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THE KAROL TUBE-WELLS SCHEME

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1. Introduction

In the United Provinces tube-well irrigation has been introduced during the last decade on a very large scale. The Punjab Government also wanted to examine the question as to whether tube-well irrigation could with advantage be applied to certain *barani* (dependent for irrigation entirely on rain) areas in this province.

With this end in view, Mr. A. M. R. Montagu, I.S.E., was appointed as Officer on Special Duty, Tube-Well Investigations, in 1937, to collect and correlate all the available data regarding the existing tube-wells in the Punjab, to carry out experiments to determine the comparative costs of irrigation from (*a*) Open wells; (*b*) Tube-wells and (*c*) Canals, and to prepare an experimental scheme for tube-well irrigation based on the data collected by him.

The Karol Tube-Wells Scheme is the outcome of the excellent work done by him in this connection. It was conceived by him and was also mostly executed under his supervision. The authors had the privilege of coming in close contact with his work and this paper is a brief description of the principal aspects of the scheme, which are considered to be of a general interest.

Prior to this scheme there were only two irrigation tube-wells functioning at Qadian in Gurdaspur District, which had been designed and installed by the Agricultural Department and handed over to the Irrigation Branch in 1937. These tube-wells were not working satisfactorily and as such their design could not be adopted as a basis for designing any future tube-wells.

2. Experiments on Open Wells

Experiments to determine the relative costs of, and deltas for, maturing different crops during *kharif* and *rabi* from open wells were carried out during *kharif*, 1937, and *rabi*, 1937-38, in the vicinity of Lahore, in the villages Ram Kishanwala and Karol. These two villages represented two widely different intensities of cultivation.

In Ram Kishanwala, which is situated very close to Lahore, the intensity of cultivation from open wells is very high, as compared to that in Karol village, situated about seven miles from Lahore. Ram Kishanwala represents conditions of cultivation typical of areas in the suburbs of big cities, where facilities regarding manure and labour are at hand. Karol, on the other hand, is typical of ordinary agricultural areas removed from the cities.

In *kharif*, 1937, a set of seven open wells was selected in Karol village and the following observations were accurately recorded daily:

(1) Number of hours of working of each well.

(2) Discharge of each well.

(3) Area irrigated.

(4) Kind of crop.

(5) Number of bullocks employed to work each well.

(6) Human labour employed.

(7) Rainfall.

In *Rabi*, 1937-38, the experiment was extended to Ram Kishanwala village also, and similar observations were recorded. It is not possible here to give all the details of these experiments or to discuss them at length.

The results are incorporated in Appendices I and II.

3. Selection of Site

The area selected for the Karol Project is a tract of land situated between the left bank of River Ravi and the irrigation boundary of the Shalamar Distributary of the Upper Bari Doab Canal and starts just beyond Shalamar Gardens towards the Amritsar side, *vide* Plate I (Index Plan).

The area lies mostly below the *dhaya* of the river (in the riverain tract) and is intercepted by river creeks and depressions. From the point of view of tube-well irrigation, its suitability is due to: (*a*) a high and fairly constant spring level and (*b*) the nearness of a market (Lahore).

Some of the area is, however, subject to flooding during very high floods, which is really a disadvantage.

4. Soil and Rainfall

The soil is generally good, barring a few villages in which it is light and sandy. The average rainfall is 18 inches during *kharif* and only four inches in *rabi*.

5. Culturable Commanded Area and Discharge

The total gross area under the project was originally 17,389 acres which has subsequently been modified to 13,280 acres. The scheme as sanctioned in the first instance consisted of 31 tube-wells of discharges varying from 1.0 to 1.5 cusecs with a total discharge of 35 cusecs. It was modified later on to consist of 20 tube-wells of discharge about 1½ cusecs each, or a total discharge of 30 cusecs.

The total culturable commanded area in the modified project is 12,722 acres which gives an average area of 424 acres to be irrigated per cusec of discharge. This figure is quite reasonable and has been based on the assumption that the pump will work for 5,000 hours annually, when the tube-well is fully developed.

It will deliver annually 417 feet acres per cusec of pump capacity, or 208 feet acres during each crop. The figure compares favourably with the actual irrigation figures on the nearest gravity irrigation channel, *viz.*, Shalamar Distributary of the Upper Bari Doab Canal. The average deltas of this distributary for the last 10 years are 2.57 feet for *kharif* and 1.55 for *rabi*. Due to the volumetric method of charging for water delivered from tube-wells, the cultivator will exercise a fair degree of economy in the use of water and as such it is reasonable to assume the deltas for tube-well irrigation, to be at least 30 per cent. less than the deltas for the canal gravity flow irrigation.

This consideration reduces the *kharif* delta to 1.8 foot and *rabi* to 1.1 foot for tube-well irrigation. Based on these figures for deltas it would be possible to irrigate 116 acres during *kharif* and 189 acres during *rabi*, or 305 acres in all annually per cusec of pump capacity. Assuming 75 per cent. intensity of irrigation, the culturable commanded area works out to be 406 acres against 424 acres assumed.

This is also borne out by the following figures of the actual working of tube-wells Nos. 6 and 2 during *rabi*, 1939-40:

Crop	Tube-well No.	Working hours	Culturable Commanded Area	Actual irrigated area	Discharge	Irrigated area per cusec discharge
Rabi, 1939-40	6	1,314	482	231	1.544	149
Rabi, 1939-40	2	1,966	631	271	1.473	184

At tube-well No. 6, 149 acres were irrigated per cusec in 1,314 hours and at tube-well No. 2, 184 acres were irrigated per cusec in 1,966 hours. In 2,500 hours, therefore, tube-well No. 6 would irrigate 283 acres per cusec capacity and tube-well No. 2 will irrigate 234 acres per cusec. This shows that it would be quite easy to irrigate the proposed culturable commanded area attached to each *chak* without unduly straining the tube-well unit. It needs to be pointed out that during the last *rabi* the watercourses were not lined but, after the lining has been done, the absorption losses will drop and irrigation per cusec will increase.

6. Diameter of the Plain Pipes Comprising Tube-Wells

The minimum diameter of the suction pipe is fixed after consideration of the maximum permissible velocity through the pipe. The frictional losses vary as the square of the velocity and directly as the wetted area. A 10-inch diameter is considered suitable for suction pipes for a discharge of 1.5 cusecs; this gives a velocity of 2.76 feet per second, which is less than 3.0 feet per second, the standard permissible velocity in water supply schemes.

7. Design of Strainer

The factors affecting the design of a tube-well strainer are: (*a*) Transmission constant of the soil; (*b*) Depression head; (*c*) Length and diameter of the strainer and (*d*) Shrouding. The transmission constant of the soil varies considerably from strata to strata.

In water-bearing sand, consisting of particles, say, 16/1000 mean diameter, a mean velocity of 0.005 foot per second has been found to move only the finest particles of a negligible diameter. This would limit the discharge to .005 cusec per square foot of the strainer surface. Large-diameter strainers are, however, very expensive and, therefore, to keep down the cost, shrouding is resorted to. From practical experience a 10-inch diameter strainer of 128 feet total length is found sufficient to give a discharge of 1.5 cusecs with a maximum depression head of 12.0 feet. The minimum diameter of the strainer should, however, be not less than that required for the optimum velocity.

The indraw into the strainer is not uniform throughout the length of the strainer and the gross discharge does not vary directly with the length of the strainer and, therefore, it would be uneconomical to have a uniform diameter of the strainer throughout its length. It has consequently been proposed to vary the diameter of the strainer to retain the optimum velocity of three feet per second as far as possible.

Suitable lengths of strainer of varying diameters from 4 in. to 10 in. have accordingly been used. A typical location chart is attached. (Plate 2.)

The saving in cost consequent on using the smaller-diameter strainers is considerable, for instance :

The cost of strainer and plain pipe for one tube-well of a uniform diameter of 10 inches throughout its length is Rs. 4,575 compared to Rs. 3,485 when strainers and pipes of varying sizes from 4 in. to 10 in. are used for the same tube-well, giving a net saving of about 25 per cent. in the cost of strainers and plain pipes.

There is, however, one objection to the use of the small-diameter strainers. The strainers of 4-in. to 6-in. diameters, especially the Tej Brass Strainers, which have been used on the Karol Tube-Well Scheme, require extreme care in their handling when lowering the same and also during the process of shrouding. Great care has to be exercised to see that the bottom of the lowest strainer is not allowed to touch the ground and to take the weight of the strainers and plain pipes while being lowered into the boring. It is a matter of simple calculation that a 4-inch diameter strainer will not bear the superimposed weight of strainers and rising pipes, especially when the bore-hole is 350 feet or over. Actually there have been two accidents in the case of tube-wells Nos. 1 and 30-31 when, due to the carelessness of the staff in charge of the operation of lowering the strainers, the 4-in., 5-in. and 6-in. strainers were crushed. In the case of tube-well No. 1 a part of the bore containing the crushed length of strainers was left out and the remaining length of the bore, which contained sufficient water-bearing strata, was made use of. However, the entire bore of the tube-well No. 30-31 had to be abandoned and a new tube-well was sunk.

In view of the extreme care required in handling the delicate smaller-diameter strainers of 4-in. to 6-in. diameters, their use was discontinued and only strainers of 7-in. to 10-in. diameters were used. The re-designed location chart is shown in Plate 2.

In the selection of strainers the final choice lay between the cadmium-plated "Phœnix" Strainer and the All-Brass "Tej" Strainer and preference was given to "Tej" Strainers in order to help the provincial industry and on account of the facility in obtaining supplies from a local firm.

Actual Discharge of Completed Tube-Wells.—Out of the twenty tube-wells, eight tube-wells have been completed and tested.

The results obtained from these tests fully justify the design as will be clear from the following statement:

STATEMENT SHOWING DISCHARGES, ETC., OF DIFFERENT TUBE-WELLS ON KAROL PROJECT

Number of tube-well	Discharge	Depression head	Mean transmission constant of the bore	Remarks
6	1.54	11.1	.000285	1. Discharge was measured on a broad-crested weir.
2	1.47	6.5	.000217	
14	1.46	7.95	.000198	2. Depression head was measured by means of a mercury manometer.
5	1.47	10.0	.000267	
13	1.64	11.62	.000183	
10	1.47	8.43	.000188	3. Transmission constants were determined by the Irrigation Research Institute.
8	1.66	6.83	.000261	
1	1.59	8.8	.000244	

8. Land

Land is required for the pump kiosk, operators' quarters, water-courses and service roads.

