PAPER No. 131.

LOCOMOTIVE AND DRINKING WATER-SUPPLY ON THE NORTH-WESTERN RAILWAY.

By J. VARDON, Executive Engineer.

1. Improving water-supply arrangements on the N.-W. Railway.

Up to a few years ago nearly all the water required for drinking and locomotive purposes on the N.-W. Railway was obtained from open dug wells or from open ground reservoirs fed by irrigation canals. A few stations were supplied from springs and rivers.

As traffic increased it was found that the available supply from these sources was insufficient, in many cases, to meet requirements. Also the water from some of these shallow dug wells was poor in quality for boilers, as well as for drinking.

The water obtained from canal supplies, though excellent for boilers, is very muddy, and frequently pollutted, making it unsuitable for drinking, and necessitating the provision of a separate domestic supply. Closures of the canals for cleaning and repairs, which caused little inconvenience in the past, when traffic was light, with increase of traffic often caused serious shortage of water at stations depending on canal supplies.

To remedy this state of affairs, which was hindering development, a special branch of the engineering department was formed, in the latter part of 1924, to undertake all work connected with water-supply requirements, and to provide installations, not only to cope with existing demands, but also capable of dealing with the anticipated increases in traffic.

There are six large rivers and a number of canals flowing through the country served by the Railway, supplying an enormous quantity of water to the alluvial deposits of the Punjab plains, and so forming a subsoil storage reservoir, many thousands of square miles in extent.

The average static water level of this huge reservoir is 30 feet below ground level, placing at the disposal of the Railway, over most of their territory, an abundant supply of water, which can be pumped up to their service tanks at a comparatively low cost.

These conditions indicated that the most suitable method of obtaining water in sufficient quantity, and of good quality, was by drilled wells, fitted with screens.

A considerable programme of work on these lines was undertaken, and the subseqent improvements that have been made in the water supply arrangements on the N.-W. Railway have contributed a substantial share towards greater operating efficiency during recent years.

These improvements have also contributed to the better health and comfort of passengers and railway staff, as the water provided is sufficient to meet demands, and is obtained from sources beyond the possibility of bacteriological contamination.

The tube-wells installed at some of the small stations have also been a boon to the people in the neighbouring villages. A crowd of men and women, from the homesteads within a radius of 2 or 3 miles of the station, around the Railway tube well pump being now-a-days not an uncommon sight.

2. Development of ground water supplied from drilled wells in the U. S. A.

The method of obtaining large quantities of water at relatively low cost from tube-wells, has been most intensively developed in the U. S. A. and the figures given below, which are taken from estimates prepared by the Department of the Interior (Geological Survey) indicate the extent to which such wells have been used to supply the water requirements for domestic, industrial and irrigation purposes of that " Dry " country :—

The estimated number of drilled water wells is	..	2,000,000
The number of water well drillers	..	10,000
The number of wells drilled annually	..	50,000
The annual expenditure on water wells	..	$25,000,000

The number of people supplied with water from drilled wells is—

Rural Districts	..	35,000,000	Total
Towns	..	10,000,00	50,000,000
Cities	..	10,000,000	

Over two million acres are irrigated from drilled wells, mainly for fruit orchards in California, and for rice in Arkansas, Louisiana and Texas.

In New Jersey at current water rates from public systems the value of ground water consumed is conservatively estimated at $150,000 a day or $55,000,000 a year equal to about 16 crores of rupees a year.

This enormous sum is paid in one State only of the 48 in the Union. Considering the fact that in many other States ground water-supplies are relatively as important for industry or irrigation as in New Jersey and California, it is obvious that the value of such supplies runs into hundreds of millions of dollars annually.

At a very early stage in the development of ground water supplies from drilled wells, the Federal Government of the U. S. A. realized its value, for irrigation purposes in opening up large unsettled tracts of country in the Middle West and South, and for providing potable water for the numbers of villages and townships that were rapidly developing everywhere.

By act of Congress a Ground Water Division was established, and attached to the U. S. Geological Survey. Thef unction of this division is to study the ground water resources of the country, and the best means of utilizing them to the advantage of the community.

This division makes a study of the various subjects connected with ground water-supplies, such as the occurrence and movement of ground water, physical properties of water bearing materials, methods of well drilling, types of wells, etc.

The results of these researches are published in the form of Water-supply Papers for the benefit of those interested, and everyone of them, prepared as the result of the most careful study, is a text-book on the subject.

The excellent work done by the division and its proved value to the community, created the demand from several of the States for State Ground Water Divisions, with a view to a closer study of the State ground water resources than it was possible for the Federal Government Division to make. These State divisions are, as a rule, attached to the State University, and keep in close touch in their activities with the Federal division.

