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LIFT-IRRIGATION

BY

ALFRED CHATTERTON

Second Edition
Revised and Enlarged.

MADRAS:
G. A. NATESAN AND CO.

PREFACE.

Some years ago, Messrs. G. A. Natesan & Co. reprinted a number of papers and articles which I had written at various times on the improvement of the methods of lifting water for irrigation. The little volume apparently served a useful purpose as it met with a ready sale and has been out of print for some-time. Through the operations of the late Department of Industries and of the present Pumping and Boring Department, which is its lineal descendant in these matters, the oil engine and centrifugal pump are now recognised as a satisfactory combination for lifting water wherever the quantity to be dealt with is large enough. Moreover quite recently considerable progress has been made with mechanically driven water lifts specially designed to deal with smaller quantities of water than can be conveniently and economically handled by centrifugal pumps. The demand for information, as to the methods to be pursued and as to the results which have been achieved, still continues and in the absence of any formal treatise on the subject, a fresh compilation of papers has been made which it is hoped will to some extent supply what is needed. In the South of India, this phase of the irrigation question is now reduced to a matter of finance. Mechanical methods of lifting water are so much cheaper than the indigenous methods that, where the quantity available is sufficient and

there is land suitable for cultivation, it is always profitable to employ them. It has taken 10 years to arrive at this point, but one may venture to hope that a much shorter period will suffice to devise means whereby landholders and ryots may obtain on reasonable terms the capital they require to develope their subterranean water supplies.

January, 1912. ALFRED CHATTERTON.

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CHAPTER I.

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WATER-LIFTS.*

In 1895 the Government of Madras appointed a special Committee to report on the merits of certain machines for raising water from wells, to which their attention had been drawn by the inventors. Of this Committee I was a member, and our reports were officially published as Bulletin No. 32 of the Agricultural Branch of the Department of Land Records and Agriculture. Our enquiries revealed the paucity of accurate scientific data regarding the working and efficiency of the ordinary water-lifts of the country, and disclosed the fact that, until such data were collected and carefully studied, it was hardly likely that any material improvement could be effected in the modes of lifting water from wells. Recognising the importance of well irrigation in India, I have, during the past twelve months, endeavoured to supply this deficiency, and, with the assistance of the Board of Revenue, represented by Mr. C. Benson, whose cordial co-operation I have to acknowledge, experiments on a number of typical water-lifts have been made, and results obtained which, it is hoped, will show the direction in which improvement is most likely to be obtained, and the available margin which exists for inventors to work upon.

* Originally published as Bulletin No. 35 of the Agricultural Branch of the Department of Land Records and Agriculture, Madras, 1897.

In the Statistical Atlas of India, the total irrigated area is stated to be 28,334,000 acres, of which 10,140,000 acres, or more than one-third, are entirely dependent upon water drawn from wells. In the Madras Presidency, excluding feudatory and tributary States and Zemindari lands, the area under irrigation amounted to 5,803,937 acres in 1894-95, and of this area 1,084,060 acres were supplied with water from 427,539 wells, whilst the lands under other systems of irrigation derived a supplementary supply from 139,136 wells. These figures will serve to indicate the magnitude of the interests involved in irrigation from wells, but possibly a clearer idea may be gained from the calculations given below, which, though based on admittedly approximate data, show in greater detail what well irrigation in India means. In Madras, the average area under each well is $2\frac{1}{2}$ acres, but in other Provinces it is larger, and for the whole of India probably averages 4 acres per well, so that the total number of wells must be about two and-a-half million. The cost of constructing 13,337 wells is given as Rs. 16,88,753 in certain returns furnished by the Board of Revenue, Madras, or an average of Rs. 126 each, and as in many places the wells are much deeper than they are in Madras, we may assume, without fear of exaggerating, that the average value of a well in India is Rs. 150, and that, therefore, the total capital invested in wells amounts to the very large sum of $37\frac{1}{2}$ crores of rupees.

Taking the duty of water for garden or well culti-

vation at 250 acres per cubic foot per second, the quantity required for over 10 million acres would be 40,000 cubic feet per second, and if we assume that the average depth from which the water is lifted is 30 feet, the work which has to be done amounts to 136,000 horse-power. Cattle, however, do not usually work more than 6 hours a day, and the efficiency of native water-lifts certainly does not exceed 50 per cent, so that the aggregate horse-power derived from cattle in India and employed in lifting water amounts to 1,088,000. Assuming that throughout the cultivation season there is an average of two bullocks at work every day at each well, there would be about 5 million cattle so employed.

The average quantity of water yielded by each well is, upon the above assumptions, 8,640 gallons per day, a volume so small as to entirely preclude the use of any, but the simplest possible appliances for lifting the water to the surface. Steam-pumping machinery is utterly beyond the means of the ryots, and the force of the wind is too uncertain, and over the greater part of India, it is too weak to be utilized profitably by wind-mills even of the most modern type. Animals are, therefore the only source of power available, and water-lifts in the future* must continue to be, as they always have been, worked either by men or cattle. Moreover, the Indian agricultural population is so singularly devoid of even the most rudimentary

* It should be remembered that this report was written in 1896 before oil engines had become the simple, practical motors they are to-day.

mechanical skill that it is absolutely necessary that machines, intended for their use, should be designed to work without complicated gearing of any kind. As will be seen in the sequel, native methods of lifting water comply with these conditions and possess at the same time, under favourable circumstances, a fairly high efficiency which renders the task of endeavouring to improve upon what is already in use exceedingly difficult.

The enormous amount of energy which is expended on raising water from wells has naturally attracted much attention, and from time to time, in different parts of India, attempts have been made to introduce what were considered improved appliances, but so far no great amount of success has been achieved, and the opinion is now generally held that little or nothing can be done. Of the special reports, which have been prepared on the subject, two at least may be cited. The first is a volume published in 1883 by the Department of Agriculture and Commerce in the North-West Provinces and Oudh, of which the most important section is a report by Captain Clibborn, an Executive Engineer, who was placed on special duty in connection with the matter, and who, after collecting a vast amount of information regarding existing practices in the North-West Provinces and carrying out a very large number of experiments on the performances of the various types of water-lift in use, expressed in unequivocal terms the opinion the Government could do little or nothing to improve or extend well irrigation

in the Provinces. The second report was prepared in Bombay by an Executive Engineer, Mr. F. D. Campbell, after spending three months on special duty, and as the final result of his enquiries he formulated the opinion that nothing can be done to introduce "new or cheaper systems of well construction or of lifts than those which the ryot is already familiar with."

In recent years, in Madras especially, these conclusions have not been accepted by a certain number of practical men who have devoted much time and ingenuity to the production of improved water-lifts and their efforts have at any rate, resulted in drawing public attention once more to the water-lift question. The trials conducted by the "Water-lift Committee" showed the necessity of studying the problem scientifically and of taking into account a factor which had hitherto been entirely neglected, *viz.*, the mode of applying animal power. Notwithstanding the number of experiments, the results of which have been published, it was found impossible to compare the performances of the new machines with those obtained from native water-lifts owing to the insufficiency of the data recorded, and though it did not fall within the scope of the reference to the Committee to obtain the necessary figures, it was considered highly desirable that a fresh set of experiments should be undertaken, so as to render it possible to make fairly exact comparative statements on the merits of totally different forms of water-lift, after trials which should be neither tedious nor difficult to carry out.

The fact that animal power is employed in all forms of water-lift renders it exceedingly difficult to make comparative trials of machines, some worked by one class of bullock in a certain manner and others worked by another, and possibly inferior, class of cattle in a totally different way. Not only have we to take account of the mechanical efficiency of the machine but also the method by which the animal is made to work must be considered, since the amount of useful energy which can be obtained from an animal depends very largely upon the way in which the muscular efforts are made. The work done by an animal in motion may be conveniently divided into two parts, which we may term internal work and external work, respectively. The latter only is available for useful employment, and, as the sum of the two is probably a constant quantity, it is evident that the more we can reduce the expenditure of energy on internal work, the greater will be the amount available externally. For instance, a bullock walking along a level road expends the whole of his strength on internal work, which simply results in the transportation of his body from one place to another, but if we yoke him to a cart, the work which he does is partly internal and used in his own movement and partly external and employed in drawing the cart.

What ratio the internal bears to the external work cannot be accurately determined, but there are some facts which enable us to form an approximate estimate. A bullock doing no work can be made to march only a

certain number of miles in a day without experiencing undue fatigue. The addition of a moderate amount of external work diminishes the distance which can be travelled, but only to such an extent as to indicate, that of the total muscular exertion the greater part is expended internally. On a horizontal road and walking at his natural gait, a bullock can exert a draught of one-tenth of his weight for a period of 8 or 9 hours a day. That is to say, he can do work in drawing a cart or a plough along the level equivalent to what he would have to do if he walked up a gradient of 1 in 10. No animal is strong enough to exert a continuous draught equal to one-fifth of his weight, for any length of time, without injury, and a draught equal to one-third of the weight can only be exerted spasmodically and for very short periods, yet a man or a bullock when in training can, with comparative ease, walk up a gradient of 1 in 3 and continue to do so for a very long time, if the pace be not too great, and if the surface walked on be suitably prepared. It is evident, therefore, that when an animal raises his own weight against the action of gravity, the external work, represented by the potential energy stored in the animal's body, bears a greater proportion to the internal work, which is uselessly expended, than is the case when the external work is due to a pull exerted through a certain distance. For instance, a bullock will walk, along the level, two miles in one hour against a draught equal to one-tenth of his weight and will do, what we may term, a unit of work, equal to raising his own weight

one-fifth of a mile; up a gradient of 1 in 3 he would probably walk $1\frac{1}{2}$ miles in one hour and raise his own weight vertically through half a mile, doing $2\frac{1}{2}$ times as much work. Even if he could only do one mile per hour up the slope, the potential energy stored in his body would still be $1\frac{2}{3}$ times as great as if he had been employed in drawing a weight up a vertical shaft by a rope passing over a pulley.

Practically we may assume, then, that an animal, with the same ultimate expenditure of energy, can do twice as much work in raising his own weight against the action of gravity as he can in the only other way it is feasible to employ him. This fact has long been vaguely known, but has not been made much use of, owing to the difficulty which has been experienced in designing suitable mechanism to embody the idea, without producing a machine both cumbrous and costly. This the Hindu cultivator has recognised, and with more than characteristic ingenuity has devised a compromise between the two methods of working in an exceedingly simple manner, as exemplified in the ordinary country mhote, in which he partially obtains the advantage of the bullocks' weight, by making them run down a steep incline when drawing from the well the bucket full of water, whilst in the picottah, which he himself has to work, the principle has been fully carried out with the result that it is capable of but little improvement, except in the direction of making it a less hazardous machine to work.

A pair of bullocks is a vague term; they may be

worth Rs. 40 or Rs. 250, and one pair may easily be capable of doing more than twice as much work as another ; yet in previous accounts of experiments on water-lifts no more definite information than this has been forthcoming as to the power employed. Dealing with water-works, engineers are accustomed to state the results of the trial of a pump something in this way. The engine driving the pump indicated 'x' horse-power and 'y' gallons of water were lifted against a head of 'z' feet in a certain time. Unfortunately, we cannot measure the work done by cattle in absolutely definite units as in the case of the steam-engine, but it is a generally accepted fact that the strength of well conditioned animals of the same species is roughly proportional to their weight, and it would therefore have added enormously to the value of former experiments on water-lifts if the weight of the cattle used had been ascertained.

The value of a water-lift depends partly upon its mechanical efficiency and partly upon the efficiency of the method by which the strength of the animal is utilized when working it. The mechanical efficiency can usually be determined but it does not seem possible to express in numerical terms the ratio which the internal work of the animal bears to that done externally. For practical purposes, however, a constant involving both terms is what is required, and this can be obtained without difficulty. The amount of useful work done in one hour, expressed in foot-pounds, divided by the weight of the animal in

pounds, represents the vertical height in feet, to which by the expenditure of a similar amount of work, the animal's body would be raised. The magnitude of this constant, which may be conveniently termed the *co-efficient of utility*, offers a simple means of stating concisely the value of a water-lift as a machine for getting work done by the agency of animal power. The determination of this constant has therefore been one of the most important objects of the trials recorded in this paper.

In trials of water-lifts, there is a liability to a serious error in estimating the outturn of work from the fact that animals can be made to work at a much faster rate for a short time than they can sustain for a prolonged period. With experience it is possible to judge if animals are seriously over-driven ; or, if experiments can be extended over a sufficient number of hours, over-driving at the start will be revealed by a gradual slackening of the rate of doing work. In the present series of trials, every effort was made to secure that the animals should be driven at their normal speed, and it is believed with success ; but as in most cases there was only a limited time for experiments, the rate of working was checked against the animal's weight. Agricultural authorities, in calculating the rations for draught cattle, assume the working day to be eight hours and the rate of doing external work to be 0·25 foot-tons per lb. of weight per hour. This is considered to be the maximum amount of work which can be obtained, without affecting the health of cattle, and an

increase, either in the rate or in the total quantity of work done, soon produces deterioration and sickness. There appears to be no data available as to the amount of work which can be got from cattle in India, but it is probably rather less than in temperate climates, and the value of the figures obtained in these trials lies chiefly in the fact that they enable us to judge at what rate the cattle were worked. It will, of course, be understood that the more the weight of the animal was used, the greater should be the rate at which work can be done, and that the highest rate should be obtained for lifts in which the animal exerts no draught, but simply raises himself up an inclined plane till it overbalances the resistance to be overcome, and useful work is done by the steady descent of the animal under the action of gravity. In this case the rate of working ought to be about 0·5 foot-tons per lb. of weight per hour.

More than 50 years ago a Mr. F. W. Simms communicated to the Institution of Civil Engineers the results of some observations which he had made on the amount of work which horses can do at various rates of working. The average weight of the horses was 1,176 lbs. and the results are concisely stated in Table I.

TABLE I.

Working day in hours.	Foot-pounds of work done per horse per minute.	Relative amount of work done in a day.
8	23,412	100
6	24,360	78
4½	27,056	65
3	32,943	53

In Captain Clibborn's report on well irrigation in the North-West Provinces are given the results of an extensive series of experiments made on the quantity of water raised from wells of different depths by various methods, from which it appears that the work done by cattle varies very greatly, depending on conditions not explicitly stated, but of which the most important, evidently were, the size and strength of the animals, the depth of the wells and the type of water-lift employed. In Table II, a few of the results have been extracted and the capacity of the bucket is given to serve as an indication of the size and strength of the cattle as it is evident that only big, powerful beasts could exert a draught of over 500 lbs.

TABLE II.

Depth to water surface in feet.	Capacity of bucket in gallons.	Work done per head per minute in foot-pounds assuming efficiency of lift to be 50 per cent.
57	16·2	9,384
37	28·7	7,426
17	25·2	3,136
12	21·8	2,490
53	47·7	11,678

In the same report, it is stated that with men, working the dhenkli, the useful effect obtained averaged 1,120 foot pounds per minute, which would mean that, after due allowance had been made for the imperfect efficiency of the machine, the men were doing

about 12 foot-pounds of work per lb. of weight per minute. Assuming that the men weighed 112 lbs., the coefficient of utility in this case would be 600.

In Table III the results of the experiments made in Madras are collected together, and sufficient details given to show that the variations in the output of work are mainly due to the different methods of making use of animal power, and it will be seen that they occur exactly as one would be led to expect from the conclusions arrived at when discussing this point.

The figures obtained with picottahs worked by men are very striking, especially when it is borne in mind that the work of one man is almost entirely confined to guiding the bucket rod and emptying the bucket, and that only the two men perched on the see-saw lever are employed in lifting the water. Compared with the dhenkli, in which the water is raised by pulling with the arms at the end of a balanced lever, the resultant effect is more than twice as great.

With the exception of the Persian wheel and modifications such as the chain pump, all the water-lifts used on wells in India consist essentially of a combination of two distinct parts. They are (1) a bucket or buckets for holding the water and (2) an arrangement of some kind by which animal power can be conveniently applied to do the work of raising the full buckets from the well. The buckets are usually made either of leather or iron and may be divided into three classes: (1) a simple leather bag such as is used very largely in Northern India, which requires a man to be specially

TABLE III.

Name of lift.	Nature of work.	Weight of cattle.	No.	Footpounds of work done per minute per animal.	Footpounds of work done per minute per lb. weight.
		lb.			
Stoney's double mhote.	Draught in a circle, intermittent.	1,146	1	12,060	10·52
		1,438	2	5,410	7·52
		1,146	1	10,308	9·00
Single mhote by Subba Row.	Draught down an inclined plane.	1,348	2	12,180	18·07
See-saw water-lift.	Walking up an inclined plane and reversing.	700	1	9,625	13·75
Sultan Mohideen.	Draught in a straight line and reversing.	1,596	2	6,425	8·05
Andrew's Persian wheel.	Draught in a circle continuous.	985	2	6,695	13·58
Single mhote, Bellary.	Draught down an inclined plane.	2,688	4	12,225	18·20
		2,058	4	5,762	11·21
Single mhote, Coimbatore.		774	2	6,180	15·99
Do.		1,320	2	9,430	14·29

TABLE IV.

Name of lift.	Nature of work.	No. of men.	Weight of men in lbs.	Foot-pounds of work done per man per minute.	Foot-pounds of work done per minute per lb. weight.
Picottah ..	Walking on see-saw lever.	3 3	308 331	2,610 2,737	25·4 24·81

stationed at the mouth of the well to tilt it over to discharge its contents, or a plain iron bucket or dish of the type generally used with picottahs; (2) cylindrical iron buckets suspended from stirrups so as to automatically tilt over and fill when lowered into the water, but which require a tilting bar or some equivalent device to empty them; (3) leather or iron buckets fitted with valves. The most ingenious and simple of all these is the common leather mhote, used all over the South of India which consists of a roughly hemispherical leathern bag, suspended from an iron ring and fitted at the bottom with a leather trunk or discharge pipe, the end of which is held by a separate rope above the level of the water in the bag, whilst the latter is being drawn up the well. The ropes are so adjusted that on reaching the top of the well the bag continues to rise whilst the trunk is drawn inwards, with the result that the water is rapidly and completely discharged. Of iron buckets fitted with valves various forms have been proposed, but the only one, that has

so far obtained any vogue, is that used with the Sultan water-lift; it is cylindrical in form with a flat bottom, in which is placed a large flap valve opening upwards when the bucket enters the water, and kept closed by the pressure of the water on it during the ascent, till at the top the valve is raised by a system of levers which are depressed by coming into contact with a fixed stop.

Of possible mechanical arrangements for applying animal power to raise the buckets an indefinite number could be devised, but owing to the necessity for extreme simplicity and cheapness, there are few that can be considered of any practical importance. A single bucket, suspended by a rope passing over a pulley, fixed over the mouth of the well, and attached directly to a bullock's yoke is the simplest and almost universal way of working throughout India and when the details are arranged to suit the local conditions the single mhote, as it is called, can hardly be surpassed by any more elaborate method. When two buckets are in use they can be made to balance one another by carrying the ropes round the drum of a gin or whim in opposite directions, so that when one ascends, the other descends, as exemplified in the ordinary double mhote. Reversing gear, to obviate the necessity of making the cattle turn round after each bucket is emptied, could easily be provided, but would seldom be used as it would render the whim too costly to construct. By the use of bevel wheels, the whim can easily be adapted to work Persian wheels and allied types of

water-lift, which continuously revolve in the same direction. In the Sultan water-lift, the buckets are balanced by being suspended at the ends of a rope which is carried over a series of pulleys so arranged that a pair of bullocks can be yoked directly to the rope, which when pulled in one direction raises one bucket and when pulled in the reverse direction raises the other bucket. Lastly, there is the picottah with its balanced lever worked by men and the various modifications of it which have been proposed to render it suitable for employment with cattle.

Experiments have been carried out either by the Water-Lift committee or by Mr. Benson and myself since the submission of its report on all the types of water-lift enumerated above, but no attempt was made, nor was it deemed desirable, to experiment with pumps and other devices of modern mechanical engineering, as the investigation has been purposely confined to appliances used by ryots or likely to come within the scope of their very restricted resources.

Methods of measurement employed in the experiments:—All weights were determined and draughts measured with a Salter's Spring Balance, recording to 500 lbs. and indicating differences of half a pound, which, previous to the commencement of the experiments, was tested with dead weights. Measurements of draught and friction were made by inserting the spring balance which was used as a dynamometer in the line of action of the forces exerted by the bullocks and employing a number of coolies to work the lifts in

their place. In machines like water-lifts, which of necessity are somewhat roughly constructed, no great amount of labour is expended on fitting the moving parts together; and, in consequence, the working is not perfectly smooth and the friction varies considerably in a single operation of the machine. The measurement of draught is, therefore, not very easy and the results are, in every case, the mean values obtained from a large number of observations. In most instances the average quantity of water brought up by a bucket was measured by passing the water into a tank of known dimensions and counting the number of buckets required to raise the water-level by an amount which was carefully measured. The tank was always filled and emptied several times and the mean result was undoubtedly very accurate. In one or two instances no tank could be procured and the water was measured in a rectangular trough dug in the ground, and, with proper precautions taken to ascertain the loss due to percolation, it was found a satisfactory method. The cattle employed during the trials were in every instance weighed on platform weighing machines, the wells chosen for the experiments being specially selected with reference to the facilities for weighing in the neighbourhood.

Stoney's water-lift:—The principle feature in this lift is the employment of buckets of wrought iron suspended in a stirrup by two adjustable pivots, attached to the bucket very slightly above the centre of gravity of the bucket when full of water. The mouth of the

bucket is inclined and the lower ends of the stirrup are turned outwards and formed into rings sliding on steel wires which are suspended in the well from screwed eyebolts attached to the framing above. The wires are fastened by some convenient means to the bottom of the well and act as guides to the bucket ascending and descending and prevent it from either turning round or swaying to and fro, and thus striking the sides of the well or the second bucket. On the bucket being lowered into the water it turns horizontal and as it sinks fills with water. On being drawn up it assumes a vertical position and rises steadily till the discharging level is reached, when the upper side of the inclined mouth comes into contact with an iron bar fixed across the framing of the lift and the stirrup continuing its upward motion causes the bucket to revolve about the point of contact of the bucket with the iron rod, and thus discharges its content into the delivery trough. The lift was worked by carrying the ropes which hold the buckets over guide pulleys to a whim. Two buckets are attached and the ropes arranged so that as one bucket ascended the other descended, and the dead weight of the buckets was balanced. The whim consisted of a drum built of wood and was carried by an iron spindle on the top of a post firmly built into the ground. The bullocks worked at the end of an arm which was 3·85 times the radius of the drum. The whim was worked alternately in one direction and the other, the cattle being made to turn round whilst the bucket was discharging its contents.

Improved single mhote of M. R. Ry. Subba Rao :—The improvement on the ordinary single mhote is effected by attaching a rope to the draught rope and carrying it on to the large drum of a kind of windlass erected at the end of the inclined plane and at a considerable height above the level of the end of the run. Ropes wound round two smaller drums, one on each side of the large drum, carry weights which balance the weight of the empty bucket so that at the end of a lift as soon as the bucket is emptied the draught rope automatically rises in the air and the bullocks are able to turn round and walk up the inclined plane in a natural easy manner instead of being forced backwards as with the common plan. The improvement effected is undoubtedly very considerable as not only is the weight of the empty bucket balanced but the animals are also spared the cramped and unnatural backward walk up a steep incline which probably tires them more than their exertions in drawing the bucket out of the well.

See-saw water-lift of M. R. Ry. Subba Rao :—In this form of water-lift the bullock is made to walk along a platform supported on a roller and by his weight it is caused to oscillate up and down. Two ropes are attached to one end of the platform and wound round two small drums forming part of a windlass, round the large drum of which a rope working an ordinary single mhote is passed. The platform is not supported in the middle but at some distance therefrom, so that the working end of the plat-

form greatly preponderates and the bullock has to walk to the free end of the platform to tilt the longer segment up and lower the bucket into the well. To diminish the shock, when the free end falls and the bucket is lowered into the water, iron rails are fastened underneath the platform by a short chain so that just before this end of the platform reaches its lowest position the rails rest on the ground and their weight ceases to act. Thereby the platform comes to rest more gently than would be the case if the velocity of descent continued to accelerate to the very end.

Single mhotes.— Experiments with single mhotes were made at Palladam in the Coimbatore District, where they are worked with a single pair of cattle, which are trained to walk backwards up the ramp. The slope of the run is therefore limited to 1 in 5 which is about the maximum that the cattle can be backed up. At Bellary, where experiments were also made, the lift is usually worked with two pairs of cattle, each pair drawing up alternate buckets of water. At the end of the run, the rope and bucket are detached from the yoke and fall back into the well, assisting the driver who grasps the end of the rope, to return up the steep slope, whilst the bullocks turn round and walk up a side path, which is not nearly so steep as the ramp. When the bucket is again in the water, the second pair of bullocks are hitched on to the rope and draw up another bucket full of water whilst the first pair are leisurely walking up the incline, so as to be ready at the top by the time the driver returns with the rope. With this

system of working, it is possible to make the slope of the ramps very steep and the gradient is usually from 1 in $2\frac{1}{2}$ to 1 in 3. The weight of the bullocks is therefore more effectively utilized, and a much larger bucket can be used than in the Coimbatore District.

The modification of the single mhote invented by M. R. Ry. Subba Row enables most of the advantage of this system of working to be obtained with one pair of bullocks. Moreover, the bucket is balanced, but it is doubtful if this contributes any real increase to the efficiency of the lift, as the friction of the extra pulleys absorbs power and more work is thrown on the driver since the unbalanced bucket materially assists the driver in climbing the steep ramp.

The Persian wheel.—Mr. Andrew, a missionary of the Free Church of Scotland stationed at Chingleput, has erected a form of Persian wheel at the Christian Settlement of Melrosapuram which he invited me to test. It is built on a framing of old railway rails over a circular well about 24 feet 6 inches in diameter. The rotating drum was 6 feet in diameter and 3 feet 8 inches wide and carried a double chain of sheet iron buckets each holding 1·80 gallons. The axis was prolonged on one side and driven through a pair of bevel wheels by a whim of the ordinary type. Each bucket was provided with a leather flap valve to permit of the escape of air from the descending buckets as they entered the water. The design was carefully worked out and the water-lift was very strongly made, so that it worked very satisfactorily during the trial.

The Sultan water-lift:—This is a direct draught water-lift with balanced buckets, the details of which have been very ingeniously worked out, but the paramount necessity for keeping the cost down has resulted in the use of an unsatisfactory system of construction, which prevents to some extent the full advantages of the design being realized. The buckets are fitted with valves, as already described, which when new are water-tight; but in ordinary daily use they soon get slightly out of order and then leak considerably. Trials were made on one which had been put up in a garden in Tondiarpett to the north of Madras by M. R. Ry. Sundaram Sastri and on one, which has recently been erected near Bellary, in a garden belonging to M.R.Ry. Aerada Rudrappa. The only important difference between the two lifts was that the former was fitted with hemp ropes and the latter with wire ropes. I should have preferred to have tested a water-lift under the management of the makers but, though I offered to do so, they declined to place one at my disposal.

In the following tabular statement (Table V) are given the results of the trials which I have made. None of the trials were very prolonged, but they were all made under normal working conditions, and the results are only so much better than would ordinarily be obtained in practice* as may be fairly ascribed to

* Subsequent experience of the working of native water-lifts leads me to think that the results obtained during our trials were about 33 per cent. better than those usually obtained by the cultivators under normal working conditions.

TABLE

Name of water-lift.	Date of trial.	Mean lift in feet.	Duration of trial in minutes.	Gallons raised per hour.
Double mhote, Saidapet.	18 July 1895	22·125	180	1,867
Stoney's improved double mhote.	16 July 1895	22·625	90	2,594
	16 July 1895	23·24	166	2,489
	17 July 1895	22·87	111	2,991
Stoney's improved double mhote.	9 July 1896	23·5	427	2,097
	11 July 1896	23·5	422	2,220
Subba Row's improved single mhote ..	18 July 1895	23·00	60	2,178
Subba Row's sea-saw lift.	23 July 1895	18·1	45	1,903
Sultan water-lift ..	30 July 1895	21·0	60	2,570
Andrew's Persian wheel.	27 Feb. 1886	10·895	95	3,661
	27 Feb. 1896	12·375	120	3,204
Single mhote, Palladam.	30 May 1896	38·75	63	1,345
	31 May 1896	38·75	180	1,523
	31 May 1896	32·25	120	1,110
Single mhote Bellary.	22 June 1896	35·50	102	3,766
	25 June 1896	35·50	240	3,347
	23 June 1896	13·0	165	3,511
Picottah.	10 June 1895	19·25	16	1,959
	20 July 1896	14·417	420	2,735

V.

Foot-pounds of useful work done.	Number of animals employed.	Weight of animals.	Co-efficient of utility = useful work done in foot-pounds in one hour ÷ weight of animals in lb.	Slope of bullock run.	Delivery of buckets in gallons.	Draught.	
						Mean.	Maximum.
		lbs.				lbs.	lbs.
413,000	1	1,146	360	level.	28·0	90	90
586,900							
575,500	1	1,146	498	level.	28·0	92	122
546,900							
492,795	2	1,438	343	level.	28·0	..	..
521,700	2	1,438	362	level.	28·0	..	..
500,940	2	1,348	271	1 in 5·28	24·2	383	410
942,540	1	700	492	1 in 2·66	23·5	..	..
539,857	2	1,596	338	level.	22·75	296	330
398,890	2	985	404	level.	1·776	95	95
395,500	..	..	..	..	..	..	..
539,700	2	1,320	409	1 in 7	29·1	390	420
..	..	..	..	..	..	..	..
358,039	2	774	462	1 in 5·33	24·4	327	351
1,337,000	4	2,688	497·4	1 in 3	51·48	625	700
..	..	..	..	..	..	..	..
456,400	4	2,058	221·8	1 in 2·5	33·88	480	510
375,810	3 men	308	1,220	..	6·32	..	..
394,310	3 men	331	1,191	..	9·50	..	..

the fact that care was taken to have the water-lifts in good working order and the cattle in good condition and that no time was wasted whilst the trials were in progress. The results are strictly comparable and represent the performances of each water-lift under favourable conditions.

From the experimental results presented in Table V, it seems justifiable to draw certain conclusions, of which the most important is undoubtedly that the native methods of lifting water under favourable conditions have not yet been surpassed by the best and most improved inventions of recent years. The mechanical efficiency of modern water-lifts is higher, but the mode of applying animal power, to which sufficient attention has not been paid, is distinctly inferior, save in one case, and the final result is, that as yet, no advance has been made, which will in any degree compensate for the increased cost of the new water-lifts. The see-saw water-lift of M. R. Ry. Subba Row alone seems to offer prospects of being developed into something which will be materially better than anything at present in existence. The machine examined by the Water-lifts Committee was mechanically very imperfect, yet the *co-efficient of utility* obtained was very high, and as it demonstrated clearly the possibility of using cattle to work oscillating platforms, it must be regarded as the first step in what may ultimately prove the direction in which the greatest improvement can be made.

Stoney's improved double mhote is undoubtedly, from a mechanical point of view, the best water-lift that has yet been constructed and it has accordingly been made the subject of more extensive experiment than any other. The efficiency is very high and does not appear to be capable of any further improvement, but the animal or animals have to walk in a circular path and are in consequence unable to exert as powerful a draught as when walking straightforward. This is particularly the case if two bullocks are yoked to the revolving arm when the inside bullock works under great disadvantages and most of his energy appears to be consumed in *internal* work. Probably the best results would be obtained with two comparatively small bullocks yoked to separate arms, radiating from opposite sides of the drum so as to balance one another; but, if this would necessitate two drivers, the increased cost would more than counterbalance the improvement in the conditions of working. The time wasted whilst the bullocks are turning round at the end of each lift is a serious defect especially on low lifts when it occupies a very considerable portion of the working cycle and it materially increases the amount of energy wasted in *internal* friction. With a single bullock of exceptional size, the *co-efficient of utility* is the highest that has been recorded but, with a pair of animals of average size, the figure is reduced by more than one-third, clearly demonstrating, if proof, indeed, be needed, that they were working under unfavourable conditions.

The Sultan water-lift was the subject of experiment on two occasions, once in Tondiarpett under very favourable circumstances as it had been in use for eight months and the animals were a very fine pair of bullocks that had been thoroughly trained to the work and once near Bellary on the most recent type of lift, but with animals which were apparently scarcely strong enough and in consequence they did not work well. Unfortunately, their weight could not be determined as the owner was unable to allow them to be marched into Bellary to be weighed and the observations have, therefore, not been included in the tabular statement. The lift possesses two very serious defects which are rendered more apparent by the light construction of the parts: (1) The buckets are filled and emptied by means of a valve, which is liable to get out of order and leak, and which at all times requires a strong pull to depress the lever which opens it when the full bucket is drawn up to the discharging point. (2) The draught is direct and is exceedingly heavy, being equal to the weight of water lifted, the weight of the bucket and the force necessary to overcome the resistance of the rope passing over a number of small iron guide pulleys. The buckets are supposed to be balanced and are so except near the end of each lift when the empty bucket sinks into the water but the friction of the ropes is so great that the weight of the empty bucket is not more than sufficient to drag the length of slack rope, to which it is attached, back into the well. The lift near Bellary was supplied with 30-gallon buckets and I worked it with

twelve coolies through the dynamometer. The buckets discharged about 27 gallons and the pull averaged 370 lbs. towards the well and 350 lbs. away from it, and at the end of each lift rose to 500 lbs. due to the force which had to be exerted to hold the bucket of water in the air and depress the levers which open the valve against the pressure of water on it. Similar results were obtained in Tondiarpett, though the figures were smaller, as 25-gallon buckets were in use. Only the very highest class of cattle can exert such heavy draughts and even upon them the work tells very severely and they rapidly deteriorate. The draught could, of course, be lessened by the use of smaller buckets, but the outturn of water would be correspondingly decreased and the percentage of power wasted in friction would rise so much as to make patent the defects of this method of rising water. The use of larger guide pulleys, a more rigid system of construction and the introduction of a simple system of pulley blocks to diminish the draught by one-half, would increase the efficiency of this water-lift very materially, but, at the same time, would add so largely to the cost as to render it prohibitive.

The Rev. Mr. Andrew's Persian wheel, which was the first he had made, possesses the great advantage that the cattle do not have to reverse the direction of motion of the whim at frequent intervals, and that consequently no time is lost or energy wasted in useless work. It was well constructed, and though capable of minor improvements, it may be taken to

represent fairly the capabilities of this class of water-lift. The continuity of action renders it extremely suitable for shallow wells in which the water level varies but little and for such conditions a smaller wheel and smaller, but more numerous, buckets would undoubtedly increase the efficiency. From a ryot's point of view it is too costly, and contains too many working parts, to ever have a chance of being extensively used in this country in any other than the crude form already in use in the North.

The double mhote is inferior to Stoney's modification which has already been discussed and its defects are most conspicuous on deep wells as the motion is so slow that the leakage from the leather discharging trunks—and they always do leak more or less—becomes a serious matter, and a bucket which starts on its upward journey full of water often arrives more than half empty. It has been extensively tried in certain districts and has answered well when care was taken to keep the buckets in very good order, but that they should be so maintained for any long period is more than could be expected from the ryots of this country and the troubles from leakage have, therefore, caused the double mhote to be regarded with disfavour.

The two systems of working the single mhote as practised in Coimbatore and Bellary, and known in Northern India by the terms *Lagor* and *Kili*, respectively, have already been described. It is difficult to say what circumstances have determined the

ryots in their choice between these two systems as they are often to be found working on apparently the wrong system, but it is easy to see that for shallow wells and small cattle the time lost, in detaching the cattle at the end of each lift and attaching another pair, is not compensated for by getting rid of the necessity for backing the cattle up the incline. With a shallow well and a small bucket or bag, each lift represents the expenditure of only a small amount of work, whilst with a deep well and a big bucket, a large amount of work is done in each cycle of operations. With the heavy cattle, which must necessarily be employed where buckets of large capacity are used, there is probably greater difficulty experienced in getting them to back up the inclines and, therefore, more time wasted and more fatigue incurred than is usual with small cattle. Where the ryots are poor and the cattle undersized the *Lagor* method of working is often only adopted, because they cannot afford to work *Kili* and it may be generally laid down that the first system is best suited to shallow wells, probably under 25 feet in depth, and the second systems to deep wells, especially, when they are worked by heavy cattle. The modification in working due to M. R. Ry. Subba Row will probably be found to be of the greatest use in places where the *Kili* system is not used, either from want of a sufficient number of cattle on the part of the ryots, or because the wells are of small capacity and too rapidly exhausted when more than a single pair of cattle are worked on them. To obtain

good results with the single mhote, it is necessary that the capacity of the bucket should be suited to the size of the cattle and the gradient of the run, and it is evident that in many cases this is not so, with the result that the external work done bears a small ratio to the total muscular energy developed. Where the proper system of working is adopted and the capacity of the bucket is suited to the weight of the cattle, the single mhote is an exceedingly simple, cheap and effective water-lift and is especially convenient from the fact that a varying depth of water in the well causes absolutely no trouble whatever in working. Yet it is not without its disadvantages, and the ryots would gladly welcome any suitable substitute for leather * in the discharging trunk, so as to be able to dispense with the necessity of employing chucklers to repair it. Stout canvas has been used in some instances with great success, both in respect to durability and cheapness, and if a knowledge of this fact was widely diffused, it would confer no small benefit upon the ryots of Southern India. So far as I am aware, self-filling iron buckets have not been tried with the single mhote though there seems to be no reason why on Stoney's system, at any rate, they should not be a success.

* Leather manufactured by the chrome process has recently been introduced for water buckets and experience shows that it is a great improvement on the material supplied by village chucklers or country tanneries. In recent years, also, owing to the great rise in the price of leather, iron buckets are much more largely used than was the care when these experiments were made.

In conclusion, it seems desirable to attempt some estimate of the cost of raising water by means of cattle. A careful study of the figures given in Table V leads me to the conclusion that under normal circumstances the coefficient of utility for Indian cattle, kept at work for about 6 hours a day will be 350, and that a pair of animals weighing 1400 lbs. will lift 1960 gallons per hour from a depth of 25 feet, and that a fair day's work may be taken to be 12,000 gallons raised 25 feet. The cost of keeping such a pair of animals including interest on their value and allowing for their depreciation together with the expenses incidental to the upkeep of a *mhote*, will be about 12 annas per day or assuming that they are at work on three-fourths of the days in the year, the cost per working day will amount to one rupee. For that sum therefore, three million foot-lbs. of useful work can be done. To cover an acre of land to a depth of one inch involves the application of 22,687 gallons of water and the cost of raising this from a depth of 25 ft. will be Rs. 1-14-3.

It is seldom, however, that these expenses are defrayed in cash. The ryot breeds his own cattle and, from the land cultivated, their food is wholly or partly obtained, whilst the servant who looks after them receives the greater part of his wages in kind. Any considerable extension of well cultivation, in a few years, would materially change this primitive state of affairs, but there is neither capital nor labour available to allow of any rapid increase in area and both capital and labour will have to be provided.

CHAPTER II.

UNDERGROUND WATER-SUPPLY.*

During the past few years India has been visited by two famines over widespread areas and several severe droughts, which have affected smaller but still very considerable tracts of country. The agricultural population, and those directly dependent on them, have been thrown out of employment and their slender resources being soon exhausted, in enormous numbers they have been forced to seek for the means of subsistence on the relief works which Government have opened. In good or even average years the exports of wheat and other food stuffs from the country prove that the area under cultivation is still in excess of the requirements of the rapidly-growing population. In famine years the surplus produce of the non-affected parts of the country is diverted from the export trade and carried by the railways to places where there is a local deficiency, so that in the worst years there is enough food for all and it is simply the poverty of the people that puts it beyond their reach. A succession of favourable seasons would materially improve the condition of the land-owning classes but it would lead to no accumulation of grain in the villages and the labouring classes during these years of plenty will

* *The Indian Review*, June 1900.

simply increase in numbers and the next failure of the rains will find them as now—only more of them—in complete destitution.

The problems which Indian Administrators are called upon to face in the immediate future, to combat this deplorable state of affairs, are very difficult and the solution of them will make as heavy demands upon the energy and resources of the executive as have ever been made in the past. It is generally agreed that the most pressing necessity is the development of industrial occupations whereby new sources of wealth may be opened out and the land relieved of the excessive proportion of the population which is now entirely dependent on it. The mineral wealth of the country must be utilized to supply its own requirements, new industries must be introduced and old ones resuscitated. Instead of exporting nothing but raw materials, it will be necessary to send them out in a manufactured state and the internal trade of the empire will have to be worked up with some semblance of the energy and perseverance which the Japanese have displayed in rendering themselves independent of foreign manufacturers.

Work of this kind, however, proceeds very slowly and it will be many years, if ever, before India can be justly ranked among the manufacturing countries of the world, and in the meantime more attention must be paid to the great work which has been going on all this century, that of rendering the work of the cultivator as far as possible independent of the variations of the

seasons. By anicuts and canals we have practically made use of all the water in our great rivers which can be relied on to flow continuously through the cultivation season. By huge reservoirs or tanks many irregular sources of supply have been turned to account and nearly all the obvious sites for storing water have been occupied. In the future, therefore, the work will be more difficult and more costly than it has been hitherto and it is hopeless to expect that the splendid financial results of the past will be again repeated. Yet in the South of India, at any rate, much can be done to economise water by improving the means of distribution and preventing the ryots from using it with actually harmful extravagance. The whole question of what is technically known as the "duty of water" requires years of careful study and experiment, and it can hardly be doubted that the time has come when a special branch of the Public Works Department should be established for the scientific investigation of this and other problems peculiar to Indian engineering. The work that is going on now at Assouan on the river Nile where a huge dam is under construction to store up part of the flood waters in a long narrow reservoir will probably be repeated on some of our Indian rivers and the investigation and designing of projects of this kind will call for the highest possible ingenuity and skill to render them at all feasible and within the limits of our financial resources.

In fact, the storage of water is likely to become the great Indian engineering problem and attention will

doubtless be paid to that portion of the rainfall which is absorbed by the earth and disappears from sight, to find its way by deep and tortuous passages to the sea. Two and one-half million wells irrigating fully ten million acres of land attest the importance of the subterranean supplies of water and indicate that in this direction there are immense possibilities. Underground water in India, has never been studied properly by engineers or geologists, and wells are sunk, in a happy-go-lucky manner to a haphazard depth. They are constructed with primitive appliances and at small cost. Expectations are not usually great and, as they are generally realized, the people are content. Some wells dry up in the hot weather, some wells always respond to the demands that are made upon them, but nothing is really known about their capacity to supply water. A few elementary calculations, however, will show that the quantity of water drawn from most wells is but an insignificant fraction of the stores that must be below and which are continuously passing away through permeable strata till they ultimately reach the sea. Where the average rainfall is 30 inches per annum we may assume that one-third of this sinks below the surface and that, therefore, each square mile of land receives 640,000 tons of water. If but one-half of this quantity could be extracted from the earth by pumping from wells it would yield a continuous supply of one cubic foot per second for 136 days, which, with economical use, would fully suffice for the irrigation of 250 acres. Thirty-six mhotes and thirty-six pairs of

bullocks working steadily for six hours a day would draw out this quantity of water from a depth of 20 feet. Now there are no data available as to the number of wells per square mile. In parts of such districts as Coimbatore they are very numerous, and the total yield of water from them may exceed one cubic foot per second per square mile, but over the greater part of India nothing approaching this quantity is obtained. From such data as are available, I estimate that wells in India yield about 40,000 cubic feet per second, a very large quantity of water but equal to only one-thirty-fifth of a cubic foot per second from the 1,400,000 square miles of total superficial area. Over a great part of India the rainfall is more than 30 inches a year and we know nothing as to what becomes of the vast quantity of water which annually sinks into the earth. We know that in some districts there are many wells with a good supply of water, in others few wells and the yield very precarious. Sometimes the reason is obvious from the nature of the surface and the configuration of the ground, but in most cases it is just the reverse and many wells have been sunk by engineers in what were considered likely spots and have turned out useless.

The great majority of wells in this Presidency range from 20 to 40 feet in depth. They, therefore, derive their supply of water, with the exception of such wells as actually tap under-ground springs, from an inverted conical mass of earth, the axis of which is the well and the vertex the water-level. Each well is the

centre of a certain mass of earth which absorbs water from the surface percolation until it is saturated and any excess slowly moves along the line of least resistance. The well alters the direction of these lines and some water flows into it, but the greater part of the water sinks vertically till it reaches impervious strata. The deeper the wells the greater is their action in deflecting the lines of sub-soil flow and in some cases there is no doubt that vigorous pumping after heavy rain would materially increase the volume of the cone influenced by the well. This, of course, is the time when wells are left alone and advantage is not taken of such opportunities to form lines of sub-soil flow towards the well.

Artesian wells have been carefully studied in many lands but wells of the types found in India have been neglected and we know practically very little about them. Isolated experiments will not teach us much owing to our inability to see what is going on inside the cone of influence round the well. The intelligent ryots of the country have probably a good deal of information about the behaviour of their own wells and of those belonging to their neighbours and skilful examination of villagers in well-irrigation districts might lead to the collection of some useful preliminary data which might serve as the starting point for further enquiries. Very few wells exist which are known to yield enough water to offer any inducement to employ mechanical arrangements for pumping water from them. It is easy to see why this is so. The depth

of the well is limited by the fact that the primitive methods of sinking in vogue among the ryots prevent them going more than a few feet below the hot weather level of the water. With an engine and pump to keep the well dry much greater depths might be attained and possibly the supply of water enormously increased.

It is generally considered that mechanical methods of pumping water for irrigation are too expensive to be employed and it is generally supposed that animal power is the only means available. Let us consider an imaginary case and then see how far the conditions are likely to be realized in practice. The well is a deep one and yields half a cubic foot per second with a water-level about 40 feet below the ground. It is provided with an oil engine and a pump. The engine is only worked for 16 hours per day and, therefore, has to lift 250 gallons per minute throughout that period.

Allowing an efficiency of 40 per cent. for the gearing and centrifugal pump, the engine would have to develop $7\frac{1}{2}$ brake-horse-power and would consume one gallon of kerosine oil, costing 7 annas per hour. The monthly expense which such an engine would entail may be taken as follows :—

	Rs.
Fuel for 24 days at Rs. 7 per day ...	168
Wages for 2 drivers at Rs. 12 & 10 per month...	22
Lubricating oil, waste and stores ..	15
Interest and depreciation on capital outlay, cost of repairs, etc., at $12\frac{1}{2}$ per cent. per annum on Rs. 3,000	32
Total ...	237

Compare this with the cost of working with cattle. In the paper on "Water-Lifts" we obtained the result that with a mhote for one rupee three million foot lbs. of work could be done. In this case the oil engine develops $7\frac{1}{2}$ per cent., of which 40 per cent. is used effectively, so that the work done by the engine is equal to 48 horse-power hours, one horse-power hour is equivalent to 1,980,000 foot lbs. of work in one hour, 48 horse-power hours represents the performance of 95,040,000 foot lbs. of work, which at 3,000,000 per rupee would cost Rs. 32 nearly. That is to say the engine and pump will do as much work as 32 pairs of cattle, the cost of maintaining which will be Rs. 720 per month. As the engine only costs Rs. 237 per month it is obvious that it will raise water at one third the cost of doing the work by cattle.

A further economy can however be effected by using liquid fuel at As. 3 per gallon in place of kerosine oil at As. 7 per gallon. The consumption would be the same and a saving of As. 4 per gallon or Rs. 4 per day would be effected. Making an allowance for the kerosine oil necessary to start the engine every day the monthly charge would be reduced to Rs. 144 which is exactly one-fifth of the cost of keeping 32 pairs of cattle.

It would be useless to follow up the comparison between the two methods of pumping any further. It is sufficiently demonstrated that the employment of oil engines for pumping water is a perfectly practical method and can be employed with advantage whenever the quantity of water to be dealt with amounts to half a

cubic foot per second. The initial capital outlay is beyond the means of the ordinary ryot but it is not beyond those of many landowners, and if only sufficient interest could be aroused among them in the improvement of their estates, the ultimate benefit to the country at large would be incalculable.

The two and one-half million wells in India represent a capital outlay not far short of forty crores of rupees and what is wanted almost as much as new wells is the systematic improvement of those already in existence. Many are probably far too shallow and others are too small and do not present a sufficient area for percolation. To jump holes from 10 to 30 feet in depth and a few inches in diameter at the bottom of some wells is not a very difficult matter and the value of the tube would probably be greatly enhanced if the rock at the bottom were loosened by the explosion of two or three small charges of dynamite. To run short adits in the hot weather from the bottoms of many wells is perfectly feasible and both methods, if tried, would yield results far in excess of the cost. Yet these things are not done because the ryots do not know of their value; and even if they did, they would regard them with suspicion as innovations to be classed with many other attempts, by Europeans, at agricultural improvements. These are suggestions which have been tried in other places with success but so little do we know about this subject that I put them forward with diffidence and simply with a view to drawing attention to the urgent necessity which now exists for a systematic

attempt to investigate the conditions under which the stores of subterranean water exist.

The matter is one surrounded with difficulties and it is only by an intelligent co-operation of wealthy land-owners, who can afford to install engines and pumps for the irrigation of their lands or the cultivation of their gardens, with persons possessing a sufficient knowledge of engineering and geology that anything can be done. In this country we rely too much upon official efforts and too little is done by the enterprise of educated and enlightened private individuals. In England, the late Mr. G. J. Symonds enlisted the services of thousands of meteorological observers and established a system of recording data connected with rainfall in the British Isles which has proved of national importance. The agricultural experiments carried out on the Rothamsted farm by Sir John Lawes and Sir Henry Gilbert, for more than half a century, is another instance of private work which has done much to convert rule of thumb practice into a scientific procedure and farming all over the world has greatly benefited from their disinterested labours. Nothing of this kind has ever been attempted in India and I venture to think that the problems presented by well irrigation would be a fitting subject for investigation and one in which many workers might profitably engage themselves. I have endeavoured to show how little is really known and I cannot doubt that if the work were started it would gradually result in additions to our knowledge which would prove of great benefit to the whole community.

CHAPTER III.

WELL IRRIGATION.*

In June 1900 I contributed a short article to this Review on the very important subject of "Underground Water-supply" in which I endeavoured to show that the information available regarding the ultimate disposal of the rainfall in India was very limited, and that consequently it was desirable to scientifically study the question with a view to utilizing a much larger proportion of the subterranean water for irrigation than is at present done. As a preliminary step it was obvious that more powerful and cheaper methods of lifting water than by water-lifts worked by cattle were essential, and I showed that the oil engine when employed to pump from a well yielding on an average throughout the day half a cubic foot per second or 190 gallons per minute was considerably cheaper and more convenient than any form of water-lift worked by means of animal-power.