A plot 110 ft. × 110 ft. or 0.28 acres is taken for each pump kiosk and operators' quarters.

The land width required for watercourses is dependent upon the filling required for command, the discharge being constant for all tube-wells, and has been worked out from reach to reach.

The land required for the service roads is a strip of 10 feet width, which is considered ample.

9. Masonry Works

The masonry works consist of pump sump and kiosks, measuring devices and operators' quarters.

The design adopted for the pump sump and kiosk is shown in Plate 3, which is self-explanatory. The floor of the pump sump is kept 7.5 feet below spring level. It has been kept so low to accommodate the sluice-valve, the reflux valve, the duck-foot bend and the pump and, to keep the centre of the pump two feet below normal spring level to make it self-primed. The floor which is subjected to a 7.5-foot head of water consists of 2 feet thick mass cement concrete which is skipped in between the R. C. kerb and is covered with a R. C. slab one-foot thick.

The measuring device is of the broad-crested weir pattern with a two feet wide gullet. This has been given preference over a rectangular or a v-notch on account of the comparatively low head required for passing the discharge; and a low pumping head means a saving in the cost of pumping. Removable grids were provided in the first instance, for use at the time of the periodical check of the discharge. However, a tapering Hume-Pipe has been introduced between the delivery sluice-valve and the measuring device, which gives an exceptionally steady flow and the removable grids were dispensed with later on. The measuring device has been shown in Plate IV.

Operators' Quarters.—The operators' quarters provided at each tube-well consist of two rooms with a front verandah and a courtyard. The design is based upon the accommodation provided to a *patwari*.

10. Selection of Pump Sets

Selection of a suitable type of pump is of primary importance in any tube-well scheme. Before making the final choice, different kinds of pumps and headgears installed in the United Provinces and elsewhere were examined.

Centrifugal pumps with horizontal spindles are usually installed at the normal lowest level of the sub-soil water-table to ensure constant priming. Due to the occasional rise of water-table during the monsoon season, when the demand is slack, the installation is in danger of being drowned by the rise of the seepage water in the well. Actually, a number of motors are said to have been ruined in the United Provinces in this manner.

This difficulty has been overcome by using centrifugal pumps with vertical spindles and driven through vertical shafts from vertical spindle motors installed 8 to 10 feet above the pump. The only drawback with this type of pump as offered by the tendering firms was that its discharge varied more rapidly with a variation in the total pumping head than in the case of other types of pumps, otherwise it is the most suitable type and has been proposed to be used on the Karol Tube-Wells Scheme.

The propeller type of pump gives a fairly constant discharge against all heads, but its efficiency is comparatively lower than that of the centrifugal pumps.

The bore-hole type of pump was also examined but, on account of its lower efficiency, it has not been adopted for the Karol Scheme.

The vertical-spindle centrifugal pumps which have been used were specially manufactured by the Harland Engineering Co., Ltd., and are known as the "Spiroglide Pumps," illustrated in Plate V. The following special features of the Spiroglide Pump set are noteworthy:

Pump and Motor.—The pump is provided with cutless rubber bearings instead of the standard ball and roller bearings. This arrangement renders the bearings immune against the effects of dampness or flooding of the well. It also means that the pumps require no periodical lubrication, one gland being the only part requiring occasional attention.

The headgear is extended downwards and provided at its lower extremity with a steady bearing. The unsupported length of vertical shafting is thereby considerably reduced, giving additional rigidity and freedom from vibration.

This feature avoids the necessity for the provision of an intermediate steady bearing for the vertical shafting carried on a girder spanning the pump chamber, such bearings being prone to get out of alignment in course of time due to the settlement of masonry walls of the chamber, which alter the position of the girder supporting the bearing, thereby causing vibration in the vertical shafting.

The weight of the vertical shaft and pump motor is carried on a thrust bearing located in an accessible position in the headgear, where also is the means of adjusting the position of the shaft and the impeller in the pump casing.

The vertical shaft between pump and motor is of an abnormal strength, being of 3¼-in. diameter. The reason for using vertical shafting of such a large diameter is to ensure that the first critical speed of the shafting is beyond the full load speed of the pump sets, so that when the pump is being started when running and when being shut down, the shaft does not pass through a critical speed which would cause vibrations.

The motor-supporting headgear is of massive construction and has a large area base, machined on the under-side for supporting on the machined surface of two rolled steel joists spanning the pump chamber. After erection, dowel pins are fitted through the headgear base into the girders so that should the necessity arise for the headgear to be renewed there is no difficulty in re-erecting the pump set in correct alignment, the girders being levelled when first installed, so that no packing strips or shins are used between the headgear and the girders.

The motors used are also of Harland manufacture, specially designed for use with the pump.

The Control Gear.—The control gear comprises of star delta starter with ammeter and triple-pole main switch and fuse unit all mounted on an angle iron framework, arranged for wall mounting and complete with V. I. R. connections carried in conduit tubing between the switch and the starter, wood-bushed holes being provided for the incoming cable to the switch and the outgoing cable to the motors.

Efficiency.—The efficiency of these pumps is high and their actual performance is in accordance with the claim of the manufacturers. Up till now only eight pumps have been tested. Their performance is shown in the statement, *vide* Appendix III.

It will be observed that in six out of the eight pumps, the observed overall efficiency is greater than the stipulated efficiency; in the remaining two cases the slightly lower efficiency is due to the unbalanced current because of defect in motors, which are proposed to be set right.

These pump sets are, however, not absolutely flawless. The pump sleeves wear out by the action of the sand present in the water and the replacing of sleeves adds to the cost of maintenance. Special filters for providing sand-free water for the lubrication of rubber bearings will be installed to overcome this defect.

11. Description of Different Operations

Boring.—Boring is done by the percussion system. To accommodate 10-in. rising pipes and strainers and allow for 4-in. thick shrouding 18-in. casing pipe is sunk by means of a sludger. The sludger with a steel cutting shoe and a non-returning valve is either worked by power plant or manual labour depending upon the hardness of the strata.

Strata Samples.—Soil samples are taken at every 10 feet depth and also at every change of strata. They are preserved in a compartmented box and are also sent to the Irrigation Research Institute for the determination of transmission constants and measurement of percentages of clay and *kankar*.

Water Samples.—Water samples of each water-bearing strata are taken in a properly cleaned and steamed Winchester quart bottle and sent to the Irrigation Research Institute for the determination of the pH. value, conductivity, salt index, quantity of salt present in water, as also the total solids, in order to find out whether water is suitable for irrigation or not and its probable effect on the life of the strainer.

Water Levels.—During the process of boring, observations of water levels in the bore are recorded regularly twice a day before starting the work and after finishing it for the day. The difference in the water levels observed on the close of a day's work and the next morning before starting the work gives an indication of the recuperation of water levels in the bore and the nature of the strata at the bottom of the casing pipes.

Location of Strainer and Shrouding.—After the completion of a bore, a location chart of strainers and rising pipes is designed, guided by (*a*) the transmission constants of the soil strata ; (*b*) the analysis of samples of water, and (*c*) the water levels in the bore.

After the strainer has been lowered in the bore according to the location chart, the process of shrouding and extraction of the casing pipes is started simultaneously. Shrouding consists of ¼-in. Pathankot *bajri* retained on 1/10-in. mesh. An accurate record of the material used in shrouding is maintained, showing its calculated quantity as also that actually used. In certain cases, specially at the junction of sandy and clayey strata, big cavities are formed which require considerable quantities of the shrouding material to fill them. During the location of the strainer, great care has to be taken so that the strainer and rising pipes are always suspended and are not allowed to rest on the bottom of the bore as otherwise the strainer at the bottom is subjected to unsafe loads, and is liable to be crushed.

To ensure that the strainer has been located and the shrouding has been done without any damage to the strainer, it is necessary to take soundings inside the tube-well at frequent intervals. A history sheet for each tube-well is maintained at site, giving complete information regarding each bore.

Testing the Tube-Well.—After the extraction of the casing pipes is finished, the tube-well is tested for its discharge. If the yield of the tube-well is satisfactory, *i.e.*, it yields a discharge of about 1.5 cusecs for a maximum depression head of 12.0 feet, the construction of the masonry part of the work is taken in hand.

The most interesting feature of the construction of a tube-well is the putting in of a water-tight joint between the top of the rising pipe and the suction sluice-valve. This joint is 7.0 feet below spring level and it is not possible to fit the suction valve when water is rushing out of the rising pipe under this much head. To overcome this difficulty a mechanical rubber stopper has been devised by Mr. A. M. R. Montagu, (see Plate VI). The stopper completely staunches the flow of water in the rising pipe. It is then quite easy to put in the pump foundation after the suction sluice-valve has been put in position.

12. Watercourses

The area attached to all these *chaks* is rather uneven and is interspersed with depressions and river creeks. In fixing the boundaries of the *chaks* an attempt has been made that the creeks form the limiting boundaries of the *chaks*.

In spite of the precaution, a number of depressions had to be included in some of the *chaks*. The watercourses have been so aligned that they pass through the highest land in the *chak* and the depressions are altogether avoided. If, however, it is not possible to do so, these are crossed at the highest levels.

Watercourses have been so designed that no field in the *chak* is more than half a mile or so from the nearest government watercourse. From the government watercourses, subsidiary watercourses are constructed by zamindars, leading to their fields. A field command of 0.2 feet and a bed slope of 1 in 3,000 in subsidiary watercourses and 1 in 5,000 in government watercourses have been provided.

Tube-wells are run free of any charge for a sufficient period to allow for the consolidation of the government watercourses and the construction of subsidiary watercourses.

Lining of Watercourses.—The lining of watercourses is deferred for one full crop till such time as field *nakkas* (outlets) are finally established and consolidation of the watercourses is sure and complete. Experiments were carried out for the selection of a suitable lining medium. A non-erodable plaster, suggested by the Irrigation Research Institute, consisting of 7.5 c.ft. earth, 1.5 lbs. sodium carbonate, 0.6 mds. molasses, 0.6 mds. white lime and 7.5 c.ft. sand, was tried out but it did not prove satisfactory as the plaster with such a strong mixture developed cracks on drying, especially on the slopes. Moreover, it is not proof against cattle trespass. It has, therefore, been proposed to line the watercourse with ordinary 1½-in. tiles laid in cement mortar (1 : 4) as the most suitable type of lining.

