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THE TUBE-WELL PRACTICE OF THE PUBLIC HEALTH CIRCLE, P. W. D. PUNJAB.

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1. Introduction.

This paper attempts to describe the practice followed in the Public Health Circle in the design and construction of tube-wells and gives generally the conclusions derived by the author regarding the lines on which experimental investigation is desirable together with indications as to the most suitable sizes of wells and types of plant, likely to be useful for irrigation and other purposes.

Although tube-wells of the type now in use in the Punjab had been employed on an extensive scale in the United States of America for many years previously, the first developments of comparatively large tube-wells in India took place about 20 years ago by the introduction of the Brownlie and Ashford strainers patented and manufactured in India. This development was of considerable value in connection with proposals for water-supply for towns and institutions and a number of such schemes have, during the past 16 years been based on tube-wells as sources of supply.

These include the Lahore Water Works where at the main Headworks at Badami Bagh, the supply is drawn from batteries of percolation wells as well as from tube-wells, while in the civil station there are a number of independent tube-wells operated by the Municipal Committee, each of which supplies a definite portion of the distribution area. At Sialkot, Multan, Campbellpur and Dera Ghazi Khan the supply is drawn from tube-wells, while at Ambala, tube-wells intended to augment the supply, were sunk in the beds of the percolation wells originally provided in connection with the Handesra water-supply headworks.

The chief advantage of tubewells as sources of supply rests in the complete immunity of the water from pollution if drawn from a sufficient depth below the surface, which is not obtainable with any other water, without some form of treatment.

For this reason tube-wells have been employed largely as sources of supply for smaller schemes in connection with public and private institutions, particularly at Lahore where subsoil conditions are very favourable, and early in 1928 there were upwards of 82 tube-wells in operation at

Lahore made up as follows :—

	No. of wells.	*Estimated average daily supply in gallons.*
1. Government Tube-wells ..	21	453,000
2. Municipal Tube-wells ..	19	1,800,000
3. N.-W. Ry. Tube-wells ..	5	623,000
4. Private Tube-wells ..	37	270,000
Total ..	82	3,146,000

The estimated average supply above given only represents the water actually pumped from the wells, which in most instances is much below that which could be obtained with continuous pumping during day light hours.

Many of these wells, particularly those owned by private persons are small, being only designed to supply the requirements of their owners.

The wells are mostly equipped with electrically driven centrifugal pumping sets, varying in size from 1 B.H.P. to 30 B.H.P., or more ; most of these are of the horizontal direct coupled type, but some of the Railway wells and also one well at the Mayo Hospital, are fitted with electrically driven vertical spindle pumps.

Tube-wells, as sources of water not only in connection with public and private water supplies, but also for industrial and irrigation purposes are rapidly increasing in those areas where subsoil conditions permit.

The work of the Public Health Circle relates to the provision of public water supplies of towns and of water for institutional and industrial purposes, and the tube-wells under such conditions form comparatively small although important, portions of the complete schemes which also include storage reservoirs, distribution pipelines, rising mains and other incidental works ; moreover, the hours of operation are restricted as compared with those of wells employed for purposes of irrigation or prevention of water logging, while the sizes of the wells, being governed in many instances by moderate daily demands for water, are small, in comparison with the most economical type of well suitable, say, for irrigation purposes, where it is necessary to obtain the greatest volume of water compatible with the smallest capital and operation costs.

2. Types of strainers in use.

The following strainers have been used from time to time :—

(*a*) **"Cook Strainer".**—This is manufactured in America and consists of a solid drawn brass tube slotted with wedge shaped horizontal slots. The slots are cut with a circular cutting tool from inside the tube to various gauges to suit the coarseness of the sand, the usual gauges in the Central Punjab varying between 6/1,000" and 16/1,000." The strainer is sometimes used in America, fitted inside a perforated wrought iron or steel casing pipe, but this type has not been used in the Punjab as far as the author is aware. The strainer lengths are generally jointed together by means of screwed collars of brass.

This strainer has been used with satisfactory results in the following tube-wells :—

Sialkot Waterworks	..	1	Tubewell.
Multan Waterworks	..	1	,,
Mayo Hospital, Lahore	..	1	,,
Dera Ghazi Khan Waterworks	..	1	,,

(*b*) **"Tej Strainer".**—This is manufactured by the Reliable Water Supply Service of India at Lahore, and consists of a brass sheet bent round to form a tube, the vertical joint being brazed. The slots are wedged shaped, cut before the sheet is bent, to various gauges to suit the coarseness of the sand. The strainer is made in 8' lengths generally, and from 3" dia. upwards, the lengths being joined together by means of screwed collars of brass.

This strainer has been used with satisfactory results so far in the following tube-wells, amongst others :—

Lahore Race Course,
Lahore Water Supply Extensions (10 wells),
Rasul School of Engineering,
Female Mental Hospital, Lahore,
Thanesar Fair, Kurukshetra, (3 wells),
Hydraulic Research Laboratory, Lahore,
Central Jail, Lahore,
Gazetted Officer's Estate Water Supply, Lahore,

and the following tube-wells are now about to be completed or are under construction :—

Multan New Central Jail (2 Tube-wells).
Chauburji Gardens, Lahore (2 Tube-wells).
Sialkot Water Supply, Tibba Tube-well.
Kasur Sub-Jail, Kasur.
High Court, Lahore.
Mayo School of Arts Boarding House, Lahore.
Police Lines, Lahore.
Mayo Hospital, Lahore, 2nd Tube-well.

This strainer is similar to the Cook Strainer, except that as it is not made from a solid drawn tube it is not so robust as the Cook nor are the slots cut so accurately. It possesses the advantage of being considerably cheaper and is easily obtainable, being locally manufactured.

(c) Layne and Bowler Strainers.

There are at least two types of strainers, *viz.*, an iron slotted strainer with shrouded oblique slots, and a wire wound strainer. The former type has not been used in this Circle, but three tube-wells with the latter have been installed in connection with the Multan Waterworks. The strainers are made in America and consist of wedge shaped steel wire, wound to a suitable pitch round a slotted or perforated steel or wrought iron pipe, the lengths being joined together by screwed collars. The strainer is heavy and robust and can stand rough usage, but having to be imported from America, it takes considerable time to get delivery.

(d) Ashford Strainer.

This strainer, the patent of Mr. John Ashford, late Superintendent, Central Workshops, Amritsar, consists of a wedge shaped brass or copper wire wound mechanically over an polygonal wrought iron or steel skeleton frame work.

The strainer is generally made in 8 feet lengths, the lengths being joined by half rings bound with wire and soldered over. The strainer has to be very carefully handled lest the wires are broken or displaced.

Recently, the strainer has been much improved by the provision of soldered strips externally, the full length of each edge of the polygonal cylinder, which makes it more difficult to displace the wires, and the manufacturers are now offering to provide screwed couplings to join the various lengths of strainers together, in place of wire wound half rings, at an extra of about 15 % on the cost of the strainer. The horizontal rings of the frame work of the strainer are now made of malleable iron for all sizes over 3". Up to about 2 years ago this was the strainer generally used in the Public Health Circle, and many tube-wells have been fitted with it ; such as for example :—

Maclagan Engineering College, Lahore.
Veterinary College Tube-well, Lahore.
Industrial Buildings, Shahdara.
New Maternity Hospital, Lahore.
Government House, Lahore.
Government College, Lahore.
Government College Hostel, Lahore.
Central Training College, Lahore.
Jullundur Municipality, Empress Gardens Tube-well.
Legislative Council Chamber, Lahore.
Medical College, Amritsar, and many others.

The strainer is manufactured by the Empire Engineering Co., Ltd., Cawnpore.

(*e*) Brownlie's Convoluted Strainer.

This was the patent of Mr. T. M. Brownlie, Agricultural Engineer to Government Punjab, and is manufactured by the Empire Engineering Company, Limited, Cawnpore. The strainer consists of a polygonal convoluted steel tube round which a copper mesh strainer consisting of heavy parallel copper wires woven with copper ribbon is placed. This strainer has not been much used in this Circle for a considerable period, as it was a competitor of the Ashford, which was more favoured at the time.

(*f*) Leggett cleanable strainer.

This is a new strainer provided with cleaning devices in the shape of cutters which can be turned in the slits and it is claimed, by this means, that the "clogging" of the strainer by the deposition of solid matter on the outside of the strainer and in the slits, found by experience to take place, can be prevented.

The cutters are operated from the surface. The strainer is said to be somewhat expensive and has, so far, not been tried out in the Public Health Circle, but recently it has been installed in a tube-well at Dera Ghazi Khan Waterworks as an experiment.

American writers mention the Johnson strainer as being very satisfactory. It consists of a strip of brass of special section spirally wound. Successive turns of the strip interlock, forming a continuous cylinder of any desired length and diameter. Between the strips a narrow slit of any desired width is formed on the outside, through which the water passes into an interior annular ring, and thence through large circular holes into the well, the slit being from '004 to '02 inches wide. This strainer has not been used in this department.

3. Comparison of various strainers.

The Brownlie and the Leggett strainers are not dealt with, as the author has not had personal experience of them, so far.

The points considered are :—

(*a*) cost,

(*b*) ease of handling,

(*c*) general robustness,

(*d*) liability to electrolytic action,

(*e*) convenience in obtaining,

(*f*) yield.

The table below gives in order of merits, the strainers in respect of the first five points, based on the author's personal experience.

(a) Cost.	*(b) Ease of handing.*	*(c) General robustness.*	*(d) Liability to electrolytic action.*	*(e) Convenience in obtaining at Lahore.*
1. Ashford.	Cook.	Layne and Bowler, Cook.	Cook, Layne and Bowler	Tej, Ashford.
2. Tej.	Tej.	Tej.	Tej.	Cook.
3. Layne and Bowler.	Layne and Bowler.	Ashford.	Ashford.	Layne and Bowler.
4. Cook.	Ashford.			

The question of yield is dealt with separately later.

There are 2 other points which should influence the determination of the relative merits of various types of strainers. The first is freedom from clogging. This is discussed later.

The second is convenience in purchase. It is obvious that boreholes cannot be kept open for indefinite periods awaiting delivery of foreign strainers which take months to obtain, and very often it is inexpedient to order forward strainers until the borehole is made. We have, therefore, been more or less driven to the utilization of strainers made in India largely as a matter of convenience, apart from the fact that their cost is lower.

4. Cost of strainers.

The cost of American-made strainers of the Cook type in particular is prohibitive in India, but the wire-wound Layne and Bowler strainer compares favourably with the Tej strainer, for medium sizes.

The cost of the 3 Indian made strainers, Ashford, Brownlie and Tej is tabulated below :—

Diameter.	*Rate per foot.*			
	Ashford with ring joints.	*Ashford with screwed couplings.*	*Brownlie.*	*Tej.*
	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.
2″ ..	8 10 0	8 15 0	..	..
2½″ ..	..	..	8 10 0	..
3″ ..	9 12 0	11 2 0	..	8 0 0 (1/16″ thick)
3½″ ..	..	..	9 12 0	..
5″ ..	13 6 0	15 6 0	13 6 0	24 0 0 (1/8″ thick).
7″ ..	18 10 0	21 7 0	18 10 0	32 8 0 (5/32″ thick).
9″ ..	22 12 0	26 3 0	14 4 0	54 0 0 (3/16″ thick).
10″ ..	14 4 0	27 14 0	..	54 0 0 (3-16″ thick)
12″ ..	30 6 0	34 15 0	30 6 0	..

The Reliable Water Supply Service who make the Tej strainer, state that the cost of a 12" Tej strainer would be about Rs. 60 per foot and and that of a 14" Tej strainer Rs. 70 per foot. Recently it has been brought to notice that a firm in England Messrs. S. H. Marden and Co., Ltd., London is arranging to turn out a solid drawn brass strainer of the Cook type at a cost delivered in India which is likely to be competitive with the present rates charged by the makers of the Tej strainer.