The importance of well irrigation was fully recognized by the Irrigation Commission and a large amount of evidence was tendered by many witnesses. The report of the Commission may be expected to contain practically a complete summary of all the information available and will serve as a starting point for further investi-

* *The Indian Review*, August 1902.

gations. Funds have already been placed at the disposal of the Madras Government for experimental work in this direction and during the next few years there is no doubt that a serious effort will be made to render available for agriculture a very large quantity of the water which now runs to waste beneath the surface of the earth.

In the year 1900-01, there were in the Madras Presidency 615,520 wells from which water was drawn for irrigation and the area of cultivated land partially or entirely dependent upon them was 1,171,346 acres of first crop and 498,878 acres of second crop. Each well on the average supplied water to only two acres of land and naturally the question arises—Is full use made of the stores of water below the soil ? In many cases, possibly in a numerical majority of the cases, there is little doubt that all the available supply is utilized but in what may perhaps be a comparatively insignificant minority of wells the available supply is enormously greater than the present demand and vast quantities of water remain unused. It must be within the personal knowledge of most people that there are wells which yield a good supply of water throughout the year and never dry up even in years of severe drought. Such wells should be examined and attempts should be made to pump them dry. Many wells are only made use of to the extent that tanks would be, if they were only provided with high level sluices through which the upper water in the tank, and that only, could pass through the bund to the irrigation channels.

In the south of India well-sinking is a very primitive business and the better the supply of water, generally the shallower the well. A ryot wants a well and, having selected a spot which he thinks suitable, he sets to work and either sinks a hollow cylinder of brickwork into the ground till water in sufficient quantity to satisfy his expectations is reached, or he excavates a big rectangular hole in the disintegrated rock which forms the sub-soil and goes on deepening it till the inflow of water is greater than can be dealt with by the modest water-lifting applicances at his disposal. Year after year in the hot weather when the water level is low, he may increase the depth by adding to the number of mhotes on the well and in this way many valuable water-yielding wells have been sunk. Let us suppose, however, that the unwatering of the well in the hot weather is accomplished by a powerful engine and pump, the work of excavating will be easy and the depth may be rapidly increased till either the inflow is greater than can be dealt with or practical considerations clearly indicate that it is not worth while to go any deeper. For water to flow into a well the level in the well must be lower than in the sub-soil and the greater the difference in level, the greater is the force tending to make the water flow into the well. But the lower the level in the well, the greater is the amount of work which has to be done to raise the water above the surface and ryots prefer numerous shallow wells to a few deep ones. The number of cattle employed in lifting water is enormous and it is improbable that any

great extension of well cultivation can take place under the present system for lack of animal power to do the necessary work of extracting the water. A ryot must have cattle and while the crops are growing they can be profitably employed in raising water, but directly he has to keep cattle specially for the purpose, well irrigation becomes expensive and unprofitable. A pair of good serviceable bullocks in constant work cannot be kept for less than Rs. 22-8 per month including the wages of a driver and the work they do can be far more cheaply performed by a good oil engine or steam engine. But these machines, even when of the smallest size practicable, are far too big for the work of drawing water from ordinary wells and they can only be employed when the conditions are unusual in respect to the volume of water to be obtained from a well. A 3½ horse-power oil engine, which is the smallest size it is advisable to employ, can be worked for 16 hours a day at a cost of 3½ rupees and will do as much work in lifting water as 15 pairs of good cattle costing Rs. 337-8 a month. Working 24 days in the month the engine will cost Rs. 84 so that the cost of pumping by an oil engine of this size, driving a three inch centrifugal pump, is almost exactly one-fourth what it is when bullocks are used, provided only that there is sufficient work to keep the engine fully employed for the time specified.

Before developing further the idea of employing oil engines for well irrigation I propose to briefly describe an experiment now in progress. About 6 miles from Chingleput is a small Christian settlement founded

by Mr. Andrew of the Free Church of Scotland Mission. About 50 acres of land are under cultivation and the crops are watered by 5 wells which have been sunk since the settlement was started eight years ago. Greatly interested in the question of well irrigation Mr. Andrew offered to allow me to conduct experiments on his wells and with the assistance of funds placed at my disposal by the Madras Government, at the instance of the Chief Engineer for Irrigation, Colonel Smart, R. E., I have been able to put to the test of practical working the idea of using oil engines. I selected what was supposed to be the best well on the settlement and at the beginning of March I tried to unwater it by working a Persian wheel continuously night and day by means of relays of bullocks. I soon found it desirable to increase the pumping power and accordingly a picottah was set up and worked by gangs of coolies night and day. The draught on the well amounted to about 2,500 gallons per hour or allowing for irregularities to between fifty and sixty thousand gallons per day. This resulted in a gradual lowering of the water-level till the depression amounted to $5\frac{1}{2}$ feet, when the level became stationary and the inflow was equal to the amount withdrawn. Arrangements were then made with Messrs. Massey & Co. of Madras, to supply a $3\frac{1}{2}$ horse-power Hornsby-Ackroyd oil engine and a 3-inch centrifugal pump, the combination being capable of lifting 170 gallons of water per minute to a height of 30 feet. Pumping was started at the end of March and in a few hours the well was emptied. An attempt

was then made to deepen the well and a central hole 15 feet in diameter was sunk 7 feet when hard rock was met with. To increase the area through which percolation could take place, adits were run horizontally from the bottom of the well through the partially disintegrated rock. Four were started, but two of them had to be given up before they had been run out 10 feet on account of boulders, the other two were carried outwards about 25 feet and 20 feet respectively, and the percolation through their sides forms the main source of inflow to the well. The cost of the adits was Re. 1 per foot run, and they were stopped as soon as the rate for excavating them rose above that amount. The result of the operations was to increase the inflow from 40 to 66 gallons per minute or from 60,000 to nearly 100,000 gallons per day. Pumping has continued all through the hot weather and the inflow has somewhat decreased. On the 20th July it was measured and found to be about 67,000 gallons per day. With the advent of the rains it is expected that the inflow will materially increase, but how much is quite uncertain. At present the engine runs nine hours a day, in three periods of from two to three hours each. When pumping ceases, the water accumulates in the well and at the beginning of each working interval there is about 5 feet of water to be removed. The average lift is 25 feet and the engine consumes about 2 gallons of oil per day costing as. 12. The wages of the driver are Rs. 7 per month, so that the total cost of running the engine, including the cost of stores, amounts to only

Rs. 35 per month. Later on, with longer running hours, it may amount to Rs. 60 per month and for this sum, 20 acres of dry cultivation will be fully supplied with water. The capital outlay on the engine and pump and the cost of fixing the same amounted to Rs. 2,500, and an allowance of Rs. 40 per month for interest, repairs and depreciation will be a very liberal provision, making the total monthly charges Rs. 100 when running, and about Rs. 50 when standing. Assuming that water is required for eight months in the year, the total cost of this engine and pump will be Rs. 1,000 per annum. For this sum 20 acres of dry crop will be watered and I am inclined to think that possibly, with the supply of water to be expected, the area may be larger, but only a continuance of the experiment over several years will enable this to be definitely determined. The conditions under which this experiment is being conducted, are by no means favourable and much better results could be obtained in many places. The well yields a fair supply of water, but there are undoubtedly very many which would give a much greater volume. The engine and pump, worked to their maximum capacity, would raise 250,000 gallons a day to a height of 30 feet. or nearly half a cubic foot per second, sufficient for from 100 to 125 acres of dry cultivation. Under such circumstances, the cost of supplying water to the land would not amount to more than Rs. 12 per acre per annum. This is a result so very satisfactory that, when it becomes known and fully realized, it ought to lead to an extensive employment of these modern methods of lifting water.

It is well known to engineers that the cost of generating a unit of power rapidly decreases as the amount of power generated by a single engine increases. In view, therefore, of the fact that the great majority of wells are unable to yield sufficient water to give adequate employment to even the smallest engines, it has occurred to me that possibly large tracts of land could be supplied with water from wells by electrically driven centrifugal pumps, the power being generated at a central station and distributed by overhead conductors. From an engineering point of view the problem is a comparatively simple one and its practicability simply depends upon the cost of the installation, both as regards capital outlay and working expenses. I have, therefore, obtained estimates of the cost of the machinery from well-known firms in England and with the information thus obtained I have worked out two imaginary schemes, assuming conditions that could be realized in many places in this Presidency. The first scheme is a comparatively small one for the irrigation of five or six hundred acres. All the land is assumed to be situated within a rectangle 2 miles long and 1 mile wide. The water-supply is derived from twelve wells scattered over the area. Each well may be assumed to cost Rs. 500, though under favourable conditions they would not cost more than half this amount as the depth is not to exceed 35 feet. The water would be lifted by a 3-inch centrifugal pump, driven by a direct coupled $3\frac{1}{2}$ horse-power electro-motor, the pump and

motor complete and fixed in the well costing Rs. 750. The current would be supplied from a generating station situated near the centre of the area, and 5 miles of overhead conductors costing about Rs. 650 per mile, would be required for distributing the energy. The generating station might be supplied with a steam engine and boiler costing Rs. 4,000 or with an oil engine, in which liquid fuel could be used, of the same power costing Rs. 5,000, driving a dynamo costing Rs. 1,800, which would give out a current of 27 amperes at 550 volts pressure, equivalent to 20 electrical horse-power and capable of driving 4 of the pumps under full load, or 5 under the average load which would come upon them. Each pump would discharge 150 gallons per minute, so that with 5 pumps going the supply of water would be 2 cubic feet per second or sufficient for 500 acres of land. The method of working would be to run a motor till the well was emptied and then shut off the current and allow it to fill up by percolation, whilst the current was employed in driving another motor in another well. With 5 motors running out of 12, water would be drawn from each well an average of 10 hours per day. Including all items, the total cost of the installation would be as follows:—

	Rs.
Engine house	2,600
Engine and dynamo	6,800
Switch board, etc.	500
12 Wells at 500/	6,000

	Rs.
12 Pumps and motors at 750/ ...	9,000
5 Miles of line at 650/ per mile ...	3,250
Contingencies 10 per cent ...	2,850
Total ...	31,000

The working expenses would be as follows :—

	Rs.
Repairs, interest and depreciation at $12\frac{1}{2}$ o/o	3,875
Liquid fuel at As. $3^{\frac{6}{8}}$ per gallon, at 2 gallons per hour for 5000 hours...	1,875
Superintendence and labour Rs. 130 per mensem for 12 months	1,560
Miscellaneous stores	200
Total ...	7,510

This is the cost of watering 500 acres of land and is equivalent to Rs. 15 per acre per annum, the land being under cultivation practically the whole time. This is a high charge for ordinary wet crops, but it is by no means excessive for garden cultivation, such as is practised in agriculturally advanced districts like Coimbatore. For projects of this kind to pay, it naturally follows that when all the resources of modern engineering are devoted to the problem of supplying water and a considerable outlay in machinery and plant is involved, the agricultural operations must be of a similar character and the cultivators must be prepared to put capital and labour into their fields to obtain the

best possible results. The selection and rotation of crops must be judicious, the lands must be well manured and in general terms what is known as *intense* cultivation must be practised.

Let us now consider the possibilities of operating on a much larger scale and for this purpose we will assume that there is a strip of land about 10 miles long and from one to two miles wide lying alongside a river channel. Such a piece of country actually exists on the Palar River, not far from Chingleput. The land near the river will probably be at a slightly higher level than further away and as the wells will draw their water-supply mainly from the subterranean flow of the river they will all be situated near the river bank. The wells will be sunk near the river bank at an average distance apart of one-fourth of a mile. In all, there will be 40 such wells and the power station will be situated in the middle, with 20 wells on either side, the most distant well being $4\frac{7}{8}$ miles off. Assuming that the average inflow into each well is half a cubic foot per second and that the average lift is 30 feet, the total actual work which will have to be done by the pumps will be 68 horse-power. To determine the power required at the generating station, we may make the following assumptions regarding the efficiency of each part of the system of power distribution :—

Efficiency of dynamo	...	90	per cent.
Efficiency of transmission	...	90	per cent.
Do. motor	... ...	80	,,
Do. pump	... ...	45	,,

Combined efficiency of whole system 30 per cent. so that the engines will have to furnish 227 horse-power. The following estimate of the cost of the plant may be taken as approximately accurate :—

	Rs.
Engines	45,000
Dynamo	9,000
Engine house	7,500
Switch board and fittings	2,000
40 wells at Rs. 500 each	20,000
40 motors and pumps at Rs. 750 each	30,000
Overhead conductors 10 miles at Rs. 1,500 a mile	15,000
Contingencies, 10 per cent. ...	13,700
Total ...	1,42,200.

The working expenses on an assumed running of 5,000 hours per annum would be :—

	Rs.
Fuel for engines	11,250
Superintendence and labour...	3,600
Repairs, interest and depreciation at 12½ per cent. ...	17,775
Miscellaneous stores ...	1,000
Total ...	33,625

The area that could be irrigated would be between four and five thousand acres and the annual charge for pumping would amount to not more than Rs. 8 per acre. The case considered is perhaps a favourable one, but without doubt a careful examination of the country would reveal many such, and it is eminently desirable that advantage should be taken of the natural facilities where such exist.

So far we have only considered the question of well irrigation when the power is supplied by steam, gas or liquid fuel engines, but it is open to us to go one step further and consider what use can be made of water-power, which in certain districts is available in vast quantities throughout the greater part of the year. Without going into details, one or two general facts may be noted which tend to show that there is a wide field open to engineers in India, in utilizing the power of water-falls to lift water from wells over very extended areas. For industrial operations a continuous supply of water all the year through is generally essential, and expensive storage works have to be constructed to tide over the period of scarcity of water during the hot months of the year. When the water-power is to be used for pumping water from wells the failure of the supply of power during the hot weather is of little or no importance, as the cultivation can be so arranged that the land requires no water at that season. Water-power can, therefore, be provided at much less expense for such schemes as we are now discussing, and if it be a profitable undertaking to generate power at the Cau-

very falls and carry it over 90 miles to the Kolar mines, under onerous conditions regarding failure of the supply, it is obvious that it will be still more profitable to utilize water-power under the much less exacting conditions which would prevail in irrigation pumping.

The report of the committee on utilization of water-power at Periyar stated that electric energy could be delivered in Madura, 80 miles away, for Rs. 22-8 per horse-power per annum, and in Madras for double that sum or Rs. 45. It is more than doubtful, however, if this result could under any circumstances be attained and it would be safer to assume that the actual cost would be about three times as much; but even then it would appear to be practicable to lift water from wells or rivers by the agency of electrically transmitted energy over the greater part of the South of India. The minimum power available at the Periyar during ten months of the year is officially stated to be 30,000 horse-power and there is reason to suppose that the efficiency of the whole system of generation, transmission and utilization would be one-fourth, so that 7,500 horse-power would be the work actually accounted for by the water lifted. On an average lift of 40 feet this would be equivalent to 1,650 cubic feet per second, or sufficient for 412,500 acres of land. At Rs. 10 per acre for annual charges this would amount to 41¼ lakhs, and would permit of a capital expenditure of at least 3 crores of rupees, probably a much larger sum than would actually be needed.

I have drawn attention to the possibilities attendant on the utilization of water-power for pumping purposes because, ultimately, I think they will be realized on an exceedingly big scale; but that day is yet distant, and the business of immediate practical importance is the smaller schemes which I have outlined in this note. They involve but a small expenditure; each one, started and proving successful, adds to the store of information we must gather about underground water, and places us in a position to ensure that in subsequent undertakings the risk of failure will be a constantly diminishing quantity. The exceeding simplicity of working, characteristic of good oil engines, and their remarkable economy in the matter of fuel, has changed the conditions under which water-lifting can be undertaken. It is necessary to reconsider the position and demonstrate by practical working, that the primitive appliances of the ryot can be superseded by methods of water-lifting so greatly superior as to open out entirely new possibilities regarding the utilization of subterranean water.

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CHAPTER IV.

IRRIGATION WITH OIL ENGINES.*

I.

The problem of lifting water from one level to another presents many phases and under certain conditions calls for the highest engineering skill and mechanical ingenuity. The natives of India, as the result of the accumulated experience of centuries, have with the Persian wheel, the mhote, the piccotah and the basket scoop, reached a high degree of perfection in their methods of applying animal or human power to the raising of water for the irrigation of small patches of cultivation. Over and over again the defects of native appliances have led to attempts being made to improve them, and especially in recent years a very large number of patents have been taken out for water-lifts by all sorts of people. Some of these by dint of advertising have met with ephemeral success, but in no instance has a modern water-lift survived the test of time. The piccotah and the mhote, each in its own way, are better suited to the conditions under which the Indian ryot works than any of the more efficient but more complex machines for raising water which have been devised.

The experiments which the Government of Madras are now undertaking to test the feasibility of employing

* *The Madras Mail 1905.*

modern motors and pumps for irrigation on an extensive scale have attracted a great deal of interest throughout the Presidency, as evinced by the correspondence which from time to time appears in most of the daily papers. A careful perusal of the letters which have been published shows that very little is known about the question and that most erroneous views prevail everywhere. It is therefore proposed in this and in future articles to state, as far as possible in simple and non-technical language, the facts regarding the possibilities of the various forms of motive power which can be employed in this country for the purpose of raising water.

The millions of wells scattered all over the country attest the enormous importance of well-irrigation, but it is estimated that throughout the length and breadth of India not more than 1 per cent. of the total rainfall is recovered from the water stored beneath the soil. A survey of the wells of the Presidency reveals the fact that by far the great majority yield a supply of water less than or just sufficient to keep a single water-lift at work. That is to say, the capacity of the wells is determined by the capacity of the means employed in unwatering them at the time they were sunk. More powerful pumping appliances would have enabled a much greater depth to have been obtained, and it is unquestionable that the available quantity of water would in consequence have been enormously increased. It must, however, be fully recognised that the effect of pumping on a large scale will be to lower the level of saturation;

and the amount of work which will have to be done to obtain a larger supply of water will be greater in proportion to the quantity obtained than at present. It therefore follows, that if improved methods of doing work are to be successful they must be not only more powerful but also very much cheaper.

From experiments which have been made in various places it appears that the cost of raising water by native methods is by no means so cheap as is generally supposed. Experience extending over many years at the Agricultural College, Saidapet, has enabled the authorities there, to state that they were able to raise 4,000 c. ft. of water 1 foot high for 1 anna, which means roughly that the cost of irrigating an acre of land to a depth of 1 inch from a well 25 ft. deep is about Rs. 1-8. This may be accepted as the cost of irrigation under favourable conditions in normal years. But in seasons like the present the cost of keeping cattle in good condition and fit for the heavy work of water-lifting is more than doubled, and it would be certainly within the mark to say that at the present time to lift an acre inch of water from a well 25 ft. deep costs more than Rs. 3. It is, therefore, almost impossible to obtain accurate figures regarding the cost of native methods of lifting water. It is always a heavy item, but it is difficult to express it in currency terms. It varies materially from year to year, and unfortunately in dry years when water is most wanted, then the high price of fodder makes the cost of water-lifting extremely heavy.

Now, with mechanical appliances the conditions are much more favourable. The seasons do not affect the price of fuel, and though throughout the year interest charges have to be paid and a man must be kept to look after the engine, yet when the rainfall is favourable and little water is required the cost of running and the depreciation are very small. On the other hand, in times of drought when the quantity of water required is very large, it is easy to run the engine for longer hours to obtain a much larger supply, and the extra cost of doing this is usually more than compensated for by the enhanced prices which the products of agriculture then yield.

From the experiments which have been in progress throughout the last three years it has been possible to obtain fairly accurate figures regarding the cost of raising water with oil engines and pumps. But any attempt to compare these figures with those which would have been obtained had native appliances been used is rendered almost impossible owing to the extreme difficulty in estimating what would have been the cost of doing work under such conditions. I shall certainly not overstate the case in favour of the oil engine and pump when I claim that they are capable of doing the work at less than one-half the cost of native methods; and this too when the scale of working is unfavourably small. Where the area to be irrigated is large and the supply of water abundant, there is no comparison between the two methods. To lift 500 c. ft. a second, to a height of 15 ft. with cattle power is outside the region of practical working; yet it presents no difficulty what-

ever to the engineer and, in a comparatively short time, those interested in the adoption of these new methods of raising water will be able to see an installation of this size at work in the Kistna District. The larger the units with which we can work, the greater the economy that can be effected. The difficulty with motors and pumps is to get them to work cheaply when the volume of water available is small.

The statistics of well irrigation in this Presidency show that the average area under each well is only 2½ acres, and that therefore the quantity of water taken out probably does not amount to more than the one-hundredth of a cubic foot per second, or, say, 12 gallons per minute during the working hours of the day. Many wells are, of course, capable of yielding a much larger supply than this, but few have a capacity sufficient to give full employment to even the smallest size of engine and pump which it is considered advisable to install. It must not, however, be imagined that because such wells do not exist they could not be constructed if it were advantageous to do so. Enquiries, supplemented in some cases by experiments, during the last few months have placed beyond doubt the fact that wells yielding large volumes of water can be obtained over considerable areas of country. And perhaps what is still more important, it has been ascertained that there are large supplies of water available in many nullahs and streams which could be used for irrigation by the application of adequate pumping power. It would be unwise to attempt ot

estimate the extent to which in the future it is possible that engines might be used for pumping, but it seems clear that there is room for the profitable employment of a very large number of such installations.

II

In a report on water-lifts written in 1896, I said:—"Steam pumping machinery is utterly beyond the means of the ryot, and the force of the wind is too uncertain, and in general in India it is too weak to be profitably utilised by windmills, even of the most modern type. Animals are therefore the only source of power available, and water-lifts in future must continue to be, as they always have been, worked by cattle." In the main this is still true, but within less than a decade the advances, which have been made in the generation of power by internal combustion engines, have been so extraordinarily rapid that it is quite possible now to compete with cattle whenever the work to be done is as much as would require the services of three or four pairs of oxen. Expressed in engineering terms, the work done by an average pair of cattle may be taken as one-fourth of a horse power, which is equivalent to the lifting of 33 gallons per minute from a depth of 25 feet. At this rate half-an-acre of land will

be covered to a depth of one inch in about 6 hours; or, to put it in the language of the ryot, a pair of oxen can water half-an-acre of land a day, and the cost of watering will amount to Rs. 1-14-3 per acre.

Now a Hornsby-Akroyd oil engine, developing $3\frac{1}{2}$ h.p. and employed to drive a 3-inch centrifugal pump, will do as much work as 15 pairs of cattle if it be run for 16 hours a day. In this time it will cover nearly 8 acres with water to a depth of one inch and as the running expenses will be Rs. 3-8-0 the cost of watering each acre will be only seven annas. So that where there is an adequate supply of water the cost of pumping is only one-fourth that entailed by doing the work with cattle. When the supply of water is insufficient to keep such an engine and pump running for 16 hours a day, the cost of working will be greater; and when the pump can only run for two hours a day the cost of lifting water will be the same by either method. The average discharge of the pump may be taken as 11,000 gallons per hour; so that roughly the minimum supply of water which should be available, if an engine and pump is to be installed with advantage is 45,000 gallons per day, or sufficient to give one watering to 2 acres of land. Of the more than half-a-million wells, from which water is drawn for irrigation in this Presidency, comparatively few would be able all the year round to yield the minimum supply required; but even if the number were only one per cent. we could profitably employ something like 5,000 oil-engines and pumps. Whether one per cent. of the

wells are capable of yielding the supply of water or not, it is impossible to say, as there are no data to go upon; but it is almost certain that a very much larger percentage of wells than this could, at a comparatively small cost, be improved so as to yield a good deal more than the minimum quantity of water required. All that is necessary is to deepen them and to pump out the water from a lower level, so that the gradient of the subsoil water flowing to the well may be increased.

The smallest size of centrifugal pump, which we can conveniently employ for irrigation work, is one having suction and delivery pipes of 3 inches diameter. Pumps of smaller size than this are made, but owing to their small diameter they have to be run at a very high speed, and the friction of the water, both in the pump and the piping, absorbs a very large proportion of the power, and their efficiency is extremely low. In general, the efficiency of centrifugal pumps increases with their size, up to a certain point, provided that the lift be not too small.

A 3-in. pump will deliver 11,000 gallons of water per hour, and if the inflow to a well were equal to that amount, the daily yield of water should be more than a quarter of a million gallons, which is six times the minimum quantity required. An inflow of 2,000 gallons per hour is sufficient to make it worth while to install an engine and pump, but it will be necessary to provide sufficient storage capacity to enable the water to accumulate at the bottom of the well till it amounts

to a sufficient volume to make it worth while to run the engine. This is what has been done at Melrosapuram, where, to start with, the well was 21 ft. in diameter and 21 ft. deep, with a central hole 15 ft. in diameter and 7 ft. deep, the latter capable of holding 7,700 gallons of water. Observations showed that the rate of percolation into the well decreased very rapidly if the water rose above the rim of the central hole. To pump out the central hole took about an hour, and then the engine had to be stopped till it filled again. Both storage capacity and percolation area were materially increased by running adits horizontally from the bottom of the well. The total length of these adits was 68 ft. and their average width 2 ft. and, as they were about 5½ ft. high, they held when full, 4,575 gallons of water. It was desirable, however, to increase the storage capacity considerably beyond this, and accordingly a new well, 30 ft. in diameter was sunk a short distance from the original well and the two connected by prolonging one of the adits. The total area at the lowest level from which water is drawn is now 1,044 sq. ft., and with 5ft. depth in the well, the storage capacity is nearly 33,000 gallons, or sufficient to keep the engine running for three hours without taking into account the percolation during that time. The advantage of this large storage capacity has been fully realised during the last few months when, owing to the long drought, the rate of percolation into the well has fallen as low as 1,500 gallons per hour. By allowing this to accumulate, it has been possible to

extract, with fair economy, every drop of water that could possibly be obtained and to keep the cultivation going on about 12 acres of land. This very small quantity of water, supplemented by the local rainfall, has proved sufficient to keep the crops in fair condition, though it is probable that the outturn this year will not be as favourable as usual.

Where the height to which water has to be raised is small, engines of less than 3½ h.-p. may be employed. A 2 h.-p. engine will drive a 3-in. centrifugal pump on a 12 ft. lift, and this is about the smallest combination of engine and pump which can be used with profit. The advantages of a large storage capacity seem to have been fully realised by the ryots, and many of their wells have a much larger storage capacity than that which has been provided at Melrosapuram. In not a few cases, by going deeper a much larger volume of underground water will become available. The depth, from which ryots draw water, varies considerably in different parts of the country and is probably deepest in Coimbatore and the Ceded Districts, where it is not uncommon to lift water from a depth of 40 ft. So far, in Madras, centrifugal pumps have not yet been employed on lifts exceeding 40 ft., but at the Coimbatore Jail an oil engine is driving a pair of plunger pumps which lift the water 75 ft. As experience accumulates we shall probably find it profitable to go deeper and deeper and there is no reason why with centrifugal pumps we should not be able to profitably lift water to a height of as much as 100 ft.

Since these irrigation experiments were started, a very large number of proposed sites for pumping stations have been investigated, and the greatest difficulty experienced, in working out profitable schemes, has not been the height to which it was necessary to lift water, but the expensive arrangements which were found necessary to cope with the enormous variations in the water-level at different seasons of the year. Fluctuations of 40 ft. or 50 ft. are not at all uncommon where the water supply is derived from river beds or nullahs; and even in wells the range may be not far short of this. With centrifugal pumps the maximum length of the suction is about 25 ft., and up to that limit the variations in the water level give no trouble; but beyond that point special designs must be employed.

Another difficulty, which we have encountered in our investigations, is the very gradual slope of the land between the place where water can be obtained and the place where it can be utilised. This entails the construction of high earthern banks to carry water over the low ground, or the employment of iron pipes in which the water can be carried under pressure. Either expedient is costly and there is no alternative except when large quantities of water have to be dealt with. Then, the difficulty may be got over by dividing the total lift into stages and employing two or more sets of engines and pumps, one at each stage. This plan has been adopted at the pumping station which is now under construction for the experimental farm on the Hagari River, in the Bellary District. In this case

a 25 horse-power engine and 10-inch pump lift the water from the river a vertical height of about 16 ft.; and it is then carried about a mile from the river bank, the channel gradually getting into a deep cutting, till, at a convenient point, such water as is required for the irrigation of the high level land is lifted out by a second engine and pump.

III

Makers of centrifugal pumps invariably state their capacity in gallons per hour; but in dealing with irrigation work the units are inconvenient, and it is preferable to employ a unit of volume rather than one of weight. Engineers in India have adopted the cubic foot per second abbreviated into "cusec," which is admirably adapted for dealing with the discharges of canals or channels of large systems of irrigation. In America, where the farmer's influence predominates in irrigation works, the acre-inch or acre-foot, that is to say, the quantity of water which will cover an acre of land to a depth of an inch or a foot, is the unit most commonly employed. Now, a cusec is equal to 3,600 c. ft. per hour and an acre-inch is equal to 3,630 c. ft., so that for practical purposes a cusec flowing for one hour is equivalent to an acre-inch.

It has already been stated that for irrigation work it is not convenient to employ anything smaller than a 3-inch centrifugal pump, and that such a pump is capable of delivering half a cusec, or sufficient water to cover an acre to a depth of one inch, in two hours. Our experiments have also led to the conclusion that unless

a well can supply sufficient water to keep the pump running for four hours a day, it will not be worth while installing an oil engine to lift the water; that is to say, the minimum yield of a well must be two acre-inches or 7,260 c. ft. per day.

The question, therefore, whether a well will yield sufficient water to make it pay to put down an engine and pump is not a difficult one to answer, if observations are made on the well at the right time of the year, or better still if observations are made on the well two or three times during the year. Applications are very frequently made to me for the expression of an opinion as to the possibility of obtaining sufficient water from a well, and as the experiments to obtain data for framing an answer are extremely easy to carry out, I propose to detail at some length what should be done so that any intelligent person may be able to obtain an answer himself.

The rate of percolation into a well depends partly on the depth of water standing in the well. If no water is drawn from a well for several days, the level of water in the well will be the same as the level of the water in the surrounding strata, and a state of equilibrium will be established. Immediately water is removed from the well, the level sinks, the equilibrium is disturbed and water from the surrounding strata begins to flow into the well. Obviously, the lower the water level in the well is depressed, the more rapid will be the inflow, and the maximum will be reached when the well is quite empty.

Quite recently I was asked by the Court of Wards whether certain wells on the estate of a Minor would yield enough water to make it worth while to put down an engine and pump. One of my assistants was sent down to make a survey of the place and to carry out the experiments necessary to obtain some notion about the quantity of water which could be obtained from the wells. A brief account of what he did, the results he obtained, and the deductions which have been drawn from his observations will exemplify the way in which we endeavour to solve such problems.

He found that there were two wells about 250 yards apart, both approximately rectangular and sunk through decomposed rock. The northern well was 65 feet long and 35 feet broad, with a water surface of 2,200 sq. ft. It was possible to bale water out of the well with two mhotes, which were worked together and the combined capacity of which was found to be 8 c. ft. When baling was started the lift was 17·22 ft. and the cattle were able to lift 224 buckets in the course of the first hour. A gauge, reading to feet and decimals of a foot, was fixed in the well and arrangements were made to count the number of buckets lifted each hour and to record the level of the water at the time. Baling was carried on continuously for 41 hours, at the end of which time it was found that the cattle were not able to lower the water level in the well any further. Starting with 224 buckets per hour, with a lift of 17·22 ft. the number decreased to 144 buckets per hour when the water was raised 24.32 ft. The

results recorded have been plotted in diagrammatic form and I find that from the start, till the water level was lowered to 24 ft., the inflow increased proportionately to the lowering of the water level, but that from this point onwards the rate of increase was more rapid being from 424 c. ft. per hour with a level of 24 ft. to 576 c. ft. per hour when the water level was lowered an additional 4 inches.

Beyond this the experiment unfortunately could not be carried as no further pumping power was available. There was still 3ft. of water in the well and the inflow would have probably gone on increasing if this could have been removed. I have therefore expressed the opinion that the well will yield sufficient water to justify the establishment of an engine and pump, though I am not prepared at the present time to say how much water can be counted upon. That is a matter which only the experience of two or three years' irrigation will enable us to decide. I have advised that a 4-in. pump should be fitted up and driven by an engine of sufficient power to lift the water from a depth of 35 ft. below the present discharging level. This would enable the well to be deepened, if necessary, another 10 ft. and would undoubtedly increase the flow into the well. The pump will lift about 3,000 c.ft. per hour and will be capable of dealing with the inflow to the well under existing conditions in about five hours a day. It is impossible to say how much larger an inflow will be obtained when the well is deepened, or whether it will continue for any length

of time, as after the rains are over the subsoil water-level gradually sinks, and in a corresponding way the inflow to the wells decreases. Where extensive pumping is carried on it seems obvious that these changes will take place more rapidly and that a very considerable volume of rock may be drained of water during the year by a deep well. In this case, if we assume that the well is deepened to 36 ft. and that the surrounding strata contain 10 per cent. of water, the pump, if worked for eight hours a day, will in the course of 200 days, which may be taken as the interval during which time the subsoil water receives no replenishment, drain an inverted cone of rock about 2,270 ft. in diameter at the ground level. At first the diameter of the cone will be small and the hydraulic gradient steep, so that percolation will be rapid, but as the water is drawn off from the rock the base of the cone will extend and the rate of inflow will diminish.

The southern well on this estate is very nearly square, the dimensions being 55 ft. by 52 ft. and the water surface 2,800 sq. ft. Baling was carried on for 51 hours with the result that the water level was lowered and the lift was increased from 22·36 to 28·6 ft., when the water level remained constant under a draught of 465 c. ft. per hour. With a similar depression of the water level in the northern well the inflow was only 360 c. ft. per hour, so that, if anything, this well is likely to yield more water than the northern well. It is probable, therefore, that a 4-inch pump might also be

installed in this well with great advantage. After a time the pumping from one well will begin to affect the inflow to the other and the total quantity of water raised from the two wells will be not much more than that which would be obtained from either of them separately, assuming that the other is not worked. In this case I have suggested that only one engine should be installed, and that it should be placed in the well more conveniently situated for the irrigation of the lands belonging to the estate. If this well be deepened sufficiently it will almost certainly drain the other well.

These two wells are of a type common enough in this country. If sunk to a sufficient depth they may safely be reckoned to yield a moderate supply of water for a fairly long time. In ordinary seasons the ryots draw from them but a small proportion of the water which might be obtained, but in dry seasons, like that we have just experienced, the whole of the water supply is made use of. Many of these wells are very old and have passed through a number of abnormally dry seasons, so that they have reached the maximum depth that it pays to sink them when the water has to be drawn from them by cattle-power. As a rule, on examination they are generally found to contain a considerable quantity of silt, and the fact that this has been allowed to accumulate through a number of years seems to indicate that the ryots find that it does not now pay them so well as it formerly did to lift water from a great depth for well cultivation. This evidence

is not very conclusive by itself, but it is borne out by the fact that all over the country, wages, food and fodder are steadily rising in value and the cost of raising water is therefore increasing. The value of produce is also rising, but, whether at an equal rate or not, it is difficult to say. What seems to be more certain is that the soil is becoming exhausted and that either poorer crops are raised or more money has to be spent on manure.

In the coast districts, wells are sunk through beds of alluvium till water-bearing sands are reached. The rate of percolation in such wells is usually very slow, on account of the compact nature of the sand, and as the wells have to be constructed by sinking cylinders of brick-work they are seldom over 20 feet in diameter. Consequently, they possess but little storage capacity and engines and pumps can be used only in a few of them. Where these water-bearing sands are within a moderate distance of the surface the best way to get a large supply of water from them is to make an open excavation, and at the bottom of it sink a number of wells in a line, connecting the wells one with the other by iron pipes, which can be worked through from well to well if the intervening space be not too great. The wells from which Mr. Panduranga Moodelliar is pumping water near Cuddalore belong to this type. He started with one well, 12 feet in diameter, and has sunk alongside it a second well 20 ft. in diameter, and now he proposes to sink a third well so as to obtain an increased area of percolation

and a large storage capacity for water. His wells are already 36 feet deep and further progress is barred by the fact that they now rest on a bed of clay. Under this bed of clay, which has been proved to have a thickness of more than 50 feet it is not at all improbable that water-bearing sands or gravels may be met with, and it is quite possible that by sinking the bore-hole to a sufficient depth we might obtain an artesian or sub-artesian supply of considerable volume.*

In old river beds the sand is often much coarser and yields water very freely. In such places there is but little difficulty in getting sufficient water for pumps of even considerable size. The chief difficulty lies in constructing the wells, which require to be of large dimensions so as to give a sufficient area for percolation. If the wells are small the water level will have to be lowered to produce sufficient flow to feed the pump and the incoming water brings sand with it and speedily fills up the well. A pumping station at a well of this type has recently started work near Villupuram and a second one will shortly be installed at Pandur, near Trivalur.

Wells which derive their water supply from fissures or springs are extremely numerous in certain parts of the Presidency. Many of them are of great depth and storage capacity, but the quantity of water they yield depends entirely upon the nature of the water-bearing fissures which are met with. The volume of water, which a well will yield, can be measured in the way already

* *Vide* "Irrigation by Artesian Wells."

described; but beyond the actual figures obtained nothing of any value can be deduced. As a general rule, deepening the well will open new fissures and bring in a larger supply of water, but this is not necessarily always the case, and information obtained from borings furnishes no indication as to what will happen. In some cases holes have been "jumped" at the bottom of these wells with long iron jumpers, and fairly big charges of dynamite have been exploded in them with extremely satisfactory results. New fissures have been opened and an increased water-supply obtained. As yet we know very little about subterranean water in this Presidency. In course of time the records from pumping stations will add very largely to our information; but in order that we may fully avail ourselves of the water-supply which can be got at a reasonable depth, boring must be carried out on a very extensive scale.

IV

The experiments in irrigation by pumping, now going on in various parts of this Presidency, are an attempt to introduce into the country new methods of working which have been rendered possible by the enormous advances which have been made during recent years in the methods of producing power. The application of the steam-engine to pumping water for irrigation or drainage is no new thing. In some instances it has been done on a large scale. Along the Nile, in Egypt, and in the Western and Southern Coast States of America steam-engines and pumps have been largely used for

irrigation work; whilst in the Fen Districts of England, in the marshes of Italy, and the low lying tracts of Holland, they have remedied the natural defects of the drainage, and vast quantities of water have been raised at a comparatively small cost. In India the steam-engine and pump have been occasionally used both for irrigation and drainage, but, as a rule, the work never proceeded beyond the experimental stage, as the scale on which operations were conducted was too small to make it pay.

Fully five and twenty years ago the Otto gas-engine proved a practical rival to the steam-engine when small amounts of power were required. But such engines could only be used where a supply of gas was available. The obvious field open to an engine of the internal combustion type which would be independent of a town gas supply, led to the production of the earlier types of oil-engine. One by one the practical difficulties connected with their working were overcome, and for some years past it has been possible to obtain motors, suitable for agricultural work, which could be placed in the hands of people possessing very little mechanical skill.

Compared with the steam-engine the oil-engine is extremely economical. A small oil-engine uses no more fuel per brake horse-power developed than the largest and most economical type of steam-engine. The steam-engine will develop power on a large scale very economically in places where coal is cheap, but in small engines, even where fuel is

cheap, the efficiency of the process by which the heat of combustion of the fuel is converted into work is so very low that the cost of power generated in them is extremely high. In large engines, a brake horse-power can be developed by burning from 1 to $1\frac{1}{4}$ lbs. of good coal in the boilers, but in small portable engines, such as are frequently used by contractors for driving centrifugal pumps, the quantity of fuel required per brake horse-power varies from 6 to 10 lbs. On the other hand, small oil-engines can be run with an average expenditure of 1 pint of kerosine oil or liquid fuel per horse-power hour developed. So long as kerosine oil and liquid fuel were expensive, the advantages of the oil-engine were not apparent; but at the present time kerosine oil can be purchased at from 4 to 8 annas a gallon and liquid fuel is available in Madras* for 2 annas a gallon, or Rs. 30 a ton.

In the beginning the gas-engine was only suited for small powers and was worked with comparatively rich gas. The discovery that an extremely poor gas, which could be manufactured in enormous quantities at a very low rate, could be utilised with advantage in the gas-engine led to the production of engines of large power; and now at the present day engines up to 5,000 horse-power are being worked with producer gas or the waste gases from blast furnaces. Still more recently it has been discovered that the gas-engine can be combined with a small gas producer, in which the gas is manufactured according to the demand of the

* The price is now As. 2-9 per gallon or Rs. 41-4 per ton.

engine. These plants, which work on the suction principle, have, within the last two or three years, proved an unqualified success and for all but the smallest powers are likely in the future to be more than rivals of the oil-engine. Unfortunately they require either anthracite coal, coke or charcoal, and the ordinary bituminous coal which is available almost everywhere is not suitable.

The items which go to make up the cost of running a pumping plant are—

(1) Fuel.
(2) Stores.
(3) Interest and depreciation.
(4) Repairs.
(5) Superintendence.

The relative importance of these varies greatly, depending upon the type of motor employed and the local conditions as regards supply of fuel and cost of labour. The reason why irrigation by pumping with the oil-engine is proving successful is due to the fact that not only is the cost of fuel low, but the running of the engine can be entrusted to intelligent coolies who have received a little special training. As the demand for oil-engine drivers is steadily growing we have established a training class for them in the School of Arts, and the idea is to supply a course of training lasting for six months, the pupils being sent up to learn the work from the villages in which they will subsequently drive engines. If a fitter is employed to drive an engine he usually requires from Rs. 15 to Rs. 20 a month pay; but if a local man receives

sufficient training to run the engine and knows how to keep it clean and in good working order, he will do just as well and will be content with, and in fact will consider himself well off, on Rs. 7 or Rs. 8 a month. At the present time* there are about 200 engines of different kinds at work in this Presidency, and the majority of these are, so far as my information goes, in the hands of people who are paid but little more than ordinary coolie wages.

The convenience of oil-engines as a source of power has made them extremely popular all over the world, and there are a large number of manufacturers who make a speciality of these motors. When kerosine oil is used as fuel there is but little to choose between them, the better engines being the more highly priced ; but kerosine oil is expensive when compared with the liquid fuel which is available in Madras and which is equally suitable for generating power, if the engines are specially adapted for it. Till some time last year there were only two types of engines on the market which would work satisfactorily with liquid fuel ; *viz.*, the Diesel Engine and the Hornsby-Akroyd. The former is undoubtedly the best and most economical oil-engine which has been produced, but its initial cost is very high and it would certainly not be safe to trust it in the hands of the class of people we are employing as oil-engine drivers. Moreover, from a purely commercial point of view the economy in fuel consump-

* November 1905. Six years later the number of oil-engines in the Madras Presidency is estimated to be about one thousand, of which probably 500 are driving pumps.

tion is more than counterbalanced by the extra cost of the labour to look after it and by the increased interest charges entailed by its high price; so that for engines of below 40 or 50 horse-power its use is only to be recommended where skilled mechanics must be employed irrespective of the type of engine in use. In the School of Arts we have an 8-horse-power Diesel Engine at work which runs very satisfactorily when it is in good working order; but in so small an engine the mechanism of the valves is rather delicate and they are a source of considerable trouble.

The Hornsby-Akroyd engine works on a totally different principle and engines of as small as 2 horse-power can be obtained which work very well. Last year the master patent on the engine expired, with the result that the principle of working has now been adopted by many makers of oil-engines; and it is no longer true. as it was last year, that the Hornsby engine is the only one on the market which will work with liquid fuel. When it was selected as the type of engine to be employed in these irrigation experiments, it was the only one available, and though now there are others, it still stands first in the estimation of those who have most to do with them. In 1904, Mr. Dugald Clerk, probably the greatest living authority on oil and gas-engines, delivered the James Forest Lecture to the Institution of Civil Engineers, his subject being "Internal Combustion Motors." In the notes appended to his address he remarks as follows regarding the Hornsby heavy oil-engine:—

"This engine is the most extensively used of all the 'heavy' oil-engines of the world, Messrs. Hornsby having built many thousands of them in England. The success of this engine shows very clearly that it is often better to be content with a lower heat efficiency in order to obtain a practical engine free from delicacy of construction and easily kept running under the most adverse conditions."

With the new cheap fuel engines of other makers I have no practical experience. Some of them may be as good, but it is certain that none of them are better than the Hornsby engine, which for the present has been selected as the standard engine to be used in all irrigation pumping installations, the funds for which are provided by Government either directly, or through the operation of the Agricultural Loans Act. Not only is there nothing to be gained by introducing a multiplicity of types, but very considerable advantages accrue from the fact that the whole supply is in the hands of one firm. It becomes an important part of their business and it is well worth their while to devote their attention to it, to stock parts which occasionally require renewing and to attend to repairs and breakdowns with the least possible amount of delay. Later on, when pumping engines are in common use all over the Presidency, there will be plenty of room for several types of engine, but at present this is not the case and rapid development is only to be looked for by concentration of effort along one line. It must not be imagined for a single instant that the best results can

be got from an oil-engine by a driver who understands no more than the purely mechanical details of working it. A good deal of skill, knowledge and experience are required to set up these oil-engines and to adjust them to their work; but when once adjusted they ought to remain in good running order for a long time. The idea underlying our system of working is that when an engine, ceases to work satisfactorily it should be overhauled by a thoroughly skilled and competent mechanic. Our experience during the last two or three years tends to the conclusion that pumping work is exceedingly hard upon an oil-engine, and that unless it is in perfect working order the results are unsatisfactory.

V

The main reasons which led us to select the Hornsby-Akroyd engine for pumping water for irrigation were (1) the simplicity of the working parts of the engine; (2) the fact that liquid fuel could be used in place of the more expensive kerosine oil; and (3) the general excellence of the design, workmanship and materials of its construction. As in most other oil and gas-engines, the working cycle is effected in two revolutions. At the commencement of the cycle the piston is at the back end of the cylinder, the air valve is open and as the piston moves forward, the cylinder is filled with fresh air. At the same time the oil pump injects a jet of fuel into the hot vaporiser behind the piston, where it is converted into vapour. During the return stroke of the piston the air is

compressed in the cylinder and driven through the contracted opening between the cylinder and the vaporiser into the vaporiser itself, where it mixes with the oil vapour. The capacity of the vaporiser is so adjusted that when the piston has completed the return stroke, the pressure and temperature of the mixture of oil vapour and air are such that an explosion takes place and the piston moves forward, making the working stroke of the engine. Just before the completion of this stroke the exhaust valve opens and the burnt gases pass into the exhaust. During the second return stroke, the piston drives out of the cylinder all the burnt gases, and the exhaust valve closes as the air valve opens for the next cycle. It will thus be seen that energy is generated in the engine and work done on the piston during only one stroke out of four. During two strokes the piston is running almost free, and during the fourth stroke it is working against a gradually increasing back pressure. It is obvious, therefore, that a fairly heavy fly wheel is necessary for steady running.

To start the engine, a lamp is used to heat the vaporiser to a temperature just below red-heat. This takes from 5 to 10 minutes, depending on the size of the engine. After that the heat generated by the successive explosions in the cylinder maintains the vaporiser at a sufficiently high temperature. The working parts of the cylinder, and the neck connecting the vaporiser with the cylinder, are kept cool by means of a water jacket, through which water is con-

stantly circulating. The hotter the cylinder the greater is the thermal efficiency, but the smaller is its capacity for doing work, as when the cylinder is very hot a less weight of air is drawn into the cylinder and therefore a less weight of explosive mixture is formed. Provided the vaporiser is kept hot enough to produce a well-timed explosion, the cooler the cylinder the greater the amount of power which can be generated by an engine; and in this country, where it is difficult to obtain cold circulating water, it is desirable to have sufficient water passing through the jackets so that the temperature is not raised beyond what is bearable to the hand. With pumping installations it is easy to obtain a sufficient supply of water, and instead of employing cooling tanks, as is the common arrangement when oil-engines are used in Workshops and Factories we generally employ either a small auxiliary pumps to force water through the jackets, or, where the irrigation water is raised above the level of the engine cylinder, a branch pipe takes off from a small tank which is kept full by the main pump. A cock or valve on this pipe enables the flow of water through the jackets to be adjusted so as to obtain a satisfactory result

The liquid fuel we are using in these engines is obtained from Messrs. Best and Co., the local Agents of the Asiatic Petroleum Company. It comes from Borneo, and is similar in character to what is known as *astatki* on the Russian oil-fields. It is the residue which is left after the lighter oils have been removed by distillation. Usually it contains a small percentage

of water, which gradually settles at the bottom of the storage tank, and it requires to be carefully filtered before running it into the engine tank. If that is not done, the very fine passage through which the oil is squirted into the cylinder invariably chokes with dirt of some kind. This liquid fuel is of high specific gravity and generally ranges between 0·95 and 0·97. A sample, which was analysed, proved to have a specific gravity of 0·967, the flashing point was 206° F., and the heating value was 19,050 British thermal units, which is from 5 to 10 per cent. less than that of ordinary kerosine oil.

Our experience with the working of these engines extends altogether over a period of about five years, and we find that they are subject to very little depreciation on account of wear and tear. Certain parts require from time to time to be renewed, and if this be done the engine remains practically unaffected by use and is as good after five year's work as when it was first put in. If the engines are properly looked after, repairs and renewals cost very little; but even when they are badly treated the amount of harm done is surprisingly small. The vaporiser, which is a separate casting bolted on to the back of the cylinder, lasts, when the engine is not overloaded, from one to two years, and then requires to be renewed. In the brasses of the connecting rod there is a certain amount of wear, and they also from time to time require renewal. But when the engines are kept properly cleaned this should be at fairly long intervals. The pump spindle is also

subject to wear, especially when the glands are too tightly packed, which will be found to be frequently the case with native drivers: but this is a very small matter. At very long intervals it is probable that the cylinder liner will require renewal, and more frequently it will be necessary to insert new piston rings. None of these items are very costly; and it may be safely said that if an engine is kept in good running order, and renewals made from time to time as they are required, its life will be indefinitely prolonged, and it is hardly necessary to set aside anything for depreciation. When liquid fuel is used in the engine, a deposit of carbon forms in the vaporiser, which it is necessary to remove after about 12 hours running. To enable this to be done the back of the vaporiser can be taken off, by unscrewing two nuts, and the interior exposed to view. When the engine is properly adjusted to the work which it has to do, and the temperature of the vaporiser is not too high, this deposit of carbon is soft and friable and very easily removed; but if the engine is allowed to work with a red-hot vaporiser, the carbon deposit is extremely hard and somewhat difficult to detach from the ribs of the vaporiser.

It is extremely important that there should be no air in the pipe between the pump and the spraying nozzle, as this causes a practically continuous stream of oil to dribble into the vaporiser, when there ought to be only a short sharp jet lasting for a small fraction of a second, and quite complete before the compression stroke begins. This is a very common defect in the

working of these engines and one which gives rise to a great deal of trouble, although it is easily remedied.