13. Service Roads

Roads connecting different tube-wells have been provided so that all the tube-wells are easily accessible. In the first set of 10 tube-wells, service roads have been constructed 6 inches above the natural surface, whereas in the second set of the remaining 10 tube-wells the service roads have been placed at natural surface. In addition to the service roads, watercourse crossings, where necessary, have been constructed. Simple chain barriers have been proposed for controlling traffic where service roads cross village and district roads.

14. Establishment

One operator is employed for each tube-well. His duties are: (*a*) to start and stop the pump; (*b*) to record the time and the meter reading at the beginning and end of each cultivator's turn; (*c*) to record the area irrigated and the crop sown; (*d*) to issue the cultivators' receipts, (*e*) to prepare the daily routine returns and (*f*) to look after government channels.

He is provided with rent-free quarters located adjacent to the well. The scale of his pay is Rs. 25—$\frac{1}{2}$—35.

The operator at each tube-well is assisted by one *beldar* to look after the service roads and government channels and cleaning, oiling and greasing the machinery. When the operator is busy in booking irrigation, the tube-well is attended to by the *beldar*. He gets Rs. 12 per mensem.

A *zilladar* has been employed to check the work of the operators relating to the entries of irrigation and electricity consumption and to enquire into all complaints and prepare certain consolidated returns. So long as the project is not fully developed, the most important part of his duties is to make the cultivators understand the economy of tube-well irrigation as compared to irrigation carried out from open wells, and to instruct them as to the most suitable and profitable crops to grow.

A supervisor, who is both an electrician and a mechanic, looks after the electrical and mechanical maintenance and attends to the replacement of defective equipment with the least possible delay. He is allowed a consolidated pay of Rs. 125 per mensem.

15. Method of Charging Water Rate

The operator maintains a printed and bound log book containing information regarding:

(1) Date.
(2) Time of starting and stopping the motor.
(3) Meter reading at starting and stopping.
(4) Units used by cultivator.
(5) Value of electricity used.
(6) Field numbers irrigated.
(7) Name of crop.
(8) Area irrigated.
(9) Gauge in measuring tank.
(10) Total volume pumped in cubic feet.

In addition to the log book, the operator maintains a cultivators' receipt book. This is in triplicate. When a cultivator has finished irrigation, he signs the receipt which shows the time of starting and stopping the pump, the number of units consumed and the amount assessed. The operator keeps the counterfoil with himself, sends the duplicate to the *zilladar* and hands over the triplicate to the cultivator to enable him to check his water bill at the end of the crop.

On receipt of the cultivator's receipt, the *zilladar* posts the units used in a ledger in which he leaves a page for each cultivator. This forms the basis of the demand statement. The ledger is also kept in duplicate. The duplicate copies are distributed to the cultivators at the end of each crop and take the place of the *parcha* (demand notice), vernacular form No. 8-A, used in canal-irrigated areas.

Water charges have been fixed per 1,000 c.ft. of water. Actually, however, the rate is converted into electrical units by actual measurement.

At the beginning of each crop, a complete test of each tube-well is carried out with respect to its discharge, electrical consumption, delivery and suction head, pump efficiencies, etc. etc. Electrical consumption per 1,000 c.ft. of water and the cost of an electrical unit for each tube-well is worked out and intimated to the *zamindars* concerned by posting notices.

The rates per thousand c.ft. of water are uniform for all the tube-wells, but the rate per unit of electricity varies from well to well, depending on the number of units required to raise the standard volume. The advantage of this system is that the cultivator can read the meter before and after his turn starts and knows exactly how much is to be debited to his account.

16. Water Rates

Water rates per 1,000 c.ft. of water are the same as charged in the United Provinces.

These are three annas six pies per thousand c.ft. of water for *kharif* and two annas four pies per thousand c.ft. of water for *rabi*. These correspond to Rs. 2.12 per watering of four inches in *rabi* and Rs. 3.18 per watering of four inches in *kharif*.

Assuming deltas of 1.8 and 1.1 for *kharif* and *rabi* (*vide* paragraph 5) the cost of maturing one acre of *kharif* crops works out at Rs. 16.7 and of *rabi* crops at Rs. 6.81.

The deltas assumed both for *kharif* and *rabi* are higher than customary in open-well irrigation as indicated by the experiments on open wells, the results of which are incorporated in Appendices I and II.

The actual *rabi* deltas of tube-wells Nos. 6, 2, 14 and 5 for *rabi*, 1939-40 were .72, .82, 1.01 and 0.60 respectively which are less than 1.1 foot. The *rabi* rate is, therefore, quite a fair rate and *zamindars* have the same feeling about it. They, however, consider the *kharif* rate rather high. This can be judged only after the working of one or two *kharif* crops.

17. Working of Tube-Wells during "Rabi," 1939-40

At the end of *rabi*, 1939-40, eight tube-wells had been completed and were supplying water for irrigation purposes. The following table shows the dates when each of the eight tube-wells started functioning as well as the dates from which water rates were charged. During the interval between these dates water was supplied free of cost to the *zamindars* :

Tube-well No.	Date of starting tube-well	Date from which water rates were charged	Number of hours for which the tube-well worked free during *rabi*, 1939-40	Number of hours for which the tube-well worked on water-rate basis during *rabi*, 1939-40	Total
6	28-5-39	1-10-39	*Nil*	1,314	1,314
2	16-6-39	1-10-39	*Nil*	1,966	1,966
5	19-7-39	1-12-39	744	226	970
14	10-7-39	1-12-39	694	264	1,158
13	9-10-39	1-3-40	1,570	69	1,639
10	24-11-39	1-3-40	995	89	1,084
8	11-12-39	15-3-40	651	30	681
1	24-12-39	15-3-40	492	37	529

From the above it will be seen that only two tube-wells, *i.e.*, Nos. 2 and 6, functioned for the whole of the *rabi* season on water-rate basis and the rest were either run free of charge for part of the season or were completed during the *rabi* season.

It is, therefore, premature to form an accurate estimate of the working of these tube-wells, which is only possible after a fair number of tube-wells have functioned for at least two or three successive crops.

Tube-Wells No. 6 *and* 2.—These tube-wells were the first to be completed and they started functioning during *kharif*, 1939, but water rates were charged from the 1st October, 1939, *i.e.*, the beginning of the *rabi* season.

They are, therefore, the only tube-wells the data with respect to which truly represents the whole of the *rabi* season, 1939-40. The working of these tube-wells has been very satisfactory as will be seen from the number of hours they have run and the area irrigated from them. Against the forecast of 200 hours for the first *rabi* season, as per project report, they have worked for 1,314 and 1,916 hours, irrigating 231 and 270 acres out of the commanded culturable areas of 482 and 631 acres respectively, which is really a marvellous achievement for the first crop.

As the remaining six tube-wells did not function on a water rate basis for the whole of the *rabi* crop, it is not possible or desirable to form an accurate estimate with regard to their working or capability.

It can, however, be definitely stated that all the tube-wells have behaved splendidly, maintaining a uniformly high rate of efficiency without any deterioration whatsoever in the discharges delivered by them. The discharges of all these tube-wells are about 1.5 cusecs and are obtained with pretty low suction heads.

The overall efficiencies of the pump sets are also very high. The average number of units (for the eight tube-wells) consumed per 1,000 cubic feet of water pumped works out to 0.95 against the forecast of 1.46 units, which means that the pumps are doing 35 per cent. better than the forecast. This is a most gratifying result.

18. Stability of Subsoil Water-levels

To study the effect of withdrawal of subsoil water on the spring levels near the tube-wells, special observations were carried out on tube-wells Nos. 6 and 2. Observatory pipes were let down below the spring level radially at 25, 50, 100, 150, 200, 250, 500, 750 and 1,000 feet from the tube-wells in two directions, *viz.*, towards the river and away from the river. Such pipes were also fixed at a distance of 2,500 feet from the tube-wells in all the four directions.

It was observed that there was little effect of even seven days' continuous working of tube-wells on the subsoil water-levels beyond a radius of 1,000 feet, and it took comparatively very little time for the levels to recuperate. This shows that the subsoil reservoir is fairly stable. The depletion and recuperation curves for tube-wells Nos. 6 and 2 are attached, *vide* Plates 7, 8, 9 and 10. In the case of tube-well No. 2, the proximity of the canal which has an independent effect on the subsoil water-levels, explains the abnormal variations in depletion and recuperation.

19. Cost of a Tube-Well

The cost of a tube-well works out to Rs. 11,870 as per details below. It includes the value of land, the cost of constructing operators' quarters, etc. etc. The cost of land required for the kiosk, service roads and watercourses is quite a big item :

		Rs.
1.	Constructing and sinking tube-well kiosk and constructing measuring device	1,040
2.	Boring and test-pumping tube-well ..	1,960
3.	Constructing operator's quarters	705
4.	Providing strainers and blind-pipes for tube-well	3,485
5.	Supplying pumping equipment	1,987
6.	Boring $1\frac{1}{4}$-in. G. I. pipe near tube-well ..	22
7.	Constructing watercourses and watercourse crossings	751
8.	Constructing falls and *nakka* outlets of watercourses	35
9.	Constructing service roads connecting chaks ..	35
10.	Land	1,773
	Total ..	11,870

20. Financial Aspect

It is too early to forecast with accuracy the financial aspect of the project. However, judging from the results so far obtained, especially on tube-wells Nos. 6 and 2, which were the only two tube-wells that were operated on a water-rate basis during the last *rabi*, it can be stated with a fair degree of confidence that the scheme is going to be sound financially both for the Irrigation and the Electricity Branches of the Public Works Department. The Revenue Department is also sure to benefit through an increase in the land revenue due to the enhancement of the value of land.

The total expenditure on tube-wells Nos. 2 and 6, which worked for the whole of the crop, amounted to Rs. 1,037 and Rs. 975 respectively and the total revenue receipts were Rs. 1,355 and Rs. 1,048 respectively resulting in a net profit of Rs. 318 and Rs. 73 on the two wells.

If even during the very first crop the tube-wells can show a profit (however small) it can safely be stated that on full development of the project it should prove a sound proposition financially. And this is in spite of the fact that the Hydro-Electric Department charges a very high rate for energy supplied, *viz.*, 15 pies per unit.

