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WATER SUPPLY.

PART I.—WATER SUPPLY WITH THE FIELD ARMY.

CHAPTER I.

ORGANIZATION.

1. *Character of the work.*

1. The Royal Engineers are responsible for the supply and distribution (except by road transport) of water for all purposes to all arms and departments of an army in the field. Occasions may arise on active service where units will find and supply themselves with water.

The Royal Engineers jointly with the R.A.M.C. are further responsible for the purity of all water supplied to the troops, and for assistance in this respect specially qualified personnel will be allotted to certain engineer units.

The purity of the water obtained under regimental arrangements is the responsibility of the regimental authorities, assisted by medical officers and special sanitary personnel.

When special engineer work is undertaken in connection with water supply, the Royal Engineers are responsible for the whole of the work required, including arrangements for the testing of the water (*see* Sec. **69**, para. 5, and Sec. **74**, para. 9) by experts and the installation and operation of the necessary purification plant; the Royal Engineers are not responsible for the purity of the water once it has left the installations maintained by them.

It is the duty of the R.A.M.C. to test the water supplied for the use of the army frequently and to make recommendations accordingly.

2. In the planning of a campaign, although at first sight it may appear that field operations will have to be confined to tracts adjacent to rivers, further investigation will usually show that water can be obtained from subterranean sources, transported from a distance by road, rail, or barge, or pumped through a pipe-line. The facilities offered by modern water engineering practice may thus have a very direct influence on the success of military operations, especially in tropical and waterless countries, or where exceptional concentrations of troops and animals in a limited area are required.

3. The amount and character of the water supply work that can be carried out in the field depend entirely on the conditions of the campaign, the degree of mobility of the forces to be provided for, and the hydrology of the country occupied.

4. General principles can be laid down, but methods and practice must vary. Though, during mobile warfare, little time is available for the execution of waterworks other than the rapid development of existing resources, the movement of troops may be held up until sufficient water for their needs is produced.

5. Waterworks practice at the Base camps and at fixed camps on the L. of C. will approximate to peace-time methods. The work undertaken by the field army may come into line with this practice during periods of position warfare, but will become more rudimentary and more limited to bare essentials as the war of position changes to that of movement.

6. Water engineering in the field is essentially a compromise between what is desirable and what is absolutely necessary. It must be remembered that a better and more efficient service of distribution will result in a higher standard of health of the troops and less wastage of man-power.

7. In the field the difficulties usually experienced are either that there is an absolute shortage of water, or that available supplies are highly contaminated and require purification. In some cases supplies may be both scarce and bad.

Water supply work involves the supply and distribution of :—

(*a*) *Potable* or drinking water for troops.

(*b*) Water for animals, ablution water, water for locomotives and steam engines, &c.

(*a*) must be safe to drink, while (*b*) need not be so.

In some cases a common supply meets both requirements, and in such cases the difficulty is usually that of obtaining water in sufficient quantity. In others, surface water may be plentiful but often polluted, and here the distribution of a safe potable water presents the more difficult problem.

8. In compiling a manual of instruction of this kind for military purposes, the chief difficulty is that of keeping the book within reasonable dimensions. The reader must therefore realize that the objects with which this manual has been produced are :—

(*a*) To set forth the basic principles involved.

(*b*) To give detailed information regarding the particular varieties of water engineering practice obtaining in the field.

For training purposes students must not hesitate to consult the standard text-books covering the various branches of the subject.

The complete conception and execution of a water supply scheme in peace-time calls for the expert direction of a constructional engineer, a mechanical engineer, a water chemist, a bacteriologist, and a geologist. The field water engineer, though recognizing the limitations of his own knowledge in these particular branches, must yet be sufficiently in touch with them to appreciate properly the information supplied by experts, or in default of such skilled advice, to carry through the scheme himself.

In the arrangement of the subsequent chapters of Part I of this manual, the general case has been assumed of an army first landing at a base port and then engaged in purely mobile warfare. It is then assumed that a period of position warfare ensues, followed by a deliberate attack and successful advance.

It is necessary, however, to read each chapter in conjunction with the remainder, since so many varieties of conditions may occur, each merging into the other.

2. *Special technical staff.*

1. The provision of water for the enormous concentrations of troops and horses occurring in modern warfare will usually demand a special engineer organization. The details of and methods to be adopted by this organization must be settled according to the hydrological conditions of the country encountered.

The engineer organization formed for this purpose must be solely concerned with water supply work. It will carry out all work required in the development of supplies, and be responsible for the purity of the water up to the time it reaches the consumer; it will control all methods of distribution that may be adopted, such as transport by motor lorry, &c.

Water supply practice in the field is governed to such a great extent by natural *hydrological* conditions, that it is only by a specialized application of personnel and material that really efficient results can be obtained. The development of a working system requires the establishment of a standard practice, and this can best be secured by unified control of specialized personnel definitely allotted for water supply work.