A solid drawn strainer is naturally stronger than a brazed strainer, nor is there so much liability to damage or distortion of the slits as in the case of a strainer made from a sheet of brass in which the slits have been previously cut.

Since the introduction of the Tej strainer in the market about 2 years ago, the manufacturers of the Ashford strainer have effected improvements in design.

5. Discharge per unit area of strainer.

The discharge of a strainer appears to be proportionate to the depression head subject to a correction for friction in the well itself.

A statement of particulars of various tube-wells and their initial yields is given in Appendix No. I annexed. It will be observed that the discharge per unit area of strainer varies considerably not only from place to place, but also with a series of tube-wells put down close together. It is thus impossible, in the light of information available, to attempt to draw more than very rough and ready approximations as to the yield to be expected from various lengths and sizes of strainers.

In a battery of 4 tube-wells at Multan Waterworks, placed at 600 feet intervals, the yield on test varied from 8·7 gallons to 17 gallons per hour per square foot of strainer per foot depression head, the average working out to 12½ gallons per hour per square foot per foot depression head.

In a battery of 10 tube-wells put down in 1927-28 at Minto Park, Lahore, in connection with Lahore Waterworks, with nine 5" Tej strainers and one 7" Tej strainer, varying in length from 12 feet to 80 feet per tube-well, the yield per square foot per foot depression head varied from 10 to 32 gallons per hour, the average yield being about 22 gallons per hour per square foot per foot depression head.

At Lahore where subsoil conditions are very favourable, the present practice in installing tube-wells with 5" Tej strainers is to calculate the area of strainer on the basis of from 5,000 to 6,000 gallons of water per hour for 80 square feet of strainer with a depression head not exceeding 4 or 5 feet. This is equivalent to a yield of about 15 gallons per square foot of strainer per foot depression head and is on the safe side.

The above figures do not apply generally by any means.

At Multan where the upper 200 feet of subsoil is very good, the writer has allowed in two recent tube-wells for 14 gallons per hour per square foot per foot depression head, with 7" Tej strainers.

At Sialkot, conditions are very similar to Lahore and the average yield from 3 new 10" tube-wells installed in 1925-26, each equipped with 80 feet of strainer, one being a Cook strainer and the other two Ashford, was nearly 20 gallons per hour per square foot per foot depression head. In this case, the yield from the Ashford and from the Cook strainers is not known separately. These replaced Ashford strainers put down in 1916 which practically failed in 10 years.

At Campbellpore Waterworks, the yield actually obtained from an Ashford strainer placed in sand, excellent for water bearing purposes to all external appearances, was less than 5 gallons per hour per square foot per foot depression head.

These results show that the safest way of designing tube-wells is to do so on the results obtained under similar conditions in the same area.

There are many causes for divergence in yield. The greatest, no doubt, is that the water bearing and water yielding characteristics as well as the stratification of the sands are continually varying, within very short distances, horizontally and vertically.

Various types of strainers have various sizes of openings to let the water through and in addition there are varying losses of head due to friction, not only in the tube-well strainers but in the plain pipes above.

This latter factor is not taken into account generally, but in the case of a deep well of small diameter with a high discharge it might form an appreciable proportion of the depression head.

In regard to the comparative yield of various types and makes of strainers, it is impossible, in the absence of comparative tests of various types, *put down in tube-wells side by side close together in the same strata* to give definite information, but it would appear from the general results obtained, that, size for size, a tubular slotted strainer such as a Cook or a Tej is able to give an appreciably greater initial yield per square foot than a wire wound or meshed strainer of the same size at the same depression head, under similar conditions. The cause is probably the greater smoothness of bore and less constriction of water-way inside a strainer of the tubular type.

6. Clogging—Life of a well.

No experimental work on " Clogging " has been carried out, but it has been found generally in the Punjab that all types of strainers have tended to diminish in yield with the progress of time.

A marked example is Dera Ghazi Khan, where the strainers used in the town water-supply scheme became coated with calcium carbonate and iron and there was a diminution in yield of 60 % in two years.

At the Sialkot Waterworks, the average discharge of 6 wells sunk in July 1916 and fitted with 5" Ashford strainers, was 148 gallons per minute against 4 feet depression head, while in January 1923, the average discharge with the same depression head was 55 gallons per minute. In

this case, the reduction in yield was 63% in 6½ years. A tube-well with 48 feet of 7" Ashford strainer at the Legislative Council Chamber, Lahore, put down in 1920, yielded initially approximately 10 gallons per hour per square foot of strainer per foot depression head. In May 1928, its yield had dropped to 6·9 gallons per hour per square foot of strainer per foot depression head, representing a decrease of 31 % in 7½ years. The well was worked on the average between 3 and 4 hours daily and the deterioration would probably have been greater if the daily hours of working had been longer.

The causes of clogging are not definitely known. The subsoil waters of the Punjab invariably possess a certain degree of temporary hardness and traces of iron are almost invariably found. There is also generally, carbon dioxide in solution. One theory is that due to reduction of pressure owing to pumping, some of the carbon dioxide is evolved and calcium carbonate precipitated. Another contributory cause may be a tendency for the sand to get packed and consolidated round the strainer, thus diminishing its porosity and if there are clay particles mixed with the sand, these, drawn by the flow of water will travel towards the strainer and further reduce the porosity by blocking up the passages between the sand grains.

It is probable that whatever may be the cause of "clogging," the comparative rate of "clogging" will be found to be in relation with the quantity of water drawn through the strainer for any given well. This being so, wells pumped for long periods daily or to considerable depression heads would seem to be likely to clog at a faster rate than wells worked for short hours or to low depression heads.

The deterioration or depreciation in yield due to clogging is not peculiar to the Punjab or to India and the same phenomenon has been observed in the case of tube-wells in America equipped with strainers, with narrow openings, of the types used in the Punjab, although there is no proof that the cause of clogging is the same.

A perusal of the figures given in Appendix No. 4 (I) attached will show that the average depreciation on irrigation wells in favourably subsoil, ranging from ½ cusec to 2 cusecs in capacity, due to clogging, is responsible for a share of the total annual charges inclusive of pumping, varying from 17 % to 26 %, depending on the size of the well.

This is on the basis of an average 10 years' life. If by eliminating clogging, the life of a well is extended to 20 years the saving in operation charges will be from 8½% to 13%. While this saving is not as great as might be imagined on first thoughts, nevertheless it is still a very important and considerable item and any improvement of strainers likely to be successful in preventing clogging action is worthy of being given a full trial.

The first Leggett strainer has recently been installed in a tube-well at the Dera Ghazi Khan Waterworks. It will be some little time before it will be possible to report whether the claims made for

this strainer have been completely fulfilled and also whether the apparatus for clearing the slits has withstood the test of time. The Dera Ghazi Khan Waterworks are notorious as being a bad place for clogging, and on this account, the results of the trial will be of immense value.

7. Size of slits or openings.

The Ashford and the Brownlie strainers are generally supplied with openings of a standard gauge, while the tubular slotted strainers such as the Cook and Tej are slotted to various gauges, generally from 6/1000" to 20/1000".

It does not appear to be essential to provide slits of varying gauges within limits. This is proved by the fact that Ashford strainers and Cook strainers with more or less uniform sizes of openings have ben used in varying qualities of sands. At the same time, it would appear more reasonable to attempt if possible to fit the size of the slits to the size of the sands. This is done generally in the case of the Cook, Tej and Layne and Bowler strainers.

The method reported to be adopted by the makers of the Tej strainers is to sieve a sample of the sand, after drying it, through sieves of 4/1000" 6/1000", 8/000," 10/1000," 12/1000" and so forth, commencing with the smallest sieves. until a certain proportion of the sand is passed through. The strainer slits are cut to the gauge of the last sieve used. They state that in the case of tube-wells fitted with air lift plants, they make the strainer slits of the size of the last sieve used when about 80% of the sand is passed through, while for wells equipped with centrifugal pumps, the slits are cut to the size of the last sieve used after from 40% to 60% of the sample is passed through.

When a tube-well is first pumped, fine grains of sand and silty matter from the outside of the strainer are drawn through by the water into the well thereby loosening the surrounding strata and causing its porosity to increase.

There is certainly arch action of the sand grains, against the slits of the strainer as well, but this not fully effective. Pulsating action, such as that caused by the action of a reciprocating pump tends to break down the arch action and this results in more sand passing into the well.

For the ordinary "coarser" sands, the sizes of the slits in the Cook or Tej strainers normally used, vary from 8/000" to 16/1000".

The area of slits or openings per square foot of strainer is greatest in wire wound or meshed strainers. In the Ashford strainer this generally works out from 14 to 20 square inches per square foot of strainer. In the case of the Cook or Tej strainer, the figures are much less and are as follows as actually measured from a section of 5" strainer of the Cook type recently inspected.

Area of openings in Cook Type Strainer.

Size of slits.	Area of slits per square foot of strainer.
16/1000″	.. 10·24 sq. inches.
14/1000″	.. 8·96 ,,
12/1000″	.. 7·68 ,,
10/1000″	.. 6·4 ,,
8/1000″	.. 5·12 ,,
6/1000″	.. 3·84 ,,

The area of slits or openings, between the limits above given, do not appear to influence the initial yield of the tube-well to any appreciable extent.

This is in consonance with theory.

The discharge through small orifices may be taken as

$Q = C A \sqrt{2gh}$

Q = discharge in cusecs

C = Coefficient of discharge, taken at about ·6

A = Area of orifice in sq. ft.

h = Head in feet.

Take the case of a tube-well fitted with a strainer 5″ i/d by 60 feet long provided with slits of area 10 sq. inches per sq. ft. of strainer, and giving a discharge of 10,000 galls : per hour at 6 feet depression head.

$Q = {\cdot}45$ cusecs, $C = {\cdot}6$, $A = 5{\cdot}46$ sq. ft.

$$Q = {\cdot}45 = {\cdot}6 \times 5{\cdot}46 \sqrt{32h}, \quad \sqrt{32h} = \frac{{\cdot}45}{{\cdot}6 \times {\cdot}546}$$

$$32h = \frac{({\cdot}45)^2}{{\cdot}6 \times 5{\cdot}46} = {\cdot}02\ h, = {\cdot}006 \text{ ft.}$$

The loss of head with constant discharge varies inversely as the square of the area of the orifice.

If the slot area is halved, the loss of head will be ·025 feet which is 4 times as much.

The probable advantage of providing for greater slit area than actually required theoretically is that by this means the discharge per unit area of slit is reduced and interference due to clogging may be delayed thereby ; furthermore, after clogging action has been in progress for some considerable time, if the slit area orginally provided is many times in excess of that required theoretically, the throttling effect upon the yield of the strainer will be delayed. There are no records available of any tests showing the effect of slit area on the depreciation of yield due to clogging.

8. Screening or Shrouding.

Shrouding is not needed with tube-wells sunk in the ordinary water bearing sands met with in the Central Punjab equipped with any of the strainers generally employed, and where shrouding of coarse sand has been so used, no beneficial effects have been observed. On the contrary, with a light wire wound strainer such as the Ashford, or even with a light tubular slotted strainer such as the "Tej" there is a certain amount of risk of the screening or shrouding material gripping between the casing pipe and the strainer and displacing the wires or otherwise damaging the strainer in the course of the withdrawal of the pipe.

No case of collapse or settlement round a well due to the ommission of shrouding between the casing pipe and the plain pipe or strainer is known to the writer. In certain circumstances, however, there might conceivably be settlement or collapse due to the space between the casing pipe and the plain pipe above the strainer being left unfilled. This could be remedied by introduction of sand filling between the casing pipe and the well after the casing pipe has been withdrawn clear of the strainer.