In the earlier patterns of engines the clearance space, when the piston is on its back centre, can be varied by altering the effective length of the connecting rod. But in the later patterns of engine the connecting rod is of fixed length, and a special adjustable cover is provided, whereby the volume of the clearance can be varied. The larger the clearance space, the lower is the compression pressure and the higher the temperature necessary to obtain a satisfactory explosion. In practice, we find that with liquid fuel the compression pressure should amount to from 50 to 60 lbs. per square inch to obtain satisfactory results. When this pressure is not reached, a larger quantity of fuel has to be injected into the engine and the temperature of the vaporiser becomes very high. Often, when the engine is called upon to develop its maximum working horse-power, the vaporiser gets so hot that the explosions take place before the end of the stroke and a very inconvenient back pressure is set up which seriously diminishes the power of the engine and causes it to lose speed.

For the pumping installations which we first put down, it was considered desirable to keep the capital outlay as small as possible, and accordingly, engines were provided which, to do the work required of them, necessitated the generation of their maximum horse-power throughout the greater part of their running time. Experience has shown that this is not altogether

satisfactory and it is desirable to allow a fair margin, as in pumping water the load never varies except that, when emptying a well, it gradually increases from start to finish.

The amount of power which can be generated by an oil-engine of a given size is affected very considerably by the height above sea-level of the place in which it is worked, and oil-engines require careful adjustment for the elevation, if the level be more than 2,000 or 3,000 feet above the sea. In the high ranges of the hills in Southern India, where oil-engines are used for driving tea factories and coffee pulping machinery, the loss of power due to the rarity of the atmosphere must amount to as much as 20 per cent. even when they are properly adjusted and a sufficient terminal pressure is reached at the end of the compression stroke. When this is not attained they can never work satisfactorily and the fuel consumption must always be extremely high. In practical working it is doubtful if the Hornsby engine is quite as economical in fuel consumption as some other types of engine, as the simplicity of the method of ignition is to some extent purchased by sacrificing thermal efficiency. A high compression is conducive to efficieney, but if it exceeds a certain amount in the Hornsby engine, then pre-ignition takes place with bad result.

The practical management of these engines is extremely simple, and can be entrusted to intelligent coolies who have received a short course of instruction. Where the load on the engine varies considerably, it is

desirable to vary the stroke of the pump so as to adjust the fuel supply to obtain as nearly as possible an explosion at every stroke. When the engine is working satisfactorily the governor sleeve should be just floating and occasionally the oil supply should be cut off. The lubrication of the engine is a very important matter and a serious item in the total cost of running it. The lubricators should always be kept in good working order and the best oil that is procurable at a reasonable price should be employed. Nothing better than a good mineral oil can be used, but they are comparatively expensive, and an engine can be run fairly well with castor oil for the main bearings and a mixture of cocoanut and kerosine for lubricating the cylinder.

VI

The rivalry between the makers of oil and gas-engines as sources of motive power is keener now than at any previous time and except for very small installations it is difficult to say which is best adapted for pumping water for irrigation. For installations requiring less than 10 h.-p. it will, I think, be generally accepted that a cheap fuel engine of the Hornsby type cannot be surpassed, wherever liquid fuel can be obtained at a rate not much in excess of Rs. 45 a ton. In the south of India the great majority of our pumping stations will be under 10 h.-p. and with liquid fuel available in Madras at 2 annas a gallon, or Rs. 30 a ton, there are not many places where it will cost more than Rs. 15 a ton for carriage from Madras. When more than 10 h.-p. is required, the gas-engine

n conjunction with a suction gas producer using charcoal as fuel is likely in some instances to prove a more satisfactory method of obtaining power.

Many years ago, in the early days of the gas-engine, their use was greatly extended by Mr. Emerson Dowson, who invented a method of manufacturing gas suitable for generating power which was very much cheaper in working than the ordinary coal gas manufactured in towns for illuminating purposes. In his producer a jet of steam under pressure was introduced beneath the fire bars of a closed furnace, and was arranged so as to serve as an air injector. The mixed air and steam in fairly definite proportions passed between the fire bars and through a mass of incandescent fuel, resulting in the production of large volumes of gas consisting mainly of a mixture of nitrogen, carbon-monoxide and hydrogen. Valueless as an illuminating gas, it was admirably adapted for gas-engines and the very economical results obtained with it gave a great impulse to their development, and to-day it is employed in a very large number of plants. The system is simple, but requires a boiler in which steam under a pressure of from 30 to 50 lbs. per square inch is maintained and a gas holder in which the gas is stored till required. Obviously, therefore, it requires a certain amount of skilled supervision and is not adapted for working on a small scale. The fuel used must be anthracite of a good quality, aud this further limits the field in which it can be usefully applied. These disadvantages have been fully recognised by

gas-engine makers, and in their efforts to meet the ever increasing competition of oil-engines they have succeeded in making enormous improvement in the methods of manufacturing gas, and have finally succeeded in producing plants which in conjunction with gas-engines are likely to obtain a final victory.

The suction gas producer plants now on the market require no boilers, no gas holders, and can be worked without skilled labour. From an Indian point of view they possess the further advantage that they can easily be manufactured in the country by existing engineering firms, and they can be worked with charcoal, of which large quantities could be readily furnished by the Forest Department if there was a steady demand for the same. Apart from the possibility of obtaining cheap supplies of liquid fuel from Burma, we are at present entirely dependent upon foreign sources for our oil-engine fuel, and, though it may be a minor matter, yet it is not one to be altogether disregarded, that the suction gas producer solves the problem of obtaining a cheap supply of power without having to go outside the country for the fuel used.*

Of suction gas producers the number already on the market is very large; but, like bicycles, there is not much difference between the productions of the various makers, and most of them may be reckoned

* Suction gas producers are now made which can be worked with wood. With a mechanical arrangement for separating the tar from the gas before it enters the engine they are eminently satisfactory and where wood is cheap they are very economical. The smallest size ordinarily made is suited for an engine of about 35 horse-power.

upon to do satisfactory work. Essentially they consist of a vessel containing water which is kept boiling after the apparatus is once started by the hot gases coming from the furnace. The air, which is drawn in, passes over this water and thence into the closed ash pit of the combustion chamber. Passing through the mass of incandescent fuel the water vapour is decomposed and hydrogen set free. The oxygen of the air and the oxygen from the water combine with the carbon of the fuel and produce carbon-dioxide and carbon-monoxide. The former is valueless, but the latter is the principal source of energy in the resultant mixture of gases. From the combustion chamber the hot gases are drawn round the boiler already mentioned into a coke scrubber, where the dust and solid practicles are removed by the action of water continuously trickling over the coke. A tar separator follows and then the gases pass to a small reservoir, generally known as the anti-fluctuator, and thence to the gas-engine. To start the manufacture of gas, a small hand fan is provided to drive the air through the apparatus; and the products of combustion are allowed to escape past a valve into the chimney, till the apparatus is beginning to yield gas of sufficiently good quality to drive the engine. The hand fan is then stopped, the valve to the chimney closed and the engine started. Thenceforth, air is drawn through the producer by the suction action of the piston of the gas-engine, and the quantity of gas generated is exactly that required to meet the demands of the engine. Pumping water is almost an ideal load, as it

remains either constant or is a steadily increasing one. In the producer apparatus, when at work, the pressure is always less than atmospheric; there is therefore no danger of escaping gases, and the steam generator being at the same pressure is in noway a source of danger if neglected.

The usual fuel is anthracite, but where this cannot be obtained at any reasonable price, good hard coke or charcoal may be employed. The gas producer must be looked upon as part of the power-generating plant, and for any given size of engine the producer must be of corresponding capacity. It is possible to obtain these suction gas plants of very small size, but they are much more costly than oil-engines of corresponding power, and it is doubtful if they are so economical. The lowest limit of size seems to be about 10 horse-power, and the largest at present in use are capable of generating about 300 horse-power. With anthracite coal, the consumption of fuel per brake horse-power is extremely small, and in practical working medium sized plants may be safely reckoned upon to yield one brake horse-power hour per pound of anthracite, or per pound and a quarter of coke. Properly carbonised charcoal will give about the same results as good coke, and it will be a safe estimate to assume the one ton of good charcoal will give 1,500 b. h.-p. hours. The cost of charcoal in India varies a good deal. In Madras at the present time it is about Rs. 25 a ton, but in large quantities it will probably be possible to secure a supply for Rs. 20 a ton.

Some years ago there was a discussion as to the possibility of manufacturing iron in the Salem District from charcoal, and Mr. C. W. Brasier, who was then Forest Officer in that District, estimated that charcoal could be manufactured on a fairly large scale and delivered at a distance of ten miles for Rs. 8-8 a ton. This was probably a sanguine estimate, but there is very little doubt that in most parts of the Madras Presidency it would be possible to obtain charcoal at Rs. 15 a ton, if there was a steady demand for it. This means, that for one rupee we can obtain 100 brake horse-power hours. Using liquid fuel in an engine of about the same capacity, we could hardly expect to work with less consumption per brake horse-power hour than four-fifths of a pint. This would mean that 100 brake horse-power hours would require 80 pints or 10 gallons of liquid fuel, which in Madras would cost Rs. 1-4-0 and in most places Rs. 2. Roughly, therefore, we may say that under favourable conditions the fuel charges for a suction gas producer plant are about one-half those of a Hornsby oil-engine. The other items which go to make up the sum total of the working expenses are not very different in either case, though the capital outlay for a suction gas producer plant and gas-engine is about 20 per cent. greater.

It will thus be seen that the popularity of the suction gas producer rests upon a thoroughly sound basis, and although as yet but few of them have reached India, any one requiring power, whether in small or large qaantities, would be very ill-advised not to con-

sider the claims of this comparatively new method of obtaining gas suitable for motive purposes. Within the last few weeks a plant of this description has been installed in the Mount Road to drive a dynamo for electric lighting work. Since it was started I have had it under careful observation, and I have come to the conclusion that it can be run as easily as an oil-engine at a slightly smaller cost.

As a typical instance where a suction gas producer plant can be installed with advantage I may cite a case which was recently under investigation. At the foot of the hills in the Godavery District a natural lake of considerable extent has been formed by the gradual closing up of the mouth of a lateral valley by silt deposited during floods in the river. It is estimated that this lake is capable of supplying sufficient water for 500 acres of land, and I have recommended the installation of engines and pumps to lift the water out of the lake to a height sufficient to command the land. Three sources of motive power were practicable, (1) Diesel engines, (2) Hornsby oil-engines, and (3) gas-engines. The third was finally selected, because, it involved the owner of the land in the smallest annual outlay. Within a short distance from the pumping station are situated considerable tracts of forest land which belong to him and from which he can obtain supplies of charcoal at a very low cost. By working his forest systematically he can obtain enough charcoal from an acre of land to supply power sufficient for an acre irrigation. This is a very satisfactory result, as

there is scarcely any doubt that the forest land will greatly improve by systematic felling. The suction gas producer is comparatively new to India, but there is scarcely any doubt that it has a great future in front of it.

VII.

In conclusion, it is necessary to discuss briefly the methods by which the power generated is actually applied to lifting water. This part of the business is open to treatment in great detail. But the discussion is mainly one for technical papers and is not susceptible of popular treatment. The simplest and cheapest method of lifting water is by means of the centrifugal pump. But, unfortunately, the centrifugal pump as ordinarily installed is by no means an efficient machine. The loss of power ranges from 60 per cent. in pumps with a 3-in. suction pipe to 45 per cent. in pumps with a suction pipe 10 or 12 inches in diameter. More favourable results than this are frequently claimed by makers of centrifugal pumps, but it is doubtful if in ordinary practical working they are ever realised.* A centrifugal pump with a 2-in. suction pipe would be a most convenient size to employ on a very large number of wells in this country. But the efficiency is extremely low, and on a lift of 30 ft. probably three-fourths of the power put into the pump would be wasted. The centrifugal pump as an irrigation machine has never been

* There has been marked improvement in the efficiency of centrifngal pumps since the above was written pumps can and now be obtained with efficiencies ranging from over 60 to 75 per cent.

studied with sufficient care, but it is likely that this omission will be remedied in the immediate future as both in California and India the matter has been taken up and a great deal of preliminary work done.

Of the loss of energy which occurs in centrifugal pumps when they are worked, part is lost in the pump chamber itself, and part in the suction and delivery pipes; and the proportion that the latter bears to the former is often a considerable one. Where the level of the water which has to be lifted fluctuates a great deal, the ordinary centrifugal pump can only deal with it when the range of level is not greater than the suction height of the pump. In ordinary practice this is limited to 20 ft., but if the foot valve is carefully designed so as to present but little obstruction to the flow of water and if the suction pipe is of sufficient diameter to carry the water at a moderate velocity, it is possible to work with the suction length as great as 28 ft. For instance, the ordinary 3-in. pump has a 3-in. suction pipe, and the pump should be placed not more than 22 ft. above the minimum water level. But if a 4-in. pipe be employed with the same pump, the suction height can be increased to as much as 28 ft. and the loss of energy in working the pump correspondingly decreased. In many wells in the south of India the level of water fluctuates a great deal more than this and may amount to as much as 40 or 50 ft. In such cases it is most convenient to use a centrifugal pump with a horizontal propeller supplied with power through a vertical shaft. Such pumps may be

employed with a suction pipe from 25 to 28ft. long and can therefore be easily fixed when the water is moderately low and they will work perfectly satisfactorily when submerged. The engine is placed near the mouth of the well and the vertical shaft in the pump carries a pulley fixed in position so that it can be driven by the engine through a quarter twist belt. This arrangement is somewhat expensive on account of the necessity of keeping the shaft in perfect alignment; but it is very simple and the cheapest way of dealing with large quantities of water. In America, where water is often raised from great depths, the vertical shaft and the horizontal pump are very commonly employed with the best possible results, and in not a few cases the shaft is driven by an electric motor either mounted direct on the upper end of the shaft or at some little distance off and driven through a quarter twist belt.

Where the quantity of water to be lifted is not very large, bucket pumps might be employed with great advantage. In this matter also we must look to America mainly for examples to copy. English practice in the matter of pumps is exceedingly good and substantial, but it is generally too expensive. What is wanted in this country is for the local engineers to manufacture a class of pumping machinery which avoids the flimsiness so frequently apparent in American designs without running to the other extreme, as is the case with English makers. It is inevitable with pumps of this type that they should be expensive and

heavy when compared with centrifugal pumps; but, on the other hand, this disadvantage is to a large extent compensated for by their superior efficiency, as it is not difficult with a lift of 40 ft. or more to obtain a return in the water lifted of 80 per cent. of the energy put into them. That such pumps have not been used hitherto is mainly due to the fact that they require a good deal more skill in the design and erection of them. But now that the matter has been taken up by Government, it is reasonable to hope that this difficulty will disappear. In selecting a pump for irrigation work, the question of efficiency is of extreme importance. It is often better to pay two or three times as much for a more efficient pump, as it means that a smaller engine can be used to drive it and the saving in cost of the engine may be sufficient to pay for the extra cost of the pump. The final result is that the working expenses are diminished by the smaller amount of power which has to be generated to drive the more efficient pump.

The majority of wells in this country do not yield a sufficient supply of water to make it worth while employing engines and pumps; and, as in most places where well irrigation is extensively carried on, there are numerous wells in close proximity to one another; it has been frequently suggested that it would be profitable to employ a portable engine and pump, which might make a daily round, lifting out the water from a number of wells. This is by no means impossible; but the plant will be costly and will require skilled

men to supervise it, so that it is hardly likely that it could be done with any profit.

A more practicable plan, but one which has not yet been tried in this country, will be to put down a central power station and distribute energy to a considerable number of wells in the neighbourhood. There are at least three ways in which this could be done.

(1) On the oil fields in America it is a common practice to work a number of deep well pumps by wire ropes attached to a large eccentric driven by an oil or steam-engine. On the Kern Valley Oil Field in Southern California I saw in some instances the pumps of more than a dozen wells being driven by one centrally situated engine, which, through a pair of bevel wheels, drove a vertical shaft carrying two eccentrics, to the sheaves of which wire ropes radiating in all directions were attached. The shaft made about 15 revolutions a minute, and the eccentric throw being about 12 inches gave the pump a stroke of 2 ft. The wires were suspended in slings attached to cross arms on wooden poles and the pumps could be worked satisfactorily up to a distance of half a mile from the engine. It will not be difficult to adapt this system to well irrigation in India, and there are hundreds of places where clusters of wells could easily be found and from which sufficient water could be obtained to give employment to engines of considerable power.

(2) Electric motors and pumps might be installed in each well and the energy supplied to them from a

central power station.* This system is hardly applicable on a small scale but could be used with great advantage where there are a large number of wells.

(3) At a central power station the engines might be used to drive air compressors and the power distributed through pipes to wells, in each of which would be installed a Pohle air-lift. This system is better adapted to tube wells which are carried to a great depth. But it is also possible to adapt it to wells sunk in beds of sand where the fluctuations in the water level at different seasons of the year are not very great. The air-lift is extremely simple, and if properly designed, is fairly efficient. It has been extensively used both in Europe and America; and under certain conditions it might be advantageously employed in irrigation work.

* A scheme working on these lines has been started by the Theosophical Society in the Adyar to the South of Madras.

CHAPTER V.

IRRIGATION FROM ARTESIAN WELLS.

In the third section of the article on "Irrigation with oil-engines" I wrote:*—"The wells from which Mr. Panduranga Moodeliar is pumping water near Cuddalore derive their water-supply from beds of sand near the surface. He has started with one well 12 ft. in diameter and has sunk alongside it a second well 20ft. in diameter and now he proposes to sink a third well so as to obtain an increased area of percolation and a large storage capacity for water. His wells are already over 30 ft. deep and further progress is barred by the fact that they now rest on a bed of clay. Under this bed of clay, which has been proved to have a thickness of more than 50 ft., it is not at all improbable that water-bearing sands or gravels may be met with, and it is quite possible that by sinking the borehole to a sufficient depth we might obtain an artesian or sub-artesian supply of considerable volume."

It is interesting now† to be able to report that Mr. Panduranga Moodeliar has employed some well-borers from Pondicherry to test the truth of this conjecture, with the result that it has proved correct. At a depth of 84 ft. from the surface he struck artesian water which rose in his well to within 14 ft. of the level of the ground. At first the supply was very copious and a considerable volume of sand and

* In 1905. † In 1906.

mud was brought up with it, but after a few days the supply decreased and the water came up clear. The internal diameter of the tube is 7″ and the discharge amounts to 140 gallons per minute or, say, 200,000 gallons per day. During the day time, while the engine and pump are at work, the water is kept down in the well so that the mouth of the tube is free, but as soon as pumping ceases the water begins to steadily rise in the wells and the static level, or the level to which the water rises when none is drawn off, is 14ft. below the surface of the ground. This is, therefore, what is usually termed a sub-artesian supply. As Mr. Panduranga Moodeliar's engine and pump can easily deal with a discharge of 300 gallons per minute, I have advised him to put down two more 7″ boreholes in his larger well and this he has agreed to do. As the well is 31 ft. deep at the place where the borings will be started, it will only be necessary to carry them down slightly over 50 ft., and the cost of doing this will be about Rs. 100 for each borehole.

As already stated, the well-boring operations were carried out by men from Pondicherry, and from them we learnt that a very large number of artesian wells are in use in the country south of Pondicherry for irrigation of paddy crops. It is, I believe, well known that there are a number of artesian wells in Pondicherry, and the general impression regarding these sources of water supply is fairly accurately stated in the Report of the Irrigation Commission, in which the Commission-

ers mention that they have received information regarding 11 artesian wells in Pondicherry yielding a total supply of $5\frac{1}{2}$ cusecs. No allusion is made to any irrigation under these wells and I think the general impression, which I have hitherto shared, is that the artesian water-supply in Pondicherry and its neighbourhood is not of much importance. That this is erroneous will be seen from the following facts which I gathered during a brief visit to the French territory in company with Mr. Panduranga Moodeliar. The road from Cuddalore to Pondicherry crosses the Ponniar river about a mile and a half out, and almost immediately begins to wind its way through alternate French and British villages. For some miles on either side of the road the country at this time of the year is dry and barren, but almost immediately after passing the Customs House, which is six or seven miles from Cuddalore, patches of bright green paddy are to be seen and beyond the Kilinjar river the greater part of the land on both sides of the road is under cultivation and presents a strange contrast to the burnt-up fields which here and there intervene and which can be seen all along the road in the far distance. Leaving the main road beyond the Kilinjar river we inspected a number of wells in various villages, and as we were accompanied by two well-boring maistries and by the owners of most of these wells, we were able to get fairly accurate information regarding them. All the wells are bored the same diameter, *viz.*, 7 in., and in depth they vary from 150 to 250 ft. The tubing is made of sheet iron

riveted together in lengths of 4 ft. and the ryots measure the depth of a well by the number of tubes employed. One of the best wells we saw had been sunk to a depth of 184 ft. and apparently yielded a supply of about half a cubic ft. per second. The irrigation under it was said to be 20 acres, and the cost of putting down the well Rs. 300. The water in many of the wells appears to contain salts of iron as the channels flowing away from them bore evidence of this. In one village, Pudukuppum, there were 10 wells, and in another village, Kilinji-kuppum, there were 12 wells, the total area under irrigation in these two villages being 150 acres, or an average of about 7 acres per well. One of the well-boring maistries, Manika Gownden by name, informed me that he had learnt the trade from a man brought to Pondicherry by the French Government, and that during the last 10 or 12 years he had sunk between 200 and 300 wells, whilst the other maistry claimed to have put down independently 210 wells. These figures may or may not be correct, but I am quite certain that there are many hundreds of wells to the south of Pondicherry and that probably more than a thousand acres are under irrigation from them. I was told that there are a considerable number of people engaged in well-boring and that about 25 sets of well-boring apparatus are in use. No attempt has been made anywhere except in the well belonging to the Anglo-French Textile Company at Pondicherry to increase the natural flow of the wells, and the result is that most of them yield only a com-

paratively small quantity of water. It would seem that the greater number of wells are in French territory but there is also a considerable number in the British villages scattered throughout the country between the Ponniar and the Kilinjar Rivers.

One or two attempts to obtain artesian water have, been made in Cuddalore ; but they ended in failure, or supposed failure, because no water rose above the level of the ground. Mr. Panduranga Moodeliar's boring on the banks of the Ponniar River shows that the bed of artesian water is of enormously greater extent than has higherto been supposed, but that in its southern extension the pressure is not sufficient to bring the water above the level of the ground. Although the number of boreholes which have been put down is very considerable, the quantity of water drawn from these sands is by no means large, and it is probable, nay practically certain, that by pumping it could be enormously increased. The villagers told me that in the rainy season the wells yield rather more water than in the hot weather, but that there is no great difference in the yield throughout the year.

The value of this water-supply depends very much more upon the fact that it is constant throughout the year than upon its actual volume. But, unfortunately the poverty and indolence of the ryots precludes them from making any use of its perennial character. Usually, where artesian water is available, two crops of paddy are grown and the land is heavily manured with

castor cake. There seems to be scarcely any doubt that, if a number of small pumping stations were installed throughout this tract of country, several thousand acres might be brought under sugar-cane cultivation and the wealth of the people enormously increased. There are no large landholders, and individual ryots are quite unable to undertake the operations neccessary to fully utilise the value of these stores of subterranean water.

When a well yields more water than the owner requires for the irrigation of his land he sells the rest to his neighbours, taking one-third of the gross produce of the land in return for the water. Possibly some such system as this might be adopted on a large scale, but it would be better if it were undertaken by private enterprise than through any Government agency, as not only would it be necessary to find capital for the pumping machinery but also for advances to the ryots to enable them to undertake improved methods of cultivation. Where water is supplied to the ryots by pumping, the cost is naturally greater than when it comes from a tank or channel, though it is always very much less than that which the ryot incurs when he bales out water from a well by means of a picottah or mhote. Nevertheless, he is extremly unwilling to pay a water rate which may amount to Rs. 15 or Rs. 20 per acre per annum, although this is very much less than he is actually paying when he employs coolies or cattle to lift water for him. In the one case he has to pay money down, and the ryot dislikes parting with

money, whilst in the other the payment is made in kind and is usually a part of the produce of the land itself. The introduction of the *varam* system seems to be the most likely way in which it will be practicable to bring to the aid of the ryot capital which would be freely available before ready means of applying it can be devised. Sugar-cane cultivation offers the most favourable field for experiments in this direction, and the country round Cuddalore possesses unusual facilities for the growth of such a crop.

The cretaceous deposits of Pondicherry are well known to geologists and have been the subject of several learned memoirs, but the artesian water-supply derivable presumably from the extension of these beds has not received the attention which it deserves. I have no information as to the position or the area of the out-crop of these water-bearing sands, yet from an economic point of view it is important that these should be thoroughly investigated, so that some estimate may be formed as to the capacity of the subterranean reservoir.

CHAPTER VI.

THE VALUE OF WIND-MILLS IN INDIA.

Previous to the advent of the steam-engine the wind-mill was held in high repute as a means of obtaining motive power, and it was largely used for grinding corn and for raising water for the drainage of low lands. The old fashioned mill was cumbrous and expensive, and, as a rule, it was so heavily loaded that it only worked in strong winds. The disadvantages attendant on its use were many and serious and it is not surprising that it fell into disrepute. Subsequently the invention of the dynamo and the electrical accumulator again drew the attention of Engineers to the wind as a source of energy and the modern aermotor or wind-engine was gradually developed. The expectations based upon the conversion of the power of wind into electrical energy and its storage in accumulators have not been realized mainly because of the large capital outlay involved in the plan. But a field for the use of wind-engines has been found in employing them to pump water either for domestic purposes, for drainage or for irrigation, and at the present day many thousands are doing useful work in these directions. In no part of the world would there be more scope for them than in India where millions of cattle are daily employed in raising water from wells for the irrigation of land, but unfortunately, they are too expensive for the individual

ryot, and there is a generally prevalent idea that the wind-currents in India are too light to make the amount of energy derivable from them of any material value.

About two years ago I was asked by the Board of Revenue to furnish them with information regarding the utility of wind-mills for irrigation work, and as there was no trustworthy information available, I proposed to Messrs. Parry & Co., the Madras Agents of the Chicago Aermotor Company, that, if they would place an aermotor at my disposal for purely experimental work, I would undertake to collect and place on record the observations. After consultation with their principals in America, it was settled that a 16 ft. aermotor mounted on a 70 ft. tower should be handed over to me to experiment with and the Board of Revenue agreed to furnish the necessary funds.

A new aermotor was accordingly sent out, and I had it put up in the compound of the School of Arts, Madras. An attempt was made to sink a well, but the sub-soil proved so unsatisfactory that the well was abandoned and a masonry tank 10 ft. square and 5 ft. deep was constructed under the aermotor tower. It was originally intended that the aermotor should drive a rocking lever at the ground level, to which lever two pump rods were to be attached, one working an 8-in. pump, the other a 6-in. pump, both to be fixed 25 ft. below ground level in the well. But when the well had to be given up it was found impracticable to arrange for driving two pumps except at a greater

expense than was warranted and only the 8-in. pump was fixed in the tank.

The object of the experiment was to ascertain the quantity of water which the wind-mill would lift to a certain height every day in the year, and as there was no necessity to use the water for any purpose it was decided that the pump should be arranged to lift the water 25 ft. and allow it to fall back into the tank. To obtain the information required, a tacheometer was fitted to the pump to record every stroke, and to obtain the quantities of water lifted, it was only necessary to ascertain, as accurately as possible, the delivery of water per stroke. To do this, another tank 10 ft. square and 5 ft. deep was built above the level of the ground and the water discharged from the delivery pipe was carried to it by a two-inch main fitted to the bottom of a wooden funnel into which the water lifted by the pump was discharged.

The aermotor and tower were bolted together horizontally on the ground and were then lifted into a vertical position by means of a derrick. The plan followed was the very ingenious one devised by the Aermotor Company, but it gave us a great deal of trouble, as the tower, though it has proved to be amply strong enough in the erect position, was not well adapted to resist the strains brought upon it during the process of lifting, notwithstanding the fact that the instructions of the Aermotor Company were carefully carried out in regard to the addition of temporary bracing to resist the bending stresses. The wind-wheel was

geared down to work the pump in the ratio of $3\frac{1}{2}$ to 1. The diameter of the pump was 8 inches, and the length of the stroke 16 inches, so that the theoretic discharge of the pump was 2·9 gallons per stroke. Careful experiments repeated a great number of times by recording the number of strokes required to fill the measuring tank showed that the average quantity of water delivered by each stroke of the pump was 2·5 gallons or 86 per cent. of the theoretic delivery. After preliminary experiments a daily record of the work done by the wind-mill was kept from the end of March, 1902, and readings of the tacheometer were taken every morning at 8 A.M., at mid-day and at 4 P.M. It was at first intended to set up an anemometer to record wind velocities, but after careful consideration of the matter it was finally decided to dispense with the anemometer readings and to obtain all the information regarding the wind movements from the Observatory in Madras which is situated not much more than a mile away. The aermotor was 70 ft. above the ground and well above the influence of obstructions to the wind caused by buildings and trees, and as the whole country, for miles round, is a practically dead level plain, it was thought that, considering the observations were to be extended over a long period of time, it would be better to accept the Observatory anemometric determinations than to admit a new set with instruments not so carefully calibrated as those of the Government Observatory.

The aermotor has now been in operation for more

than one year and sufficient information has been obtained to decide the question as to the suitability of these machines for irrigation work in India. Mr. R. Ll. Jones, the Deputy Director in charge of the Madras Observatory, has been kind enough to furnish me with a copy of the Observatory wind records for the whole year, and this statement gives not only the daily wind velocity in miles but also the movement of the wind in miles for every hour throughout the year. He has also been kind enough to furnish me with other data regarding wind movements in India of which, as will be subsequently seen, considerable use has been made in this paper and I am greatly indebted to him for his courtesy in this matter. Mr. J. Cook, of the Central College, Bangalore, and Director of Meteorology in Mysore, has also been kind enough to send me valuable extracts from the records of his Observatories, and I am glad to acknowledge my indebtedness to him for the same.

It seems unnecessary to publish the whole of the data which have been collected, but as a sample of the records for the whole year, Table I summarizes the results of the observations made during the month of June.

To determine the ratio between the work done by the wind-mill and the daily velocity of the wind in miles was the main object of the experiments and this was easily done by plotting the observations on section paper, taking as ordinates the number of gallons of water lifted 25 ft. per day and as abscissæ the wind

movement in miles per day. When the observations had all been plotted, it was found that a straight line having the equation $X = 175\ (Y - 53)$ represented the results very satisfactorily, where X is equal to the number of gallons of water lifted 25 ft. per day and Y is the daily movement of the wind in miles.

General observations of the working of the wind-mill show that the strongest and steadiest winds generally blow in Madras from noon till about 5 o'clock in the afternoon, and from an examination of the Observatory records, it was found that, on a considerable number of afternoons during the year, the wind blew with an almost constant hourly velocity, and from a selection of such days, a second curve was plotted having as ordinates the work done by the wind-mill from 12 to 4 P.M. and as abscissæ the total wind movement during that period. The equation $X = 156{\cdot}87\ Y$ represents these results with very great accuracy whenever the wind velocity averages more than 8 miles per hour during the period. Careful observations on several days with an anemometer fixed to the wind-mill tower showed that it required a steady breeze of about $7\frac{1}{2}$ miles per hour to keep the wind-mill in continuous motion, but that, when the wind velocity exceeded 3 miles per hour, a certain amount of work was done as the result of puffs of wind. From the first equation it will be seen that, when the daily wind velocity is below 53 miles per day, the amount of work done by the wind-mill is negligible, but that above that velocity it steadily increases in direct proportion

to the increased rate of the movement of the wind. This same result is also obtained from the second equation, and it is one of extreme importance because makers of wind-mills invariably claim that the work done by a wind-mill is proportional to the cube of the wind velocity; and in their catalogues and price lists they publish fictitious tables showing the work done by the wind at various velocities.

Table II has been compiled from the average wind velocities measured at the Observatory in Madras during the 30 years 1866—1894, using equation (1) to determine the average amount of water which the wind-mill can lift.

The other columns in this table show (1) the depth to which an acre of land would be covered during the month by the water lifted by the wind-mill; (2) the average monthly rainfall; and (3) the depth of water which would be supplied to 10 acres of land by adding to the natural rainfall the quantity of water lifted by the pump. The months of February and October are the least windy in the year; but, during the former the harvest is in general progress whilst during the latter the rainfall is usually heavy. In March and April there is practically no rain, but the water delivered by the wind-mill would be more than sufficient for the seed-beds required for an area of over 10 acres. During May, June and July strong winds are prevalent and the water lifted by the wind-mill added to the average rainfall would cover a field of 10 acres to a depth of over 6 inches. This is sufficient with careful

TABLE II.

Month.	Wind; daily velocity in miles.	Rainfall in inches during the month.	Gallons of water lifted per day 25 feet.	Inches, depth on 10 acres per month.	Total rainfall and water lifted inches on 10 acres.
January ...	144	0·89	15,920	2·18	3·07
February ...	122	0·28	12,070	1·49	1·77
March ...	152	0·39	17,318	2·37	2·76
April ...	191	0·62	24,140	3·20	3·82
May ...	227	2·12	30,450	4·09	6·21
June ...	220	2·11	29,215	3·87	5·98
July ...	198	3·87	25,380	2·47	7·34
August ...	174	4·56	21,180	2·89	7·45
September..	156	4·69	18,020	2·39	7·08
October ...	123	11·00	12,240	1·62	12·62
November...	165	13·21	19,600	2·60	15·81
December ..	183	5·28	22,740	3·11	8·39

use for the irrigation of almost any crop, and I am therefore of opinion that a 16-ft. aermotor will do sufficient work in Madras to irrigate 10 acres of land when the water has to be lifted 25 ft.

Before discussing these results further, it will be well to give a brief *resume* of the results of experiments on wind-mills which have been made in other parts of the world. "The Water Supply and Irrigation Papers," published by the United States Geological Survey No. 20, give an account of an extensive series of experiments with wind-mills made by Mr. Thomas Perry. The experiments were carried out with extreme accuracy and with very elaborate apparatus and the results of them may be summarized as follows:—

(1) The maximum work which can be done by a wind-mill is proportional to the cube of the wind velocity.

(2) The starting power of a wind-mill is proportional to the square of the wind velocity.

(3) The speed of an unloaded wheel increases in a somewhat greater ratio than the velocity of the wind, but, for practical purposes there will be but little error in assuming that the unloaded wheel revolves at a speed proportional to the wind velocity.

(4) The best speed for a wind-mill is from 0·55 to 0·70 the speed at which it runs when unloaded.

(5) The best load for a wind-mill at any given velocity of the wind is from one-half to two-thirds the maximum starting force at the velocity of that wind.

A large number of experiments were made to determine the best form for the vanes of a wind-mill and the best result obtained showed that a 12-ft. wheel having an area of 113 sq. ft. developed 6,836 foot-pounds of work in a ten-mile wind, or, in other words, that a 12-ft. wind-mill could be made to develop 0·207 h. p. in a ten-mile wind. This result is corroborated by experiments conducted in Denmark at the Government Experimental wind-mill erected at Askov. There it was found that the best result that could be obtained, when applied to a 12-ft. wind-mill would give 0·234 h. p. in a ten-mile wind. Those results can be very approximately expressed in the following way. *The maximum work which can be done by a wind-mill in a ten-mile breeze is equal to one foot-pound per second per square foot of wind surface.* A 16-ft. wind-wheel has an area of 201 sq. ft. and should therefore supply in a ten-mile wind 201 foot-pounds of work per second

equivalent to 0·373 h. p. From the equation $X = 156·87 Y$, it is found that the actual work represented by the water lifted is 0·198 h. p. or 53 per cent. of the maximum work that can be obtained from the wind. Allowing for the friction of the gearing and the loss of energy in the pump, the efficiency was satisfactory and the load on the pump was evidently suitable.

A careful consideration of these results leads to several very important conclusions which are entirely confirmed by the experiments on the aermotor. Although the maximum work which can be done by a wind-mill is proportional to the cube of the wind velocity, the actual amount of work which it does when pumping water is proportional to the wind velocity, because the work done depends upon the number of strokes of the pump, and the number of strokes of the pump depends upon the velocity of rotaion of the wind-mill, and this, we have seen, is approximately proportional to the wind velocity. This result is fully borne out by these experiments since the work done by aermotor is found to be exactly proportional to the wind velocity. A similar result was obtained by Mr. W. H. Moreland, I.C.S., the Director of the Department of Land Records and Agriculture in the United Provinces, who, in " A Note on Trials of an Aermotor in Well Irrigation " published as bulletin No. II of the Agricultural Series of his Department, gives a table on page 3 which shows that the quantity of water raised at different velocities of wind was approximately proportional to the wind velocity. The practical meaning

of this is that the wind-mill works with the greatest efficiency when the velocity of the wind is just sufficient to keep it in steady motion, and, that at any other higher velocity of the wind only a portion of the useful work which the wind-mill could do is utilized. If a convenient arrangement could be devised whereby the load put upon the wind-mill varied with the square of the wind velocity the work done by these machines would be much greater. An attempt to realize this is made by the Chicago Aermotor Company who provide means whereby three different lengths of stroke of pump can be obtained, but in practice, it is found inconvenient to alter the length of the stroke. The most satisfactory way to vary the load on a *wind-mill is to provide it with two pumps worked through a rocking lever fixed at ground level. One pump can be permanently attached to the rocking lever and the other whenever the wind velocity is sufficient to justify doing so.

Table II has been compiled from the results obtained with a single pump of 8 inches diameter and 16 inches stroke, but it is certain that for the greater part of the year for several hours each day the aermotor would have been capable of working two such pumps with practically no loss of speed.

Table III gives the mean hourly movement of wind at Madras irrespective of direction and by using

* A wind-mill has since been erected at Melrosapuram in which the pump is worked through a rocking lever and the point of attachment of the pump rod to the rocking lever can be shifted by a traversing screw In this way the stroke of the pump can be altered through a range slightly more than double the minimum.

TABLE III.—*Mean hourly air movement of Madras (irrespective of direction).*

	Jan.	Feb.	Mar.	April	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.
Mid— 1 ...	3·70	2·68	3·34	4·94	8·45	8·37	7·64	7·19	5·68	3·18	4·78	4·62
1— 2 ...	3 37	2·48	2·93	4·10	7·90	8·42	7·56	7·25	6·00	3·20	4·59	4·49
2— 3 ...	3·22	2·30	2·58	3·62	7·45	8 09	7·23	6·61	6·01	3·40	4·47	4·28
3— 4 ...	3·15	2·28	2·52	3 41	7·21	8·01	6·86	6·51	6 02	3·55	4·73	4·04
4— 5 ..	3·03	2·15	2 67	3 29	6·97	7·64	6·70	6 08	5 83	3·33	4·70	3·99
5— 6 ...	3·00	2·20	2·53	3·16	6·84	7·17	6·33	5·77	5·53	3·24	4·52	4·08
6— 7 ...	3·09	2·21	2·55	2·87	7·52	7 54	6·26	5·68	5 68	3 45	4 64	4·15
7— 8 ...	3·43	2·82	4·16	6·92	9 82	9·34	8·02	6·85	7·08	4·60	5·59	5·15
8— 9 ...	5·51	4·67	6·41	8·92	10·62	11·14	9·83	8·44	8·64	5·68	7·13	7·37
9—10 ..	7·66	6·38	7·78	9·86	10·78	12·28	11·21	9·51	9 54	6·43	8 72	9·72
10—11 ...	9·27	7 45	8·77	10·91	10 80	12 63	11·90	10·10	9·54	7·18	9·96	11·11
11—Noon...	10·11	8·43	10·14	12·53	11·76	12·72	11·97	10 12	9·56	7·59	10·77	12·01
Noon—13 ..	10·43	9·29	10·86	13·41	12·36	12·33	11·45	9 90	9 34	8 11	11·20	12·35
13—14 ...	11·13	10·06	11·68	14·16	13·31	12·51	11·42	9·97	9·21	8 64	11·38	12·69
14—15 ...	11·14	10·22	11·91	14·05	13·44	12 46	10 90	9·63	9·10	8·75	11·33	12·45
15—16 ...	11·04	10·14	11·91	13·89	13·31	12·09	10·59	9·15	8 53	8·49	11·28	12·25
16—17 ..	10·37	9·81	11·24	13 07	12·48	11·18	9 64	8 02	7·66	7·76	10·14	11·24
17—18 ...	8·75	8·50	9·70	11·14	11·59	10·18	8·77	7·35	6·26	5·84	8 21	9·03
18—19 ...	6·57	6·37	7·43	9·41	10·40	9·42	7·94	6·27	5·06	4 58	7·05	7·28
19—20 ...	5·86	5·43	6·53	8·40	10·03	9 00	7 86	5·95	5·13	4·07	6·58	6·74
20—21 ...	5·34	4·87	5·89	7·83	9 81	8·90	7·89	6·10	4·98	3·66	5·98	6·34
21—22 ...	4·91	4·48	5·41	7·22	9·70	8·80	8·09	6 71	4·91	3·44	5 68	5·92
22—23 ...	4·43	3·68	4·78	6·48	9 33	8·67	7·69	7 01	5·30	3·22	5 33	5·50
23—Mid ...	4·07	3·30	4·09	5·86	8·86	8·43	7·57	7·26	5·65	3·24	4·95	5·11

this table we can approximately estimate what extra work would have been done if it had been possible to attach a second 8-inch pump to the wind-mill whenever the velocity of the wind was sufficient to drive two pumps. With a wind velocity of 8 miles per hour and one 8 inch pump the wind-mill works steadily; with double the load, since the power of the wind-mill is proportional to the cube of the velocity of the wind, a wind velocity of 10·08 miles per hour would be required.

From Table III, Table IV has been compiled by taking out for each month the average number of hours in the month during which the wind velocity was over 8 miles per hour, and also the number of hours in each month during which the wind velocity averaged over 10·08 miles per hour. From the totals it will be seen that the wind was strong enough during 3,791 hours to drive one pump and sufficiently strong during 1,985 hours to drive two pumps. This means, that, neglecting any work done by the wind when the average velocity was below 8 miles per hour, the total quantity of water raised by the wind-mill during the year would have been increased by 52·4 per cent. if another pump could have been attached when the wind was favourable. To drive three pumps the wind velocity would have to be 11·54 miles per hour and the table shows that this velocity was exceeded during 917 hours in the year, so that the addition of a third pump would have increased the work done by a further 24.3 per cent. If a 10-inch pump had been attached to the wind-mill

TABLE IV.

Number of hours in each month the wind movement per hour exceeded 8 *miles* (A), *exceeded* 10·08 *miles* (B), *exceeded* 11·54 *miles* (C), *exceeded* 9·28 *miles* (D).

Month.	A	B	C	D
January ..	248	186	..	217
February ..	196	56	..	140
March ..	248	186	93	217
April ..	360	240	180	360
May ..	558	341	217	496
June ..	630	300	210	360
July ..	372	217	62	279
August ..	279	62	..	186
September ..	240	..	..	120
October ..	120	..	..	..
November ..	270	180	..	283
December ..	270	217	155	363
Total ..	3,791	1,985	917	2,795

instead of an 8-inch pump, a wind velocity of 9·28 miles per hour would have been required.

Table IV shows that during the year the wind exceeded this velocity during 2,725 hours and the quantity of water which would have been lifted by the 10-inch pump would have been almost exactly equal to that which was lifted by the 8-inch pump, as when the 10-inch pump is working, it will in any given time lift 1·345 times as much water of the 8-inch

TABLE V.—*Mean hourly wind velocity—Bangalore.**

—	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Mid—1 ..	9·5	9·5	8·2	7·4	10·2	12·2	12·3	10·5	8·3	6·8	7·2	8·7
1— 2 ..	9·0	8·4	7·3	6·9	10·1	11·9	12·2	10·5	7·8	6·3	6·9	8·5
2— 3 ..	8·7	7·9	6·5	6·7	9·9	11·6	11·9	10·3	7·5	6·1	6·8	8·3
3— 4 ..	8·5	7·6	6·1	6·2	9·1	11·5	12·0	10·1	7·3	5·8	6·4	8·2
4— 5 . .	8·1	7·2	5·7	5·9	8·7	11·1	11·8	9·8	8·0	5·6	6·3	8·0
5— 6 ..	7·9	6·7	5·2	5·4	8·6	10·9	11·6	9·8	6·7	5·2	6·2	8·4
6— 7 ..	7·8	6·4	5·1	5·8	8·7	11·4	12·1	10·0	6·9	5·6	6·1	8·4
7— 8 ..	8·4	7·2	6·2	7·0	9·8	12·9	13·5	11·4	8·2	7·1	7·8	10·3
8— 9 ..	10·5	9·0	7·8	7·3	9·9	14·4	15·1	12·6	8·9	8·2	9·4	12·5
9—10 ..	11·0	10·5	8·8	7·4	10·1	15·2	16·1	13·7	9·4	8·5	10·2	12·9
10—11 ..	11·7	11·3	9·8	7·5	9·9	16·0	17·3	14·3	9·8	8·9	10·6	13·0

11—Noon ..	11·6	11·4	10·1	8·0	9·8	16·3	17·8	14·5	10·0	9·2	10·2	12·9
Noon—13 ..	11·3	11·3	11·0	9·1	9·5	16·3	17·8	14·5	9·8	9·1	9·8	12·4
13—14 ..	11·3	11·6	11·6	9·7	9·3	16·3	18·1	14·4	9·6	9·1	9·8	12·1
14—15 ..	11·1	11·8	11·9	10·6	9·3	15·8	17·5	14·0	9·5	8·9	9·5	12·1
15—16 ..	10·9	10·9	11·4	10·7	9·5	15·4	17·5	13·7	8·8	8·8	9·2	11·4
16—17 ..	10·4	10·6	10·9	10·6	9·3	15·1	16·9	12·6	8.3	8 0	8·6	10·8
17—18 ..	8·8	9·4	9·8	9·8	9·1	14·7	15·5	11·6	7·1	6·8	7·0	8·8
18—19 ..	7·5	8·0	8·1	8·0	7·6	13·4	14·1	10·1	6·2	6·1	6·5	8·1
19—20 ..	8·3	9·0	8·8	7·6	7·1	12·4	13·4	9·9	6·3	6·0	7·1	8·4
20—21 ..	9·0	9·9	10·0	8·4	7·7	12·5	13·2	10·2	6·8	6·4	7·6	8·5
21—22 ..	9·3	10·6	10·1	8·4	8·5	12·6	12·9	10·4	7·3	6·5	7·3	8·8
22—23 ..	9·4	10·7	9·9	8·0	9·4	12·5	12·7	10·4	7·8	6·5	7·5	9·0
23—Mid. ..	9.4	10·3	9·2	7·7	10·0	12·1	12·4	10·4	8·0	6·9	7·5	8·9
Total ..	229·0	227·2	209·1	189·8	220 8	326·9	345·9	279·5	193·1	172·2	191·3	239·0

* The figures in this table are taken from the Memoirs of the Mysore Meteorological Department and are comparable with the figures for Bangalore in Table VII.

TABLE VI.

Number of hours in each month the wind movement per hour exceeded 8·28 *miles* (A), *exceeded* 10·43 *miles* (B), *exceeded* 11·94 *miles* (C), *exceeded* 9·50 *miles* (D).

Month.	A	B	C	D
January ..	620	279	..	310
February ..	448	308	..	364
March ..	434	155	..	320
April ..	240	90	..	155
May ..	651	..	..	341
June ..	720	720	540	720
July ..	744	744	651	744
August ..	744	403	279	744
September ..	300	..	..	150
October ..	217	..	..	..
November ..	270	30	..	180
December ..	651	279	217	310
Total ..	6,039	3,008	1,687	4,328

pump. An examination of the figures given in Table IV shows that with the 8-inch pump the volume of water lifted is more uniformly distributed throughout the year than would be the case if the larger pump were used, and we may fairly assume that an 8-inch pump is more suitable for work with a 16-feet aermotor in Madras than a 10-inch pump would be. It is important to notice, however, that the difference is not very material and that, in places

where the wind distribution is anything like that at Madras, the size of the pump may vary within considerable limits without materially affecting the quantity of water which would be lifted.

Table V. extracted from the Mysore Meteorological papers gives the mean hourly velocity during the four years (1895 to 1898) at Bangalore, and from the data thus furnished. Table VI. has been made out, similar to Table IV., in order to frame an estimate of what would be the work done by an aermotor in that locality. As the station is over 3,000 feet above the level of the sea, the density of the air is less and may be assumed to be 0·9 of that at sea level. Since the work done by the wind is proportional to the mass multiplied by the cube of the velocity a wind of 8 miles per hour at sea level will be as effective as one of 8·28 miles per hour at 3,000 feet elevation. The totals of the columns of Table V. show, that a single 8-inch pump could be worked for 6,039 hours, and that two pumps could be worked for 3,008 hours, whilst three pumps could be worked for 1,687 hours, giving an increase to the amount of water lifted of 50 per cent. for two pumps and a further increase of 28 per cent. for a third pump. If a 10-inch pump were used, it would work for 4,328 hours ; this number multiplied by 1·35, the ratio of the work done by the two pumps in any given wind shows that the 10-inch pump would only lift 96·7 per cent. of the water lifted by an 8-inch pump, and an examination of the table shows that the greater part of this work would be done during three monsoon months and that during the rest

of the year the 8-inch pump would be immensely more effective than a 10-inch pump. From these figures, it would appear that the wind movements in Bangalore are so much stronger than in Madras that the work, which a 16-ft. aermotor would do, would be 60 per cent. greater. It would be interesting to extend this method of investigating the prospects of a wind-mill to a number of other places in India, but the hourly data are not available, and we must content ourselves with the daily returns published by the Meteorological Department. In Table VII. the average daily wind velocity for each month in the year for some 28 stations fairly evenly distributed over India is given.

We have seen that the work done by the aermotor in Madras is proportional to the daily velocity of the wind, the equation being $X = 175(Y - 53)$. Applying this equation to the figures giving the average daily velocity throughout the year we obtain the ratio given in the horizontal line $\left(\frac{M-53}{165-53}\right)$. This method is based upon the assumption that an 8-inch pump is in use. But in places of low wind velocity it would be advisable to use a smaller pump, and in places of much higher wind velocity better results will be obtained with a larger pump. We have seen that the energy of the wind is proportional to the cube of the velocity and that the starting power of the wind is proportional to the square of the velocity, and it therefore seems not unreasonable to assume that the energy which can be derived from the wind may be

TABLE VII.