2. While this principle is extremely important, it must be remembered that it is impossible to maintain and employ in peace-time a special water supply organization. When it is apparent that important water supply operations are likely to be required for a campaign, the requisite organization must be worked out. This must be done on broad and far-seeing lines; an adequate and competent executive staff must be appointed, and efficient personnel and materiel provided. Although in small campaigns the amount of water supply work required may not initially appear to justify the development of a special water supply organization, the situation must be carefully watched so that operations may not be hindered by lack of it at some later date. Under some conditicns, indeed, it may be necessary to devote almost the whole of the available engineers to water supply work, when the units concerned are virtually converted into water supply units.

3. The organization of the office of an Engineer-in-chief with a force in the field provides for a chief water engineer's branch to deal with the general technical control of all water supply work, both for the field army and on the L. of C.; and attached to the staff of the C.E. of each army, and L. of C., and of the C.E. of each corps there will be a water engineer specially qualified to assist the C.E. in the design and supervision of water engineering work. These officers will assist the C.R.Es. of divisions and districts with their technical advice, and, where circumstances require it, a field engineer may be posted to the staff of the C.R.E. specially to deal with water engineering work.

All work in connection with water supply will be under the technical control of the E.-in-C., C.Es., and C.R.Es., in the same way as other engineering work.

The provision of mechanical plant for pumping and well-boring comes under the chief electrical and mechanical engineer on the E.-in-C's. staff and the army and corps electrical and mechanical engineers.

4. A close and consistent liaison is requisite between the water engineers and electro-mechanical engineers employed on water supply. The dividing line of responsibility will normally lie at the delivery connection of the pump with the pipe-line.

In many cases, however, it may be advisable to organize water supply units self-contained as regards mechanical personnel. It is essential, therefore, that officers appointed as water engineers should have had mechanical experience.

When specialist water supply units are formed for employment with the field army, they must be regarded as combatant field units, and armed and equipped accordingly, so that their services as such may be instantly available when and where required. It would be useless to form specialist water supply units for work with the field army if their degree of mobility is not equal to that of the force. When roads are available, the transport will consist mainly of motor vehicles.

5. The technical personnel employed on water supply must work in complete harmony with the remainder of the army in order to achieve the intentions of the commander. It will be the business of the water engineers of formations, under their respective engineer commanders, not only to carry out work definitely ordered, but to put forward suggestions for the most efficient employment of the units allotted for water supply work. To this end, water engineers of formations must be in close touch with the military situation, and should have prior information as to impending developments, so that the water supply policy may be framed accordingly.

The administrative staff must be kept posted by the engineer staff as to the progress of water supply development. Area maps showing where water can be obtained (not technical plans) must be prepared as occasion demands for distribution, through the administrative staff, to units.

6. The foregoing remarks apply more particularly to circumstances in which a considerable amount of water supply work is required, as would be the case during the preparations for and during the advance of armies on the continental scale, or when operations are in progress in a waterless country. When, however, the number of troops engaged is small, water supply work will have to be done by all engineer units as part of their regular duties, and a specialized organization may not be necessary or possible.

During mobile warfare on a large scale subsequent to a period in which special water supply units have been engaged, a unit may have to be split up into small sections for work with the more scattered bodies of troops, and its organization should allow of this being done, while its mobility must be equal to that of other engineer units engaged. Such detachments would, of course, be under the engineer commander of the formation to which they are attached, and, if there was insufficient water supply work to keep them employed, they would be used for other duties. With this end in view, the personnel of all water supply units should receive a general training in field engineering.

3. *Organization of water supply units.*

1. No definite war establishments are or can be laid down for the various units which may be needed, since the British Army may be required to fight in any part of the world, and, as has already been pointed out, everything depends on the conditions of the campaign.

The organization provided must be flexible to meet the varying grouping of troops and changes of terrain.

The personnel who are to carry out the work must, of course, be organized in units, and the units must be self-contained, of a sufficient degree of mobility, and large enough to work economically. They must, however, not be so large as to prejudice the flexibility of the whole organization.

2. During the Great War, field companies, R.E., working in Egypt were placed on a camel transport basis, and organized and equipped so as to specialize on water supply. A field company was organized to provide twelve **well units** (*see* Sec. 5, para. 7). Each of these detachments carried L. and F. pumps, water-troughs, and a waterproof tank to store water, also tools to dig shallow wells and material with which to line them. An officer of the R.A.M.C. was attached to each company to test the quality and salinity of the water supplies developed. This example is given to illustrate the necessity for a broad-minded adaptation of existing establishments to meet special conditions.

3. As a general rule, army troops companies and field companies will carry out water supply work as part of their normal duties, but in large operations specialist water supply units may be necessary.

The following varieties of the latter may be required :—

(*a*) **Water supply companies, R.E.,** for general water supply work.

(*b*) **Mobile lorry or barge purification units, R.E.,** for installing and operating purification plant.

