using either a small diameter (5 inch or 6 inch) casing or the production bore (8 inch diameter or larger) casing.

(b) Proper formation sampling and logging of strata penetrated, especially of aquifers, are essential.

(c) Sieve analysis of aquifers to be screened and developed must be made in order to determine the most suitable screen for each bore i.e. length of screen, and slot width to be adopted.

(d) It is not possible to obtain the best results by guessing the screen slot widths suitable to any aquifer - only sieve analyses can provide the essential information enabling selection of the correct screen slot width for each bore. (See appendix B).

(e) When selecting a screen for any bore, consider the most suitable length of the screen. If possible allow at least 3 feet of aquifer to extend above the top of the screen - more if practicable. It is a mistake to attempt to screen the full depth of an aquifer unless gravel treatment is intended.

Some "free-board" of aquifer must be allowed above the top of the screen so that when development by surging is undertaken a margin is available for movement and possible subsidence of the aquifer. It also minimises the possibility of "washing up" behind the casing, which can result in a collapse of the upper formations.

(f) The specific capacity of a screened bore from most aquifers is largely related to the effective length of screen used. It is not sound practice to "skimp" on screen length if a high yield is desired. Make full use of the available aquifer by inserting an adequate length of screen - keeping in mind the need to retain a safe margin of several feet of aquifer above the screen.

If an aquifer is 30 feet in thickness up to 25 feet of screen may be used - in a 10 ft. aquifer not more than 7 feet of exposed screen may be used with safety unless the material above is stable, or gravel stabilisation is contemplated.

(g) Careful and intelligent development by surging and pumping to a plan, and as local conditions indicate, are essential to successful screen bore construction.

(h) Over-development, imprudent, or violent initial surging must be avoided. Build up the surging rates, and alternate surging within and above the screen to gradually improve the permeability and stability of the aquifer until maximum yield is obtained.

(j) Under-development may be as great a fault as over-development. The poor results may not become evident as quickly as in over-development but an under-developed screened bore never yields the supply of which it would be capable were it correctly and fully developed, whilst it almost invariably falls off in yield after a period of pumping and may finally fail altogether.

(k) A fully developed and stable screened bore is one which has been carefully and completely developed until little or no sand can be induced into the screen by surging or pumping at high rates before final test pumping is carried out.

(l) A "sand-pumper" is a "bad" bore and a menace to the owner. No correctly screened developed and tested bore should pump any sand. If it does it has not been properly constructed.

(m) No bore should be equipped with a permanent pump having a discharge rate so high that there is no margin of safety for draw down "creep" and "fall off" in pumping capacity over long periods of pumping, or during prolonged dry spells when water tables may fall and yields may be correspondingly reduced. Always allow a margin based on results of a complete and correctly conducted pumping test.

(n) Gravel Packing is defined as the procedure of introducing selected graded gravel (or coarse sand as the case may be) either by means of pilot or gravel feed bores, or per medium of a large diameter temporary outer casing, for the purpose of remedying a collapse, or filling a cavity in a formation above the screen, where initial drilling, surging or pumping has caused the subsidence of an unstable formation overlying an aquifer.

In this procedure the gravel is introduced above the screen, fills the cavities and replaces the lost material, packs the bore hole and the aquifer, and, with the correct size material, permits of development through the screen to completion.

(o) Gravel Stabilisation involves the introduction of selected graded gravel (or coarse sand) for the purpose of providing a higher percentage of coarser grains of material around the screen where an aquifer is of mixed grain size but in which finer materials predominate.

This has the effect of replacing the finer materials extracted by development through the screen, preventing slumping or collapse of the aquifer and providing a better grading of material immediately surrounding the screen, thereby increasing permeability within the aquifer around the screen and effecting a higher degree of stability.

In this process the gravel is introduced via pilot holes or an outer large diameter casing throughout the required depth at which stabilisation is necessary and working upwards to and above the top of the screen.

Gravel stabilisation treatment may be adopted to obtain maximum results where aquifers are overlain by unstable or friable materials, or where the upper section of an aquifer above the screen consists of sands appreciably finer than the screened section.

(p) The Gravel Envelope method of treatment is normally used for the purpose of increasing stability of and yield from an aquifer of uniformly grained materials which is not practicable of natural development. As the term indicates, it involves the process of placing an "envelope" only a few inches in thickness of selected graded material between the outside of the screen and the aquifer.

Material used for the envelope is of a coarser grain size than the natural aquifer, thus permitting use of a larger screen slot. The envelope material must be selected and graded of such size that the finer aquifer materials will not pass through or into the envelope to cause a reduction in permeability or a blockage. No surging or development other than appropriate rate pumping, and perhaps some light back-washing with a test pump, should be attempted with this treatment. See Appendix A.

(q) Materials used for all work of gravel packing, gravel stabilisation, or gravel envelope must be selected and graded to suit each aquifer being dealt with. Rounded water worn gravels or coarse sands should be used. Crushed metal having a large percentage of flats and angles is of little value. (See Appendix B).

(r) Locating the most favourable sites for high production screened bores is a problem which must be given consideration by landholders and drillers alike. It cannot be expected that good aquifers will be found in all bores and it must be accepted that test boring is the only way by which the best available sites for production bores can be located.

A planned test boring programme is necessary in most areas and, in alluvium, test bores should be drilled at intervals across the valley, at right angles (or thereabouts) to the direction of flow.

A test boring programme usually "pays off" as it is the only means of locating the most favourable sites. It is more economic to spend a reasonable amount on test boring to locate a site on which a screened bore will produce a high yield, than to accept a low yield from the only site tried.

APPENDIX "A".

DETERMINATION OF GRADING, SIZE AND SELECTION OF GRAVELS AND SANDS FOR USE IN GRAVEL PACKING, GRAVEL STABILISING AND GRAVEL ENVELOPE TREATMENT OF SCREENED BORES.

All materials used for these purposes must be rounded water worn gravels or sands, as uniform as possible not sharp angular materials, and in particular, flat sided angular materials such as crushed basalt (blue metal) or crushed gravel must be avoided, as they are not effective, for obvious reasons, and in many instances their results in a reduction rather than an improvement in both the stability and yield of a bore or well.

The basis for determination as to a suitable size material for use in gravel treatment is the sieve analysis of the aquifer to be treated, the aquifer being the governing factor.

It is rarely possible to obtain material of ideally uniform size, therefore it is usually obtained within specified limits by sieve sorting to pass a given sieve number or diameter and to be retained on a suitable given smaller sieve number or diameter e.g. passing ¼ inch and retained on 3/16 inch screens.

The purposes and functions of gravel treatment being somewhat different as between gravel packing or stabilising and gravel enveloping the basis for selection of materials also varies.

Bennison suggests that a bore in an aquifer sand with a uniformity coefficient greater than 2.0 need not be gravel packed. His principal reason for suggesting that number is that an aquifer sand with a high coefficient could be developed "naturally" so as to produce its own gravel pack. This may be correct in theory but in practice it is quite often necessary to assist natural development by artificial gravel pack or stabilisation according to conditions obtaining.

It is evident from this study that the greater the uniformity coefficient of the aquifer sand, the finer the gravel in the pack must be, in order to be satisfactory.

Since many operators are convinced that the gravel in a pack must be coarse, it is easily understood why so many of them get into trouble and have failures, particularly when they attempt to gravel pack bores and wells in aquifers with high uniformity coefficients.

Coarse gravels have such large voids that the finer aquifer sands are carried into the pack or through the pack into the bore or well, resulting either in a clogged gravel pack (reduced yield) or into the bore through the screen (a sand pumper and a failure).

It must be understood that gravel packing or gravel stabilising methods are used where natural development of mixed grade aquifers is the principal objective and that the gravel treatment is used for the purpose of assisting in that objective.

The gravel envelope is adopted in finer sand aquifers having a high uniformity coefficient and in which no "natural" development is practicable. The function of the gravel (envelope) in this case being rather different in that it is designed not to assist in natural development or in stabilising a mixed sized aquifer by introducing additional desirable sized material but to:-

(a) provide a coarser material filter surrounding the screen which will increase the effective diameter of the screen;

(b) permit of the use of a screen having a larger slot opening designed to hold back the pack material, not the aquifer material;

(c) increase permeability within the immediate surrounds of the screen thus reducing head losses at the screen.

The envelope material must be of a size which will control the movement of aquifer sand into the envelope, or through the envelope material into the screen.

It will almost certainly be found that no sand aquifer is entirely uniform in grain size, and that there will be some percentages of larger and smaller grain sizes than the greater percentage of grains of approximately uniform size, on which the uniformity is assessed.

For practical purposes the percentage of larger grain size material can be disregarded, as can the percentage of smaller grain size/s provided that these latter are not in excess of 15% of the total.

The size of the gravel envelope material to be selected is therefore based upon the size of the sand grains comprising the major percentage of the total, ignoring the small percentage of larger grain sizes and also the percentage of smaller grain sizes, provided the latter do not exceed 15% of the total.

For example a dune type sand aquifer may on sieve analysis show the following results:-

3% - larger than 0.020"
10% - between 0.011" and 0.020"
78% - between 0.008" and 0.011"
9% - smaller than 0.008"

Selection of a gravel envelope material is based upon the 78% of the total which is between 0.08" and 0.011" ignoring the 13% larger than 0.11" including the 3% larger than 0.020", also the 9% smaller than 0.008.

Adopting .010" grain size as representing an acceptable major percentage ratio, the gravel (sand) envelope material in this case should be 0.040" to 0.050" i.e. 4 to 5 times the size of the basic size of the aquifer material. For practical purposes the envelope material could be 3/64" i.e. 0.046" sand or even quality placed with a thickness of 3" to 5" around a screen having a slot width of 0.035".

Where very large diameter outer casings can be installed in dune sand type aquifers as above described, a double envelope may be of advantage if placed in pre-pack form on the screen by the use of gauze telescopic cylinders.

In such case the outer layer of the envelope should be of 0.046" (3/64") sand 2-3 inches thickness over an inner 2 or 3" layer of gravel of approximately 0.20" material around a screen having a slot width of 0.150".

Little is published by way of results of design criteria for gravel packing and gravel enveloping in screened bore construction, there being so many variables that most workers appear to have been reluctant to specify formulae.

However the bulk of opinion seems to show that the most effective gravel envelope grain size ratios are 4 to 5 times the diameter of the basic aquifer sand diameter as above illustrated, and in practice in a large number of bores over a period of some 25 years this has been borne out with satisfactory results.

In gravel pack and gravel stabilisation work the uniform gravel pack material has been found to be effective when the particle size in the aquifer material covered a large range.

The basis for design of gravel pack material for stabilisation of naturally developable aquifers must however be related to the sieve analyses results and the slot width of the screen selected on sieve analysis.

It is accordingly good practice to select a gravel pack material which is within the range of the higher percentage of natural material to be excluded by the screen and forming the natural gravel pack around the screen by normal development.

The lower size range of material in a gravel pack must be larger than the screen slot width by a suitable margin (say 20-25%) so that it will not pass through the screen, and the higher range size material should be not more than 25% greater diameter than the smaller, the ideal being uniformity throughout, if attainable.

Gravel packing or gravel stabilising is only required and adopted where "natural" development of the aquifer is practicable, and it may be adopted either for the purposes of assisting the processes of development where a high percentage of material is by design being extracted, or it may be, and frequently is used to stabilise an aquifer or a bore hole where a cavity has developed or instability has resulted from some cause known or unknown, during the process of development.

APPENDIX B

SIEVE ANALYSES AND THEIR INTERPRETATION

Methods for extracting, preparing, and sieve analysing aquifer sands and gravels are discussed in the main paper, wherein it is emphasised that selection of screens both in respect of length and slot opening/s must be based upon consideration of the bore log and the mechanical analysis of materials comprising the aquifer proposed to be screened.

For greater accuracy in interpreting the results of aquifer sieve analyses it is desirable that they be plotted in graph form, (as per example attached) to show the various grain sizes of materials retained throughout the range of sieve aperture sizes used, and whereby interpolation will indicate the intermediate percentages between aperture sizes of sieves used.

An aquifer consisting of grain sizes having a high uniformity coefficient is usually the best type in that it will have a high permeability factor provided the grain size is not too small; it is clean, free of colloidal materials such as clays, and is adequate both in thickness and extent. Well sorted or mixed grain size materials usually do not constitute a high yielding aquifer, i.e. where throughout the range of grain sizes constituting the aquifer there are fairly evenly distributed percentages of each size of material down to and including the fines. Obviously in such an aquifer the interstices of the larger materials are occupied by the smaller materials throughout the range resulting in restricted permeability.

Whilst development may create a satisfactory re-distribution of material close to the screen the capacity of the aquifer as a whole to transmit water, because of its wide range of grain sizes, a continuous aquifer of this type has not a high specific yield.

It is axiomatic that the best designed and constructed screened bores cannot yield greater quantities of water than the aquifer as a whole is capable of transmitting to the developed and more permeable area around the bore screen.

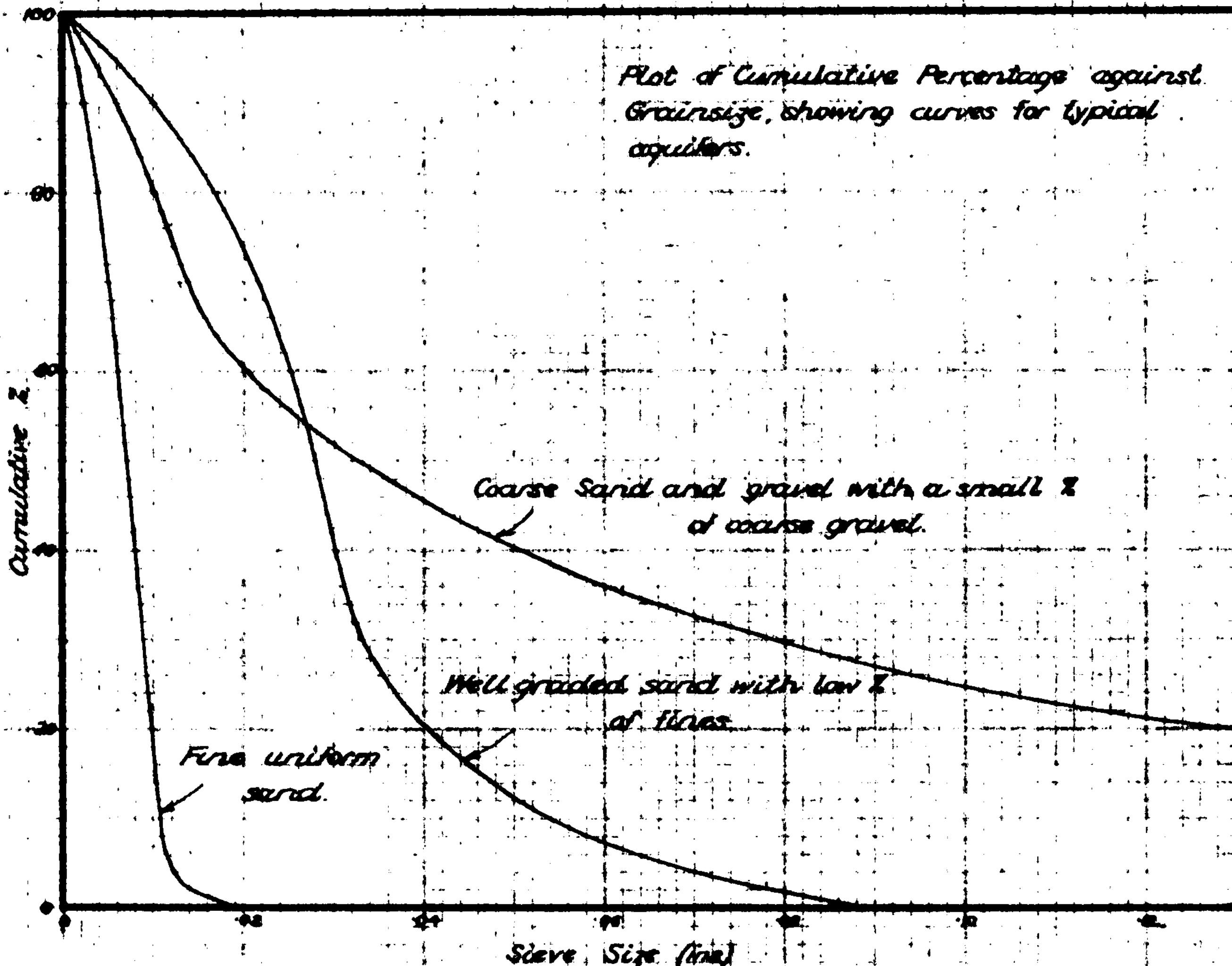
The problems of screen selection and estimation of potential from an evenly graded, perfectly clean gravel or sand are fairly simple, but these conditions rarely occur. It is more likely that an aquifer will be found to comprise a variety of sand gravel mixtures of varying thicknesses and characteristics in addition to having varying clay mixture content.

An accurate assessment of the actual clay content of an aquifer or sections of an aquifer is often difficult, and it must be accepted that completely accurate and undisturbed samples of unconsolidated aquifers are virtually impossible to obtain.

However an assessment of the general characteristics including clay content is essential and these factors must be considered in conjunction with sieve analysis results when interpreting conditions as most likely to be obtaining within an aquifer for the purposes of selecting a screen.

Thickness of the aquifer in relation to screen length and desired yield, together with appropriate consideration of the overlying strata, especially that immediately overlying the aquifer, require to be taken into account with sieve analysis when selecting a screen and planning a procedure for development.

Experience is the best instructor in many of these phases of the work, and there can be no set rules by which to be solely guided due to the many variables which may be involved and the fact that in a bore hole, in situ conditions cannot be observed.


Plot of Cumulative Percentage against Grainsize, showing curves for typical aquifers.
Cumulative %
Sieve Size (ins)
100
80
60
40
20
0
Coarse Sand and gravel with a small % of coarse gravel.
Well graded sand with low % of fines.
Fine uniform sand.

Whether or not 40%, 50%, 60% or any other percentage of aquifer material is designed to be removed will depend upon the characteristics of the aquifer material as revealed by the sieve analysis curve, the thickness of the aquifer and the type of formation immediately overlying the aquifer.

In practice it has been found that extraction of from 40% to 50% is usually applicable and satisfactory, but in some instances 25% to 30% has been the safe limit having regard for the characteristics of the aquifers, whilst as high as 70% extraction can be accomplished in some cases.

Obviously a thin aquifer having an unstable silty overburden must be treated much more conservatively than a thick aquifer of fair to good developmental characteristics having a tight clay overburden, even though gravel treatment may be considered an essential part of development from the outset.

Some aquifers and conditions will accept a considerably higher percentage of extraction than others, and it is safer to err on the conservative rather than on the optimistic side, provided a reasonable degree of development is allowed for.

In finer aquifer materials screen slot widths can be quite critical within a very limited range, for natural development, but in the coarser aquifer materials a greater margin of possibly up to 0.010" may well be available without undue loss of efficiency or risk, provided the sieve analysis shows that extraction percentage will not be upset to any serious extent by so doing. Skimping on screen length is usually false economy. For maximum results use a greater rather than a lesser length of screen to take advantage of the maximum thickness of an aquifer, due regard being given the provision of a safe margin of aquifer above the screen where natural development is proposed.

APPENDIX "C"

THE USE OF "CALGON" IN BORES

Clay, either as interbedded layers or disseminated through an aquifer, often causes considerable difficulty in obtaining maximum results from screened and developed bores.

Normal development procedures including surging and backwashing are very often found to be inadequate for the purposes of removing clays to a degree necessary for adequate development.