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—	Calcutta.	Cuttack.	Patna.	Allahabad.	Lucknow.	Meerut.	Lahore.	Peshawar.	Karachi.	Deesa.	Surat.	Belgaum.	Sholapur.	Poona.	Nagpur.	Jabbalpur.	Secunderabad.	Bombay.	Karwar.	Madura.	Salem.	Bangalore.	Mysore.	Trichinopoly.	Madras.	Masulipatam.	Bellary	Gopalpur.
January ...	62	34	48	81	58	43	43	64	239	208	125	249	184	134	93	53	90	239	73	130	117	184	212	113	141	125	81	156
February ...	80	53	70	100	79	68	54	82	249	211	130	237	174	149	123	60	97	254	86	120	128	175	188	98	119	122	92	240
March ...	118	84	82	110	96	66	70	91	281	209	156	272	190	190	133	72	105	270	96	98	126	168	192	91	150	163	109	283
April ...	169	122	106	117	106	60	77	104	329	228	192	320	213	234	161	84	113	264	98	86	110	158	195	96	185	211	127	348
May ...	172	122	115	149	103	64	79	116	407	325	305	424	255	342	228	108	173	247	128	89	98	176	249	144	219	214	201	319
June ...	142	96	101	166	101	64	88	113	423	397	374	556	316	360	240	127	217	376	128	115	113	263	358	221	212	226	251	278
July ...	122	77	86	151	94	57	80	107	415	351	377	647	336	386	243	120	249	450	123	110	108	267	348	238	191	233	282	271
August ...	115	62	77	134	72	48	69	93	397	278	326	517	296	327	191	110	203	376	87	89	93	237	312	197	166	187	263	218
September...	98	202	70	128	67	46	50	73	356	200	221	385	245	274	147	82	150	267	58	82	82	176	240	170	149	154	223	173
October ...	67	46	46	66	46	31	39	60	235	161	122	241	193	139	102	50	96	226	54	70	60	139	176	91	118	106	104	151
November...	62	41	36	49	34	29	32	51	193	181	142	267	199	138	95	43	88	235	60	91	74	167	206	101	156	132	77	168
December...	61	31	41	60	41	37	33	61	217	194	120	299	182	133	83	43	81	236	66	118	92	195	256	120	178	137	76	166
Average daily wind Movement, M. ...	106	81	73	109	75	52	60	85	312	245	216	368	232	234	153	79	139	287	88	100	100	192	244	140	165	167	157	231
M.—53.	53	28	20	56	21	0	7	32	259	192	160	313	179	181	100	26	86	234	35	47	47	130	191	87	112	114	104	178
$\frac{M-53}{165-53}$	0·47	0·25	0·18	0·50	0·18	0	0·05	0·29	2·32	1·71	1·43	2·80	1·60	1·62	0·89	0·23	0·77	2·09	0·31	0·42	0·42	1·24	7·0	0·78	1	1·02	0·93	1·59
$\left\{\frac{M}{165}\right\}$	0·64	0·49	0·443	0·662	0·452	0·314	0·36	0·512	18·76	1·485	1·307	2·425	1·405	1·415	0·92	0·48	0·839	1·735	0·534	0·605	0·606	1·163	1·48	0·848	1	1·013	0·952	1·40
$\frac{M^2}{(165)^2}$	0·41	0·24	0·19	0·44	0·20	0·10	0·13	0·26	3·52	2·20	1·72	5·90	1·97	2·00	0·86	0·23	0·70	3·02	0·28	0·37	0·37	1·35	2·19	0·72	1	1·05	0·90	1·96

165 is the average daily wind movement in Madras where these experiments were made.

taken as approximately equal to the square of the daily wind velocity. In Table VII. is given the ratio of the average wind velocity at each place to the average wind velocity in Madras $\left(\frac{M}{165}\right)$ and the squares of these numbers $\left(\frac{M}{165}\right)^2$. A comparison of the two sets of figures, $\frac{M-53}{165-53}$ and $\left(\frac{M}{165}\right)$ shows that only in places of extremely low or extremely high wind velocity there is any very material difference, and for this reason, I am inclined to think that the latter method of estimating the probable amount of work which can be obtained from a wind-mill in any locality is the more accurate.

It will be seen that at the great majority of stations the wind forces are so slight that we may unhesitatingly say that wind-mills are of no value. There remains, however, a certain number of stations where the conditions are favourable, and as these represent the wind conditions prevailing over a large tract of country, we arrive at this result: that though over the greater part of India including the whole of Northern India, the energy of the wind is of no practical value, yet, there are many places in peninsular India where it should be profitable to make use of wind-mills for irrigation. Along the sea coast from Karachi to Bombay and from Diamond Harbour to Negapatam, over a large tract of the Deccan, over the Mysore Plateau and probably in most of the hill stations, it will be found that wind-mills if not absolutely ideal machines for lifting water, are by far the cheapest and most convenient of mechanical devices available.

From the equation which has been obtained as the result of observations in Madras, it is easy to calculate the effective horse-power obtained from a wind-mill, and it will be seen that when the load is fixed, as it is by the size of the pump and the height over which the water is lifted, the actual horse-power of the wind-mill is not very large even when strong breezes are blowing. On the other hand, it must be remembered that a wind-wheel of from 12 to 20 ft. in diameter would be sufficiently large to extract all the water that can be obtained from the majority of wells sunk in this country, and that, as it is most effective in hot dry weather, it is a more convenient aid to irrigation than at first sight might be expected. We have seen that the amount of effective work which a wind-mill can do is increased 50 per cent. by the addition of a second pump, and as the cost of this addition is compartively small compared with the cost of a wind-mill tower and pump, I strongly recommend that all wind-mills erected for lifting water should be arranged so as to be able to drive two pumps during periods when the wind velocity is sufficiently high.

Taken as a whole, the movements of the wind in India, though very much feebler than in temperate climates, are fairly reliable and conveniently distributed, the maximum wind force usually occurring in the afternoon when the water in the well will probably be at its lowest level and the work of lifting it out therefore greatest. It may also be noted that, as a rule, during rainy weather the wind movements are

feeble, but water for irrigation is not wanted then; whilst hot dry weather, when water is most wanted, is usually accompanied by strong winds. The actual results of irrigation with aermotors should therefore be somewhat more favourable than calculations based on average returns indicate.

As the result of experience with the working of the aermotor supplied by the Chicago Company, I am of opinion that these machines are not sufficiently strongly constructed for work in India. A good many minor breakages have occurred during the course of the experiments, but the most serious defects were due to the bad fitting of the valves in the pump chamber. The design seems to be excellent but the execution was bad and much trouble might have been obviated if the pivots on which the flap valves turn had been made larger and fitted into better designed sockets. A wind-engine and pump cannot be placed in inexperienced hands; they require carefully looking after, and the slightest defect or damage should be remedied immediately it occurs. It will not pay to keep an experienced fitter to look after a single wind-mill, but the man could easily look after a dozen mills and where such colonies of wind-mills can be established they should prove remunerative investments.

A 16 feet aermotor mounted on a 40-ft. tower and fitted with an 8-inch pump will cost, when erected over a well, about Rs. 1,500, and we may assume that the cost of maintaining the same in good order will be about Rs. 5 a month. Such investments should yield

about 6 per cent. interest on the capital expended, or Rs. 7–8–0 a month. Ten per cent. for depreciation is perhaps an excessive amount to allow, but it will be well on the safe side if we do so. This comes to Rs. 12–8–0 a month, making the total cost of the wind-mill Rs. 25 a month. Now, this wind-mill will do as much work as at least 2 pairs of good cattle, and if fitted with two pumps, it will be equivalent to 3 pairs of cattle and the cost of lifting water with them will amount to from Rs. 45 to Rs. 67 a month, showing a margin in favour of the wind-mill of from Rs. 20 to Rs. 40 a month. This is the result that can be obtained in Madras, but there are thousands of square miles of country in India where much more favourable results can be obtained, and I therefore conclude this brief account of my observations on a wind-mill in Madras with the statement that there is a wide field in India open for the profitable employment of wind-mills in lifting water for irrigation.

CHAPTER VII.

EXPERIMENTS WITH WIND-MILLS.

In the summer of 1903, the Royal Agricultural Society of England made an extensive series of trials of Wind Pumping Engines at Park Royal, and the gold medal of the Association was awarded to the Goold, Shapley & Muir Co., Limited, of Brantford, Ontario, Canada, for their Imperial Canadian Wind Engine. The most important feature in which this wind-mill differs from others is the gearing whereby the motion of the main shaft is transmitted to the pump. It consists of two vertical parallel racks with a connecting semi-circular rack top and bottom, in which the pinion on the main shaft alternately engages, the rack being thrown over at the end of each stroke by means of cams, thus reversing the direction of the travel of the pump rod. The rack is guided between four steel rollers, and to ensure the even working of the pinion in the rack a steel guide plate working against a flanged roller is provided. This enables a very long stroke of the pump to be used, and throughout the stroke the plunger travels at a uniform velocity, assuming that the main shaft itself is revolving uniformly.

As it was considered desirable to make further experiments on wind-mills for irrigation, an English-built wind-mill of this type was purchased from Messrs. Rickman & Co., and erected at Melrosapuram.

The wheel is 16 feet in diameter and it is erected upon a tower, 40 feet high. The cost of the wind-mill was £67-10*s*. A special irrigation pump was provided fitted with an arrangement whereby the stroke of the pump could be varied from 22 inches as a maximum to 10 inches as a minimum. The pump is double acting and the plunger has a diameter of 12½ inches. The pump has been erected by the side of an existing well at Melrosapuram in a shaft about 6 feet in diameter, connected at the bottom with the infiltration well. The pump delivers the water into a reservoir with brick walls, 40 feet square, and capable of holding about 4 feet depth of water. The storage capacity is, therefore, about 40,000 gallons, or more than the maximum quantity which is likely to be delivered by the wind-mill in a single day. The cost of the installation complete was about Rs. 3,000 the price of the pump with the gearing for varying the length of the stroke being Rs. 1061.

From the 1st April, 1906, an attempt has been made to keep a record of the work done by the wind-mill and a similar record has also been kept for a 10-feet wheel made by the Chicago Aermotor Company which is also at work at Melrosapuram lifting water from another well. The observations to be made were of the simplest possible character, but before any use could be made of them every day's record had to be carefully scrutinized and nearly half of them rejected. The instructions were that at 7 O'clock every morning the depth of the water in the storage tank should be

TABLE I.—*Wind-mills of Melrosapuram.*

Month.	Canadian aermotor, 16 feet diameter, average work done per day in foot-lbs.	A equivalent gallons of water lifted 25 feet per day.	Number of days recorded.	Chicago aermotor, 10 feet diameter average work done per day in foot lbs.	B equivalent gallons of water lifted 25 feet per day.	Number of days recorded.	Raties of A and B.
1	2	3	4	5	6	7	8
1906.							
April ...	3,012,954	12,051	19	1,017,469	4,070	27	2·96
May ...	3,890,588	15,562	20	1,086,182	4,344	31	3·57
June ...	3,806,530	15,226	18	1,091,080	4,364	27	3·48
July ...	3,299,605	13,198	15	1,192,924	4,768	28	2·76
August ...	3,065,578	12,263	11	846,809	3,387	18	3·62
September ..	2,920,128	11,680	20	897,524	3,590	28	3·25
October ...	1,760,41¢	7,042	13	369,952	1,480	28	4·76
November ...	1,163,649	4,654	22	225,762	900	30	5·15
December ...	918,005	3,672	18	198,474	793	29	4·63
1907.							
January ...	801,116	3,204	18	173,258	693	29	4·62
February ...	648,546	2,594	28	314,333	1,257	28	2·06
March ...	1,486,071	5,944	29	555,813	2,223	29	2·67
April ...	2,031,958	8,128	22	686,470	2,745	30	2·96
May ...	2,354,940	9,420	24	958,356	3,833	31	2·45
June ...	4,744,080	18,976	29	1,379,240	5,517	30	3·44

measured and the sluice opened till the tank was empty. At the same time the depth from which the water was being lifted was to be recorded. After the wind-mill had been at work a short time, it was found that the arrangement for varying the length of the stroke of the pump was not very effective, and that the rocking arm required to be balanced. Further experience clearly indicated that the variable stroke was of no great advantage and finally the maximum stroke of the pump was accepted as being the most satisfactory load to put upon the wind-mill. All the gearing was then removed and the pump rod made continuous throughout.

The results of the observations are shown in Table I which contains a record of the working of the wind-mills for a period of 15 months. The comparison between the working of this wind-mill and that of the Chicago Aermotor in Madras (vide p. 137) shows that the results at Melrosapuram have so far been extremely unsatisfactory and that only during the last month on the record was the outturn at all comparable with the results obtained in Madras. Melrosapuram is only 29 miles south of Madras, but it is 14 miles from the sea and the wind velocities are apparently much smaller that on the Coast. Just at the time when the records from this wind-mill were becoming interesting and fairly satisfactory, it met with an unfortunate accident. A tooth of the mangle rack broke off and jammed between the pinion and the rack with the result that the gearing was smashed to pieces. This most unfortunate accident has necessitated the dis-

mantling of the wind-engine and its removal for what is practically a reconstruction.

In Table I the work done by the Canadian Aermotor is compared with the work done by the Chicago Aermotor, the wheel of the former being 16 feet in diameter and of the latter 10 feet in diameter. The ratio of the surface exposed to wind is therefore 2·56. Usually it is considered that small wind-mills are in proportion to their size more efficient than large ones, but in this case the results obtained are all in favour of the larger wind-mill. During the months of the cold weather, when the winds are very light, the effective work done per square foot of surface exposed to the wind is as much as double, but during the months when the winds are much stronger, the ratio is by no means so great.

Throughout the period under review the wind-mill was employed to irrigate sugar-cane, and the area watered amounted to $3\frac{1}{2}$ acres, but during the months of February and March the supply of water was insufficient for the cane and a supplementary supply was obtained from the oil-engine and pump. This amounted in February to 340,000 gallons and in March to about 200,000 gallons. The observations recorded here must be extended over a period of several years before any general conclusions can be drawn from them. All that can be safely said at present is that the capital outlay at Melrosapuram on this wind-mill and pump is hardly justified by the results.

CHAPTER VIII.

WIND-MILL IRRIGATION IN AMERICA.

There is a generally prevalent idea that in the United States wind-mills are very largely used for lifting water from wells for irrigation, and during a recent visit to that country I availed myself of such opportunities as came in my way to find out exactly what a practical race like the American farmers have been able to get out of the wind. Not very long ago a typical American wind-mill was lent to me by the Chicago Aermotor Company and I kept it under observation for a year in the compound of the School of Arts, Madras. At the end of that time I felt justified in expressing the opinion that "there is a wide field in India open for the profitable employment of wind-mills in lifting water for irrigation," but that "the aermotor supplied by the Chicago Company was not sufficiently strongly constructed for work in India." In the United States I saw many thousands of wind-mills, but very few of them were used for irrigation. They are nearly all employed either to drive light agricultural machinery, to raise water for domestic purposes, for watering stock, or for a small garden round the house. The water is raised from a well and stored in a tank from 10 to 20ft. above the ground, the tower of the wind-mill being usually made strong enough to carry the tank. In most instances

the supply of water required is not very large, and as soon as the tank is filled, the wheel is thrown out of the wind. Even when a good breeze is blowing it is not uncommon to see the majority of the wind-mills in a village or small town standing idle. Experience has shown that the cheap wind-mills of America rapidly wear out, and so they are carefully looked after and not allowed to run unnecessarily.

Most of the wind-mills are of small size, 8ft. and 10ft. diameters being most numerous. I visited the works of the largest firm of wind-mill makers in the world, and in conversation with the Manager he claimed that his firm had sold 400,000 mills in the last few years and that they were exported to all parts of the world. Judging from the size of the works and the very complete mechanical equipment, there seemed to be nothing improbable about the statement of output. But I was surprised to hear that they themselves did not consider their wind-mills strong enough for regular irrigation work. To sell large numbers of mills it was essential that they should be cheap, and to keep the cost of construction down to the lowest possible limit economy of material is practised to such an extent that the factor of safety is reduced to a minimum and there is very little margin for wear and tear. In the design lightness is considered of extreme importance so as to save expenditure on materials and transport, and methods of construction are adopted not because they are the best that can be devised but because they require little skilled labour in the fitting of the parts and the

erection of the whole. The result is not satisfactory from an irrigation point of view, and this is borne out by the fact that wind-mills are not largely used in the United States for irrigation, except in certain areas where the local conditions are unusually favourable.

Progress is so rapid in the States that it is difficult to get accurate statistical information, and even when such information is obtained it soon gets out of date and possesses little practical value. In consequence the following figures and statements taken from the sixth volume of the U. S. Census returns, which relate to the year 1899, cannot be accepted as accurately representing the state of affairs at the present time, for, there is not the least doubt that there have been considerable developments since then. Nevertheless, they help to substantiate the conclusion I have come to that no very great use is being made of the wind to lift water for irrigation. In 1899 there were about 170,000 acres of irrigation under wells, of which over 152,000 acres were in the State of California. And as to the motive power employed for raising the water it is remarked:—"Wind-mills are not generally employed, even the smaller plants being operated by steam, gas or electricity." In the States of Kansas and Nebraska wind-mill irrigation is generally regarded as having reached its highest developments; yet it does not amount to anything material, since in 1899 there were only 1,909 acres irrigated by 599 wells in Kansas, and in Nebraska only 843 acres of such irrigation. Even if these figures could to-day be multiplied ten times,

which is doubtful, they would not represent anything very important.

Of the neighbourhood of Garden City, Kansas, Mr. E. C. Murphy, of the U. S. Geological Survey, writes:—"Perhaps nowhere in the United States is irrigation from wells by the use of wind-mills carried to the same extent as there, where may be found hundreds of wind-mill pumping plants furnishing water to irrigate for 1 to 15 acres each." During the irrigation season, which extends from April to September, the average daily wind velocity is 295 miles, and the water-supply is contained in beds of sand and gravel situated at depths below the surface varying from 8 to 40 ft. The wells are usually 3 to 4 ft. square and sunk as far as can be conveniently done into the water-bearing beds. They are lined with wood, and from the bottom perforated galvanised iron tubes from 6 to 12 inches in diameter are put down so as to increase the area of percolation into the well. Nearly all the pumps are of the reciprocating piston type and are, as a rule, 6, 8 or 10 inches in diameter. They are well designed, and the valves can easily be withdrawn for examination and repair. The working efficiency on lifts of over 20 feet is usually 75 per cent. or more. From the results obtained in Madras with the aermotor it would appear that under such conditions a 16-ft. aermotor should be capable of lifting an average of 42,000 gallons per day from a depth of 25 ft. or enough water to irrigate 20 acres of land. The conditions, therefore, are very favourable for the employment of wind-mills

and it is not surprising that they have been made use of. The only wonder is that more of them are not at work.

Undoubtedly the main reason is the unsatisfactory character of the ordinary wind-mill, which is so lightly built that it can only be allowed to work in moderate winds and is, therefore, arranged to gradually move out of the wind as its velocity increases. This is a serious defect, as the power of a wind-mill is proportionate not to the velocity of the wind but to something more than the square of the wind velocity. Obviously the wind-mill should be so constructed that its efficiency as a motor remains nearly constant through a wide range of wind velocities. In order that this may be the case the initial load should be extremely small, so that the mill will start in a very light wind. As the velocity increases the load should increase in nearly the same ratio, and the work done will then be proportionate to the square of the wind velocity. To attain this result in a pumping-mill is a very difficult matter and has never yet been satisfactorily accomplished. It can only be done by using a pump of variable stroke, and introducing some simple device for making the length of the stroke proportionate to the velocity of the wind. Any arrangement which is not automatic is of very little value, except, perhaps, the device of driving through a rocking shaft two or more pumps provided with simple means for throwing them in or out of gear. With light winds one pump can be used, with stronger winds two and in

some places it might be profitable to employ a third pump. In America this method of working would probably be of little value; as it would entail periodic visits of a man to adjust the load to the wind, and this would be costly. But in India it would be quite practicable, as labour here is very cheap and the diurnal variations in the wind velocity are very regular.

Our limited experience in India and the results of my enquiries in America are in complete accord. The cheap American wind-mill outfit is not suited for irrigation work, and a stronger, stiffer design is absolutely necessary if it is to find favour in this country. The manufacturers should aim at producing a wind-engine with a wheel about 16ft. in diameter, mounted on a tower 40ft. high, which is sufficient for most places. The wheel should be geared down to the pump shaft in the ratio of 3 to 1, and the pump should be from 10 to 20. inches in diameter, depending on the lift, and fitted with mechanism yet to be invented, which would enable the length of the stroke to be varied automatically with the velocity of the wind. The design should provide for utilising the full force of the wind up to 30 miles per hour, but beyond this velocity the governor should come into play and as quickly as possible throw the wheel out of the wind. For such a wind-engine and pump erected over a well it would be practicable to pay from Rs. 1,500 to Rs. 2,000,or from £100 to £130. The pump is a comparatively simple matter, but it requires careful design and must be well made so that it will be but little likely to get out of

order. Bucket leathers are probably the source of most trouble, but I am informed chrome leather makes a much more durable material for such fittings than the ordinary bark-tanned leather which is now universally employed. If this be so, it is an important improvement and should be adopted. In any case, it should be possible to remove all the valves from the pump and replace them with certainty even when the pump barrel is deeply submerged in the water. The wind-engine pump invariably does all the work on the up-stroke, and to obtain a fairly uniform resistance to the turning moment of the crank shaft, the weight of the pump rod and bucket should be more than counterbalanced so that on the down-stroke work is done which is restored during the up-stroke. This can be effected by floating the pump rod in the delivery tube or by the use of counterbalance weights. By suitably proportioning the section of the pump-rod to the section of the delivery pipe, a very satisfactory distribution of the work can be obtained with a fairly uniform delivery of the water.

For irrigation it is absolutely necessary that the pump should deliver the water into a storage reservoir which can be most cheaply made with earthen banks, provided these can be made water-tight. The banks should be about 15ft. wide at the base, 2ft. wide at the top and 4ft. 6in. high. The reservoir should be square in plan, with sides not less than 60 ft. long on the inside of the banks at their base, and it should be filled to a depth of 3 ft., so as to supply water for

about 2 acres at a time. The reservoir should be provided with a small outlet to the well at the 3ft. level to prevent overfilling, and with a fairly large masonry sluice so that its contents may be discharged rapidly, as otherwise there will be a great waste of water if it is run on to the land in a small stream. In America, and especially in California, much greater attention is paid to this point than is usual in India, except in gardens where masonry conduits are in common use. If the practice were extended to fields under well irrigation, the greater duty obtained from the water would amply repay the extra cost.

To conclude, wind-mills have not yet had a fair trial in India. Some have been set up in Districts where there was insufficient wind; and all have been too lightly built for the heavy work they have been called upon to perform where the wind was strong enough. In America better results have been obtained; but even there the present cheap type of mill is recognised as unsuitable, and manufacturers are considering whether the demand for an irrigation mill is sufficient to make it worth their while to meet it.

CHAPTER IX.

THE COST OF POWER.

In the Madras Presidency industrial enterprise is somewhat handicapped by the high price which has to be paid for fuel. It seems therefore desirable to endeavour to ascertain as far as possible the actual cost of generating power both in small and large units by different methods, so that in future data may be available to enable those who may have need of power to obtain it at the minimum cost.

The sources of power are :—

1. Steam engines using wood or coal as fuel.
2. Internal combustion engines using kerosine oil, liquid fuel or producer gas.
3. Water-power generated at natural waterfalls and transmitted electrically.

Of steam engines and boilers there are many varieties, and where fuel is cheap, as in the neighbourhood of Singareni or of the coalfields of Bengal, for a large scale of power development they are still the cheapest sources of motive power. Small steam engines, however, even under most favourable circumstances are much less economical and when not in perfect order are frequently extremely inefficient methods of producing power and it is probable that everywhere in India, for engines developing less than 20 horse-power

steam engines must give way to either oil or gas-engines.

Although the number of steam engines at work in the Madras Presidency is considerable and although most people keep accounts which enable them to approximately ascertain what they spend on power, yet few of them know exactly how much power is used and are consequently unable to state even with approximate accuracy what each unit of power costs them. These remarks do not, as a rule, however, apply to cotton mills, and from information which has kindly been supplied to me by Messrs. Binny & Co., and by Messrs. Best & Co., it has been possible to ascertain the cost of working some of the largest and best managed power-generating stations in this Presidency.

From the tabular statement, A. which has been prepared, it will be seen that the most economical steam engines at work in this Presidency develops nearly 1,500 h. p. and requires 1,993 lb. of coal per indicated horse-power per hour. Including 6 per cent. interest on the capital outlay and 5 per cent. depreciation, both of which are proper figures to take, the cost of working this engine amounted to 10·305 annas per hour per indicated horse-power. Another engine slightly larger, working with coal which cost Rs. 14 a ton instead of Rs. 12–8–0, uses 0·044 lb. of coal per indicated horse-power and the working expenses amount to 0·388 annas per indicated horse-power per hour. The tabular statement also contains informa-

tion regarding engines of 650 h. p., of 150 h. p., and 100 h. p., and from the figures given it will be seen that the smaller the engine the higher the cost of power per unit. It is a matter of regret that no figures could be procured for any engine between 100 h. p., and 7 h. p., as these would be directly comparable with those given in Table C, for oil-engines. The figures relating to a small single cylinder portable steam engine and boiler which was ascertained to develop on an average 7 b. h. p., are interesting. The cost of running it amounts to 1·684 annas per brake horse-power hour; that is to say the cost per unit of power is $5\frac{1}{2}$ times as much as in the case of the most efficient large steam engine. This engine is kept in good working order and may be regarded as a favourable specimen of its class and it is not improbable that there are a number of small steam engines of this kind working in the Presidency in which each brake horse-power hour costs at least 3 annas.

For comparison with figures obtained from small oil-engines and certrifugal pumps Table B. has been prepared from data kindly furnished by Mr. W. Hutton, the Sanitary Engineer to the Government of Madras. It may be taken that Municipal Water Works Pumping Stations should represent a very high average of engineering efficiency and that results obtained with Worthington Compound and Triple Expansion Condensing Engines and Pumps should be good as can be got with steam as source of motive power for lifting water. In the tabular statement the cost per indicated horse-power per hour

TABLE A.—*Cost of generating power—(a) Steam engines.*

Description of Engine.	1,500 H. P. Triple expansion 4 cylinder, surface condensing corless valve gear. Built 1893.	Horizontal, double tandem triple expansion, jet condensing.	Compound corless, jet condensing. Built 1877.	Compound corless, jet condensing. Built 1887.	Vertical compound, surface condensing. Built 1901.	Vertical compound, surface condensing. Built 1900.	Single cylinder semi-portable.
1	2	3	4	5	6	7	8
	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
Capital expenditure ...	2,50,000	1,50,000	1,50,000	1,30,000	30,000	30,000	4,000
No. of hours at work per annum.	3,550	3,680	3,550	3,550	3,550	3,550	2,628
Average 1 H. P. ...	1,488	1,600	653	696	130	100	7
Interest on capital 6 per cent.	15,000	9,000	9,000	7,800	1,800	1,800	240
Depreciation 5 per cent. ...	12,500	7,500	7,500	6,500	1,500	1,500	200
Repairs per annum ...	5,000	2,250	3,000	2,000	1,500	1,500	220
Cost of fuel ...	58,750	1,12,000	35,787	36,575	8,000	6,000	876
Cost of oil and stores ...	4,050	3,000	2,000	2,000	500	430	220
Establishment charges ..	5,000	9,000	3,000	3,000	750	720	180
Miscellaneous ..	450	*Nil.*	350	470	75	75	...
Total cost of power generated	1,00,750	1,42,750	60,637	59,345	14,125	12,025	1,936
	As.	As.	As.	As	As.	As.	As.
Cost per 1 H.P. per hour ...	0·305	0·388	0·418	0·384	0·490	0·542	1·684
Lb. of coal per 1 H.P. ..	1·993	3·044	2 767	2·653	3·107	3·029	...

NOTES.—Cost of coal per ton for Nos. 1, 3, 4, 5, 6 was Rs. 12-8-0. Wood was burned in No. 7.
Do. do. No. 2 was Rs. 14.

has been estimated from the other data on assumptions as to the efficiency of the pumps and engines combined, but the figures relating to the cost of lifting one acre-foot one foot are actual results based upon the working expenses of the pumping stations to which has been added a suitable amount for interest and depreciation. Excepting the large pumping station at Trichinopoly the cost per unit varies between $4\frac{1}{2}$ and 6 annas and is slightly more than the cost at which we work the small irrigation pumping stations which have a sufficient supply of water to keep the engines and pumps running for an average of at least 10 hours a day. That is to say, the oil-engine and pump can hold their own in this part of the world against the most advanced practice in steam pumping on a considerably larger scale of operation.

There has been a great development in the use of internal combustion engines during the last few years on account of the reputation they have gained not only for economy but for ease and convenience in working. In oil-engines, either kerosine oil or liquid fuel, may be used, but the former costs about three times as much as the latter and should only be used in small engines where convenience of running is important and where extreme economy in working expenses is not essential. Liquid fuel has a somewhat higher specific gravity than kerosine oil and bulk for bulk the same amount of power is obtained, but an oil-engine set for running with liquid fuel can only be counted upon to generate about 85 per cent. of the power it will develop when

TABLE B.

Cost of generating power—Water-works engines.

Town.	Type of engines and pump.	Millions of gallons pumped per annum.	Head against pumps in feet.	Expenditure including interest and depreciation.	Cost of lifting one acre-foot one foot in annas.	Cost per 1 H. P. per hour.
1	2	3	4	5	6	7
				Rs.		
Conjeeveram ...	Worthington horizontal compound, non-condensing.	168·19	42·11	8,392	5·15	1·88
Madura ...	Worthington horizontal triple expansion, surface condensing.	512 67	32·45	21,713	5·67	2·07
Tanjore ...	Do.	308·18	80·74	26,729	4 67	1·71
Trichinopoly ...	Worthington vertical triple expansion, surface condensing.	666·10	56·19	35,539	2·71	0·99
Do. (sub-station).	Worthington horizontal triple expansion, surface condensing.	91·55	55·44	6,925	5·92	2·16

kerosine oil is used. For industrial purposes only engines capable of working with liquid fuel need be taken into consideration and of these there are two types :—

(1) The Diesel engine which stands in a class by itself, and

(2) Such engines as the Hornsby Cheap Fuel engine, the National Oil engine and the Crossley engine.

The Diesel engine generates power with a smaller consumption of fuel than any other engine which has yet been invented, but its initial cost is somewhat high and it is too complicated an engine for very small powers. Roughly it uses from one-half to two-thirds the quantity of liquid fuel required by other types of oil-engine ; on the other hand, it requires much more skilful supervision and the interest charges are nearly double.

In the tabular statement C. particulars are given of the working of a Diesel engine of 225 h. p. developing an average brake horse-power of 198. The fuel used amounted to 0·471b. per brake horse-power and the cost was 2 annas a gallon. A gallon of the fuel weighs 9·4 lb. so that the cost of fuel per brake horse-power amounted to exactly one-tenth of one anna as compared with 0·178 anna, the cost of the coal used in Engine No. 1, Table A. The actual cost of working per brake horse-power of the Diesel engine is given as 0·352 anna as compared with 0·305 anna per indicated horse-power, so that we may take it that

TABLE C.

Cost of generating power—(b) Oil-engines.

Description of engine.	Diesel oil engine (3 cylinders).	Hornsby-Ackroyd.	Hornsby-Ackroyd.	Hornsby-Ackroyd.
1	2	3	4	5
Capital expenditure	Rs. 50,000	Rs. 7,200	Rs. 1,500	Rs. 2,000
Number of hours at work per annum ...	3,400	4,518	2,103	2,628
Average B. H. P.	198	32	5	6
Interest on capital 6 per cent.	Rs. 3,000	Rs. 432	Rs. 90	Rs. 120
Depreciation 7½ per cent.	,, 3,750	,, 540	,, 75	,, 100
Repairs per annum	,, 1,500	,, 228	,, 56·12	,, 60
Cost of oil (fuel)	,, 4,156	,, 2,912	,, 196·11	,, 256
Cost of lubricating oil and stores ...	,, 1,100	,, 672	,, 117·12	,, 164
Establishment charges	,, 1,200	,, 782	,, 171·30	,, 120
Miscellaneous	,, 100	...	...	...
Total cost of power generated ...	Rs. 14,806	Rs. 5,566	Rs. 707·6	Rs. 820
Cost per B. H. P.	As 0·352	As. 0·617	As. 1·070	As. 0·832
Fuel per B. H. P.	lb. 0·47	lb. 0·880	lb. 1·125	...
Cost of fuel per gallon	As. 2	As. 3	As. 2.	As. 2.

a Diesel engine developing not more than 200 b. h. p. is nearly as economical as a triple expansion steam engine of 1,500 h. p. It should moreover be remembered that in calculating the cost of working the Diesel engine depreciation had been allowed at the rate of $7\frac{1}{2}$ per cent. per annum. It is doubtful whether so high a depreciation is necessary, also as to whether in an average year repairs and renewals will amount to as much as Rs. 1,500.

Taking as a base for calculations 300 working hours per month and liquid fuel costing As 3 per gallon, it may be assumed that the fuel consumption in the two engines is in the ratio of 2 to 3. Then the total cost of running each engine is made up of the following items.

(1) Interest and depreciation.
(2) Repairs and renewals.
(3) Cost of fuel.
(4) Cost of stores.
(5) Cost of labour and supervision.

For both engines the first item is taken at $12\frac{1}{2}$ per cent. on the capital outlay, the second at $4\frac{1}{6}$ per cent. and for the fourth it has been assumed that the cost of stores and lubricating oil is the same for both engines and proportional to the brake horse-power developed. Under these conditions the running costs of both types of engine are the same when 80 b. h. p. is developed. In actual practice where so much as 80 horse-power is in use there will generally be available without extra cost the skill and experience necessary to supervise the running of a Diesel engine and this will material-

ly reduce the economical limit for the employment of of Diesel engines.

Taking all the factors into consideration, one is justified in stating that for generating power, a Diesel engine supplied with liquid fuel at Rs. 30 a ton is on a par with the most economical steam engine which has so far been fitted up in this Presidency and which burns coal in its boilers costing Rs. 12-8-0 a ton. The Diesel engine is however a motor which requires a fairly skilled mechanic to look after it and it will probably be not unfair to the Diesel engine to say that for any size of engine the cost of labour and superintendence will not be less than Rs. 900 a year. On the other hand, engines of the Hornsby type are often placed in the charge of drivers who do not get more than Rs. 15 a month and in some cases only half that sum, so that although these engines use 50 per cent. to 100 per cent. more liquid fuel per brake horse-power, yet they are more economical as the saving of labour and interest charges more than counterbalances the cost of the fuel. The larger the quantity of power generated the more important becomes the saving in the cost of fuel and there is some rate of power generation at which the cost is the same for both the Diesel and the Hornsby engines. Below that point the Hornsby is cheaper, above that point the Diesel is the more economical motor.

In the tabular statement C. particulars of the running of two small oil-engines are given—one of 8 and the other of $6\frac{1}{2}$ h. p., which show that the cost is ap-

proximately one anna per brake horse-power hour for small engines of this type when liquid fuel at 2 annas a gallon is available.

A very cheap source of motive power for medium sized units is the gas-engine and suction gas producer combined. This method of generating power is only just coming into use in Madras and I am unable to present any accurate figures regarding the cost of working. To my knowledge, so far, only 5 or 6 plants have been established, one of which uses imported anthracite as fuel, one is worked with mixture of Bengal coke and charcoal, and the other plants have been run on locally manufactured charcoal. From observations made on an electric light plant I have ascertained that the consumption of fuel is about $2\frac{1}{2}$ lb. of charcoal per brake horse-power running at two-thirds the maximum load for only about 6 hours per day. With charcoal at Rs. 22–8–0 a ton this is equivalent to 0·4 anna for fuel per brake horse-power hour. The cost of coal for a steam plant running alongside and under equally unfavourable conditions was about 8 times as much.

Although I have had no opportunity to obtain accurate data regarding the cost of running suction gas producer plants with charcoal as the fuel, Messrs. Massey & Co., have carried out some interesting tests on a Hornsby-Stockport plant of 28 b. h. p. under my supervision. The engine was run on a water cooled brake which was set to absorb 24 b. h. p., and two tests were made. In the first test the fire was kept

going in the generator for 48 hours and the engine was run for 7 hours one day and 8 hours the next. The total number of h. p. hours was 360 and the total consumption of charcoal 513 lb. equivalent to one b. h. p. for 1·42 lb. of charcoal. As it was known that some of the charcoal used was very damp a second trial was made lasting 24 hours with charcoal which had been specially dried. In this trial the engine ran for 8 hours and developed 192 b. h. p., hours with a fuel consumption including the stand-by losses in 16 hours of 268 lb. of charcoal, equivalent to 1·39 lb. of charcoal per b. h. p. The very slight difference in the two results was quite unexpected and it seems possible that damp charcoal is more efficient in the gas generator than dry charcoal.

The manufacture of charcoal from wood is, in India, conducted in an extremely primitive manner and the development of this method of generating power will largely depend upon improvements in the manufacture of the fuel. Roughly 5 tons of wood are sacrificed to make a ton of charcoal and all the available bye-products are allowed to escape into the atmosphere. By charring wood in closed kilns and collecting the bye-products it should be practicable to supply charcoal at Rs. 15 a ton, and at that price suction gas producer plants will prove as cheap if not cheaper sources of power than Diesel engines.

Information regarding the cost of generating water-power in the south of India is extremely scanty

and it has only been made use of on at all a large scale in three places :

(1) At Sivasamudram on the Falls of the Cauvery where nearly 10,000 horse-power is now developed and transmitted to the Kolar Gold Fields, to Mysore and to Bangalore,

(2) At the Kateri Falls which supply power for the Cordite Factory at Aruvankad,

(3) Near Ambasamudram where a Cotton Mill of considerable size has for many years been driven by water-power.

In regard to the Cauvery power scheme which is now in the fifth year of its running the average price charged per horse-power delivered at Kolar has been Rs. 321 per annum, and this is equivalent to 0·586 anna per horse-power per hour, assuming that the power is available throughout the whole year. As a matter of fact the power was not available throughout the whole year and it may be taken that the mines have paid hitherto at least 0·6 anna per horse-power per hour. At the end of the fifth year they will only pay Rs. 150 per horse-power which makes the cost of power practically 0·3 anna per indicated horse-power per hour. This is of course much cheaper than power could be generated by other means on the field, but it is very nearly as much as is paid in Madras for power developed by steam engines on a large scale.

At the Kateri Falls the electric installation has been put down to supply power to the Cordite

Factory at Aruvankad. The cost of the installation was 5¼ lakhs of rupees and the running expenses averaged Rs. 2,300 a month. At the present time the turbines are only run for about 9 hours a day, but there is no reason why they should not run for at least 16 hours a day, and with but a slight increase in the staff it would be practicable to run them continuously. Under the circumstances the actual figures relating to the cost of running are misleading, and it is only practicable to furnish an approximate estimate of the cost of the power which could be delivered at the Cordite Factory. Allowing for loss in transmission and in the transformers, it seems probable that the Factory could be supplied with 10,000 horse-power hours per day or 300,000 per month. Ten per cent. for interest and depreciation on the capital outlay amounts to Rs. 4,350 a month and the running expenses to Rs. 2,300 a month, making a total of Rs. 6,650. This is equivalent to 0·35 anna per b.h.p. hour. With a comparatively small additional capital outlay the output of the generating station could be greatly increased and there is no question that, if the plant were worked under ordinary commercial conditions, the result would be much more favourable.

In all schemes for the utilisation of water-power by generating electricity and transmitting it to a distance, the cost of a brake horse-power is invariably made up of two unequal items. The first is the running expenses which are generally small and the second is the interest on the capital outlay which is

usually large. It is only under exceptional conditions that the full output of the plant can be utilised for more than 10 hours a day and even in the south of India where fuel is expensive, the conditions are usually unfavourable for making use of such supplies of water-power as actually exist. The enormous improvements which have been made in the efficiency of the various forms of internal combustion engine now on the market have rendered the utilisation of water-power a less urgent matter than seemed probable some years ago. A square mile of forest properly worked could be made to yield 300 tons of charcoal per annum in perpetuity, and it is quite certain that this charcoal can be sold for power producing purposes at Rs. 20 a ton, and each ton of charcoal would generate 1,500 horse-power hours, that is to say, a square mile of forest would keep a 150 horse-power gas engine at work for 10 hours a day for 300 days in the year. The capital outlay involved will be about Rs. 30,000; the total working expenses including interest, depreciation and renewals will amount to about Rs. 1,100 a month, which is equivalent to 0·5 anna per horse-power per hour, which is about as good a result as can be obtained with a medium sized steam engine using coal at Rs. 12-8-0 a ton.

Improvements in the methods of manufacturing charcoal, especially in the direction of recovering the bye-products, would undoubtedly reduce the cost very considerably. A great deal of interest has been excited in the question of utilising water-power, but these

figures serve at least to indicate that in the forests of this Presidency it is possible to find stores of power of even greater economic importance, and it is probable that in this direction we shall find the best solution of the problem of providing for the promotion of industrial development.

CHAPTER X.

COST OF LIFTING WATER.

Although the number of pumping stations now at work is fairly large it has been impossible to obtain figures relating to the cost of working except in the case of a very few and these have not been worked under conditions which would yield the best results. The principal items which go to make up the cost of running a pumping station are :—

(1) the cost of the fuel used in the engine which may be either kerosine oil, liquid fuel or a mixture of both ;

(2) the cost of stores, including oil, waste and belting ;

(3) the cost of labour employed in running the station ;

(4) the cost of repairs to keep the plant in good working order ;

(5) charges on account of interest on the capital outlay.

It will be convenient to make a few remarks under each of these heads :—

1. Liquid fuel is sold in Madras at 2 annas per gallon and for a pumping station we must include the transit charges which will bring up the cost to an aver-

age of 3 annas per gallon. In some cases it will be a little more and in others less. At present the price of liquid fuel in Madras does not fluctuate.* Kerosine oil can be obtained all over the Presidency at rates varying from 5 to 8 annas a gallon depending upon the quality of the oil and the place in which it is sold. The specific gravity of kerosine oil varies from 0·80 to 0·82, whilst the specific gravity of liquid fuel is between 0·94 and 0·96 and for practical purposes we may assume that the same amount of power may be generated from equal volumes of the two liquids. The cost of fuel for generating power will therefore be from two to two and a half times as great when kerosine oil is used instead of liquid fuel. Large pumping stations can be worked much more economically than small ones as, not only are capital outlay and labour charges per unit less, but the engines and pumps are more efficient.

2. Besides fuel for running the engine, certain stores are necessary, including kerosine oil, for the vaporiser lamp, lubricating oil for the piston and bearings, cotton waste and belting. The total amount expended on these items depends very much upon the way in which the driver does his work. As a general rule lubricating oil is shamefully wasted and belting from sheer neglect has scarcely ever half the life it ought to have. For the lubrication of the piston it is better to use a high class mineral oil but for the bearings castor oil may well be employed.

* This is no longer true. The price of liquid fuel in Madras is now $2\frac{3}{4}$ annas per gallon.

3. With large engines the cost of the driver's wages does not form a very large percentage of the total cost of running and it is therefore better to put the engine in charge of an experienced fitter and driver. Such a man can be obtained for about Rs. 30 a month and should be quite competent to do all the work connected with keeping the engine in running order himself. With small engines it is necessary to employ cheaper men and wages may range from Rs. 7 to Rs. 15 a month, but as yet it is probable that cheap labour has involved an increased outlay on repairs which has not been compensated for by the saving in wages.

4. When an oil-engine is well looked after the expenditure on repairs ought to be very small, but unfortunately, it has so far figured very unduly in the cost of running most of the stations we have started. This has been partly due to bad drivers and partly due to the fact that the engines were overloaded. Where the conditions were more favourable the result has been very satisfactory and the bill for repairs almost nominal. The Vapouriser is the most vulnerable part and requires renewal from time to time. The cover at the back end is held on by studs and the practice of taking the cover off while the nuts are still hot generally results in the stripping of the threads and the necessity for new studs. Carelessness in cleaning the hole, through which the oil is sprayed into the cylinder, ends in making it too large for the purpose and new spraying plates or nipples are required. The plates themselves

are of very little value but there is considerable difficulty in drilling the exceedingly fine hole necessary for the successful working of the engine and this makes them somewhat expensive. Properly treated, however, the nipples should last for several years. These are the only special points about the wear and tear of an oil-engine. For the rest it behaves like any other machine well and solidly constructed. The cylinder is liable to slight wear, brasses have to to be renewed from time to time and the pump plunger wears at the gland if the packing is not carefully attended to. The main parts are not subject to wear and tear and 5 per cent. on the capital value of an engine and pump should be an ample allowance to keep them in perfect working order.

5. Government are prepared to lend money under the Agricultural Improvement Loans Act at $6\frac{1}{4}$ per cent., and in calculating the charges for interest and depreciation I have allowed 10 per cent.—5 per cent. for interest and 5 per cent. for depreciation. If the amount allowed for depreciation be invested at 5 per cent., it provides for the renewal of the engine at the end of $14\frac{1}{2}$ years.

We may now frame an estimate of the cost of pumping water with oil-engines and pumps under what may be termed good working conditions. The installation we will assume consists of a $7\frac{1}{2}$ h. p. oil-engine and a 4″ pump and the maximum lift is 25 feet. This plant will raise 18,000 gallons of water per hour and we will assume there is sufficient water available for 12

hours running per day. The engine and pump will cost in Madras Rs. 2,000 and an allowance of Rs. 1,000 will cover other charges connected with the installation making the total cost Rs. 3,000. Ten per cent. for interest and depreciation will amount to Rs. 300 per annum and 5 per cent. for maintenance and repairs to Rs. 150 per annum, the two sums being equal to a daily charge of Rs. 1-4-0. The engine will use three-fourths of a gallon of liquid fuel per hour or 9 gallons per day for which 3 annas per gallon may be allowed. The working expenses may therefore be tabulated as follows :—

	Per day.		
	Rs.	A.	P.
Fuel, 9 gallons at 3 annas a gallon ...	1	11	0
Driver at Rs. 15 a month	0	8	0
Lamp and lubricating oil, waste and stores	0	8	0
Interest and depreciation 10 per cent. / Maintenance and repairs 5 per cent.	1	4	0

making the total cost of working Rs. 3-15-0 per day. That is to say, if we run the engine every day in the year the daily cost will amount to Rs. 4, and obviously the daily cost will increase as the number of days in the year during which the engine is not worked increases. If the engine is run on every day in the year, the working expenses will be Rs. 1,460 and for every day on which no work is done a saving of Rs. 2 is effected, so that if the engine runs on 200 days in the year, the daily cost of working will be as much as Rs. 5-10-2. The quantity of water lifted per hour is 18,000 gallons 25 feet, equivalent to 72,000 cubic feet 1 foot or in the course of a day to 864,000 cubic feet 1 foot.

Many years ago on the Saidapet Farm lengthy experiments on lifting water with cattle gave the cost of working as 4,000 cubic feet of water lifted 1 foot for 1 anna. Rates are much higher now than they were then and it would certainly not be understating the case in favour of lifting water by means of cattle if we accept as the present cost 3,000 cubic feet lifted 1 foot for 1 anna. Under the favourable circumstances we have detailed above, the engine and pump will lift 13,500 cubic feet 1 foot for 1 anna, that is to say, the cost of working will be less than one-fourth the cost with cattle-power. If the engine worked on only 200 days in the year 9,600 cubic feet would be lifted 1 foot for 1 anna and the cost of working would be less than one-third that with cattle-power. This method of stating the cost of pumping is not a very convenient one and the more convenient unit might well be adopted in this country which has been adopted in America, viz., the quantity of water required to cover an acre of land to a depth of one foot. This is equal to 43,560 cubic feet or 272,250 gallons. An acre-foot of water lifted one foot is a convenient unit of work and on this basis the cost of lifting water per unit is As. 3-3 when the pump is worked on every day in the year and As. 4-6 when it is only run on 200 days. These figures fairly represent what the cost of working should be and it will be interesting to compare them with the actual figures which have been obtained since these pumping experiments were first instituted.

Melrosapuram.—This station is fully described

in Bulletin No. 54 of the Department of Agriculture, Madras. The water-supply is drawn from the well by a 3-in. pump driven by a 3½ h. p. engine. With regard to the cost of working the following are extracts from the Bulletin :—

"In 1903-1904 the pump was worked for 831 hours at a cost of Rs. 746-8-4, of which amount it should be observed that no less than Rs. 300 is allowed for interest and depreciation. The cost per hour amounts to 14·38 annas and for that sum it may be approximately assumed that 1,440 cubic feet of water has been raised 25 feet. This is undoubtedly a very high rate. But it is mainly due to the very small number of hours during which the engine worked and the very large number of times that it was started and stopped. In all, the engine was started 334 times and the average duration of each run was in consequence only 2½ hours, so that the amount of fuel used in starting the engine was out of all proportion to the amount of work done. This unsatisfactory result, however, has a more pleasing aspect from the irrigator's point of view as the small number of hours which it was necessary to run the pump was due to the fact that the season as a whole was an extremely favourable one and the assistance of the pump was only required to a very moderate extent.

"In 1904-1905 the conditions were materially different. The rainfall throughout the year was slight, the north-east monsoon was a complete failure and it was necessary to withdraw from the well

all the water that could possibly be obtained. The engine was started 568 times and ran for 2,074 hours, giving an average of 3·65 hours for each run. The working expenses amounted to Rs. 1,088-1-10 equivalent to 8·39 annas per hour. This is a very material reduction upon the figures for the previous year, but it is by no means satisfactory and it should yet be possible to materially reduce them.

"In 1903—1904 the consumption of oil amounted to 786 gallons or 0·945 gallons per hour. In 1904—1905, 1,691 gallons of oil were required to run the engine 2074 hours, giving an average consumption of 0·815 gallons per hour. During the first year practically nothing but kerosine oil was used; but in 1904-1905, 728 gallons of liquid fuel costing 3·15 annas per gallon were mixed with 963 gallons of kerosine oil costing 6·7 annas per gallon. An oil-engine which develops 3½ h.p. with kerosine oil cannot be reckoned to be of more than 3 h.p. with liquid fuel and it unfortunately happens that the power required to drive the centrifugal pump at Melrosapuram when the water is low in the well is fully 3½ h. p., so that liquid fuel by itself cannot be used. If liquid fuel alone had been used, there would have been a saving of Rs. 213 in the cost of fuel and the cost of working the engine per hour would have been reduced to 6·75 annas."

In 1905-1906 the season was an extremely unfavourable one owing to the total failure of the north-east monsoon, and the yield of water in July and

August, 1905 fell to not more than about 20,000 gallons per day. The engine was run for 944 hours on an average lift of 27½ feet and the working expenses amounted to Rs. 822-9-8 equal to As. 13-11 per hour made up as follows :—

	Rs.	A.	P.
Oil	305	0	8
Driver's wages	72	0	0
Repairs	145	9	0
Interest and depreciation at 12½ per cent.	300	0	0
Total ...	822	9	8

From these figures the final result arrived at is that in 1903–1904 the cost of lifting one acre-foot one foot was Rs. 1-1-5, in 1904-1905, As. 10-2 and in 1905-1906, As 15-4. The conditions at Melrosapuram are such that the cost of pumping must necessarily always be extremely high. In the hot weather months, the supply of water is very limited and the engine seldom works more than 2 or 3 hours a day. It would be useless therefore to compare the cost of lifting water by the engine and pump, under these circumstances, with the cost of lifting it by cattle working at a uniform rate, but it is quite certain that if cattle had to be employed at Melrosapuram to do the work which was done by the engine and pump, the cost would be very much greater and quite beyond the means of the settlement.