21. Bibliography

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APPENDIX I

OPEN-WELL IRRIGATION

(*In rabi*, 1937-38, *in Ram Kishanwala village.*)

Serial No.	Name of crop	Area under crop	Average delta used	Average number of waterings	Cost of irrigation per acre	Cost per acre foot
					Rs. a. p.	Rs. a. p.
1	Potatoes ..	35.94	1.39	9	22 5 2	16 0 11
2	Wheat ..	6.32	0.66	4	12 8 3	18 15 4
3	Oats ..	14.48	0.62	3	13 0 8	21 0 6
4	*Senji* ..	3.29	0.62	3	12 2 6	19 9 8
5	Vegetables	0.78	0.99	6	20 9 8	20 12 11
6	Nursery ..	0.08	0.62	4	13 2 5	21 3 4

APPENDIX II

OPEN-WELL IRRIGATION

(*In Rabi*, 1937-38, *Karol Village*.)

Serial No.	Name of crop	Area under crop	Average delta used	Average number of waterings	Cost of irrigation per acre	Cost per acre foot
					Rs. a. p.	Rs. a. p.
1	Wheat ..	29.66	0.48	2	9 2 9	19 1 9
2	Oats ..	6.39	0.76	3	18 13 11	24 13 4
3	*Senji-Shaftal* ..	7.02	1.53	7	31 11 2	20 11 6
4	*Shalgam* ..	1.82	0.76	3	18 0 6	23 11 7
5	Barley ..	2.21	0.51	3	12 4 8	24 1 7
6	*Senji* ..	2.70	0.72	3	17 1 7	23 12 0
7	Nursery *kharif* vegetables	1.00	0.50	3	12 7 6	24 15 0

APPENDIX III

TESTS AT FULL-LOAD OF DIFFERENT TUBE-WELLS

Serial No.	Details	Number of Tube-Wells							
		5	10	2	1	6	8	13	14
1	R. P. M. ..	1420	1468	1463	1432	1462	1464	1466	1473
2	Amp. scale reading ..	34.2	33.8	34.2	41.08	40.3	42.66	39.6	35.1
3	Amp. per phase ..	8.51	8.43	8.5	10.23	10.0	10.63	9.85	8.75
4	Voltmeter ..	119	109.64	120	120.54	114.5	114.9	112	113.6
5	Line Volts ..	412	381	416	417	396	398	389	393.7
6	K. V. A. ..	6.08	5.55	6.13	7.39	6.87	7.34	6.62	5.96
7	Watt Meter reading ..	0.39	0.379	0.372	0.458	0.47	.5073	.466	.41
8	Total K. Watts ..	4.68	4.54	4.468	7.39	5.64	6.09	5.59	4.92
9	Power Factor ..	0.77	0.82	0.729	0.743	0.82	0.83	0.843	0.825
10	Total H. P. ..	6.27	6.10	5.99	7.37	7.55	8.16	7.49	6.6
11	Maker's efficiency at above K. W. Load ..	0.87	0.87	0.87	0.88	0.88	0.885	0.879	0.87
12	B. H. P. ..	5.46	5.31	5.20	6.148	6.67	7.23	6.59	5.76
13	H. P. available ..	5.26	5.11	5.00	6.28	6.47	7.03	6.39	5.56
14	Delivery heads ..	13.2	13.91	15.95	16.01	17.3	18.075	16.2	16.63
15	Suction Head ..	10.0	8.43	6.5	8.8	11.1	6.825	11.62	7.95
16	Total Lift ..	23.2	22.34	22.45	24.81	28.4	24.9	27.82	24.58
17	Discharge cusecs ..	1.466	1.466	1.473	1.594	1.5425	1.6575	1.638	1.46
18	Water H. P. ..	3.87	3.725	3.76	4.5	4.97	4.69	5.174	4.06
19	Pumping efficiency ..	73.6%	72.9%	75.3%	71.6%	77%	66.7%	96%	73.45%
20	Overall efficiency ..	61.6%	61.1%	62.8%	61.1%	65.7%	57.5%	69.06%	61.87%
21	Designed efficiency ..	59.4%	59.4%	59.4%	63.2%	63.2%	63.2%	63.2%	59.4%

DISCUSSION

While introducing the paper, one of the authors, Mr. H. L. Vadera, said that as the Karol Tube-Wells Scheme had not been completed so far, it had not been possible to do full justice to certain aspects of the scheme in the paper. It was too early to express any definite opinion on the working of the tube-wells, though two tube-wells, No. 2 and 6, which had been worked for the whole of *rabi*, 1939-40, had given very hopeful results.

A statement showing the detailed working of eight tube-wells installed so far had been prepared. This would clearly show the efficient working of all the tube-wells with respect to the discharge pumped and suction-head. All these tube-wells had each been giving a discharge of 1·5 cusecs with the depression-head varying from 6 to 12 feet. In case of these tube-wells, the actual hours run in each crop had been compared with the forecast. The results were very encouraging.

Again the authors felt that the financial aspects of the scheme had not been dealt with satisfactorily. They had prepared two statements dealing with the financial aspects of the scheme, which showed that the scheme was bound to give a good return after the project had been fully developed. It needed to be mentioned that development of any irrigation tube-well project would not only depend upon the efficient working of the tube-wells, but it would depend a great deal on the co-operation which they would get from the Zamindars owning land to be irrigated. No dealer could force his commodity on his customers. He could only display its efficient and good working. (Statements referred to above are printed at the end of the discussion.)

Mr. A. M. Montagu said that it gave him pleasure to open a discussion on the paper by Messrs. Vadera and Talwar on the Karol Tube-Well Scheme. Many of the kind remarks made in this paper about him personally were undeserved, but the fact remained that one of the numerous Punjab investigations into tube-wells were certainly carried out by him. For reasons into which it was unnecessary to go, the investigations carried out between 1937 and 1939 resulted in the actual execution of a small experimental tube-well scheme near Lahore in the area known as "Karol"—from the name of one of the large villages therein.

The actual area had been proposed by Mr. Bigsby, lately Chief Engineer of the Irrigation Branch, under whose general direction the investigation had been carried out. This area had several advantages, some of which would not be found in other tube-well areas, and it was extremely doubtful if so many advantages would ever again be found in any one area selected for irrigation by tube-wells.

To begin with, the area was near a large city, which facilitated the sale of vegetable produce. The area was closely cultivated, and therefore, offered economical distribution of the tube-well water. The area was near the river which promised regular and adequate recuperation of the sub-soil water from which the tube-well supply was drawn. The area was near a distribution point of the Punjab Electricity Department which promised economical supply of electricity at the pump kiosk. The soil was fertile and had already been irrigated by open-wells. Open-wells had been proved to be expensive and inefficient when compared with a properly designed tube-well scheme. So the substitution of open-wells by tube-wells had been a relatively simple matter.

The credit for spotting the combination of these advantages and advocating the area as the site for the first experimental tube-well scheme undoubtedly belonged to Mr. Bigsby.

Mr. Talwar had been employed as Sub-divisional Officer on many of the trial bores carried out for one or other of the investigations conducted by the Officer on Special Duty: Tube-well Investigation. The speaker understood that it had been due to this experience that Mr. Talwar was selected for the Lahore sub-division, within which the Karol Tube-Well Scheme was now included. It had been as Executive Engineer, Majitha division, that Mr. Vadera had been responsible for the completion of construction and the organization of the system when it had begun to function.

Continuing the speaker said that he did not propose to review there his own report to Government on tube-wells. Officers who were interested in his conclusions might read the printed report in original and offer any criticisms which their own experience suggested. He would try to confine his remarks strictly to the Karol Tube-Well Scheme.

The Karol scheme really was an experiment to test the accuracy of the prognostications on two separate heads:

(*a*) the technical, and
(*b*) the agricultural.

On the technical side, he had emphasized various fundamentals in the design of tube wells.

It was necessary to know the mean transmission-constant of the area influenced by the tube-well pumping. Unfortunately, the only opportunity which the engineer had of determining these transmission-constants was that given by soil tests of the spoil from the bore. Clearly, those were only the roughest indications of the mean transmission-constant of the soil as a whole. Nevertheless the fact remained that it was all that the engineer had to go upon. The speaker emphasized that, in this respect at least, all tube-well design was very much a matter of instructed guess work.

Another point which he believed had first been brought to prominence in that report to Government, was the necessity to reduce the velocity of approach to the tube-well strainer to such an extent that fine particles of soil should not be moved. The surface area of the strainer was controlled by that consideration.

Yet another point was the advisability of shrouding uninterruptedly from the top to the bottom of the tube-well bore. The object and reason for this operation were mentioned frequently in various books and papers on the subject, but so far as he had been aware, that had not been the practice in the Punjab in any earlier tube-well schemes, whether for irrigation or water supply.

Yet another point in design which had been tested in the Karol project, was the possibility of successive reductions in diameter of the tube-well pipe and strainer, with a view to economy, and even more important, with a view to securing a certain minimum velocity in the rising water. Such design was directed to prevent the settlement of the finest particles which undoubtedly were drawn in through the strainer, and in the absence of adequate velocity, must necessarily settle to the bottom of the tube.

The authors had referred to the extreme care required in handling 4-inch diameter strainer pipes. It should be clearly understood that the speaker did not, and would never, recommend the use of fragile brass strainers. When submitting the project originally, he had recommended another type made of mild steel, with pressed slots—a very robust construction protected from corrosion by cadmium plating. The Chief Engineer at that time, however, had ordered that a brass strainer should be used, on the grounds that it was manufactured in the Punjab. This patriotic motive had led to the use of a strainer which had proved to be definitely unsuitable on the score of strength and difficulty of locating without damage. The speaker noted with regret the decision which had been taken subsequent to his departure not to use strainers of lesser diameter than 7 inches.

The experience in the United Provinces had largely dictated the design of the pumping equipment. With a vertical spindle, the pump could be placed 8 or 10 feet below the motor so that should the dry pump-well be flooded, the motor could be started and the well dried out, before the electric motor was damaged by the rising water. As it happened, that particular difficulty had been eliminated by care in construction, for which Mr. Creaner, the Sub-divisional Officer in charge, had largely been responsible. The brick dry-wells, housing the pumping equipment, had been well-built and carefully sunk. The concrete in the floor had been skipped in with care and subsequently finished off in such a manner that all the pump wells had, he understood, remained consistently dry. He could not over-emphasize the importance of such care in construction in future projects.

The authors had made kind references to the type of plug designed by the speaker and constructed by the firm who had supplied the pump equipment. Here again the necessity for such arrangements had been obvious from the difficulties experienced in U. P.

construction. This plug, described on page 234 of the paper, unquestionably facilitated depression of the entire pumping equipment to such point that the pump remained constantly primed. The elaborate arrangements made for priming the pump had, therefore, been unnecessary.