In many areas aquifers contain varying proportions of clays either in lenses or as an admixture with sands and gravels, or both, which cannot be sufficiently "developed out" unless with the assistance of a suitable dispersing agent.

"Calgon" provides an excellent medium for this purpose, and its appropriate use as a routine developmental "tool" has been found to improve yields upwards of 50% in some bores after normal mechanical development has been completed.

"Calgon" effectively disperses accumulations of clays from screens and surrounding aquifers and is also effective in removing accumulations of iron oxide and calcium carbonate from screens and aquifers. It may therefore be used to advantage in old bores in which yields have fallen off due to clogging by any of these materials.

It has also been found most effective in restoring yields in screened bores in which aquifers and screens have become clogged as a result of clay and silt laden floodwaters flowing into unsealed bores. "Calgon" is safe and quite easy to handle and methods of application are simple, but to gain maximum benefits, treatment must be carried out in a manner ensuring its proper placement and periodic agitation within the screen and aquifer being treated.

"Calgon" a well known trade name for sodium metaphosphate is obtainable in flake or powder form, but for bore treatment work "T. Flake Calgon" is preferable, being easier to dissolve without "lumping".

It is available in 56 lb. pails at about 2/6 per lb. in capital cities in Australia. A leaflet on its uses in bores and wells is available from the manufacturers Albright and Wilson (Aust.) Pty. Ltd.

Where practicable, it is recommended that Calgon T. Flake be introduced in solid form directly into the screen, either by slowly pouring into a bore casing a sufficient quantity to fill the screen, or in the case of an equipped bore it can be introduced into the annulus between the bore casing and the pump column.

Calgon may also be introduced in liquid form by dissolving about 35-40 lbs. in each 100 gallons of water.

Wherever possible it is desirable that liquid calgon be introduced into a bore or well by means of a drop pipe to ensure of its placement at the required position, i.e. generally throughout the full length of the screen with an additional 25-50 gallons above the screen.

When introduced in solid form it is essential that dissolving be assisted by agitation without undue displacement of water within the bore. This can be accomplished by very light surging in the water above the screen. By running a tool to bottom it can be ascertained when dissolving is complete.

Agitation of the liquid Calgon is necessary to force the solution back into the aquifer and to ensure of its acting upon the material to be dissolved and loosened.

Each treatment should be carried out over a period of not less than 24 hours whilst a 48 hour period should be adopted if practicable.

Throughout the period of treatment agitation should be carried out at least once every two to four hours and at 6-8 hourly intervals a quantity of water should be added to the bore to force the calgon further back into the aquifers. The quantity of water added each time should be calculated to cause penetration of the aquifer by about one foot on radius. Regular agitation by surging or backwashing should be carried out immediately following and between additions of water.

Local conditions, circumstances and available equipment may vary both method of application and procedure, but the purpose of this treatment is to get the calgon through the screen and as far out as practicable into the water bearing strata, at the same time allowing it sufficient time to thoroughly act on the materials to be dissolved or dispersed so that they may later be removed from the aquifer and screen in liquid or semi liquid form.

Regular and continued agitation is essential in order to allow the calgon to continue "working" on new material, and at the same time allowing sufficient time to dissolve and disperse the materials in each section as completely as possible.

Upon completion of calgon treatment the bore must be bailed or pumped at a reasonably high rate to remove the calgon and the material "loosened" by it.

Final "cleaning up" is then undertaken by alternate surging and pumping until all loosened material is removed from the bore.

Repeat dosages of calgon are frequently necessary to obtain maximum improvement and cleaning of an aquifer, but whether or not a second treatment is necessary depends upon the results of first treatment.

APPENDIX "D"

PUMP TESTING

No bore or well can be considered as being completed unless and until the very important work of pump testing has been carried out and the results analysed.

Some so called pump tests, especially when of short duration are little more than an indication that the bore or well will produce some water.

Pump tests must be adequate both in form and duration for determination of the hydraulic characteristics of the bore, the rate at which it may be pumped for the purposes intended, and to provide essential information as to the characteristics of the aquifer itself.

A number of mathematical and hydraulic factors are involved in interpretation of results of pump tests. There are several types of tests which may be carried out, each having its limitations and particular application depending upon the scope of information sought and the facilities available.

Many technical papers and bulletins for reference by engineers, hydrogeologists and others relating to pumping test analysis and their interpretation are available possibly one of the most practical being "Selected Methods for Pumping Test Analysis" by Bruin and Hudson issued by the Illinois State Water Supply Division, Urbana, Illinois, U.S.A.

Of the several types of pumping tests which may be used, perhaps two can be considered as more generally adopted and most useful for general purposes.

These are "The single rate" or "Constant Rate" and "The Multiple Stage" or "Step - Drawdown" pumping tests which are shown on Figures 1 and 2 respectively. These figures show analyses of test data obtained from two screened and developed bores in the Lachlan Valley in New South Wales.

The "Single Rate" method is considered to have wider application and to be generally more satisfactory, particularly if observation bores or wells are available, when aquifer conditions in addition to bore characteristics may be interpreted.

The Multiple Stage Test yields analysis data mainly in respect of the bore performance and relatively little of aquifer characteristics unless extended in time at the final stage.

Instances of anomalous behaviour in multiple stage tests of bores in confined aquifers have been referred to by Williamson in a short paper included in Newsletter No.1 of the Underground Water Conference of Australia.

It is important that adequate equipment be available for a satisfactory bore pump test, and the essentials include:-

1. A reliable pump of sufficient capacity and flexibility, yet providing a suitable annulus between the bore casing and the pump column to allow the use of an electric probe for accurate water level measurements during testing.

2. A prime mover of adequate power, preferably a diesel engine with variable speed control, and with direct drive to the pump. Alternatively, belt drive must be adjustable to reduce slip, and consequent pump discharge variations, to a minimum.

3. An accurate means of measuring pumping rate or rates such as a cold water meter, an orifice plate meter, a measuring weir, or a tank of known capacity and a stop watch, in that order of preference.

4. Battery operated electric probes for measuring water levels at regular intervals in the bore being test pumped and in any observation bores which may be available.

5. Tacheometer for checking pump spindle and prime mover pulley speeds.

A preliminary test pumping run is necessary for assessment of the probable potential of the bore so that appropriate placing of the pump inlet and the rate or rates of pumping may be determined prior to commencing the main test.

A test run also provides opportunity for checking and testing equipment for operation and accuracy before the main test is commenced.

If observation bores are used in connection with a pump test it is essential that they freely reflect conditions in the aquifer being utilised.

All measurements of static water level/s, pumping rate/s, draw down levels and recovery levels must be recorded accurately against times, so that results may be interpreted and assessed.

Pump test must be of sufficient duration to reflect hydraulic and mechanical conditions. The minimum for a single rate test should be not less than 8 hours continuously at the predetermined rate which should be towards the maximum rate within the limits of available draw down.

When bores are intended as sources of water supply for municipal or other purposes where long term continuity of supply is required, pumping tests of 24 hours continuous duration should be regarded as a minimum.

Irrespective of the efficiency and adequacy of any pump test its results cannot reflect the long term effect of such factors as a general fall in water table or excess withdrawl of water via other bores or wells in the area.

Observations of water table or piezometric levels over a long period including such dry times as may occur within that period provide the only guide as to what allowances should be made in any new bore as a margin of safety in assessing permanent pumping rate or in other words the "safe yield".

Behaviour of existing wells or bores, and variations in water table conditions often obtainable in respect of older wells or bores are generally the only guide to these factors, and they are not always very reliable. Nevertheless any available information should be considered when assessing probable effects on permanent pumping installation and rates of withdrawal from new bores, and appropriate allowances made, avoiding ultra conservatism and over optimism in final assessment.

Procedure in test pumping for the single rate method is suggested along the following lines:-

From time of commencement of pumping at the pre-determined rate, record draw down measurements at five (5) minute intervals for 30 minutes; then extend reading intervals to 15 minutes for the following 1½ hours. Half hourly readings and recordings are then adopted for the remaining six hours of an eight hour test or ten hours of a twelve hour test.

Similar interval readings and recordings should be adopted for 24 hour tests, but after 12 hours one hourly readings may be more convenient and are satisfactory. Two to four hourly readings can be adopted for tests of duration exceeding 24 hours.

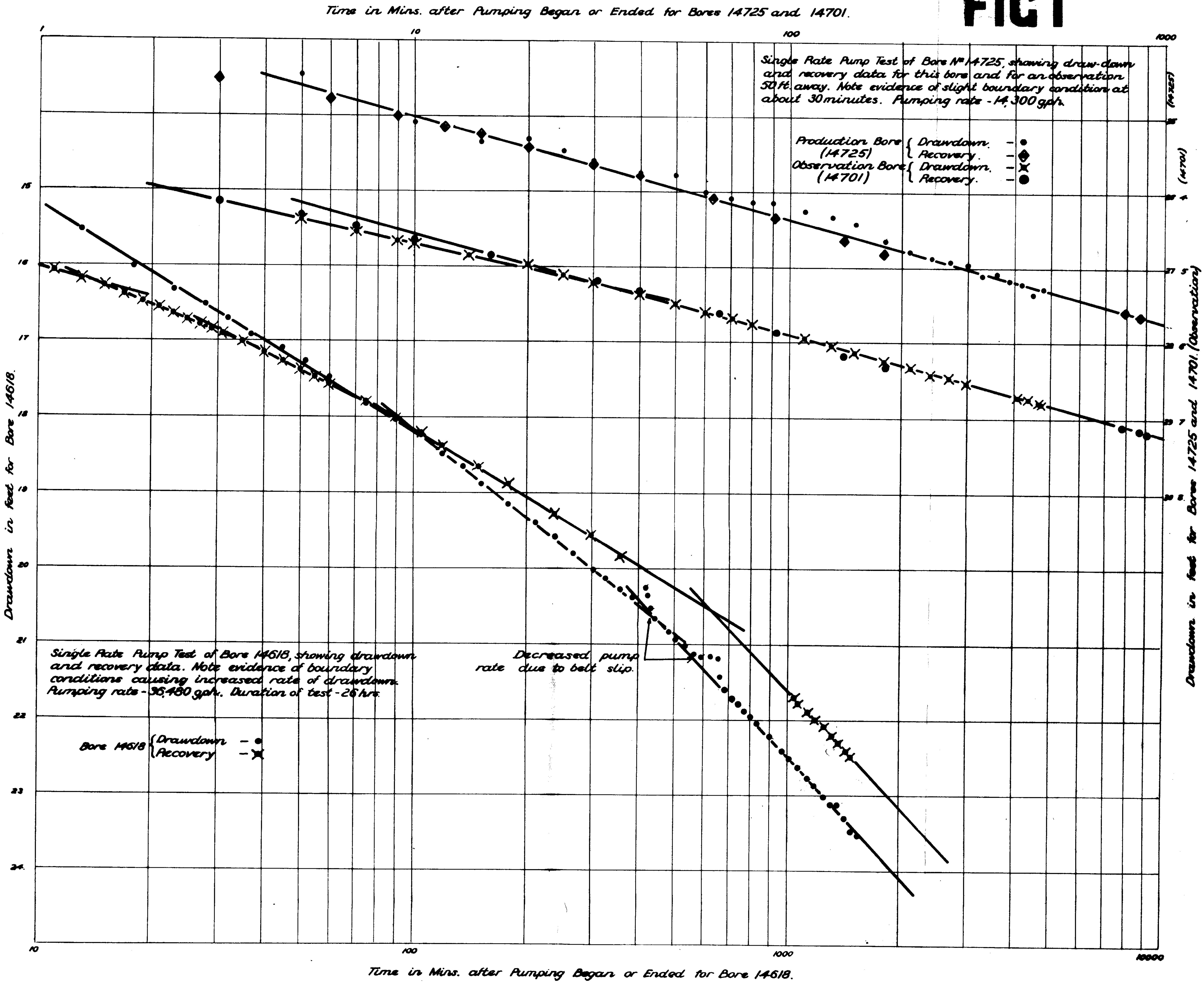
In multiple stage tests each stage must be treated as a new one, i.e. from the commencement of each pumping rate readings should be recorded at five minute intervals for the first thirty minutes, extended to fifteen minute intervals for the following $1\frac{1}{2}$ hours and so on.

Recovery data is of considerable significance and should be recorded after a single rate test has been concluded. Water levels should be taken and recorded at two or three minute intervals after pumping ceases, extending to five minute intervals for the next thirty minutes, half hourly for two hours, then hourly until eight hours have elapsed, or until full recovery.

If full recovery has not taken place within 12 hours a measurement should be taken 36 hours and 48 hours after cessation of pumping, if practicable.

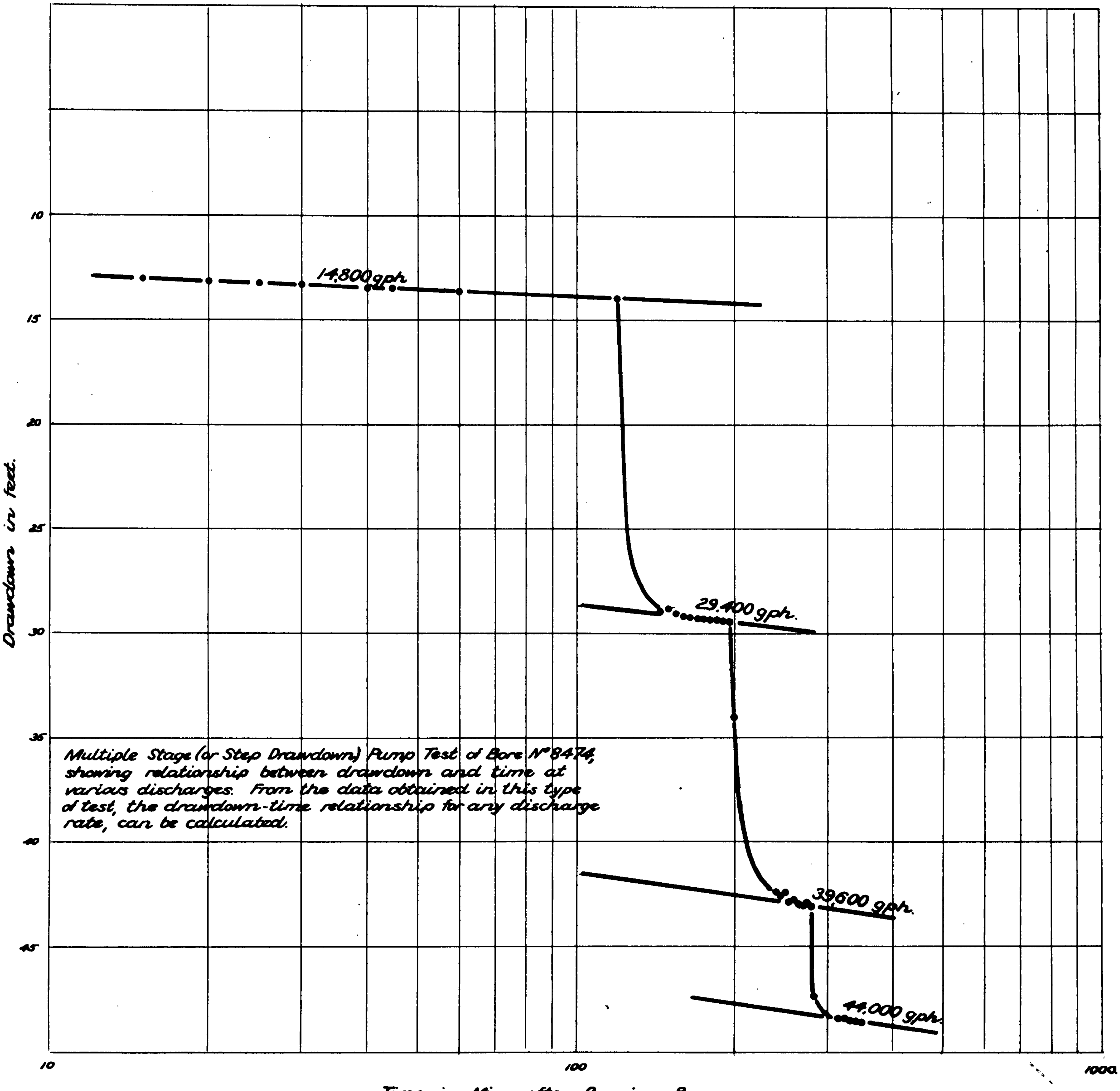
All draw down and recovery measurements should be taken to the nearest hundredth of a foot (or $\frac{1}{8}$th of an inch) if possible.

FIG I



Time in Mins. after Pumping Began or Ended for Bores 14725 and 14701.
1
10
100
1000
Single Rate Pump Test of Bore Nº 14725, showing draw-down and recovery data for this bore and for an observation 50 ft. away. Note evidence of slight boundary condition at about 30 minutes. Pumping rate - 14,300 gph.
Production Bore (14725) { Drawdown. - ● Recovery. - ◆
Observation Bore (14701) { Drawdown. - ✕ Recovery. - ●
15
16
17
18
19
20
21
22
23
24
Drawdown in feet for Bore 14618.
Drawdown in feet for Bores 14725 and 14701. (Observation)
Single Rate Pump Test of Bore 14618, showing drawdown and recovery data. Note evidence of boundary conditions causing increased rate of drawdown. Pumping rate - 36,480 gph. Duration of test - 26 hrs.
Decreased pump rate due to belt slip.
Bore 14618 { Drawdown - ● Recovery - ✕
10
100
1000
10000
Time in Mins. after Pumping Began or Ended for Bore 14618.

FIG 2



14,800 gph
29,400 gph.
39,600 gph.
44,000 gph.
10
15
20
25
30
35
40
45
Drawdown in feet.
10
100
1000
Time in Mins after Pumping Began.
Multiple Stage (or Step Drawdown) Pump Test of Bore N° 8474, showing relationship between drawdown and time at various discharges. From the data obtained in this type of test, the drawdown-time relationship for any discharge rate, can be calculated.

APPENDIX "E"

METHOD OF RECOVERING SCREENS FROM BORES

The occasion arises from time to time when it becomes necessary to withdraw a screen from a bore, and the "sand-pack" method should be adopted in all such cases. The use of fishing tools such as spears or swedges should not be attempted as damage to the screen inevitably results.

The "sand-pack" method will not damage a screen and it is both simple and reliable in operation. It consists of a sand pack between the inside of the screen and a pulling pipe or pulling bar, by which means a strong friction hold is established over the whole inside area of the screen.

Heavy walled water piping or turbing of a diameter which will provide a sufficient space between it and the inside of the screen for a good sand pack is the most suitable for screen pulling.

Short lengths of screen which have not been in a bore for a lengthy period can be pulled by means of a drilling cable with a light bar used as the "pulling tool", but the pulling of a long screen, or one which has been in a bore for a long period, should not be attempted by the above means.

A substantial pull is often required to initially free a screen because of the high friction "grip" usually obtaining on the outside of the screen. Encrustation on an old screen will also add to the "friction grip" on the outside of a screen.

A satisfactory screen pulling tool to permit an effective sand pack grip on a screen can be made in several ways. The three principal ones are:-

(1) Welding an inverted steel cone to the bottom of the pulling pipe.

(2) Welding or screwing of a round steel plate to the bottom of the pulling pipe.

(3) Securing a substantial ring of bagging or heavy hessian around the pulling pipe above a socket screwed to the bottom of the pipe.

When using any one of the above tools, strips of bagging or heavy hessian should be secured by one end to the pipe immediately above the cone, plate, or ring to form a bulky and springy seal for the sand to rest on.