Shrouding is necessary in the case of a tube-well fitted with a strainer with comparatively wide openings or slits, in order to act as a filter to prevent large volumes of sand being drawn into the well. At the Baku Waterworks in South Russia, the wells put down in 1913 are provided with coarsely perforated iron strainers surrounded by graded shrouding consisting of small gravel, in order to keep back the sands of the water bearing strata which consists of water borne gravels and coarse sands.

The gravel developed wells of America would seem to be designed on similar lines except that the gravel shrouding is fed from the surface from time to time to take the place of sand pumped out with the water, and ultimately extends over a wide diameter round the well, sometimes many feet in thickness.

Such wells have not been tried in the Punjab as far as the author is aware, but it would be of value to make extended experiments to determine the feasibility and cost of similar wells, as it is possible that these may prove cheaper and more successful in the long run than the present type of "strainer" wells.

9. Development of tube-wells.

The yield from a strainer type of tube-well generally increases to an appreciable extent after the well is first put into use. This is due to the loosening of the sand strata in close proximity to the strainer, the finer grains of sand silt and clayey matter being drawn through by the water. While this is proceeding, the water is charged to a varying extent by fine sand and silt and it takes from a few hours to a day or more to clear the discharge to such an extent that it is fit for human consumption, while fine sand and silt is carried through the strainer in a less degree for longer periods, extending to several weeks sometimes.

It is desirable to draw through as much fine material as possible in order to increase the porosity of the strata round the well. With this object, the well should be pumped continuously to as great a depression head, as possible till the water is cleared.

10. Sand Samples.

The Kennedy test and also, sieve tests of sands have been employed and in both cases satisfactory results have been obtained although neither method does more than give comparative results *i.e.*, indicate generally whether a specified sand is likely to be suitable in water yielding capacity. In determining the probable yield, it is absolutely necessary wherever possible to take into consideration the yield actually obtained from similar strata in the neighbourhood.

The yield does not depend so much upon the coarseness of the sand as upon its grading.

For example, at the Minto Park tube-wells put down for the extensions to the Lahore Water Supply Works recently, the best yields were obtained from the finer sands and not from the coarsest strata, probable because the former were more uniform in size and, therefore, more porous.

11. Discharge of single wells in relation to.

(a) length of strainer, (b) diameter of strainer (c) continuity.

It has been supposed in the past that the yield of a strainer depends upon its diameter and length, but there are no experimental data based on actual working conditions whereby any precise relationship has been determined and there are too many varying and indeterminate factors of which the greatest is the varying characteristics of the subsoil itself, to allow of the yield of any specific strainer to be predicted with any precision.

The following are the general results obtained :—

(a) The yield per square foot, per foot depression head, with small diameter strainers averages much larger than with large strainers, so much so indeed that it would appear in some instances that the total yield for the same length of strainer is nearly independent of the strainer diameter, within certain limits of sizes.

(b) The yield per square foot, per foot depression head, with short strainers averages larger than with long strainers. This is probably due to the fact that there is greater scope for selection of the best water bearing strata when dealing with short strainers.

It is very difficult to lay down any hard and fast rules and the above are given only as rough indications of the lines on which experimental research is desirable.

Very little data is available as to the effect of continuity of strainer on the discharge and in the writer's practice this factor is disregarded entirely as being of little importance as compared with the advantage of placing the strainer lengths in those layers of strata which, by sieve test or Kennedy test, appear to be the best for water yielding purposes.

The conditions are not the same for wells put down for prevention of waterlogging, as for those required purely for water supply or irrigation. In the former class it is necessary to keep the strainer lengths above any thick impervious layers which may tend to shut off the surface water from the more deep seated supplies and the same selection or choice of strata will probably not be available as in the case of water supply or irrigation wells which can be sunk deeper.

For wells for domestic water supply, it is an advantage to go deep in order to avoid risk of pollution and it is the practice not to place any strainer above 50 feet below the surface in such wells.

In order to obtain the best yields out of strainers, the top of the highest strainer in the well should be placed below the lowest level to which the water is likely to be lowered by pumping. This will of course depend on the discharge to be pumped and on the type of pumping plant employed.

12. Effect on subsoil water surface of wells singly or in groups.

(*a*) *Source of the water.*

As already pointed out, the character of the alluvial subsoil strata varies enormously within a comparatively short range, The various layers or deposits appear to be lenticular in shape, and the thicker any homogenous layer may be, the greater would appear to be its persistence in any direction horizontally.

There are still greater differences between the general character of the upper subsoil in various parts of the Province. In the Ravi basin at Lahore, a boring at Minto Park has disclosed that down to over 500 feet depth, there are almost continuous beds or layers of water bearing sands separated, here and there, at few places, by bands of clayey strata which seems to appear and die out at various levels.

At Ambala which is near the water-shed between the Indus and the Gangetic basin, there are mostly bands of clayey and five sandy strata, extending down to over 1,600 feet depth.

At Multan, Amritsar and Sialkot the Upper subsoil is somewhat similar to the Lahore subsoil, while in the Sourthern Punjab clayey, sandy-clayey and kankar beds generally persist.

The impersistent nature of the stratification of the alluvium, leads to the conclusion that there is likely to be a more or less general interconnection of water bearing strata laterally in many directions and this is supported by the fact that it has almost invariably been found that water level remains almost constant in the various water bearing strata pierced by any single boring. Any comparatively thick imperious bed, however,

is likely to cut off to a considerable extent the rapid passage of water to and from the beds above and below, in the event of water being abstracted from one or more of them. For this reason wells dewatering waterlogged areas should, if possible, not pierce imperious strata of appreciable thickness.

The source of the water in the subsoil is rainfall, originally, and the general lenticular formation of the alluvium is largely helpful in the matter of feeding water to the subsoil from the rivers and extensive canal system as well as from the porous detrital formations lying at the base of the hills.

(*b*) *Area affected by wells.*

The writer has no definite data in regard to the area of subsoil water surface affected by heavy pumping from a single well or a group of wells, such as might be required to dewater a piece of country side or to provide lift irrigation.

Experience, however, shows that pumping operations from a single well or group of wells to the moderate extent required for town water supply schemes (as opposed to irrigation or similar purposes) does not affect appreciably an area extending beyond a short distance from the confines of the headworks. The fact that such wells are not continuously pumped, generally, may have considerable effect on this question however.

(*c*) *Interference of wells.*

The effect of pumping to an excessive depression head has not been observed, but it would be well worth while to make experiments, keeping the bore of the tube-well as large as possible in order not to cause undue friction losses in the well above the strainer.

There are no data available as to the amount of interference felt between tube-wells at various spacings subject to heavy pumping, but it is known from experience that with tube-wells of moderate size, utilized for water supply works, spaced at intervals of 200 or 300 feet, the interference is not appreciable, possibly due to the fact that generally only a single line or two lines of wells are provided. If several lines of wells closely spaced were installed, the interference would be more felt and might necessitate greater spacing. It will be necessary to make special experiments with several lines of wells before any decisive data on interference can be obtained.

13. Sinking of wells.

For alluvial tube-wells of depth from 50 to 400 ft. say—the existing hand operated percussive system now in use is as cheap as any and in good easy subsoil strata a 250 feet or 300 feet tube-well can easily be bored and completed in 8 weeks.

At Thanesar, Karnal District, in October, 1928, with continuous day and night working, a 12″ bore was sunk to 300 feet depth, the strainer lowered and the casing pipe withdrawn in 19 days, but this of course was emergency work.

If the boring work is carried out by direct labour in good sandy strata, the labour charges of putting down a 6″ bore to 200 feet depth and withdrawing will not exceed from Rs. 2 to Rs. 2-8 a foot, or say Rs. 3 or Rs. 4 a foot for a 12″ bore. The cost of boring through hard clay or kankar is much higher and may amount to Rs. 10 to Rs. 20 a foot. Where a gravel or boulder stratum is likely to be encountered, with stones of 3″ to 6″ dia, it would be cheaper to sink a 12″ bore than a 6″ bore as the larger diameter lends itself better to the extraction of the boulders. A case of this sort was a bore made sometime ago at Musakhel in the Indus Valley. Tube-well contractors generally ask from Rs. 5 a foot for a 6″ bore to Rs. 7 or Rs. 8 a foot for a 12″ bore, inclusive of withdrawing and the use of all casing pipes and tackle and risk of loss of pipes and plant, carriage charges on plant, being extra.

Boring plant is liable to excessive wear and tear and for plant in continual use, heavy depreciation should be charged, the derricks, tubes, jacks, etc., being written off in say $2\frac{1}{2}$ or 3 years, while ropes, bags and timber must be written off much quicker still.

Under these circumstances, considering all factors and risk of losses, the rates asked by tube-well contractors for boring works are not high, for isolated tube-wells. If batteries of wells are put down close together, there is much saving of time and trouble to the contractor in waiting for plant and materials and a corresponding reduction in rates for boring work could be made.

The makers of the Tej strainer, generally charge nothing for lowering the strainer (*i.e.*, the cost of this is included in the price of the strainer). Other contractors charge 0-8-0 to Re. 1 per foot for lowering a strainer or plain pipe.

There is a small extra charge for making the joint between the strainer and the plain pipe.

The jet system of boring is used much in Bengal. This system is ideal in sandy and similar strata and could be employed in the Central Punjab. In strata consisting of bands of hard clays and kankars, however, the jet system is useless.

14. Possibility and cost of withdrawal of strainers.

Ashford strainers and Tej strainers have been withdrawn. A 7″ Tej strainer 84 feet long placed at a depth of 80 feet to 190 feet at a tube-well at Sialkot was recently withdrawn at a cost of Rs. 720 inclusive,

made up of the following items :—

	Rs.
Travelling expenses, etc.	87
Wages of Mistri and labour ..	345
Special bonus to Mistri	100
Miscellaneous charges	16
	548
10% contractor's profits	55
	603
Carriage of tools and plant to and from Lahore	175
Total Rs.	778

This may be considered a typical case of withdrawing. No case is known to the writer of an Ashford strainer having been withdrawn, being fit for reuse ; but two cases have been reported of Tej strainers having been withdrawn and reused. One of these is said to have occurred recently in a private tube-well at Sanda Road, Lahore, 16′ of 5″ strainer placed at 76′—92′ below ground level, having been lifted.

Generally, there would not be great difficulty in withdrawing a Tej strainer 50 to 80 feet long from 100 feet depth in favourable sandy strata, but failures would also certainly happen. The chances of success would be about even.

If it is intended to arrange, as a matter of routine, to draw all clogged strainers, strainers of a much heavier pattern than those now in use would be required and the strainer cost would be at least 50 % and possibly double. A strainer placed in a heavy perforated steel or wrought iron pipe, coupled by heavy screwed joints, would be best suited to such conditions and even then success could not be assured in all cases. It would probably be of considerable assistance in withdrawing, to provide means of attaching a cable or tension rods to the bottom end of the strainer.

15. Methods of installing strainers.

There are 2 methods of installing the tube-well strainers. The old method is to pass the strainer and the plain pipe forming its continuation up to the surface, through the borehole casing pipe to the correct depth, so that the strainer occupies its proper position in the water bearing strata. The strainer and its plain pipe are not strong enough to support their weight and, therefore, it is necessary that they should be continuously suspended in position by a rope from the surface, while the total depth of the boring should be about 10′ more than that of the completed tube-well to ensure that there is no chance of the bottom of the strainer touching the bottom of the bore. Care must be taken to test the depth of the bore just before lowering the strainer to make sure that the sand in the bottom of the bore has not risen.

The withdrawal of the casing pipes is commenced as soon as the strainer is lowered to the correct position, and as the casing pipe is raised the water bearing sandy strata moves into contact with and introduc lateral support to the strainer, until, when the final casing pipe is remc ed, the strainer is entirely supported laterally and there is no furt danger of buckling.

The top of the plain pipe of the well is generally fastened to girde at the top of well.

The boring or casing pipes are used over and over again in successive bores until they are worn out.

With strainers of the Cook or Tej type and where the subsoil to be bored through is good, light wrought iron or steel screw jointed casing pipes of " Steam pipe " strength can be used for the boring.