Yet another feature of this pumping equipment had been the equally elaborate means designed to take up possible sinkage in the pump-well or movement in the tube-well pipe. He had been given to understand that there had been no breakage of any sort, of the equipment from these causes. Whether it was due to absence of movement in the solidly constructed wells or whether it was due to the elaborate flexible joint, he did not know, and he suggested that the authors should inform him on that point. Records of other projects and U. P. experience indicated that some such arrangement was at least advisable.

In regard to discharge, the prognostications had been more than fulfilled. The demand for water had been considerably greater than had been expected and the pumps had in the majority of cases actually delivered more water than had been anticipated with the designed depression head. He did not suppose that anyone would be deceived into imagining that they had discovered the secret of successful tube-well design. To be quite frank, he had made liberal allowances at every stage to compensate for errors in observed data and uncertainties in the theory. He was deeply indebted to the U. P. Engineers for their frank explanation of all their difficulties which had enabled him to make those liberal allowances and so ultimately to secure the very high efficiency which the Karol project had attained.

On the agricultural side, the water allowances had been calculated as a result of an elaborate investigation carried out on open wells and already described in the paper. What they really had desired to ascertain by the investigation, had been the delta required for the average cropping in the area in *kharif* and *rabi*. The various steps required to determine this figure from the observations made, were somewhat complicated and were dealt with in full in the original report on the Karol Tube-Well Irrigation Scheme. They had arrived at a figure of 1·8 feet for *kharif* and 1·1 feet for *rabi*, and the tube-wells had been sited and designed and the chaks drawn to provide this delta. At this stage, also liberal allowances had been made for error.

He noted from the authors' paper that the water-courses had not yet been lined. He sincerely trusted that this step would be taken. Apart from the advantage to the cultivator, it was fairly easy to prove that the lining of water-courses which ordinarily ran for 1,000 hours per annum, was quite definitely an economical proposition.

The authors had dealt with the question of water rates. Here he desired only to express a personal opinion. Cultivators were only human and naturally took every opportunity to assure Government that they had been on the verge of bankruptcy and could not possibly afford to pay the iniquitously high rates which the Government levied for water. To use a conversationalism, such grumblings were "a lot of hooey". Government supplied water from tube-wells to the cultivator at a rate of approximately $\frac{kharif}{rabi}$ Rs. $\frac{9{\cdot}54}{6{\cdot}36}$ as compared with the rate of *kharif* and *rabi* Rs. 20 to Rs. 40 per acre-foot, which the same water will cost the cultivator to raise from open-wells.

Moreover Government did all the *bandobast* and left the cultivator free to utilize his energies in growing the crop with the water supplied. The water is available almost at the will of the cultivator. "The proof of the pudding is in eating thereof." The open-wells in the Karol area if not already completely abandoned, were largely so and the demand for the extension of the Karol tube-wells was loud and persistent. In the face of the above facts any suggestion that the water rates were cruelly high was comical in the extreme.

It was true that Government had varied the rates between *kharif* and *rabi* crops. When grumbling, the cultivator carefully refrained from referring to this comforting adjustment made by Government. To the irrigation officers he did not need to emphasize that the money-making crops were grown in *kharif*. To charge more for water supplied during the time of high consumption and keen demand was not only a business proposition but was economically and socially justified by the greater return to the cultivator from *kharif* crops.

The authors' paper was the first one in the annals of the Punjab Engineering Congress dealing with an existing tube-well irrigation scheme in the Punjab. The subject was so large that it was impossible to deal with it as a whole within the confines of one paper. Nevertheless in introducing the paper to the discussion of this assembly, he had found it hard to confine himself strictly to the Karol Tube-Well Project. He confessed that he had introduced matter of more general interest.

The practical application of tube-wells to irrigation had only just begun in the Punjab. It was a subject of absorbing interest and was well worth a special study by those who felt a keen interest in it. It was true that tube-well irrigation did not deal with large bodies of water and great masonry works. But it did deal with highly efficient irrigation, the sub-soil water, a highly scientific branch of mechanical and electrical engineering. Indeed it offered a wide and interesting field for the experts in more than one subject. The first paper of Mr. Vadera and Mr. Talwar was especially interesting in breaking new ground in the Punjab and he personally sincerely hoped that some of the younger engineers will be induced to make a special study of tube-well engineering with a view to its application to advancement of the interests of the population of the Punjab.

S. Hukam Singh thanked the authors for presenting such an interesting paper. He did not profess to know much about tube-well irrigation, but, having been responsible for sinking scores of tube wells and fitting pumping machinery thereon, he could present nothing new on the technical side but would relate certain facts concerning everyday practice in the Public Health Circle to cope with similar situations.

Beginning with the tube-well, he found mentioned in para 11 rather an elaborate method of testing sands and finding transmission constants.

They in the Public Health Circle, in order to find out the coarseness of sand, and determine its suitability for water-yielding purposes, used Kennedy's test with the simple apparatus consisting of a metal container holding approximately 12½ ounces of the sand and a precipitation tube with glass cylinder, graduated in ten parts, each part to contain 1·25 ounces of sand or the whole cylinder 12½ ounces of sand.

The contents of the container were poured in the precipitation tube from the top, and by the help of a stop-watch, the time in seconds was noted for each 1/10th part of the volume of the sand settling in the lower glass cylinder. The results thus obtained were plotted on a graph with time taken thereon horizontally and each tenth portion of sand vertically.

This method, which could be used in the field, obviated the necessity of elaborate apparatus and scientists to work them.

In the Public Health Circle, a tracer of the Circle Office and a khalasi made this test.

These tests had been found to give satisfactory results for nearly six hundred borings.

Coarseness of sand was not always the only ruling factor which established its water-yielding capacity. Sometimes in fairly coarse sand very little water was available as at Ambala and Gujrat and in some cases great volumes of water were available in moderately coarse sand.

In taking samples from borings, it was probable that fine materials and colloids lying in the sands at site were washed out in the samples which were pulled through the water and this might create a wrong notion of the amount of water which could be yielded. This was probably a factor affecting conditions at Ambala where the existence of such fine clayey admixture with the water bearing sands was known.

The speaker very much liked the author to tell him what steps had been taken by him to stop the colloidal or fine materials in the sand from being washed away while pulling out the sludger containing the samples.

In para 7, the author had mentioned a good deal about optimum velocity and the use of tapering strainers.

In tube-wells required to yield over 1 cusec and taken down to depths of 200 feet or more, the use of strainers less than 7 inches internal diameter was not a good practical proposition.

It had been proved that the yields of various sand strata were not the same. The speaker believed that Mr. Ashford or Mr. Leggatt at Amritsar, many years ago, had tested the flow in a tube-well at various points by a velocity metre and had discovered some amazing results which proved this. Under these conditions, there was no advantage whatsoever in using tapered strainers.

It had been found from experience and results obtained from a very great number of tube-wells that the yield from tube-wells of moderate size under reasonable conditions might be expected to be not less than about 12 to 13 gallons per hour per square foot of strainer area per foot depression head for the whole length of the strainer used. Therefore in comparatively small thickness of good water-bearing sands, a larger strainer could be used and very great depression-head could be caused to great advantage.

The North Western Railway at one tube-well at Ambala pumped to a draw-down or depression-head of as much as 60 to 70 feet or more to get the required quantity of water from a rather small depth of water-bearing sands. At Ambala, Saddar Bazar, two tube-wells recently put in were pumped to about 42 feet depression-head.

Taking these depression-heads into account, the old idea that depression-head must be kept below about 15 feet or so, no longer held good. It might be any amount found desirable.

Regarding choice of strainer, having used both the Phoenix and Tej Strainers under identical conditions, the speaker had found beyond doubt that the Phoenix strainer is not suitable for use in hard waters while the Tej strainer acquitted itself quite well both in soft and hard waters and patriotic motives for its use did not come in.

It was not shown in the drawings as to how the completed tube-well was supported to avoid the whole of it to drop or sink down. He enquired if any settlement of tube-wells had taken place.

In the Public Health Circle for the last twenty years where the strainer was suspended from top, they supported the tube-well on two girders with a fair-sized bracket or flange.

Regarding the selection and design of the pumping machinery described in the paper, the speaker felt that it could have been improved or simplified a lot.

Wells had to be sunk nearly 10 feet below spring level and very thick expensive floors built 77 feet below the water-table to keep the pump top two feet below spring level so that the pumps remained self-primed.

Well, if this was the only object of undergoing all this trouble, it could have been achieved easily by use of a simple fitting called the "Seaborne interceptor." The "Seaborne interceptor" could be coupled up to any type of centrifugal pump such as a cheap horizontal spindle, centrifugal pump and if connected with the vertical spindle pump used on this scheme, would have enabled the pump floor to be kept above S. L. and do away with many construction difficulties, including working the plug watertight which was not watertight, reducing the cost of structural work and entirely obviating the chances of disturbing alignment of shaft by settlement of the well.

"Seaborne interceptors," installed even on pumping plants for roughly screened sewage, did not have to be cleaned out for long periods and had been working satisfactorily for several years past.

It was not correct to generalise that the discharge of horizontal spindle centrifugal pumps varies more rapidly with variation of total heads when compared with the vertical spindle centrifugal pump, that the efficiency of bore-hole type turbine pumps was less than that of the vertical spindle centrifugal pumps installed at Karol and that use of cutless rubber bearings was a great improvement.

Horizontal spindle, or bore-hole type centrifugal or turbine pumps were just as much centrifugal as the vertical spindle centrifugal pumps installed at Karol and can give the same efficiency and work under the same conditions as the vertical spindle, centrifugal pumps at Karol. As a matter of fact, there are some bore-hole pumps installed in the Public Health Circle, giving an over-all efficiency of over 70 per cent. and there was no inherent advantage either in design or in operation in the particular form of pump installed at Karol.

In the speaker's opinion, the chief advantage of fitting pumps, near spring level or below, was that if and when the yield of the tube-well started deteriorating, the required quantity of water could then be drawn out by increasing the depression-head and thereby lengthening the useful life of the tube-well.

If this was the object in fitting the pumps at Karol below S. L. then the class of pump most suitable for this type of work was the 'Borehole' or deep well centrifugal or turbine pump.

A 1·5 cusec bore-hole pump working against a total head of not more than 50 feet can be housed in a 10-inch internal diameter tube, but it was better to use a larger tube. This tube could be made out of $\frac{1}{4}$ inch thick mild steel plates welded together locally instead of using expensive pipes.