When the bottom end of bagging or hessian strips are secured to the pulling pipe, the loose ends are drawn together evenly upwards around the pipe and temporarily tied with light wire or string, then when the tool is lowered onto the top of the casing, the top tie should be released to allow the strips to spread.

The tool is then lowered to the bottom inside of the screen and fine to medium clean sharp sand should be poured slowly and evenly down the bore hole between the casing and pulling pipe. Pour the sand around the pipe for even distribution. Allow ample time for the sand to sink to bottom and avoid bridging of the sand on the way down by pouring slowly, and shaking the pulling pipe or rope.

Measure the quantity of sand introduced so that it will not fill beyond the top of the screen. The quantity of sand required is the volume of the inside of the screen less the volume of the pulling tool and pulling pipe or bar inside of the screen. Filling above the screen will cause a sand lock to be built up in the casing above the screen rendering pulling much more difficult.

Allow the sand pack time to fully settle in the screen and around the pulling tool, say 10-15 minutes, then, with jacks, take an upward strain on the pulling pipe at the surface.

Allow a light strain to remain for a time before jacking further to permit the sand pack to compact inside the screen to secure a friction grip.

Jack the pulling pipe steadily until the screen is freed and drawn up into the casing, after which it can be pulled with the drilling plant or other tackle.

The sand pack is easily removed from the screen by washing and the pulling tool withdrawn.

The size of pulling pipe or pulling tool in relation to the inside diameter of the screen is not of vital importance, provided there is at least one inch of annular space for the sand pack between the inside of the screen and the outside of the pipe.

APPENDIX "F"

PUMPING FROM SCREENED BORES - SOME OPERATIONAL PROCEDURES WHICH SHOULD BE OBSERVED

A properly constructed screened bore can confidently be regarded as a quite dependable structure, provided it is reasonably treated throughout its effective life.

The capital cost of ascreened bore equipped with a bore hole pump is appreciable, and is a valuable asset on any property. It is therefore well worthwhile for the owner to ensure that it is correctly operated at all times.

Overpumping and incorrect pump operation can be causes of damage to screened bores resulting in disturbances to the aquifers which can cause reduction in supplies.

From a correctly carried out staged draw down pumping test it is practicable to estimate the maximum safe rate at which the bore may be pumped when permanently equipped for the purposes intended.

Not under any circumstances should an owner attempt to pump at a rate in excess of the maximum rate advised by a competent authority as a result of a properly conducted test.

When a bore supply is used for spray irrigation, it is essential that the pump and irrigation equipment be designed specifically to suit the individual bore output rate through the required number of spray heads at the designed pressure at the spray heads.

Using excess pressure at the spray heads involves a corresponding increase in discharge rate per spray head so that the overall pumping rate will be increased above the designed rate.

Conversely a lower than designed pressure at the spray heads will result in inefficiency, a poor spray pattern and distribution, whilst the maximum benefit is not being obtained from the bore.

The small cost of two pressure gauges, one at each end of a spray line is a well worthwhile investment. Alternatively one gauge may be fitted to the discharge pipe at the pump and the other on the spray line.

The only times that any sudden pressure changes occur within a bore are when starting up or stopping the pump.

Sudden and violent pressure variations, the release of large quantities of water down the pump column, or overpumping, are the only possible causes of turbulence and upset of stability in a properly constructed screened bore.

All three can quite easily be avoided and it is essential that permanent equipment installed be designed to guard against these. The rest is up to the operator, and he should see that the correct simple "drill" is gone through each time the pump is started and stopped.

Every bore hole pump should have a gate valve and a reflux (non-return) valve fitted on the delivery side, between the discharge outlet and the rising main. See that both valves are included in the equipment to be supplied and installed.

An even better arrangement is to have a non-return valve fitted to the pump inlet if such is practicable with the type and make of pump installed.

Before starting up the pump, <u>close</u> the gate valve well down - at least half to three quarters closed. No damage is likely if the valve is fully cosed, but it is not necessary that it be fully closed. Some types of bore hole pumps build up a higher than normal head under full close down of discharge outlet.

The purpose of closing down the valve is to ensure that the pumping rate does not exceed the capacity of the bore whilst the rising main and spray lines are being filled, before full operational pressure is reached and the spray heads are working.

When the pump is operating at normal speed slowly open up the gate valve, but do not fully open the valve until it can be seen that the rising main and spray lines are full and water is issuing from the spray heads.

Before stopping the pump partially close down the gate valve, shut off the motor or engine then quickly close the gate valve. When a reflux (non return) valve is fitted to the rising main, it is not essential that the gate valve be closed before stopping the pump.

Observance of the above simple rules can go a long way towards obtaining the best from a bore and retain its maximum efficiency. They are so important that they bear repeating:-

1. Ensure that the bore is not pumped beyond its rated capacity.

2. Always fit both a gate valve and a non-return valve on the delivery line of a bore hole pump installation. Alternatively fit the non-return valve to the pump inlet.

3. Start up the pump against a half to three quarter closed down gate valve on the delivery line and slowly open the valve until the lines are nearly full, and only then fully open the valve.

4. Before stopping the pump close the gate valve and leave it closed until starting up again next time.

When an automatic time switch is fitted to stop an unattended pump at a pre-determined time, it is essential that a non-return valve be fitted. Also in the event of a power failure it will prevent the inflow of water from the mains to the bore.

It is well worthwhile to have an air-line and pressure gauge fitted to a bore hole pump so that static water level and draw-down levels may be checked from time to time.

Record these measurements at regular intervals for future reference and guidance.

A flow measuring device is also a useful piece of equipment for installation with a bore hole pump. A check can then be made from time to time of pumping rates.

Vacuum sealing, or "pumping on a vacuum" is a practice sometimes resorted to for the purpose of increasing the yield or a bore.

Unless there are good reasons for so doing, permanent vacuum sealing cannot always be recommended, as it can be detrimental to the life of a pump.

It is always wise to consult the manufacturer of any make of pump before installing a vacuum seal.

Generally it may be accepted that pumps designed for high head operation are more susceptible to "cavitation" and corrosion troubles when operated under vacuum than are pumps designed for low or medium head operation.

When water tables become lowered, perhaps as a result of long dry spells and prolonged pumping, or both, the available supply from a bore may be correspondingly reduced. Increased yield by reason of a vacuum seal can then be most useful for the purpose of maintaining efficient operation of a spray irrigation system during such times.

Be assured that the pump obtained is one best suited to the duty required. A wide range of pumps is available to suit almost any capacity-head conditions likely to be required and each user should ensure that he obtains a unit which will pump the required quantity of water against the desired head efficiently and economically. In short, ensure that both pump and associated equipment, including spray irrigation plant are designed to suit individual requirements.

If the bore hole pump is one on which impeller adjustment is required, ensure that this adjustment is correct and accurate according to the manufacturers recommendations. If in doubt ask the manufacturer or his accredited representative to advise on or carry out the adjustment. The efficiency of this type of pump is largely governed by correct impeller adjustment, and bad adjustment can cause serious damage to both impellers and seats.

Where pumping from depth is necessary, thereby involving the use of long shafting, a certain amount of "shaft stretch" is possible if a head overload is imposed. In such cases it is advisable not to start up the pump with the gate valve so closed down as to impose a higher than normal operational head.

It is generally a wise precaution and well worth the small extra cost to have a bore hole pump installed by the manufacturer or his accredited agent. Furthermore, should difficulties arise the manufacturer is more likely to stand by any guarantee if his own representatives carry out the installation.

When in difficulties or in doubt about pump operation or maintenance consult the manufacturer or his accredited representative.

GROUNDWATER LEGISLATION

by

E. R. SMITH.
Water Conservation & Irrigation Commission, N.S.W.

In the majority of the more developed countries of the world and in most States of Australia, "The right to the use and flow and to the control of the waters in all rivers, lakes which may flow through, or past or are situate within or are adjoining the land of two or more occupiers, and of the water contained in or conserved by any works, is vested in an appropriate authority. This is essential for its more equal distribution, conservation and protection from pollution etc. and for preventing misuse, wastage or obstruction, for the public benefit".

This is an accepted fact, and laws have prevailed to ensure appropriate protection, development and distribution of surface waters for very many years.

Groundwater is no less valuable and essential than surface waters to the development of all States in Australia - in fact in some States groundwaters are the principal water resources, and are threfore more valuable than the very meagre surface supplies.

Only in two States, New South Wales and Queensland has Groundwater Legislation been enacted and the appropriate Authorities thus given the power to conserve, control and prevent exploitation, excess wastage and spoiling of groundwater supplies.

Even in those two States Legislative Powers need to be extended and Acts amended for better state wide control and protection of groundwaters and their development in the future, if the best use for the greatest number is to be ensured, as water use requirements increase and populations grow.

Only in Queensland does existing legislation vest in the Crown the right to the use and flow and to the control of groundwater, as is the case with surface waters in other States.

New South Wales was the first State to bring down legislation relating to groundwater by virtue of the Water Act of 1912. Numerous Amendments have since been made, but as yet the full right to the use and flow and to the control of all groundwaters has not been vested in the Water Conservation and Irrigation Commission for the benefit of the Crown.

Amending legislation to this end has been drafted but has not as yet become law.

The New South Wales Water Act 1912-1955 gives the Water Conservation and Irrigation Commission quite wide powers relating to the control and development of groundwater, and these powers are adequate for all practical purposes as related to Artesian waters.

All bores in the State of New South Wales are required to be licensed by the Commission and all landholders are required to apply for and be granted a license before constructing a bore, well or excavation for the purposes of utilising groundwater for any purpose whatsoever.

Such conditions as may be deemed appropriate and fit may be included in any License issued, both as regards construction requirements and the use of water.

Landholders to whom bore licenses are issued are required to furnish bore logs and other data relating to each bore constructed, including pump test results, water samples for analysis etc.

No Driller may operate in New South Wales unless he has applied for and has been issued with a Driller's License. Insufficiently experienced operators may be refused a license - and penalties are provided for in the case of failure to comply with license conditions, incompetence or the like. For good and sufficient reasons a Driller's License may be cancelled, in which case he cannot operate as a driller within the State.

For other than artesian bores no charge is made for licenses issued and no charge is currently made for a Driller's License. A fee of £5. 0.0 is charged for an Artesian License - under the Act.

Generally similar Legislation applies in Queensland with some variations. The Queensland Act has been operative for some 50 years.

In my paper dealing with "Artesian Bore Construction and Specifications" some background was given relating to the quite shocking exploitation and waste which occurred in the early days of development within the Great Artesian Basin, and the quite early evidence of a high rate of pressure loss and flow diminution as a result of uncontrolled and unenlightened exploitation of these most valuable resources.

The facts did not go unnoticed by the few engineers and geologists associated with this work at that time, but their pleas fell on deaf ears mainly because of the political and economic powers of the squatters and graziers of the time.

Nevertheless the engineers and geologists of State Departments were taken notice of to the extent that the First Interstate Artesian Conference was held in 1912, the same year in which the Water Act was brought in, in New South Wales, and a series of Interstate Conferences ensued up until 1928.

Voluminous and very useful reports were issued following each of those conferences and much work was carried out in the intervening years.

Some of the theories, proposals and recommendations made by the conferences may be seen today as being somewhat "off the beam" but the work accomplished both in the field under most arduous conditions and in the respective State offices was quite monumental.

Unfortunately only New South Wales and Queensland politicians saw fit to bring down legislation to assist their officers in the work so important at the time, and for lack of which later generation have and will continue to pay the penalty for irretrievable losses.

We do not have to reflect only upon what has happened here to realize the importance of each State having appropriate legislative control to deal with groundwater - and the valuable data which has been lost because of the lack of groundwater legislation.

Most countries of the world where groundwater is an important national asset, have exploited those assets, some of them to ultimate destruction, others have brought in controls too late to achieve anything better than saving the residual.

The United States of America provides many classic examples of what can happen to groundwater resources if uncontrolled exploitation is permitted. The San Joaquin Valley in Southern California is a well known and documented example.

Fourthly - Any Act should include appropriate provisions for the prevention of waste or improper use of groundwater, and to enable the appropriate Authority to direct such work to be done as would control flows, effect repairs or carry out any other work as may be considered necessary in the interests of preventing wastage or improper use of water.

Provision should be made for enforcement of owners to construct and maintain in good order and condition all distributory systems, including channels and bore drains by which groundwater is distributed or reticulated.

Provision should also be made that water flowing or pumped from any bore shall not be used for purposes other than those authorised in terms of the license.

Fifthly - Legislation should provide for the Authority responsible to be empowered to from time to time as adequate factual data becomes available designate any area or underground water basin and subdivision thereof and declare them "Restricted Groundwater Areas" as future conditions may require and factual data justify, may alter the boundaries thereof.

Within the designated boundaries of any declared Restricted Underground Water Area the Authority may require the licensee of any bore to restrict the rate of flow or pumping therefrom, the quantity of water which may be allowed to flow or be pumped therefrom in any determined and stated period of time and it may direct any such other precautions as may be deemed necessary to control the rate, manner of extraction, the quantity of water withdrawn, its usage, improper usage, wasteful usage and waste from any bore or source of underground water supply.

The Authority may specify minimum distances at which any bore may be constructed from any other bore or bores, and where considered necessary, specify minimum standards of bore construction including bore hole and casing diameters, casing materials, screen diameters and materials of screen construction, bore hole to casing, or intercasing pressure cementing, or clay plugging.

It may also direct such other measures and/or precautions as may be considered necessary to be taken for the protection of the quality and the prevention of pollution or contamination of underground waters wherever pollution or contamination is or may be caused by improperly constructed, abandoned or defective bores, through the interconnection of strata or the introduction of unsuitable surface waters into underground waters.

Within the boundaries of any declared Restricted Underground Water Area the Licensee of any bore shall, if required by the Authority furnish monthly, quarterly or half-yearly as the case may be, or at such other intervals as may be required, a report of static water level in the bore from a predetermined point of measurement at or about the surface level at the bore site and/or a report of the quantities of water pumped from the bore, such report to be furnished on forms provided by the Authority.

If so directed by the Authority the Licensee of any bore within a defined Restricted Underground Water Area from which water is used for any industrial or manufacturing purpose whatsoever, or for irrigation shall provide, fit and maintain an acceptable metering or measuring device which will adequately and continuously record the quantity of water pumped from the bore.

Upon completion of a new bore within a defined Restricted Underground Water Area from which the water is to be utilised for any other than stock, domestic or home garden purposes, the licensee shall within 90 days of completion of equipping the bore furnish to the Authority detailed particulars of equipment installed including the capacity of the pump.

For the protection of the quality, the prevention or abatement of pollution or contamination of underground waters wherever such pollution or contamination is or may be caused by the disposal of drainage or stormwater runoff, factory or trade or other waste materials in either liquid or solid forms within aquifers or on or within areas connected with or associated with underground waters or aquifers, the Authority may invoke the assistance of the appropriate State Water Pollution Control Authority to remove the causes of and prevent recurrence of whatsoever may be the causes of pollution and/or contamination of underground waters.

To augment the storing of water underground including the diversion of streams, drainage systems and catchment run-offs and the flowing of water on lands necessary to the accomplishment of underground water replenishment or storage the Authority may designate any area a Groundwater Recharge Area and make such diversions of stream water drainage and catchment run-off waters as may be deemed necessary and practicable for the purposes of replenishment of underground water supplies.

THE RELATIONSHIP BETWEEN GEOLOGY AND GROUNDWATER QUALITY

by

W. H. Williamson

Water Conservation & Irrigation Commission, N.S.W.

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THE RELATIONSHIP BETWEEN GEOLOGY AND GROUNDWATER QUALITY

1. Introduction

The quality of groundwater may be governed by many factors. Usually, but by no means always, the nature and composition of the host rocks play a major part in determining the chemical characteristics of the water, and it is this aspect that will be examined here. However, it should be realized that, quite commonly, the dominant factors causing a given water quality have been impressed on the water before it enters the groundwater storage. Neglecting connate water for the moment, it is evident that the quality of water being added to groundwater storage will be affected to varying degrees by the chemical composition of the rainfall; climate, particularly amount, intensity and frequency of rainfall; evapotranspiration; soil type and thickness; vegetation; topography; intake condition; and finally, the conditions encountered in the soil and rocks en route to the storage zone.

In considering the effect of the host rocks, it is obvious that the extent to which the water can become mineralized is largely a function of the nature of the minerals in the rock, the opportunity the water has to come into contact with them, and the duration of such contact. However, it does not follow that the constituents going into solution will be in the same proportions as those in the rocks. In fact, the constituents that most affect water quality are often present only in small proportions in the rock, and vice versa.

With the above points in mind, consideration can now be given to the effect of the various types of host rocks.

2. Igneous Rocks

Igneous rocks are, for the most part, practically impermeable so that appreciable water circulation in them is virtually confined to their joint or fracture systems. Consequently, water contact with minerals is somewhat restricted, particularly for the instrusive rocks. In the extrusive rocks there is rather more contact opportunity because they tend to be more closely jointed (e.g. columnar jointing in basalts), and there may also be vesicular phases and permeable interflow zones.

The chemical classification of igneous rocks is based on the silica content. (Silicon is the dominant element in the major proportion of rocks. In order of abundance in the earth's crust it is exceeded only by oxygen). The igneous rocks very rich in silica (65-80%) are termed acid, those relatively poor in silica (45-55%), basic, and if less than 45%, ultra-basic. At the acid end of the scale, (note that the term "acid" used here refers to the silicic acid radicle, and does not indicate acidity in the sense of having a low pH) and considering only the plutonic rocks, e.g. granite, the essential minerals consist of free quartz, potash felspar dominant over sodic felspar, and a small percentage of ferro-magnesian minerals. Proceeding towards the basic end of the scale there is a gradual transition - free quartz disappears and then potash felspar, while ferromagnesian minerals increase and eventually dominate the felspar which has become a calcic-sodic type. In the ultra-basic rocks even the felspar may disappear.

Looking at this array, one might expect that a characteristic feature of water in contact with the acid rocks would be that they would contain far more silica than those in contact with basic rocks. Also, if ever water was going to contain more potassium than sodium, it should be in the acid rocks. Actually neither is the case.

While there is a tendency for higher silica content in waters in acid rocks it is by no means invariable, e.g. analysis No.5, of a (basic) basalt water, shows a much greater proportion of silica than analysis No. 8, a granite water. So far as free quartz (which is silica) is concerned, it can be virtually ignored as a source of silica in water because it is an extremely stable mineral. In point of fact, the silica content is derived from the decomposition of the felspars, and, to a lesser extent, the ferromagnesian minerals. However, basic rocks are rich in the latter, which decompose more readily than felspars.

With regard to the potassium content, it is almost invariably found that potassium is quite subordinate to sodium in groundwater, in spite of the fact that the host rock may be far richer. This is mainly because potassium is more prone to enter into the formation of secondary insoluble minerals, particularly of the illite group of clay minerals, and thus be removed from solution.

In the basic rocks, because the felspar is essentially a calcic type, and because of the high proportion of ferromagnesian minerals, it is usually found that the waters are characteristically hard, as shown by the relatively high calcium and magnesium content of the basalt water in Analysis 5. Analysis 2 is also relevant here.

The chlorides which are often prominent in igneous rock waters are generally present in too high a proportion to be accounted for by the chloride content of the host rock. The sources of chloride in granite, for instance, are from apatite (which is only an accessory mineral) and to a lesser extent, possibly biotite and hornblende. It is known, too, that it occurs in brine in tiny pore inclusions in some of the minerals, especially quartz. However, in spite of its high solubility, there is insufficient to account for the chloride content of the waters, it must usually be attributed to the external source, e.g. concentration of chloride in rainfall by evapotranspiration.