Some of the State divisions backed by the Federal division have recently started Associations of Water Well Drillers, and Contractors, in their States, to foster the interests of the industry, diffuse knowledge of local geological conditions, and generally advance the theory and practice of underground water-supply engineering.

These Associations meet annually at Conventions where papers are read on subjects connected with their work.

I was privileged to attend one of these Conventions held at Green Bay, Wisconoin in November 1927 and I can testify to their popularity and utility.

3. Conditions in the Punjab.

Is to it much to expect the Punjab to establish a Ground Water Division in the Province on the lines of the State Ground Water Divisions referred to above.

Here in this Province we have the N.-W. Railway, the Irrigation Branch, the Roads and Buildings Branch, the Sanitary Branch of the P. W. D. and the Agricultural Department, all dealing with watering or dewatering problems, each working in watertight compartments, possessing knowledge and information that are invaluable to each other, and yet seldom hearing of what is being done by one another.

Can there be any doubt that large sums of money are spent each year by these departments in trial borings, tube-wells and pumping equipment for tube-wells, that might have been used to greater advantage, if there had been a general exchange of knowledge and experiences between them, or a Provincial Ground Water Division where expert advice could be obtained.

If a Ground Water Division were to be formed, the engineers dealing with water-supply works could provide a valuable collection of data on which the Division could work. The N.-W. Railway for example could provide geological sections of more than 300 borings, and yield test reports of completed wells, giving information as to the yield of the well, yield per s.ft. of screen used, and the static and working water levels, for the measured yield.

In view of the outstanding importance of ground water supplies to this Province in particular, and its enormous possibilities for domestic irrigation, railway and industrial purposes, such a division cannot but prove a valuable asset to Government, and to the community.

4. Watering arrangements on the N.-W. Railway prior to the formation of Water-supply Division.

Till the formation of the Water-supply Division the sources of suppld for our 316 watering stations on the N.-W. Railway were, as detailey below :—

(*a*)	Open percolation wells	156	Stations.
(*b*)	Canals	50	,,
(*c*)	Combined supply from canals and open Percolation wells	9	,,
(*d*)	Combined supply from canals and tube wells	1	,,
(*e*)	Tube-wells	5	,,
(*f*)	Combined supply from open percolation wells and tube-wells	12	,,
(*g*)	Pumped from rivers and springs ..	20	,,
(*h*)	Gravity supply from springs ..	49	,,
(*k*)	Local Municipalities	14	,,
	Total ..	316	

I am not aware of the date on which this record was prepared, but it is certainly prior to 1925, the year the Tube Boring Division commenced functioning, as none of the new tube-wells installed by this Division are included in the record. It also does not contain any of the watering stations on the lines recently constructed.

Of the 316 watering stations the supply is reported to be—
Bad in quality at 46.
Insufficient at 71.
Or 117 unsatisfactory supplies equal to 37% of the total.
Omitting the 63 stations provided with Municipal, and gravity supplies, there were 253 watering stations for which the Railway provided—

246 Open percolation wells of all sizes.
118 Storeage reservoirs, both pucca and kutcha.
17 Tube wells.
447 Pumps.

5. Comparison between tube-wells and open wells for Railway water supplies.

Experiments have proved that with a head of 7′-0″, wells sunk in the normal Punjab sands will yield 16 gallons per hour per square foot of well area.

This means that a—

16′-0″ dia. well will yield. .. 3,072 gallons per hour.
20′-0″ ,, ,, .. 4,800 ,, ,,
25′-0″ ,, ,, .. 7,500 ,, ,,
30′-0″ ,, ,, .. 10,800 ,, ,,

The working rules of the Railway lay down that the daily water requirements of a station should be supplied in 8 hours pumping. This rule was framed to provide a safety factor for " Rush Traffic," and for possible break downs of machinery.

With the advance in the reliability of pumping machinery, and by the duplication of wells and pumps, the time has come when the present limit of 8 hours might be safely increased to 16 or even 24 hours, thereby permitting of smaller wells and smaller pumping units for the same daily supply. But, with the 8 hour limit rule as it exists, it is interesting to work out the size, number, and cost of wells that would be needed for our present requirements.