In the Public Health Circle, as a rule, this larger size of tube for say 50 to 80 feet below S. L., was installed and the bore-hole pump was placed well below the lowest possible depression-head which was likely to be caused in normal working.

Under these conditions, the pump being under water always remained primed. If the yield of the tube-well started deteriorating the pumping head could be increased by adding another stage or bowl, and if the spring level dropped, the pump could be kept in commission by increasing the length of the shaft by adding additional sections, thus lowering the pump bowls into the tube-well to the greater depth required for operation.

The lubrication of the driving-shaft, consisting of a turned, ground and polished steel shaft encased in a water-tight tube and as such not affected by the sand contents of the water pumped, was effected by means of an automatically operated drip-feed lubricator feeding lubricating oil at the rate of three to five drops a minute to the bearings.

The speaker had found that this type of design gave excellent results. There were dozens of makers of these pumps in America and all of them turned out a good pump not liable to cause trouble.

Vulcanised, water-lubricated bearings were also used in these pumps but his experience was that such bearings were not so trouble-free as the oil lubricated type, especially with tube-well water containing some sand or silt such as would be pumped on the Karol scheme and he was not surprised to find that filters were now going to be put in.

The head of the deep well or bore-hole pump was fitted above ground level. It did not need a large and expensive pump-house therefor or any valve on the suction side or expert supervision, being self-primed. If electrically driven it could be provided with automatic starter with slot mechanism to start up when a coin was inserted and to stop when the current worth the coin put in is used up.

The cost of providing a bore-hole pumping plant with its pump-house would, he felt sure, not exceed the cost of pump kiosk and pumping equipment installed, as given by the author in para 19(1) and (2).

Bore-hole pumps of various different makes were in use in the Public Health Circle, and had been found to be very efficient and some had been in use for the last six years working regularly almost 10 hours daily without having to be dismantled or taken out and their efficient condition showed that they did not need such attention.

The irrigation problems with tube-well irrigation in this country were somewhat similar to those in some parts of the United States of America, where very extensive use was made of bore-hole pumps on tube-wells which, according to the reports the speaker had seen, were a great success in every way.

In view of the long experience of people in the U. S. A. with the use of such bore-hole pumps, it was difficult to swallow the justification put forward by the author for not using similar plant here. The speaker inquired if it was suggested that the Americans were not as keen about efficiency of machinery as we were in this country.

Bore-hole pump could be driven by a directly coupled motor or by a motor alongside, driven by Vee-belts. In the latter case, if it was found necessary to alter the speed of the pump, all that was necessary was to change one of the pulleys—a very simple operation.

A very large bore-hole pump with a discharge of about $1\frac{1}{2}$ cusecs had been installed in the Municipal tube-well nearby and could be seen by any member who liked to see it working.

MR. G. R. SAWHNY congratulated the joint authors for writing this paper and giving us the results of this rather important experiment so soon after its commencement.

He suggested that carbonate of soda added to 'Bhusa' plaster should be tried for lining the watercourses instead of the proposed rather expensive tiles laid in 1 : 4 cement mortar. As a safeguard against cattle trespass all that was needed was to build small drinking tanks for them on either side of the watercourses at their crossings with important village roads. This arrangement had lately been tried with success in the Military Farm at Okara.

The speaker asked if any allowance had been made while charging on the meter-reading for the fields which were at a greater distance from the pumps than the others.

The multifarious duties of the operator seemed to him rather difficult to perform efficiently. If Beldars could be trusted to look after the pumps for short periods, he would suggest that one operator should be kept to look after the working of two or three pumps and special men employed to do the field work and preparation and issuing of parchas, etc.

The authors were lucky to have cultivators who could read the meter, and keep an account of such readings for verification of their bilis. Ordinarily one rarely met a cultivator who knew any better than just putting his thumb impression on a piece of paper.

The cost of watering *kharif* crops seemed rather high and for making this experiment a real success, it would have to be reduced somehow or other.

He would like to know if the total expenditure for the year included depreciation of machinery and interest on investment or not, and if not how much would be the net profit after making such allowances.

MR. KANWAR SAIN remarked that the authors deserved to be congratulated for the clarity and the brevity with which they had dealt with their subject. The paper appeared to be somewhat incomplete without the figures of capital spent and the running expenses and the percentage of outturn anticipated from the Project. These figures had since been supplied by the authors.

The authors stated that the Irrigation Department, the Electricity Department and the Revenue Department should all benefit. They failed to mention the most important party—the cultivator and the land owner. It might be added that the Project was entitled to a credit on account of the enhancement in the land revenue. Mr. Montagu had, during the discussion, shown how the water-rates had been arrived at. It would have been a useful addition to the paper if the outturn per acre from the tube-well was compared with the open-well and the canal irrigation. A detailed comparison of the cost and the revenue of tube-well irrigation with the open-well and the canal irrigation system should also be useful.

Mr. Ishar Das remarked that after Mr. Vadera had left, he stepped in and remained in immediate contact with the problems of those interesting works during the last six months. He would like to say a few words which in his opinion needed consideration :

The authors had referred on pages 231 and 232 of the paper regarding choice of pumping sets. To his mind more information was needed on this important subject.

To feed the ever-increasing population, increased irrigation would be a necessity. The Irrigation Department had already tapped almost all the natural resources of supply. Large areas were still lying unirrigated and to irrigate them would be feasible by the tube-wells. In coming years tube-wells would perhaps become a common feature of their irrigation policy.

To dismiss the other types of pumping sets in favour of those with vertical spindles because of the claim of the makers that their efficiency was above other types was, to his mind, not fair to the other types. He would rather have liked parallel sets of different types working side by side and giving them necessary experience at this initial stage of the experiment with that type of irrigation. He proposed that some other type like the bore-hole pump could even then be erected for trial. The efficiency of bore-hole type was probably not very high but improvement could be made. Their fool-proof working and easier maintenance, due to their being installed at the ground level, than that of the vertical-spindle pumps in the pit, many feet below ground, were other advantages in favour of the bore-hole pumps.

In case of the vertical-spindle pump, it was yet to be seen what the maintenance cost would be. He had just plotted the electric energy consumed for a cusec hour for each month. The comparison was not altogether uniform and the period the plant had been under observation had been rather short. Overall efficiency at the first trial after erection had been about 60 per cent. Another test had been asked to be carried only last week but the staff had not been available to do this.

The use of rubber bearings under submerged conditions would perhaps be an advantage but it was yet to be seen how long they lasted. It had already been found necessary to change the sleeves.

When the bearings wore out, the vertical spindles would naturally lose their verticality and in that case the torque will be tremendous indeed and would adversely affect the working of the whole system. It should not be forgotten that the lubrication of rubber bearings was by water of the well itself. Too much reliance on the efficiency of rubber was also dubious, sometimes one might get old rotten stuff which might result in a great loss. Sand, drawn up at times with water, would also affect adversely the rubber bearings.

During the course of construction there had been two mishaps while doing the boring operations :

(*i*) the first one was in case of well No. 1, when about 30 feet length of the strainers was lost, involving a loss of Rs. Rs. 800 to the Government. This length was alleged to have been crushed under the load of the upper pipes and strainers. Proper care in shrouding and keeping the upper pipe suspended to a beam would have avoided the damage.

(*ii*) In the second case in wells No. 30-31, the boring was alleged to have gone slightly out of the vertical, but to his mind the cause of damage might have been the same as was in case of well No. 1, *i.e.* the high load of upper pipes sat down on lower strainers which buckled. The whole well had to be abandoned, and a length of strainer was crushed causing a total loss of Rs. 780 to the Irrigation Department and much more to the Agricultural Department.

A third mishap occurred only recently. The tube-well still lay buried deep. After the tube had been sunk it was tested and while testing pumps were still intact on the pipe it was found after three days that the well had sunk. The exact cause of this had yet to be determined. It was always through failures that one succeeded. These failures should always be remembered to avoid similar ones.

Perhaps the type of strainers used was fragile and not strong enough for the purpose for which it was used. But to his mind lack of a rigid connection with the beam on the surface accounted for the mishap. Besides, too much of shrouding robbed the pipes of the grip with earth. This aspect also needed re-examination.

To take advantage of the fact that the exact quantity of water supplied to each field was known he had drawn up a graph on the actual quantity of water taken for maturing each crop. This graph would show the progressive delta. The work was still to be carried out and in due course the progressive delta required for growing and maturing each kind of crop will be available.

Another point which deserved a mention was regarding consumption of electric energy. Just at present they were taking power at each well, through a small transformer fixed to a pole. The question was whether it would be feasible to take electric power at a much cheaper rate in bulk at a sub-station built by the department and then distribute energy to the different wells. The capital cost involved in erecting a line of poles and wires would have to be calculated as also the working expenses for maintenance. Only then could one form an idea as to which was the cheaper arrangement for supplying electric energy.

The speaker said that they were yet in the initial stage of using electric power and probably to maintain this small show under a separate maintenance staff might not then be found economical. But surely when the system grew and they had enough work for the establishment, the maintenance cost would probably be reduced to the level of that of the private enterprises which took electric energy in bulk from electric supply companies and did their own distribution.

MR. C. L. HANDA wanted to knew from the authors whether the bore-hole type pump had also been compared with the centrifugal pumps used on the scheme. There were certain advantages in the case of bore-hole pumps and the speaker wanted to draw the attention of the house to the successful adoption of this type of pumps on the Thal project where installation of 8 such pumps was under completion within his charge.

The efficiency figures were given by the authors on page 232. It was stated by the authors that the bore-hole pump was also examined but on account of its low efficiency it had not been adopted for the Karol scheme. In this connection the efficiency figures of 87 to 88 per cent. given in the paper in the table on page 244 are the Maker's figures. Those presumably were meant to be the motor efficiency figures. Pumping efficiency was given as 66·7 to 75·3 per cent. This, it was presumed, was the pumping efficiency at the pump shaft. Now, in the case of a bore-hole pump of the Kimball-Krog type or Johnston type of $1\frac{1}{2}$ cusecs capacity, the efficiency figures guaranteed by the makers gave a motor efficiency of 88·5 to 89 per cent. and a pump efficiency of 74 to 80 per cent. Thus the overall efficiency for the same static lift would be about 7 per cent. better. Again, in the case of small lifts as were met with on the Karol tube-wells, it was an important consideration that the friction losses should be the very minimum. With a centrifugal pump there were two sluice-valves, one reflex valve and 4 bends. These would be eliminated in case a bore-hole pump had been used and it would be worth while to design and obtain pumps of the bore-hole type for low lifts.