Agricultural College, Saidapet.—This installation consists of a 6½ h.p. engine and a 4″ pump and was intended to work on a maximum lift of 25 feet. Unfortunately, owing to the unprecedently low rainfall and probably also to the effect of pumping from the river, the maximum lift in August, 1905, was over 30 feet. In consequence, the engine worked very unsatisfactorily and finally an accident happened, due partly to the carelessness of the driver and partly to the fact that the engine was overloaded, which necessitated very expensive repairs. Under these circumstances good results could hardly be expected. The engine worked for 1,820 hours on 202 days and lifted 23,379,000 gallons of water an average height of 24 feet. This is equivalent to 2,061 acre-feet lifted one foot. The total cost of running the engine, including repairs and interest and depreciation, was Rs. 1,345-8-7 equal to As. 10-6 per acre-foot foot. Excluding repairs caused by the necessity of having to run the engine at a much higher lift than it was designed to work against, the total expenditure was Rs. 748 equivalent to As. 6-9 per acre-foot foot. This result was obtained using part of the time liquid fuel and part of the time, kerosine oil. 776 gallons of liquid fuel costing Rs. 103 and 600 gallons of kerosine oil costing Rs. 170-6-6 were used. If we exclude the abnormal repairs the result shows fairly what can be done with oil-engines and pumps and justifies the claim that the cost of working is less than half the best result that can be obtained with cattle.

M. R. Ry. S. Panduranga Mudaliar's Installation, Cuddalore.—The water-supply is derived from two wells coupled together, at the bottom of which tubes have been sunk which tap a sub-artesian supply. From the figures furnished me by the owner I find that he ran the 3½ h.p. engine for 915 hours and lifted 1,200 cubic feet per hour an average height of 27 feet. The total working expenses amounted to Rs. 372-7-0 equivalent to 6½ annas per hour which gives the cost of lifting water at As. 8-10 per acre-foot foot. In the latter part of the year a 9½ h.p. engine driving a 4″ pump was substituted for the smaller plant and the same ran for 640 hours lifting 3,000 cubic feet per hour an average height of 27 feet. The working expenses amounted to Rs. 478 or practically 12 annas per hour and the cost of lifting one acre-foot foot was As. 6-6. This installation is entirely in the hands of a private owner and it will be difficult to very materially improve upon the final result.

Panampattu Pumping Station.—The accounts for this station are only available from August, 1905 to March, 1906, or for the 8 months during which time it was worked by Messrs. Parry & Co. The installation consists of a 9 h. p. engine and a 6″ pump, lifting water from a large well, the lift varying at different seasons of the year from about 11 feet to 18 feet. During the 8 months the engine was worked 813 hours and lifted, 3,935,000 cubic feet of water an average height of 13·37 feet. This is equivalent to 1,243 acre-feet lifted one foot. The working expenses amounted

to Rs. 382 and the charges on accouut of interest depreciation Rs. 333. The cost of lifting one acre-foot one foot was therefore As. 9-3. The small number of hours the pump worked was mainly due to the undeveloped state of the cultivation, but also partly to the favourable rainfall during 4 months out of the 8.

Kadiampatti.—The plant here consists of a 6½-h. p. engine and a 4″ pump drawing water from a well, partly fed by percolation from the surrounding strata, but mainly supplied with water from a small stream draining a valley on the western flanks of the Shevaroy Hills. The installation belongs to Government who have lent it to Mr. Andersen, a retired Danish Missionary, who has settled in that neighbourhood. The engine and pump worked on 272 days for 1,877 hours and lifted 5,400,000 cubic feet of water to an average height of 20 feet. During the hot weather the supply of water ran very short, whilst in the monsoon months the ground wanted but little water. The work done by the pump was 2,486 acre-feet feet and the working expenses amounted to Rs. 739, together with Rs. 375 charges for interest and depreciation. The cost of lifting water was therefore As. 7-2 per acre-foot foot.

Coimbatore Jail.—The plant here, which was taken over from the Public Works Department, consists of a Ruston Proctor Oil-engine driving a pair of plunger pumps. The engine will not work with liquid fuel and the water is raised from a deep rectangular excavation in the rock, characteristic of wells in the Coimbatore

district. 859,000 c. ft. of water were lifted to an average height of 62 feet in 1,630 hours. The working expenses amounted to Rs. 727, and the interest and maintenance charges to Rs. 663, the capital outlay being Rs. 5,304. The work done was equal to 1,222 acre-feet feet and the total expenditure Rs. 1,390, making the cost of working Rs. 1-2-6 per unit. With so high a lift far more favourable results might have been expected, but the quantity of water to be dealt with is limited and the installation is saddled not only with heavy interest charges, but it is compelled to use kerosine oil, the cost of which amounted to Rs. 490

The results obtained from these six pumping stations, which are all from which fairly accurate figures are procurable, are typical of the rest and illustrate how much more expensive pumping water for irrigation actually works out than would be the case if the supply were inexhaustible and the demand continuous. It really matters little how these figures compare with the cost of lifting water by men or cattle. The oil-engine and pump do work which has never been attempted with cattle and utilises, to an extent absolutely unknown previously, the quantity of water available for irrigation.

CHAPTER XI.

FLOW OF WATER IN SAND.

A few inches, or at the utmost a few feet, below the surface of the sand, which fills the beds of most of our rivers, water will be found and below the line of saturation every cubic foot of sand contains two gallons of water or a little more. When we consider the aggregate area of all the river-beds and the depth of sand which they contain, it is evident that they constitute an enormous reservoir of water from which it is possible large quantities may be obtained, if only suitable methods for withdrawing the water from sand are employed. It is generally assumed that, when all visible flow of water has ceased down a river-bed, there is still a slow underground flow which carries off to the sea a very large quantity of water which would be of great value if only it could be intercepted.

The dry beds of Indian rivers have, however, received but little attention from Engineers, and it is only when the water-supply for a town has to be drawn from them that they have evoked any interest. A cubic foot a second is equivalent to 540,000 gallons per day, and none of the towns in the south of India which derive their water-supply from river beds require more than 4 or 5 cubic feet per second, and it would seem that if there is any flow of water at all through the sand of an Indian river-bed, there should be no

difficulty in obtaining this quantity of water. Yet, as a matter of fact, experience has shown that the wells have to be numerous or the intercepting galleries of very considerable extent, and that at times the quantity of water flowing into these strangely falls off. From most sandy rivers the ryots in the hot weather obtain water for irrigation by means of what are known as spring channels, and the study of this ingenious method of irrigation, leads me to think that our ideas regarding the movement of water beneath the sand in our river-beds require revision.

The spring channel is a ditch which is made to run up-stream at a slope considerably less than that of the river-bed. At first it runs through dry sand till it reaches the level at which the water is standing in the river. Thence onward its bed is below the water-level and water from the surrounding sand trickles into the channel and flows downward. At some point the water in the channel begins to rise above the level of the water in the river, and thence onward, it flows back into the sand and would continue so to flow, were it not that, after a time, the sand becomes saturated with water and the flow from above passes onward, till finally, it reaches the river bank through which it passes in an open cut. Now, if water flowed readily or even very slowly through sand, so great is the length of these spring channels that it is certain the water which drained into the upper section of the channel would disappear by percolation in the lower section ; but, as a matter of fact, it does not do so. Water can only flow

in sand when the hydraulic gradient of the water surface is sufficient to overcome the resistance to the flow of water offered by the sand. The surface fall of most South Indian rivers is below 15 feet a mile or roughly one in three hundred and is frequently less than 5 feet a mile or one in a thousand. If water flowed through the sand it would rise to the surface in the lower reaches of the river, but this it does not do. Practically everywhere the water is about the same average depth below the surface of the sand and lies exposed where the sand is below the level of the water plane. The upper reach of a spring channel is continually pouring water into the lower reach, and when the sand in the neighbourhood of that cutting has received a certain amount of water, it can take no more and the whole supply can be passed into the channel through the bank. Cross sections taken on the Palar river have verified this completely. Where the spring channel was in deep cutting and water was percolating into the channel, the slope of the water to the level in the channel was 1 in 250. Similarly in cross sections lower down where the water-level in the channel was above that of the river, the slope was about 1 in 250 away from the channel. That is to say, the water in the lower half of the spring channel is carried upon an embankment and this embankment is formed, because, when the slopes reach a gradient 1 in 250, the water is unable to move through the sand. This, I think, may be taken therefore as conclusive evidence that water does not move down the sandy beds of rivers unless the

slope of the sand is greater than that of the hydraulic gradient necessary to make the water move. The question will then be asked what becomes of that quantity of water which undoubtedly is disposed of in some way or other in the river-beds during the hot weather when visible flow ceases. As an example we may take the Cauvery, down the bed of which we have certain evidence that a considerable quantity of water passes, since it comes under observation at the Power Station at Sivasamudram. Some of this water is evaporated from the sand, some of it is drawn off by spring channels but the bulk of it probably passes down the river from pool to pool.

Generally in the deep bed of a river there are a series of pools in which the water is apparently standing. Each pool is a level sheet of water and between successive pools there is often a considerable fall. Where the slope exceeds the hydraulic gradient at which water will move in sand, there must be a flow from the upper pool to the lower pool. In this way unquestionably large quantities of water may be passed down a river in the hot weather. The moving water is confined to the pools and to little cascades in the sand which separates pool from pool. The great bulk of the water stored in the sand remains motionless and it can only be drawn upon by creating artificial hydraulic gradients sufficiently steep to cause the water to move. This is done whenever a well is sunk in the river and water baled out of it, or when an intercepting gallery is placed at some considerable depth below the

water-level in the river from which the water is lifted by means of pumps.

Accepting the fact that water does not move down a river-bed except in the way described, it becomes possible to determine with a fair approach to accuracy the quantity of water available at any one point, assuming that it is not supplemented by drainage from visible pools. If a well be sunk into the sand of the river-bed and the water-level lowered by pumping, a cone-shaped mass of sand will be drained of water, the vertical axis of which will be the well, round which the cone will be described by the revolution of a line inclined at the limiting hydraulic gradient at which the water will flow in the sand. If the well be of small diameter the real vertex of the cone will be considerably above the level to which the water will be reduced by pumping, owing to the hydraulic gradient being steeper in the neighbourhood of the well. This is due to the greater pressure necessary to cause the water to move through the gradually decreasing area of sand round the well. It will be convenient to give one or two examples to show the quantity of water which can be obtained from a river-bed under what may be considered average conditions :

(1) Suppose a well is sunk in a river-bed and arrangements made so that the vertex of the cone of depression is 10 feet below the static water-level in the sand. Then assuming that the hydraulic gradient is 1 in 250, the cone of depression will intersect the water surface in an ellipse and the volume of sand

involved will be 52 million cubic feet and the water content about 100 million gallons or sufficient to supply a cubic foot per second for over six months. When pumping first commences the inflow to the well will be rapid, as the hydraulic gradients artificially set up in the sand outside the well will be steep, but as the volume of sand becomes drained of water, the gradients will become flatter and the flow slower, and ultimately it will cease when the limiting gradient is reached. It should be remembered that, for the full development of the cone of depression, the bed of sand must be 5,000 feet wide or approximately a mile.

(2) If, instead of sinking the well in the middle of the river-bed, a culvert or intercepting drain were run across it at right angles, the volume of sand which could ultimately be drained of water would not be greatly different as, instead of the cone, we should have an inverted triangular prism, the volume, which on the same assumptions would be 83 million cubic feet, yielding about 170 million gallons of water, that is to say, the enormously great expenditure entailed by the construction of the culvert would not produce twice as much water, but it would very materially affect the rate at which the water could be drained from the sand.

These two examples show that there is no necessity for the water in the sand to be moving to account for the large quantities which we can withdraw and which we actually do withdraw for the water-supply of towns like Madura, Trichinopoly and Conjeeveram.

It should also not be forgotten that the rain which falls on a sandy river-bed is all absorbed by the sand and the major portion of it becomes at once available.

So far as I know, experiments have not been made to determine whether there is any loss of the underground water by evaporation from a sandy bed. If there is any at all, it is probably very small and not comparable with the loss of water from an exposed surface.

It is unfortunate that we must accept the conclusion that there is no subterranean flow of water in sand, as it necessarily reduces enormously the volume of water which can be obtained at any one given point. It is well, however, that we should have clear ideas on the subject and that our attention should be drawn to very large volumes of water which are actually available and which can be made use of, if only satisfactory methods are devised for separating the water from the sand. For the water-supply of towns the question presents no difficulty, as money can be found for the necessary works, but if the water is to be used for irrigation it is quite a different matter. A cubic foot per second will irrigate from 100 to 150 acres of garden crop, and at the most the cultivators will not be able to pay, under favourable conditions, more than about Rs. 5,000 a year for the same, and of this sum a considerable amount—probably half—will be absorbed by the pumping expenses so that not more than Rs. 2,500 will be available to meet the interest charges and upkeep of

the infiltration works. This is not a large sum when one considers that as a rule the works will have to be constructed to resist the action of heavy floods and must therefore be of a permanent and very substantial character.

One very important result arises from the determination of the fact that water does not flow beneath the sand of the river-bed. If we know the minimum hydraulic gradient at which water will flow in the sand, then it becomes an extremely simple matter to determine the areas from which water has been drawn by spring channels, wells or intercepting culverts in the past, and new works can be designed for the withdrawal of further quantities of water from rivers without interfering in any way with the existing water rights. Obviously, since the water does not flow down the river, new pumping stations may be erected above those already in existence without interfering with their supply, provided that care is taken to place them sufficiently far apart, so that the areas affected by the depression in the water-level at the pumping stations do not overlap. This of course must be modified to some extent by the fact that these areas will in some instances get their water-supply partially or wholly replenished by the water travelling down the deep bed of the river from pool to pool.

CHAPTER XII.

WELL-BORING.

When the construction of a well is undertaken there is almost always some uncertainty regarding the volume of the water-supply that will be obtained. This is due to the fact that what lies below the surface of the ground is always more or less a matter of conjecture. In some cases our knowledge of the subsoil is sufficient to render the risks of well-sinking of no practical importance, but in the majority of cases it is otherwise, and a preliminary examination of the ground, if it can be made at comparatively small expense, is of distinct advantage. This can be done by boring or jumping a hole of small diameter to such depth as is necessary with the aid of specially constructed tools. The material removed from the hole affords information as to the nature of the strata through which the well will pass, and this information studied in the light of the experience which has accumulated from the sinking of many thousands of wells, enables us to form a fairly accurate idea as to the quantity of the water likely to be obtained. Where the subsoil is soft or sandy, the hole must be provided with an iron liner to prevent it from filling up as fast as it is made, but where the hole is in stiff clay or rock, the boring work can be done without any such artificial support.

In a brief note it is impossible to describe in detail the tools employed, but it is not difficult to

explain the principle upon which they work. Just as a hole is bored in wood by means of an auger or bit, so through the soft strata of alluvial deposits holes can be driven by similar tools of much larger dimensions. As the auger consists of a handle, a shank and the cutting edge, so the boring tools are similarly constructed. Various types of auger head are used and these can be screwed to steel rods which are usually 10 feet long, and as many as are necessary are employed to reach from the surface of the ground to the bottom of the bore hole. At the top there is a swivel head by which the rods can be lifted and the handle of the auger is formed by clamping iron levers to the boring rod at a convenient height above the ground, so that men by walking round in a circle can rotate the auger. When the material to be bored through is fairly stiff, the auger takes the form of a worm or an open shell, and from time to time it has to be lifted from the hole to remove the clay which has gradually worked into it. When the soil is of a loose character the auger has to be fitted with a shell above to hold the material removed by the cutting edge, otherwise it will fall back into the hole whilst lifting the auger to clean it. These shell augers are fitted with various shapes of cutting edges depending upon the nature of the material to be removed, which may vary from fine sand to soft sandstone. When hard rock has to be pierced rotary tools worked by hand are not effective, as the speed of working is too slow and recourse must be had to the percussive action of

variously shaped chisels for the breaking of the rock. The chisel is attached to the boring rods and a heavy blow is given by lifting them a few inches and allowing them to drop. Care must be taken to slowly turn the boring rods so that each blow of the chisel falls on a different diameter in the borehole. When the chisel has pulverized a sufficient quantity of rock, it is withdrawn from the hole and a plain shell lowered which collects the mud when it is rapidly jerked up and down in the water at the bottom of the hole. To work a set of boring tools it is necessary to have a derrick which may be conveniently made of 4 casuarina poles about 25 feet long. At the top of the derrick is fastened a pulley over which the lifting rope passes from the swivel head to the winch. This latter may be attached to two legs of the derrick and should have a lifting capacity of at least 2 tons. Besides the chisels and augers there is a great variety of tools which can be attached to the boring rods, most of which are ingenious devices for removing broken tools from the hole.

As the hole proceeds through soft material, lining tubes must descend with it and this is usually effected by rotating them, their own weight being sufficient to make them descend. If the pipes stick badly a suitable cap must be placed on the top and the methods commonly employed in pile driving resorted to. If the lining tube has to pass through a layer of stiff clay, the work is often facilitated by rymering the hole bored out by the auger to a larger size. If it is not intended to bore holes to a greater depth than 50 feet, a set of tools,

working in a 3-inch liner, will be a convenient size to employ; but if the holes are to run to a depth of 100 feet or more, the diameter of the lining tube should be at least 4 inches. Where it is known that artesian or sub-artesian water exists it is necessary to use pipes of much large diameter if it is desired to obtain an abundant supply of water.

Well-boring has been developed in the French territory of Pondicherry much more extensively than in any part of the Madras Presidency, and it is possible to procure sets of boring tools from the blacksmiths in Pondicherry at very reasonable rates. They do not however, supply the tools necessary for withdrawing the lining pipes and the sets are therefore not convenient for exploratory work, as in such work the lining tubes are usually removed from the holes as soon as the necessary information has been obtained. Messrs. Burn and Co., of Howrah supply suitable sets of tools. A set with lining tubes to bore a hole to a depth of 50 feet costs about Rs. 700, delivered in Madras, whilst a 4-inch set of tools with lining pipes costs about Rs. 1,100. Considerable experience is required to make satisfactory use of a set of boring tools, and difficulties and obstructions frequently occur which can only be dealt with by men accustomed to such work. In boring, the tools are subjected to rough usage and repairs are frequently found necessary. It is therefore desirable to have a fair number of duplicate parts so that the work of boring need not be stopped while repairs are being effected.

The cost of boring varies considerably, depending not only upon the diameter of the borehole and its depth, but also upon the character of the soils or rocks pierced. In the alluvial deposits along the coast in the Chingleput District where some 400 boreholes have been put down, the average cost for a 3-inch borehole is about 4 annas a foot up to a depth of 20 feet, thence on to 40 feet it costs 6 annas a foot and beyond that up to 60 feet, 12 annas a feet; from 60 to 70 feet the cost is Re. 1 a foot and from 70 to 80 feet, Rs. 1-4-0 a foot. Beyond this depth only a few boring have been made and the cost of the work done has varied considerably. These rates it should be pointed out do not include the cost of carrying the tools from one place to another. This is a small item when many holes are to be put down in one neighbourhood but becomes of importance when the tools have to be carried a long distance to bore a single hole.

The principal sources from which subterranean water can be derived are beds of sand, and rock which is highly fissured or partially decomposed. By putting down a borehole information on these points can be obtained and the exact depth at which the water-bearing strata is met with can be easily determined or its absence definitely ascertained. Sometimes in fissures the water exists under pressure and a borehole from the bottom of an existing well tapping a fissure will often deliver considerable quantities of water into the well from which it can be removed either by baling or by pumping. Along certain parts of the Coast, beds of sand

are found enclosed between impervious beds of clay. Some of these are of considerable extent and thickness and they contain water under pressure. Boreholes penetrating the upper impervious layer enable the water to rise to its static level and, when this is above the ground, flow takes place and the supply is termed artesian. More frequently the static level is below ground level and the water can only be obtained by sinking a well round the borehole to a few feet below the static level. Water will then flow into the well and can be removed by baling or pumping. If the borehole is made sufficiently large a suction pipe or pump may be put down the hole and the water drawn off by lowering the static level in the borehole itself. Ordinarily, however, borings do not penetrate artesian basins, and the character of the water-supply likely to be derived from sinking a well must be determined by an examination of the materials through which the borehole has passed. Gravels usually yield water most abundantly, then coarse sand and lastly fine sand. When the sand is coarse, or the water supply is derived from gravel, a well of small diameter will generally yield a large quantity of water, but when the sand is very fine, a well of large diameter is required to obtain a large supply of water and that again is only possible when the bed of sand is of considerable thickness. When the borehole has passed through rock and the chisels have to be used, no very definite information can be gained from an examination of the material brought out of the borehole, but by putting a tube well pump down the borehole, and ex-

hausting the water we can ascertain the rate of the inflow from the surrounding rock into the borehole under a given pressure. Apart from fissures this enables a rough estimate to be formed as to the water-yielding capacity of the rock.

The experience so far gained in the south of India is undoubtedly to the effect that large supplies of water are generally only to be obtained from beds of sand or gravel but occasionally wells in fissured rock yield an abundant supply of water, whilst percolation wells in porous or decomposed rock seldom yield more than moderate quantities of water. That is to say, they may yield 3000 or 4000 gallons of water per hour, but not 10,000 or 12,000. So far the largest supply of water derived from any single well in the south of India is 45,000 gallons per hour. This is not however the limit of the capacity of the well but that of the pump working on it. During the last year or two, oil-engines and pumps have been installed in many places to lift water for irrigation and the size most commonly employed is a 4″ pump which will deliver sufficient water for from 20 to 25 acres. This is equivalent to from 18,000 to 20,000 gallons of water per hour, and although there are few indigenous wells which will yield this supply, it has not been found difficult to obtain it from wells sunk after a preliminary investigation of the ground has been made by the use of boring tools. There is undoubtedly a vast amount of subterranean water which has never yet been made use of and to locate it definitely boring tools must be used.

CHAPTER XIII.

STEAM PUMPS IN THE KISTNA DELTA.

In 1892, when the experiments which form the subject of this paper were started, the area under the Kistna Delta irrigation project had reached the limit contemplated in the completion estimates, and there still remained an enormous area of land commanded by the canals, for the irrigation of which it was thought that no certain supply of water could be obtained from the Kistna. Most of this land is waste and without water is valueless; but with irrigation it is capable of yielding valuable paddy crops. It therefore became desirable to examine other possible sources of water-supply, to ascertain if it was feasible to make use of any of them, either to supplement the flow into the canals when the river was low, or for the irrigation of small areas independently of the great delta system. The first step in this direction was to suggest that the waters of the river Upputeru, which forms the outlet for the drainage passing into Colair Lake and which separates the Godavari from the Kistna delta, might be utilized for the irrigation of the tract of low-lying flat country which extends for several miles from the left bank between the villages of Kondangi and Pedalanka. The river is tidal, with a rise and fall of about 3 feet, and levels subsequently taken showed that the whole of this plain was from 1 to 3 feet

above high tide level and that to irrigate it would not entail lifting the water an average of more than 6 feet. The scheme was investigated and proposals submitted for carrying it out; but, as the project was a novel one and there were no reliable data on which to form an estimate of the quantity of water which it would be necessary to pump, it was suggested that an experiment should first be made to determine the suitablity of the land for cultivation, and of the water for irrigation, also to obtain information as to the duty which might be expected from the water. A tidal lock was then under construction at Lakshimapuram to connect the Bantumilly canal with the river Upputeru, and as the foundations were completed, there was available close at hand a 4 h. p. (nominal) portable engine with which the experiment could be made. After some delay an estimate was sanctioned. The site selected for the experimental cultivation was near the village of Mattagunta, where two ryots were found with sufficient enterprise to construct the necessary earthworks, provided they were allowed to cultivate 150 acres and were charged no water-rate. An 8-inch centrifugal pump was procured, and before finally fixing it in position it was temporarily set up at Lakshimapuram for the purpose of measuring the quantity of water which it would discharge. A long, straight trench, of uniform width, had been dug on the site of the future approach channel to the lock, and after the sides had been carefully sectioned and gauges fixed at each end, it was suitable for measuring

the water coming from the pump. The experiments were made by pumping for a certain number of minutes, noting the boiler pressure, which was kept constant, the height the water was lifted, and the rise of the water level on the gauges in the trench; then, from the dimensions of the trench, the number of cubic feet of water delivered per second could be calculated.

Table I. is a summary of the results.

TABLE. I.

——	I.	II.	III.	VI.	V.
Speed of engine revolutions per minute ...	75	74	64	82	Not taken.
Speed of pump ...	375	370	320	410	
Boiler pressure lb. per square inch ...	57	52	36·5	52	52
Lift of water in feet ...	5·03	5·03	4·70	5·67	6·02
Volume pumped in cubic feet ...	3,306	2,268	3,257	3,879	572
Duration of run in minutes ...	20	15	30	25	5
Discharge in cubic feet per second ...	2·75	2·52	1·81	2·58	1·906

Subsequently at Mattagunta the engine was worked with a boiler pressure of 45 lb. per square inch, and as the average lift did not exceed 5 feet it may be assumed

without any great amount of error that the discharge of the pump was about 2·0 cubic feet per second. As soon as these trials were completed, the engine and pump were taken to Mattagunta and pumping was started on the 21st July and carried on whenever water was wanted till the 10th of October, after which date there was very heavy rain and the river rose and flooded the area under cultivation to a depth of about 2 feet, which rendered any further pumping unnecessary. In Table II. is given a summary of the season's work.

TABLE II.

Month.	Total number of hours of pumping	Average discharge of pump in cubic feet per second.	Duty of water in acres per cubic foot per second.
July 21-31 ...	130·5	0·99	125·5
August 1-10 ...	44·5	0·37	336·0
August 11-20 ...	91·0	0·70	163·5
August 21-31 ...	55 0	0·42	295·5
Sept. 1-10 ...	138 0	1·15	108 0
Sept. 11-20 ...	94·0	0·78	159·5
Sept. 21-30 ...	61·0	0·51	243·7
October 1-10 ...	80·0	0·67	185·5

The area cultivated was carefully surveyed and found to be 124·34 acres, and after the crop was cut in December, it was weighed and the yield proved to be 35 tons 874 lb. of thrashed paddy and 39 tons 1,887lb. of straw, and was valued at Rs. 1,835. This was a

poor result and was mainly due to the late date of starting pumping, and to the fact that the ryots, who had never seen an engine or pump before, were every sceptical about the experiment and made no preparations for cultivation till they had seen what the pump could do.

It was therefore the end of August, before transplanting was well in hand and by that time the seedlings, many of which had been procured from seed-beds under the delta canals, were too old to produce good sturdy plants; moreover, the land occupied had never been cultivated before and it is well proved by the experience on similar lands under some of the delta channels that the first crop is always the worst and that in each succeeding year it improves till a limit is reached depending on the natural fertility of the soil and the amount of manure used. The experiment, therefore, was inconclusive, the conditions under which it was carried out were distinctly unfavourable, and the character of the season so unusual that no data of any value were obtained as to the quantity of water required for irrigation. The ryots, however, were very pleased with the result, and as it was desirable that the experiment should be repeated the following arrangements were made with them. That the experiment should be again made next year on a much larger area and that all the expenses connected with it should be borne by Government, but that the ryots should pay water-rate and land-cess for the area they cultivated as they would have done had the water been supplied from

the delta channels. Accordingly, in 1893, a 12 h.p. portable engine, as well as the 4 h.p. portable engine used in the previous year, were to have been sent down from the Bezwada Workshops as soon as the canals opened in June, but unfortunately, owing to pressure of work in the shops, the engines were not delivered till the end of the month and much valuable time was lost. The 4 h.p. engine was replaced in its old position and was arranged to drive one 8-inch centrifugal pump whilst the 12 h.p. engine was fitted up with two large pulleys, one on each side, to drive two 8-inch pumps, which were the largest size available. The pumps were mounted on stout wooden frames, placed across inlet trenches from the river. As the lift was small, no delivery pipes were used, but on the top flanges of the pumps a wooden casing was bolted which carried the water into the channel, and, whilst preventing any spill, offered no resistance to the free flow of the water. Pumping was started on the 3rd of July, but the 12 h. p. engine soon gave trouble; and as the men left in charge of it could not get it to work satisfactorily for any length of time, a 10 h. p. engine which was standing in the shops at Bezwada was hastily got ready and sent down to replace the 12 h. p. engine. It was, however, the 10th of August, before the new engine started work, and as there had also been some delay in the supply of coal for the smaller engine, progress with the experiment had so far been unsatisfactory; but afterwards everything went on well

and pumping was carried on day and night till the transplanting was completed. From June, till the end of August, the rainfall was very much below the average and though the area cultivated was much smaller than would have been the case if the weather had been more favourable, still the fact that the cultivation was almost entirely due to the water supplied by the pumps, makes the results obtained more trustworthy and the data with regard to the supply of water more valuable than would have been the case if there had been even an average rainfall. In Table III. is given a summary of the season's work.

TABLE III.

Month.		Number of hours engines were at work.		Average discharge of pumps in cubic feet per second.	Rainfall in inches.	Duty of water in acres per cubic foot per second
		4 H.P.	10 H. P.			
July.	1-10..	101	10	2 10	0·40	390·9
	11-20..	159	95	6·61	1·20	124 2
	21-31..	182	217	10·98	1·80	74·8
Aug.	1-10..	105	124	6·91	0·20	118·8
	11-20..	217	211	12·41	0·90	66·1
	21-31..	146	176	8·88	2·37	92·4
Sept.	1-10..	17	32	1·61	3·63	509·8
	11-20..	13	19	1·00	2·64	820·8
	21-30..	47	68	3·62	..	226·7
Oct.	1-10..	100	182	9·25	..	88·7
	11-20..	..	40	1·66	3·50	492·6
	21-30..	56	53	2·86	..	287·0
Nov.	1-10..	64	67	3·89	5·85	211·0
	11-20..	..	..	..	4·58	..
	21-30..	..	52	2·17	..	378·2

The area under cultivation was returned by the Revenue authorities as 820·8 acres, assessed at Rs. 4,624, which was more than sufficient to pay cost of pumping. The crop was cut in December and the yield on a number of fields was weighed so as to obtain an approximate estimate of its value. The fields were divided into four classes, according to the quality, and the results in each class are given in Table IV.

TABLE IV.

Class.	Area of fields on which the crop was weighed in acres.	Weight of thrashed paddy in lbs.	Yield per acre in lbs.
I ..	50·98	88,538	1,736
II ..	57·40	63,475	1,106
III ..	58·53	48,147	822
IV ..	49·20	12,452	253

The crops on nearly all the land included in the lowest class suffered from the attack of a species of blight locally known as "Kodu" and said to only affect plants which have been transplanted late in the season. As a similar fate befell the crops irrigated by the Kistna and Godavari canals, it is evident that the blight, which only occasionally appears, is not due to the use of water from the river Upputeru. Excluding, then, the lands in class IV. and remembering that most of the land was under cultivation for the first time, the general result may be considered very fair, and for the lands under class I. extremely good.

It had been originally intended that the whole of the water pumped from the river should be passed over a rectangular notch with a sharp edge, the depth of the water on which would have been taken at regular intervals and the discharge calculated, but owing to the delay caused by the break-down of the 12 h.p. engine, it became desirable to pump the water as fast as possible; and as the notch required a clear overfall, which meant lifting the water at least one foot more than would be necessary if it were dispensed with, this method of determining the daily quantity of water lifted was abandoned. Instead, a record was kept of the numbers of hours per day that each engine worked, and the pressure of steam in the boilers. In December, after the irrigation was over, the notch was fitted in its place and a series of experiments were made to determine the quantity of water lifted at various stages of the tide and with various boiler pressures. To ensure accuracy and to eliminate any velocity of approach to the notch, the banks of the channel had been made up so as to form a small tank about 60 feet square, into which the water from the pumps flowed and from which the water passed out over the notch. The result of the experiments are given below in Table V.

The engines usually worked with a boiler pressure of 60 lb., and with the admission valve fully open. Under these conditions the two engines working together on a lift of 5·18 feet pumped 14·01 cubic feet per second, whilst the 4 h. p. engine alone raised 4·38

TABLE V.

Engine.	Boiler pressure.	Speed of pumps.	Lift in feet.	Depth on notch in inches.	Discharge in cubic feet per second.
4 H. P. ...	60	445	2·50	10·25	13·23
12 H. P. ...	60	560			
4 H. P. ...	70	495	2·53	11·125	14·96
12 H. P. ...	70	620			
4 H. P. ...	70	485	5·03	11·125	15·21
12 H. P. ...	70	633			
4 H. P. ...	60	440	5 18	10·65	14·01
12 H. P. ...	60	594			
4 H. P. ...	50	390	5·37	9·75	12·27
12 H. P. ...	50	528			
4 H. P. ...	40	345	5·40	8·70	10·33
12 H. P. ...	40	463			
4 H. P. ...	70	490	5·70	10·90	14 51
12 H. P. ...	70	553			
4 H. P. ...	60	445	3 07	4·90	4·38
4 H. P. ...	70	465	3·45	5·00	4·51
4 H. P. ...	50	405	3·58	4·10	3·72
4 H. P. ...	40	350	3 74	3 72	2·89
4 H. P. ...	60	460	5·05	4·45	3·79
12 H. P. ...	70	640	5·50	8·75	10·43
12 H. P. ...	60	581	3 80	8·55	10 08

cubic feet per second on a lift of 3·07 feet, and 3·79 cubic feet per second on a lift of 5·05 feet and the 10 h.p. engine on a lift of 3·80 feet raised 10·08 cubic feet per second. It has therefore been assumed that as an average the 10 h. p. engine raised 10 cubic feet per second and 4 h. p. engine 4 cubic feet per second on lifts varying 2·5 feet to 5 feet, the greater work done by the two pumps driven by the 10 h.p. engine being due to the higher speed at which they were driven. Using these figures, the results given in Table III., under the columns headed "Average discharge of pumps in cubic feet per second"

and "Duty of water in acres per cubic foot per second" have been calculated.

With the conditions under which wet cultivation is carried on in the Kistna delta, the duty of water should be calculated by taking the area irrigated and dividing it by the maximum mean supply over a period of forty days. The result for the area under the pumps is a mean discharge of 9·795 cubic feet per second from the 21st July to the 31st August, which for an area of 820·8 acres gives an average duty of 83·8 acres per cubic foot per second. In this particular case the method is scarcely fair, as owing to the difficulties connected with the start and the failure of one of the engines, the quantity of water pumped during the first twenty days of July was not sufficient to comply with the requirements of the cultivators, and an extra supply had therefore to be given later on. A more accurate result would therefore be obtained by taking the averages over the whole of July and August, and if this be done the mean discharge is 7·98 cubic feet per second and the duty, 102·86 acres per cubic foot per second. The experiment fully demonstrated the feasibility of the proposal to irrigate these lands by pumping from the Upputeru, but the scheme was never carried out for the very satisfactory reason that it was subsequently considered possible to supply the lands with water from the delta canals. The results of these experiments, however, induced a native firm in Guntúr to start pumping from the

Colair Lake for the irrigation of some of the higher Lankas or islands. And after seven years' experience they are so well satisfied with this method of irrigation that they are now arranging to carry it out on a very extensive scale.

CHAPTER XIV.

DEVELOPMENT OF LIFT-IRRIGATION.

In the Report of the Indian Irrigation Commission, it is stated that the total area throughout the country dependent upon wells for irrigation is not less than 16 million acres, and the Commissioners, after discussing the prospects of utilising a larger proportion of the subterranean water, remark, "that it may not be sanguine to look forward to a period when the area under well irrigation throughout India will have doubled." An exhaustive survey of the possibilities of extending irrigation by the construction of new works on a large scale led them to propose a programme for expending 44 crores of rupees in 20 years from which they anticipated an additional $6\frac{1}{2}$ million acres of irrigation. That is to say, the Commission are of opinion that in the future, well irrigation will be of greater importance than it has been in the past, and of the land in India yet to receive the benefit of irrigation, not less than 70 per cent. will have to derive its supply from wells. At the present time only about 30 per cent. of the irrigation is under wells, but if the anticipations of the Irrigation Commissioners are realised, eventually the proportion will be much greater and may ultimately amount to as much as 45 per cent.

Obviously, therefore, every possible aspect of well irrigation is a subject needing careful study and investigation and not the less so, because in the past it has not been deemed worthy of the serious attention of engineers. In various ways, in different Provinces of of India, well irrigation has been encouraged by Local Governments, and to some extent material assistance has been rendered under the Agricultural Land Improvement Loans Act by the system of "Takkavi" advances, but nothing has been done to help the agriculturist in selecting the site for a well, nothing to show him how best to tap such water-supply as may exist, and very little, and that of no practical utility, to indicate the best means by which the water may be raised above the surface of the ground. What has been done in the past has been done by the ryot himself, what yet remains to be done must necessarily be on much the same lines. But it is possible that valuable assistance may be given him in various ways and the range of his operations greatly extended.

In other countries notably in the arid regions of the United States, an enormous amount of work has been done to bring to the surface water for the irrigation of land, which would otherwise remain a sterile waste. Mainly the work has been done by private efforts, but in America its importance is now being recognised by the State and the Federal Department of Agriculture devotes a large amount of time to the collection of data and the publication of the results of experiments. Bulletin No. 158 of the

Office of Experiment Stations is a record of Irrigation and Drainage Investigations carried out in 1904. No inconsiderable portion of the 743 pages of this report deals with subterranean water and its utilisation, whilst the extensive development of pumping from rivers, lakes and backwaters receives the attention which it deserves. To Indian readers the record is interesting as showing what can be accomplished by intelligent enterprise and abundant capital. But the conditions in the far West are so different from those that prevail here, that very little can be gleaned that is directly applicable to the circumstances with which we have to deal. Here, as in America, we must start *de novo* and work out the problems which will present themselves.

Under the Madras Government, irrigation by pumping has received more attention than probably in any other part of India, and the history of work in this direction goes back as far as 1892. In his interesting report on the Divi Pumping Project which is now being carried out in the Kistna District, at a cost of more than 18 lakhs of rupees, whereby 50,000 acres of land will be irrigated by pumping from the Kistna river below the anicut, Mr. R. N. H. Reid, the Executive Engineer who designed the installation, remarks :

" The favourable financial position of the project naturally raises the question of whether the like cannot be done elsewhere, but before considering this, a brief retrospect may be taken of what has been done in the District since Messrs. Ussher and Chatterton first sug-

gested the use of pumps for irrigation in 1892. In that year an area of 125 acres of land at Mattagunta in the Gudivada Taluk was irrigated by lifting water from the right bank of the Upputeru river which constitutes the outlet for the Colair Lake. The average lift was under 5 feet, and a 4 horse-power portable engine was used to drive an 8-inch centrifugal pump. In the following year, 1893, a second engine of 10 horse-power, driving two 8-inch centrifugal pumps was added to the plant of the previous year and an area of 820 acres was successfully cultivated. It was then decided to bring these lands at Mattagunta under anicut distribution by constructing the Pedalanka channel and the pumping experiments were accordingly discontinued.

Native enterprise then came forward and a firm of Guntur and Bezwada merchants were granted a concession, enabling them to cultivate by means of pumping machinery, an area of 1,000 acres on the margin of Colair Lake for which they were to pay no water-tax. In the years 1894 to 1897, in spite of many difficulties from alternate flood and drought, they successfully cultivated several hundred acres. A want of expert advice hampered their efforts. The centrifugal pump employed, which had a discharge pipe 15 inches in diameter, was too large to be economically driven by the small 10 horse-power engine, and the irrigation channels were far too large. A second native firm which came from Ellore started pumping in July of last year (1900) and successfully cultivated about 200 acres of land on one of the Colair Lankas. They im-

ported from Glasgow a 9-inch pump driven by a direct acting vertical engine.

The successful pumping at Mattagunta naturally led to the suggestion of Divi Island as a suitable field for pumping on a large scale. Here was an area many times larger than any available on the margin of the Upputeru river and which, moreover, was quite cut off from the surrounding delta. I was in charge of Divi Island at the time as Sub-division Officer and in 1894, submitted a report with outlined estimate for irrigating 50,000 acres at a cost of about 14 lakhs of rupees in machinery and works. In 1896, a small establishment was sanctioned for taking levels and an alternative estimate was submitted for irrigating 30,000 acres of waste land, leaving the existing wet cultivation to be supplied from tanks as before.

Sanction was accorded in G. O. No. 1081—I., dated 22nd December, 1900, for the installation of a small pumping plant at Yetimoga which is 10 miles from the sea. Two twelve horse-power portable engines were brought to the site and employed to drive three centrifugal pumps of 7, 8 and 10 inches diameter, the whole being housed under a galvanised iron-shed. Water was pumped from the latter end of June, 1901, into the village tank from which the ryots had been in the habit of cultivating from 50 to 100 acres whenever the river freshes were favourable. An area of 830 acres now is under cultivation. With the low water-tax of Rs. 3 for the year 1901, it was found that the net revenue paid 4 per cent. on the capital

outlay. With the rate raised to Rs. 5 as in 1902, the return should be much higher. The plant now at site can irrigate 1,500 acres against the 830 acres of 1901.

The ryots at first viewed the experiment with their customary diffidence. No preparations for cultivation were made till the water was seen flowing from the pumps. It so happened that the season was very unfavourable for the old system of tank irrigation. In Yetimoga, instead of 830 acres not more than 50 would have been cultivated. The whole island suffered from drought, and in place of from 5,000 to 10,000 acres of wet cultivation under all the tanks the actual area brought to maturity was only a few hundreds. The area under the pumps at Yetimoga exceeded the total of all the rest of the Island put together, with the result that the ryots of all the other villages are now petitioning for the extension of a similar system to their lands."

The Island of Divi, which is to be the scene of the largest development of lift-irrigation which has hitherto been attempted, is situated at the mouth of the Kistna river, being cut off from the mainland, on the one side by the main river and on the other by the Puligadda branch. It was originally intended to build an aqueduct across this branch to carry the waters of the Kistna canals to the island. But as the water supply available is barely sufficient for the lands already commanded by the Kistna canals, this project has been definitely abandoned and it is now

intended to pump water from the bed of the river on to the island. The works, in course of construction, provide for lifting 560 c. ft. per second to a height of 12 feet and the plant will consist of 9 Diesel Oil-engines, of 160 horse-power each, driving 39-in. centrifugal pumps. The water in the river is tidal and is only fresh during the irrigation season which begins in June, and ends in December, so that the irrigation will have to be confined to paddy cultivation. The annual working expenses are estimated to amount to not more than Rs. 2 per acre and as the water rate charged will be Rs. 5, it is obvious that the project will prove highly remunerative. Apart from the shortness of the season during which water can be pumped from the river, the conditions at Divi Island are unusually favourable for a pumping scheme; especially is this so in regard to the variations in water-level, as the vertical range between the low spring tides when the upland water has ceased to flow and the maximum flood level is unusually small. In high floods no pumping is necessary and the greatest lift at the end of the irrigation season is expected not to exceed 12 feet. The small range of the tide at the mouth of the Kistna is largely responsible for the very favourable conditions of which advantage is now being taken.

The volume of water passing down many Indian rivers and now flowing uselessly to the sea is not only enormously great, but the flow continues for a sufficiently long time to render it practicable to make use of the water for irrigation, if only it could be obtained

at a sufficiently high level to command lands suitable for irrigation. The Divi Island scheme may possibly be the forerunner of not a few similar installations, but much greater difficulties will have to be faced and the financial prospects are at the present time by no means so satisfactory.

Outside the deltas the rivers run in valleys and not only is the range between summer water-level and maximum flood-level very considerable, but the height to which water has to be lifted to command the land is generally so great as to preclude the possibility of pumping on anything but a very large scale. Nevertheless, it is certain that if the hydraulic conditions of the rivers in India are carefully studied, it will be found that there is an enormous field for the development of lift-irrigation. In the south of India, from many rivers large quantities of water are drawn off every year by the ingenious system of Spring Channels and where conditions are favourable this system of irrigation is fairly satisfactory. But in most cases it is only possible to obtain a small percentage of the water available and that by an expenditure of labour inordinately great. If the labour had to be paid for at anything like current rates for cooly labour, the cost of irrigation by Spring Channels would be found prohibitive. But Spring Channel irrigation is possible because it utilises in the slack agricultural season of the year labour that would otherwise be unemployed.

At the present time * we know very little about the

* Vide "The flow of water in Sand" p. 177.

water in the sand of river-beds during the dry season of the year. There is some evidence to show that the quantity is fairly considerable, and that it might become a very important factor in the extension of irrigation if only it were properly looked after. It is certainly worth while to consider the question at some length. In the hot weather a typical Indian river presents a vast expanse of dry sand. A few inches or a few feet below the surface of the sand, water is invariably found. By digging channels in the sand with the bed slope much less than that of the river, the upper end of the channel will have its bed considerably below the line of saturation of the sand, and water from the river-bed consequently flows into the channel. Proceeding downstream the channel gradually gets shallower and finally its bed coincides with the bed of the river. Before this point is reached, there is a point at which the water-level in the channel coincides with the water-level in the sand. Above that point water flows from the river-bed to the channel; below that point the water collected in the channel begins to flow back into the river and the sooner, therefore, the channel can be got out of the river and the bed made impermeable to water, the greater the quantity of water that will be available for useful work. If a Spring Channel with a slope of 2 feet per mile is carried up a river, the bed slope of which is 6 feet per mile, at the end of 2 miles its bed will be 8 feet below the bed of the river and if the line of saturation is 4 feet below the river-bed, there will be, say, two feet of water in the channel at its head.

Half a mile lower down the water in the channel will coincide with the level of the water in the sands; from this point onwards the channel will begin to lose water into the sand and the volume will gradually diminish till it is diverted from the river-bed into the more or less impermeable material of the banks. Obviously, therefore, a Spring Channel only taps the superficial layers of water-bearing sand and most of the water is allowed to remain unutilized.

A succession of Spring Channels, one below the other, is what is usually found in a river of this type. Beyond the head of the lowest channel all the water is wasted and in many cases this is undoubtedly a very large quantity, but how much, it is extremely difficult to say. In addition, there is probably a very large loss of water by evaporation from the vast expanse of sand but what this may amount to, there are absolutely no data by which to frame an estimate, though it would not be difficult to devise some simple experiments which would give practical information on this point.

From the foregoing sketch it will be seen that the extreme simplicity of the spring channel by no means compensates for its very obvious defects and it seems most probable that a well-devised system of lifting water from a river-bed by means of pumps would be more economical and would enable us to obtain a considerably larger quantity of water. Spring Channel irrigation is only possible with *Kudimaramat* labour, of which it is difficult to express the money value. A

low rate will put the cost of such irrigation at 2 annas per acre per day or, say, Rs. 4 per acre per month. This is, in itself, a fairly high charge but the real defect is the small proportion of water utilised of that which is available. In rivers with a fairly rapid bed-fall and no great depth of sand the Spring Channel is most satisfactory, but when the bed slope is small and the depth of sand great, the Spring Channel cannot get at more than the water in the superficial layers of sand.

It is easy to point out in a general kind of way the advantages of lift irrigation from rivers, but when we come to the working out of details very serious difficulties present themselves, and as yet no attempt has been made to solve them. The water-supply of certain towns like Conjeevaram, Trichinopoly and Madura depends upon the storage capacity of the sand in the riverbeds of the Palar, Cauvery and Vaigai rivers respectively. The expense to which a town may go to obtain a pure water-supply is very much greater than what is permissible when the water is required for irrigation and the experience of the Sanitary Engineer who constructed these water supply scheme is, therefore, of little value to us in this matter.

Mr. Tota R. V. Ramanujam Chettiar, of Trichinopoly, was the first Indian to grasp the possibilities which may be realised by pumping water to supplement the deficiencies of spring channel irrigation. He and his partners own a tract of 300 acres of land on the right bank of the Cauvery, a few miles below the junction of the Amaravathi with

the main stream. These lands are watered by a spring channel which takes off from the Amaravathi some distance above its junction. The supply of water is always precarious and in recent years has often failed, so that the return from the land is very small. With the assistance of a loan of Rs. 8,000 from Government which has been granted to him under the Agricultural Land Improvement Loans Act, Mr. Tota Ramanujam Chettiar has erected a pumping station on the banks of the Cauvery in the immediate vicinity of the land to be irrigated. The pumping station is situated on the high-berm within the river flood banks and the engine house is placed at such a level as to be above even extraordinary floods. Two wells, one 15 feet and the other 20 feet in diameter, have been sunk in the sand about ten feet below the normal hot weather water level and connected together. In the smaller well two centrifugal pumps one with a suction pipe 12in. in diameter and the other with a suction pipe 8in. in diameter have been fixed and for driving them a 25 horse-power Hornsby liquid fuel engine has been installed. This engine is capable of driving one pump at a time but not both together. When the water level is fairly high the 12″ pump can be conveniently run but if the water level sinks very low there is only sufficient power to drive the 8-in. pump. Between the engine and the pumps is a counter shaft fitted with pulleys which renders this alternative arrangement possible. The two wells do not supply sufficient water to keep the 12-in. pump at work and for the present a channel

has been dug through the high-berm into the lower bed of the Cauvery to a sufficient depth to bring to the pumps enough water to keep them going. This channel differs, however, very materially from the ordinary spring channel as its bedfall is practically the same as that of the river and it terminates suddenly with its water level below that of the water in the adjoining sand, so that it is simply an open filtration gallery.

This installation has been at work for one season now with great success. There has been trouble with the engine owing to certain defects in the arrangement for driving the pumps, but the land has been thoroughly irrigated and bears valuable crops of plantains and sugar-cane whilst the neighbouring lands, which entirely depend upon the spring channel, have borne anything but satisfactory crops. During the latter half of the year the spring channel is the principal source of supply and it is when the water from that source fails that the engine and pump are set working. From the experience of a single year it would be very unfair to estimate the financial results which are likely to be obtained, but there is no doubt whatever that even in the first year the transaction has proved highly profitable and in years to come when the whole of the land has been brought under intense cultivation, the results will be still more satisfactory. This pumping station has been carefully watched by a number of other landholders, and there is not much doubt that there will be many more

applications for assistance to put up similar pumping stations in other places. The maximum lift in this instance is not more than 16 feet and the pump does nothing more than raise the water which is collected by a sort of infiltration gallery. The larger pump raises about 7 c. ft. per second and the withdrawal of such a small quantity of water has no appreciable effect on the Cauvery river. Even if twenty such installations were put up, the effect would probably be slight, provided they were not in too close proximity to one another.