The strainer is lowered through the bore pipes to its correct position. The upper 4 or 5 feet of the strainer is left blank and the casing pipe is withdrawn till its bottom edge is just above the top slits of the strainer so that the strainer and the casing pipes overlap by about 4 or 5 feet. An annular lead ring is attached to the top of the strainer and caulked by a special heavy annular hammer into the space between the top of the strainer and the casing pipe to make the joint watertight.

The casing pipe is generally an inch or two bigger than the strainer, and the thickness of the annular lead ring joint should preferably be about $^3/_8$" or $^1/_2$", as thicker joint rings are liable to be forced out more easily. The advantages of this method over the old method are :—

(*a*) There is no heavy plain pipe likely to press on the strainer and damage it.

(*b*) The casing pipe also acts as the plain pipe and there is no cavity between it and the side of the bore, liable to cause a collapse.

The strainer can be withdrawn leaving the casing pipe in the ground The lead ring joint in this case has to be forced out by the withdrawing of the strainer.

About 20 wells have been contracted by this method in this Circle during the past two years and no case of failure has occurred so far.

16. Boring plant.

The equipment for a boring gang consists of casing or boring pipes, tripod or derrick, loading frame with a pair of crowbar winches, pulley blocks and rope tackle, sludgers or sand pumps, chisels, swivel hooks and rods, clamps, clips, screw jacks, sleepers and miscellaneous tackle depending upon the size of the boring, its depth, and the nature of the strata to be pierced.

The most expensive portions of the equipment are the casing pipes, while in regard to wear and tear, wire ropes, jacks, sludgers, bags and clamps form important items.

For shallow bores or for deeper bores in soft strata consisting mostly of sands, ordinary jointed wrought iron or steel pipes of steam strength will serve the purpose, but if casing pipes are to be sunk in hard clayey or kankar strata, or are intended to be used over and over again, the very best and thickest class of pipes, fitted with special screwed couplings such as swelled and crest joints which obstruct the passage of the pipes through the ground as little as possible should be employed.

All the leading steel pipe manufacturers such as Messrs. Stewart and Lloyds, Ltd., and Messrs. The British Mannesman Tube Co., Ltd., manufacture suitable standard steel casing pipes which are serviceable.

In the writer's practice, the length of casing pipes has been fixed at 10 to 12 feet in order that it may not be necessary to employ very tall and heavy tripods.

A number of failures have occurred from time to time due to boring pipes breaking, generally during withdrawal. The chief causes of failure of such pipes are as follows :—

(*i*) *Using pipes with defective joints.*

After a time the threads of the pipe joints wear and rust and the joints get stripped when tension is brought to bear on the pipes in the course of withdrawal.

(*ii*) *Screwing up joints cross threaded.*

This results in damage to the joints causing stripping when considerable tension is brought to bear on the joints.

(*iii*) *Not screwing up all joints fully.*

All joints should be threaded for a sufficient length that the joints can develope the full ultimate tensile strength of the pipe. Due to dirt and rust, it frequently happens that joints are not fully screwed up, with the result that stripping occurs when withdrawal is in progress.

(*iv*) *Eccentric loading.*

Cases have occurred of boring pipes having bent due to eccentric loading when sinking. It is necessary to avoid this by taking care to load the pipe centrally and support it in a vertical position during sinking operations, otherwise a considerable strain may be thrown on the pipe and it may fail at its weakest point, *viz.*, the joint. In this way, fracture may occur during sinking, but it may not show itself till withdra takes place, when the joint snaps and the casing pipes part compa

In order to avoid accidents as far as possible, the exposed thre all joints should be kept clean and oiled and protected by loose pr rings and all joints should be carefully inspected before the pipes into the ground.

All ropes should be specially flexible so as to pass round th provided in connection with the tripod, without risk of damage damaged or worn rope should be used, as a broken rope may mean of delay in fishing out boring tackle from the bottom of a borehole

17. Pumping plant for tube-wells.

(*a*) Conditions governing selection of pumping plant.

In considering the most suitable type of plant to be installed in any well, the following points have to be considered :—

(*i*) *Diameter of well.*

(*ii*) *Discharge.*

The diameter of the well must be fixed with proper regard to the discharge so that the friction looses due to the passage of the water may be kept within low limits. In the case of vertical spindle centrifugal submerged pumps and of borehole type reciprocating pumps there are limits to the diameter of plain pipe for pumps of various capacities of the best efficiency while in the case of other pumping plants, the diameter must be such as to permit of suction pipes and suction foot valves of reasonable size to be fitted inside. Generally the velocity of water in the suction should not exceed about 5 feet per second. Frequently these conditions necessitate the plain pipe of a tube-well to be made considerably larger in diameter than the strainer. The suction foot valve is required to be of a special design so as to pass through the smallest diameter possible consistent with low friction losses. The valve itself must also be light and strong. The actual discharge itself is also one of the most important factors governing the selection of the most suitable type of pumping plant.

(*iii*) *Depth of the well.*

To obtain the best efficiency with air lift plants, there is a minimum depth of submergence of the air pipe as compared to the total lift. This necessitates a definite depth of tube-well depending on the total pumping lift and independent of the length of strainer required.

(*iv*) *Depth of spring level.*

Where spring level is comparatively deep, the installation of pumping plant outside the well, such as horizontal centrifugal pumps or ordinary reciprocating pumps becomes an expensive and comparatively difficult matter, increasing in cost with the depth to spring level, as dry wells or shafts, chambers, tunnels and other structures will be required in order to instal the plant.

In the case of oil engine or steam driven horizontal centrifugal pumps, ·mps must be installed close to water level and special shafting and ·ay be required to enable the pump to be driven from the surface or · mover and pump may be installed underground close to water

.he case of reciprocating pumps, the same alternative methods of . also apply, but it is generally found preferable to erect the prime at the surface and transmit the power to the pump which is fixed ·e distance above water level, through gearing, rods, etc. When

pumping plants have to be installed deep below the surface, electricity is the best form of prime mover as electrically driven pumping plants are more compact, lighter, cheaper and easier to run and maintain than any other variety.

(*v*) *Variation of spring level.*

(*vi*) *Depression head.*

(*vii*) *Probable decrease in yield due to clogging.*

There are natural variations of spring level everywhere, the highest level of water being just after the monsoon while the lowest is just before the monsoon. The variation at Lahore is generally about 4 feet, but in places it may be as much as 10 feet, or more. If a horizontal centrifugal pump is employed under such conditions, the pump is generally fixed about 2 feet above the highest spring level, the loss of head in foot valve and suction pipe may be about a foot, leaving only 7 feet available for depression head when the maximum suction lift is 20', with spring level at its lowest.

If the life of a well is to be extended as long as possible, it is essential that the available depression head should be as great as possible. Take the case of a well in which there is a decrease of 8 % on the original yield annually, the initial depression head being 4 feet. The depression head required to maintain the yield will in course of time increase as follows, approximately :—

	Depression head.
1st year	4 feet.
2nd ,, ...	4·3 ,,
3rd ,, ...	4·8 ,,
4th ,, ...	5·3 ,,
5th ,, ...	5·9 ,,
6th ,, ...	6·7 ,,
7th ,, ...	7·7 ,,
8th ,, ...	9·0 ,,
9th ,, ...	11·1 ,,
10th ,, ...	14·3 ,,
11th ,, ...	20·0 ,,

Such a well fitted with a horizontal centrifugal pump would only be able to maintain its initial yield for about six years, but if it were provided with a pumping plant capable of dealing with a depression head up to say 30 feet below highest spring level, the well would be able to maintain its yield for more than 11 years.

Such high depression heads can only be obtained with vertical spindle centrifugal pumps, reciprocating borehole pumps or air lift plants.

(*viii*) *Pumping head.*

The pumping head is an important factor governing the selection of the most suitable type of pumping plant as certain types of plants are only suitable for operation within definite limits of pumping head and discharge.

(b) Types of Plants.

The following types of plants have been used from time to time :—

(*i*) Air lift.
(*ii*) Reciprocating,
(*iii*) Horizontal centrifugal.
(*iv*) Vertical spindle centrifugal.

(*i*) *Single air lift plants.*—are comparatively expensive and their efficiency is very low, *i.e.*, below 30% even under the best conditions. Although this is a serious disability from the point of view of economical pumping of water, this method should not be discarded entirely. Each case should be treated on its merits and the air lift installation should be compared both as to first cost as well as in cost of operation with other suitable methods, because in spite of low efficiency, it lends, itself easily to the pumping of water from a group of tube-wells, the compressed air being generated in a central compressor station, thus requiring much less costly operating staff as compared with other methods which may be far better in mechanical efficiency. It is possible, also under such circumstances, that the saving on plant and, therefore, on interest and depreciation charges, repairs and renewals as well as in staff charges will more than compensate for the comparatively low efficiency.

In this type of installation there are no moving parts in the well and this makes for reliability and long life. Where reliability of a water supply is a matter of primary importance, this type of plant is likely to prove one of the best, particularly when water level is deep below the surface.

Portable air lift plants, mounted on wheeled trucks, which can be moved from place to place over katcha roads and tracks, are the most suitable for testing and developing tube-wells before the permanent plant is fitted, as the discharge can be varied and the well pumped against high depression heads, facilitating the removal of the finer sands and silts in the strata surrounding the well and improving the yield. The plant is also useful is removing the effect of packing of sand and clayey materials round the well after a period of pumping and one or more portable air lift sets should always be available in connection with any organization for putting down or operating a large number of tube-well installations. The annual depreciation on the moving parts of air lift plants such as electric motors, switchgear, oil engines, compressors, etc., may be taken at 6 $^{2}/_{3}$ % tand repairs and renewals at 5% per annum.

(ii) Reciprocating Pumps.

There are two main types of reciprocating pumps which may be considered, *viz.*, borehole or deep well pumps placed within the tube-well, and horizontal or vertical pumps placed outside the tubewell in a dry well. The reciprocating borehole pump is popular in Europe in connection with boreholes and deep wells sunk generally into hard or solid water yielding formations such as the magnesian limestone or the chalk and is generally fitted with buckets and clacks of a comparatively high efficiency from the point of view of water losses. A modern reciprocating borehole pump fitted with multiple beat buckets and valves such as the "Pernis" type will give an efficiency of not less than 80 per cent. Its cost is comparatively high as it is a slow moving pump.

The pump can be operated by steam, oil engine, or electric motor through belt drive or gearing and the annual depreciation may be taken at 5 per cent. on the pump, $6\frac{2}{3}$ per cent. on oil engine or electric plant and 5 per cent. on steam plant while annual repairs and replacements may be taken at 3 per cent. on the pump, 5 per cent. on oil engine or electric plant and $2\frac{1}{2}$ per cent. on steam plant.

The pulsating action of pumps of this class has a tendency to destroy the arch formation of the sand grains outside the strainer slits and to cause the sand to be drawn through into the strainer, rendering this type of plant not very suitable for tube-well purposes. Where spring level is very deep there may be no feasible alternative however.

The reciprocating pump placed outside the well may be a single or multiple action horizontal or vertical ram or bucket pump driven by steam, oil engine or electric motor by belt, chain or gearing.

This type has the same inherent disadvantage of pulsating action already condemned in the case of reciprocating borehole pumps, but in the case of a multi-throw pump drawing water from more than one tube-well, this disadvantage is reduced to a sufficient extent to render such plant useable.