Another point touched by the speaker was the question of the cost as it would be affected in case the bore-hole type pump had been adopted. The cost of constructing and sinking of the *kiosk* was given by the authors as Rs. 1,040. This *kiosk* could be dispensed with in the case of a bore-hole pump which could be accommodated in a small pump-house costing about R. 400. Thus on each installation a saving of about Rs. 600 could have been effected.

It would interest the house to know that the running and maintenance of bore-hole pumps was smooth as well as economical. The lubrication of the pumps was automatically arranged and the pumps were available for electric as well as oil-engine drive. By modification of the number of stages, the pumps could be made to suit the head for which the service was required.

Mr. G. M. Khosla remarked that the paper under discussion was mostly a descriptive one and therefore did not call for any criticism but he would like to bring two points to the notice of the members.

(*i*) The discharge obtained from Karol tube-wells worked out to less than 9 gallons per square feet area of strainer per foot depression-head per hour, in spite of shrouding. Much higher discharges had been obtained from tube-wells sunk for drinking-water supplies even without shrouding by developing the tube-wells by air-lift pumping. By developing was meant constant pumping for some days by air-lift plant at a very great depression-head from 50 to 70 feet, or even more. A good proportion of the fine particles of the sub-soil sands was removed by this method and consequently the porosity of the sand was improved. This method of getting more yield from tube-wells did not seem to have been looked into by the Designers of Karol scheme. The speaker had the opportunity of developing three tube-wells recently, one at Pasrur Government College and two at Ambala Saddar Bazar. The results had been astonishing as would appear from the following comparative yields before and after developing:

Pasrur Tubewell 22 ft.	5″ Strainer.
Discharge before developing	.. 200 gallons an hour.
Discharge after developing	.. 9,000 gallons an hour with 35 ft. head.
	4,200 gallons an hour with 14 ft. head.
Ambala Tubewell 56 ft.	6″ Strainer.
Discharge before developing	.. Practically nothing.
Discharge after developing	.. 6,600 gallons an hour at 42 ft. head.

(*ii*) It was noted by the authors of the papers that bore-hole type of pump had also been examined but on account of its lower efficiency had not been adopted. A larger number of bore-hole type pumps had been installed and worked by the speaker, while the efficiencies of these pumps were slightly lower than those mentioned for vertical spindle centrifugal pumps for small sizes of pumps. The bore-hole type pump had certain other advantages which made it more suitable for tube-well pumping, *viz*:—

(*a*) Its suitability for pumping at much greater depression heads and consequently getting more water from each individual tube-well. This might so favourably affect the overall costs of a scheme that the slightly smaller efficiency of bore-hole type pumps might be more than compensated by reduction in the number and consequently the cost of tube-wells.

(*b*) The bore-hole type of pumps with modern automatic lubrication needed practically no attention in working and was fool-proof.

(*c*) The efficiencies of these pumps even in bigger sizes were better. The bore-hole type pump installed on Ambala well was a 9 $\frac{5}{8}$-inch pump and had an efficiency of 70 per cent. A bigger pump only needed the top section of the tube-well to be of larger diameter which did not add to the cost very much, especially where spring level was shallow.

Rai Bahadur A. N. Khosla remarked that the paper on the Karol Tube-Well Scheme was of great practical importance to the irrigation engineer in view of the fact that there was not much spare water in the Punjab rivers for further extension of flow irrigation. The speaker was indebted to Messrs. Vadera and Talwar for presenting the paper. Mr. Montagu who was the pioneer in this line, so far as the Punjab was concerned, had done a great service to the Province in bringing to light the potentialities of tube-well irrigation. With cheap hydro-electric power which would become available if and when the Bhakra or some alternative scheme materialised, the prospects of tube-well irrigation in the Province would brighten up. All that was needed was sweet water and cheap power to bring that water to the surface. Given these, the depth of sub-soil water below the surface would not really matter. Cases were known in Los Angeles, California, where water had been lifted 500 feet and the farmers still made Rs. 3,000 per acre from grape fruit orchards.

It was gratifying to note that the Karol experiment had been a financial success.

Mr. J. S. Sethi said that practically all the points that he wished to bring forward had been already mentioned by his predecessors. But there was one point which had been omitted. In the last para, under 'efficiency', on page 233 of the paper, it was stated that the pump sleeves wore out by the action of the sand present in the water and the replacing of the sleeves added to the cost of maintenance, and that special filters for providing sand-free water for the lubrication of rubber bearings would be installed to overcome this difficulty.

There was no reason why sand should be present in the water, if the tube-wells had been properly put down and developed. The only reason why these sand particles were found in water was that these were being drawn in through the slots in the strainer. The strainer slots should have been properly designed, so that no sand particles could go through. The only course now open was to develop the tube-wells by creating a bigger depression head in order to increase the discharge, so that with the higher velocities that would thus be created in the tube-well all the finer particles would be drawn out in a few days' work and when the normal pumping was resumed no sand particles would be found in the water. He had been responsible for putting down over 50 tube-wells in the Public Health Circle and in no case he had experienced this trouble.

Very little had been said about the bore-hole type of pump. But if this type of pump had been installed on these tube-wells, replacing of sleeves or installing of special filters would not be necessary, as the driving shaft in that type of pump did not come in contact with water at all and was housed in a separate tube, so that no wear could take place on account of sand in the water.

Mr. S. M. Illahi said that he would not have made any comments on the paper, as it would look impolite on his part to do so, but he was afraid his silence might be considered to mean that the views expressed by the authors had been accepted by the Agricultural Department and it might prejudice the minds of the readers. It was, therefore, desirable that a few lines of dissent might be recorded in the case.

A statement had been made by the authors on page 225, para 4, that prior to this scheme, there had been only two irrigation tube-wells functioning at Qadian in Gurdaspur district, which had been installed and designed by the Agricultural Department, etc., and that these tube-wells had not been working satisfactorily and as such their design could not be adopted as a basis for designing any future tube-wells. The truth was that there were many thousands power and animal-driven irrigation tube-wells working in this province, and that both the Qadian tube-wells were handed over by the Agricultural Department to the Irrigation Department in perfect working order, and under a clear receipt. Their unsatisfactory service had not been due to faulty installation or design. It was a matter of great regret, that the Irrigation Branch could not maintain these two very good wells in satisfactory working order.

Similarly, in para 3, page 229, it was stated by the authors that "there have been two accidents in the case of tube-wells Nos. 1 and 30/31, when due to carelessness of the staff in charge of the operation of lowering the strainers, the 4 inches 5 inches, and 6 inches strainers were crushed." The facts were that the design of the strainer string prepared by the Irrigation Branch was extremely unsatisfactory. No Engineer could imagine to load a perforated brass tube less than $\frac{1}{8}$ inches thick, with more than four tons of super-imposed load and expect it to stay. The accidents had been due solely to wrong design, and not to any negligence or carelessness on the part of the staff handling the fragile strainer tubes.

In paras. 2 and 3 on page 225, it had been stated that the Karol Tubewell Scheme was the outcome of the excellent work done by Mr. A. M. R. Montague, I.S.E., who had been appointed as an Officer on Special Duty Tube-well Investigation in 1937, to collect and correlate all the available data, regarding existing tube-wells in the Punjab, etc. It was plain that the author of the scheme had had at the best only a few months of theoretical experience, in the design and installation of the wells. It is, therefore, natural that there were many serious flaws in the design and no pretence could, therefore, be made in respect of the thoroughness of design. For instance the proposed size of boring-tube is wrong. Design of the string of strainer is faulty to the extreme, and the selection of the pump and the design of the pump *kiosk* was not happy. The result of this faulty design had been responsible for untold botheration and worry to the staff employed on the work of making Karol Tube-Wells Project. Time taken in installing the tube-wells and borings, etc., could have been reduced very considerably by telescoping the bore-hole at proper depth. The cost of the work could also have been appreciably reduced by selecting a proper make of strainer tube and pump.

Mr. D. A. Howell in a written discussion remarked that he had been unable to get an opportunity to contribute to the oral discussion on this interesting paper at the Congress. At the same time there were a few points which he would like to clarify.

Bore-holes at Lahore and its vicinity had proved the existence of several excellent layers (probably lenticular) of good water-bearing sands down to about 400 feet depth and the sub-soil of the Lahore area was one of the best—in fact probably the most suitable in the Punjab for tube-well development. These strata, during the past 20 years or more, had been utilized as sources of tube-well water supplies to a very considerable extent by Government, Lahore Municipality, the North Western Railway and private individuals, and the total number of successful tube-wells probably exceeded 200. Some of these tube-wells had individual discharges not less in volume than those of the Karol scheme and so far, in spite of the considerable draw-off, there had not been any indication that the strata were being depleted. Probably, the close proximity of the river Ravi was an important and favourable factor in the matter. As a result of the experience gained with these numerous existing tube-wells, a great deal of information was gleanable from various sources; not the least important being bore-hole contractors, and it was easier to predict the probable yield of a tube-well intended to be sunk in this area than anywhere else in this Province, where less was known of the geological conditions of the deeper sub-soil.

The authors in para 7 mentioned "shrouding" as a factor affecting the design of a tube-well strainer and stated that this had been resorted to to keep down the cost; and that from practical experience, a 10-inch diameter shrouded strainer of 128 feet length had been found to give a discharge of 1·5 cusecs with a maximum depression head of 12 feet. This was equivalent to a yield of only 8·4 gallons per square foot of strainer per foot depression-head, per hour. The following were the particulars of discharge and characteristics of a few tube-wells put down by the 1st Lahore Public Health Division, P. W. D., at Lahore recently :

No.	Name of Tubewell.	Year of completion	Length and size (dia.) of strainer	Discharge on test, gallons per hour	Yield per square foot strainer per foot depressions head Gallons per hour	Date of test
1	2	3	4	5	6	7
1	Veterinary College	1940	72 ft., 8″ dia.	10,000	17·30	June 1941
2	Government College Hostel ..	1930	74 ft., 8″ dia.	7,440	14·77	June 1941
3	Punjab College of Engineering and Technology ..	1940	76 ft., 7″ dia.	6,440	24·11	June 1941
4	Punjab Mental Hospital ..	1940	71′–5″ 6″ dia.	6,600	24·55	June 1941

These tube-wells were fitted with "Tej" brass strainers, without shrouding, and the figures of yield given in column 6 spoke for themselves. They threw very considerable doubt, at any rate, on the alleged advantages of "shrouding" so far as improvement of yield was concerned. There is nothing new about "shrouding." It had been used on large artesian wells in the Caucasus with which the writer had been connected in 1912 and had been also used in all tube-wells, in which cadmium-plated strainers had been installed under the writer's charge since about 1933, but primarily its object had been to alleviate variations in the slots of the strainers and not for improving the yield.