Some of the simpler chemical equations relevant to the above are as follows:-

$$2K\ Al\ Si_3O_8 + 2H_2O + CO_2 \longrightarrow Al_2\ Si_2O_5\ (OH)_4 + 4SiO_2 + K_2CO_3$$

(Orthoclase) (Kaolin)

$$Ca\ Al_2\ Si_2O_8 + 2H_2O + CO_2 \longrightarrow Al_2\ Si_2O_5\ (OH)_4 + CaCO_3$$

(Anorthite) (Kaolin)

$$CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca\ (HCO_3)_2$$

$$5\ Mg_2\ SiO_4 + 4H_2O + 4CO_2 \longrightarrow 2\ H_4\ Mg_3\ Si_2O_9 + 4\ MgCO_3 + SiO_2$$

(Forsterite) (Serpentine)

$$MgCO_3 + H_2O + CO_2 \rightleftharpoons Mg\ (HCO_3)_2$$

It will be noted that carbon dioxide plays an essential role in these reactions. It is an extremely important weathering agent and usually enters the system in solution in the infiltrating water, being mostly derived either from the atmosphere or from decaying organic matter.

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$$CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca\,(HCO_3)_2$$

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(Forsterite) (Serpentine)

$$MgCO_3 + H_2O + CO_2 \rightleftharpoons Mg\,(HCO_3)_2$$

It will be noted that carbon dioxide plays an essential role in these reactions. It is an extremely important weathering agent and usually enters the system in solution in the infiltrating water, being mostly derived either from the atmosphere or from decaying organic matter.

The final quality of water in igneous rocks then is due to the combination of the initial quality entering the system, reactions of the above nature, and the degree and duration of contact of the water with the rock minerals. The latter factors are governed by the extent of weathering of the rock and the hydraulic gradient. As a generalized statement, it may be said that the more weathered the rock and the lower the hydraulic gradient, the more saline the water is likely to become.

3. Sedimentary Rocks

The usual initial geological classification of sedimentary rocks is based on modes of origin, giving the broad classification of mechanically, chemically and organically formed sedimentary rocks. However, Hem (1959) considers that the classifications proposed by Goldschmidt are better suited to studies where chemical composition is involved, and it is well worth while considering them here, even though they are subject to limitations.

The divisions of Goldschmidt's classification that are of consequence here are as adopted by Rankama & Sahama (1950). They are (a) resistates, (b) hydrolyzates, (c) precipitates and (d) evaporates These may be defined as follows:-

(a) Resistate: A rock composed of residues not chemically decomposed in the weathering of the parent rocks.

(b) Hydrolyzate: A rock composed of insoluble products formed by chemical reactions in the weathering of the parent rocks.

(c) Precipitate: A rock formed by chemical precipitation of mineral matter from aqueous solution.

(d) Evaporate: A rock formed by deposition of solutes upon evaporation of the water in which they were dissolved.

It is apparent that there will be overlaps and deficiencies in these subdivisions, but nevertheless they provide a useful approach for present purposes.

3.1 Resistates

The ideal resistate is composed of grains of minerals which are practically insoluble, e.g. quartz, zircon etc. However, depending on the conditions causing weathering of the parent rocks, and of transportation of the sediments, resistates can also have varying amounts of minerals which are subject to further decomposition, e.g. felspars and ferromagnesian minerals. Even pebbles or grains of the parent rocks can be present.

An example of the effect of varied composition in unconsolidated resistates is given by the alluvial formations in the Lachlan River valley, N.S.W. Here, the Lachlan Formation (of late Pliocene age) occupies the deepest section of the valley, and contains aquifers consisting almost entirely of quartz sands and gravels. On the other hand, the gravels of the aquifers in the overlying Cowra Formation (probably Pleistocene age) contain representatives of the various resistant rock types in the present catchment, and these rocks are subject to further decomposition. The nett effect is that with distance downstream the quality of water in the Cowra Formation gradually deteriorates, but the water in the quartz gravels of the underlying Lachlan Formation still retains its good quality even when transmitted some 200 miles downstream into low rainfall areas. (Williamson, 1964).

Shales and allied rocks may be very porous, but have extremely low permability, so much so that they are generally termed aquicludes. Consequently, they may still retain what is essentially connate salt, and yield highly saline groundwater, even though in associated more permeable beds such as sandstones (resistates) or limestones (precipitates) any connate salt has been long since flushed out.

Analysis 11 is of a water from hydrolyzate rocks, the Wianamatta shales in the Sydney district, N.S.W. where in spite of a 30-45 inch rainfall, these shales still yield saline water. The very low sulphate content in such a saline water may be due to sulphate reduction which will be considered later.

3.3. Precipitates and evaporates

These rocks correspond to the more generally used classification of "chemically formed" sedimentary rocks. Because of the processes involved in the formation of such rocks they tend to be relatively pure chemical compounds, or associations of compounds. Consequently, groundwaters in contact with such rocks can be expected to be characterised by the nature of the compounds forming the rock.

In the precipitates, limestone and dolomite are the most common rocks. Analysis No. 10 is characteristic of a water influenced only by limestone, and it will be seen that it contains little else other than calcium bicarbonate.

In the case of evaporates such as salt beds and gypseous deposits, the groundwater simply becomes a solution of the salts present, the proportion of salts in solution being governed by the relative solubilities of the salts in the evaporate.

4. Metamorphic rocks

Since any kind of rock may be subjected to metamorphism it is apparent that extreme variations could occur in the groundwater characteristics of the metamorphic rocks. For example, depending on the intensity of metamorphism, a shale, initially a hydrolyzate sediment, could be converted to a slate, phyllite, schist, gneiss, or a rock indistinguishable from an acid igneous rock. Consequently, little general guidance can be given as to the characteristics of water in metamorphic rocks, except that each case must be considered on the basis of the mineralogy of the particular rock type and any evidence as to opportunity and duration of groundwater contact. Some metamorphic rocks will normally allow predictable qualities, e.g. quartzites usually yield good quality water because they consist essentially of the stable mineral quartz. Marbles, of course, should give similar qualities to limestones. Hard slates are usually more favourable than weathered slates so far as water quality is concerned, because they restrict the water contact to joint planes. However, it should be kept in mind that the provisions given in section1, i.e. that the quality characteristics may be impressed on the water before it reaches groundwater storage, still apply. This is evident in Analysis No. 9, of groundwater in hard slates, but in a low rainfall area, with the consequence that the water is of stock quality only.

5. Modifying factors

The explanation of a water quality will often not be immediately evident because the quality may have been modified by one or more factors.

5.1. Precipitation

In some cases, precipitation processes may cause variations in quality, although they may not necessarily markedly change the characteristics of the water. Examples are the precipitation of calcium carbonate due to pressure reduction causing loss of CO_2; deposition of silica from waters that have been hot but reach a position where they are able to cool; and precipitation of ferric hydroxide when waters containing ferrous salts are oxidized.

5.2. Ion exchange

The replacement of adsorbed ions in aquifer material by ions in solution is often a very important factor in modifying water quality. The ion exchange process of greatest significance involves cations, and is usually referred to as "base exchange". This is a much studied phenomenon in soil science, where it is known that waters having a high sodium content, relative to calcium and magnesium, will replace adsorbed calcium and magnesium ions in the clay minerals (particularly the montmorillonite group) by sodium, and adversely affect soil structure. The action is a reversible one, and the principle is used in water-softening units, where the exchange medium is regenerated by circulating sodium chloride solution (brine) through it. In rocks, normally calcium and magnesium ions from solution replace adsorbed sodium on the exchange material, and it is this process which is considered to account for sodium bicarbonate waters such as are often found in sandstones of large sedimentary basins. This is well illustrated by Analysis No. 6.

It may be mentioned that the likelihood of ion exchange phenomena must be taken into account in any project involving artificial recharge of groundwater.

5.3. Sulphate reduction

In some waters which could reasonably be expected to have a relatively high sulphate content, analysis shows only a low sulphate content. This is commonly due to the process of sulphate reduction which is due to the action of certain types of bacteria in the presence of oxidizable organic material. The reaction is usually postulated as -

$$SO_4^{--} + CH_4 \xrightarrow{(bacteria)} HS^- + H_2O + HCO_3^-$$

It will be seen that bicarbonates and sulphides are produced at the expense of sulphates. Consequently, where this process has been in effect, the water will be low in sulphate (or lower than expected), high in bicarbonate, and will often contain H_2S. However, the latter does not always apply, since the gas may have been able to escape from the system or react with metals to form metallic sulphides, e.g. iron sulphides are common in rocks which show evidence of being deposited in swampy conditions.

Sulphate reduction has probably played a part in determining the quality of the water in Analysis No. 11.

5.4. Salt-water intrusion

Salt-water intrusion, or its possibility, is often a critical problem. If it does occur, or has occurred, it is usually found that the resultant water quality is not simply a mixture of the original formation water and the saline water, and this is due to various modifications that can come into effect. Examples of these are (a) base exchange reactions may occur, leading to loss of sodium and increase in calcium and magnesium content of the saline water, (b) sulphate reduction may occur, leading to lowered sulphate content and raised bicarbonate content, and (c) solution or precipitation may occur. Thus, if the saline water comes into contact with sulphates, e.g. gypsum, it will increase in sulphate content. And if more calcium enters the system in this way it can cause precipitation of calcium carbonate, since sea water is generally saturated with calcium carbonate.

Revelle (1941) points out that the chloride ion is the only major ion that will not be affected by the above processes, and suggests that the Cl/HCO_3 ratio could be used as a criteria to indicate whether intrusion of sea-water has occurred. His basis for this is that the ratio of Cl/HCO_3 in sea-water is about 190:1, whereas bicarbonate (HCO_3) is a common constituent of normal groundwaters. However, a difficulty that may occur is that if sulphate reduction has been effective it will have also increased the bicarbonate content.

5.5. Biogenic processes

Sulphate reduction is an example of the action of bacteria, but numerous other effects can be caused by the life processes of plants and animals. Much remains to be established in this subject, but one that has been given attention of late is the reason for the presence of nitrates in some groundwater where organic pollution or fertilizers could not have been the cause. Plant and animal life acting as links in the nitrogen cycle are generally considered to be the cause of such nitrates.

Even man, not so much by biogenic processes but by his activities, has often caused marked changes in groundwater quality. Examples are (a) saline intrusion caused by over-development of groundwater resources, (b) return drainage from irrigation projects (this drainage is not only more saline than the applied water, it may also carry material from fertilizers), and (c) pollution by organic and inorganic wastes.

BIBLIOGRAPHY

HEM, J.D. 1959 — "Study and interpretation of the chemical characteristics of natural water". U.S.G.S. Water Supply Paper 1473.

RANKAMA K., & SAKAMA T. — 1950 "Geochemistry" Chicago University Press, Chicago.

REVELLE R., 1941 — "Criteria for recognition of sea-water in groundwater". Trans. Am. Geophys. Union, Pt. 3, 22nd Ann. meeting, pp. 593-597.

WILLIAMSON, W.H., 1964 — "The development of groundwater resources of alluvial formations".

Paper B11 in "Water Resources Use and Management" University Press, Melbourne.

APPENDIX 1: Examples of Groundwater Analyses

Number	Depth in feet	CO_3	HCO_3	Cl	SO_4	SiO_2	Ca	Mg	K	Na	Total ions	pH	Conductivity E.C. at 25°C	Remarks
		Expressed in parts per million												
1	32	-	537	2725	1189	23	876	596	n.D	388	6334	7.48	9540	Well in Hunter Valley alluvium, draining Permian Coal Measures and Marine Series.
2	36	-	598	590	37	N.D	79	105	N.D	333	1742	7.40	2740	Well in Hunter Valley alluvium, draining basalts.
3	27	-	580	1410	182	5	278	212	N.D	495	3162	7.26	5305	Well in Hunter Valley alluvium, draining Carboniferous Kuttung Series.
4	120	-	164	26	12	N.D	20	18	N.D	27	267	6.80		Bore in quartz gravel, Macquarie River alluvium, Dubbo, N.S.W.
5	?	-	430	40	3	29	42	32	1.6	75	655	7.65	742	Bore in basalt, near Gurley, N.S.W.
6	2000+	39	595	66	Trace	11.4	0.8	0.5	1.6	290	1006	8.50	1181	Glenroy Artesian Bore, N.S.W.
7	768	-	50	94	11	N.D	9	12	N.D	52	228	5.3	-	Bore in Hawkesbury Sandstone, Mulgoa, N.S.W.
8	?	-	640	575	10	30	189	160	4	84	1662	7.17	2747	Bore in granite, Marulan, N.S.W.
9	350	-	122	1043	800	-	64	239	N.D	583	2858	6.0	4514	Bore in Ordovician slates, Tallenbung, N.S.W.
10	-	-	146	3.5	4	8.4	46	4.2	0.8	1.5	214	7.0	250	Spring in limestone, Alabama, U.S.A.
11	140	-	851	6802	9	N.D	469	340	N.D	3542	12013	6.9	-	Bore in Wianamatta Shale, Sydney. Basin.

CHEMISTRY OF GROUND WATER - RELATION TO USE FOR IRRIGATION

By M.G. Chatfield* A.S.T.C.

It would be difficult to conceive that any water available for irrigation would be entirely free from dissolved substances, more particularly water which has had free contact with the earth crust either by surface contact or deep penetration. Therefore all irrigation waters may be said to contain dissolved solids, the principal constituents usually being calcium, magnesium sodium, bicarbonate, chloride and sulphate, with traces of many other elements. Waters vary widely both as to total dissolved solids and as to the ratios of various constituents. Scientific research into the effect of soluble salts on production yeilds of various species of plant life has suggested an arbitrary classification of crops into three main groups; those of High tolerance of Medium tolerance and those of Low tolerance.

The following is a much publicised classification of the relative tolerance of some crops to salt which is in the main based on the findings of the United States of America Department of Agriculture. The classification and order of tolerance are for American species. Generally Australian species of the same botanical genera may be taken to fall within the same salinity groups but not necessarily in the same order of tolerance within the groups. Crops within each group are given in descending order of tolerance, the higher tolerance being given first in each group:-

RELATIVE TOLERANCE OF CROPS TO "SALT".

In the following lists, crops are listed in descending order of tolerance unless otherwise stated. "Salt" is a term used to cover all combinations of salts normally present in solution in soil water available to the plant.

(1) Fruit Crops:

High Salt tolerance: ECe x 10^3 range Water max. $/10^5$	Date Palm
Medium tolerance: ECe x 10^3 range Water max. $/10^5$	Pomegranate, Fig, Olive, Grape, Cantaloup, Mulberry.
Low tolerance: ECe x 10^3 range Water Max. $60/10^5$	Pear, apple, orange, grape-fruit, prune, plum, almond, apricot, peach, strawberry, lemon.

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Fruit Crops (continued)

Very low Tolerance:(not in order of relative tolerance).

ECe x 10^3range Water max. $40/10^5$	Papava, Avocado, Loquat, Persimmon, Blackberry, Gooseberry, Strawberry.

(2) Vegetable Crops:

High tolerance: ECe x 10^3range $12_5$10 millimbhos Water Max. $185/10^5$	Garden beets, Kale, Asparagus, Spinach.
Medium tolerance: ECe x 10^3 10-4 millimhos Water max. $165/10^5$	Tomato, Broccoli, Cabbage, Bell pepper, Cauliflower, Lettuce, Sweet Corn, (White Rose Variety), Carrot, Onion, Peas, Squash, Cucumber.
Low tolerance: ECe x 10^3 range 4-3 millimhos. Water max. $60/10^5$	Radish, Celery, Green beans.

(3) Forage Crops:

High tolerance: ECe x 10^3 range 18-12 millimhos Water max 250/105	Alkali sacation, Salt grass, Nuttall Alkali-grass, Bermuda grass or Couch, Rhodes grass, Rescue grass, Canada wildrye, Western Wheatgrass, Barley (hay species), Birdsfoot trefoil.
Medium tolerance: ECe x 10^3range 12-4 millimhos. Water max. $185/10^5$.	White sweetclover (Melilotus alba), Yellow sweetclover (Melilotus officinalis), Perennial ryegrass, Mountain brome, Strawberry clover (Tribolium fragiferum), Dallis grass (Paspalum dilatatum), Sudan grass (Sorghum sudanese), Hubam clover (Meliolotus alba), Lucerne (Medicago sativa), Tall fescue, Rye (hay variety), Wheat (hay) Oats (hay), Orchard grass or Cocksfoot (Dactylis glomerata), Blue grama, Meadow fescue (Festuca elatior), Big Trefoil, Smooth brome, Reed Canary gras (Phalaris arundinacea), Tall Meadow Oat grass, Cicer milkvetch, Sour clover, Sickle milkvetch (Astragalus falcabus).
Low tolerance: ECe x 10^3range $4\text{-}2_5$ Water max. $60/10^5$	White Dutch clover (Trifolium repens), Meadow foxtail, Alsike clover (Trifolium hybridum), Ladino clover (Trifolium repens Variety latum), Red Clover (Trifolium pratense), Burnet.

Supplementary List (not in order of relative tolerance)

Forage Crops (continued)	
High tolerance:	Sea barley grass (Hordeum maritmum), Barley grass (Hordeum murinum), Wimmera Ryegrass (Lolium rigidum). Kikuyu grass.
Medium tolerance:	Phalaris tuberosa.
Low tolerance:	Subterranean Clover(Trifolium subterraneum).

(4) Field Crops:

High Salt tolerance: ECe x 10^3 range 16-10 Water max. 250/10^5	Barley (grain type), Sugar beets, Rape, Cotton.
Medium tolerance: ECe x 10^3range 10-6 Water max. 165/10^5	Rye(grain), Wheat(grain)Oats (grain)Rice, Sorghum(grain) corn (field, Flax.
Low tolerance: ECe x 10^3range 4-3 Water max. 60/10^5	Sunflower, Castor beans, field beans.

(5) Flowers and Shrubs: (Not in order of relative tolerance).

High salt tolerance: ECe x 10^3range. Water max. /10^5	Carnations, Clematis orientalis.
Medium tolerance: ECe x 10^3range. Water max. /10^5	Bougainvillea, Sansevieria, Hibiscus, Oleander, Chrysanthemum, Stock.
Low tolerance: ECe x 10^3 range. Water max. 60/10^5	Orchid tree(Banbinia)Red leaf banana (Musa), Japanese Yew (Porocarpus), Poinsettia (Euphobia), Asters, Gladioli, Roses.
Very low tolerance: ECe x 10^3range. Water max. 40/10^5	Violet, Gardenia, Camellia, Azalea, Magnolia, Primula, Hydranges, hortensis, African Violet (Saintpaula)

The above lists have to a degree been compiled from the published findings of the United States Department of Agriculture in co-operation with the 17 Western States and the Territory of Hawaii. The classification and order of tolerance are for American species. In the main, Australian species of the same botanical genera may be taken to fall within the same salinity groups but not necessarily in the same order of descending salt tolerance. Supplementary lists have been compiled from published works both from Australian and overseas investigations.

The E.C.e(Electrical conductivity of saturated extract of soil) values where shown are those published by the U.S.D.A. but the Water Max. values representing the upper salinity of irrigation water allowable are those suggested by the N.S.W. Department of Agriculture to limit E.C.e. values to U.S.D.A. values.

It is stated that the E.C.e values shown are associated with a 50% decrease in crop yields when compared with side by side cultivation using non saline water.

More recently the following list has been proposed for adoption under Australian conditions, the E.C.e. values being generally lower than those of the U.S.D.A. lists in an endeavour to improve crop yields.