Omitting the watering stations recently constructed on the new lines the requirements at—

(*a*) 256 stations are .. 6,250 gallons per hour.
(*b*) 30 ,, ,, .. 12,500 ,, ,,
(*c*) 7 ,, ,, .. 20,000 ,, ,,
(*d*) 4 ,, ,, .. 31,000 ,, ,,
(*e*) 10 ,, ,, .. 44,000 ,, ,,
(*f*) 9 ,, ,, .. 60,000 ,, ,,

Omitting all fractions of wells, the following statement shows the number, size and approximate cost of open wells required to provide water for each of these groups, and the approximate cost of a tube-well of equal yield :—

Group.	Number of open wells.	Size of open wells.	Approximate cost of open well.	Cost of Tube-well of equal yield.
			Rs.	Rs.
(*a*) ..	1	25′-0″ dia.	9,500	4,000
(*b*) ..	1	30′-0″ ,,	12,000	6,000
(*c*) ..	2	30′-0″ ,,	24,000	7,500
(*d*) ..	3	30′-0″ ,,	36,000	8,000
(*e*) ..	4	30′-0″ ,,	48,000	15,000
(*f*) ..	6	30′-0″ ,,	72,000	18,000

In making the comparisons of the capital cost of these 6 groups of open wells with that of tube-wells that would yield an equal amount of water, certain assumptions have been made, for the conditions available for open dug wells, and for tube-wells. These assumptions are reasonable, as experience proves that they are likely to be realized over large sections of the Railway.

The assumptions made for open dug wells are :—

(*a*) Static water level is 20′ 0″ below ground level.

(*b*) Good water bearing sand is available from 35′ 0″ to 50′ 0″ below ground level.

(*c*) That the well is only sunk to a depth of 45′ 0″ which means 20′ 0″ of dry excavation and 25′0″ of well sinking.

The assumptions made for tube-wells are :—

(*a*) Same as for open wells.

(*b*) Good water bearing sand is available somewhere between 180′ 0″ and 260′ 0″.

(*c*) That the screens are located somewhere between 180′ 0″ and 260′-0″.

It is desired to emphasize the fact, that in most cases good water bearing sands are found at much higher levels than 180′ 0″, but these are deliberately discarded for our tube-wells, because, in every station on the railway, an appreciable proportion of the daily supply is used for drinking purposes by passengers and railway staff.

By drawing on the water from the deeper strata, we ensure that the supply is free from bacteriological contamination. This factor cannot be taken into consideration in the comparison of costs of the two types of wells, but as everyone will agree, it is probably one of the most valuable factors in favour of the tube-well.

The chief points in favour of tube-wells can be summarised as follows :—

(*a*) Larger supplies can be obtained from a single well (up to about 2 cusecs) than is possible from the largest open well that it is practicable to sink.

(*b*) A tube-well can be installed in much shorter time than an open well.

At Kurukshetra for the last "Mela" a —13″ well was sunk to 192′ 0″, strainers installed, casing withdrawn, and the well tested for yield (which for this well was 10,000 gallons per hour) in 12 days, working 2 shifts of 8 hours each.

(*c*) The capital cost of a tube-well is from one half to one quarter that of an open well or wells of equal yield.

(*d*) A tube-well can be sunk to tap water beyond the limit of bacteriological contamination, and so sealed at the top that the water cannot be polluted. It is almost impossible to do this with an open well.

(*e*) A tube-well can be sunk to water bearing strata that may exist at depths to which an open well cannot be sunk, or can only be sunk at very great cost.

(*f*) Only one pumping unit is required per well for yield up to about 45,000 gallons per hour whereas in the case of open well one unit can seldom be used for more than one well, limited to 10,000 gallons per hour.

6. Comparison between Tube Wells and Canal Supplies.

Canal supplies are undoubtedly very suitable for boilers, as the water is free from injurious salts in solution. The only slight objection to it is the large amount of solid matter in suspension, which, though not injurious to the boiler, deposits as a soft sludge, necessitating frequent "blow down."

When, however, this water is mixed with tube-well waters from adjoining stations, which contain even a small quantity of salts in solution, violent "foaming" results. The salts in the tube-well water may be perfectly harmless to the boiler, and suitable in every way for locomotive use, but the mixture with the canal water containing solid matter in suspension causes a deal of steaming trouble.

Experiments were recently carried out on the N.-W. Railway which conclusively proved that "foaming" was caused in a boiler, not by brackish waters, but by a mixture of brackish waters with water containing solid matter in suspension. Tube-well waters are invariably free from solid matter in suspension.

As to the comparative merits of canal and tube-well waters for drinking purposes, there is no question that the latter is to be preferred, whereever it can be obtained.

Another feature to be dealt with in making a comparison, between canal and tube-well supplies is cost.

For the six months 1st April to 30th September the Railway paid to the Irrigation Department Rs. 31,030-9-0 for canal water supplied to our ground water reservoirs in Lahore for Loco. requirements, or Re. 0-1-4 per 1,000 gallons.

The cost of pumping this water into the H. S. tanks works out at 9 pies per ‰ gallons, for power, drivers and cleaners wages, lubricating oil, waste, etc., or a total of Re. 0-2-1 against 11½ pies the cost of the same items for water pumped from eube-wells to H. S. Tanks.