* This year a similar experiment will be made on the banks of the Hagari river, at the experimental farm which is being established by Government to deal with the question of irrigating black cotton soil. The pumping plant is now in course of erection and it will probably commence work at the beginning of June. A 28 h. p. oil-engine and a 10-in. pump have been purchased and the latter is to be erected over a well sunk at the edge of the bank of the river, and penetrating the water-bearing sand through its whole extent. There will be a certain amount of percolation into the well but it is not likely that it will be anything like sufficient to keep the pump supplied with water. Arrangements to effect this have yet to be devised. Probably, in the first instance, an open cut will be made similar to that which has proved satisfactory with the Cauvery plant, but if the percolation into the well is free, a permanent infiltration gallery may pro-

* 1905.

bably be constructed of sufficient length to yield the quantity of water required. An essential part of the programme, however, is to pump as much of the silt carried by the water during floods as possible, and arrangements have been made to let the flood waters have free access to the pump.

The land to be irrigated by this installation runs back from the river for about a mile and the slope of the land in that distance is about 8 feet. This introduces, in a very mild form, one of the greatest difficulties which will have to be contended with in connection with the introduction of pumping from rivers. In this case the difficulty will be got over by pumping in two stages. The water lifted from the Hagari river is carried back in a channel which runs in a bank about 4 feet high close to the pumping station and gradually diminishes in height till it becomes level with the ground and then runs in cutting up to the farm buildings where it is lifted into a channel running in bank by a second engine and pump. A similar plan has been adopted to deliver the water pumped from the bayous of Louisiana and Southern Texas on to the rice fields which, in recent years, have developed to such an enormous extent.

The variations in water level of the Hagari river are well within 20 feet, and as the suction of a centrifugal pump will work well enough up to 25 feet, there has been no difficulty in placing the engine above any probable water level. But in most rivers the range of water level is much greater than this, and it is by no

means a simple matter to arrange the machinery so that the engine is not submerged in high floods. Where the banks of the river are steep or almost vertical, the problem is a comparatively simple one as a well can be sunk in the river close to the bank and carried above the maximum flood-level. In the bottom of the well a horizontal centrifugal pump with a vertical spindle can be fixed and driven by a shaft, carried up the well, on which a horizontal pulley is fixed above the flood-level. The engine can then be fixed on the bank and drive the pump through a quarter-twist belt. The permanent masonry work connected with such a scheme must be fairly heavy and correspondingly expensive, and consequently the capital cost of an installation of this kind will amount to a good deal per acre unless the volume of water to be dealt with is large and the cost of the machinery is a considerable percentage of the total outlay. As yet no such installation has been erected in India and although pumping from the Nile in Egypt by means of steam engines and pumps has been practised on a very large scale, the prevailing conditions there are quite different to anything experienced in India except possibly in Sind with the Indus river.

In the case of most rivers the summer water-level is far below that of the surrounding country and the slope of the ground is not steep enough to allow of pumping the water in a single stage, except by incurring the cost of very deep cuttings, which would give an immense amount of trouble in flood time. Under

such circumstances small pumping installations are out of the question, as the capital outlay required will be too great. Where abundant water is available and there are large tracts of land to be irrigated it is probable that in most cases the engineering difficulties can be surmounted. It may be assumed that there is no objection to allowing the pumps to be drowned during the high floods but it is essential that the engines should be placed above the flood-level. The electric transmission of power would get over the difficulty provided the motors could be run back on rails whenever floods were expected. A large central generating station would be a very economical arrangement for pumping from a big river like the Godavery or the Kistna, especially if it were necessary to lift the water in two or more stages, and continuous pumping might be ensured even in flood time by the use of fairly long suction pipes and by making the stages overlap so that the suction pipes of the pumps on the second stage will begin to draw water from the main stream before the pumps on the first stage are drowned. In this case it will not be practicable to make the vertical stages more than 20 feet in height except the last one. Where the lift is high and the slope of the ground gradual it will be necessary to provide a rising main and in this connection it is possible that the employment of armoured concrete or armoured cement pipes may be found practicable and much cheaper than cast iron. All this, however, is more or less a matter of speculation and it is pretty

certain that lift irrigation from rivers can only be gradually developed as one class of difficulty after another is practically surmounted.

On the Adyar river to the South of Madras, for irrigation purposes, two pumping installations have been erected. The first, which was put up nearly two years ago, supplies water to part of the land of the Agricultural College at Saidapet. Many years ago when these lands formed part of a garden belonging to the Nawabs of the Carnatic, a well was sunk near the river and connected thereto by a culvert. A few hundred yards lower down the river is a small masonry anicut which holds up a pool of water extending some distance beyond the Marmalong Bridge on the Mount Road. On the side of the well, away from the river, a massive brick-work retaining wall was built which formed the end of an earthen bank thrown up to carry the water to the lands of the garden which are some 15 to 20 feet above the normal water-level in the river. Formerly a pair of country mhotes was employed to lift water from this well, but two years ago we installed a 6½ h. p. oil-engine and a 4-in. pump and on an average about 150,000 gallons of water per day have been lifted up for the irrigation of certain sections of the farm. The power available was hardly sufficient during the last hot weather when, owing to the drought, the river sunk to an abnormally low level.

A few miles further up the river at the village of Chittatur we have erected a 14 h. p. oil-engine and a 5-in. pump for M. R. Ry. Appaswami Mudaliar.

The river there consists of a series of rocky pools which have never been known to dry up and for a considerable part of the year there is a slight flow of water down from pool to pool owing to the leakage from the Chembarambakam tank and the drainage water from the lands under it. The banks of the river are fairly steep and the lift is about 23 feet. Some distance back from the hot weather channel, a well has been sunk and connected to the river by a culvert terminating in an open cut. In very high floods the pump will be submerged but the engine stands at a somewhat higher level and it is expected that the highest floods will not reach it. A moderately high bank carries the water from the pump to the level of the land, the lift being divided into about 16 feet of suction and 7 feet of delivery. The installation was only completed early this year at a cost of about Rs. 5,000 and it is hoped will provide sufficient water for 100 acres of land. So far the pumping seems to have had no appreciable effect upon the water-supply in the river, and if this be so, it may possibly be practicable to set up several other installations of the same kind.

It is well known that a considerable quantity of water passes down the Palar river in the wide sandy bed, and in August, 1902, a scheme was outlined for sinking wells at intervals alongside the river and pumping water from them with power supplied from a central electric station. The scheme was submitted to Government in the Public Works Department and the proposal was so far approved that money was pro-

vided for establishing a single pumping station to test the practicability of getting at the water of the river by means of wells. In 1904, a site was selected near the village of Attur, about three miles from Chingleput and a well 15 feet in diameter sunk at a spot which it was thought would prove satisfactory, and a sufficient area of land was acquired to test the practicability of irrigating by means of the water so raised. The well was sunk to a depth of 35 feet, or nearly 20 feet below the water-level in the river, but except for a few feet of blown sand on the surface and one or two thin layers of sand lower down it passes through practically impermeable strata. A boring was then put down from the bottom of the well for another 50 feet with unsatisfactory results. The well was found to yield about 20,000 gallons of water a day and was obviously a failure. I then had borings taken at various places on the land which has been acquired for experimental purposes and in some places more favourable indications were obtained. Finally a spot was selected about 250 yards from the existing well and a small pot well 2 feet 6in. in diameter sunk. This well only extends 5 or 6 feet below the level of the river-bed and its flow was recently tested with a hand-pump. Over 1,500 gallons of water per hour were taken out of the well and the depression of the water-surface was not more than 2 feet. This would mean that a 15 feet well with the same depression will probably yield 10,000 or 12,000 gallons per hour and by increasing the depression to 5 or 6 feet it is probable that,

without blowing up the bottom of the well, a supply of as much as 20,000 gallons of water per hour can be counted upon. The land acquired in the neighbourhood of the well has been converted into an experimental farm and placed under the charge of the Deputy Director of Agriculture. The anticipated supply of water will be more than sufficient for the irrigation.

The failure of the well at Attur and hundreds of similar failures which have occurred to ryots in well-sinking elsewhere, strongly point to the necessity of a preliminary exploration of the ground before incurring the expense of sinking large wells.

For this purpose, well-boring tools capable of putting down holes about 4 inches in diameter are sufficient, and generally it is not necessary to go to a greater depth than about 100 feet. But over extensive tracts of country it will probably be found advantageous to put down boreholes of much larger diameter and to a much greater depth in the hope of tapping either artesian or sub-artesian supplies of water, or to penetrate beds of gravel from which water may be freely obtained by the use of deep well pumps. In Pondicherry and the country to the south of it, the existence of an artesian water supply has long been known, but it is not so well known that many hundreds of artesian wells have been put down by the ryots and that from these wells the water rises above the ground level and irrigates their fields. The quantity of water yielded by the wells varies very much, but in no case does it amount to more than about half a cubic foot

per second. If pumping were resorted to, there is not the slightest doubt that many of these wells could be made to yield a very large supply of water. Quite recently, Mr. Panduranga Mudaliar who, for nearly two years, has been irrigating his lands near Cuddalore with an oil-engine and pump, has, with the aid of some men from Pondicherry put down a borehole at the bottom of his well. At a depth of 84 ft., he struck water and it rose up the borehole which was 7 inches in diameter with considerable force and filled the well to within 13 ft. of the surface of the ground. The engine and pump were set to work and about 300 gallons per minute were removed from the well. This resulted in lowering the water-level to about 20 ft. from the surface of the ground, but gradually the flow up the borehole decreased and eventually the well was emptied. With the borehole terminating at 28 ft. below ground level, a permanent discharge of about 140 gallons per minute was obtained. Subsequently, a second borehole of similar diameter was put down with a similar result, and Mr. Panduranga Mudaliar is now able to keep his engine and pump at work as long as he likes lifting over 300 gallons per minute from a depth of about 18 ft.

This discovery of a sub-artesian water-supply, as far south as Cuddalore, is of great importance as indicating that the beds from which the supply is derived are of considerable extent and probably of great capacity. Doubtless, numerous other boreholes will now be put down and eventually the demand for water will be

so great that the natural flow of the wells will cease, and pumping will have to be resorted to everywhere to obtain a supply of water. This is what has happened over and over again in America and though enterprise and capital are not so freely forthcoming in this country; yet, when the value of a perennial supply of water is fully realised, there can be but little doubt that the same sort of thing will occur here. The Pondicherry well-borers are very expert at their work and under favourable conditions put down boreholes to depths of as much as 300 ft. very cheaply and very expeditiously. Their skill and experience might well be utilised in many parts of the Presidency, and if such work were systematically carried out, under competent supervision, whatever the direct results might be, there is no question but that the indirect results would be of immense value and would enable us to avail ourselves to the uttermost of such stores of subterranean water as actually exist.

Mineral explorations in the agency tracts of the Godaveri District have resulted in the discovery of fairly considerable supplies of artesian water and in the Chingleput District near Tiruvellore, Messrs. Best and Co., whilst boring for coal, have struck a fairly strong supply of artesian water at a great depth below the surface. In the neighbourhood of Cocanada and Samalcotah just to the north of the Godaveri Delta, artesian water has been found and a number of boreholes put down. But so far no attempt has been made to increase the flow of these boreholes by means of pump-

ing. In Coimbatore where the water-supply for irrigation is derived from many thousands of wells, the sinking of boreholes at the bottom of the wells has frequently led to tapping supplies of water under sufficient pressure to rise considerably above the bottom of the well. Generally speaking, boring for water in the south of India has not been carried on very extensively, but the results of such work as has been done are of so encouraging a nature that further development in this direction is extremely desirable, and in course of time, it is not unreasonable to hope that the whole of the country will be carefully explored wherever the geological conditions are such as not to obviously preclude the possibility of finding artesian water in considerable volume.

In the Madras Presidency the general slope of the country is from west to east but the ridges forming the water-sheds between each river basin gradually become less prominent as they approach the alluvial tracts along the East Coast, so that variations in level of but a few feet would change the course of not a few of the rivers. In many places there are considerable tracts of water bearing sand overlaid with alluvial deposits marking the ancient courses of rivers which may now be found working their way to the sea some distance off. Such beds of sand are invariably full of water, and in not a few cases where the lie of the land permits of it, the water can be brought to the surface by what is locally known as a 'springhead'. This consists of a channel dug at right angles to the contour

lines with a very small slope so that eventually it pierces the layer of water-bearing sand and the water escaping by this artificial spring is conducted away for the irrigation of the lower lands. In practice this method of getting at the subterranean water involves a considerable amount of labour at the outset and only taps the surface of the water available. By sinking wells into the sand and lifting the water out vertically much larger quantites can be obtained though, naturally, the cost of getting at the water is much greater. Our enquiries during the last twelve months have revealed the existence of very large areas of land from which such supplies of water can be obtained, and in certain places we have sunk wells with considerable success.

In the village of Pannampattu near Villupuram, we have installed a $9\frac{1}{2}$ h. p. engine and a 6 in. pump. The pump draws its water from a circular brick well which has been sunk on one side of a large open excavation. The water-bearing sands which rise within a few feet of the surface yield an ample supply and it is quite practicable to extract 1·50 cubic feet per second continuously from this one well. The soil round the well is extremely porous, otherwise such a supply of water would be sufficient for about 200 acres of garden crop. An effort is now being made under the direction of Messrs. Parry & Co., to ascertain what area of land can be irrigated and what crops should be grown to obtain the most profitable results. About 10 miles to the west of Villupuram, at Siruvannur, Mr. Pandurangam Mudaliar has sunk a well of the

ordinary type employed in that locality. He has put in a 3 in. centrifugal pump and has been driving it for some time with an oil-engine. The pump lifts about half a cubic foot per second and can be worked continuously day and night, the water-level in the well sinking very little. A similar well was sunk at Manamadura on the banks of the Vaigai river about two years ago and it has never been possible to unwater it with a 3 in. pump. Again at Pandur near Trivellore in the Chingleput District several wells on the Lutheran Mission Settlements have been tested with a 3½ h.p. engine and a 3 in. pump. In one case a sub-artesian supply was tapped and sufficient water obtained to keep the engine and pump fully at work and in other cases though the wells did not yield so much water, yet the quantity was sufficient to indicate that if a couple of wells were sunk and connected together, the percolation would be sufficient to keep the engine and pump running. At Pannampattu the sand yields water extremely freely but it also flows in easily so that it is difficult to separate the sand from the water and special arrangements will have to be devised to do this. At Siruvanur and Manamadura the sand is much coarser and no difficulty has been experienced in taking out the water.

In these tracts of land underlaid by water-bearing sands where the lift does not exceed 16ft., the piccotah is universally employed and the area under well-cultivation is limited by the number of men available to work the piccotahs. This I have been assured is

the case wherever I have made enquiries as to why when such a plentiful supply of water is available more use has not been made of it. Similarly, as in the country to the north of Trivellore where the water-bearing sands lie at greater depth and the country mhote is used, the area under irrigation is limited by the number of cattle available for such work. The great majority of ryots are unfortunately far too poor and their holdings much too small to enable them to avail themselves of engines and pumps. If co-operation were possible something might be done, but it is almost hopeless to expect anything in this direction and it is to be feared that many years will yet elapse before full use is made of the available stores of water which lie but a few feet below the surface of the ground over extensive areas in the Carnatic districts of this Presidency.

The vast majority of wells from which water is lifted for irrigation in this Presidency are little better than holes sunk in the shattered and disintegrated rock which occurs near the surface. In some of them a fair water-supply is met with at a moderate depth. In other cases the holes are sunk to a great depth with less satisfactory results. As a rule, it does not pay to irrigate land when the water in the well is more than 40 or 50 ft. below the surface of the ground, but it is suspected that in many cases this is just about the level of the water plane in the dry season of the year. Where solid crystalline rocks are not encountered, the deeper the well is sunk in disintegrat-

ed and shattered rocks, the greater is the water-supply available and the greater the certainty that it will not fail. With modern pumping appliances it is possible to take out water very much more cheaply than is practicable with cattle, and there is not the slightest question that a very considerable percentage of the several hundred thousand wells sunk in the rocks of Southern India could be enormously improved if they were sunk still deeper and provided with adequate pumping machinery. Investigations in this direction are now in progress, and in certain cases where wells have been deepened, the supply has been materially increased. As instances of this I might mention the well at Melrosapuram and the well in the Jail compound at Coimbatore where in both cases oil-engines and pumps have been in use for several years. Other experiments in the direction are in progress, and though the time has not yet arrived when we can definitely ascertain the results, there is but little doubt of the correctness of the idea that the deeper we go the larger is the volume of water that can be obtained.

CHAPTER XV.

LIFT-IRRIGATION.*

My object in presenting this paper to the Industrial Conference is to draw attention to the advance which has recently been made in the Madras Presidency in the scientific study of subterranean water and well irrigation, and to place at the disposal of those interested in the improvement of the agriculture of India the information which has been gathered in the Irrigation Pumping Department during the four years it has been at work.

Although wells and subterranean water are worthy of the attention of Engineers it is a matter of regret that in India they have been very much neglected in the past and that the cultivators have been left almost entirely to their own resources. In 1882, Captain Clibborn, who was afterwards Principal of the Roorkee Engineering College, submitted a long report on well irrigation in the North-West Provinces and Oudh, arriving at the result that "well irrigation is only profitable under favourable conditions and that there is reason to believe that in most districts cultivators have already very fully availed themselves of their opportunities." In Bombay, Mr. F. D. Campbell, an Executive

* Contributed to the Industiral Conference held at Surat in December, 1907.

Engineer of the Public Works Department of that Presidency, spent some months on special duty and as the final result of his enquiries formulated the opinion that "nothing can be done to introduce new or cheaper systems of well construction or of lifts than those which the ryot is already familiar with." Much later in 1896, in a report on water-lifts recording the results of some experiments on the efficiency of various systems of water-lifting, I wrote "Steam-pumping machinery is utterly beyond the means of the ryots, and the force of the wind is too uncertain and in general in India it is too weak to be profitably utilised by wind-mills even of the most modern type. Animals are, therefore, the only source of power available, and water-lifts in the future must continue to be, as they always have been, worked by cattle. Moreover, the Indian agricultural population are so singularly devoid of even the most rudimentary mechanical skill that it is absolutely necessary that machines intended for their use should be designed to work without complicated gearing of any kind."

At that time it seemed as though the last word had been said on the subject of well irrigation, as all the attempts to improve on indigenous methods of lifting water had led to no decisive results, and the engineers who tackled the problem retired baffled by the difficulty of providing a water-lift of superior efficiency to the native water lifts without incurring too great an initial outlay and without forcing the cultivator to use a machine too complex for his comprehension and be-

yond the resources of the ordinary village artisans when it needed repair. Further the opinion was generally held throughout the Madras Presidency that few wells could be found which would yield sufficient water to keep even small pumps of modern constuction at work for a sufficient time to make it worth while to instal them. It was also very erroneously assumed that the cultivator must keep his bullocks for agricultural work and that in their off time they could be employed working mhotes on the wells and that such work practically cost nothing.

In 1900 in an article on "Underground water-supply" I wrote: "Underground water in India has never been studied properly by engineers or geologists and wells are sunk in a happy-go-lucky manner to a haphazard depth. They are constructed with primitive appliance and at small cost. Expectations are not usually great and as they are generally realized the people are content. The depth of the well is limited by the fact that the primitive methods of sinking, in vogue among the ryots, prevent them going more than a few feet below the hot weather level of the water. With an engine and pump to keep the well dry much greater depths might be attained and possibly the supply of water enormously increased." And again in 1902, in an article on "Well Irrigation" the following passage occurs: "In the south of India well sinking is a very primitive business and the better the supply of water generally the shallower the well. A ryot wants a well and, having selected a

spot which he thinks suitable, he sets to work and either sinks a hollow cylinder of brickwork into the ground till water in sufficient quantity to satisfy his expectations is reached, or he excavates a big rectangular hole in the disintegrated rock which forms the sub-soil and goes on deepening it till the inflow of water is greater than can be dealt with by the modest water-lifting appliances at his disposal. Year after year, in the hot weather when the water-level is low, he may increase the depth by adding to the number of mhotes on the well, and in this way many valuable water-yielding wells have been sunk. Let us suppose, however, that the unwatering of the well in the hot weather is accomplished by a powerful engine and pump, the work of excavating will be facilitated and the depth may be rapidly increased till either the inflow is greater than can be dealt with or practical considerations indicate that it is not worth while to go any deeper."

These remarks were consequent upon experience with the working of oil engines. For small powers they had been found to be inexpensive reliable motors, that required no great amount of skill to run them Even with kerosine oil as the fuel it was obviously practicable to employ them for lifting water under favourable conditions, but when later on it was found that there was no difficulty in using the much cheaper liquid fuel which is imported into India, the posibilities of their employment were vastly increased. It was not very difficult to convince the Government of

Madras, in the Irrigation Department, that experiments in this direction were well worth trying, and that in fact the time had arrived when the question of well irrigation might again be taken up with some prospect of doing useful work and of evolving means of making much greater use for irrigation purposes of subterranean water than had been previously possible. Moreover increased experience in the management of the indigenous industrial work had led me to think that the mechanical inaptitude of the people of this country can be cured if proper means for training them are provided.

One of the causes of the poverty of the people of India is the little use they make of mechanical appliances and efforts should be made to effect a change in this direction. The great rise in the price of foodstuffs, accompanied as it is by an equivalent or even greater rise in the wages of the labouring classes, has brought many of the wealthier agriculturists to a similar conclusion, and it is certain that in the next few years a great advance will be made by the substitution of oil and gas engines for bullock-power in many of the processes for preparing agricultural produce for the market. It is necessary that this opinion should gain ground and be more widely accepted and that mechanical engineers should be induced to devote their ingenuity and skill to providing simple machines capable of being driven by engines of a few horse-power, for such operations as extracting oil from seeds, the juice from the sugar-cane, hulling paddy or grinding wheat. It is true that most of these operations

can be carried out in an extremely satisfactory manner if the scale of working is only sufficiently large, but the day for big enterprises of this kind has not yet arrived, and for the present it is desirable to provide special machinery which can be worked on a small scale and which can be purchased and set in operation with the comparatively small amount of capital which as yet is available among individuals. Co-operative enterprise is still a thing of the future and till that is realized our efforts must be directed to providing for the small capitalist.

It is true that there are many machines for doing this kind of work already on the market, but save in the case of sugar mills I do not think that any of them are quite satisfactory and their use is not extending as rapidly as would be the case if they were better adapted to the work they have to perform. Fortunately for lifting water the centrifugal pump is almost ideally suited to the work which it has to perform. Its first cost is small, it is extremely simple and fairly efficient and combined with the oil-engine there is likely to be a wide field for its employment in this country.

It must not, however, be imagined that the oil-engine and centrifugal pump will replace to any appreciable extent the indigenous methods of lifting water. According to the latest returns (for the year 1905—1906) there are in the ryotwari tracts of the Madras Presidency upwards of 628,400 wells in good working order and a further 61,000 out of repair.

The number in the Zamindaris is not known, but the total for the whole Province may well be over three quarters of a million. To lift water from these wells either the picottah or the country mhote is used, the number of special forms of water-lift being absolutely insignificant. Only a small percentage of these wells yield water sufficient to keep more than a single mhote or a single picottah at work. Not that many of them could not be made to yield a much larger supply of water, but the owners either have not enough land to use the water on or are too poor to provide the labour necessary to lift the water.

The idea is generally prevalent that native methods of lifting water are extremely cheap since the cattle must be kept under any circumstances, but careful investigation shows that it is only true within certain limits and those limits have already been reached. Well cultivation is carried on to the utmost extent possible under the existing conditions and if any great extension is to take place in the immediate future, it must be by supplying the ryots with additional power for lifting water. At the same time the cost of that power must be very much less than that they now pay for any work done in the way of lifting water which is beyond the capacity of the cattle they keep for general agricultural purposes.

It is therefore a most important matter that we should endeavour to ascertain the actual cost of lifting water by native methods and at the outset it may be conceded that within the limits already referred

to the ryot can lift water fairly cheaply. The question is what he will have to pay, and what does he pay, for lifting water when cattle have to be kept specially for the work, or when he has to hire cattle. Five and twenty years ago at the Agricultural College Farm, Saidapet, Mr. Benson, as the result of long and careful trials, came to the conclusion that the cost of keeping a pair of good cattle amounted to 12 annas per day and that they were capable of lifting 240 cubic feet of water to a height of 25 feet for 8 hours a day. Or in other words 4,000 cubic feet of water could be raised one foot for one anna, or an acre-inch of water could be raised 25 feet for Rs. 1-6-8. In the last 25 years rates have risen very considerably and the cost of lifting water has increased, so that under the conditions of Mr. Benson's estimate it is hardly likely that 3,000 cubic feet can now be raised one foot for one anna.

Simple as the problem may seem, it is extremely difficult to find out how much work is done by a pair of cattle under normal conditions. Any attempt at an experiment interferes with the normal conditions, the efficiency is temporarily increased and better results are obtained than are possible without some kind of special supervision. Two years ago I made some enquiries in the Chingleput district and I found that a fair day's work for a single mhote was as follows :—

On a lift of 20 feet, using a bucket holding 20 gallons of water, 30 lifts per hour would be made for 9 hours a day. The minimum cost of keeping the cattle

was Rs. 15 a month and the usual rate for hiring them was Re. 1 per day. Taking the minimum figure this works out at 2,160 cubic feet lifted one foot for one anna. These figures are corroborated by some data collected by the late Mr. H. A. Moss who was Executive Engineer in the same district. In a report on "Wells and Well Irrigation in the Chingleput district" he states :—

"Water is usually raised by picottah when the lift is 15 feet and under, when more, bullock mhotes are used. The cost of raising water for about 6 to 10 feet is about 4 pies per thousand cubic feet per one foot lift. From 10 to 15 feet the cost comes to about 5 pies and from 15 to 20 feet it is about 6 pies per thousand cubic feet per one foot lift."

The Chingleput district is in no way exceptional and the figures obtained will more or less apply to the rest of the country. Any great exactitude is impossible, but it will not be far from the truth then to put the cost of lifting water either by means of the picottah or the mhote at one anna for every 2,000 cubic feet lifted one foot. Under favourable conditions and with water-lifts specially adapted to the work better results than this can be obtained. For instance, in South Arcot, where there is an abundant water-supply at about 15 feet below the surface of the ground, double mhotes worked with a rotary whim are largely in use and are very much more efficient than the ordinary water-lift in other parts of the country. It is not, however, with the extremely favourable cases that we have to deal. If

lift irrigation is to be extended largely the conditions will generally be more difficult to deal with than has hitherto been the case and the means provided must be capable of working under a fairly wide range of conditions.

During the last four years, through the agency of the Irrigation Pumping Department, we have been gradually introducing the use of oil-engines and pumps for irrigation work and have tried them under a great variety of conditions, many of them being extremely unfavourable and none of them ideal. I do not propose to burden this paper with technical details, as evidence regarding the statements which will be made is furnished in full in the various official reports which from time to time are issued by the Department.

Oil-engines and pumps are only economical and their employment therefore can only be recommended when the quantity of water to be dealt with is fairly large. If a well yields a thousand cubic feet a day, it will give ample employment for a mhote, but to make it worth while to instal an engine and pump the yield should be not less than 10,000 cubic feet a day for the greater part of the year. It is true that engines and pumps are working, and working at a profit, where the supply falls below this limit, but the circumstances are more or less special and it is doubtful if they could be repeated indefinitely. The following figures taken from the administration report of 1906-07 show what has been the actual cost of working at a number of installations :—

	Number of cubic feet of water lifted one foot for one anna	
	1906-07.	1905-06.
Melrosapuram	3,900	...
Kadiampatti	4,013	6,400
Villupuram	3,230	5,800
Cuddalore	9,370	6,750
Saidapet	8,300	4,126
Katalai	...	6,500
Bezwada	3,340	3,200

In the report for 1905-06 it was shown that under very favourable conditions a small oil-engine and pump, dealing with 216,000 gallons of water per day on a lift of 25 feet, could raise 13,500 cubic feet one foot for one anna. This may be considered a maximum seldom if ever attained under actual working conditions. The figures given in the table fall very far short of the ideal, but the worst are as good as the best that can be obtained from cattle-power and the best show that water can be lifted at from one-third to one-fourth the cost of doing it by cattle. The larger the scale of pumping operations, the more cheaply can each unit of work be done whilst the indigenous methods of lifting water are only applicable on a very small scale and would utterly break down if any attempt were made to use them for lifting large quantities of water.

In the report by Mr. Moss already alluded to some information is given regarding the duty of water. He says:

"The cost of irrigating paddy from wells alone is expensive especially when the rainfall is at all deficient. On the other hand, the return per acre from well-irrigated paddy is much more than from that irrigated by tanks and channels. It is generally half as much again and may be even twice as much, six months paddy usually requires 40 waterings of about 2,000 cubic feet per acre. The cost from a well about 15 feet deep may be taken at one rupee per watering. If the land is far from the well it will be more, owing to the loss by absorption. If the rainfall is bad, 60 waterings would be required and the outturn without the rain is always deficient. As the water in the well will be low the return to the ryot is very small and paddy is not worth cultivating under such circumstances.

"Four months paddy requires usually 30 waterings at a cost of about Rs. 30. The cost of watering is less than that for 6 months paddy but the return in grain is less."

The average area irrigated by a well is about 3 acres and as paddy requires more water than any other crop grown under wells, it is obvious that the average yield of the wells is less than that which can be deduced from observations on paddy cultivation. Taking Mr. Moss's figures we find that 1,333 cubic feet of water per day are required for 3 acres of paddy. It is therefore probable that the average yield of the wells in this presidency is not more than 1,000 cubic feet per day and in many cases it is certainly less than this.

In the large irrigation systems where the distribution of water is under proper control, the duty of water is from 90 to 100 acres per cubic foot per second, that is to say, a continuous flow of one cubic foot per second will irrigate from 90 to 100 acres of land. The water used by the ryot yields a duty of 195 acres, or practically twice as much, and this is probably the best result that can be obtained, as we may be fairly certain that the accumulated experience of many generations of paddy growers instinctively prevents the Indian cultivator from using too much water. In the note on "Irrigation by pumping from a well at Melrosapuram" published as an Agricultural Bulletin, the data collected at that station are furnished, and they corroborate this estimate. The high figures at Melrosapuram are largely due to the use of masonry channels for conveying the water from the well to the field. Even to the ryot the loss of water by soakage from his channels is a serious matter, though the land to be irrigated is close to the well. To the man who uses an oil-engine and pump it is still important as the length of channel is much greater, and generally it may be assumed that the larger the irrigation system and the greater the area deriving its water from one source of supply the larger will be the percentage lost from the canals and the distributaries themselves.

The cost of lifting water for irrigation by mechanical means depends very largely upon the continuity of the supply and the number of days during the year on which water is supplied. Interest and depreciation

bulk very largely in the total cost of running the plant and an economical result can only be obtained when the percentage of working hours is large. The ryot in one way or another pays from Rs. 5 to Rs. 8 a month for the irrigation of an acre of land. In most cases this heavy charge is not severely felt, as it is met by the utilisation of what would otherwise be bye-products, but as soon as these bye-products are exhausted the full cost is felt and the ryot realises that it is impossible to grow the ordinary crops at a profit. With oil-engines and pumps the cost of irrigation varies considerably and for small schemes of from 20 to 40 acres it may be taken that the irrigation will cost from Rs. 1-8-0 to Rs. 3 per month. The larger the scheme the lower the cost of irrigation will be; the best result being that which will probably be obtained in the Divi Island Pumping scheme where 50,000 acres of land are to be irrigated and where the water may have to be lifted to a maximum height of 10 feet. It is estimated that the working expenses will not amount to more than Rs. 2 per acre for the season or an average of about 8 annas per acre per month. As a lift irrigation scheme, the Divi Pumping Project is exceptional in regard to the size of the plant and the extent of the area irrigated, but in many places along the Coast similar schemes of a smaller character are practicable, and where the lift does not exceed 10 or 12 feet paddy cultivation may be carried on profitably. For the most part, however, pumping will not be under such favourable conditions, the lift will usually be greater,

the supply irregular and the plant much smaller. Even if paddy cultivation pays, there is no reason why it should be encouraged, as other and more valuable crops can equally well be grown. People who have the enterprise to instal engines and pumps generally take a great deal of interest in the cultivation under them, and as usually they have some command of capital, the tendency is to go in for intense cultivation and to grow crops which yield a very much larger profit per acre than can possibly be obtained when the common food-grains are cultivated. So far sugar-cane, plantains and ground-nuts have yielded the best results, but large profits are also made in the cultivation of tobacco, turmeric and the ordinary garden crops. A supply of water which can be relied upon all the year round is practically wasted if it is not utilized for crops which require water the whole year through. These are the crops which yield the largest return to the cultivator, partly because the extent to which they can be grown is limited, and partly because their cultivation necessitates the possession of a considerable amount of capital. With a perennial supply of water under engines and pumps the gross return from the cultivated area ought to be never less than Rs. 100 an acre, and it often amounts to two or three times this sum.

When the Experimental Pumping Department was first started, the impression generally prevailed, among those who were best acquainted with the agricultural conditions of the country, that the scope for its operations would be extremely limited

because of the difficulty of finding sites where a sufficient water-supply could be obtained combined with landholders in the neighbourhood who would have sufficient capital to avail themselves of it. The fact that there are now about 100 pumping plants at work* in the Madras Presidency is evidence that there is a much wider field for their employment than was anticipated, and the investigations which have been carried on, before installing these plants, have put us in possession of a large amount of information of a most satisfactory character. Certainly there will be absolutely no difficulty whatever in irrigating hundreds of thousands of acres by engines and pumps if only the capital required to lift the water can be found, and the ryots can be taught to make use of the water in a proper way.

The great obstacles to progress are the poverty of the people and the extraordinarily minute way in which the land is sub-divided. The smallest area which can be profitably cultivated by an engine and pump is from 10 to 15 acres, and the number of such holdings in one block is small. Still there is a sufficiently large number to enable a great deal of work to be done in exploiting this method of lifting water, and long before the possibilities of large holdings are exhausted, the owners of smaller holdings will perceive the advantage of combining together and by co-operation securing to themselves the benefits conse-

* November 1911. The number of engines and pumps is now nearly 400.

quent upon this cheap method of lifting water. I do not think it is any exaggeration to say that oil-engines and pumps will prove, and in fact are proving, extremely potent agents in the development of the material resources of the country. Already in some of the rural tracts the ryots are familiar with them, recognise their merits and regard them as desirable things to possess; whilst those who have got them have been led to take a much deeper interest in agriculture than they did before and being intelligent men with capital, their farms are becoming the centres for the diffusion of improved agricultural practices throughout the country. I am in hopes that in the course of a year or two it may be possible to form an Agricultural Association every member of which will be the user of an oil-engine and pump, the main object of the Association being to encourage the extension of the use of such methods of lifting water and to supply the members with information which will enable them to make the best possible use of the water at their command. So far Agricultural Associations in this country are an exotic growth and without official support few of them would be in existence. The Association I am contemplating will stand on a different footing, its members will all be agriculturists operating on a fairly large scale and keen to make the most of the capital they have put into their land.

The supplies of water sufficiently large to give employment for engines and pumps are mainly to be found in the Coast districts and along the margins of

some of the big rivers. In such districts as Coimbatore, where well cultivation has reached its highest development on indigenous lines, there are apparently not less than 5,000 wells which will yield sufficient water to give employment to an engine and pump. They are mostly deep wells and the supply of water is derived from a thick layer of disintegrated rock resting in situ on the igneous or highly metamorphosed rocks which prevail over the greater part of that district. The well should invariably penetrate the whole thickness of weathered rock as the water annually absorbed by the ground always tends to move down to the lowest layers of permeable rock. This is by no means the practice of the ryot as the great depths at which the water would stand in the hot weather would prove an insuperable barrier to extended use of the water. On the other hand in South Arcot, Chingleput and North Arcot abundant evidence has been obtained that over very considerable tracts of country the ordinary native wells can easily be improved so as to yield enormously greater supplies of water than have hitherto been drawn from them. In these districts the water mainly occurs in vast beds of coarse sand which form subterranean reservoirs of considerable but as yet quite unknown extent. In some cases the sand is covered by a comparatively thin layer of alluvial deposit and the water can be found by sinking wells from 15 to 20 feet deep. In other cases the sand lies at a considerably greater depth and is overlaid by impervious beds of clay, which have to be

pierced, to get at the water. In the South Arcot district between Pondicherry and Cuddalore these beds are more than 200 feet below the surface of the ground, but the water is under pressure sufficient to force it up the boreholes and form true artesian wells. To the north of Madras similar sand beds are found at a much smaller depth, but the pressure is not sufficient to constitute true artesian wells and the water has to be lifted in some way or other. Some hundreds of boreholes have been put down in the bottom of existing wells and rather more than half have successfully tapped the sub-artesian water-supply. Most of the pipes are of 4″ diameter and the yield of water varies from 50 to 200 gallons per minute. It is probable that in most cases a much larger flow could be obtained by either inserting a pipe of larger diameter or by deepening the well and lifting the water from a lower level so as to diminish the pressure against which the water is forced up from below. In one case two 7″ pipes have been put down and the yield of water is over 500 gallons a minute which is lifted out of the well by a 12 h. p. engine driving a 6″ centrifugal pump. In nearly every case these improved wells will yield sufficient water to justify the installation of engines and pumps, but as yet the people are too poor and too dubious about the continuance of the flow of water to do anything in this direction. In a year or two they will be in a better position to realize the value of the water beneath their lands and may then be anxious to avail themselves of any means whereby they

can secure to a larger extent of land an unfailing supply of water.

In the tract of country to the south of Pondicherry many hundreds of boreholes have been put down and the water-supply derived from the artesian beds is very considerable and it is not improbable that to the north of Madras the development of sub-artesian water will be found to be of similar extent. In other places there is reason to suppose similar water-bearing deposits exist, but as yet they have not been explored and their capacity is entirely unknown. Where the water-bearing sands occur nearer the surface and where the surface slope of the country is considerable they have been drained to some extent by 'spring heads' or *kasams*. These consist of a pond, often of considerable size, which has been excavated till the water-bearing sands are reached. From the pond a deep channel with a small bed-fall leads the water out on to the lower lands. This channel is generally a mile or two long and a good deal of the water drained from the pond must be lost on its way to the land. The supply in the pond is apparently maintained by percolation from the beds of sand which lie at a higher level. The sand in these *kasams* is usually very coarse and the flow of water consequently very free. As a rule in the hot weather they dry up altogether, or the water has to be lifted out of them by baling with picottahs or mhotes. Unquestionably the installation of engines and pumps would enable a very much larger body of sand to be drained of water and it is probable that in

most cases a perennial supply of water could be obtained in place of the present supply which is only sufficient for a single crop.

Where the slope of the country is small it is obvious that irrigation by *kasams* is impracticable, but very extensive beds of coarse sand exist and have been tapped and tested in many places and at no very great cost it is practicable to put in wells which will yield from 200 to 300 gallons of water per minute. A considerable number of these have already been sunk and there is no doubt that they will steadily increase in number. It is impossible to say what area of land is underlaid by these waterbearing sands in the Madras Presidency, but it certainly runs into thousands of square miles and there is probably water sufficient for the irrigation of several hundred thousand acres. The withdrawal of large quantities of water will lower the level at which it is found, but there is fair ground for assuming that most of these sand deposits are in direct connection with the main drainage lines of the country and every fresh which passes down an adjoining river will tend to restore the original water level.

There does not seem to be much hope that deep-seated artesian water-supplies will prove of value for irrigation. In the Godavari district artesian water has been tapped in several places,—by mining prospectors in the Polavaram Zamindari, by the Madras Railway at Ellore and by various people in the neighbourhood of Samalkota and Cocanada. At Ellore a borehole was put down to a depth of 430 feet and cost nearly Rs.

13,000, whilst the yield of water does not appear to have been much more than about 3,000 gallons per hour.

The sandy beds of most of our rivers are probably the next most important source of water-supply and one which, as yet, has been but little made use of. The indigenous method of getting at the water is extremely ingenious, but it involves the expenditure of a very large amount of labour. Channels or ditches are dug in the beds of the rivers with a bedfall considerably less than that of the river. In the upper part of the channel the water from the surrounding sand drains into the channel, flows down it and is carried away through a cut in the river bank. In some districts "doruvu" wells are employed to some extent. They are wells sunk in or close to the river bank and derive their water-supply from the sand. Apparently the engineering work involved is beyond the ordinary ryot and such wells are not popular. Where they exist they require study and where they do not exist it is desirable to encourage them as much as possible.

It has always been assumed in the past that there was a slow flow of water beneath the sand in the river-beds and it was tacitly accepted that the spring channels probably drew off most of the available water as no large supply could ever be obtained at any one point. A careful review of the evidence furnished by the partial failure of several attempts to get at the water in the sandy beds of these rivers led to an examination of the conditions under which spring channels work, and it was then found that the prevailing

ideas were erroneous and that there is no flow of water in the sand of a river-bed except between pool and pool, where the slope of the water plane in the sand may be very steep. Below a certain level the sand in the beds of rivers is saturated with water which remains motionless unless a local hydraulic gradient is established sufficiently steep to cause the water to flow.

Every cubic foot of sand below the saturation level contains rather more than 2 gallons of water, so that a square mile of sand 10 feet deep is a reservoir containing over 550 million gallons of water, or sufficient for the irrigation of a thousand acres of land. Allowing for the fact that the sand in the river-beds is not always 10 feet deep and that it is impossible to extract all the water from the sand but without taking into account any water 20 feet below the level of the saturation line it is quite certain that for every square mile of river-bed we might have an equivalent of square mile of irrigation. The problem which remains unsolved is how to get at this vast quantity of water. In this matter our experience is gradually increasing and one certain conclusion is that owing to the resistance which the sand offers to the motion of water it is impossible, except at great expense, to collect any large quantity of water at one point. On the Hagari river we found it a simple matter to obtain 150 gallons a minute and for a moderate outlay* we are drawing 750 gallons a minute from the river-bed, but to obtain more water than this at our pumping station seems likely to prove

* Rs. 2,300.

a difficult matter. By sinking wells in the river-beds it is found that in most cases a comparatively small well will yield 300 or 400 gallons of water per minute so that, if a large quantity of water is to be withdrawn, a large number of wells should be sunk at a sufficient distance apart to prevent one well materially interfering with another. In many cases these wells can be sunk inside the river bank, in others quite close to the bank and when this is practicable the pumping work may be done by power distributed electrically. To get at the water in the middle of the river-bed when the bed is very wide is a much more difficult matter and may be considered for the present outside the range of practical engineering.

All the experience we have gathered so far points to the fact that with brick wells from 12 to 15 feet in diameter we can get enough water to supply a 4″ centrifugal pump with a depression of the water surface of 3 or 4 feet. Some day I think there will be a chain of such wells extending along both banks of most of our rivers and at intervals of about 10 miles there will be electric generating stations supplying current to electro-motors to drive those pumps.

The perennial flow of most of our rivers is already diverted by means of anicuts which in the upper reaches of the river, where the bed is rocky, are often very numerous. Still there are a few cases where the water-supply is wasted by being allowed to flow into the sandy expanses in the lower reaches of the rivers and the remedy is obviously to instal engines and

pumps. Of installations of this kind there are already one or two at work, and there would be more if permission to pump could be obtained.

On the West Coast, in Cochin and Travancore, there are extensive tracts of irrigated land formed by bunding off the backwaters and draining them. The system of irrigation is of great antiquity, but of late years it has been modified by the introduction of pumping machinery and there are a large number of steam and oil engines now employed in draining these lands. A great deal of enterprise has been exhibited in this work but not much engineering skill and unquestionably the Kole cultivation, as it is called, could be enormously improved by combining irrigation with drainage and by putting the operations in each section under one control.

In some of the swamps along the coast and in lakes like the Kolair, between the Kistna and Godavari rivers, there is a considerable body of fresh water which only requires to be lifted a few feet to render it available for the irrigation of the neighbouring lands. Years ago in the Kolair Lake and in the Lankas bordering on the Uppeteru river such cultivation was established under steam pumps and proved moderately remunerative, but gradually interest in the matter died out and the pumping stations were abandoned. The successful working of the oil-engines has revived interest in the matter and pumping has recommenced, all the available land being now brought under cultivation.

In connection with the development of this modern phase of lift irrigation the improvement of existing wells is a matter of great importance and if only a small percentage are found suitable for working with oil engines and pumps, the absolute number will be large and they may become important inasmuch as they will often occur in those tracts of country which are most liable to be affected by the vicissitudes of the seasons. Owners of wells have generally some vague idea of the quantity of water they will yield, but they have very little notion as to the quantity of water which a 3″ centrifugal pump will lift, and it frequently happens they want to set up pumps when the water-supply is quite inadequate. The most satisfactory way of investigating cases like this is to first ascertain the yield of the existing well towards the end of the hot weather and then put down an exploratory borehole to determine the nature of the surrounding rock. The borehole will generally furnish sufficient evidence to enable an opinion to be formed as to whether it is worth while to deepen the well. Sometimes the borehole taps fissures carrying water under pressure and materially increases the flow into the well; sometimes it reveals beds of porous rock which only require opening out to yield a copious supply of water. Where the rock is hard and the water is mainly found in fissures, the explosion of a charge of dynamite at the bottom of the borehole will sometimes materially improve the supply.

As yet we have done very little work in this

direction, but I am not without hopes from the experience already gained that when wells can be sunk to a much greater depth than has hitherto been the native practice, it will be found that the inflow will in many cases justify resorting to pumping machinery. Where we can keep our engines fully employed, which means wherever we can command from 150 to 200 thousand gallons of water per day, the depth from which it can be lifted, before this becomes an unprofitable operation, is much greater than is the case in ordinary well irrigation. With this the limit is about 40 feet whilst 150 feet will probably be found practicable with oil engines and pumps. It is not so much the height to which the water has to be lifted as the risking of a large capital outlay in what must of necessity always be an uncertain undertaking which makes it at present doubtful whether sinking wells to any very great depth is to be encouraged. In some cases we have found that a very slight addition to the depth of a well enormously increases the inflow and it is just at this point that native well-sinkers have to stop as the unwatering of the well becomes an exceedingly difficult operation when only mhotes or picottahs can be employed.

Where the water is contained in sand it is not difficult to frame an estimate of the cost of getting at a certain quantity of the water and we do so by putting down an exploratory borehole to ascertain the thickness of the deposit of sand, which sand is itself examined to determine the size of the grains of

which it is composed, but with wells sunk in rock we are in no such satisfactory position. We have but little more knowledge and much less experience than the professional well-sinkers of the country; and we shall have to make many experiments before we can teach the people of this country anything. To this end we have recently ordered a portable petrol-pumping plant which can easily be carried about and can be put down any well and used either for baling during construction work or for observations on the rate of inflow. The Government of Madras have also sanctioned a sufficient sum of money for a systematic series of tests as to the advantage or otherwise of torpedoing boreholes sunk in hard rock. Our progress with wells of this type is not likely to be very rapid unless we can secure the interest and co-operation of the more intelligent men who are interested in the improvement of water-supplies for irrigation. Throughout the country there is doubtless a good deal of empirical information the collection and study of which would be of value. It would help us to make a better start, but I do not think it will carry us very far on our way as the water-supplies, which we are searching for, must lie at a much greater depth than is within the range of indigenous experience and to make them available we require an enormously greater supply of power than has ever been at the disposal of the owners of wells in the past.

The financial aspects of this method of lift irrigation have already been dealt with to some extent when

we were discussing the relative cost of lifting water by the old and by the new methods, because in the figures given for the new methods a full and proper allowance has been made for interest and depreciation of the capital outlay involved in setting up a plant. In an appendix to this paper will be found figures giving the actual cost of a number of a installations which have been set up. The cost, per acre brought under irrigation varies considerably. It may be as low as Rs. 50 an acre or as much as Rs. 200 an acre, but obviously for high-class cultivation where the yield per annum may be valued at Rs. 400 or Rs. 500 an acre it may pay very well to expend a great deal more than Rs. 200 per acre to get a good supply of water. In the Deccan, under some canals near Poona, Rs. 50 per acre is the water-rate on land growing sugar-cane, and in this Presidency many gardens and plantations could easily stand a water-rate of a similar amount. It would have afforded me very great satisfaction to have presented accurate figures regarding the working expenses and return on a number of farms where this new system of lift irrigation prevails, but no one cares to furnish them. There is, however, ample evidence that it is very profitable and the best indication that it is appreciated is to be found in the fact that the rate of increase in the number of installations is greatest in those places where the number is already largest or where they have been longest at work. In ordinary years and under normal conditions, given a sufficient water-supply, there should be

no difficulty in turning it to very profitable account, but often with oil-engines and pumps the greatest profit will be made in years when the season is unfavourable, scarcity prevalent and prices high.

In many cases oil-engines and pumps may be used to supplement other sources of supply and convert agriculture of an uncertain type into one of great certainty. One of the earliest installations in this Presidency was erected on the banks of the Cauvery, from which river the water-supply to the pump is derived. The lands ordinarily depend upon channels from the river for irrigation water, but this is extremely uncertain, and partial or total failure of the crops occured at such frequent intervals that the owners of the land derived nothing from it and the ryots who cultivated it earned a precarious livelihood. Over a tract of 300 acres a 12″ pump has completely changed this. The natural water-supply may fail, but the pump is there to take its place and the whole area can be converted to perennial irrigation. The owner reports that during the last eighteen months 55 acres have been under plantain cultivation and have yielded a gross return of over Rs. 400 per acre, or about one-and-a-half times the whole of the capital outlay on the pumping plant. In a good year the return from paddy cultivation would have been about Rs. 50 per acre and the net profit very small. Under plantains the net profit on the 55 acres must have been sufficient to pay 50 per cent. on the initial expenditure. The area under perennial irrigation, such as plantain

or sugar-cane, would have been much larger, but it is restricted to 60 acres at this place by the Revenue authorities lest the water-supply to lands lower down the river should be interfered with.

From the figures given in the appendix it will be seen that the minimum cost of a pumping installation is about Rs. 2,000, and the actual out-of-pocket working expenses, being the necessary expenses for fuel, lubricating oil, stores and repairs, will be about Rs. 50 a month. The installation of engines and pumps is therefore a financial operation of considerable magnitude even with comparatively wealthy ryots. Very few, if any, have sufficient ready money, and a certain number of installations have been paid for by loans under the Agricultural Land Improvement Loans Act, such loans being usually repayable in twelve annual instalments. This method of financing these pumping schemes would be entirely satisfactory were it not for the difficulty which the borrowers experience in finding the necessary security. My experience is that the majority of the applications for loans are rejected for this reason and it may possibly be desirable in the future to amend the Act so as to provide greater facilities for obtaining loans for the purchase of engines and pumps. If the machinery could be taken into account when assessing the value of the security for the loan, there would be no difficulty and loans would be freely applied for. Greater success has attended the sale of engines and pumps under the hire-purchase system which has been worked out by Messrs. Massey & Co. Under this

method the would-be owner of the pump has to pay one-fourth of the money down and the balance in instalments generally extending over two or three years during which time he has to pay 9 per cent. interest on the balance debited to him. He is thus able to get his engine and pump for a comparatively small initial outlay and to pay the balance out of profits accruing from the use of the pump. So far the system of working has proved satisfactory and it is probable that it will be resorted to very largely in the future when it becomes more generally recognised that irrigation under oil-engines and pumps can be made a very profitable business. The hire-purchase system is a very vicious one when applied to afford facilities for the purchase of unproductive goods by those who cannot afford them, but it has distinct merits in some cases and is an extremely simple method of financing small industrial undertakings as it provides the small capitalist with the equivalent of money on fairly easy terms. It is possible that a great deal more might be done in this way if Government took the matter up, purchased the engines and pumps themselves and sold them on easier terms than private firms can do. The risk of loss will be very small as the engines and pumps would remain the property of Government till they are fully paid for, and they would never be sold except for use under conditions which after investigation by the expert officers of Government are reported to be satisfactory.