TABLE 3

MAXIMUM ELECTRICAL CONDUCTIVITY (IN MILLIMHOS AT 25°C).

SATURATED SOIL EXTRACT (E.Ce.)

2-3 mmhos.	4-6 mmhos.	6-8 mmhos.	30-12 mmhos.
	Fruit Crops		
Apple			
Apricot			
Banana			
Cherry			
Citrus			
Grape			
Passionfruit			
Peach			
Pear			
Plum			
Strawberry			
	Vegetables.		
Carrot	Corn(Sweet	Brussel Sprout	Asparagus
Celery	Lettuce	Broccoli	Beetroot
Cucumber		Cabbage	
		Cauliflower	
Bean			
Onion			
Parsnip	Potato		Spinach
Pea	Potato(Sweet)	Tomato	
Squash	Pumpkin		
Rock Melon	Swede		
Water Melon	Turnip		
	Miscellaneous Crops.		
Tobacco	Maize	Oats	Cotton
	Sugar Cane	Wheat	Barley
		Sorghum	Beet (sugar)
		(various)	
	Pastures - Annual.		
Subterranean Clovers	Medics (Trefoils)	N.Z.H.I. Ryegrass	
Vetches		Wimmera Rye	
		Millets (Fodder)	
		Italian Ryegrass	
	Pastures - Perennial		
White Clover	Cocksfoot	Lucerne	Rhodes Grass
All Trifolium Species		Paspalum	Kikuyu
		Phalaris	Sudan Grass
		Perennial Rye	
		Strawberry Clover	

NOTE: The quantity of water required for leaching calculated from the higher conductivity figure in the range at the head of these columns should be taken to be the minimum for control of salinity affecting satisfactory crop yields. Calculations based on the lower conductivity figures are more desirable.

There are two main factors to consider in respect to crop salt tolerance. They are firstly:-

* The amount of salt present in the water in contact with the root cells, and secondly -

* the composition of these salts contributing to the salinity.

A high concentration of salts will affect the growth of the crop mainly due to their influence in restricting the amount of water readily available to the crop whilst the composition of the salts (even in water of acceptable salinity level) may be unbalanced there being too much of any particular element present compared with the amount of other elements which are also necessary to form a "balanced diet" for the plants. It would be as well to discuss each of these factors separate y.

The salt content of soil-water;

Irrigation water on entering the soil mixes with water already there and becomes soil-water or soil solution. Naturally the soil-water will contain salts dissolved from the soil because of their solubility in the water. If the soil at commencement of an irrigation project was to be completely free from soluble salts and the water applied was also salt free, there would be no salinity in the soil solution other than from subsequent changes which may take place in the solubility of soil minerals from time to time. If on the other hand there is both salt in the soil before irrigation and the irrigation water is also saline, there will be be salt in the soil-water in contact with the plant root cells. As this soil-water becomes more and more saline, it becomes limiting to plant growth and recognition of critical salinity levels for many crops has led to the compilation of the lists of relative salt tolerance given herein.

Build up of Salinity in Plant-Root Zones:

Water in soil enters the plant root cells and passes up from the roots to the leaves where it is transpired (evaporated) into the atmosphere through the stomata in the leaves or foliage. It should, however, be clearly understood that due to the mechanics of "Osmosis" (a process involving membranes and saline solutions) the water entering the plant root cells is largely desalinised by the protoplasm of the plants root cells acting as membranes. Whilst ever the cells are functioning properly, ninety nine per cent of the salts originally in the soil water are rejected by the plant, and mainly desalinised water enters the cells. In this way it might be considered that plants distill the soil water. As with all distillation processes the residue in the still (in this case the soil) is much more saline. If half the soil water is "distilled" off the concentration of salts in the remaining soils water will be doubled.

Immediately after cessation of irrigation the soil will be at its wettest and the soil-water at its weakest salinity level. Hereafter as day by day the plants transpire, the concentration of salts in the soil water will increase and often good management practice will be necessary to see that concentration or build up of salinity does not exceed the plants' ability to continue growth or even survive. Experiments have shown that decrease in growth of plants in many cases is linear with salt build up in the soil-water.

Irrigation water can be analysed to determine its salinity and an assessment made of the hazards associated with its use. Most State Departments of Agriculture perform this service for landholders and in New South Wales some 2000 samples of water are examined each year and a report furnished. Soils required for major irrigation projects can also be analysed to determine their salinity status, one method in common use being based on the electrical conductivity of their saturation extracts.

Saturation Extracts of Soils

As the name implies saturation extracts of soils are an aqueous extract available by pressure or vacuum extraction from any soil sample which has been brought to its maximum water holding capacity. In this condition all the pore spaces have been filled with water and any soluble salts present distributed throughout the water to form a homogenous solution.

The determination of the electrical conductivity of the electrical conductivity of the extracted liquid (ECe) affords a reasonably accurate measure of the salinity of the soil at saturation and enables the salinity of soils of varying texture to be related to each other. Any change in cultural practices from year to year affecting soil texture are therefore cancelled out in assessing changes in salinity status of the soil and further since their is a reasonably acceptable co-relation between the water holding capacity of soils at Saturation Field Capacity and at Permanent Wilting point it further enables an assessment of the salinity of soil solution in contact with the plant root cells at moisture levels in soilat or in between these recognised levels.

The following classification of irrigation waters is that in current use by the N.S.W. Department of Agriculture:

TABLE

"C" GRADING	ELECTRICAL CONDUCTIVITY RANGE EXPRESSED IN MILLIMHOS PER CENTIMETRE @ 25°C.	EQUIVALENT SALINITY RANGE PARTS SALINE MATTER PER 100,000 WATER	EQUIVALENT TO HUNDREDWEIGHTS (CWT.) OF SALT PER ACRE INCH APPLIED WATER.
C_1	0 to 0.9	0 to 60	Nil to 1.2
C_2	0.9 to 1.5	60 to 100	1.2 to 2.0
C_3	1.5 to 2.5	100 to 165	2.0 to 3.3
C_4	2.5 to 5.0	165 to 330	3.3 to 6.6
C_5	Above 5.0	Above 330	-------

"C_1" -Low salinity water can be used for the regular irrigation of most crops on a variety of soils with little likelihood that soil salinity will develop. Some leaching will be required, but this can be achieved by normal irrigation practices and by reasonable seasonal rainfall. However, soils should be permeable and attention to specific toxic hazards may be necessary.

"C_2" -Medium salinity water can be used under conditions of more generous leaching. Plants with a moderate tolerance of salt can be grown where conditions of soil drainage are favourable and in most cases special measures for salinity control may not be necessary.

"C_3" -High salinity waters should not be used on soils with restricted drainage. Even with adequate drainage, measures for salinity control will probably be necessary and only crops with a good tolerance of salt should be attempted.

"C_4" -Very high salinity waters are not suitable for irrigation under ordinary conditions, but may be used in special circumstances.

Soils must be permeable and drainage adequate. Considerable leaching will be necessary and only crops of very good salt tolerance should be selected for trial.

"C_5" -Waters of this grade are too saline for any irrigation project, but may be suitable for drinking water for stock, subject to salinity limits laid down by the Department.

Usage of Water by Crops

Almost any crop (fruit trees included) will transpire or by combination of transpiration and evaporation from bare soil, at least one inch of water per acre (one inch) per week during the time of normal foliar growth. In many instances influenced by long daily hours of sunshine, atmospheric temperatures and dry winds, the water usage is double and even up to four times this figure.

If the water available were to be of the 300 parts per 100,000 quality, the use of 2 inches per week would add 12 cwt. of salts to each acre of the soil. Repetition of this on a weekly basis would mean that in four weeks 4 x 12 equals 48 cwt. of salts would have been put into the soil per medium of the irrigation water. It is obviously only a matter of time before the build up of salt in the soil will cause the death of even the most salt tolerant crops and the soil will become barren.

Salt removal from Soil

Salt can only be removed from soil be leaching and in order that the soil occupied by the plant roots (plant root zones) may be kept below hazardous levels of salinity, water must be added to the soil in sufficient quantity to allow of an excess being available to saturate the root zones and by gravitational pull pass on down below to drain or other outlets. Good drainage is therefore essential for salinity control be leaching.

Where soils are permeable rain water can enter and pass on through the soil to effect leaching, providing sufficient rain has fallen. Rainfall that only wets the surface 6 inches is quite ineffective as a leachant on many soils, as is irrigation water applied in similar quantity. The practice of turning the hose on for half an hour (when saline irrigation water is in use) is bad as the water which can only penetrate to a shallow depth must leave its content of salts in the soil at that depth. Less frequent but heavier applications are more beneficial in salinity control and coupled with soil mulching to minimise surface evaporation can be quite effective.

Soil-Water Nutritional Balance

As mentioned previously, all plant life requires a reasonably balanced diet of elements for healthy growth, and it is from soil water that approximately 13 elements are made available to pass into the plants per medium of the root cells.

Sodium, Calcium, Magnesium, Nitrogen, Potassium, Phosphorus and Sulphur are the major elements of plant nutrition, whilst the minor or trace elements of Zinc, Iron, Copper, Molybdenum, Boron, etc. are also in part or whole essential.

The minor or trace elements are not normally expected to be available in irrigation water as applied to the soil, but are solubilised by the soil-water from their minerals in the soil. Where deficiencies of these trace elements occur, they can be added to the soil as a supplement.

A major imbalance between sodium and calcium and magnesium in irrigation water can exist, however, and where chemical analysis shows an imbalance, it may be necessary to make amends by applying soil dressings of the deficient elements. When sodium is in some excess over the calcium plus magnesium (considered together), a hazard exists both as to healthy crop growth due to excessive uptake of sodium by the plant or the restriction of uptake of calcium and magnesium together with other elements. Sodium in excess is also detrimental to the maintenance of good soil structure especially of fine textured soils such as clays and clay loams. These soils absorb sodium onto their complex, in many cases causing a breakdown of the soil crumbs into finer particles which pack together to form pugs when wet with impaired drainage and consequent increased liability to a salinity build up.

Irrigation waters, even those which are relatively low in total saline matter (low "C" gradings) may be therefore hazardous due to high sodium (a poor balance between sodium and calcium and magnesium in the water), and "S" gradings S_1, S_2, S_3, and S_4 have been determined in indicate the degree of the hazard.

The Bi-carbonate or "Residual Alkali" hazard

When by analysis an irrigation water is shown to have a higher content of Total Alkali (expressed as Na_2CO_3) than the amount of Calcium and Magnesium (expressed as $CaCo_3$), the excess of alkali is called "Residual Alkali".

Eaton, a well known researcher in agriculture, has postulated that "Residual Alkali" in irrigation water constitutes a hazard to crop growth and soil structure because of its ability to cause precipitation of soluble calcium and magnesium salts from soil solution. In these circumstances plants and soils are deprived of a supply of readily available calcium and magnesium leaving the element sodium particularly dominant in the soil solution in contact with the plant root cells.

All plant life requires calcium and magnesium for growth, some having a particularly high demand for these elements.

The Specific Ion hazard is associated with the adverse effect of certain ionic concentrations in soil water, and the following notes on specific toxicities are included for consideration.

1. Selenium, Lithium and Fluoride

Ordinarily Selenium and Fluoride do not affect plant growth but can accumulate in plant tissue and have serious effects on animal life by ingestion.

Lithium in irrigation water in a fraction of one part per million produces tip and marginal burning and defoliation of citrus leaves.

2. Sodium

Besides its indirect effect on plant growth due to soil structure changes, if sodium in soil is high, almonds may develop tip burn and avocados leaf scorch.

3. Chloride

To many species of plants chloride salts are not more toxic or inhibitive to growth than equivalent concentrations of sulphate salts.

Specific chloride ion effects have been however reported for peaches and other stone fruits, Pecans, Avocados, lemon cuttings, Navy beans and Dwarf milo. Tobacco leaf burning quality is adversely affected by excessive chloride but beneficial affects from soil dressings of chloride salts have been noted for Table beets, Sugar beets, Tomatoes and Spinach.

4. Sulphates

Specific sensitivity to high SO_4 ion has been reported for Tomato, Flax, Cotton and Coxfoot and high concentrations of SO_4 in the substrate are said to limit the activity of calcium ions and thereby condition cationic uptake of Ca by plants.

5. Bicarbonate ion

Tends to reduce the uptake and translocation of iron in many plants causing chlorosis. Apples, beans, Dallis grass and citrus are examples.

6. Boron

Which is a minor constituent of practically all waters is essential to the growth of most plants:

1 p.p.m. or less is considered excellent for most crops.
1 to 2 p.p.m. as satisfactory.
Up to 3 p.p.m. satisfactory for more tolerant crops.
25 p.p.m. as optinum for carrots.
0.3 p.p.m. as maximum for citrus.

7. Ammonium toxicity

Certain bedding plants exhibit intolerance to the NH_3 ion. Phlox and Verbena suffer severe leaf burn, Carnations, Sweet Alyssum and Stocks may lose their roots and Cotyledons turn yellow. Petunia on the other hand has been reported to thrive on moderate concentrations of ammonium ion.

8. Hydrogen Sulphide (H_2S) even in very small amounts is toxic to plant life.

9. Nitrites (NO_2). Toxic to plant roots when present in more than a few parts per million.

Management has always been the key to success in any field of endeavour and this is no less true in agriculture. Where inferior waters have to be used management will play a big part in the success of the project.

ABSTRACT FROM U.S.D.A. CIRCULAR NO.969-NOVEMBER,1955.

Electrical Conductivity of Saturation Extract ECe millimhos per centimetre at 25°C.	Related Crop Response
0 to 2.0 millimhos/cm.	Salinity effects mostly negligible.
2.0 to 4.0 millimhos/cm.	Restricted yields of the more sensitive crops such as: Avocado, citrus, strawberry, peach, apricot, almond, plum, prune, apple, pear, beans, celery, radish, most clover species, meadow foxtail.
4.0 to 8.0 millimhos/cm.	Yields of many crops restricted. The more sensitive crops in this group include: Grape, cantaloup, cucumber, squash, peas, onions, carrots, bell, pepper, potatoe, sweet corn, lettuce.
	The more tolerant crops in this group are:Olive,fig,pomegranate, cauliflower,cabbage,broccoli,tomato oats,wheat,rye,lucerne,Sudan,grass, Dallis grass,strawberry, clover, perennial ryegrass,Sweet,Clovers, Flax, Corn and Rice.

<u>8.0 to 16.0 millimhos/cm.</u>	Only salt tolerant crops yield satisfactorily.These include: Date, palm, asparagus, kale, garden beets, Birdsfoot trefoil barley, many species of wheat grass and wild ryes, Rhodes grass, Bermuda grass, salt grass.
<u>More than 16.0 millimhos/cm.</u>	Satisfactory yields from only a few very salt tolerant species, e.g. certain native range plants.

CHEMISTRY OF GROUND WATER -

PART 2: RELATION TO USE FOR STOCK WATERING.

By M.G. Chatfield, A.S.T.C.*

The adverse effect of inadequate supply and/or unsuitable quality water on the welfare of stock cannot be overemphasized.

As with plant life, the animal body requires a readily available supply of water at all times to maintain blood, bone and tissues in healthy condition.

Water comprises almost 80 per cent of the new born calf, and even at maturity it is as high as 60 to 70 per cent depending on the condition of the animal, over fat beasts having a somewhat lower content than those in prime condition.

It is essential as the vehicle whereby nutrients from the blood stream enter the tissues to energise muscles and promote cellular growth and for returning to the blood stream waste products for disposal by the kidneys and lungs. More water is said to leave and re-enter the blood stream each minute than is contained in the whole blood circulatory system.

As with man, our farm and range animals also use water to maintain stable body temperatures. By processes or evaporation (perspiration, sweat, exhalation, etc.) the disposal of heat absorbed from the sun and generated by metabolic reactions is achieved.

So very important is water to the animal body that it is generally accepted that whilst stock may lose all of their fat, one half their protein, depletion of water in blood and tissues by ten per cent will often result in death. Merino sheep have a somewhat higher tolerance to dehydration (body water depletion) and this is also true for the camel and certain desert native fauna.

Tolerance to dehydration is therefore highly desirable especially in times of drought, more stock being lost due to this factor than by undernourishment. Even under average conditions, stock which have a tolerance to partial dehydration are better enabled to seek food and graze at some distance from water.

What then are the specific requirements of stock? Do stock vary in their requirements and do species within each classification vary from each other?

It is generally well known that Zebu cattle can stand dryer and hotter conditions than many other breeds, and that the Merino sheep is more adaptable than some others. The ability of any stock to survive under adverse conditions is largely a matter of conservation of available water within the body and tolerance of dehydration by individual species reflects their better capabilities in maintenance of a suitable balance between the amount of water available and its critical use in body functions when under water stress.

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SOURCES OF AVAILABLE WATER

The water requirements of stock are met from three main sources:

* Feed water
* Metabolic water
* Water supplied as drink

and the sum of these three is the available water for maintenance of health and growth.

Feed water is as the term suggests that portion of the animal's intake contained in the ingested feed, which may contain anything from 10 to 90 per cent of water. Grain and hay are in the lower category, with the succulents offering the highest contribution in this source of supply of body water.

Metabolic water is formed within the body by chemical processes associated with the storage and use of protein carbohydrates and fats in maintenance of the animal body. The importance of metabolic water cannot be overlooked especially under drought feeding conditions when the stored proteins and fats in the body are catabolised to provide energy to maintain life.

Water supplied as drink is essentially the balancing source of supply for the animal's needs. Where feed and metabolic sources offer low contributions then drinking water becomes of paramount importance.

BALANCE - SUPPLY AND REQUIREMENTS

We have discussed briefly the water requirements of stock and should now look a little more closely at the reason for these requirements.

Firstly, it is basic that the daily water loss from the body must be made up to avoid partial or more severe dehydration leading from unthriftiness to death.

As with water input there are also three main sources of water losses from body. They are:-

* Water lost in faeces
* Water lost in urine
* Water lost by vaporisation.

In milking stock there is another important source of body water loss. Milk may account for about 20 per cent of the water lost by a milking cow, whilst other animals in milk, succouring their young, have considerable losses in this category.

Water lost in faeces: This very significant source can account for up to 40% of the total daily loss of water. If for any reason stock are scouring, the loss from this source will be greater. Scouring if allowed to continue will cause dehydration and consequent death especially when the available drinking water is highly saline or otherwise unsuitable.

Urinary water losses are of the order of 20 per cent in dry and milking cows and it is probable that this is much the case for other stock. Under drought conditions, the variable ability of stock to conserve body water by concentration of the urine before discharge can be a major factor contributing to their drought tolerance and ability to accept saline water as a drink.

Water lost by vaporisation: Maintenance of body temperature within acceptable limits is of considerable importance, and animals will endeavour to achieve this by discharge of excess heat from the body. Heat can be dissipated in voided faeces, in urine and in milk but a very important factor in maintaining correct body temperature is by evaporation from cutaneous tissue (the skin) and by exhalation (breathing).

Horses are particularly sensitive to heat and sweat profusely in an endeavour to maintain balanced body temperature.

The ability of the camel to withstand high temperatures and dehydration conditions is in some way attributable to its capacity to store heat during the day and return to normal in the cooler hours of the night.

SHADE TREES ESSENTIAL

Sheep in wool may tolerate long hours of strong sunlight and consequent high temperatures. However, off the shears or for young lambs, the provision of adequate shade is essential to prevent losses. It cannot be overemphasized that the provision of shade especially by clumps of trees will pay dividends under arid conditions.

CONSERVATION FOR SURVIVAL

During drought therefore it is evident that because available drinking, feed, and metabolic water for maintenance is limited, survival will largely depend on the stocks' ability to limit losses to bare essentials.