This arrangement is in force at the Lahore Waterworks (Badami Bagh Headworks), where a pair of large steam triple expansion rotative ram pumping engines of a capacity of 180,000 gallons per hour each, draw water through a long system of suction pipes from a number of open percolation wells as well as from 11 tube-wells. The mechanical efficiency of large modern pumps of this type is well over 90%, while the coal consumption per pump or water horse power per hour is under 3 lbs. The first cost of such plant is very high, considerable skilled supervision and attention is required over its operation and it is not suitable for low head pumping schemes such as tube-wells intended for irrigation or water-logging alleviation. The ram type of pump possesses a great advantage over a pump of the internally packed piston type or of the bucket type, inasmuch as it is able to main its original efficiency practically unimpaired for a long period of time provided the pump valves are kept in order and so long as the glands, which are externally packed, are looked

after, whereas any slight wear in the barrel or piston of a piston pump or of a bucket pump may lead to heavy water losses.

These pumps being positive, are capable of a maximum suction lift of 25 or 26 feet under good working conditions, as against about 16 feet for centrifugal pumps. The depreciation charges on large steam reciprocating pumps and steam boilers may be taken at 5 per cent. per annum, and repairs, replacements and renewals, 2 per cent. per annum on the first cost.

(iii) Horizontal Centrifugal Pumps.

This is the cheapest type of plant in first cost and is the one generally fitted on tube-wells in the Punjab, where spring level is not too deep.

For example at Lahore, where spring level is from 18 to 24 feet below the surface the Government tube-wells with one or two exceptions are provided with duplicate sets of horizontal centrifugal pumps operated by direct coupled electric motors. These plants are generally placed in circular wells or chambers ranging from 10 feet to 15 feet internal diameter (depending on the size of the plant) built of 14 inches brickwork, with floor level about 2 or 3 feet above normal spring level. Access is provided by means of a flight of reinforced concrete circular stairs in an access shaft from 6 to 8 feet in diameter. A large ventilator with removeable reinforced concrete slab cover is provided on the roof of the pump chamber. This slab cover is removed to enable the plant to be lowered and installed or withdrawn for repairs. The pumps have a common delivery pipe from 3″ to 6″ diameter on which a suitable Helix meter (interchangeable mechanism type) to register the discharge of the well, is fitted as standard. There is a common suction pipe, generally from 3″ to 6″ diameter passing into the well to a depth of 18 or 20 feet on which a specially compact cast iron or brass foot valve with leather faced or ground in valve is fitted, the head of the well being closed by a flange bolted up in two halves round the suction on the top of the well pipe, in order to prevent anything from being thrown into the well accidentally. There is one sluice valve fitted on the delivery side and one on the suction side of each pump, while each pump is provided with a 6″ pressure gauge reading in lbs. per square inch and feet head of water, and a 6″ compound gauge.

Most of the wells perform the double duty of supplying domestic water, pumped to high level tanks or reservoirs against a head varying from 50 to 90 feet, and also irrigation water for lawns, playing fields, gardens, etc., against a head varying from 20 to 40 feet.

In order to provide for this, where direct current electricity is available, shunt regulation is employed.

Generally, the pumps are of the horizontal split casing double inlet type, with the impellor shaft supported by two long ring oiled bearings, on either side of the pump, independent of the glands, and it has been found to pay everytime to put in good quality of pumps even at extra initial cost.

The switchgear consists of the usual standard wall mounting type and an ammeter is always fitted, the attendant being instructed how to regulate the speed without overloading the electric motor.

These installations have to be kept working regularly every day as there is no alternative source of supply. Experience has taught under such circumstances, it is necessary to duplicate the pumps in order to provide a standby for emergencies. The cost of water obtained from these installations, based on the cost of maintenance and operation of the plant and repairs to works such as pipelines, tanks, fittings, etc., varies from 4 annas to 8 annas per thousand gallons of water. This figure does not include interest and depreciation charges.

The chief disadvantage of this type of plant is the limited suction lift, which may be taken as 15 or 16 feet under normal conditions. The efficiency varies from about 40 per cent. in the smallest sizes to about 80 per cent. for very large units, while the depreciation may be taken at $6\frac{2}{3}$ per cent. per annum and cost of repairs and replacements, say 5 per cent.

Highly skilled supervision is not required in operation and maintenance.

By reason of the low suction lift, the pump must be placed within a short distance of water level and long suction pipes must be avoided. The pump, not being positive cannot prime itself. For these reasons, it is not suitable for drawing water from a series of tube-wells. The life of a tube-well equipped with this type of plant will be generally shorter than that of a tube-well equipped with plant capable of dealing with a large depression head such as air lift or vertical spindle borehole pumps. The installation also requires structural work of appreciable if not considerable cost, depending on the depth of water level below the surface, in order to house the plant near water level.

These are serious disadvantages, more particularly on the case of wells designed for irrigation supply, where it is essential that water shall be provided at a minimum cost. It is desireable therefore to obtain the greatest possible life out of the well and to spend the least money on permanent structural works.

(*iv*) *Vertical Spindle Centrifugal Pumps.*

There are two main patterns, *viz.*, the open type vertical spindle and the borehole or deep well vertical spindle, in which the pump and vertical spindle is slung from the surface inside the borehole tube, the impellor, or the lowest impellor, if there is more than one, being placed below the lowest depressed level of the water, if possible.

The shaft bearings of the borehole type of pump in the water can be lubricated by water, oil, or grease while there are various types of impellors and propellors such as radial flow, axial flow and combinations of both.

These classes of pumps are ideal for use for tube-well pumping schemes and can be driven electrically by direct coupled vertical spindle electric motors over the well, or by belt drive with or without gearing

from oil engines placed at ground level. Pumps of the "Turbine" type are preferable for low heads applicable to water-logging or lift irrigation schemes.

The efficiency varies considerably with the discharge and the head and it is necessary that wells of comparatively large diameter should be provided in order to allow of the plant giving the greatest efficiency possible.

Pumps of this class are manufactured by a number of British, Continental and American firms.

The following are figures furnished by the courtesy of Mr. C. King, the Resident Manager for India of the Byron Jackson Pump Company of California, relating to their standard vertical spindle Turbine pumps for boreholes operated by A. C. Electric Motors, 400 volts, 3 phase, 50 cycles.

Turbine Pumps for Tube-wells.

Working head 40 feet—Depth to spring level 15 feet.

1. Capacity of plant ..	½ cusec	1 cusec	1½-cusecs	2 cusecs.
2. Minimum dia. of well ..	8″	10″	12″	14″ }
3. Recommended dia. of well	10″	12″	14″	16″ }
4. Speed of pump ..	1,450	1,450	1,450	1,450
5. Guaranteed pump efficiency	58 %	61%	67%	70%
6. Guarantee motor efficiency	85%	87%	90%	88%
7. Motor rating (35° temperature rise) ..	5	7·5	10	15

For a large scheme for tube-wells, it is desirable that vertical spindle pumping units whether electrically driven or operated by oil engines or other prime movers, should be standardized as far as possible with interchangeable parts and in addition, the installations should be designed so that the pump may be rapidly dismantled and withdrawn from the tube-well and replaced so that no time is lost when it is found that a pump requires to be repaired or replacements are fitted.

This type of plant is one of the most suitable generally for tube-well purposes, as, coupled with a comparatively high efficiency, it also permits of pumping to a large depression head. All centrifugal pumps are inherently self-regulating to varying extents, which means that as the working depression head increases, the discharge is reduced. This characteristic fits in with the characteristic of tube-wells.

The other class of vertical spindle pumps, *viz.*, the open type, offers no advantage over horizontal centrifugal pumps generally and their cost is higher. They are not suitable for tube-well purposes therefore.

The rate of annual depreciation on both classes of pumps may be taken at 6 ⅔ per cent. and the same figure applies to electric motors and oil engines and gearing. The cost of repairs and renewals for the pumps, electric plant and oil engines may be taken at 5 per cent. per annum.

Summarizing briefly, it is suggested that for tube-wells to be installed for irrigation or water-logging, either air lift plants, or vertical spindle borehole type centrifugal pumps should be installed. The final choice between these in respect of each scheme should be made, after considering their capital and operating costs in detail under the conditions required. These conditions may differ with various installations to such an extent that whereas for one scheme, air lift may be better, for another, vertical spindle centrifugal pumps may be cheaper.

18. Cost of Wells.

In Appendix No. 2, the estimated approximate comparative cost of tube-wells of ½ cusec, 1 cusec, 1½ cusecs and 2½ cusecs suitable for irrigation water supply, is given, assuming Tej strainers are installed and that favourable water bearing sands are available down to 250 feet depth, *i.e.*, that the conditions are ideal. Spring level has been taken at 15 feet and the wells are of such size as to permit of the installation of efficient vertical spindle pumps to pump to a maximum depression head of 30 feet. Subsoil conditions vary so much over the Province that it is impossible to give figures of approximate cost of wells suitable for every sort of condition.

In Appendix No. 3 is given the approximate cost of cheap vertical spindle pumping plants, driven electrically and by oil engines, with foundations and pumphouses, for the wells given in Appendix No. 2.

The pumphouses would be of a semi-permanent nature built of B. B. in mud, with roof of galvanised iron sheeting, or alternatively would be wholly of galvanized iron. In the case of vertical spindle borehole pumping plants it is desirable either that the pumphouse containing the well head should be easily dismantled to enable a derrick to be erected over the well to withdraw and relower the pump rapidly, or alternately, a permanent arrangement should be provided in the pump house to allow the easy and rapid withdrawal of the pump.

19. Operating Costs.

In Appendix No. 4, approximate estimated operating costs of single tube-wells for irrigation of ½ cusec, 1 cusec, 1½ cusecs and 2 cusecs are given for electrically driven and for oil engine driven vertical spindle centrifugal borehole pumps respectively on the assumption that the average spring level is 15 feet below the surface, that the average depression head is 15 feet, that the water is delivered 5 feet above ground level and that the plant will be operated for 9 hours daily for 300 days annually. In the case of electrically operated plant, it has been assumed that the cost of electric power at the tube-well would be one anna per unit. At this rate, oil engine operated plant works out more expensive than electrically driven plant.

APPENDIX No. I.

PARTICULARS OF TYPICAL TUBE-WELLS CARRIED OUT BY THE PUBLIC HEALTH CIRCLE, P. W. D., PUNJAB.

No.	Year of Installation.	Situation.	Type of strainer.	Dia. of strainer.	Length of strainer.	Approx. position in the ground.	Discharge in gallons per hour per sq. foot of area of strainer per foot depression head.
			I—5″ *Ashford Strainers.*		Feet.		
1	1926	K. E. M. College Hostel, Lahore ..	Ashford ..	5″	60	..	19·0
2	1925	Intermediate College for Women, Lahore ..	Ashford ..	5″	48	..	23·1
3	1927	New Maternity Hospital, Lahore ..	Ashford ..	5″	56	79′—135′	18·3
			II—5″ *Tej Strainers.*		Feet.		
4	1927	Lahore Water-Works Extensions Well A ..	Tej ..	5″	30	53′—61′ 73′—81′ 87′—105′	27·0
5	1927	Do. Well B ..	Tej ..	5″	60	88′—148′	18·4
6	1927	Do. Well 2B ..	Tej ..	5″	40	52′—72′ 76′—96′	19·2
7	1927	Do. Well C ..	Tej ..	5″	80	60′—76′ 126′—142′ 183′—199′ 232′—264′	10·0

8	1927	Do.	Well E	..	Tej	..	5″	44	100′—108′ 137′—145′ 166′—174′ 196′—204′ 228′—240′	14·15
9	1927	Do.	Well No. 7	..	Tej	..	5″	20	52′—56′ 68′—72′ 76′—80′ 84′—88′ 92′—96′	32·0
10	1927	Do.	Well No. 8	..	Tej	..	5″	32	58′—70′ 78′—98′	24·8
11	1927	Do.	Well No. 9	..	Tej	..	5″	12	60′—64′ 72′—76′ 96′—100′	30·0
12	1927	Do.	Well No. 10	..	Tej	..	5″	32	60′—76′ 84′—100′	31·6
13	1928	Central Jail, Lahore		..	Tej	..	5″	60	190′—203′ 228′—276′	23·0
14	1928	Hydraulic Research Laboratory, Lahore			Tej	..	5″	60	223′—267′ 283′—299′	17·8
15	1928	Female Mental Hospital, Lahore		..	Tej	..	5″	64	130′—142′ 154′—174′ 238′—246′ 258′—282′	10·4

APPENDIX No. I.—(contd.).