The number of oil-engines in use in this Presi-

dency for minor industrial undertakings as well as for lifting water is growing rapidly and there has naturally sprung up a rather keen demand for men capable of driving the engines. The extreme simplicity of the oil-engine renders it possible to train fitters to look after them in a few days and there has never been any great difficulty about getting drivers, but a good fitter is rather wasted when put to drive a small oil-engine and his pay adds quite unnecessarily to the working expenses. In Madras we have started a school for Oil-engine Drivers, where practical instruction is given in the driving of various kinds of oil-engines and the pupils are put through an elementary course of fitting so as to enable them to take the engine to pieces, clean the parts and fit them together again. Anything more than this it is not considered necessary that a driver should know. If the engine really gets out of order, it is better that it should be overhauled by a skilled mechanic and the driver in charge of it should be nothing more than a driver. A good many people, who have bought engines, have sent their men or servants up to this school to be trained, and after a course of instruction lasting from 3 to 6 months they are generally found quite capable of looking after the engine. In this way Oil-engine Drivers can be provided at a cost no greater to the owner than if he had to provide a man to look after a pair of bullocks. With large engines the saving in this direction is not a matter of much importance, but with small plants the fact that local men could be

trained to do all the work that is necessary has tended much to increase the popularity of these engines. The Engine Driving school was originally started in the School of Arts, but it has now been taken over by and forms part of, the Chengelroya Naiker's Technical Institute. The class is popular as the men who pass through it can always obtain work.

The fact that large monetary transactions are involved wherever oil-engines and pumps are set up and where the fuel for working them has to be purchased and paid for in cash has in a remarkable way led to a more definite appreciation of the monetary value of irrigation. This is still more emphasized by the rise in the price of food stuffs and the tendency to pay farm labourers in cash instead of in kind. The farm is no longer so self-contained as it was, the working of it necessitates transactions outside the village and the crops have to be selected by the ryots not merely with a view to their own internal requirements and to meet the demands of Government and the District Board, but also to meet the charges connected with the working of the engine. Outside markets have to be studied to a greater extent than formerly and the cultivator is brought into more intimate contact with the outside world. Of course the movement is a very small one at present, but the tendency is one in the right direction and should ultimately conduce to the development and education of the agricultural community.

In the South Arcot District where more pumps have been fitted up than in any other part of the

country and where nearly all the wells have an unfailing supply of water, the owners of pumping plants are beginning to raise water and sell it to their neighbours when they do not want it themselves. At the Panampet pumping station which was leased to Messrs. Parry & Co. two systems of selling water were tried. Ground-nut crops were irrigated for Rs. 5 per acre per month and for other crops the whole supply of the pump was sold to any ryot who wanted water for a fixed rate per hour. This practice is very largely in vogue in the Western States of America where water for irrigation is a vital necessity, and if it is once recognised in this country that water is a commodity which can be bought and sold, it will probably greatly simplify some of the problems connected with the development of this kind of irrigation. Where the water-supply is very abundant and where the ryots have no capital and the land is sub-divided into small plots, it might be practicable to establish local water-supply companies who would raise water and sell it to the ryots either for a share in the produce of the land, or for a fixed rate per unit of volume or a fixed charge per acre irrigated. If anything of this kind is to be brought about, it will probably be necessary for Government to pioneer the way and to provide sufficient legal protection to induce capital to flow in this direction.

It must be recognised that only in a few places will it be possible to pump large quantities of water

from a single source of supply. The wells must be numerous and it will probably be found most economical to have a single power-generating station and to distribute the power electrically, driving centrifugal pumps with electro-motors. Large power-stations are much more economical than small ones, and it is quite possible to put in motors and pumps that require no more supervision than that a man should go round and oil them once a day. Such water-supply corporations exist in America and have worked successfully for years past, and it is quite certain that there are no engineering difficulties worth speaking of. On the other hand in India, it will require an immense amount of tact and patience to get the advantages of such a system acknowledged. To make it profitable, intensive cultivation must be adopted, and even if the capital is forthcoming to enable this to be carried on, it is doubtful if the ryots possess the requisite experience to make it a success. After studying the question of the better utilisation of subterranean water for but a very short time I am convinced that there are no serious difficulties from the Engineer's point of view, either as to a sufficiency of supply or as to the cost of raising it above the ground so as to make it available. On the other hand, the practical administrator, who would like to make use of this water and apply it to the land so that the people may be placed in a position which will enable them to carry on their agricultural work with a fair amount of certainty, will find the achievement of his wishes a task of extreme difficulty.

The purchase of land is a favourite form of investment in this country and the line of least resistance seems to lie in the direction of encouraging people who have amassed wealth to purchase land which is capable of improvement and to reserve a considerable amount of their capital for the improvement of the land they have purchased. Money invested in land yields a very poor return, but, judiciously invested in the improvement of land, the results are likely to be much more profitable and the value of the land permanently increased. The work which is being done in this direction by men like Mr. Gopinatha Tawker, at Surapet, Mr. Tota Ramanujam Chetty, at Katalai, Mr. Panduranga Mudaliyar, at Cuddalore, Mr. Tilla Govinda Gramani, at Nellikuppam, Mr. Abraham Pandither, at Tanjore, and by many others, is pioneer work of the utmost public value and deserves recognition at the hands of their fellow countrymen.

Irrigation by pumping is still in its infancy, but the success which has already attended the earlier installations renders it certain that it will grow rapidly and there is a vast field for it in Southern India. What has been accomplished so far is the direct result of the modern developments of the internal combustion engine in its various forms, and there is reasonable ground for hoping that further improvements may be effected in the future rendering motive power still cheaper and pumping appliances more effective.

CHAPTER XVI.

IRRIGATION BY PUMPING.*

One of the many difficulties which have to be faced, by those who are striving to improve the economic situation in the South of India, is the high price which has to be paid for fuel, owing to the fact that nowhere south of Singareni in the Hyderabad State has coal been found to exist in workable deposits. The few possible sites, where water-power can be obtained, are in remote and almost inaccessible situations, and the time has not yet arrived for the vast schemes which must be worked out to enable such of those natural sources of power as we possess to be utilised. Much must be done before a rival can be set up to the great electric system of power distribution which the Mysore State has created within its own territory. There are no great engineering difficulties to be faced, and the generating stations could be set up cheaply enough. The difficulties are due to the lack of industrial organisation and the petty nature of the widely scattered demand for power which would render the cost of distribution prohibitive. Under these circumstances the internal combustion engine, which has lately been brought to such a high degree of perfection, has proved an ideal source of motive power.

* Contributed to the Industrial Conference held in Madras in December 1908.

Within the last year or two, hundreds have been purchased and are now supplying power for pumping water for irrigation, for the water-supply of towns, for drainage works and for driving rice hulling machinery, oil mills, coffee pulpers and tea-making machinery. For a variety of miscellaneous purposes they are also employed, but in the main for those already specified.

So long as liquid fuel is available at somewhere about the present prices the ordinary type of oil engine is the most convenient form of internal combustion motor to employ for small powers, but for units of over 20 h. p., especially in the neighbourhood of forests where timber is cheap and charcoal can be manufactured in large quantities, the suction gas producer plants are unquestionably superior; whilst in special cases, where very large amounts of power are required, the Diesel form of oil engine working with liquid fuel furnishes the most economical motor at present available. Kerosine oil is too expensive a fuel to employ in oil engines and the continuance of the supply of liquid fuel at the present prices, or in fact at any reasonable price at all, is by no means a certain matter. It is therefore desirable that as far as possible efforts should be made to extend the field in which suction gas producer plants can be employed with advantage. It is important to remember that the charcoal they need is a local product, an extensive demand for which would greatly benefit the very large areas of reserved forest in this Presidency. It would, I think, be almost a fatal error to build up an indus-

trial system in Madras based upon foreign sources of fuel supply and the oil engine should be regarded as a temporary expedient which must ultimately give place to engines using gas. Obviously therefore we, in Madras, should devote ourselves to the introduction of suction gas producer plants and the improvement of the methods by which the wood in our forests and plantations may be converted into charcoal and the various bye-products for some of which there is a considerable demand. The destructive distillation of wood is a chemical industry of considerable importance in other parts of the world where the natural facilities for carrying it on are no greater than those which exist in the south of India. For more than a year past, it has therefore been the subject of detailed study and investigation with very promising results. Unfortunately it is a highly specialized industry of which we possess no experience in this country and if it is to be worked with commercial success it must be started on a large scale. The enquiries made out here must therefore be supplemented by further investigations in Europe and America before it can be definitely stated that it would be wise for private enterprise or Government to provide the founds required for the first factory.

In the present paper I do not propose to pursue these ideas any further, as it would lead us into the discussion of highly technical matters which had best be left for the consideration of experts. Last year one of the papers, which I presented to the Industrial

Conference held at Surat, dealt with lift irrigation and I would ask you to regard this paper as a second contribution on the same subject. My excuse for bringing it forward again after so short an interval is that it is one of great importance and the movement in favour of employing mechanical means for lifting water is making rapid progress. Experiments were first started early in 1902 and at the end of the following year the results obtained were considered sufficiently valuable to justify working on a more extended scale and a special staff was provided to carry on the work. In April 1905 eleven oil engines were at work, in 1906 thirty-five engines, in 1907 fifty-four engines and in 1908 ninety-four engines, whilst at the present time (December 1908) it is probable that there are about 150 engines either actually pumping or in course of erection. During these five years the Madras Government have expended upwards of a lakh of rupees on this work, chiefly in maintaining an establishment to assist private persons in installing such means of lifting water and in putting down boreholes to ascertain whether water-bearing strata exist at any reasonable depth below the surface of the ground. In a small way experiments have also been made to ascertain the effect of torpedoing, or blowing up with dynamite, boreholes put down from the bottom of the large rocky wells which are found in many parts of this Presidency.

As not a few insllations have been at work for a considerable time it ought to have been possible to

have collected a large amount of valuable information regarding their working; but unfortunately my efforts in this direction have met with but a small degree of success. This is for two reasons: (1) Many of the owners of engines and pumps are averse to giving any information regarding them, as they fear it may be subsequently used to their detriment whenever the next revision of the settlement occurs, and (2) others, and they probably form the majority of pump owners, see no necessity for keeping accurate accounts, and as no small part of their transactions are still in kind it is difficult to get at the real facts. However they express themselves satisfied with the working of their engines and pumps and their neighbours are following their example, so that it may be concluded that they have done well by themselves. Already the number of pumping stations is so large that it is impossible to keep in touch with them all and I am unable to supply any accurate summary of the work which they are doing. The total horse power is over 1,200 and the total capacity of the pumps nearly five million gallons per hour. If our estimates regarding the quantity of water which should be supplied to dry crops are at all accurate this volume of water for ten hours per day would suffice for the irrigation of about 11,000 acres, but it is quite certain that the actual area irrigated is far below this figure. This is partly due to the fondness of the ryot for cultivating paddy, which requires a very large quantity of water, but from which, at the present prices, he derives con-

siderable profits even when the water has to be lifted by an engine and pump. It is probable that about 5,000 acres are irrigated by engines and pumps and the whole of this area is either double cropped or devoted to the cultivation of such crops as sugar-cane, plantains, and turmeric which remain on the ground throughout the whole year and which yield very large returns.

From the details of cultivation, furnished by the owners of pumping plants and carefully scrutinized by my Supervisors, it will be seen that the irrigators are inclined to adopt a very intense system of cultivation and that as a rule the gross value of the crops per acre is seldom less than Rs. 100 and often a great deal more. The necessity for artificial manures has been forced upon the attention of the cultivators and a good deal of experimental work is in progress to determine the best way of preventing the exhaustion of the soil. There is a tendency to use too much water, a mistake seldom made when it has to be lifted by cattle power or by men working picottahs. This is due, in most cases, to the owners of wells being able to obtain more water than they really require for their land and the remedy will probably be found in the more extensive adoption of the system of selling water, which has already been introduced. The owners of most of the pumping stations are intelligent and energetic men with capital at their disposal, and any assistance which can be given them by the Agricultural Department is

likely to prove labour well spent and to be productive of good results.

The following notes regarding the working of a number of installations have been compiled from information supplied by the owners of engines and pumps. The data have been carefully checked and I think they may be regarded as sufficiently accurate for practical purposes. In very few instances have any records been kept of the number of hours the pumps were at work so that the figures regarding the cost of working afford no information as to the actual cost of lifting water. In almost every instance it will be seen that the cost of lubricating oil is a very large percentage of the cost of running the engine and there is reason to suspect that in this direction there is considerable waste. This is counterbalanced, however, by the low cost of wages :—

(1) Installation of a $7\frac{1}{2}$ h. p. engine and 4″ pump at Kalinjikuppam. This was put down by M. R. Ry. V. Desikacharri, a retired pleader at Tiruvendipuram in the South Arcot district. The well is 20 feet in diameter and 26 feet deep, and it irrigates 18 acres of land which was formerly dry. Dealing with the year ending September 1908, 8 acres of paddy were grown between October and March and the value of the crop was Rs. 270. A second crop on the same land between May and August yielded Rs. 480. Groundnut and ragi were grown on 10 acres between January and July. The groundnut crop was worth Rs. 1,000 and the ragi Rs. 500, the total value

of the crops during the year amounting to Rs. 2,250. The working expenses of the engine amounted to Rs. 552-8-0 made up as follows :—

	RS.	A.	P.
Liquid fuel	300	0	0
Wages of driver at Rs. 6 a month	72	0	0
Kerosine oil	24	0	0
Lubricating oil	90	8	0
Repairs	6	0	0
Total ...	552	8	0

No accurate figures have been furnished regarding the cost of cultivation, but the following estimate is probably not far from the truth :—

	RS.
Each paddy crop at Rs. 20 per acre ...	320
Cost of groundnut cultivation at Rs. 40 per acre	400
Cost of ragi cultivation at Rs. 25 per acre	250
Total ...	970

The total working expenses were therefore Rs. 1,522– 8—0 and the profit Rs. 727—8—0. The cost of the installation was Rs. 3,065.

(2) Installation of a 5 b. h. p. engine and 3 in. pump at Panamkuppam belonging to M. R. Ry. Srinivasa Gounden. The water-supply is derived from a well 9 feet in diameter and 20 feet deep and the

area cultivated is 20 acres of land which was formerly dry. The whole area has been leased to ryots at a rental of Rs. 75 per acre and the net yield to the proprietor is Rs. 1,500. His son drives the engine and the expenditure during the year was Rs. 250. Allowing Rs. 10 a month as the value of the services of the driver the gross profit on the installation amounted to Rs. 1,130. This is a very good return on the capital cost of the installation which amounted to Rs. 1,707.

(3) Installation of a 9 b. h. p. engine and 4" pump at Nellikuppam belonging to M. R. Ry. S. Tilla Govinda Gramini. The well is 20 feet in diameter and 18 feet deep and derives its water from a bed of coarse sand. The water-supply is more than ample, as the area under cultivation is only 15 acres. From March to July the whole area was under groundnut and from September to January under paddy. The value of the groundnut crop was Rs. 2,625 and of the paddy Rs. 1,575 making a total of Rs. 4,200. The cost of working the engine amounted to Rs. 683-1-4 made up as follows :—

		RS.	A.	P.
Liquid fuel...		318	15	4
Lubricating oil		138	2	6
Kerosine oil		47	7	6
Repairs and belting ...		58	8	0
Driver's wages ...		120	0	0
Total ...		683	1	4

Cultivation expenses amounted to Rs. 513-12-0 for the groundnut crop and Rs. 597-3-0 for the paddy crop. Against a gross yield therefore of Rs. 4,200 the expenditure amounted to Rs. 1,794-0-4 and the gross profit to Rs. 2,406. The cost of the installation was Rs. 2,750.

(4) Installation of a $7\frac{1}{2}$ b. h. p. engine and 4″ pump belonging to Mr. Balagurumurthy Chetty at Punjerikuppam. The well is 17 feet in diameter and 23 feet deep and the area under cultivation is 23 acres. Fifteen acres were under groundnut and subsequently under ragi, 5 acres under gingelly and 3 acres under paddy. The value of the crops grown was as follows :—

	RS.
Groundnut	2,280
Ragi	720
Gingelly	155
Paddy	450
Total ...	3,605

No accounts were kept of the cost of running the engine or the agricultural expenses, but they may be estimated approximately as follows :—

	RS.
Engine	600
Groundnut crop	600
Ragi	375
Gingelly	40
Paddy	120
Total ...	1,735

This leaves a gross profit of Rs. 1,870. The cost of the installation was Rs. 3,200.

(5) Two installations belonging to M. R. Ry. S. Panduranga Mudaliyar of Cuddalore, one a 9 b. h. p. engine and 4″ pump and the other a 9½ b. h. p. engine and 4″ pump. Each of these installations works on a well 36 feet deep from which a certain amount of water is derived by percolation, but the main supply is derived from beds of sand in which the water exists under sufficient pressure to rise to within 15 feet from the ground. In both the wells the borings are lined with a 7″ pipe, sunk in one case to a depth of 84 feet from the ground level and in the other to a depth of 58 feet. The total area under the two installations is 48 acres and during the year the following crops were grown :—

Crop.	Area.	Cultivation expenses.			Value.		
	ACS.	RS.	A.	P.	RS.	A.	P.
Paddy	10·22	201	0	0	535	0	0
Plantains	2·75	202	8	0	688	0	0
Sugar-cane	4·28	430	14	0	192	0	0
Groundnut	6·15	348	0	0	701	0	0
Ragi	9 83	252	0	0	240	0	0
Groundnut	11·83				1,348	0	0
Groundnut	2 00				220	0	0
Gingelly and Indigo ...	15·48	131	12	0	80	0	0
					216	0	0
Ragi	3·00	76	0	0	135	0	0
Total ...	...	1,642	2	0	4,355	0	0

The working expenses of the two engines were Rs. 904 made up as follows :—

Liquid fuel	...	...	440
Lubricating oil	...	...	148
Kerosine oil	...	...	40
Driver's wages	...	...	204
Repairs and belting	...	...	72
	Total	...	904

The gross profit amounted to Rs. 1,808—14—0 whilst the capital cost of the two installations was Rs. 7,000.

(6) Installation of a $9\frac{1}{2}$ b. h. p. engine and 6″ pump belonging to Government and leased to M. R. Ry. V. Subramania Aiyar of Panampet near Villupuram.

The water is derived from a tank 60 feet square and 18 feet deep. The pump is mounted on a well 8 feet in diameter and 26 feet deep at the edge of the tank. The land under irrigation belongs to the ryots of the village and they buy the water-supply from the pump, paying for it at the rate of 11 annas per hour. The area irrigated during the year was 70 acres, which from January to June was under ragi and groundnut together ; whilst in July, August and September 50 acres were under Kambu and 20 acres were under thenai. It is only possible to form an approximate estimate of the value of the crops :—

	RS.
Ragi	2,240
Groundnut	6,300
Kambu	750
Thenai	825
Total ...	10,115

From January till the end of August the engine worked 2,323 hours as follows :—

	HOURS.
January	153
February	235
March	305
April	481
May	540
June	382
July	183
August	44
Total ...	2,323

Assuming the average discharge of the pump was 25,000 gallons per hour, the duty of water obtained in April and May was 95 acres and 84 acres per cusec. This low duty is mainly due to the porous character of the soil, which is a light loam overlying a bed of coarse sand.

The working expenses amounted to Rs. 1,018-1-6 made up as follows :—

	RS.	A.	P,
Liquid fuel...	492	15	0
Lubricating oil	104	8	0
Kerosine oil	28	6	3
Driver and watchman ...	184	0	0
Repairs and belting ...	208	4	3
Total ...	1,018	1	6

The income by sale of water was Rs. 1,534-9-0 and the net profit to the lessee was Rs. 516-7-6. The cost of this installation was about Rs. 5,000, so that selling the water from the pump at 11 annas per hour was not a very profitable transaction and the price charged would probably have been much higher had not the installation been handed over to the lessee free of rent for a period of three years as an experiment. On the other hand the ryots benefited very considerably as is shown by the demand for water which in May necessitated running the engine for 540 hours. At first ryots were very averse to running their engines more than seven or eight hours a day and entirely opposed to running them during the hours of darkness, but already where the water-supply permits of it the engines are run day and night whenever necessary.

(7) Installation of a 7½ h. p. engine and 4″ pump belonging to M. R. Ry. A. Venkatasubba Reddiar,

Arukilavadi village near Arkonam. The water is derived from a well 10 feet in diameter and 20 feet deep. The total area under cultivation during the year including second crop was 41⅓ acres yielding the following return :—

	ACS.	RS.
Paddy	20	1,291
Ragi	5	280
Groundnut	8	300
Gingelly	6	220
Plantains	1	100
Garden produce	1⅓	70
Total ...		2,261

The cost of cultivation amounted to Rs. 760 and the working expenses of the oil engine to Rs. 568 leaving a gross profit of Rs. 933. The cost of the engine and pump was Rs. 2,535.

(8) Installation of a 5″ pump and a 12 h. p. engine belonging to M.R.Ry. Govidaswami Nayudu of Natham near Gudiatham. The pump is located in a well 20 feet in diameter and 16 feet deep, and in the bottom an inner well 14 feet in diameter has been sunk. The cost of the installation was Rs. 3,100 and previous to its erection sixteen pairs of cattle were kept. The engine and pump enabled the owner to dispense with ten pairs of cattle which he sold and for which he realised Rs. 1,500. The working expenses of the engine and pump averaged Rs. 8 0

month and the following returns so far have been received :—

	ACS.	RS.
Paddy	12	1,200
Ragi	2	100
Cocoanuts	13	400

The cost of keeping sixteen pairs of cattle is stated by Mr. Govindaswami Nayudu to be Rs. 240 per month or Rs. 15 per pair. The saving effected by dispensing with ten pairs of cattle is Rs. 150 per month against which must be set the cost of the engine, about Rs. 80 per month. Apart from the fact that he has now a much better water-supply, a net saving of Rs. 70 per month is effected equal to Rs. 840 per annum which is 50 per cent. on the net expenditure incurred after allowing for the value of the cattle which were sold.

(9) At Melrosapuram, which was the first pumping installation started, there is a $3\frac{1}{2}$ h. p. engine and 3″ pump raising water from a well. During last year the Rev. Mr. Andrew reports that the engine ran for 1,005 hours and raised 1,870,305 cubic feet of water an average height of 23 feet. The area under cultivation was 17·66 acres which yielded crops worth Rs. 1,691. The cost of running the engine was Rs. 303-10-9 to which may be added another Rs. 300 for interest and depreciation making the total cost of irrigation per acre Rs. 34·1. The details of the running expenses were as follows :

		RS.	A.	P.
Liquid fuel	..	111	6	6
Kerosine oil	...	35	10	0
Lubricating oil	...	48	1	6
Wages	..	74	0	0
Repairs	...	34	8	9
	...			
Total	...	303	10	9

(10) At the Agricultural College, Saidapet, a 6½ h. p. engine and a 4″ pump were employed in lifting water from the Adyar river. During 1907—1908, 25,660,000 gallons of water were raised an average height of 21·57 feet the lift varying between 19·3 and 24·1 feet. The total cost of working the engine was Rs. 620-14-3, to which may be added Rs. 350 for interest and depreciation. The area of land irrigated was 25·71 acres and the cost of irrigation per acre Rs. 37·7. The details of the working expenses were as follows :—

		RS.	A.	P.
Liquid fuel ...	...	173	12	0
Kerosine oil ...	...	19	12	0
Lubricating oil	...	87	13	9
Wages	...	238	4	4
Repairs and belting	...	97	13	0
Miscellaneous	...	3	7	2
Total	...	620	14	3

The pump was run on 194 days for 1,976 hours or an average of 10·19 hours per day. The volume of liquid fuel consumed was 1,200 gallons, at the rate of 0·61 gallons per working hour.

(11) Installation of a 4″ pump and a 6½ h. p. engine on a small tank at Surapet belonging to Mr. Gopinatha Tawker. Subsequent to the installation of the engine and pump a boring at the bottom of the tank tapped a sub-artesian supply which, through a 4″ pipe, furnishes sufficient water to keep the engine running 12 hours a day. The cost of installing the engine and pump and making channels for the distribution of the water was Rs. 3,242. The area under irrigation is 28 acres and consists of a mango and cocoanut tope the trees of which have not yet come to bear fruit. Between the trees plantains have been cultivated, there being about 450 to the acre against an average of 900 to the acre in an ordinary plantain garden. The accounts now furnished extend over two years and show that Rs. 2,833-1-0 was realized from the sale of the plantains and Rs. 871 from the sale of a crop of paddy which was grown on 21 acres after the plantains were removed. The expenses of cultivation during the two years amounted to Rs. 1,704 for the plantains and Rs. 277-8-0 for the paddy. The cost of running the engine during the two years was Rs. 869-15-6 so that against gross receipts of Rs. 3,704-1-0 the total expenditure amounted to Rs. 2,221-7-6 leaving a surplus of Rs. 1,482-9-6. An allowance of Rs. 405 a year should be made for interest on the capital outlay and depre-

ciation in value of the plant, but against this must be set the increased value of the mango and cocoanut topes which during the two years have been well watered.

(12) Installation of a 3″ pump and a 5 h. p. engine belonging to M. R. Ry Muniappa Gramani at Tondiarpet. The lift varies from 12 to 25 feet and the engine works from 9 to 11 hours a day and waters two cocoanut plantations each of about 4 acres One of these gardens is let out on lease for Rs. 100 a month the water being supplied free. The other the owner works himself. The yield of toddy is about 70 measures a day and is sold for 3½ annas a measure. The total monthly sales average Rs. 400 and the expenditure Rs. 140 leaving a net profit of Rs. 260 a month. No details are kept regarding the cost of working the engine but it amounts to an average of Rs. 60 a month and repairs and renewals average Rs. 120 a year. The total expenditure therefore is Rs. 2,520 and the income Rs. 6,000 leaving a gross surplus of Rs. 3,480 which is unquestionably a good return on a garden of not more than 8 acres.

(13) Installation of a 7½ h. p. engine and 4″ pump belonging to M. R. Ry. T. S. Narayanasawmi Aiyar of Tirukkarugavur. The water-supply is derived from a tank 120 feet square and the pump is carried on a circular well 9 feet in diameter sunk in the bank of the tank. There is more than sufficient water-supply and the land under irrigation consists of surgarcane 3 acres, plantains 5 acres, cocoanut garden 7 acres

and paddy 13 acres. The owner writes as follows:—"The gross income is Rs. 700 from sugar-cane and Rs. 300 from plantains. With the assistance of the plant I am able to sow seed-beds very early and thus reap the first crop so that my second-crop transplantation is simultaneous with the single crop lands of my neighbours. By this I get Rs. 15 per acre more than my neighbours who, though they grow double crops, have to wait for water from the channels to sow their seeds, while I can transplant the first crop when they begin to sow their seed-beds. The total cost of the plant including Rs. 1,000 spent on the well and tank was Rs. 3,900 and apart from my own cultivation my additional income from 39 acres of wet land is Rs. 595."

From the above notes the following Table has been compiled to show the actual cost of supplying each acre of land with water.

The data upon which the figures for the duty of water have been calculated are approximatious. It is hardly worth while to discuss them in detail as the only object in inserting them in the tabular statement is to dispel the idea that very high duties are obtained under pumps. It is not improbable that the low duty in some cases is attributable to the limited area under the pumps and that more water was given to the fields than was really necessary or desirable. Both the nature of the crop and the physical condition of the soil are important factors to be taken into consideration in estimating the duty of water and to these

Reference number of installation.	Diameter of discharge pipe of pump in inches.	Area irrigated in acres.	Duty of water in acres per cusec.	Working expenses.	Interest and depreciation.	Total.	Cost of irrigation in rupees per acre per annum.
				RS. A. P.	RS. A. P.	RS. A. P.	RS.
1	4	18	81	552 8 0	383 2 0	935 10 0	52·0
3	4	15	67·5	683 1 4	343 12 0	1,026 13 4	68·5
4	4	23	103·5	600 0 0	400 0 0	1,000 0 0	43·5
5	4 (2)	48	108	904 0 0	888 12 0	1,792 12 0	37·4
6	6	70	95	1,018 1 6	666 4 0	1,684 5 6	24·10
7	4	21·3	96	568 0 0	317 0 0	885 0 0	41·5
9	3	17·66	240	303 10 0	300 0 0	603 10 0	34·1
10	4	25·71	119	620 14 3	350 0 0	970 14 3	35·7
11	4	28	126	435 0 0	405 0 0	840 0 0	30·0
12	3	8	54	840 0 0	237 8 0	1,077 8 0	134·6

must be added the character of the distribution of the rainfall as well as its total volume. With so many variants it is impossible that any one set of observations should be of great value. If the most is to be made of a supply of water risks must be run and experience is the only safe guide in such matters. To secure absolute certainty means that in four years out of five the water-supply is not fully availed of. Agriculture is the most speculative of industrial occupations and irrigation only eliminates one element of uncertainty.

The total cost of pumping has been estimated by adding $12\frac{1}{2}$ per cent. of the capital outlay to the running expenses to provide for interest and depreciation on capital. It will be seen from those figures that the cost of irrigation from wells, even when water is lifted by engines and pumps, is a very considerable item. Excluding the cocoanut gardens it ranges from Rs. 25 to nearly Rs. 70 an acre; nevertheless, as we have seen, the profits realised are very considerable. The ryots appreciate this and the popularity of oil engines and pumps is steadily increasing. Yet, through the sub-division of the land into small plots, the smallness of individual holdings and the large capital outlay involved in each installations, it is difficult for landowners and ryots to become possessors of such aids to cultivation, and I think there is not much doubt that for every ryot who owns a pumping installation there are at least a hundred who would be glad to have one, if only their circumstances would permit of it. With

rising prices and with a sure water-supply the agriculturist is in a very satisfactory condition and in places there is evidence that by co-operation they are trying to secure for themselves the advantages of cheap methods of raising water.

Some little time ago the villagers of Atmakur formed a limited liability company with a capital of about Rs. 14,000 and with this money we have erected for them two 10 inch pumps on the banks of the Kistna Western Delta main canal and through a channel which extends to a length of nearly four miles they are irrigating 500 acres of land considerably above the full supply level of the canal. In certain Taluks of the South Arcot District, where it is easy to obtain a water-supply, some of the wealthier ryots have pumping installations and are selling the water they do not require for their own lands to their less wealthy neighbours. In the case of the Panampet installation alluded to above, the water is sold at the rate of 11 annas per hour which is equivalent to about 2,000 gallons for one anna. At this rate a cubic foot per second will fetch nearly Rs. 17 a day and will be worth at least Rs. 2,000 during the ordinary irrigation season of four months. In the Kistna Delta the duty of water rises to as much as 100 acres per cubic foot per second and for this a water-rate of Rs. 5 per acre is charged, or roughly one-fourth of that paid by the ryots in the Panampet village. Nevertheless the water-rate in the Kistna Delta is sufficiently high as the whole project pays a very high rate of interest on

the total capital expenditure involved in the construction of the Kistna Delta irrigation system. It is the same with many of the other great irrigation systems in this Presidency. The lands under them are supplied with water at very low rates and the undertakings are at the same time very profitable to the State. The very careful and detailed examination of the country by the Irrigation Commission, which met a few years ago, has placed beyond doubt the fact that very little water can in the future be made available for irrigation on similarly favourable terms, although the percentage of the total water-supply which is so utilised is extremely small. Vast projects involving an enormous capital outlay are feasible, but their construction can only be justified when it can be clearly shown that they offer a fair prospect of an adequate return on the money which must be invested in them.

The skill and ingenuity of the irrigation officers of the Public Works Department will probably yet succeed in some cases in providing additional supplies of cheap water for irrigation, but the limits prescribed by the scale of charges for water have been nearly reached and there must inevitably ensue a period of stagnation in the extension of irrigation unless efforts are made in other directions. Engineering science has made enormous strides since Sir Arthur Cotton first held up the waters of the Godavari river by the dam which he constructed across it at Dowlaishwaram, and many projects are feasible now which would have been impossible then. As an example

attention may be directed to the splendid pumping station which has been provided to lift the waters of the Kistna river for the irrigation of some 50,000 acres of land on Divi Island, whereby water which ran uselessly to the sea is now made to fertilise lands which have hitherto lain waste or yielded at best a very precarious harvest. Again in the mountains of Travancore the waters of the Periyar river, which formerly flowed into the Arabian Sea, have been diverted through the watershed ridge to irrigate a vast extent of land in the Madura district, thereby rendering it secure from scarcity and famine. It would be easy to multiply examples of this kind; it is not however my object to glorify the engineering profession but to draw attention to the fact that in other directions, here in India, we have not made similar progress.

The resources of the hydraulic engineer are by no means exhausted and he could still do much to render the occupation of the great bulk of the people of this country much less precarious if only it were possible for them to second his efforts and display a more intelligent appreciation of the value of the water which he supplies. It would not, I think, be difficult to show that in this Presidency the area under wet cultivation could be doubled if the ryots, who are now without the benefits of irrigation, were prepared to pay a much higher water-rate than that now paid by those whose lands are so favourably situated that they are commanded by the channels from existing works. The question is can they do so? Is it possible for the ryot to pay

from Rs. 15 to Rs. 20 an acre for water instead of the Rs. 5 or Rs. 6 which is regarded as the normal rate under Government irrigation channels? The enquiry is not whether existing water-rates should be enhanced, but whether lands not now irrigated could be made to yield a sufficient return to make it worth while supplying them with water at a much greater cost than has hitherto been deemed practicable. It is generally considered that irrigation greatly enhances the value of land, partly by increasing the yield of the crops and partly by diminishing the risks of cultivation. The bulk of the irrigation supplies in this Presidency are devoted to the cultivation of paddy and it is only under spring channels and wells that what we know as garden cultivation may be said to exist. The fact is that paddy cultivation pays fairly well and the cultivators have an easy time of it; but when the ryot has to lift his water from a well or contribute his share of the labour of digging spring channels in hot sandy river-beds, he learns to appreciate its value, and by putting more labour into the land he obtains from it a more generous return.

The information which has been collected regarding the cost of lifting water by engines and pumps and the evidence that such water can be profitably used is, I consider, extremely valuable, but I do not wish to spoil my case by basing generalizations on it which are not justifiable. The irrigation under the oil engines and pumps, which has been referred to above, is all of an exceptional character. Admittedly, they

are selected cases to show what can be done when capital, energy and intelligence are forthcoming. They are, however, typical instances of irrigation with oil engines and pumps, where an adequate water-supply has been found, and I have reason to believe that there is room for many thousands of such installations in the Coast districts and on the margins of many of our rivers. Their influence on agricultural developments is already considerable and not a few are regarded in their own neighbourhood as model farms. The results obtained in them have awakened a new interest in well cultivation and throughout the Presidency there is a growing demand for the exploration of the sub-soil with boring tools. The demand is for a perennial water-supply which will enable irrigation to be carried on all the year round so that more valuable crops, which require to be on the land for a long time, may be cultivated.

Government irrigation works connote paddy cultivation, because almost invariably the supply of water is only available for a portion of the year. To some extent this must also be the case in the future, but by no means entirely so. All the great projects now under investigation will involve the construction of enormous storage works, partly to regulate the supply during the irrigation season and partly to raise the flood waters to a sufficiently high level to command the lands that require irrigation. When the water has fallen below the sills of the regulators which will control the supply to the high level

channels there will still remain a vast quantity of water stored in the river-beds behind the dams, and this may be drawn off at such a rate as to provide for the perennial irrigation of very considerable tracts of land. On these lands very high water-rates should be realised as very valuable crops can be grown. In the Bombay Presidency, by the aid of storage works which have been constructed in the Deccan, sugar-cane cultivation is extensively pursued, notwithstanding the fact that a water-rate of Rs. 50 per acre per annum is charged. Such cultivation involves considerable capital outlay and a large expenditure in manure. It is analogous to the oil-engine cultivation which we are developing on this side and it is my object to point out that such cultivation might be developed on a much larger scale if, in the future, it is found feasible to construct the great masonry dams which have been projected for holding up the waters of the Kistna, the Cauvery, the Tungabhadra and other rivers. More irrigation in the South of India we must have, and because we have exhausted all the easy methods of obtaining water for irrigation there is no reason why the country should stand still and accept the fact that nothing more can be done. If water cannot be obtained at Rs. 5 an acre, it is an undoubted fact that large supplies could be given at a cost of Rs. 10 an acre, and still larger supplies if it could be shown that water is worth Rs. 20 an acre. The cultivation under oil engines and pumps, the enormous area under irrigation from wells and the high rates

paid for water in the zemindari tracts all tend to show that there is still a very wide margin for the irrigation engineer to operate on.

Accepting the figures, which I have placed before you as accurately representing what can be done under the conditions specified, there can be no doubt that if such work could be carried on over thousands of acres as it is now carried on over tens, it would be a comparatively simple matter to finance the great engineering works which will be necessary to supply water. Unfortunately it is practically certain that at the present time the cultivators are not in a position to take large volumes of water on the same terms as are easily obtained in all the cases I have brought to your notice. The average ryot lacks capital, lacks initiative and above all is imbued with the idea that irrigation means an easy life and not a strenuous one. Before the great irrigation works of the future can be carried out the average ryot who cultivates dry land, will have to be brought to understand that his slovenly and lazy methods of working can be no longer tolerated, and that if he wishes to continue in the possession of his land he must be prepared to cultivate it properly. There is much for him to learn and the problem is how to teach him. The extension of irrigation by pumping will probably prove one of the most effective means of diffusing throughout the country a better knowledge of the principles of agriculture, and all means which are adopted to encourage the extension of this method of lifting water will tend to bring about

the desired end. Nearly everywhere it is the poverty of the individual and the extreme sub-division of the land which makes progress slow. Nevertheless where the conditions are favourable great strides have been made.

In the South Arcot district in the Villupuram and Cuddalore taluks the conditions in regard to water-supply are unusually favourable. Vast beds of sand lie at no great depth below the surface of the ground and from these it is practicable to obtain a supply of from 20,000 to 30,000 gallons of water per hour from wells not more than 15 or 20 feet in diameter sunk into the sand. Already over 50 pumping plants have been installed in these two taluks and many more are under consideration. In not a few instances the whole capital outlay involved has been realised within the first year and in nearly every case, within two years, the cost of these pumping installations has been recouped. In place of 50 engines and pumps there is probably room for 1,000, and that too without seriously affecting the water-supply. If private enterprise were stronger and capital more abundant the irrigation problem in these two taluks would be easily dealt with. The ryots have water and land and if supplied with power to lift the water so as to make it available for cultivation, they can obtain large profits. Under these circumstances the capitalist would step in and provide power on terms which would be advantageous both to the supplier and the user. A central power station would be established either near the railway or away on the

borders of the Salem district in the middle of the forest from which it could derive its supply of fuel. The combination of a wood distillation plant with a central power station should prove a very remunerative undertaking if worked on proper lines. In the forests the timber would be cut down and converted into charcoal. The charcoal on the spot would be used in large suction gas plants to generate electricity. Electric currents under high pressure would be carried across the country to the points where the power could be used and there it would be transformed down to a reasonable pressure, and from each sub-station wires would radiate to the wells in the neighbourhood.

In many cases ryots already own wells which will yield large quantities of water or which can be greatly improved by sinking them a few feet deeper. If the Power-supply Company would instal its own motors and pumps and undertake to lift the water there is scarcely any doubt that the demand would be considerable. The ryots can afford to pay as much as one anna per thousand gallons and probably by charging a fixed rent for the motor and pump, plus a rate for the actual amount of power taken, there would be no difficulty in putting the distribution of power on a sound commercial basis. The charcoal manufacturing plant should be of a modern type fitted with all the apparatus necessary to obtain the valuable bye-products of which the most important are acetate of lime, methyl alcohol and tar. Of course, such a plant can only be worked with profit when the scale of operation

is sufficiently large. Half the charcoal manufactured in the wood distillation plant would be required for the recovery of the bye-products and for working them up into a marketable condition whilst the other half would be available for the suction gas plants which would supply gas to the engines driving the dynamos. Three thousand horse power would, I think, in a short time be taken up within the area I have mentioned, as not only would it be used for pumping water but also for driving oil mills and other machinery. To a limited extent there will be a demand for lighting purposes and it can hardly be doubted that, once a supply of power was available, a considerable number of miscellaneous ways, in which it could be usefully employed, would soon be discovered. A plant, with an average output of 3,000 horse power for 12 hours a day, would require 20 tons of charcoal per day or roughly 7,000 tons in the course of a year; so that if all the bye-probucts were recovered upwards of 14,000 tons of charcoal would have to be manufactured every year. This would involve the carbonization of about 50,000 tons of wood per annum, and assuming that the annual increment in the forests is one ton of wood per acre per annum, an area of 50,000 acres of forest would be required. This could be reduced if suitable plantations of casuarina or some other quick growing timber were made. Already there are in the South Arcot district some 11,000 acres of private plantations and a large extension of these to supply fuel for power purposes would ultimately be of immense benefit to the district.

It is useless at the present moment to endeavour to work out such a scheme as I have outlined in any detail. My object in bringing it forward is to indicate one of the directions in which work might be undertaken in future. The scheme I have outlined is typical of the way in which industrial problems must be tackled. Whilst it is possible to do a great deal by establishing a large number of small centres of industrial activity, it must be remembered that these are, as it were, the pioneers who clear the ground for the greater undertakings which must follow. In South Arcot the small undertakings are proving exceedingly profitable and their rapid increase in numbers can be safely counted upon. They will bring wealth and prosperity to those parts of the district which benefit by them, and ultimately I am sanguine enough to anticipate that there will be an accumulation of surplus profits seeking for new outlets.

I have put forward these ideas simply to suggest the direction in which we are moving and to indicate in faint outline the tendency of the policy we are pursuing in this particular instance. The industrial regeneration of India is a vast problem which can only be achieved by steady persistent effort continued for a long period. The difficulties to be faced are enormous and the first step must be to educate the people to a sense of their own deficiencies and to bring them to gradually take an interest in the practical solution of the problems presented. I think I may claim that the success, which has attended our efforts to introduce oil

engines and pumps for lifting water, marks the first stage in the new movement and it has awakened in the minds of thousands of landholders and ryots an interest in mechanical methods of doing work which is entirely new to this country. Considering the marked inaptitude of the agricultural community for mechanical methods of working it is surprising how easily they have learnt to manage oil engines and pumps and I think it is unquestionably because they fully appreciate the advantages which they confer and are willing to take the necessary trouble to understand how they work. Quite recently I have inspected a considerable number of these pumping stations entirely managed by the ryots themselves and I think there is no doubt that the engine and pump is to the ryot who possesses it what the motor car is to the average European. The one is spreading a knowledge of mechanics through the literate classes of Europe and the other through the illiterate classes of Southern India.

APPENDIX.

The following table gives information under the various heads enumerated regarding a number of the installations which have been erected. In many cases the ultimate area which will be irrigated will greatly exceed the area noted as full advantage is not yet taken of the water-supply available :—

Name of Installation.	Horse power of engine.	Diameter of delivery pipe of centrifugal pump in inches.	Maximum lift in feet.	Total cost.	Area irrigated.	Nature of water-supply.
				RS.		
Alinjivakkam ...	5	3	20	2,000	7	Well.
Kumaravaram ...	5	3	19	2,310	15	"
Salai	5	3	22	2,046	13	"
Panamkuppam ...	5	3	19	1,707	15	"
Tondayarpet ..	5	3	25	2,000	8	"
Orrakadu ...	6	4	19	2,240	14	"
Anamali ...	6	3	27	2,445	12	River.
Panjetti... ...	6	4	21	2,375	15	Sub-artesian.
Kolianur ...	6	4	20	2,092	18	Well.
Anichambalayam .	6	4	16	2,055	20	"
Siruvanur ...	6½	4	21	2,615	40	"
Thattanpalayam. .	6	4	26	2,380	31	"
Surapet... ...	7½	4	18	3,241	28	Sub-artesian.
Kalasti	7½	3	30	2,096	10	Well.
Ravanasamudram.	7½	4	23	2,749	15	"
Sothuperambedu .	7½	4	24	2,487	11	"
Vichur	7½	4	21	2,696	12	Sub-artesian.
Surapet... ...	7½	4	22	2,185	14	"
Mangudicherry ...	7½	4	21	2,277	7	Well.
Arugalavadi ...	7½	4	23	2,535	22	"

Name of Installation.	Horse power of engine.	Diameter of delivery pipe of centrifugal pump in inches.	Maximum lift in feet	Total cost.	Area irrigated.	Nature of water-supply.
				RS.		
Kirumambakam...	$7\frac{1}{2}$	4	17	2,200	17	Well.
Kaliyanur ...	$7\frac{1}{2}$	4	25	2,398	20	,,
Manavanthangal .	$7\frac{1}{2}$	4	21	2,266	12	,,
Thirukarugavur...	$7\frac{1}{2}$	4	14	3,900	28	Tank.
Kalinjikuppam ..	$7\frac{1}{2}$	4	25	2,435	40	Well.
Punjerikuppam ...	$7\frac{1}{2}$	4	23	2,300	23	,,
Kadamangalam ...	$7\frac{1}{2}$	4	18	2,195	18	,,
Valavanur ...	$7\frac{1}{2}$	5	20	2,285	21	,,
Ariyalur ...	$7\frac{1}{2}$	5	17	2,586	45	,,
Melrajankuppam .	$7\frac{1}{2}$	5	18	2,516	50	,,
Sholavalli ...	9	4	15	2,380	16	,,
Nellikuppam ...	9	4	16	2,750	15	,,
Cuddalore ...	9	4	30	7,000	48	Sub-artesian.
Do.	$9\frac{1}{2}$	4				
Palur	9	6	19	3,700	34	Well.
Do.	$10\frac{1}{2}$	4	15	2,940	18	,,
Panampet ...	$9\frac{1}{2}$	6	16	5,000	70	Tank.
Kavanipaukam ...	9	4	15	2,345	20	Well.
Thukanambakkam	10	4	15	3,490	14	,,
Melpattanbakam .	10	4	23	3,340	19	,,
Achiyalpuram ...	9	6	18	2,665	35	Tank.
Surapet... ...	12	6	18	3,800	29	Sub-artesian.
Atmakur ...	12	10	8	14,500	500	Kistna western delta main canal.
Do. ...	12	10				
Gudiyattam ...	12	5	25	3,100	27	Well.
Laccavaram ...	14	6	14	5,000	20	River.
Manoor Lanka ...	16	10	7	6,000	200	Colair Lake.
Kattalai ...	25	12	16	15,000	300	River Cauvery.

CHAPTER XVII.

PROGRESS IN IRRIGATION BY PUMPING IN MADRAS.*

Although I have brought the subject of Lift Irrigation before this Industrial Conference on two previous occasions, I hardly think that any apology is necessary for referring to it again as, to the agricultural classes, it is a matter of supreme importance. There are over 16,000,000 acres under well irrigation and the total amount of power employed in lifting the water is very large. Moreover wells are not the only source of water-supply which can be utilised in this way. Evidence of this may best be seen in the Kistna district of the Madras Presidency where 25,000 acres of the island of Divi are irrigated by pumping from the Kistna river, and where a pumping plant has been installed capable of irrigating fully double that area; between three and four thousand acres are irrigated in a similar way round the margin of the Kolair Lake and finally nearly two thousand acres are irrigated by lifting water from the delta canals to lands situated above the levels commanded by direct flow. It was only in 1892 that I started lift irrigation in this district with a small portable engine and a centrifugal

* Contributed to the Industrial Conference held at Allahabad, in December 1910.

pump and, though at first it did not make much progress, yet chiefly through the efforts of Mr. R. N. H. Reid of the Public Works Department it has ultimately caught on and, large as the area is that is already supplied by lift, it is likely to be greatly extended in the future. Elsewhere in India there is no similar development although in certain other districts of Madras, such as South Arcot and Chingleput, the oil engine and pump is quite a familiar adjunct to cultivation. In these matters we are still in the infantile stage and progress is slow, but there has been no set-back, and the record of the past two years is satisfactory enough to justify confidence in future development at a more rapid pace.

The object of the present paper is to put on record what has actually been done and to suggest the directions in which progress on the engineering side of the question is likely to facilitate extensions.

Apart from the experiments in the Kistna in 1892-93 and subsequent years, in which steam engines were employed, the first attempt to use oil engines was made in 1902, and the following statement shows the progress that has been made since that date :—

STATEMENT No. 1.*

Number of oil engine pumping plants erected.

Year.	Government Installations.	Private installations with Government aid.	Private installations without Government aid.
1902-03	1	...	...
1904-05	7	3	...
1905-06	3	18	7
1906-07	...	21	...
1907-08	2	38	9
1908-09	...	51	11
1909-10	...	33	28
1910-11 (April to November, seven months) ...	...	14	Not available.
Total ...	13	178	55
		246	

This statement is complete so far as the work undertaken with Government assistance is concerned, but it is certain that we have not a complete record of the private pumping installations erected without any such assistance, and it may be taken as practically certain that, at the present time, there are more than 250 engines and pumps lifting water from wells, chan-

* The Divi Island Irrigation is not included as that is a Major Irrigation Work constructed by the Madras Public Works Department.

nels, canals, tanks, lakes and rivers for the irrigation of dry lands.

Statement No. 2 furnishes information as to the size of the pumps in the case of 211 installations, from which it will be seen that half of them are centrifugal pumps with the suction pipe 4″ in diameter. The statement also gives the normal lifting capacity of each size of pump, and from this it is easy to calculate that the 211 pumps are capable of lifting nearly 8,000,000 gallons of water per hour. Applying this average to the whole 250 pumps, the total capacity will be 9·25 million gallons per hour, equivalent to a flow of 411 c. ft. per second.