Here then is a case where a reliable comparison can be made between a canal supply and a tube-well supply from installations that are in the same station, and only one mile apart.

The pumps in both installations are electrically driven with power supplied from the Railway Power House at identical rates.

It will be seen that the canal supply costs more than double the tube-well supply, which means that in Lahore alone the railway are paying Rs. 60,000 a year more for water from a canal for the 840 million gallons required annually for Loco. purposes, than they would, if the water was pumped from tube-wells.

No account has been taken in either of the above cases of the interest on Capital, Depreciation and Maintenance, as the differences in these charges for the two installations would not be appreciable.

Other considerations that make the case for a canal supply unfavourable are :—

(*a*) A separate supply required for drinking purposes, or filtration and chlorination plant has to be installed to make the water suitable for drinking.

(*b*) If a separate drinking supply is used, pumping costs are considerably increased in operating two plants, and separate locomotive and drinking water mains and distribution pipes have to be provided. This is always a source of danger, as cross connections are probable.

(*c*) Mains are choked much sooner with a canal supply.

(*d*) Heavy cost of land at large stations, for ground reservoirs.

(*e*) Heavy expenditure is incurred in frequent cleaning of H. S. tanks and periodical cleaning of reservoir.

At one station the District Engineer calculated that we were pumping 500 tons of silt annually a height of 70 feet into our service reservoirs.

7. Watering arrangements completed by the Water-Supply Division.

Up to the present the Water-Supply Branch of the Railway has been fully occupied in meeting demands from the divisions for a larger supply of water, or for a better quality of water than was available at the time.

A good deal of this work has been completed at the larger stations, and it is hoped that opportunities will now be available for the officers of the Division to make a study of the watering arrangements at some of the smaller stations, and suggest improvements that would ensure more efficient and cheaper operation. It is considered that there are possibilities of effecting large savings in this way.

During the past $3\frac{1}{2}$ years, the division has put down 323 borings of an aggregate depth of 66,000 feet.

The number of tube-wells installed, tested for yield, and found entirely satisfactory is 67. These supply water for both locomotive and drinking purposes.

Tube-wells fitted with hand pumps have been installed at 71 non-watering stations for the supply of drinking water only.

The 67 large wells will supply about 7,000,000 gallons of water daily, and it is estimated will save the Railway over 4 lakhs of rupees a year on pumping charges.

The total expenditure on water improvement works undertaken by the division since its inception is Rs. 15 lakhs approximately, allowing for the provision of pumping units for the 21 wells that are still to be provided with them.

Of this sum Rs. 11 lakhs are for large wells, Rs. 1 lakh for drinking water installations and Rs. 3 lakhs for investigation work of all kinds such as trial borings for water-supplies, bridge foundations, etc.

The aggregate cost for salaries of officers, office establishment, workshop and stores staff, including cost of petty stores and tools, to carry out these works, is Rs. 2,10,000 or roughly 13½ per sent. of the cost of the works undertaken.

This percentage is higher than it would be if the division was kept fully occupied throughout. Owing to financial conditions this has not been possible during several months of last year and this year.

The division is now better equipped than it has ever been, and can undertake a good deal more work than is in progress at present.

The division undertakes all work, from the investigation stage for a water-supply project to the erection and testing of the permanent pumping plant, but does not arrange distribution, building of pump houses and operation of the plant.

8. Drilling.

Of the 323 borings put down 309 have been done by hand outfits and 14 by Star Drilling Machines.

For the subsoil conditions in the Central, Southern and Eastern Punjab, borings can be sunk with hand outfits almost as cheaply as they could with machines operated by such drillers as are available in India.

Hand borings have been sunk by our departmental gangs to a depth of 485 feet with a 6″ pipe at Khushab and 534 feet with a 10″ pipe at Reti, and the pipes withdrawn, at an average cost of Rs. $^{5}/_{4}$ and Rs. $^{6}/_{12}$ per l. ft. respectively.

For such borings a very light type of kerosine driven drilling machine should be a better proposition than hand borings, provided a suitable operator could be found or trained. Such machines should do from three to four times the amount of boring done by a hand outfit, and could be worked by a crew of two or three men against a gang of 14 required for a 400′ 0″ deep hand boring.

The rate at which these machines can make hole when in charge of skilful operators can be appreciated from the record of a boring that was sunk a few months ago at Bradford, Penn, where a 1260 hole was sunk in 6½ complete working days.

For the sections of our line in the Northern Punjab, the hilly tracts in Sind, Baluchistan, and the Frontier, machines are essential, as the formations are usually hard and cannot be drilled with hand boring outfits.

The advantages of machines for shallow borings, *i.e.*, borings up to 400′ 0″ are as follows :—

(*a*) Finish a job quicker.