PARTICULARS OF TYPICAL TUBE-WELLS CARRIED OUT BY THE PUBLIC HEALTH CIRCLE, P. W. D., PUNJAB—*concld.*

No.	Year of Installation.	Situation.	Type of strainer.	Dia. of strainer.	Length of strainer.	Approx. position in the ground.	Discharge in gallons per hour per sq. foot of area of strainer per foot depression head.
16	1928	Chauburji Gardens, Lahore, Well No. 1	Tej ..	5″	80	172′—180′ 208′—220′ 232′—252′ 264′—304′	Not yet tested.
17	1928	Do. do. No. 2	Tej ..	5″	76	170′—198′ 212′—224′ 242′—254′ 282′—306′	Not yet tested.
18	1928	Police Lines, Lahore ..	Tej ..	5″	48	192′—200′ 226′—266′	Not yet tested.
19	1927	Lahore Race Course ..	Tej ..	5″	32	131′—163′	21·5
20	1928	Kasur Sub-Jail ..	Tej ..	5″	48	174′—222′	Not yet tested.
			III.—7″ *Ashford Strainers.*				
					Feet.		
21	1926	Old Fort, Lahore ..	Ashford ..	7″	56	101′—157′	10·5
22	1926	Govt. College, Lahore ..	Ashford ..	7″	100	50′—150′	8·8
23	1920	Council Chamber, Lahore ..	Ashford ..	7″	48	..	10·0

			IV.—7″ *Tej Strainers.*			Feet.		
24	1927	Lahore Water-Works Well D. ..	Tej ..	7″		60	60′—68′ 86′—102′ 126′—162′	12·1
25	1928	G. O. R. Estate, Lahore ..	Tej ..	7″		48	241′—289′	14·6
26	1928	Eclipse Fair, Thanesar, Well No. 1 ..	Tej ..	7i		32	224′—240′ 272′—288′	15·4
27	1928	Do. Well No. 2 ..	Tej ..	7″		36	80′—96′ 220′—232′ 274′—282′	11·1
28	1928	Do. Well No. 3 ..	Tej ..	7″		64	163′—191′ 214′—226′ 270′—294′	8·3
			V.—*Other Strainers.*					
29	1927	Multan Water Works, Well No. 1 ..	Layne and Bowler.	8″		150	54′—204′	8·7
30	1927	Do. Well No. 4 ..	Do. ..	8″		150	56′—206′	12·2
31	1927	Do. Well No. 10 ..	Do. ..	8″		150	55′—72′ 93′—226′	13·0
32	1927	Do. Well No. 7 ..	Cook ..	$7\frac{1}{2}$″ $5\frac{1}{2}$″ $3\frac{1}{4}$″		50 50 50	58′—108′ 108′—158′ 158′—208′	17·0
33	1927	Veterinary College, Lahore ..	Ashford ..	10″		80	230′—310′	14·3
34	1928	Dera Ghazi Khan Water-Works Well No. 2A.	Cook ..	5″		50	52′—102′	23·0
35	1929	Do. well No. 1A ..	Leggett ..	10″		48	56′—114′	18·7

APPENDIX No. 2.

COST OF TUBE-WELLS WITH TEJ STRAINERS.

Tube-wells in favourable strata suitable for vertical spindle pumps.

Conditions.—Spring level at 15 ft.; hourly yield..

7″ Strainer	..14 gallons per sq. ft. per foot depression head.			Initial depression head 7 ft., pump to draw down to 30 ft., depression head maximum.
9″ Strainer	..13	Do.	Do.	Do.
10″ Strainer	..12	Do.	Do.	Do.
12″ Strainer	..11	Do.	Do.	Do.

Cost of Well. *Capacity ½ cusec.*	Rs.	Cost of Well. *Capacity 1 cusec.*	Rs.	Cost of Well. *Capacity 1½ cusecs.*	Rs.	Cost of Well. *Capacity 2 cusecs.*	Rs.
(*i*) 120 ft. 10″ boring @ 8/- ..	960	(*i*) 190 ft. 12″ boring @ 8/- ..	1,520	(*i*) 210 ft. 14″ boring @ 9/- ..	1,890	(*i*) 250 ft. 16″ boring @ 10/- ..	2,500
(*ii*) 64 ft. 7″ strainer @ 33/- ..	2,112	(*ii*) 128 ft. 7″ Tej strainer @ 33/- ..	4,224	(*ii*) 152 ft. 10″ Tej strainer @ 54/- ..	8,208	(*ii*) 186 ft. 12″ Tej strainer @ 60/- ..	11,160
(*iii*) 55 ft. 10″ plain pipe @ 8/- ..	440	(*iii*) 55 ft. 12″ plain pipe @ 11/- ..	605	(*iii*) 55 ft. 14″ plain pipe @ 14/- ..	770	(*iii*) 55 ft. 16″ plain pipe @ 16/- ..	880
(*iv*) Miscellaneous items @ 200/- ..	200	(*iv*) Miscellaneous ..	250	(*iv*) Miscellaneous ..	300	(*iv*) Miscellaneous ..	350
	3,712		6,599		11,168		14,890
Contingencies, @ 7%	260	Contingencies @ 7%	462	Contingencies @ 7%	782	Contingencies @ 7%	1,042
Total Rs.	3,972	Total Rs.	7,061	Total Rs.	11,950	Total Rs. ..	15,932

APPENDIX No. 3.

COST OF TUBE-WELL PUMPING PLANT AND HOUSING WITH VERTICAL BOREHOLE TYPE CENTRIFUGAL PUMPS.

I.—Electrically driven borehole type vertical spindle pumping plant—cost of plant and housing.
Conditions.—Spring level, at 15 feet; maximum depression head 30 feet—water to be delivered 5 feet above ground level.

Capacity ½ cusec. Overall efficiency 50%.	Rs.	*Capacity 1 cusec. Overall efficiency 53%.*	Rs.	*Capacity 1½ cusecs. Overall efficiency 62%.*	Rs.	*Capacity 2 cusecs. Overall efficiency 63%*	Rs.
(1) Plant complete ..	3,600	(1) Plant complete ..	4,200	(1) Plant complete ..	4,500	(1) Plant complete ..	5,600
(2) Pump house 8′×8′..	400	(2) Pump house 8′×8′..	400	(2) Pump house 8′×8′..	400	(2) Pump house 8′×8′..	400
(3) Erection, foundations, etc. ..	500	(3) Erection, foundations, etc. ..	550	(3) Erection, foundations, etc. ..	600	(3) Erection, foundations etc. ..	650
	4,500		5,150		5,500		6,650
Contingencies @ 7%	315	Contingencies @ 7%	360	Contingencies @ 7%	385	Contingencies @ 7%	465
Total Rs. ..	4,815	Total Rs. ..	5,510	Total Rs. ..	5,885	Total Rs. ..	7,115

II.—Oil engine belt driven vertical spindle borehole type pumping plant—cost of plant and housing.
Conditions as per I above.

Capacity ½ cusec. Pump efficiency 58%.	Rs.	*Capacity 1 cusec. Pump efficiency 61%.*	Rs.	*Capacity 1½ cusecs. Pump efficiency 67%.*	Rs.	*Capacity 2 cusecs. Pump efficiency 70%.*	Rs.
(*i*) Pump complete ..	3,000	(*i*) Pump complete ..	3,600	(1) Pump complete ..	3,900	(1) Pump complete ..	5,300
(*ii*) Oil engine complete with belting, tanks and piping ..	1,700	(*ii*) Oil engine complete with belting, tanks and piping ..	2,400	(2) Oil engine complete with belting, tanks and piping ..	4,000	(2) Oil engine complete with belting, tanks and piping ..	4,600
(*iii*) Erection, foundations, etc. ..	800	(*iii*) Erection, foundations, etc. ..	900	(3) Erection, foundations, etc. ..	1,000	(3) Erection, foundations, etc. ..	1,100
(*iv*) Housing ..	1,300	(*iv*) Housing ..	1,400	(4) Housing ..	1,500	(4) Housing ..	1,600
	6,800		8,300		10,400		12,600
Contingencies @ 7%	476	Contingencies @ 7%	581	Contingencies @ 7%	728	Contingencies @ 7%	882
Total Rs. ..	7,276	Total Rs. ..	8,881	Total Rs. ..	11,128	Total Rs. ..	13,482

III.—Oil engine driven horizontal centrifugal pumping plant—cost of plant and housing.
Conditions as per I above except that maximum depression head will be 15 feet in place of 30 feet.

Capacity ½ cusec.	Rs.	*Capacity 1 cusec.*	Rs.	*Capacity 1½ cusecs.*	Rs.	*Capacity 2 cusecs.*	Rs.
(1) Pump complete with suction and delivery piping valves, etc...	700	(1) Pump complete with suction and delivery piping and valves ..	800	(1) Pump complete with suction and delivery piping, valves, etc.	1,000	(1) Pump complete with suction and delivery piping, valves, etc.	1,300
(2) Oil engine 8 B.H.P. complete with belting,tanks and piping	1,700	(2) Oil engine 12 B.H.P. complete with belting,tanks and piping	2,400	(2) Oil engine 18 B.H.P. complete with belting,tanks and piping	4,000	(2) Oil engine 24 B.H.P. complete with belting tanks and piping	4,600
(3) Erection, foundations, etc. ..	500	(3) Erection, foundations, etc. ..	600	(3) Erection, foundations, etc. ..	700	(3) Erection, foundations, etc. ..	1,100
(4) Housing ..	1,300	(4) Housing ..	1,400	(4) Housing ..	1,500	(4) Housing ..	1,600
	4,100		5,200		7,200		8,600
Contingencies @ 7%..	287	Contingencies @ 7 %	364	Contingencies @ 7%..	504	Contingencies @ 7%..	602
Total Rs. ..	4,387	Total Rs. ..	5,564	Total Rs. ..	7,704	Total Rs. ..	9,202

IV. Electrically driven horizontal centrifugal puming plant—Cost of plant and housing.
Condition as per III above.

Capacity ½ cusec.	Rs.	*Capacity 1 cusec.*	Rs.	*Capacity 1½ cusecs.*	Rs.	*Capacity 2 cusecs.*	Rs.
(1) Pump complete with suction and delivery piping and valves..	850	(1) Pump complete with suction and delivery piping and valves ..	1,000	(1) Pump complete with suction and delivery piping and valves ..	1,200	(1) Pump complete with suction and delivery piping and valves ..	1,500
(2) 8 B.H.P. motor complete with belting, switch gear and control gear complete	900	(2) 12 B.H.P.motor complete with belting, switch gear and control gear complete..	1,100	(2) 18 B.H.P. motor complete with switch gear and control gear complete ..	1,300	(2) 24 B.H.P. motor complete with switch gear and contr ol gear complete ..	1,500
(3) Erection, foundations, etc. ..	400	(3) Erection, foundations, etc. ..	450	(3) Erection, foundations, etc. ..	500	(3) Erection, foundations, etc. ..	550
(4) Housing ..	600	(4) Housing ..	650	(4) Housing ..	700	(4) Housing ..	750
	2,750		3,200		3,700		4,300
Contingencies @ 7%..	192	Contingencies @ 7%..	224	Contingencies @ 7%..	259	Contingencies @ 7%..	301
Total Rs. ..	2,942	Total Rs. ..	3,424	Total Rs. ..	3,959	Total Rs. ..	4,601

APPENDIX No. 4.

Tube-wells (Tej strainer) and Pumping Plant.

COST OF OPERATION INCLUDING REPAIRS, DEPRECIATION, INTEREST ON CAPITAL, ASSUMING LIFE OF TUBE-WELL TO BE 10 YEARS—TUBE-WELL OPERATED 9 HOURS DAILY TO FULL CAPACITY 300 DAYS PER ANNUM.