3. The use of telescopic strainers, described at para 7 of the authors' paper, by varying the diameter, was also not new. Tube-well No. 1 of the Multan Waterworks had been equipped in 1924-25 with a 'Cooke' strainer on this principle—varying from 4 inches i/d up to 9 inches i/d.

4. The authors described accidents to two tube-wells with telescopic strainers. There was no doubt that if a small diameter strainer was fitted in a tube-well column of heavy type, especially

at the bottom, the risk of crippling, buckling or collapse in the event of a load being placed on the strainer, such as, for example, letting the bottom of the column rest on the bottom of the bore-hole, thereby transferring its weight on the small strainer, was seriously intensified. This fact had been well known and guarded against in the days of the old "Ashford" strainer; which was especially liable to become buckled, if placed under compression. Engineers who had to deal with tube-wells as part of their routine practice in those days took special precautions to ensure that crippling or buckling could not take place. They carried the bore and ensured that it was kept clear, down to some feet below the point at which the bottom of the strainer was intended to be placed, and also took care to see that the whole of the plain pipes with strainers attached were continuously supported in tension from the surface until the bore-hole casing pipes were completely withdrawn. These precautions were still observed as standard routine for tube-wells of the Public Health Circle of this Province. The head of each tube-well, in cases where the strainers and plain pipes formed a column with screwed joints, was also securely clamped or attached to a couple of long girders fixed horizontally at the floor level of the pump room or well, in order to prevent the tube-well column from slipping down in the ground. Mr. Isher Dass had mentioned a third recent accident to one of the Karol tube-wells, which seemingly, might have been avoided if this necessary precaution had been taken.

5. The inflow into a tube-well was not the same from various sand beds—some yielded more and others less water. He remembered one case where a sand strata under certain conditions of working took water out of the tube-well instead of delivering water thereinto. He had a recollection that Messrs. Ashford and Leggett made tests at Amritsar, many years ago, by lowering a velocity meter into a tube-well. If his memory served him correctly, very considerable, unforeseen, irregular variation of velocity had been observed when the meter had been placed at different points in the column, indicating that there was not, in fact, that anticipated regularity of in-flow which would justify the provision of a telescopic strainer arrangement. At the new Sub-Jail, Gujrat, some ten years ago a tube-well had been constructed with strainer placed in a layer of coarse, porous sand at a considerable depth below the sub-soil water-table, but when pumping had been started, a very small discharge—in fact a mere trickle of water—was obtained. A second tube-well was placed close by and the work was very carefully supervised in order to make sure that no mistake had been made in the geological records or setting of the strainer. The geological records, however, agreed in both bores and the strainer was set under his personal supervision, but the yield of the second tube-well again was a mere trickle, like that of the first, and the conclusion finally arrived at was that the strata tapped was a small, isolated lenticle or 'island'. A third trial was made by installing a strainer in lower bands of sandy strata and a copious

yield was obtained. In view of the factors mentioned above, the lack of definite information at the disposal of the Engineer ponsible for the design and construction of a tube-well, as to water which each strata would actually yield, claims of advantage in favour of the telescopic strainer could not be justified.

6. So far as the advantages and disadvantages of various types of strainers were concerned, both the cadmium-plated strainer and the "Tej" brass strainer, referred to by the author, had been used by him. The "Tej" strainer, made of brass, was a comparatively cheap, locally made copy of the "Cooke" strainer of the United States of America. It was undoubtedly much weaker from a structural point of view than the cadmium-plated strainer, which consists of a steel or iron tube, slotted and coated with cadmium, but so had been the "Ashford" strainer and the same disadvantage applied to many wire wound or meshed strainers, still in use in America and in India. There was no valid reason why those strainers should not prove as useful in the future as they had been in the past in spite of this disability.

7. In the cases of about two hundred tube-wells put down under his charge or superintendence in the course of the past 15 years or so, he could not recollect any brass strainer tube-well failing on account of crippling of the strainer after the tube-well had been completed. There had been a very few cases of damage to the strainers in lowering, usually due to the contractor's men permitting the tube-well column to slip through the clamps at the surface. Such accidents could only be obviated by taking the most extreme care in carrying out the work, in seeing that the plain pipes and strainers were suspended from the top and not allowed to slip. The symptoms of a crippled or broken strainer in any tube-well are so definite and positive that they could not have been mistaken. The well would rapidly sand up, *i.e.* get filled up with sand or silt, if pumped, hence the condition of the strainer must be satisfactory, *i.e.* it could not be broken or cut, if the tube-well was reasonably free from sand, *i.e.* there might be a few feet at the bottom of the tube-well, but this did not matter essentially so long as it did not increase in volume.

8. The "Tej" brass strainer has a much larger slot area per unit area of surface as compared with the cadmium-plated strainer and the slots are more accurate. It was not yet certain that the cadmium-plated strainer would have a life equal to that of a brass strainer or even a shorter life of reasonable extent sufficient to warrant its universal adoption in place of any brass strainer. He had noticed, in certain cases, that the slots of the cadmium-plated strainer had to be fettled at the tube-well site by means of steel tools in attempting to correct the slot widths, before lowering the strainers. This, of course, was liable to remove some of the cadmium coating at the most vulnerable places in the strainer, *i.e.* the edges of the slots. These drawbacks must be weighed against those of the brass strainer. He had tube-wells equipped with the "Tej" brass strainer, in service

at that time, which were about 15 years old and none had caused trouble on account of buckling, but of course some of them were deteriorating in yield due to clogging. They had given more than their anticipated life, however, and he must admit that he was far from satisfied that they should get better results by rejecting the use of the brass strainer and substituting for it, the cadmium-plated strainer.

9. With regard to the authors' notes concerning the selection of pumping-plant for tube-wells given in para 10 of the paper, there were no proper grounds for stating generally that the deep-well or bore-hole type, vertical spindle, centrifugal or turbine pump was inherently of lower efficiency than the open, vertical-spindle pump of the type installed at the "Karol" scheme.

The deep-well or bore-hole type, vertical-spindle pump was a true centrifugal or turbine pump and the only limitation which might affect its efficiency was the diameter of the bore-hole in which it is installed.

The present day bore-hole type turbine pump had been largely developed in the United States for water supply and irrigation work. It was being extensively used in that country for tube-well irrigation. Apart from other considerations, it was inconceivable that American Engineers with their advanced engineering practice and scientific attainments and their craze for efficiency, would be content with something less efficient than the best? He did not think so. In the department he was connected with, there were forty-seven wells on which these bore-hole type pumps had been installed—they were driven electrically or by oil or diesel engines. Out of these, one unit had been made at the Central Workshops of the P. W. D. at Amritsar. This had been provided with water-lubricated, line-shaft bearings. Four other sets had been built in Europe and the rest were all of American origin, the products of about five or six different manufacturers. These were all equipped with automatic, oil-lubricated line-shaft or spindle-bearings and the oldest units of these had been in use for about five years, working day in and day out, without the least trouble.

10. If suitable diameter, bore-hole pumps of this type had been installed on the Karol scheme, it would have obviated the masonry wells. No valves or suction pipes would have been needed and the friction losses caused thereby would have been eliminated. The lay-out would have been simplified, as only a small motor room, say 10 feet square, above ground level, would have been required and no risk of misalignment, cutting of bearings or other troubles would have been run.

Such pumps were easily erected and dismantled. It should not take more than a few hours to remove from the tube-well, a deep-well or bore-hole pump, examine it and replace it in the tube-well ready for setting to work.

He regretted that he was not convinced that this lay-out, using deep-well or vertical spindle bore-hole pumps, would not have been the best in the long run for the Karol scheme. With tube-well water containing sand particles as described by the authors, it was preferable to obviate the use of rubber, lignum vitae or similar bearings and standardize on oil-lubricated bearings, enclosed in an oil-tight cover tube round the vertical spindle, in accordance with the standard practice of designers of the American deep-well or bore-hole type pumps—though the makers also made pumps with special rubber bearings, water-lubricated, if required.

11. The practice, which was usually followed by him in constructing tube-wells for installing these bore-hole pumps, was to sink by boring a light casing pipe of adequate size, usually not less than 3 inches, internal diameter more than the external diameter of the pump bowls, down to not less than about 50 feet below sub-soil water level. This casing, usually consisted of locally welded-up, light steel tubing, about $\frac{1}{4}$ inch (or 5/16 inch) thick with screwed and coupled joints. This tube formed the housing pipe for the bore-hole pump.

From the bottom of this housing pipe, boring was continued with smaller diameter casing to the required depth and the necessary strainer with plain pipe attached was lowered and the casing withdrawn through the large diameter housing pipe, a cement joint about 7 feet or 8 feet long, being made at the overlap between the bottom of the large diameter housing pipe and the top of the tube-well plain pipe, or the strainer, with about 10 feet of plain pipe attached, was lowered to its place into the casing pipe and the casing pipe was withdrawn up to within a short distance of the top of the strainer, leaving an overlap of about 7 or 8 feet for a cement joint at the overlap. Another similar cement joint was fitted at the overlap between the casing pipe and the bottom of the large diameter housing pipe and the upper portion of the casing pipe was cut off and removed. Sometimes lead ring joints, hammered into position, were used in place of the cement joints. The most important point to watch for was that the large-diameter housing pipe should be sunk vertically or, at any rate, that the deviations therein should not interfere with the correct setting of the bore-hole pumps, and special arrangements were made to test this for every job. The pump bowls of the bore-hole pumps were placed at a depth of at least 30 feet below the sub-soil water table and sometimes this distance was increased to 40 or 50 feet (and even to 100 feet or more in exceptional circumstances). In selecting the pump in the first instance, care was taken to ensure that it would give the minimum discharge required even with the increased pumping head, caused by 30 or more feet draw-down.

By this means, the tube-well was assured of a long life, so far as practicable, and he believed that the results which would be obtained in practice would amply justify the comparatively small extra outlay, if any, on these precautions, *viz.* a long life of say 20 years, by which