(*b*) Can overcome strata difficulties that arise, which may be insurmountable with a hand boring outfit.

(*c*) Require less supervision, as one machine would complete on an average in a year three to four times as many borings as a hand outfit.

(*d*) Less risk of parting pipes when drawing them for two reasons :—

(1) If necessary the hole can be under-reamed when sinking.

(2) If pipes get frozen they can be jarred up.

These operations are not possible with a hand outfit.

The disadvantages with a machine are—

(*a*) Difficulty of getting good operators.

(*b*) The possibility of a serious break down which would require the plant to be sent into Headquarters for repairs, when a highly paid crew would be idle.

For deep borings we must resort to the Drilling Machine.

The N.-W. Railway have three of these in operation—

No. 1 is a medium sized Star Machine.

Nos. 2 and 3 large Star Machines.

The chief trouble we have experienced with them, is, that up to about a year ago we could not get efficient drillers. We have not yet got over all our troubles on this score, and it looks as if we never will quite get over them, until we are prepared to pay the salaries demanded by expert drillers from abroad.

9. Screens.

Because a well screen is subject to both corrosion and the movement of water through it, which removes the hydrogen protective film formed on the substance during the process of corrosion, and because it is in a position which makes it costly to replace, it should be made of material which can best withstand corrosive action.

The life of a well is determined by the life of the screen. It is seldom possible to pull the screen for replacement, and anyhow the cost of doing this is almost as great as putting down a new well.

At present a number of types of screen made of copper, brass, iron, or concrete are in use in the U. S. A. They are all subject to corrosion, except the concrete screen, which is only suitable for special conditions.

From tests it was found that an alloy of 80 per cent. copper and 20 per cent. zinc, lost least weight when exposed to the action of corrosive water. This alloy is being used in the Johnson Ribbon Screen, and the Cook Solid Drawn Tube Screen. The design of both these makes is good and the finished product is excellent in workmanship. They cost about $ 19 a foot c. i. f. Karachi for the—10" size.

On the N.-W. Railway "Ashford" and "Tej" screen have been used. The former costs about one half of the latter. Its cheapness is its most favourable feature. The "Tej" screen is of the same pattern as the "Cook's" screen referred to above, but is made from ordinary commercial brass sheets. rolled to shape and soldered. The screen costs about $ 1 less delivered in Lahore, then either of the American types c. i. f. Karachi.

Experiments are being made with non-metallic substances for screens, and it is my belief that the perfect screen, will eventually be evolved from one of these substances.

Trouble is frequently experienced with screens, due to the clogging of slots by salt deposits or cementing substances. This action can be counteracted to a large extent by regularly "Back Blowing" the well. This is very easily done if the pumping plant is an Air Lift Unit. If it is not, a Portable Air Compressor could be used.

A Railway well at Saharanpur, which had completely stopped yielding water was treated in this way for a very short time, and responded to the treatment by yielding 10,000 gallons per hour.

Opinion, as to the size of slots for screens, is increasing in favour of the large wide slot for every kind of stratum. If water is drawn from beds of gravel the slots are made from $^1/_4$" to $^5/_8$" wide, depending on the size of gravel. If the screens are located in sand the slots are cut $^1/_8$" to $^3/_8$" wide and gravel screened.

Until a chemically inactive screen material is found we would be well advised to use the highest grade of screens manufactured. The slight additional cost of these will be more than offset by the longer life of the well.

A comparison of the specific yield of the different types of screen can only be made by installing the same size and length of screen in adjacent wells, located at the same level, where subsoil conditions are identical and the wells are pumped under identical heads. Such tests have not been carried out by the Railway, nor have we heard of them being carried out by others. To my mind it is therefore impossible for anyone to say, without carrying out prolonged expreiments on these lines, that any one screen is superior to another in specific yield. There can be no doubt that information on this point would be of great value.

10. Air made Gravel Wells.

This is a process which has recently been perfected in the U. S. A. Remarkable yields from very unpromising strata have been obtained by the use of this process. When I was in the U. S. A. last year I took care to verify the claims made for it, and in every instance found that the case was not overstated.

The need for large quantities of water in localities where there were only shallow beds of water yielding strata, directed the attention of engineers and drillers in the U. S. A. to the possibility of dealing with this problem in a different way from the ordinary fine slot screen well.

The use of a screen with large slots, shrouding the screens with coarse gravel, and developing the stratum to its fullest extent has solved this problem. The development is best done with an Air Lift Pump. In fact but for the Air Lift Pump it would not have been possible to develop wells to the extent they are.