I.—Tube-wells equipped with vertical spindle pumping plant; draw down 30 feet.

Electrically driven vertical spindle pumping plant. Cost of electricity 1 anna per unit.

Capacity ½ cusec. Cost of Installation.—	Rs.	*Capacity 1 cusec. Cost of Installation.—*	Rs.	*Capacity 1½ cusecs. Total cost.—*	Rs.	*Capacity 2 cusecs. Total cost—*	Rs.
Well ..	3,972	Well ..	7,061	Well ..	11,950	Well ..	15,932
Plant ..	4,815	Plant ..	5,510	Plant ..	5,885	Plant ..	7,115
Total Rs. ..	8,787	Total Rs. ..	12,571	Total Rs. ..	17,835	Total Rs. ..	23,047
I.—Interest charges.—		*I.—Interest charges.—*		*I.—Interest charges.—*		*I.—Interest charges.—*	
4½ % on capital ..	395	4½% on capital ..	565	4½% on capital ..	803	4½% on capital ..	1,037
II.—Depreciation charges. Rs.		*II.—Depreciation charges.* Rs.		*II.—Depreciation charges.* Rs.		*II.—Depreciation charges.* Rs.	
(*a*) 10% on well 397		(*a*) 10% on well 706		(*a*) 10% on well 1,195		(*a*) 10% on well 1,593	
(*b*) 6⅔% on plant 321		(*b*) 6⅔ % on plant and foundations and housing 367		(*b*) 6⅔ % on plant, foundations and housing 392		(*b*) 6⅔% on plant, foundations and housing 474	
	718		1,073		1,587		2,067
III.—Repairs and renewals.—		*III.—Repairs and renewals.—*		*III.—Repairs and renewals.—*		*III.—Repairs and renewals.—*	
5% on plant, foundations and housing	241	5% on plant, foundations, housing ..	275	5% on plant and housing ..	294	5% on plant and housing ..	356
IV.—Electricity.—		*IV.—Electricity.—*		*IV.—Electricity.—*		*IV.—Electricity.—*	
3 units per hour for 2,700 hours @ -/11/-	506	5·63 units per hour for 2,700 hours @ -/11/-	950	7·5 units per hour for 2,700 hours @ -/11/-	1,286	10 units per hour for 2,700 hours @ -/11/-	1,688
V.—Attendance.—		*V.—Attendance.—*		*V.—Attendance.—*		*V.—Attendance.—*	
25 per mensem ..	300	30/- per mensem ..	360	45/- per mensem ..	540	60/- per mensem. ..	720
VI.—Lubricants, stores, etc. ..	80	*VI.—Lubricants, stores, etc.* ..	140	*VI.—Lubricants, stores, etc.* ..	200	*VI.—Lubricants, stores, etc.* ..	260
Total Rs. ..	2,240	Total Rs. ..	3,363	Total Rs. ..	4,690	Total Rs. ..	6,128
Water pumped.— =30,375 thousands of gallons. =4,860 thousands of cubic ft. *Cost per 1,000 cubic feet—7·4 annas*		*Water pumped.—* =9,720 thousands of cubic feet. *Cost per 1,000 c. ft. =5·6 annas.*		*Water pumped* = 14,580 thousands of cubic feet. *Cost per 1,000 cubic ft. =5·2 annas.*		*Water pumped—* =19,440 thousands of cubic feet. *Cost per 1000 cft. =5·00 annas.*	
Cost per acre foot=	20	*Cost per acre foot* ..	15·3	*Cost per acre foot* ..	14·1	*Cost per acre foot* ..	13·7

II.—Tube-wells equipped with vertical spindle pumping plants; draw down 30 feet.

Oil engine driven vertical spindle pumping plant.

Capacity ½ cusec. Cost of Installation.	Rs.	*Capacity 1 cusec. Cost of Installation.—*	Rs.	*Capacity 1½ cusecs. Cost of Installation.—*	Rs.	*Capacity 2 cusecs. Cost of Installation.—*	Rs.
Well ..	3,972	Well ..	7,061	Well ..	11,950	Well ..	15,932
Plant ..	7,276	Plant ..	8,881	Plant ..	11,128	Plant ..	13,482
Total Rs. ..	11,248	Total Rs. ..	15,942	Total Rs. ..	23,072	Total Rs. ..	29,414
I.—Interest charges.—		*I.—Interest charges.—*		*I—Interest charges.—*		*I.—Interest charges.—*	
4½% on capital ..	506	4½% on capital ..	717	4½ % on capital ..	1,038	4½ % on capital ..	1,324
II.—Depreciation charges.— Rs.		*II.—Depreciation charges.—* Rs.		*II.—Depreciation charges.—* Rs.		*II.—Depreciation charges.—* Rs.	
10% on well 397		10% on well 706		10% on well 1,195		10% on well 1,593	
6⅔ % on plant foundations and housing 485		6⅔ % on plant, foundation and housing 591		6⅔ % on plant foundations and housing 741		6⅔% on plant, foundations and housing 898	
	882		1,297		1,936		2,491
III.—Repairs and Renewals.—		*III.—Repairs and renewals.—*		*III.—Repairs and renewals.—*		*III.—Repairs and Renewals.*	
5% on plant, etc ..	304	5% on plant, etc ..	444	5% on plant, etc ..	556	5% on plant, etc ..	674
IV.—Oil fuel.—				*IV.—Oil fuel—*		*IV.—Oil fuel.—*	
4 B.H.P. @2,700 hours annually at ·75 lb. per B.H.P. hour @ 140 per ton =3·62 tons	506	IV.—7·5 B.H.P. @ 2700 hours annually at ·75 lbs. per B.H.P. hour @ 140/- per ton=6·8 tons ..	952	10 B.H.P. @ 2,700 hours annually at ·75 lbs. per B.H.P. hour 140/- per ton =9·04 tons ..	1,266	12·5 B.H.P. @ 2700 hours annually at ·75 lbs. per B.H.P. hour @ 140/- per ton=11·3 tons ..	1,582
V.—Attendance. @ 60 per mensem ..	720	*V.—Attendance.—* @ 60/- per mensem ..	720	*V.—Attendance.—* @ 60/- per mensem ..	720	*V.—Attendance.—* @ 60% per mensem	720
VI.—Lubricants stores etc. @ 20% on oil fuel ..	101	*VI.—Lubricants, stores, etc.* @ 20% on oil fuel ..	190	*VI.—Lubricants, stores, etc.* @ 20% of oil fuel ..	253	*VI.—Lubricants, stores, etc.* @ 20% on all oil fuel	316
Total Rs. ..	3,079	Total Rs. ..	4,320	Total Rs. ..	5,769	Total Rs. ..	7,107
*Water pumped.—*4,860 thousands of cft. *Cost per 1,000 cft. =10·2 annas.*		*Water pumped* 9,720 thousands c.ft. *Cost per 1,000 c.ft. =7·1 annas*		*Water pumped*—14,580 thousands of c. ft. *Cost per 1,000 c.ft. =6·3 annas.*		*Water pumped*—19,440 thousands cft. *Cost per 1,000 cft. =5·9 annas.*	
Cost per acre foot ..	27·7	*Cost per acre foot* ..	19·4	*Cost per acre foot* ..	17·2	*Cost per acre foot* ..	16·1

DISCUSSION.

MR. HOWELL in introducing his paper said he had attempted to summarise the results of the work carried out in connection with tube-wells during the past 14 or 15 years in the Public Health Circle and had avoided as far as possible overstating the case in favour of this form of water-supply and no claims had been made which could not be substantiated in practice. The Public Health Circle was not an experimental department, but had to produce water-supply schemes for certain sums of money provided in the estimates, and in the event of any failures occurring the engineers responsible had to explain the reasons why.

Some persons might state that the results described in the paper were somewhat conservative. In any case the engineers of the Public Health Circle could, on the whole, he thought, congratulate themselves on having achieved a good measure of success with tubewells. They had put down very nearly a hundred wells and out of the whole lot only two failures had resulted, one a mechanical failure of a well owing to an accident many years ago, and the other only recently, both of them being due to circumstances beyond the control of the engineers concerned.

Since writing the paper, he had noted with pleasure that Mr. Vardon had actually put down an air developed gravel well successfully at Rohtak and he had also heard the Public Health Engineering Department of the United Provinces, had put down recently more than one well, with a coarse strainer consistng of a perforated pipe, shrouded with bujri or gravel and he understood that a good measure of success had been achieved.

These wells gave an indication of the trend of the lines on which new tubewell development was likely to take place by doing away with strainers provided with fine slits.

The final criterion of all types of tubewells was the cost of the water after taking into account interest, depreciation, and pumping charges and the deterioration of the well itself affected these figures to a large extent. With the new types of wells, it was not possible to say as yet what troubles might occur and a financial comparison between strainer types of wells and the new types could only be made after the lapse of a considerable period of time. In this connection, when strainer tubewells were introduced first people thought that they would last for long periods and it was only as a result of long experience that it was discovered that "clogging" action invariably reduced the life of all wells in a comparatively short period.

MR. VARDON in introducing his paper said that the problems of railway water-supply were rather different from those which Mr. Howell had to deal with. He said that they had to put down a large number of borings out of which only a relatively small number had resulted in

tube wells; this being expained partly by the number of trial borings that were successful but for which a call has not yet been made for a tube well, due to the lack of funds, and partly from the consideration that a number of these borings had been sunk as trial wells for locomotive water-supplies, and as the quality of the subsoil water was found unsuitable for this purpose, they had to be abandoned. They had put down 350 trial borings and so far had installed 137 tubewells with a prospect of 50 more being demanded in the course of time. He said they had to learn their work by trial and error in the various stages, and by what had been done by Messrs. Brownlie, Leggat and Ashford.

The cost of tubewells is coming down to such an extent that, when in the next two years they will be duplicating their wells, the cost of duplication should not be more than 40 to 50 per cent. of the cost of the original tubewell. He was concerned with the economic side of the problem, to justify the change from the ordinary open well and Steam Reciprocating Pumping Plant to tubewells and new Oil Engine Driven Air Lift Pumping Plant that they were installing. He said that the main purpose of his paper was to deal with the economics of the tubewell programme they had undertaken for the N. W. Railway.

As regards the most recent practice in tubewells he said that his 6 months' experience in U. S. A. had given him several ideas, but he would have to obtain sanction for funds to try out a lot of what he had seen. He believed that his Chief Engineer was quite willing to allot funds for such experimental work. To him the greatest need in the tubewell business was to be able to try out methods and collaborate the information that several departments had in connection with the tubewell business.

MR. HADOW remarked that he wanted particularly to deal with one aspect of Mr. Vardon's paper, that is to say, regarding institution of a Ground Water Division. There were two papers on tubewells for discussion before the Congress and it was evidently a question which attracted much interest as five papers on tubewells had already been discussed in past years. He asked whether they had got very far with the question or whether they were not dissipating their energies instead of co-ordinating them. As a typical example he quoted the remarks in Mr. Vardon's paper regarding Air Made Gravel Wells, which appeared to be, to him at least quite new, whilst Mr. Howell stated that so far as he knew no such wells had been sunk in the Punjab. With the advent of hydro-electric power it seemed to him inevitable that tubewells for irrigation purposes must come much more to the fore than at present. There was a great deal in what Mr. Vardon said of having some general organization which would prevent dissipation of energies, waste of money, and lack of co-ordination.

He drew attention to Mr. Miller Brownlie's report written as a result of his visit to the U. S. A., in which he brought forward the very great necessity for having some law governing the use of under-ground

water ; it was evident that that must come sooner or later. In the U. S. A. there is apparently a Water Users' Association to decide disputes but he thought that if they waited for the formation of such Water Users' Association they would have do deal with vested rights, and so get into trouble. He pointed out the necessity of having proper legislation and said that as in other cases, if the Congress thought fit to make a strong case of a Ground Water Division, Government might be moved to consider the matter.