Stock vary in their requirements of ingested water in relation to the content of dry matter in feed available. In a general way water intake parallels the consumption of dry matter. Cattle and sheep drink about $2\frac{1}{2}$ to $4\frac{1}{2}$ lb. and $1\frac{1}{2}$ to 3 lb. of water respectively for each pound of dry matter in food eaten.

Under drought feeding conditions the dry matter in feed available will be higher than normal and where drinking water is limited, ability to survive on lower ratios of water to dry matter becomes important. Fortunately sheep and cattle exhibit some such ability and ratios as low as $1\frac{1}{2}$ of water to each pound of dry matter consumed have been recorded for both.

Faecal ratios of water to dry matter under dehydration stress can fall considerably, in cattle from a normal of up to 9 to 1 to as low as 3 to 1 and in sheep from 9 to 1 to 1 to 1. With restricted food intake the water thus conserved for other essential functions is quite considerable.

The ability of stock to concentrate their urine before discharge is a further means of conservation.

In normal circumstances (non drought) the composition of the feed and quality of ingested water confer an obligatory daily urine discharge. Feeds high in protein content require higher urinary excretions to remove urea formed chemically within the body from protein. The amount of other unwanted salts ingested in drinking water or formed in the body must also be taken care of.

Concentration of the urine under drought conditions depends largely on the obligatory load on the kidneys under the new conditions being experienced. Fortunately many animals exhibit ability to conserve water by urinary concentration when under dehydration stress.

Sheep may ingest 3 gallons of water containing one per cent of salt and by concentrating it to a three per cent solution before discharge as urine, two gallons of water become conserved or available in the body for other obligatory needs.

WATER QUALITY IS IMPORTANT

The question of water quality is contributory and closely associated with the health of stock and more especially is this the case in times of drought.

A number of authorities both in Australia and abroad have set arbitrary upper limits for salinity in stock waters based on research and correlation of data in information obtained from landholders, graziers etc.

The amount of dissolved salts in water is by far the most important single factor to be considered in assessing the suitability of water for stock.

In New South Wales the Department of Agriculture has adopted arbitrary upper limits of salinity for stock waters as follows:-

For	* Sheep	1400 parts per 100,000
	* Cattle	1000 " " "
	* Horses	700 " " "
	* Pigs & Poultry	400 " " "

Whilst in other States of the Commonwealth somewhat similar standards apply.

There is no set lower limit for salinity, and generally speaking the lowest salinity water available is considered the most desirable.

Dairy cattle seem to require sodium chloride (common salt) in their diet and can become unthrifty if it is lacking. Since this salt is present in most farm waters the problem of salt deficiencies seldom occurs, but the author has seen dairy cattle by-pass a non saline river water to drink out of a mud hole containing saline water. The requirements of salt for dairy stock can be fully met by ingestion of 10 gallons of water per day containing 60 parts per 100,000 of sodium chloride.

Sheep on good pasture may obtain their daily water requirements from the succulent grasses and dew, and in these circumstances may not require drink as such for several days. Here again climatic temperature would be a relevant factor. If held on dry range or if being moved along dusty stock routes with only a "dry pick" their water requirements as drink will be much larger and a good quality water is essential to maintain their condition. If at the end of a hot dry dusty journey they are forced to consume a water of high or otherwise unsuitable salinity status, many of them may scour resulting in loss of water to the body and consequent dehydration.

Cattle will be similarly affected by dry hot and dusty conditions. Dairy stock in milk are generally considered to require a less saline drink than may be readily tolerated by range cattle. This is understandable due to the fact that the water intake of milk stock is greater than the former to make provision for milk production. The increased salt ingested in the water would increase the obligatory urinary demand for its elimination.

Pigs and Poultry are considered to be in the low tolerance group with respect to salts intake. Chickens particularly may exhibit salt toxicity symptoms if their drinking water is saline and the salt content of their food is also above desirable limits. Pigs on high protein diet will require water of reasonably good quality as their otherwise obligatory urinary volume for elimination of urea is high.

TOXIC SALTS

Experiments with Merino sheep in Australia have shown that magnesium salts are less well tolerated than waters containing the same level of sodium salts.

Magnesium is usually present in the form of magnesium sulphate (Epsom Salts) and less commonly in the form of magnesium chloride. High levels of these magnesium salts supplementary to high sodium chloride in water can cause scouring, loss of condition and, in extreme cases, death.

Fluorine in water in excess causes fluorosis affecting teeth bone formation in stock. One to two parts per million of fluorine in water may be safely tolerated by most stock. Above this and certainly in the higher concentrations, fluorine causes excessive wear of teeth of sheep which limits their ability to graze with consequent dire results.

Nitrates and Nitrites are toxic to ruminants (sheep, cattle) if in excess in water and food and cases are on record of death following ingestion. The effect of nitrates and nitrites is to convert the oxyhaemoglobin of the blood into methaemoglobin, the blood in consequence being unable to carry oxygen to the body tissues.

Arsenic is not normally present in toxic concentrations in stock waters. However, due to careless handling and disposal of arsenicals by landholders it can become a killer.

To sum up:
Water is probably the most important single factor in successful stock raising. It must be readily available at all times in quantity and quality suited to their specific requirements. Under adverse conditions its quality can be the determining factor between life and death.

*WATER REQUIREMENTS OF STOCK

Many factors influence the intake of water by livestock.

The determination of water requirements involves detailed studies of the complete water balance of all classes of animals under a wide variety of feeding conditions and environments. Such studies have been made only for some classes of cattle under a restricted set of conditions. Even from these studies - because of individual variations among the animals and the variable effects of rations and level of production - we can draw no clear-cut conclusions that would help us list accurately the requirements of the farm animals.

In a general way water intake parallels the consumption of dry matter in the feed when animals are on dry feeds. Cattle and sheep drink 3 to 4 pounds of water to each pound of dry matter. Pigs, horses and fowl consume about 2 to 3 pounds of water per pound of dry feed. Those ratios and, therefore, water consumption also tends to be higher on feeds of high protein content and on rations containing a high proportion of fibre.

Another outstanding characteristic of feeds that affects water consumption is the water content of the feed itself. Variations in water consumption due to this factor are most pronounced in cattle and sheep. Mr Atkeson and Mr Warren, in South Dakota, learned that dry cows fed only hay consumed 93 pounds of water a day; when they were fed hay and silage, they consumed only 74 pounds a day. Sheep on good pasture drink little or no water; on dry pasture they may consume up to 15 pounds daily. The water consumption of cattle will also be reduced on good pasture but not to the same extent as that of sheep.

The level of production will also affect water consumption a good deal. The total water intake of steers on maintenance rations averages about 36 pound a day; on fattening rations it is about 72 pounds a day. Dry Holstein cows take in about 90 pounds of water a day; when producing 20 to 50 pounds of milk a day they may consume 160 pounds of water a day. Cows producing 80 pounds of milk a day drink as much as 190 pounds a day. Lactating ewes need 30 per cent to 50 per cent more water than other ewes. A sow may consume 38 pounds of water a day the week before farrowing and 45 pounds a day the week after farrowing. Non-pregnant sows consume about 20 pounds of water a day; when 77-114 days pregnant they consume about 30 pounds a day. The water consumption of mature pullets is about 3 to 4 gallons for each 100 birds; 100 laying hens need 5 to 7 gallons a day.

The other major factor that may affect the intake of water is environmental temperature. Moisture loss by evaporation has the effect of enabling the animal to withstand better the effects of increased temperatures, because it can get rid of large amounts of heat efficiently. This mechanism whereby heat is lost reaches a high development in horses, which sweat profusely. It has a limited effect in most domestic animals, which sweat less. Increased evaporative loss, on the other hand, raises the need for water in order to keep the water balance of the tissues.

So we see that the water needs of livestock fluctuate widely - particularly the needs of ruminants, whose rations may vary a great deal in composition and water content.

Data on the consumption of water by livestock is given in the following page.

The values given for poultry and hogs will be applicable generally and will actually approximate the water requirements, because the feeds usually given them contain little water and do not vary widely in composition. The figures given for cattle and sheep cover the maximum requirements, but because data on consumption on pasture or range are lacking and because the water content of rations varies widely, the minimum amounts cannot be stated accurately.

10 U.S. gallons = 8.33 Imperial gallons.

* Abstract from U.S. Department of Agriculture Year Book 1955.

Effect of External Temperature on Water Consumption

Hogs

Temperature	Water Consumption, Pounds per hog per hour: 75-125 lb.hogs	275-380 lb.hogs	Pregnant sows
50	0.2	0.5	0.95
60	.25	.5	.85
70	.30	.65	.80
80	.30	.85	.95
90	.35	.65	.90
100	.60	.85	.80

Dairy Cows

Temp.	U.S. gallons per day per cow: Lactating Jerseys	Lactating Holsteins	Dry Holsteins
50	11.4	18.7	10.4
50-70	12.8	21.7	11.5
75-85	14.7	21.2	12.3
90-100	20.1	19.9	10.7

Laying Hens

Temp.	Millileter per bird per day: White Leghorn	Rhode Island Red
70	286	294
80	272	321
90	350	408
100	392	371
70	222	216
70	246	286

Water Consumption of Sheep
(pounds of water per day)

Conditions	
On range or dry pasture	5-13
On range (salty feeds)	17
On rations of hay and grain or hay, roots and grain	0.3-6
On good pasture	Very little if any.

In these experiments water was available for consumption

Water Consumption of Pigs
(pounds of water per day)

Conditions	
Body weight = 30 lb	5-10
Body weight = 60-80 lb	7
Body weight = 75-125 lb	16
Body weight = 200-380 lb	12-30
Pregnant sows	30-38
Lactating sows	40-50

Water Consumption of Chickens
U.S. (gallons per 100 birds per day)

Conditions	
1-3 weeks of age	0.4-2.0
3-6 weeks of age	1.4-3.0
6-10 weeks of age	3.0-4.0
9-13 weeks of age	4.0-5.0
Pullets	3.0-4.0
Nonlaying hens	5.0
Laying hens (moderate temps)	5.0-7.5
Laying hens (Temp. 90°F).	9.0

10 U.S. gallons = 8.33 Imperial galls.

Water Consumption of Growing Turkeys
U.S. gallons per 100 birds per week.

Conditions	
1-3 weeks of age	8-18
4-7 weeks of age	26-59
9-13 weeks of age	62-100
15-19 weeks of age	117-118
21-26 weeks of age	95-105

Water Consumption of Cattle

Class of Cattle	Conditions	Water Consumption (lb. per day)
Holstein calves (liquid milk or dried milk and water supplied)	4 weeks of age	10-12
	8 weeks of age	13
	12 weeks of age	18-20
	16 weeks of age	25-28
	20 weeks of age	32-36
Dairy Heifers	Pregnant	60-70
Steers	Maintenance ration	35
	Fattening ration	70
Range Cattle		35-70
Jersey cows	Milk prod.5-30 lb./day	60-102
Holstein cows	Milk prod.20-50 lb./day	65-182
	Milk prod. 80 lb./day	190
	Dry	90

N.S.W. Dept. Agriculture
Salinity limits for stock - Sheep 1400, Cattle 1000, Horses 700, Pigs & Poultry 400. Approx. maximum levels salinity, parts per 100,000

GROUNDWATER QUALITY BACTERIOLOGICAL FACTORS

by

J. Johnstone, Engineering and Water Supply Department.

Bacteria which may be present in underground water,

(1)	Water [illegible]	indigenous
(2)	Soil bacteria	indigenous
(3)	Pollutant bacteria	introduced

<u>GROUPS 1 and 2</u> include fluorescent bacteria, chromogenic or pigmented types, spore formers, proteus etc.

<u>GROUP 3.</u> Considered first because of the importance as <u>indicator</u> organisms of pollution.

Basis of coliform/E.coli as a delicate test for excretal pollution in terms of the hygienic quality of a groundwater.

The significance of the various organisms in this group (Table II)

The importance of the Sanitary Survey as related to the results of bacteriological examination.

The bacteriological condition of underground waters as exemplified by,

(1) The Adelaide Plains Basin

(2) The South East Karst topography.

The relationship of the foregoing to the establishment of bore-hole sites for public water supplies.

1. The bore should be situated away from domestic and industrial drainage wells or natural features which receive such drainage.

2. The bore should be protected from surface drainage particularly septic tank overflows and factory waste. This is often neglected in smaller installations.

3. It should be sited, whenever hydrological considerations permit, 'upstream' of the town with respect to the underground water pattern flow.

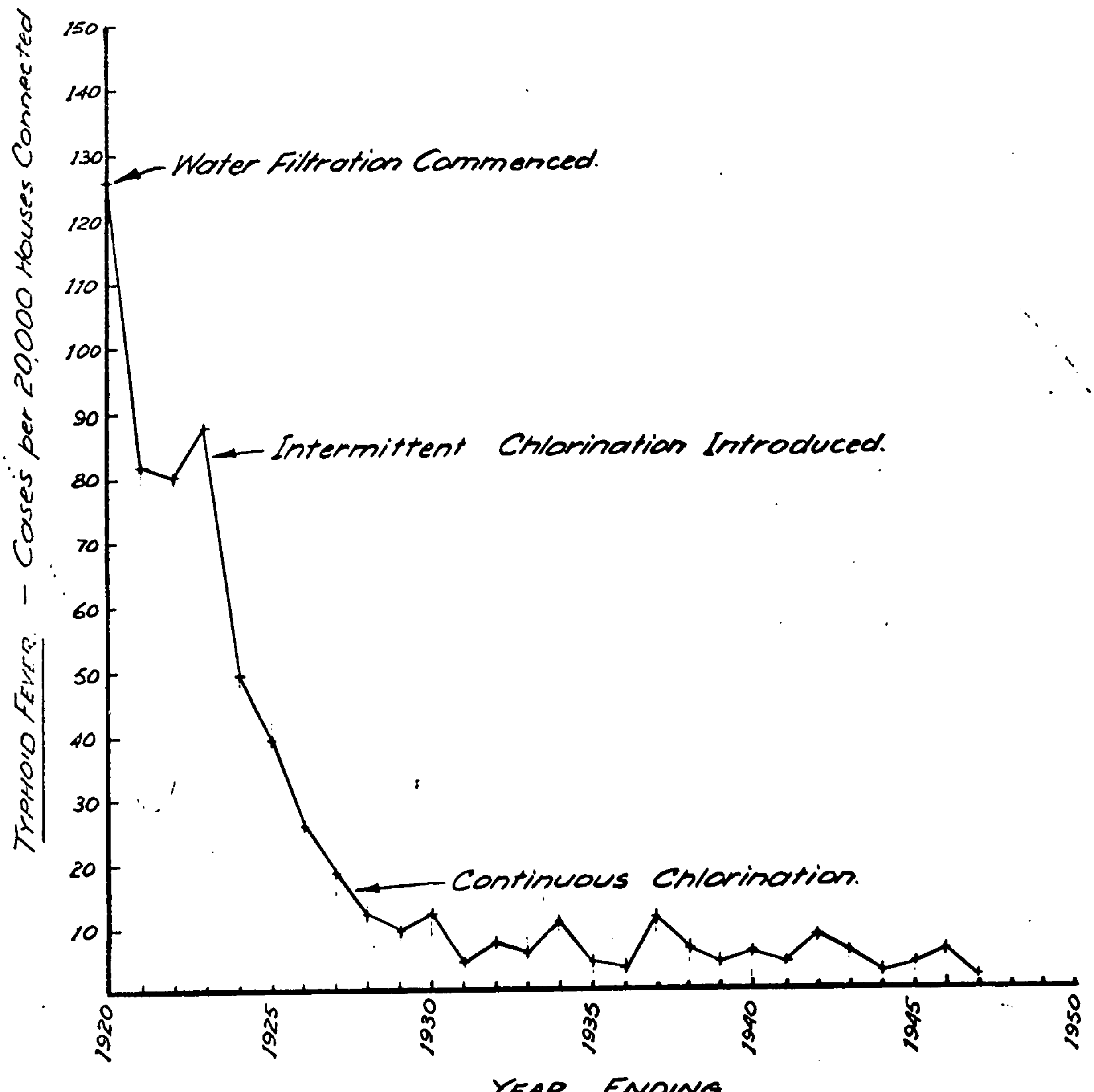
4. If the size of the scheme justifies it, a bacteriological survey of the water, together with that of any existing bore-holes, should be made under different seasonal conditions before the fore is connected to the distribution system.

The need to prevent pollution of groundwaters during storage and distribution.

GROUNDWATER SCHOOL - 1965.

TABLE I.

PROGRESS IN THE ELIMINATION OF WATER-BORNE DISEASE.



GROUPS 1 and 2 include:-

THE IRON BACTERIA.	Siderocapsa, sphaerotilus, leptothrix Gallionella etc.
THE SULPHUR BACTERIA	Beggiatoa, chromatium, thiobacillus, Desulphovibrio desulphuricans

Effect of iron bacteria on iron equilibrium.

Role of sulphate reducing bacteria in corrosion.

$$\underset{\text{(metal)}}{Fe} \longrightarrow Fe^{++} \quad + \quad e \qquad \text{anodic reaction}$$

$$\underset{\text{(moisture)}}{HOH} \longrightarrow OH^{-} \quad + \quad H \qquad \text{Cathodic reaction}$$

$$H + e = \text{nascent hydrogen}$$

$$SO_4 + 8H \xrightarrow[\text{hydrogenase}]{\text{enzyme}} S^{--} + 4H_2D$$

sulphates from
soil and water

Depolarisation is affected by bacteria

End Result = FeS and Fe $(OH)_2$

corrosion products

HYDROGEN SULPHIDE IN A SERIES OF BOREHOLES

Dissolved Gas

ppm	A	B	C	D	E
H_2S	nil	nil	0.16	0.48	0.72
CO_2	52	41	73	41	32

High H_2S and CO_2 characteristic of sulphate reduction.

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TABLE II

Nomenclature of coli-aerogenes bacteria

Common or Old Name	Reactions						New Name	Abbreviation	Probable Habitat
	Indole	MR	V-P	Citrate	44°	Gelatin			
Bacterium coli type I	+	+	−	−	+	−	Escherichia coli I	E. coli I	Human and animal intestine
Bacterium coli type I 44° negative	+	+	−	−	−	−	Escherichia coli III	E. coli III	Human and animal intestine
Bacterium coli type II	−	+	−	−	−	−	Escherichia coli II	E. coli II	Doubtful: probably not primarily intestinal
Intermediate type I	−	+	−	+	−	−	Citrobactor freundii I	Cit. freundii I	Mainly soil
Intermediate type II	+	+	−	+	−	−	Citrobacter freundii II	Cit. freundii II	Mainly soil
Bacterium aerogenes type I	−	−	+	+	−	−	Klebsiella aerogenes I	K. aerogenes I	Mainly vegetation
Bacterium cloacae	−	−	+	+	−	+	Klebsiella cloacae	K. cloacae	Mainly vegetation
Bacterium aerogenes type II	+	−	+	+	−	−	Klebsiella aerogenes II	K. aerogenes II	Mainly vegetation.