The principle of the " Air Developed Gravel Well " is simply this :—Gravel is fed down and forced around the screen with the object of artificially creating as large an area as possible, of material of low resistance to the flow of water. In other words an Air Developed Gravel Well of say 10'-0" radius has the infiltration area of a 20'-0" diameter fine screen (although a 10" diameter screen is actually used) and should therefore have 24 times the yield of a 10" fine screen installed in the same stratum in the old way.

If this is true, it is reasonable to expect the same yield from an 8'-0" depth of water yielding stratum in which an Air Developed Gravel Well is installed as from an $8 \times 24 = 192$ feet depth of the same stratum in which is installed a well in the old way.

This, as a matter of fact, is what is being achieved with the Air Developed Gravel Well. Yields as high as 14 to 18 gallons per minute per square foot of screen area are being obtained from strata which previously would be considered of little value for a well installed without development.

In a well that is to be air developed the clearance between the screen and casing should be at least 4".

When the screen and plain pipes are lowered into position, the well is ready for developing. Air and eduction pipes are lowered into the well, the submergence being calculated for a big " drop " say 50'-0" Gravel not exceeding 1" diameter and not less than $^5/_8$", carefully screened to gauge, is dropped around the screen to a depth of 1'-0" only. The casing is then drawn slowly, an inch or two at a time, and pumping started.

As the water is pumped, sand will flow freely through the slots of the screen and will be discharged with the water ; the gravel will work its way downwards and outwards around the uncovered portion of the screen taking the place of the sand drawn out. The pumping should be contin-

ued until the water clears, gravel being continually fed around the screen to replace the sand. The clearing of the water indicates that conditions around the exposed screen have stabilized.

The valve on the eduction pipe of the well is now closed (the top of the well having been previously capped airtight) and the air allowed to blow down the well. The air works its way up to the top of the well, and being under pressure, forces the water back into the ground through the slots in the screen, and with the water the gravel is driven into the surrounding fine sand disturbing the stabilized conditions. This process is known as "Back Blowing." When the well has been "back blown" from two to fifteen minutes, the valve on the eduction pipe is quickly opened, the water is discharged at high velocity, drawing with it a considerable quantity of fine sand, gravel fed from the top taking its place.

In time conditions will again stabilize and the discharge clear. When this happens the eduction pipe is again closed and the well "back blown" as before, and the operations are repeated till the stage is reached, when, after "back blowing," the water discharged is free from silt.

When this stage is reached the casing is drawn another two or three inches and the well is again pumped and "Back Blown" alternatively, as before.

When this section is dealt with by repeated "Back Blowing" with no further effect on the surrounding sand, the casing is drawn another two or three inches, and this section dealt with, and so on, until the casing is clear of the screen.

Experimental air developed wells were tried out on the N. W. Railway at Rohtak and Ambala Cantonment.

The well at Amballa Cantonment was abandoned and withdrawn, as the yield from it was insignificant. The real cause for this failure is not evident, as the procedure adopted in this well was the same as that at Rohtak.

It is possible that the well was sunk in a sand pocket, from which only a small yield can be obtained. That these pockets, or lenses of sand, are to be found all around Umballa is well known, as the samples from adjoining borings vary a great deal.

At Rohtak the air developed well must be considered a success, as the only available water boring stratum was a bed of fine sand about 9′-0″ thick between 74′-0″ and 83′-0″ below ground level. At the lower levels, *i.e.*, levels below 120′-0″ the water begins to get brackish and therefore unsuitable for use, so that this layer was the only one that could be used.

In this sand, a 6′-0″ length of 6″ bore wrought iron socketed pipe screen, with horizontal slots 4″ long × $^3/_8$″ wide was used.

The drilling was done with 13″ bore casing, so that the nett clearance, between the tube well and the casing, for the gravel to be fed through, was about 3″.

Development was carried out for 180 hours, during which period 150 c.ft. of gravel was fed around the screen.

During development the yield increased from 1,500 gallons per hour to 5,000 gallons per hour with a "Drop" of 20'-0". I am convinced that in no other way could such a large yield be obtained from such an unpromising stratum. The yield works out to 550 gallons per hour per s.ft.

It is intended to put down a few more of these air developed wells as opportunities arise. They have been an outstanding success in the U. S. A. where other types of wells have failed to yield the water required, or have clogged in a short time.

It can be readily appreciated that this type of well considerably enlarges the scope for tube wells in several ways.

It enables shallow beds of sand, of poor quality, to be used for large yields ; beds that are valueless with the fine slotted screens.

It permits of shallow borings, reducing costs of boring and cost of screens as well.

In large tracts of the Punjab only the upper water is sweet. In these areas it is not necessary to drill into the deeper bad waters for a large yield, as only 20'-0" of large slotted screens is required for yields of 1 to 3 cusecs if such wells are properly air developed.