MR. NANDA touched on the question of the clogging of tubewells and said he considered that it was inevitable.

Referring to Mr. Howell's paper page 91, in connection with the elimination of clogging by some means so that the life of tubewell might be extended from10 to 20 years, he said he did not agree with Mr. Howell because he thought that a clogged well was a diseased well and the disease is not confined to the shell of the strainer but it goes back to the outer limits of the cone of depletion.

He considered the subsoil round the strainer becomes choked for a considerable distance as happens in the case of sand filter beds.

In common with tubewells a large proportion of modern percolation wells in India have also ceased to give their original supply while many ancient wells which were either built by the State or by Private contribution of substantial make and large diameter continue to give satisfaction. Only small supplies were taken from them for irrigation or drinking purposes and from the very nature of their construction and usage met the demand for a considerable length of time. Smaller wells of more recent construction that were worked more heavily have deteriorated and been abandoned. This is not uncommon and the Punjabi applies the term *Dal* to such wells.

MR. PAVRY said that the two papers under discussion were full of interest and useful information both as regards the work done by the Punjab Government and the North Western Railway and also as regards improvement in the technique of strainer wells.

He said that the method referred to by Mr. Vardon of using wide slotted strainers surrounded by gravel shrouding appeared to be full of promise, but that until it had been successfully used in a number of cases, he did not think one could accept all the claims made for it. He said very little was known of what happened in the strata when large quantities of sand were extracted from them. In the case of the fine mesh strainer, if anything like the 40 to 80 per cent. of the finer sands were removed as mentioned in Mr. Howell's Paper, there would be considerable settlement and caving action round the strainer and possible collapse of the stratum above. Similar action would take place in the wide slotted gravel shrouded strainer if the conditions were such that the whole of the sand was removed from a considerable area round the gravel shrouding.

Without some practical proof he did not think one could accept Mr. Vardon's statement that a wide slotted tube with a gravel shrouding of 20 feet diameter had an infilteration area equal to a fine screen tube of 20 feet diameter. According to him this would only be true if the conditions as regards head of pumping and nature of sand were such that the whole of the gravel remained free of sand, but not if a certain section of the gravel shrouding remained filled with the coarser sands.

MR. SMITH said that in August last at a conference on waterlogging in Simla, Mr. Astbury proposed that they should pool all their information on tube-wells.

Accordingly he asked certain officers if they would supply him with all the data at their disposal in order that he might ascertain what was known at present about tubewells in the Punjab.

He was pleased to see that so much had been brought forward in the papers under discussion and hoped that the deliberations of the Congress would help them considerably at a formal discussion on the reports to be submitted to Government.

He then touched upon the question of the necessity for legislation and referred to the case of a landowner in Hoshiarpur District who had sunk a tubewell and had got to the lower strata (with the result that the neighbouring percolation wells had all dried up) and was actually supplying owners of the depleted wells with water on payment. He said that the necessity for legislation had long been foreseen and that Mr. Wilson had written a long note on it about two years back. He added that legislation had already been introduced in Australia and he thought that it was absolutely essential in the Punjab where activities of tubewells were bound to extend rapidly when hydro-electric power became available.

MR. NICHOLSON drew attention to the statements made by Engineer officers before the Agricultural Commission and said the question of legislation was a delicate one; but demanded immediate consideration.

MR. KING said that he had had only two months' experience in the Punjab and therefore was not intimately acquainted with the problems here. He has had experience with tubewells in the United States, both for irrigation and dewatering. He said that when he came to the Punjab he was struck with three things about the tubewells, the first being the tremendous quantity of water pulled from small wells, second, the decrease in capacity of the wells with use, and third, the high cost of the wells. He referred to the data given on page 93 of the paper by Mr. Howell, having computed the entering velocity of the water through the slits in the screen. By reference to the Kennedy Formula he showed that a well of this capacity should have been 16 inches in diameter instead of 5 inches in diameter in order to keep the entering velocity below that which would draw sand ·015 inches in diameter or larger against the slit. The present effect of wells in the Punjab is therefore to tend to pull everything through the slits. This he

did not believe to be correct procedure. In the U. S. smaller quantities were expected from the wells, and larger slits are used, as they fortunately have gravel mixed with the sand and the gravel only is kept out of the well. When a well was first pumped the water was drawn out slowly, carrying with it the finer sands. This tended to form a gravel screen around the well. He pointed out that in the Punjab there is no gravel and that in working with sand a parallel procedure to that employed in the United States might be practical. This would mean larger diameter wells and increased screen areas, with the slots in the screen small enough to keep out the course sands. In regard to the wells in the Punjab he mentioned that one of the causes for deterioration of a well might be due to mechanical clogging of slits by fine particles, but might be due to the fact that gases in the water might be released at the slit due to high velocity and the decreased pressure, hereby causing a chemical action which made a deposit at this point, gradually building up an impervious layer. He said that in California wells were put down at a lower cost because they did not use such an expensive type of well casing or strainer. He then referred to Mr. Brownlie's strainer and said that this type of strainer could be made at a low cost locally by native labor.

MR. ROBERTS drew attention to some aspects that had impressed him in connection with tubewells so far as the requirements of agriculture were concerned.

The classification of the various types of strainers and their relative value as given in Mr. Howell's paper was extremely valuable.

Another encouraging feature in Mr. Vardon's paper was that slits of $\frac{1}{8}$" and more in the strainer were being successfully tried. Mr. Ashford used to describe with great pride the closeness of the wire winding in his patent screen and used to say experience in gun winding alone had enabled him to do the work of the required fineness. The necessity for such refinement was depressing to a layman who looked to the wider adoption of tubewells for irrigation purposes.

The gravel screen mentioned by Mr. Vardon also offered great possibilities. It may be possible to construct wells of large diameter on this principle which could be repaired when out of order instead of having to be scrapped as at present.

His colleague Mr. Thomas at Khanewal had asked him to draw the particular attention of the Congress to the necessity of systematic analysis of tubewell waters both from different strata and when running. This was a routine feature in American practice.

Such analyses should in all cases embrace the following:—

(*a*) Determining whether the clogging of the screen was due to chemical, electrolytic or physical action.

(*b*) Analysing the water for drinking purposes.

(*c*) Analysing the water for irrigation purposes.

All three aspects should be kept in mind in case of all borings and should be subsidized by the State.

MR. BROMAGE said that it seemed to him that there was a considerable variation between the kind of the tubewell the Public Health Circle wanted and the type of tubewell the Irrigation Engineers might require. He pointed out that the wells sunk for the purposes of public supply may be as deep as 200 feet or even more, whereas an Irrigation Engineer might sink his well to a depth of 30 feet or so, and thus reduce capital cost of plant.

He said that Mr. Howell had referred in his paper to the clogging of the tubewell at Sialkot in 1923-24, and that clogging had got to such a state that new tubewells had to be sunk in order that the pumping plant should be able to maintain the supply of the city.

He said that with a view to reducing the rate of infiltration with a view to lenghthening the life of the strainers, the new strainers, for the same supply would each have twice the diameter and their aggregate length would be a double of the original strainers.

Time alone would show whether this policy was justified both as regards capital and interest charges and also working expenses.

Referring to Mr. Robert's remarks about the necessity of getting a chemical analysis of the water, he said that as a matter of routine no project for tubewell suppply had ever been put forward by the Public Health Circle for sanction and execution without analysis of the water being previously made. He further remarked that samples of the water at different depths were taken and sent to the Chemical Examiner for report on their suitability for domestic supply.

Referring to pumping plants he said that Mr. Howell had in his paper referred to several types of pumps and the ones with which he had had experiences were :—

(1) Direct coupled Horizontal Spindle Pump.

(2) Vertical Spindle Pump.

(3) Reciprocating Pump.

He discussed the relative advantages of the vertical and horizontal spindle pumps pointing out that where large depressions were not required the simplicity of the latter gave it many advantages over the former.

He then referred to the vital necessity of maintaining continuity of supply and pointed out that if a domestic supply were cut off even for a few hours the public would proceed to obtain water from other sources, which might be contaminated and thus start an epidemic in a large community.

He expressed the opinion that unless provided with very large air vessels on the suction side reciprocating pumps would appear to be likely to cause drawing of sand by their pulsating action.

MR. HOWELL in reply said as regards the remarks made by Mr. Vardon that the same conditions did not apply to tubewells of the Public Health Department as to those of the Railway he did not agree. Conditions of the subsoil varied throughout the Province and all engineers engaged in putting down tubewells all over the Province had to deal with all of these varying conditions.

He next referred to Mr. Hadow's comments that his knowledge of tubewell development as a whole was not up-to-date, as he had made no mention of gravel wells. The introduction of gravel developed wells, however, was a very recent development, so recent in fact that the first well claimed to be successful had only just been finished.

In regard to Mr. Nanda's remarks that his figures of cost of large tubewells for irrigation should be treated cautiously, he presumed that Mr. Nanda considered he had allowed figures of discharge per square feet of strainer, which were too low. Thus making the lengths of strainers too great, thereby increasing the costs of the wells.

In this connection he had read various pamphlets by American Engineers describing tubewell installations put down in California in coarse gravel formations. Except in one paper no particulars of yields in relation to areas of strainers were given. The average yield of the wells given amounted to about 9 gallons per square feet of strainer per foot of depression head. In the figures given in his paper he had actually taken 50 per cent. more yield per square foot of strainers per foot depression head than those given by the American Engineers. His estimated yield figures were therefore on the high side rather than on the low side.

MR. Pavry had inferred from the description of the sieve tests usually adopted by the makers of the Tej strrainers that large volumes of sand woul d be drawn into the wells thereby causing subsidence. This, however, was not correct. Fine sand was drawn through the strainer and the coarser grains soon packed round the strainer, thus preventing more fine sand coming through.

Referring to MR. King's remarks, the conditions in California were not the same in the Punjab. In California they had gravel of various degrees of coarseness intermixed with sands, while in the Punjab the water bearing strata consisted of fine sands. Any attempt at installing coarsely slotted strainers within some form of "filter" between the well and the water bearing strata would simply result in large volumes of sand being drawn into the well, causing collapse.

He agreed with MR. Bromage that for water-supply undertakings it was essential to provide standby pumping plant. They had gone in for horizontal electrically driven centrifugal pumping plants at Lahore for this reason. For wells for irrigation or for dewatering waterlogged areas, however, it was not possible to get the same life with horizontal pumps as with air lift or borehole type vertical spindle centrifugal pumps.

He had no experience of porous strainers of stoneware or concre but he imagined that the difficulty would be to keep up the prosi Such porous strainers were not likely to remain porous for very long the alluvial water-bearing strata.

In regard to Mr. Smith's and Mr. Nicholson's remarks there v no ownership of underground water in Great Britain, and as a resu particularly in the porous or fissured water yielding formations in t east and south of England, cases had been reported of pumping operatic from one waterworks, seriously affecting the yield of wells belonging adjoining waterworks, while in the coal-fields, mining operations freque ly had the effect of drying up surface springs on lands under which t Mining Company possessed no mining powers.

MR. VARDON in replying to the points raised in the discussi stated that a test was recently carried out on a tubewell at Mul Cantonment which had been continuously in operation for two years, a it was found that the yield and drop was exactly the same as when well was first brought into use.

He also pointed out that special attention was paid to the analy of the water from tubewells.

Samples of water were taken at intervals of 50′-0″ or less in water-bearing strata, when the boring was being sunk, and if these w unfavourably reported on, a tubewell was not put down.

COL. WALTON, in closing the discussion said that this subject wo receive further consideration at the Conference that Mr. Smith wo be calling shortly, and suggested that he and Mr. Hadow, as Secretai to Government, were in a position to take such action as may be deen necessary on the latter's suggestion of the need for legislation to safegu ownership rights of underground water.