TABLE III

The Most Probable Number of Organisms of Pollutional Significance present per 100 ml of Adelaide Plains Bore Water.				The Number of Bacterial Colonies growing on Nutrient Agar Plates incubated at	
Bore Number	Depth Feet	Coliforms	E. coli	20° C. for 72 hours	37° C. for 24 hours
4	180	absent	absent	600	70
8	205	"	"	1600	280
11	372	absent - 2	"	410	420
12	209	absent	"	160	15
14	573	"	"	3	1
19	490	4	"	1200	1100
20	440	1	"	28	30
21	220	absent	"	30	4
25	254	"	"	190	75
27	410	"	"	260	22
28	433	3	"	180	120
31	460	absent	absent	35	6
39	456	"	"	1000	900
50	450	1	1	4	10
66	450	absent	absent	95	36
68	362	"	"	40	16
70	423	"	"	28	8
75	396	"	"	75	5
80	485	"	"	50	35
87	228	"	"	210	180
92	428	"	"	40	5
96	474	"	"	200	100

TABLE IV

The Most Probable Number of Organism of Pollutional Significance present per 100 ml in Surface Streams of the Adelaide Plains.

Source	Coliforms	E. coli
Gawler River	170	80
Little Para River	2500	160
Dry Creek	25000	2500
Port Road Drain	35000	2500
River Torrens Outlet	5500	800
Sturt River	3500	3500

TABLE V

The Most Probable Number of Organisma of Pollutional Significance present per 100 ml of Bore Water.

Date	Coliforms	E. coli	Rainfall - points	
1961				
June 6th	2500	2500	59	wet period
" 22nd	45000	9500	79	
July 7th	950	250	136	
" 19th	1600	350		
Aug. 2nd	1600	900	61	
" 9th	1	1	-	Dry period
" 17th	13	8	-	
" 23rd	45	11	-	
" 30th	5	2	-	
Sept. 20th	80	80	-	
			Turbidity - Units	
Nov. 22nd	absent	absent	-	
" 29th	8	absent	-	
Dec. 6th	11	1	-	
* " 13th	absent	absent	-	
" 15th	9000	3500	270	
" 16th	3500	1700	200	
" 18th	900	580	70	
" 19th	550	550	25	
" 20th	160	160	10	
" 21st	550	110	5 (normal)	
" 26th	350	35	-	

* 328 points of rain between 5 p.m. 13/12/61 and 9 a.m. 15/12/61.

TABLE VI

BACTERIOLOGICAL SURVEY OF SHALLOW BORES USED FOR DOMESTIC WATER SUPPLIES

LOCATION	The Most Probable Number of Organisms of Pollutional Significance present per 100 ml		The Number of Colonies growing on Nutrient Agar per ml of water incubated at		REMARKS
	Coliforms	E. coli	20°C for 72 hours	37° for 24 hours	
Bore A	-	350	6,400	1,400	Adjacent to toilets
Bore B	greater than 1,800	greater than 1,800	52,000	30,000	Septic tank bore hole in same back yard.
Bore C	550	7	190	85	
	35	13	550	60	consistent pollution from septic tank
	1,600	35	180	370	
Bore D	-	absent	110	80	50 yards from Septic Tank
Bore E	1,700	80	1,200	1,200	35' from septic tank effluent soakage hole. Water from 12' deep.
Bore E	1	absent	360	10	Same as above, water from 18' deep.
Bore F	1,800+	550	5,000	2,000	

TABLE VII.

GROUNDWATER OVERFLOWING FROM BOREHOLE

20/3/62 KINGSTON S.E.

		Parts per million
Silica (SiO_2)		10
*Iron (Fe)		0.96
Calcium (Ca)		42
Magnesium (mg)		17
Sodium and Potassium (NaK)		315
Bicarbonate (HCO_3)		391
Sulphate (SO_4)		58
Chloride (Cl)		340
Nitrate (NO_3)		2
Dissolved Solids : Calculated		976
Hardness as Calcium Carbonate	Total	175
	Carbonate	175
	Non-Carbonate	nil
Free Carbon Dioxide (CO_2)		31

* All iron in solution at time of sampling.

DEMONSTRATION OF TECHNIQUES FOR THE BACTERIOLOGICAL EXAMINATION OF GROUND WATERS.

by

D. Lane,

Engineering & Water Supply Department, S.A.

1. SAMPLING:

(1) Since most bores are used intermittently it is essential that there be two hours continuous pumping before sampling. Experience has shown that results can be misleading if shorter pumping periods are allowed.

(2) Samples should be collected as near to the pump as possible from a tap preferably of the type demonstrated. Bores for drinking water supplies should have special provision made for the installation of a sample tap as part of the original pipework. When a number of bores supply a township it is essential to be able to examine each one periodically.

(3) Many smaller domestic bores have windmills as the pump. In such cases it is usually necessary to collect the sample from the pipe entering the storage tank.

(4) Apparatus.

(1) Special covered splash free tap.

(2) Primus burner.

(3) Sterile bottle with protective covering.

(4) Insulated ice box.

(5) Label for sampling details.

2. COLIFORM/E. COLI COUNT.

Measured volumes of the sample of water are placed into tubes of selective broth containing lactose which are then incubated at 37° C. for 48 hours. From the number of tubes showing the presence of acid and gas, the Most Probable Number of coliform bacteria in 100 ml is estimated using probability tables. Sussequent tests are made to determine the proportion of Escherichia coli in the water.

Incubation of all tubes is carried out in constant temperature water baths which control the temperature to within 0.1° C.

The procedure used will be demonstrated and the schematic outline attached gives more detail if required.

In the next room you will see a living culture of E. coli under the microscope. These motile organisms are rod-shaped and are usually 0.5 by 1.0 to 3.0 microns in size.

3. NUMBER OF COLONIES GROWING ON AGAR.

A measured volume of the sample of water (usually 1 ml or less) is placed in a sterile flat covered dish, and a nutrient solution containing 1% agar at 45° C is mixed with the water and the mixture allowed to set. (Agar solutions are solid at room temperature, melt at 100° C. but remain liquid until cooled below 42° C).

The agar plate is then incubated at 20° C. for 72 hours or at 37° C. for 24 hours after which developed colonies may be counted and the results expressed as the number of colonies growing on agar at at 20° C. for 72 hours etc.

The principle of this test is that in a solid nutrient medium at a suitable temperature a living bacterial cell will proceed to multiply and in due course will form a colony of cells which will be visible to the naked eye.

The number of colonies developing is a measure of available organic matter in the water and although a high count indicates that a water is less suitable for human consumption it does not necessarily indicate that a water is a danger to health.

Low counts are generally obtained from underground sources, but a high 20° C. count may occur due to the presence of naturally occurring water organisms.

The procedure will be demonstrated, and a typical plate is shown.

4. COMMON WATER BACTERIA.

Some plates have been prepared showing pure cultures of some organisms found in underground supplies. Many of these are chromogenic (produce a pigment which colours the colony).

5. CLASSIFICATION OF COLIFORM BACTERIA.

An attached sheet shows the various members of the coli-aerogenes or coliform group. As E. coli I is the one organism of truly faecal origin, an estimation of the proportion of this organism in the total coliform count is normally sufficient. However it is frequently desirable to distinguish between the other members and this is done by plating out a small loopful of the original culture onto an agar plate and allowing the colonies to grow. From these colonies pure cultures of individual organisms can be made and after incubation the following biochemical tests carried out:-

(1)	Production of indole:	Detected by the addition of a special reagent to a broth culture to form a deep red colour.
(2)	Methyl red test:	Production of acid, after growth in a special medium. Positive red, negative yellow.
(3)	Voges Proskauer (VP) test:	Production of acetyl. Methyl carbinol - positive pink.
(4)	Growth in citrate:	ability to use citrate as a source of carbon, positive, blue colour.

6. MEMBRANE FILTER TECHNIQUE.

This is an alternative procedure for the enumeration of coliform organisms in which a measured volume of the sample is passed through a collodion membrane with pore sizes small enough to trap bacteria. The membrane is then transferred onto a pad saturated with a specially prepared nutrient mixture and is then incubated for 18 hours at 37° C. The nutrients in the pad diffuse through the membrane and developing colonies can be counted.

This method has many advantages but its use is rather limited with turbid waters.

This technique is demonstrated using an all glass Millipore apparatus.

7. FAECAL STREPTOCOCCUS (ENTEROCOCCUS) COUNT.

The presence of enterococci in water provides a further indication of pollution and this test is often carried out to substantiate the coliform/coli count.

The multiple tube dilution method is used but employing a selective medium containing sodium azide.

Colonies of enterococci are shown growing on T.T.C. agar on which they appear bright red.

A stained slide of streptococcus faecalis shows these organisms as sperical cocci, sometimes linked together in chains.

8. EXAMINATION OF WATERS FOR PATHOGENIC ORGANISMS.

In view of the expected small numbers of pathogens in water, a large volume is passed through a membrane filter after which the membrane is placed in a selective broth (e.g. Selenite). Alternatively a large volume of water is incubated with an equally large volume of selenite broth. After incubation the pathogens if present can be removed by plating out on specially prepared solid media e.g. bismuth sulphite agar. Identification of these pathogens is carried out making use of biochemical reactions and finally serological techniques.

The demonstration shows pure strains of Salmonella and Shigella on selective media and a typical set of biochemical tests. A stained slide of Salmonella typhimurium is available for microscopic examination.

9. NUISANCE BACTERIA.

(1) Sulphate Reducing Bacteria. (Desulphvibrio Desulphuricans).

As these organisms are anaerobes (live in the absence of oxygen) their enumeration and isolation requires special techniques. The sample is mixed with a special medium in a deep tube and incubated in a sealed preserving jar containing a copper - iron couple to reduce the oxygen tension below 0.05 atmospheres. The growth of these organisms is readily detected by the appearance of a black colour (due to iron sulphide) within the medium. They are sometimes slow growers and tubes should be left for 3 weeks before discarding them as negative. This test can be made quantitative by the use of a serial dilution technique.
Sulphate reducing bacteria are usually found in locations of low oxygen concentrations such as sub-surface sands and muds and have been isolated from many bores in the South East of South Australia. Typical tubes of these organisms can be seen as well as some colonies on an agar plate.

(2) Thiobacilli.

Organisms capable of utilising sulphur are sometimes found in ground waters and a species of Thiobacillus is shown growing on a medium containing solium thiosulphate.
These organisms have oxidised the thiosulphate to sulphuric acid as shown by the reduction in pH (note change in colour of indicator).

ENGINEERING AND WATER SUPPLY DEPARTMENT

GLENELG LABORATORY

COLLECTION OF WATER SAMPLES FOR BACTERIOLOGICAL EXAMINATION.

The collection of water samples for bacteriological examination must be conducted with extreme care and unless instructions are strictly followed the results may be misleading.

The water must be truly representative of that actually supplied to consumers. Therefore the tap should be situated on the main or from a short service directly off the main.

Where samples are required from an underground supply, it is essential that the pump should be in operation at least two hours prior to sampling and the sampling tap should be located as close to the pump as possible.

A specially designed tap is available for the routine collection of bacteriological samples. Such a tap does not splash and can be covered when not in use.

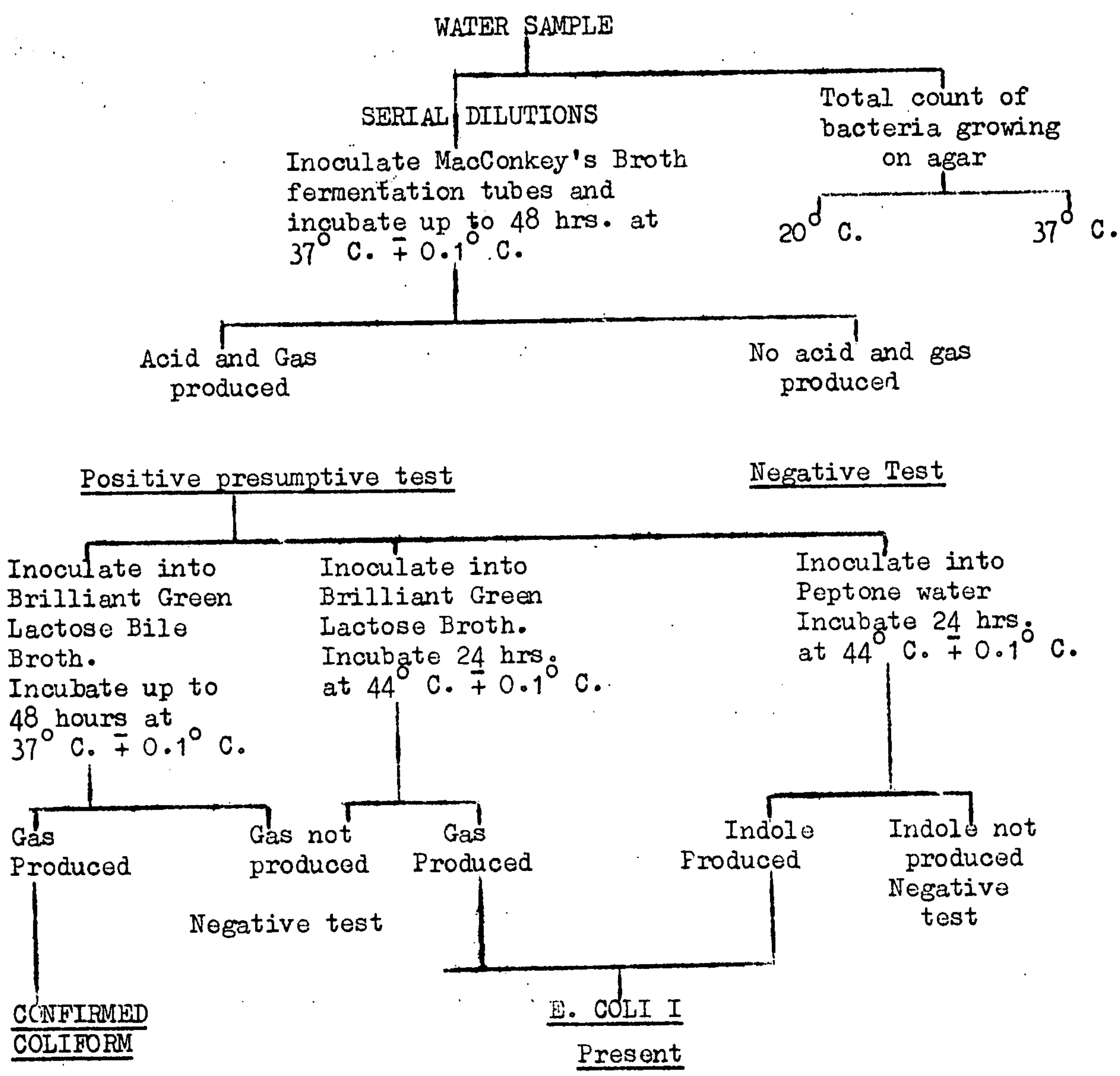
Instructions for Collection of bacteriological samples from a tap

1. Place crushed ice in outer container of box supplied.
2. Clean outside and inside of the tap paying special attention to any collection of grease, etc. inside the nozzle.
3. Turn tap on full, allow to run for 2-3 minutes.
4. Turn off tap and sterilize with a suitable burner until steam is emitted.
5. Cool by allowing water to run for a minute or so, and turn down to a small stream.
6. In collecting sample carefully remove bottle from container, then holding bottle by the bottom, with the other, hand remove stopper without taking off the metal foil, and fill sample bottle to the shoulder only, leaving an air space, while holding the stopper pointing downwards and still protected by its cover.
7. Replace stopper in bottle, turning it so as to fit firmly, but without jamming in tightly, fill in label and attach to bottle with rubber band.
8. Place bottle in container and replace metal cover. Close up box and affix printed addressed label to handle.
9. Forward to laboratory; advising laboratory of despatch.

THE ENGINEERING AND WATER SUPPLY DEPARTMENT

GLENELG LABORATORY

SCHEMATIC OUTLINE FOR THE BACTERIOLOGICAL EXAMINATION OF WATER.



The presence of confirmed coliforms and E. coli I is related back to the original serial dilution and the Most Probable Number of Organisma determined from probability tables.

TABLE II
Nomenclature of coli-aerogenes bacteria

Common or Old Name	Reactions						New Name	Abbreviation	Probable Habitat
	Indole	MR	V-P	Citrate	44°	Gelatin			
Bacterium coli type I	+	+	−	−	+	−	Escherichia coli I	E. coli I	Human and animal intestine
Bacterium coli type 44° negative	+	+	−	−	−	−	Escherichia coli III	E. coli III	Human and animal intestine
Bacterium coli type II	−	+	−	−	−	−	Escherichia coli II	E. coli II	Doubtful: probably not primarily intestinal
Intermediate type I	−	+	−	+	−	−	Citrobacter freundii I	Cit. freundii I	Mainly soil
Intermediate type II	+	+	−	+	−	−	Citrobacter freundii II	Cit. freundii II	Mainly soil
Bacterium aerogenes type I	−	−	+	+	−	−	Klebsiella aerogenes I	K. aerogenes I	Mainly vegetation
Bacterium cloacae	−	−	+	+	−	+	Klebsiella cloacae	K. cloacae	Mainly vegetation
Bacterium aerogenes type II	+	−	+	+	−	−	Klebsiella aerogenes II	K. aerogenes II	Mainly vegetation

Factors Involved in the Optimum Development of Groundwater Reservoirs.

by

J. W. HOLMES,
C.S.I.R.O., Division of Soils, Adelaide, S.A.

The optimum development of groundwater implies that the rate of yield should be not so large as to cause damage to the water resource, by diminishing the available supply, or by lowering the static water level until uneconomic pumping is needed, or by spoiling the water quality. It is essential therefore for planning purposes, to know as much as possible about the hydrologic balance of the groundwater system in question. Hydrologic equilibrium may be represented thus:-

GAIN	LOSS
Precipitation, including rain, snow, hail and dew-fall	Evaporation
Surface in-flow	Urban consumption and disposal
Sub-surface in-flow	Surface out-flow
	Sub-surface out-flow

TO BALANCE

Change in groundwater storage.
Change in surface reservoir storage.

Precipitation is usually by far the largest item on the gain side, excepting the situation of a large river traversing an arid region in its lower course, and evaporation is usually by far the largest item on the loss side. It may be useful to consider evaporation in a little detail.

1. Evaporation from the land surface.

Every leaf and blade of grass as well as the damp soil is an evaporating surface, so the complexity of detail is enormous. However, considering evaporation as a process requiring energy we may construct an equation representing the conservation of energy

as

$$H = E + A + G + p \qquad (1)$$

Where H is the net radiation (energy) absorbed at the earth's surface from sun and sky, E is the evaporation, A is the heat transfer from the surface to the air, G is the heat gain or loss by the soil and p is the energy absorbed in photosynthesis. A satisfactory consistent unit for measurement is mm per day, or it could be calories per cm^2 per day. The quantities in Equ. (1) might have the following magnitudes for an average October day, in Adelaide.

H	=	318 $cal/cm^2/day$	
E	=	198 " " "	equivalent to 3.4 mm/day.
A	=	102 " " "	
G	=	14 " " "	
p	=	4 " " "	

Another way of viewing the process of evaporation is that there is a flux of water vapour away from the evaporating surface and into the higher layers of the atmosphere. This aerodynamic process may be described by the equation

$$E = -K_w \frac{dX}{dz} \qquad (2)$$

Where E is evaporation rate, X is the water vapour content of the air, dX/dz is its gradient in the vertical direction and K_w is a transfer coefficient, also often called the eddy diffusivity. K_w depends strongly upon wind speed and stability of the lowest layers of the atmosphere. In other words, evaporation rate may depend strongly upon wind speed.

There is another way in which evaporation may be strongly influenced by wind, and that is in the situation of an oasis in a surrounding arid region. The wind blowing off the hotter dry land surface brings with it heat which can contribute to the latent heat consumed by evaporation. This amounts to regarding A in Equ. (1) as being negative in sign, in that heat is taken up from the air rather than being given out to the air from the land surface. De Vries (1959) estimated that the evaporation 100 metres inside an irrigated area could be 1.4 times the evaporation at an infinite distance from the dry-wet boundary, and that evaporation could still be 1.2 times this asymptotic value at 1 km. from the edge, basing his work upon observations in the Rochester Irrigation District, Victoria.