I estimate the cost of a well required for dewatering waterlogged country, to yield 2 to 3 cusecs, where suitable water bearing stand is available anywhere between 50'-0" and 100'-0", and Static Water Level is 20"-0' (being waterlogged country it should be less than 20'-0") at Rs. 5,020/- for labour and well material,but not for tools, plant and equipment required for development of the well, as obviously it would not be sound business to provide this type and quantity of equipment if only one or two wells are to be installed.

This sum is made up as follows :—

1.	Drilling—24" hole to a depth of 100'-0" at 8-1" 1ft.	Rs. 800
2.	20'-0" of —12" Slotted Screen at 25/- 1ft.	,, 500
3.	Cost of 80'-0" of —12" Plain Pipe for well at 10/-	,, 800
4.	Cost of 80'-0" of —24" Casing-(1.ft. for development) 24/- 1ft.	,, 1,920
5.	Development Costs	,, 1,000
		Rs. 5,020

Item 4 could be recovered after a year or more as it is possible it will not be needed after this period.

Such a well could be reckoned on to last many times longer than a fine slot screen well, and to maintain its yield undiminished, if not considerably improved.

If a suitable non-corrosive material is found for these wide slot screens, and electric power is available at a low price, it may be, the day will come when it will be as cheap to irrigate from Tube Wells as from Canals.

11. Pumps.

The Pumps used on the Tube Wells installed on the N. W. Railway since 1925 are as follows :—

(a)	Vertical Spindle Borehole Pumps	.. 3 Nos.
(b)	Direct Air Lift Pumps ..	.. 8 ,,
(c)	Air Lift Cum Centrifugal Pumps ..	.. 29 ,,
(d)	Horizontal Centrifugal Pumps ..	.. 6 ,,

Owing to lack of funds during the current financial year, pump will not be ordered for the remaining 21 wells till next year.

(a) Vertical Spindle Borehole Pumps.

The types of Borehole pumps now in use on the Railway are not greatly favoured for the following reasons :—

1. They entail the provision of a larger diameter well for the same yield than any of the other types. This means a more expensive well.
2. They are not very suitable for engine drive, as quarter turn belts or bevel gearing has to be used.
3. If the well sands at all the Impeller Shaft bearings are soon cut.
4. Any repairs to the Pump necessitates its withdrawal from the well and relowering ; an operation which takes time with the staff available.

On the other hand, these pumps are now being manufactured with the shaft completely enclosed, so that no water can get to it, and the bearings lubricated from an oil sump in the pump head. With electric power available pumps of this type are eminently suited for tube wells, especially as the designs now in use permit of much larger discharges from smaller diameter pump bowls.

Very large numbers of them are in use on tube wells for irrigation purposes in California and the adjoining States.

The complete unit for a 2 cusec discharge with electric motor would not require a larger pump house than 6′-0″ × 6′-0″.

(b) Direct Air Lift Pumps.

Is a very suitable type for water wells especially in sand formations; as they have no moving parts in the well, no mechanical troubles can be caused by sanding. They can be used at any time for back blowing to keep screen slots clear.

Compared with the centrifugal and deep well turbine pump they have the following disadvantages :—

1. Low efficiency.
2. Wells must be deep enough to give the required submergence.
3. Cost of plant is high.

To counteract part of the low efficiency disadvantage the

(c) Air Lift Cum Centrifugal Pumps have been introduced. A number of these are operating satisfactorily on the N. W. Railway.

They have all the advantages and disadvantages of the air lift pump. except, as already stated, the efficiency is much better than that of the pure air lift, and under certain conditions may be as high as that of a deep well turbine pump.

(d) Horizontal Centrifugal Pumps.

Wherever possible the Centrifugal Pump is preferred to any other type. It is the simplest in construction and operation, cheapest in first cost, efficient, easily maintained and has no moving parts in the well. It is, however, limited by its suction capacity to about 18′-0″, which means that it can only be used, when founded at ground level, in wells where the working water level is about 18′-0″. There are unfortunately, very few places on the N. W. Railway where such conditions exist. By lowering the Centrifugal into a pit the limit can be increased a few feet, but this lay out of the plant has objectionable features.

12. Hand Pumps for Drinking Water Wells.

These are of the plunger type, operated by a handle on a flywheel which is keyed to the crank in the Pump Body.

The Plunger is connected to the Crank by rods connected together by Toggle Joints.

The delivery is about 2 gallons a minute when operated by one man, and they are lifting water at some stations from a depth of 130′-0″.

The pumps require more attention than was anticipated, due to the wells sanding, and wearing the pump leathers and bearings.

We are now experimenting with a hand operated Air Lift Pump. If this is successful maintenance will be reduced to an absolute minimum, but such pumps can only be used where the depth is sufficient to give the required submergence.