It will be noticed that the areas irrigated by the larger pumps are smaller than the capacity of the pumps would seem to warrant and the reason is chiefly due to bad engineering, as these larger pumps were all put up by firms with no previous experience of the work and in most cases such plant was supplied as happened to be in stock in the country. It will be also noticed that the duty of water under the pumps is comparatively small chiefly because many of them are only run for a few hours in the course of the day; in some cases because there is not a sufficient supply of water, in others because the owner of the pump has not enough land to fully utilise his water-supply. The sale of surplus water by the owners of pumping installations to neighbouring cultivators is becoming a common practice and will probably greatly extend in the

STATEMENT No. 2.—*Centrifugal pumps.*

Year.	Diameter of suction pipe of pump in inches.										
	2	3	4	5	6	8	10	12	16	18	22
Discharge of pumps in gallons per minute ..	80	184	325	510	730	1,300	2,000	2,930	5,200	7,500	10,000
Average area irrigated by each pump in acres ..	5	15	20	36	40	100	230	300	..	..	..
1902–03 .. } 1905–06 .. } ..	1	9	9	3	1	..	1	1	..	..	..
1906–07	..	10	4	..	4	1	1	0	..	..	..
1907–08	..	6	20	5	2	..	3	0	..	..	..
1908–09	..	10	39	8	..	4	..	2	2	2	1
1909–10	1	11	26	2	2	..	2	1	..	..	..
1910–11	..	3	6	2	..	..	2	..	..	..	..
Total number of pumps..	2	49	104	20	9	5	9	4	2	2	1
Total area irrigated ..	10	735	2,080	720	360	500	2,070	1,200	600	700	350

future. This practice will greatly increase the duty obtained from the pumps.

From the data given in the above table, I estimate that the probable area under irrigation at the present time is about 12,000 acres and from the accounts available for a large number of installations, that the capital outlay expended on the same amounts to approximately 7,00,000 of rupees. The actual cost of irrigation depends on a large number of factors which vary with almost every installation. It has been carefully worked out for a number of typical installations, and applying the figures obtained to the whole area under cultivation, we find that it amounts to approximately Rs. 30 per acre per annum or about Rs. 3,60,000 for the whole area.

In 223 cases, the total horse-power of the engines is 2,138 and the great majority of these are worked with liquid fuel, of which the monthly consumption is now about 45,000 gallons.

The publication of the results of our work in Southern India has drawn the attention of engineers in England to the immense possibilities of the development of this method of irrigation and most of the large firms engaged in the manufacture of oil and gas engines and pumping machinery are anxious to do what they can to meet our requirements. The Allahabad Exhibition will to some extent show what steps have been taken to open up the Indian market. Up to the present time, we have mainly employed oil engines working with liquid fuel, which is the residue

left after the distillation of the crude petroleum is complete, but quite recently, we have employed suction gas plants and gas engines which can be worked very satisfactorily with charcoal, and we are now able to obtain plants of about 30 h. p. and upwards which will work extremely well with dry wood. It is of considerable importance to develop as far as possible suction gas plants working with the supply of fuel which can be obtained locally rather than be dependent on kerosine oil or liquid fuel which can only be obtained from a distance. There is not a single case of a steam engine lifting water for irrigation in the south of India, partly because the price of coal is so high that it cannot compete when used in steam engines with liquid fuel or suction gas in internal combustion engines and partly because internal combustion engines do not come under the Steam Boilers Act and they can be safely left in charge of comparatively unskilled men. It is only when coal is very cheap, as is the case in some parts of Northern India, that steam engines can hope to compete with oil or gas engines for small power stations. In the case of large installations the possibilities of using coal and steam are somewhat greater, but even that is not likely to be so for long, as the future belongs wholly to the internal combustion engine.

It should be remembered that irrigation by pumping has made enormous progress in many parts of the world, notably in the Western and Southern States of America, in Egypt and in Palestine, and competition

among the engineering firms to supply the machinery employed has led to material improvements in the efficiency of pumps. At the same time, equal or even greater strides have been made in reducing the fuel consumption of the prime-movers whether worked by steam, gas or oil. Finally, it seems likely that pumping, at any rate, on a large scale will be entirely revolutionised by the recent inventions of Mr. H. A. Humphrey who, in what may be termed a gas pump, has successfully combined both engine and pump and practically eliminated the moving parts with their wear and tear and necessity for lubrication. In a recent paper which Mr. Humphrey read before the Manchester Association of Engineers, he defines his system of pumping as follows:—"A method of raising or forcing liquid which consists in applying the energy of expansion of an ignited combustible mixture to one end of a column of liquid so as to propel the column along a discharge pipe, and to cause it to oscillate in the pipe under such conditions of energy of the moving liquid, that everything necessary for the next ignition is performed during one or more oscillations and wholly or partly owing to it or them." This is highly technical language and savours somewhat of a patent specification. I do not however propose to describe the pump in any detail, as I understand there will be one working in the exhibition and the extreme simplicity of the machine itself can be best appreciated by a personal inspection of its working. Some time must necessarily elapse before it can be adapted to the very varied con-

ditions under which pumps are working in India, but it seems to me certain that it will eventually come into general use. The construction of the pump itself is quite simple and the work can easily be undertaken in this country. This is a matter of very great importance, as the development of lift irrigation will in course of time create a demand for a very large number of pumps and it is well that the construction of these should be within the mechanical resources of the country. It seems to me that we are now within sight of a power-driven water lift which will involve so small an initial outlay and be so economical in working that it will almost entirely supersede cattle power. Whether the solution will come from a development of the gas pump or whether by improvements of older methods of lifting water remains to be seen.

In the latter direction, we have recently made some progress in Madras by modifying the construction of the common lift pump so as to permit it to be worked with a loose fitting tubular piston. This pump was in the first instance designed for lifting water from bore-holes and in that form consists simply of lengths of gas piping screwed together to reach to any required depth. At the lower end is fixed a valve which opens upwards. The piston consists of a length of gas piping which may be from 1′ to 10′ long depending upon the height to which the water has to be lifted. At either the top or the bottom end of this gas pipe a valve opening upward is fixed. The piston is worked by a wire rope, power being used to draw it up, whilst the downward strokes

are made by gravity acting on its own weight. The results obtained on tests with boreholes were very satisfactory and larger pumps have now been constructed which can be worked either by men applying their weight to set in motion an oscillating platform or by a small oil engine driving, through a reducing gear, a crank arm to which the end of the rope can be attached. It is recognised that the pump is only suitable for dealing with comparatively small quantities of water, generally less than that which can be lifted by a 3 inch centrifugal pump.

A single piston pump made of gas pipes 6 inches in diameter and fitted with a loose piston 18 inches long worked easily at 50 strokes a minute, the length of the stroke being 18 inches, and delivered 75 gallons of water on a lift of 15 feet. This is equivalent to about one-third of a horse-power in the water lifted. The power absorbed could not be measured, but it was probably not much more than half a horse-power. That the efficiency is very high is evident from the following experiments :—A pump made out of a 4-inch gas pipe was worked by a man weighing 110 lb. treading on an oscillating platform. The stroke of the pump was about $2\frac{1}{2}$ feet and he was able to make 20 strokes a minute lifting a gallon at each stroke to a height of 15 feet. This is equivalent to 180,000 foot-lb. of effective work per hour. This figure divided by the weight of the man, 110 lb., gives a "co-efficient of utility" of 1,636. Similar experiments with a picottah on a lift of $14\frac{1}{2}$ feet yielded a coefficient of 1,191.

When an engine is employed to drive the lift it is conveniently made of two pipes and the pistons are then connected by wire ropes to two crank pins on the same shaft separated by an angle of 180 degrees. The pistons may then be made heavy so as to descend rapidly and as one piston is descending whilst the other is ascending any excess weight in the descending piston over that required to cause the down stroke is utilised to assist the rising piston. That is to say, the double lift is completely balanced. The same result is obtained with the platform lift by adjusting the balance weight at the outer end of the platform to cause it to rise at a speed convenient to the man or men employed in working it. The pump is extremely simple in construction the only working parts being the two valves and the pulley over which the wire rope passes into the pipe. This pulley is the only part of the pump requiring lubrication and as it is only moving at a slow speed the wear and tear is negligible and it should last for many years. The valves employed are leather flap valves which will doubtless wear, but they can be repaired by any country blacksmith and experiments are in progress to ascertain how long they will last and whether there is any advantage in adopting metal hinged valves or valves of the poppet type. The latter will be more expensive and it seems hardly likely that it will be worth while to fit them.

An oil engine or electro-motor of two horse-power will suffice to drive a double 6-inch pump on a lift of 25 feet discharging about 150 gallons of water per

minute. Our experience with centrifugal pumps is that anything smaller than a 3-inch pump is very uneconomical and our present practice is to provide a 5 horse-power oil engine to drive the pump on a 25-foot lift, the discharge being 180-190 gallons per minute. The efficiency of the pump is generally slightly over 40 per cent. and the brake horse-power actually generated in the engine is slightly over three horse-power. Such a plant installed costs seldom less than Rs. 1,800 whilst a double 6-inch pump driven by a 2 horse-power oil engine will cost not more than Rs. 1,000.

The development of mechanical methods of lift irrigation depends upon our ability to provide a machine capable of dealing with the quantity of water available and in by far the great majority of sources of water-supply the quantity that can be obtained is very much less than can be dealt with by a 3-inch pump. This new water-lift provides a very efficient means of dealing with smaller quantities. By manual labour from 500 to 2,000 gallons per hour can be raised by a single man, the quantity depending on the height to which the water is raised, whilst with a small engine of two horse-power, about the smallest size that can be recommended for regular work, from six to twelve thousand gallons per hour can be raised. The pump possesses the great advantage that it can be used in a small borehole and can be worked at any depth and with any length of stroke that is convenient. The same pump has been worked on a 20-foot stroke and then, much more rapidly, on a 2-foot stroke, the

quantity of water lifted being approximately the same. The pump has a very great range of utility and adjusts itself to any change in the water level provided only that the foot valve is not uncovered.

Within the ordinary ranges of irrigation lifts gas pipes of the commonest quality will be found good enough but, where more than one length of pipe is required to get down to the full depth from which the water has to lifted, it will be found convenient to use a pipe of slightly larger diameter than the lower one, in which the piston works. The reason for this is that common commercial gas pipes are frequently dented or bent and, when this happens, the piston pipe will only work freely in them with a large clearance. It will be obvious that the piston pipe should be as close a fit to the discharge pipe as possible so that the slip may not be too great. When the lift is high, the piston pipe must be long and this means that it can only work freely in a straight length of pipe which should be of circular section throughout. Before concluding these notes on the tubular piston pump, allusion may be made to the possibility of employing one engine to drive a number of pumps in wells situated some distance apart. The wire rope transmission can be safely used up to distances of several hundred yards and, where the local conditions of water-supply are such that only small quantities can be obtained at any one point, a large number of wells, each of small capacity, can be sunk and the water lifted from them by wire rope transmission from a single station. I

have seen this method employed on the oil fields of California working deep well pumps of the ordinary type.

The popularity in the Madras Presidency of mechanical methods of pumping has led to much exploratory work for water, and boring tools are now largely employed for this purpose. The use of comparatively powerful pumping appliances has led to the discovery that over large tracts of country the coarse water bearing sands will yield, in moderate sized wells, sufficient water to keep a 4-inch centrifugal pump employed. Such beds of sand are often only a few feet below the surface but still more often they are at a considerable depth, and the sinking of boreholes is a convenient and cheap method of locating them. By the mechanical analysis of sand a good deal can be learned regarding its capacity to yield water and from empirical data which have gradually accumulated a very fair estimate can now be made as to the quantity of water which can be obtained if a well be sunk at any particular place.

The results obtained from borings have proved of extreme value. In the alluvial tracts near the Coast, a considerable area of land has been discovered under which sub-artesian water-supplies of large volume can be obtained, and even in the hard crystalline rocks, borings have proved extremely useful as they frequently open up fissures containing water under pressure. This work may be regarded as still in its infancy, although the Department of Industries have now in use

30 sets of boring tools and have put down more than 700 borings, of which slightly more than half have proved successful. In addition to this, a large number of borings has been made by private individuals who have employed well drillers from the French Settlement at Pondicherry where a very extensive development of artesian water exists.

Where the holes have been drilled in hard rock a few experiments in torpedoing have been made. The process employed is as follows :—A charge of dynamite of from 5 to 7 lb. is fitted in a water-tight tin case and lowered to the bottom of the borehole. It is then fired electrically and the resulting explosion shatters the rock at the bottom of the borehole and opens up fissures, which in some instances very materially increase the supply of water. In the absence of a suitable borehole pump, the results with these experiments have not been properly determined, as only those have been classed as successful which have yielded an increased supply of water under pressure. It is considered possible that many of these boreholes would yield a good deal of water if means were provided to pump it out, and now that we have a simple means of doing this further experiments will be made during the next hot weather. The demand for exploratory boreholes is great and the landowners are in many instances reluctant to give up at a depth of 100 feet which is usually that to which our boring sets can work. In a few cases, by providing extra boring rods, borings have been conti-

nued to a depth 200 feet, but with hand-tools this is expensive, and we are now trying power drills with which we expect to reach as much as 500 feet.

At the outset, 3-inch boring tools were mainly employed, but experience has shown that 4-inch tools, although much heavier, are more convenient when the depths to be bored exceed 50 feet.

It will be obvious from these brief notes that in no direction does finality appear to have been reached. In the beginning, when the work was first started the prospects of attaining any marked degree of success were by no means assured. Now it is certain that the use of mechanical methods of lifting water will year by year extend, and at no distant date, we shall have thousands of mechanically driven water lifts at work. In every direction, progress has been made. It is now possible to obtain much better appliances than was the case five years ago. Then, we were not certain that underground water could be obtained in sufficient volume in any great number of cases, now, we know that over large areas and in many places it is well worth while to instal mechanical arrangements to lift water. Progress has been much greater than was anticipated owing to the rise in value of agricultural products and the large profits that have consequently been made by the land-owning classes. This has, at the same time, increased the cost of cattle labour and compelled the intelligent land-owners to turn to engines and pumps as a means of reducing the expense of lifting water and at the same time of bringing a larger area

of dry land under wet cultivation. Each advance prepares the way for further improvements and indicates that the efforts now being made will in time be productive of great results.

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CHAPTER XVIII.

IRRIGATION BY PUMPING IN THE UNITED STATES.

The total area of the United States is very nearly three million square miles, and of this area not less than one and a quarter million square miles, between the Mississippi river and the Pacific Ocean is so situated that cultivation without irrigation is either extremely precarious or absolutely impossible. Till the passing of the National Reclamation Act by Congress in June 1902, which authorizes the construction of irrigation canals and reservoirs by the Federal Government, the development of irrigation has been entirely left to private enterprise. The earliest settlers were the Spaniards who came from Mexico up the valley of the Rio Grande river and found the Indians of that region, "watering the thirsty soil as their forefathers had done for unnumbered generations before them and as their descendents are doing to-day." These pioneers of European civilization remembered the wonderful fertility of the irrigated fields in the south of Spain, and the colonies which they established, in what are now the territories of Arizona and New Mexico, imitated and to some extent improved upon the primitive practices of the red-skinned savages. Later, in the middle of the eighteenth century the mission

fathers of Mexico established a chain of stations along the Pacific Coast from San Diego to San Francisco, and to them the credit is due of introducing the methods of irrigation practised in Spain.

On the East Coast, in the Carolinas and Georgias the eighteenth century witnessed the gradual growth of rice cultivation on low and marshy lands bordering on tidal rivers. At high tides the fresh water was backed up the rivers and flooded the rice fields, at low tides the water receded and the fields could be drained. From small beginnings the rice-planting became an important industry, and in the years preceding the great Civil War 80,000 acres yielded annually nearly 50,000 tons of cleaned rice. The ruin caused by the war and the changed labour conditions consequent upon the abolition of slavery led to the abandonment of many of the plantations, so that for the last forty years production of Carolina rice has been less than half what it formerly was.

Within, however, the last ten years, along the shores of the Gulf of Mexico in the States of Louisiana and Texas, rice-growing has been taken up on a very extensive scale, the necessary water being obtained by pumping from the sluggish streams or bayous which carry the drainage of the coast lands to the sea through a wide belt of marshy littoral. Nearly 300 pumping stations supply water to 610,000 acres, which yielded in 1904 about 400,000 tons of cleaned rice. Sixty-six rice mills are in operation and it is computed that fully one crore of rupees has been invested in the industry.

It would be difficult to find a more characteristic example of modern American enterprise in agricultural matters.

In California and the arid States of the west the early efforts of the Spanish settlers and monks supplied their own local requirements and ended there. The time was not ripe for the development of the country. There was no population to feed and no means of exporting surplus produce. Modern American irrigation owes its origin in the first instance to the Mormon community, which in the middle of last century sought a safe refuge from persecution beyond the Rocky Mountains in the arid plains of Utah and secondly to the necessity of furnishing supplies for the mining camps which followed the discovery of the mineral wealth of California and Colorado. The trans-continental railways opened up the country and gave the fruit-growers and stock-raisers of the West access to the Eastern markets in which there is an enormous demand for their produce.

Yet another impulse to the extension of irrigation was found in the semi-arid regions on the eastern slopes of the Rocky Mountains, where frequent periods of drought or scanty rainfall have compelled farmers to seek in the streams coming from the mountains or in the gravel beds beneath the soil for the water without which their crops were withering, their cattle dying and they themselves were being reduced to penury. The success which attended the earlier efforts of individuals led to the formation of joint-stock companies,

which undertook the construction of hydraulic works on a considerable scale to render large volumes of water available for the irrigation of extensive tracts of land. Many mistakes were made through inexperience and lack of knowledge, the cost of works was frequently under-estimated and not a few of the undertakings ended disastrously for the original shareholders. Still, on the whole, private effort has proved fully equal to the occasion and during the last 40 years at least 60 crores of rupees have been expended in bringing under irrigation ten million acres of land. Measured by the rise in value of the land or by the annual value of the crops, the investment has been extremely successful; whilst the engineering works, as an adaptation of means to an end, as a display of fertility of resource and boldness of conception, are of more than ordinary interest.

After India the United States have now a larger irrigated area than any other country in the world and as yet they are at but the beginning of things. It has been recognized that there are limits to the possibilities of development by private enterprise, so the Federal Government has taken up the work and has already provided nine crores of rupees for the great projects now being investigated. Previous to this the scientific study of irrigation problems was taken up both by the Department of Agriculture and by the Geological Survey and the valuable series of reports which they have issued, have provided reliable data upon which engineers can base their designs and legislators

frame adequate laws for the protection of water rights.

Compared with India the conditions in the States are in almost every respect diametrically opposite. Everything has been left to private individuals and they have had a perfectly free hand in every way, there were no vested interests to contend with, capital was abundant and readily forthcoming, labour was very expensive but timber fairly cheap, the farmers are educated and enterprising, for livestock there is a large market and the products of orchards and gardens realize high, and often fancy prices. The effects produced by these conditions are clearly visible. No large or comprehensive projects have been carried out, present necessities and not future prospects have controlled the situation ; conflicting interests have grown up, involving much litigation and frequent scenes of lawlessness. The paramount consideration was an immediate return on the capital outlay and in the face of adverse circumstances it has exercised a dominating influence over the character of the engineering. Problems have been tackled with a boldness which in some cases verges on recklessness and much of the work will have to be done over again. There is no doubt that the general policy was right but it was a temporary one and there is abundant evidence that a change is in progress in the direction of a demand for more solid construction and hydraulic works of a more permanent character.

When once the value of irrigation was demonstrated, it was but natural that every available source of

water-supply should be examined and the prospects of making successful use of it carefully investigated. Farmers who had no hope of obtaining a gravity supply delivered on to their land turned their attention to the subterranean waters and from wells sunk to the water bearing beds soon found it was practicable to obtain sufficient for a patch of alfalfa or a vegetable garden which proved of immense value in seasons of deficient rainfall. To raise the water above the level of the ground windmills were freely resorted to and in the long run have proved convenient sources of power when the quantity required is not large and no great storage capacity is needed to tide over periods of calm weather. Hundreds of thousands of windmills are now in use for pumping water in the United States, but only a very small percentage of them are doing much beyond supplying domestic requirements, watering stock and irrigating small fruit or vegetable-gardens. Where irrigation from wells is in vogue, the water-supply is invariably derived from beds of sand and gravel in which it is frequently found under artesian pressure sufficient to cause the water to flow up the boreholes above the level of the ground. In many cases this happy condition of affairs still prevails and there is a considerable area of land watered by such artesian wells, but in most instances the number of boreholes tapping the water bearing strata is so great that the pressure has fallen very considerably and the water now has to be raised by powerful engines and pumps.

Apart from windmills which are mainly used for irrigation in the States of Kansas and Nebraska, irrigation by pumping is most largely developed in California, Utah and Colarado and in the rice growing districts of Texas and Louisiana. The pumps employed are mostly of the centrifugal type, with either vertical or horizontal spindles, and for motive power practically every kind of modern prime mover has been tried ; whilst in California the system of lifting water by compressed air is in use and apparently with success notwithstanding the waste of energy which must necessarily occur when such a medium for transmitting power is employed,

Compared with what is known about the yield of water from wells in India those used for irrigation in America give very large supplies. Few, to which pumps are attached, yield less than half a million gallons per day and many of them several times that quantity. In consequence the units of power are very much larger than we can hope to instal here, the range being usually from 20 to 60 h. p. Where the water-supply is derived from other sources than wells, as for instance from rivers or lakes, the pumping plants are very much larger and engines of several hundred horse-power are not uncommon. The depth from which it pays to pump water varies enormously, being dependent on the value of the crops which can be grown, on the cost of motive power, which is itself a function of the price of fuel, and upon the duty of water for the crops under cultivation. Exceptional

results are possible in districts where electric energy derived from water power is obtainable or where crude petroleum oil is found. In Utah State, at American Forks, electric power is sold at from 3·3 to 4·2 pies per horse-power per hour; in California, at Bakersfield the price is 5·6 pies, at Mount Whitney 3·4 pies and at Riverside 9 pies. In Madras, oil engines will yield a brake horse-power for from 9 pies to As. 1, per hour using crude oil costing As. 3 per gallon whilst in Texas similar oil can be purchased at rates which fluctuate a good deal but probably do not average more than As. 1 per gallon. In California liquid fuel is equally cheap but it is unsuitable for oil engines on account of the large amount of asphaltum in its composition. The distillate has, therefore, to be used and the price of this is practically As. 3 per gallon or about one-half the usual price in Madras. In the other arid States these favourable conditions do not prevail and the statement would be roughly accurate, that in respect to the cost of generating power farmers in America are no better off than ryots in the Madras Presidency.

In the following notes I have attempted to summarize the vast mass of detailed information, which was kindly placed at my disposal, under convenient headings.

Windmills.—These are not largely used for irrigation work except in Kansas and Nebraska, where the winds are strong and reliable and the water bearing strata is at no great depth from the surface. For domes-

tic and other purposes requiring only small amounts of power the American windmill is used in enormous numbers, but for the sake of cheapness they are too lightly constructed and can only work in moderate winds. In favourable situations windmills are probably the cheapest engines for pumping water available but, till the load is automatically adjusted to the velocity of the wind and in the proper proportion, the maximum yield of power will not be obtained from them. Windmills have been the subject of much study and investigation in the United States but the papers published by the Geological Survey contain discordant results and there is still a good deal of doubt on the subject of loading them so as to produce the best results.

Oil Engines.—Engines of small power which require a man to look after them are not at all economical in the States as the cost of labour is very high, varying from Rs. 3 a day in the south to Rs. 7-8 in the west. Small oil engines are, therefore, not much used for pumping water, but of sizes between 10 and 30 h. p. there are a considerable number in use, especially in places where they are only required to run for a comparatively small number of days in the year. Oil engine fires are very common, so much so that the insurance rates are prohibitive. This is directly contrary to our experience in India as here we regard oil engines as perfectly safe motors and no serious accident has ever happened to disturb that belief. To facilitate starting oil engines, it is a

common practice in America to begin with petrol and only when the engine is fairly at work to turn on the oil and there is no doubt that thereby a very serious extra fire risk is introduced.

Steam Engines.—For driving centrifugal pumps or air compressors, steam engines of all types are employed, from portable engines of 8 or 10 h. p. up to compound Corliss condensing engines capable of indicating 500 h. p. About these engines there is nothing particular to note and the interest in the matter lies with the fuels used for generating steam. Wood, coal and crude oil are used and the prices paid for them depend upon the locality and the facilities for transport. In the rice irrigation tracts of Texas oil costs from Rs. 1-8 to Rs. 2 per barrel of 35 English gallons, coal nearly Rs. 15 per ton and wood from Rs. 4-8 to Rs. 9 per cord of 128 c. ft. or roughly from Rs. 3 to Rs. 6 per ton. In the Santa Clara Valley, California, distillate oil, roughly equivalent to bulk kerosine oil, costs 3½ to As. 4 per gallon, further south at Bakersfield, near the Kern Valley oil fields, and round Los Angeles, in the neighbourhood of which there are also oil fields, the price of both crude oil and distillate is much less, but liable to considerable fluctuations.

The comparative cost of pumping is conveniently expressed in terms of the cost per horse-power hour or per acre foot lifted one foot. An acre foot is the quantity of water which will cover one acre to a depth of one foot and is equal to 43,560 c. ft. or very

approximately to a flow of one c. ft. per second for 12 hours. Experiments made with an 8 h. p. portable steam engine on a lift of 26 feet using coal costing Rs. 15 per ton gave the costs, per acre foot lifted one foot, at As. 5. An exactly similar rate was obtained with an oil engine, on an lift of 33 feet, using oil which cost As. 7 per gallon. A steam engine supplied with steam from boilers fired with wood at Rs. 12 per cord or, say, Rs. 9 per ton working on a lift of 45 feet raised one acre foot one foot high for As. 3-3. This is about the cost in Madras with small oil-engines and centrifugal pumps, but it must be remembered that the above figures do not include any allowance for interest and depreciation.

Electro-Motors.—The low rates, quoted above, charged for electricity in Utah, and California have rendered it practicable to use this form of energy for driving centrifugal pumps lifting water for irrigation purposes. The current is in all cases generated by water power in the canyons of the neighbouring mountains and transmitted across country at pressures generally over 10,000 volts. The three-phase system is invariably employed and the current is transformed down at the pumping stations to 2,200 volts or to 2,500 volts and utilized in induction motors which have an efficiency of about 90 per cent. Except in the oil regions fuel is very dear in the Western States and there has been every inducement to make as much as possible of the water power available. In California, the western slopes of the Sierras presented

an unusually large number of favourable sites for the development of water power which have in many cases been taken up and the electric energy generated is raised to pressures as high as 33,000 volts rendering transmission possible to great distances with economy and efficiency. By linking up different systems power has been transmitted well over 200 miles and in the latest installation the pressures on the line have been raised to 50,000 volts. Electrically transmitted power can only be economically employed where the irrigation season lasts for at least six months and is consequently mainly to be seen in the Alfalfa fields and Orange gardens of the south.

The largest pumping station is in Utah State at Lehi, where the river Jordan debouches from Lake Utah. All the water passing down the river is diverted for irrigation and the level of the water in the lake is now so low that it has become necessary to lift the water from the lake into the river to obtain a supply adequate to the needs of the irrigation interests concerned.

Four centrifugal pumps with 54 inches suction pipes have been installed and are driven through belting by four 100 h. p. Westinghouse induction motors running at 580 revolutions per minute. The speed of the pumps is 166 revolutions per minute. The power is supplied by the Utah County Light and Power Company of American Fork, who have a water power generating station in the American Fork Canyon, distant about five miles from the town and about 11 miles from the Jordan pumping station at

Lehi. The three-phase system of transmission is in use at a pressure of 6,000 volts, which is reduced by means of three 170 K. W. transformers to 500 volts at the pumping station. The lift of the water varies with the level in the lake, the range being from 2 feet to 5 feet, and the discharge of each pump is 100 c. ft. per second. The price paid for power is Rs. 15 per horse-power of continuous supply per month. The efficiency of the motors is stated to be 75 per cent. and the total efficiency of the station including all losses when working on the maximum lift, 33 per cent. but at lower lifts the efficiency falls off. The irrigation season lasts six months and the pumps are at work 98 per cent. of that time. During the month of August 1904, the pumps were running 732½ hours out of 744. Nine hours was lost at the generating station and only 2½ hours at the pumping station. Storms and unfavourable meteorological conditions accounted for more than half the lost time. In the Utah valley lightning is often very intense and causes much damage to electrical installations, and it is generally considered better to shut down the station, when violent storms are in the neighbourhood, than run the risk of a transformer being burnt out. This pumping station cost about Rs. 1,50,000 but it can only be regarded as a temporary expedient whilst the whole question of irrigation from the Utah Lake is under investigation by the Engineers of the Geological Survey. It is beyond the scope of this paper to enter into a discussion of the interesting problems

which the irrigation in this valley has given rise to but pending their solution this electrically driven pumping plant enables 40,000 acres to be supplied with water at a comparatively small cost. The duty of the water appears to be about 100 acres per c. ft. per second and as the pumping season lasts 180 days the quantity of water delivered to each acre amounts to about 3·6 acre-feet. The working expenses are less than Rs. 1·50 per acre which is a very small charge on land the gross return from which a very low estimate places at over Rs. 100 per acre.

In the town of American Fork small electro-motors of one-half h. p. are installed in a number of gardens to drive force pumps working on tube wells for domestic supply and for watering the lawns, shrubberies and orchards round the houses. The charge for a 12 hour day service is Rs. 3 per month. The Municipal Corporation derive part of their water-supply from an artesian well sunk to a depth of 400 feet, in which the water rises to within 22 feet of the ground level. A three h. p. motor, working through a countershaft, drives an ordinary plunger pump, which raises the water into a tank from which it is delivered into the town mains. The total lift is about 36 feet and the charge for power supplied continuously day and night is Rs. 36 per month. The pump is placed at the bottom of a brick well about 6 feet in diameter, and the motor is above the ground. A small wooden shed covers the whole plant and once a day it is visited by a man to oil the bearings.

The generating station of the Power Company is situated in the American Fork Canyon, 5 miles from the town. The plant consists of two 500 h. p. Pelton water wheels worked under a head of 290 feet and driving two 250 K. W. three-phase alternators at a tension of 6,000 volts. In the town the pressure is reduced to 2,300 volts and each group of users is supplied at either 115 volts or 230 volts through small transformers fixed on the poles carrying the transmission line.

It was not possible to ascertain the extent to which electricity generated from water power has been made use of in California to raise water for irrigation. The Agricultural Department of the United States are collecting information on the subject, but their data are as yet very incomplete. The General Electric Company to whom I applied for assistance were kind enough to supply me with a list of thirteen large electrical supply companies, all of whom were furnishing power for pumping water. In consultation with the officers of the company, three irrigation stations were selected for inspection as typical of the others, and the following notes are compiled from information gathered locally.

The Bakersfield Power, Transit and Light Company has a generating station in a Canyon 16 miles from the town. The current, which is three-phase alternating, is transmitted at 10,000 volts and is used in the town for lighting purposes and by the tramway as well as for pumping water. For irrigation work 27

motors of from 30 to 40 h. p. are in use and for the water-supply of the town a further 10 or 11 motors are employed. The water is found in beds of gravel about 60 feet below the ground and an abundant supply can be secured by sinking tube wells. The water is under sufficient pressure to rise to within 15 or 20 feet of the ground. At one of the town water-supply stations two 12 in. tube wells had been sunk to a depth of 100 feet and the water was drawn from them by a centrifugal pump directly coupled to a three-phase induction motor. The pump was placed just above the wells and the suction pipe, 5in. in diameter terminated in branches, passing down the two wells. The pump was of the ordinary horizontal type and ran at 950 revolutions per minute, delivering 540 gallons of water per minute through a 6in. pipe under a total head of 110 feet. The pump was primed by running water into it from the delivery tank, both suction pipes being fitted with foot valves.

At the irrigation stations the arrangements were different as the lift was only to the level of the ground and did not in any case greatly exceed 30 feet. The electrical pumping stations all belong to the Power Company which supplies the water to the Kern County Land Company, who use it for the irrigation of Alfalfa, at the fixed rate of Rs. 4½ per cubic foot per second per day. A 30 h. p. motor will raise about 4½ cusecs, so that at the price charged the power realizes less than 6 pies per h. p. hour, and is almost exactly Rs. 21 per month. The pumping stations differ from one another

not only in the size of pumps but also in the driving arrangements. In some, the pumps are of the horizontal type and driven by a belt from a horizontal motor, in others the pumps are vertical and the motor is directly connected to the pump by means of a vertical shaft. Under the conditions prevalent round Bakersfield there is not much to choose between the two methods of running but the opinion of the men in charge of the pumping work is in favour of the belt-driven pumps. The belt is a less efficient means of carrying the power from the motor to the pump than is the vertical shaft, but the lubrication of the latter and the arrangements to resist the thrust due to the weight of the motor, pump and shaft, if not more liable to get out of order than belt-driven pumps, yet give rise to more serious accidents when anything does go wrong. The best evidence that can be adduced as to the ease and simplicity of working at these pumping stations is the fact that although they are 27 in number, they are all looked after by two young men. The wells are a considerable distance from one another and for these attendants to get round to each well once a day it is necessary to supply them with a horse and buggy. One of them accompanied me on my visit to several of the wells and I saw him start and stop the pumps without the least difficulty although but a few months before he had been a farm hand and had had no training either in mechanical or electrical engineering work. At the first station visited there were 4 tube wells of 12in. diameter sunk in a line, the distance between

them being 10 feet. The pump was of the vertical type and was placed at the bottom of a timber pit about 16 feet below the ground, the suction pipe was horizontal with four branches dipping into the four wells. While pumping is going on the water sinks in the wells about 15 feet to produce the head necessary to maintain flow, so that the maximum lift was 31 feet. The delivery of water averaged 4½ cusecs and the efficiency of the installation was 51 per cent. The motor was of the three-phase induction type rated at 30 h.p. and working under a pressure of 500 volts. The motor, pump, vertical shaft and delivery pipe were carried by a steel frame-work, square in plan, built of angles and bars and stiff enough to keep all the running parts in perfect alignment. The transformers, two in number, were in a separate shed and the connection with the high tension lines was made by a switch of simple construction placed outside, lightning-arresters were also provided, and an automatic device for switching out the motor should a temporary interruption of the current cause the pump to lose its suction vacuum.

Two other pumping stations were also visited in which horizontal belt-driven pumps were in use. The belt drive was rather long and the belt was of very ample dimensions for the power to be transmitted. At one station the pump was primed by an ordinary force pump worked by hand and the operation of starting was distinctly laborious; at the other a small pump was driven through a countershaft by a belt off the pump spindle. The pumps were placed at a level consider-

ably above that of the water in the wells and consequently the suction lift was much longer than in the case of the vertical pumps. In other respects the equipment of these stations was all of the same type.

The water delivered from each pump is run into a sump provided with fine screens to damp down the oscillations of the surface and then passed over a thin edged weir made from a sheet of steel plate. The weirs were usually 3 feet in length and the depth of water on the crest is measured by means of a hook gauge, with a micrometer screw, sliding on a graduated scale. In Bulletin No. 86 of the U. S. Department of Agriculture, discharge tables for such weirs have been computed and are found of great value in measurements of water coming from channels or streams as well as from pumps. The extraordinarily high value to which water for irrigation has risen in recent years, has naturally led to more care in its measurement than is the practice in India and sharp edged weirs, especially those of the Cippoletti pattern, are very largely used in ordinary distribution work.

Ontario.—This is an irrigation colony entirely devoted to the cultivation of citrus fruits which was started by Messrs. Chaffey Bros., of Ontario, Canada, and subsequently better known in connection with their irrigation schemes at Renmark in South Australia. When supplied with sufficient water the soil is extremely fertile and the conditions generally are peculiarly adapted to the growth of oranges and lemons for which there is a splendid market throughout the States and

admirable transportation facilities. The quantity of water available for irrigation is limited and insufficient for the area of land which could be brought under cultivation; hence there has been every possible inducement to prevent waste of water and secure a high duty. The water-supply is mainly derived by pumping from artesian or sub-artesian wells and it is conveyed to the fields in concrete pipes and the distributory channels are all of concrete. Furrow irrigation is invariably employed, and to avoid loss by evaporation, the water is sometimes carried down the furrows in pipes buried in the soil.

In Southern California flowing water is usually measured in "miners' inches," of which 50 are equal to one cusec and one miners' inch is considered sufficient for the irrigation of 10 acres of land in Ontario, so that in ordinary terms the duty of water is 500 acres per cusec. The profits from citrus cultivation are very considerable and as land without water is valueless, water rights are extremely valuable. The capitalized value of one 1 cusec is about 3 lakhs of rupees, equivalent to Rs. 15,000 per annum and equal to a water-rate of Rs. 30 per acre, but water especially in seasons of scarcity is occasionally sold for much higher rates. One man who has more water than he needs is able to dispose of his surplus at the rate of Rs. 75 per day for 30 miners' inches or 0·6 cusecs, which is considered a sufficient watering for 10 acres. At Ontario the water-supply is controlled by the San Antonio Water Company, the whole of the stock of which is held by the

fruit-growers in proportion to the area of land which they occupy. Each 10 acres is entitled to a continuous flow of one miners' inch, but as that is too small a stream for satisfactory irrigation, the custom is that each 10 acre plot gets a stream of 30 miners' inches for one complete day in the month. The electric generating station is situated in the San Antonio Canyon about 8 miles to the north of Ontario and the power is brought into the colony by overhead transmission lines at 10,000 volts pressure. The pumping plants make use of the greater part of the power but it is also employed in driving motors for miscellaneous work, for electric lighting, and for electrical cooking and heating. For these purposes the energy is retailed at from As. 1-3 to As. 1-6 per Kilowatt hour.

The wells, from which the water is pumped for irrigation, are situated in the debris at the foot of the San Gabriel Mountains and are 8 in number. A description of one pumping station will apply to all. The power for all the wells is distributed at 2,200 volts from a central transformer station where the lines from the generating station bring in three-phase current at 10,000 volts. The wells are supplied, each with a horizontal induction motor capable of working continuously at 60 h. p. output and the centrifugal pumps are of the vertical type and driven by quarter twist belts. At one station the pump was placed at the bottom of a timbered shaft 140 feet deep and immediately over a 12in. tube well sunk a further 460 feet. Owing partly to a long series of years of

deficient rainfall and partly to the very heavy demands now made upon the stores of subterranean water, the level in the wells at North Ontario is steadily falling and nearly every year it is necessary to deepen the shafts and lower the pumps. For these reasons the horizontal motors and belt drives are employed. At the time of my visit the depth of water flowing over the 3 feet measuring weir was 3·375in. indicating a discharge of 90 miners' inches or 1·80 cusecs on a lift of about 155 feet. The pumps which are two stage usually run for months without stopping but they are examined and oiled every four hours. Electrical power has been in use only some three years; previously both oil and steam engines were employed, pumping having been necessary for the last ten years.

The Gage Canal Company, Riverside:—This Company possess 13 groups of wells sunk on the banks of the Santa Ana river and a supply of about 1,500 miners' inches or 30 cusecs is obtained by pumping with power purchased from the Edison Electric Companies' system, at the rate of As. 1 per K. W. hour. One group of wells was 6 in number, each a 7 in. tube sunk 400 feet. The water rises very nearly to the ground level and the working lift was about 32 feet. The gauged discharge of the pump was 265 miners' inches or 5·30 cusecs. The pump was vertical and driven by a horizontal motor through a quarter twist belt. Most of the wells consist of a single tube 10 or 12 inches in diameter and sunk to a depth of from five to six hundred feet. Vertical motors mounted on the pump shaft are not

employed as the pumps have to be lowered occasionally and whilst the wooden shaft is being sunk it is necessary to keep the pump running. It is, therefore, suspended by a stout wooden framing from beams fixed at the floor level of the motor shed. Formerly all the wells used to flow, but now no water can be obtained except by pumping and the cost of irrigation per acre has been raised from Rs. 6 to Rs. 23.

Mr. Pedley, the General Manager of the San Jacinta Land Company, thus briefly narrates the history of the Temescal Water Company's plant. "Ten years ago this company had flowing artesian wells, but the supply gradually decreased owing to a series of dry years, and then the company began to pump from some of the weaker wells in order to supplement the supply from the stronger ones and in a short time all the wells ceased to flow. The pumping was begun with centrifugal pumps and oil engines. The water level fell steadily about ten feet per year and the wells were then dug down to water level and the pumps lowered. This process was unsatisfactory and expensive in every way. The pumps were not suitable for the greater depths and the engines were not powerful enough and so had to be changed." Then the company experimented with a steam driven air compressor and raised the water by injecting compressed air into the wells at a point about 160 feet below the surface; the bubbles of air, rising rapidly, expand as the pressure decreases, and so lighten the column of water that the pressuer at the bottom is sufficient to eject a considerable stream

of mixed air and water. The process was convenient and reduced labour because the air was all compressed at a central station and piped to about 20 different wells doing away with a number of small oil engines. It was, nevertheless, very expensive, and, finally, the Company had to adopt electric power generated at a main station and distributed to motors."

The brief account is interesting as typical of what is going in the country not only in regard to irrigation by pumping or even irrigation generally but in regard to almost all fields of activity. Some one lights upon a good thing and every one wants to be in it, over-development ensues and difficulties are created, which are met by heroic methods, the very boldness of which contributes not a little to the ultimate success. The Californian orange grower has in some respects very favourable conditions under which to work. His present prosperous condition is due not only to making the most of them but also to the display of unusual skill and energy combined with adequate capital to command the services of the best obtainable expert engineering assistance and further to what is perhaps almost as important, unbounded faith in the possibilities of modern engineering. The average American, if he reads nothing else, reads his Sunday papers and dwells with huge delight and complacency on the popular science sections, in which are recorded the triumphant applications of physical science to the solution of the material problems which

constantly arise in the strenuous efforts they are making to open up the vast territories they have occupied.

Pumping by Compressed Air.—The Pohlé Air lift is largely used for raising water from tube wells and is especially convenient where the wells are of small capacity and fairly numerous. For dealing with large bodies of water its mechanical inefficiency is against it but in other respects it is extremely satisfactory and requires no supervision outside that necessary for driving the air compressing plant. Through the kindness of Mr. J. B. Lippincott, the Supervising Engineer of the U.S. Geological Survey in Los Angeles, I was furnished with a copy of a report on the efficiency of these lifts made by Mr. David S. Macpherson. The experiments were made at the Cudahy branch where 9 wells have been sunk at distances ranging from 20 to 800 feet from the air compressors. The wells are all 12in. tubes perforated in the water bearing starta. The statical level of the water is 45 feet below the surface but the pumping lowers it about 15 feet so that the total lift during the trials was 60 feet. The power plant consisted of 4 single cylinder air compressors each 16in. by 18in. Two of the cylinders were driven by direct acting steam engines and two by a single cross compound engine. The air compressors all deliver into a common receiver and the power required to drive one of the compressors was found by indicating one of the direct acting engines and multiplying the result by four. The wells discharge into a common flume and by current meter observations the flow was determined to

be 6·014 cusecs equal to 41·1 h. p. in the water lifted. Four times the indicated h. p. required to drive a single compressor was 173·34, so that the efficiency of the plant was 23·7 per cent. In each of the wells a 6in. tube was submerged 90 feet and the compressed air from the receiver at a pressure of 45 lbs. per square inch is carried in a small pipe down the well and the end of it is turned up so as to discharge the air into the 6in. delivery pipe.

The most recent practice favours a submersion of the delivery pipe from $2\frac{1}{2}$ to 3 times the height to which the water is to be lifted and the air pressure should be just sufficient to allow a free flow. The methods by which the above stated efficiency was determined are, of course, open to criticism as lacking in accuracy but they are probably devoid of serious error and agree with the generally prevalent impression among Californian engineers that the efficiency of well established plants is in the neighbourhood of 23 per cent.

Several installations were visited in the country round Pasadena in company with Mr. J. B. Lippincott to whom I am greatly indebted for much courteous assistance when making enquiries in this matter. Part of the water-supply for the town is derived from 4 wells each of 10in. bore sunk to a depth of about 400 feet. The discharge pipes were 6in. in diameter and the lift about 60 feet. The air compressor was of the two stage type and the pressure in the receiver was 80 lbs. per square inch. The water was raised to ground level and after passing through a settling tank, to

get rid of any sand, was lifted an additional 40 feet by a centrifugal pump, driven off the fly wheel shaft of the air compressor. The plant belonged to the West Side Water Company and as its purchase by the town was under consideration, the engineer in charge was unable to afford any information regarding efficiency or working expenses.

The second installation belonged to the East Whittier Land and Water Company and consisted of 14 wells discharging into a concrete flume. The lift was about 20 feet at the time but only a few wells were being drawn upon and when full supply is being taken it is probably considerably more. The air compressor was of the two stage type and was driven by a Corless engine, which under full load was capable of indicating 500 h. p. Steam was generated in tubular boilers, liquid fuel being used. One man was in charge of the station and there is no doubt that here, where labour is very expensive, the advantages of this method of lifting water were exemplified in a high degree.

At a third station near Delmonte there are 9 wells. Three with a lift of 70 feet and the other six with lifts of from 85 to 92 feet. A Smith Vaile compound engine indicating 140 h. p. drives the compressor which raises the air to a pressure of 56 lbs. per square inch, 6·2 c. ft. of free air are used per c. ft. of water lifted.

From enquiries subsequently made in London it appears that the Pohlé Air lift is very extensively used both in Great Britain and on the Continent. Mr.

C. T. A. Hanssen, in an article contributed to the *Engineering Review* of July 1904, states that upwards of 900 installations are at work.

In a paper read before the British Association of Water Works Engineers, Mr. W. H. Maxwell, the Borough and Water Works Engineer of Tunbridge Wells, gave some interesting information regarding a Pohlé Air Lift which he had installed to supplement the water supply to the town. The boring is situated at a distance of 530 yards from the engine house, and is 350 feet deep; 200 feet is 15in. diameter and lined with solid steel tubing, 150 feet is 13½in. in diameter and lined with perforated tubing. The air compressing plant consists of two sets of two stage compressors with intercoolers. The steam cylinders are of 8in. and 12in. diameter and the air cylinders of 10in. and 6in. diameter, the stroke being 14in. The compressed air is carried to the well by a 4in. cast iron main terminating in a 2½in. pipe which descends to the bottom of the well and by a U piece delivers the compressed air into the rising main which is 7in. in diameter. The cost of the installation excluding engine house, boilers, and lining and boring well was Rs. 50,625. A number of tests of the plant have been made which show clearly that the efficiency is greatly dependent on the ratio of the immersion of the air pipe to the height the water is lifted. In the trial, which gave the best result, the lift at the beginning was 84 feet and at the end 106·6 feet, and the ratio of immersion to lift varied from 3·01 to 2·2. The average discharge was 24,100 gallons per

hour and the efficiency calculated on the I. H. P. of the engines was 36·8 per cent. and on the I. H. P. of the compressors 46 per cent.

Even better results were obtained with an Air Lift fitted up by Messrs. Hughes and Lancaster for raising sewage at Rothesham. In a well, 4 feet in diameter, a rising main 12in. diameter was fixed and immersed to a depth of 25 feet. Air under a pressure of 12 lbs per sq. in. was delivered through a 3in. pipe. The lift was 9·50 feet. During a trial 1808·6 gallons per minute or 4·823 cubic feet per second were raised with 3·441 cubic feet of air per second. The efficiency was 49·5 per cent.

A well designed Air Lift is a very convenient device for lifting water and it is the inefficiency of the methods of compressing air which are in the main responsible for the low ratio of the output of useful work to the total power expended. The Air Lift is a device applicable with advantage only to deep tube wells and is not likely to be of much use in India,* where the wells are usually shallow and under normal conditions seldom contains any great depth of water. For the water-supply of towns, and possibly also for irrigation, it might be worth while to experiment with tube wells, sunk by hydraulic jets in the deep sandy beds of some of our rivers. Air Lifts are the only practicable means of drawing the water from such wells and it is more than probable that very large quantities of water could be obtained in this way. The wells

* Except in places where Artesian supplies of water have been found.

would require protection from scour near the surface and the cheapest way would be to take advantage of some existing permanent masonry structure stretching across the river such as a bridge, anicut or causeway. American experience seems to show that the choking of the tubes by sand can easily be prevented.

Pumps.—American engineers have naturally paid a great deal of attention to machinery for lifting water and the Californian practice of to-day is the outcome of fully five and twenty years' intelligent study of the many phases of the water lifting problem which irrigation necessities have brought into existence. For dealing with large quantities of water the centrifugal pump is universally employed and the details of its design have been gradually perfected so that it is now a fairly efficient machine capable of running continuously for long periods. Pump makers are prepared to guarantee efficiencies of from 60 to 75 per cent. the higher value with the larger pumps, but in practice, when the friction of the suction and delivery pipes is allowed for, the useful work in the water delivered is seldom more than 55 per cent. of the power expended. For high lifts two and three stage centrifugals are employed, the pumps being placed at the bottom of a pit sunk to the water level. They are invariably of the horizontal type with vertical shafts and are generally driven by quarter twist belts though in some instances where electricity is used the motors are fixed above ground on the top of the vertical shafts. When the pumps are running, the down-

ward thrust is partly or wholly balanced by the upward pressure on the pump wheel due to the suction entering on the top of the pump casing. When the pumps draw water from one or several tube wells grouped together foot valves are out of the question and at starting either steam ejectors or air pumps are used to create the necessary vacuum. Where foot valves are in use the pumps are primed from an overhead tank which is kept full of water and ready for use at any moment. For the rice irrigation in Texas and Louisiana both rotary and centrifugal pumps are used. The latter are preferred though the former are more efficient. The quantities of water dealt with are sometimes extremely large but the lift is not great, averaging about 20 feet. The diameters of the pump discharge pipes range up to as much as 60 inches with a delivery of 100 cubic feet per second. Direct coupled engines and pumps are not in favour and belt or rope drives are usually employed.

The enormous development of windmills for pumping water has led to a good deal of attention being paid to the design of small bucket pumps. A careful series of tests by Professor O. P. Hood published in the Water Supply and Irrigation Papers of the Geological Survey, show that efficiencies of over 80 per cent. are easily obtainable when the speed of working is not too great. The most important feature in the design of these pumps in the provision for the withdrawal of the piston and suction valve for examination or repair when the pump is submerged. On the

oil fields of California I saw a large number of deep well pumps worked by wire ropes attached to a large eccentric driven by an oil or steam engine. In some cases more than a dozen wells were being pumped by one centrally situated engine which, through a pair of bevil wheels, drove a vertical shaft carrying an eccentric, to the sheaves of which the wire ropes radiating in all directions were attached. The shaft made about 15 revolutions per minute and the eccentric had a radius of 12 inches giving the pumps a stroke of 2 feet. The wires were suspended in slings attached to cross arms on wooden poles and the pumps could be worked satisfactorily at a distance of half a milé from the engine. It seems to me that this system is capable of very extended application in this country where there are many tracts of country with numerous shallow wells, none of which are individually capable of yielding sufficient water to give employment to the smallest practicable installation of oil engine and centrifugal pump. By installing a bucket pump in each well and coupling it up by wire rope to a central station of this kind it will be possible to employ an oil engine to pump water from all the wells situated within a radius of half a mile. The efficiency of this method of transmitting power is fairly high and it ought to prove quite as economical a method of pumping as with centrifugal pumps. To adapt this system to irrigation a great many details have to be worked out, but there appears to be nothing serious to overcome. It is certainly worth trying in this country because, if

successful, it opens out a very wide field for the application of mechanical power to the lifting of water for irrigation.

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