The purpose of presenting this very brief summary of evaporation as a physical process is to emphasise that we have no control over it. Evaporation from the land surface is entirely determined by the weather, it uses very large quantities of water particularly from irrigated land in an arid environment, and it is rare that underground water supplies are abundant enough to provide for irrigation without continuing depletion of the store of ground-water.

2. Safe yield and over-draft.

Perhaps the simplest method of measuring the safe yield of an aquifer is to keep good records of the static level of the groundwater for a number of years, and to know also the annual draft on the groundwater. Figure 1 is a plot of annual change in static level versus annual draft on the groundwater. It is unlikely that there will be a positive change in groundwater level over a year, for more than a few years, otherwise the groundwater basin would have been in a state of non-equilibrium naturally. After pumping on the groundwater has started there is a region on the plot showing no change in the groundwater static level, annually. This corresponds to a situation where the natural discharge of the annual groundwater accession has been partially replaced by the pumping. When the static level begins to decline noticeably, the draft is surely beginning to exceed the annual recharge.

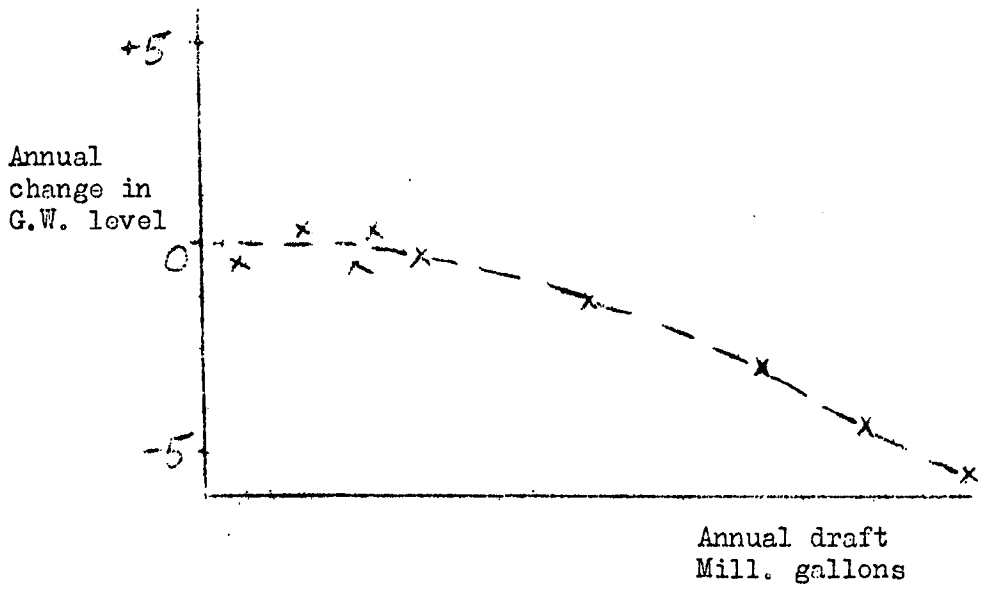


Figure 1. Estimation of overdraft.

There are many groundwater basins in arid regions which are old, in the sense that the water has taken many tens of thousands of years to accumulate. Such water may just as well be used, as allowed to remain underground. The correct approach to utilisation however, is to recognise that pumping such water is a mining enterprise with no replacement of the resource. An attempt should be made to predict the exhaustion of the water in order that an alternative supply may be planned for.

3. The water balance of a ground-water basin.

The recharge of groundwater is usually considered on an annual basis, because rainfall and evaporation from the earth's surface go through an annual cycle. Assuming that groundwater derives from rainfall, there are many shallow groundwater systems which display a seasonal rhythm in static water level. Such systems may be examined profitably by the water balance method. The equation which describes the water balance is

$$P = E + R + D + S \qquad (3)$$

Where P is precipitation, E is evaporation, R is run-off, D is the drainage or infiltration through the soil to the water table and S is the soil water store above the water table, all measured over any convenient length of time.

An example of the use of the water balance is the current attempt of C.S.I.R.O. to measure the annual recharge of that part of the Murray Basin lying in the South-East of South Australia and western Victoria. The techniques employed comprise the following:-

a. Four lysimeters, each 2m. diameter, two of them 1.8 m deep and two 2.4 m deep, were filled with soil, planted to pasture and kept as closely as possible representative of the pasture land at large. The accumulation of water in the bottom of these lysimeters, assumed to be that drainage which was the excess of precipitation over evaporation, was pumped out and measured regularly. At the same time the total water content of each lysimeter was measured with the neutron moisture meter.

b. Neutron moisture meter access tubes were installed in undisturbed pasture land, and under Pinus radiata forests. The total water content of the soil profile to the water table was determined by logging these holes with the neutron probe.

c. The fluctuations of the groundwater were observed at monthly intervals in 100 observation bores in a region 25 miles by 10 miles.

d. Evaporation from the pasture was computed by the Penman method, using measured values of net radiation.

e. Observation of the water regime of a swamp in pasture land gave an opportunity to assess the role of swamps as elements in the recharge of the groundwater.

From these varied sets of observations, the recharge of the groundwater was assessed thus:-

1. Recharge = Precipitation - Evaporation.
This relation holds if run-off is negligible. Evaporation was determined by the Penman method.

2. Recharge = Drainage in the lysimeters.
Here again, run-off to swamps is supposed to be negligible.

3. Recharge = Amplitude of the static water level fluctuation multiplied by storage coefficient (specific yield). The storage coefficient was determined from the neutron probe logs. This method gives an underestimate because it assumes negligible dissipation of the groundwater by its natural processes during the time of rise from minimum to maximum. It is, of course, possible to make some adjustment based upon rate of decline of the water table when there is no recharge, but such adjustment is subject to an unknown error.

4. Recharge = Amount of water infiltrating through the undisturbed soil profile to the water table. This is easy to measure with the neutron probe if it is zero, as it was under forest vegetation.

It would be inappropriate to give results of this experiment here. They will be reported in due course.

4. Influent and effluent streams.

The role of ephemeral streams and temporary flooding in a semi-arid environment cannot be too much emphasised in the recharge of groundwater. Usually it is by such means alone that valley aquifers are recharged under low rainfall. It is useful to distinguish between effluent and influent streams.

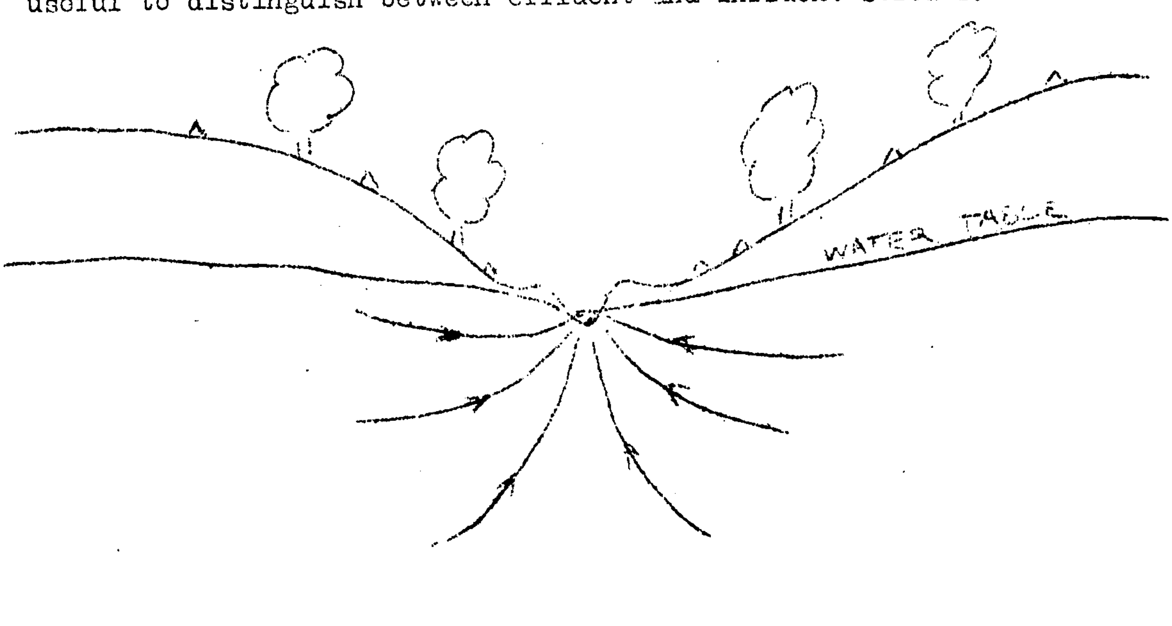


Figure 2. An effluent stream.

An effluent stream is a perennial stream usually, which drains well-watered country and to which there is groundwater flow. During dry spells when surface run-off disappears, the flow of the stream is sustained by base flow from the groundwater through the banks and stream bed.

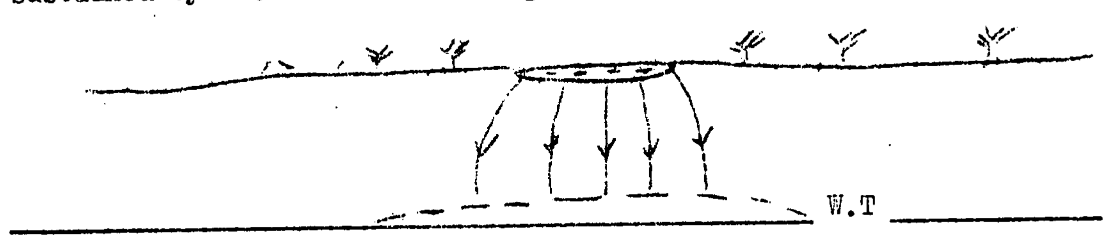


Figure 3. An influent stream.

An influent stream is an ephemeral stream usually, which suffers leakage of its flow through the stream bed to a deeper water table. Such a regime is typical of arid regions. It also occurs in coastal regions where the track to the sea is short for groundwater flow, and therefore large potential gradients may develop.

5. Artificial recharge of groundwater.

A groundwater basin that has the influent stream kind of recharge, may be artificially recharged at a rate faster than that provided by nature. There are three means of accomplishing such recharge:

a) A natural stream may have checks or low weirs constructed across its bed. In this way water may be ponded for much longer than the time of natural flow, giving enhanced intake from the stream bed.

b) A spreading basin may be constructed into which water from an ephemeral stream is diverted. Such a basin may be approximately circular in shape for economy in construction. On the other hand, the most efficient recharge is obtained from linear, or stream shaped spreading areas.

c) Recharge may be accomplished by pumping into existing bore-holes. Rarely is this method permanent. The bore-holes will clog up, usually quite rapidly.

6. Fresh-water lenses in saline water aquifers.

Because the density of fresh water is lower than that of saline water, fresh water may remain perched upon an inferior saline groundwater. The most celebrated description of this occurrence is the Ghyben-Herzberg Lens. Its main features are shown in Fig. 4.

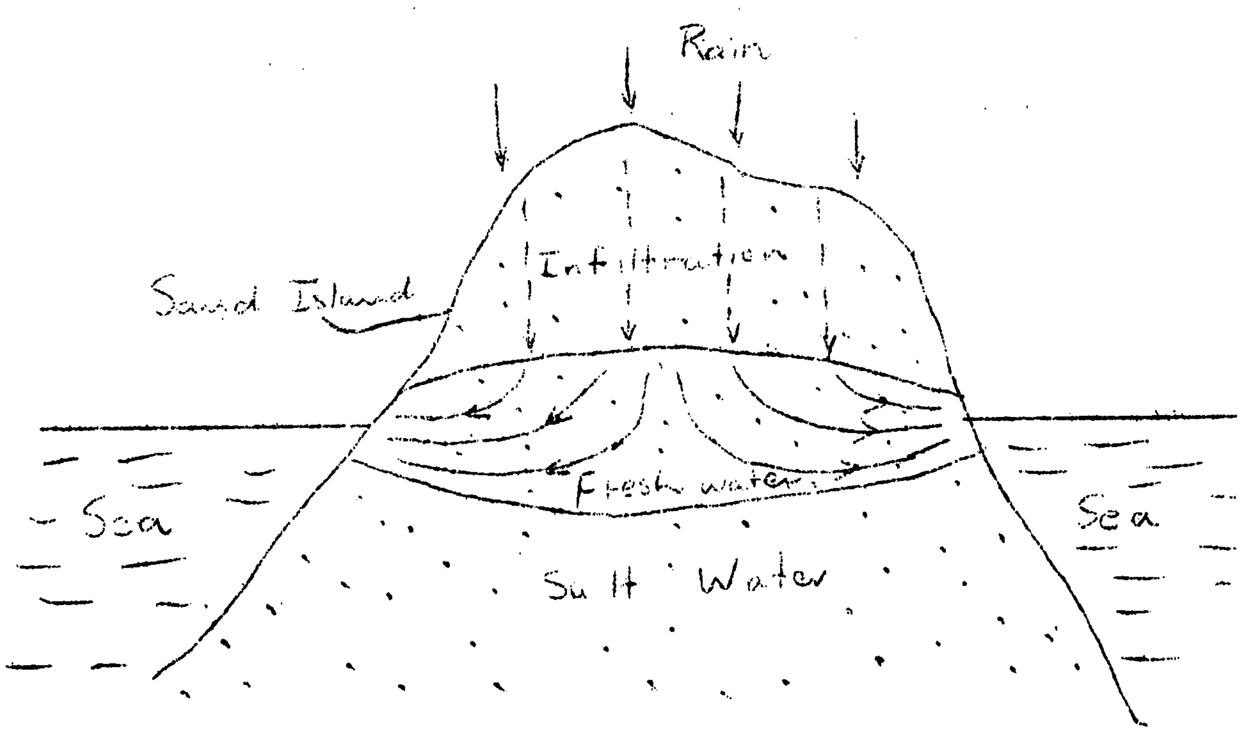


Fig. 4. The Ghyben-Herzberg lens, of fresh water overlying salt water.

Fresh-water aquifers in coastal regions always show some features of the lens so aptly shown by a section through a sand island. The exploitation of fresh water underlain by salt is hazardous and must be accomplished by methods which guard against salt-water intrusion. In Israel, in the coastal dune area, a number of observation bores have been equipped with salinity meters with the sensing electrodes set at pre-determined depths.

A rise in salinity shows on the chart, and also impulses a warning mechanism.

It is sometimes possible to obtain a larger supply of fresh water by pumping simultaneously from the fresh-water and saline-water layers, as diagrammed in Figure 5.

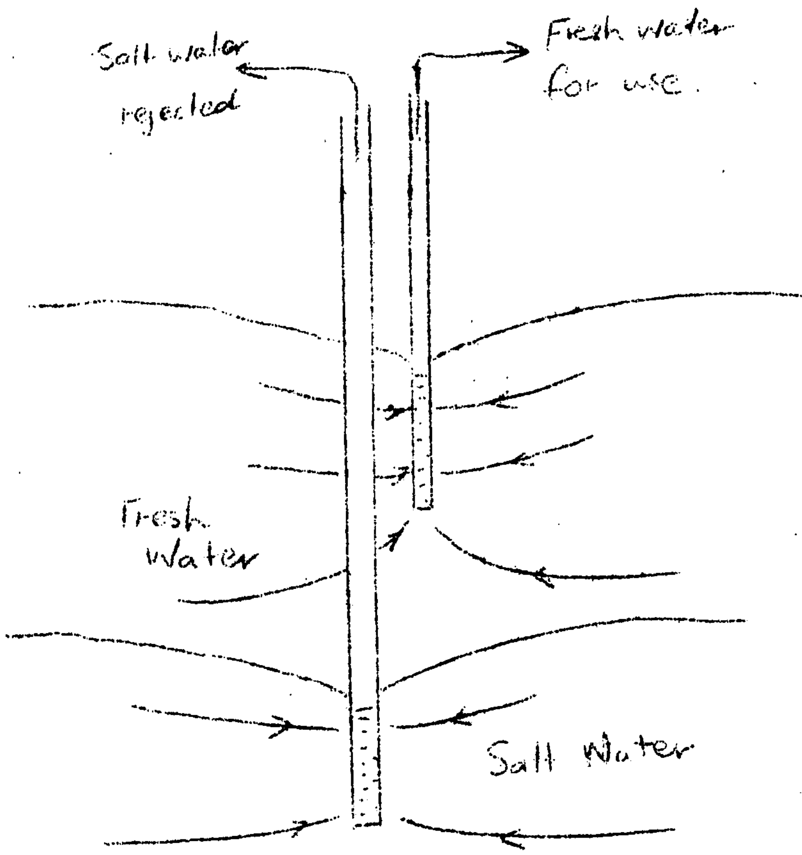


Fig. 5. Exploitation of a lens of fresh water overlying salt water.

A number of useful text-books are listed among the references.

List of references.

Collins, R.E. - "Flow of fluids through porous materials". (Reinhold, N.Y. 1961. pp.270).

Hantush, M.R. - "Hydraulics of Wells", appearing as a chapter in Advances in hydroscience. Vol. I. (Academic Press, 1964).

Harr, M.E. - "Groundwater and seepage". (McGraw Hill, 1962. pp.315)

Muskat, M. - "The flow of homogeneous fluids through porous media". (McGraw Hill, 1937 and second printing 1946, pp.763).

Polubarinova - Kochina P. Ya. - "Theory of groundwater movement". (Princeton Univ. Press. 1962, translated from the Russian edition of 1952).

Scheidegger, A.E. - "The physics of flow through porous media". (Macmillan, 1957. pp.236).

Schoeller, H. - "Les Eaux Souterraines". (Masson & Co., Paris 1962. pp.642. in French).

Todd, D.K. - "Groundwater hydrology". (J. Wiley & Sons 1959, pp.336).

de Vries, D.A. - (1959) - The influence of irrigation on the energy balance and the climate near the ground. J. Meteorology 16 : 256-270.

THE UTILIZATION OF GROUNDWATER FOR TOWN AND INDUSTRIAL SUPPLY

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SUMMARY OF POINTS TO BE DISCUSSED.

1. The basic requirements of a water supply system.

2. Quality.

   (1) toxic constituents

   (2) bacteriological levels

   (3) radioactivity

   (4) physical and chemical properties such as colour, turbidity, salt content, hardness, taste, smell, dissolved gases

   (5) industrial standards

3. Definition of adequacy.

4. The features that comprise a water supply system.

   (1) Source

   (2) Pressure control system

   (3) Treatment works

   (4) Trunk main(s)

   (5) Reticulation mains

   (6) Services

   (7) Storages

   (8) Boosters

5. Quantity.

   (1) Per capita consumption

   (2) Per service consumption

   (3) Fluctuations within a year

   (4) Ratios of fluctuations to average conditions, for

      (a) worst month

      (b) worst week

      (c) worst day

      (d) worst hours

(5) Examples of systems having

(a) very large source

(b) average conditions

(c) limited source

(d) intermittent source

6. Pressure requirements and limits.

7. Future Demands.

(1) How far ahead

(2) Population increases

(3) Per capita increases

(a) reasons

(b) amount

(4) Likely split-up of quantity

(5) Importance of gardening

(6) Application of city figures to other areas

(7) Possible design data

8. Economic Considerations.

(1) Large storages - risk when not provided

(2) Location of source in relation to activity

(3) Future cost and prices of water

(4) Reuse of effluent from sewage treatment plants

(5) Market gardens and reticulated supplies.

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