13. Financial Justification for Tube Well Installations on the N. W. Railway.

It is estimated that the total amount of water supplied daily at the 316 watering stations on the N. W. Railway for Loco and drinking purposes is about 25,000,000 gallons.

This does not take into account the 695 stations where provision is made for supplying drinking water to passengers and Railway staff, but

where no pumping charges are incurred, as the water is obtained from open wells or from Tube wells fitted with Hand Pumps.

From the installations as they existed prior to 1925 the estimated cost per 1,000 gallons of water supplied, for fuel, lubricating oil, petty consumable stores, drivers and firemen's wages is -/4/-. This figure does not include interest and depreciation charges on the Capital cost of the installation, the salaries of supervising staff, or maintenance stores.

The returns from which this estimate was made, are mainly from the largest watering stations on the line. There is every reason to believe that the cost per cent. gallons would be as high as -/8/- at the small stations.

Using this smaller figure of -/4/-, it will be seen that the Railway spends 6, 250/- per day or 23,00,000/- per year on fuel, lubricating oil, petty stores, and wages, for its water supply.

If the cost per cent. gallons could be reduced by half, the Railway would save 11,50,000/- per year.

It is not, possible for various reasons to provide new watering arrangements at all the 316 stations for some considerable time, but if this saving could be affected at 60 of the larger stations, which supply about half of the total quantity of water used on the Railway the annual saving would be 5¾ lacs of rupees a year. Working on a basis of 5% for interest and 15% depreciation, the above saving justifies a Capital expenditure of Rs. 29 lacs.

Actually from the records of 9 new installations that have been in operation for a year or more, we find that the saving being effected per 1,000 gallons is not -/2/- but -/2/9.

The returns from which the saving was calculated were supplied by the Rolling Stock Officers of four of our seven Divisions.

During the next 12 months we hope to have a further 21 Tube wells in service, and we shall have returns of their operating costs that will enable us to gauge more accurately than we can at present, what savings can be realized, as the calculated average will be made from a larger number of stations.

An Estimate, prepared from actual experience during the past 3½ years, of the cost of providing Tube Well Installations at these 60 stations is as follows :—

Stations.	Yield per hour.	Cost of Tube Well.	Cost of Pumping Plant.	Total.
30 ..	12,500	6,000	10,000	4,80,000
7 ..	20,000	7,500	14,500	154,000
4 ..	31,000	9,000	18,000	1,08,000
10 ..	44,000	12,000	25,000	3,70,000
9 ..	60,000	15,000	30,000	4,05,000
60 ..				15,17,000

To this figure we might add 13½ for Supervision Charges =2,00,000 3400/- per station for Pump House = 2,00,000/- and 1,650/- per station for Rising Mains = 1,00,000/- making a total of Rs. 20,00,000/-, a figure well within the justifiable Capital expenditure.

Up to the present we have provided an oil engine as the power unit at each of the new installations. Such an unit besides being an expensive item in first cost, needs a driver, perhaps a cleaner, lubricating oil. etc., a fairly large building, and rather expensive foundations.

With the provision of electric power at our large stations, we shall substitute electric motors for oil engines, and provide them with automatic Float Controls which will dispense with the services of a driver, which alone will reduce the operating costs per cent gallons by -/-/2 for a 30,000 gallons per hour Unit -/-/6 per cent gallons in a 10,000 gallons per hour unit, besides the reduction in interest and depreciation charges and probable reduction in power charges.

Financial Justification for Tube Well Installations on the N. W. Railway.

The first of these units was designed for the "Stand By" well at Wazirabad, but the provision of the plant has had to be postponed for lack of funds.

I am convinced that the provision of cheap electric power will give the biggest fillip to the tube well industry.

Experience has proved that to-day a Tube well can be installed for a good deal less money than was required a few years ago, because trained labour for drilling these wells is plentiful, suitable equipment in large quantities is available in the Province and a much shorter length of screen are required for the same discharge, than was used formerly. There is reason to believe that with the wide slot screen the cost of Tube Wells can be further reduced.

It is in the Pumping Unit that the biggest reductions must be made, both in Capital and Working cost, to bring the Tube Well in the Punjab to the position it has attained in the U. S. A.

Oil engines though considerably cheaper than a Steam engine, require skilled attention, and for various reasons have caused a deal of trouble to owners.

An electrically driven Pumping Unit requires very little attention, and can be automatically controlled, dispensing with the need for a driver.

The cost of such an Unit should be less than half of an Oil Engine driven Set, and with electric power at an anna or less per unit, there is no reason why ground water supplies in this Province should not be as extensively used for domestic, industrial and irrigation purposes as in the U. S. A.