(*c*) **Water control units, R.E.,** for the provision of turncocks, &c., and for police duty at water points. Their personnel are mainly unskilled.

(*d*) **Water transport companies, M.T., R.E., or R.A.S.C.,** for the distribution of water by rail, road, or canal.

(*e*) **Well-boring sections, R.E.,** for bore-hole work.

4. The establishment of equipment must be worked out for each unit at the same time as that for its personnel. No opportunity should be lost of subsequently revising this equipment in the light of experience.

As the campaign proceeds, it may be necessary to revise the equipment of other units in respect of water supply stores. For example, it may be advisable to equip field companies with small power-driven pumps, if transport can be provided.

5. The tactical situation will often necessitate the withdrawal of labour from one portion of the theatre of war to help another, and army and corps water engineers must necessarily move with their formations. The axiom should, however, be accepted that units employed on water supply should be placed on as permanent a basis as the tactical situation permits.

The handing over of executive control from one formation to another will be very much simplified, if the following essential points are observed :—

(a) Full and complete records and plans must be maintained and kept up to date.

(b) A standardized practice must be observed throughout the force.

4. *Plant, material, and practice.*

1. Subsequent to the opening stages of the campaign the initial war reserves of plant and material will quickly become exhausted, and steps must be taken to replenish them. This will be the duty of the engineer stores organization, but the responsible water engineers must see that the plant and material ordered from home is of a pattern suited to their particular requirements.

An absolute standardization of piping and fittings must be insisted upon. If plant is standardized, the provision of spare parts is very much simplified.

Ample reserves of material must be accumulated at the base, L. of C., army and corps engineer parks.

2. An adequate registration system for plant must be adopted. Various varieties of pumping plant are described in Part II, but a broad distinction should be made between what may be termed *first aid* machinery, which can be quickly installed, and that which takes a longer time to put down. The number of types of plant provided should be minimized as far as possible.

3. As soon as the particular variety of practice applicable to the country has been determined, technical engineer instructions must be issued from the chief water engineer's branch of the engineer-in-chief's office, and a standardized practice ensured throughout the force. This will simplify the supply of stores and expedite work. There will be many special appliances, the designs of which can be standardized, and these can often best be turned out in large quantities in base and other factories.

4. The preparation and maintenance of *water supply record plans* is of the greatest importance.

Plans maintained will be as follows :—

(a) 1/10,000 plans of all pipe systems, &c.
1/10,000 maps should be used where available; if the 1/10,000 map does not exist, or contains too much detail, 1/10,000 outline tracings must be prepared, and record plans made on white prints off these tracings.

(b) Isometric views, roughly to scale and dimensioned where necessary, of water points, interiors of pump-houses showing pipe connections, connections to tanks, important pipe junctions, &c. The object of these is chiefly to have a means of locating valves and fittings; the necessary information to this end must, therefore, be inserted.

(c) Large scale plans of important pump-houses, waterworks, reservoirs, service pipe systems, &c.

The conventional signs to be used on water supply record plans are shown on Pl. 1.

CHAPTER II.

WATER SUPPLY DURING MOBILE WARFARE.

5. *Arrangements whilst on the march.*

1. The water supply arrangements for an army entering the theatre of war begin at the port of disembarkation or area of concentration of the force. In the initial stages of the campaign troops will be under canvas, and water supply arrangements will be rudimentary. Camps will be constructed later. In all cases, however, watering arrangements for men and animals must be provided near by the points of concentration. These arrangements will include standpipes for water-carts, dixie fillers for water-bottles, and horse-troughs for horses. Sites for these should be carefully selected, so that concentration or disembarkation will not be impeded by troops and horses watering. When the disembarkation takes place at a well-equipped port, the supply of water will be simple, and can be taken from the town mains. When, however, concentration takes place under other circumstances, more work will be required. The water supply work required will be carried out by the advanced party of engineers, supplemented perhaps by civil labour in a friendly country, and must be worked out as part of the plan of campaign.

2. When a forced landing is contemplated, water supply becomes of the first importance. Unless water is definitely known to exist on shore in adequate quantities, arrangements must be made for a sea-borne supply (*see* Sec. **8**).

Parties of engineers must be told off beforehand for water supply work on landing, and provided with adequate supplies of tools and materials. In almost all cases an initial supply of sea-borne water will be required, since a delay of some hours must elapse before water can be obtained even from shallow wells. The landing troops should each carry two filled water-bottles, and, if regimental transport allows, extra water should be carried in water-carts and small receptacles such as petrol tins, &c.

3. As soon as a watering place has been opened it must be marked as follows :—

i. Watering places for men (white flags).
ii. Watering places for animals (blue flags).
iii. Places where water for washing purposes may be drawn (red flags).

This applies to all watering arrangements carried out.

4. Water supply arrangements for troops on the march usually resolve themselves into the supply of water at the next halting place, and an engineer officer will proceed ahead for this special duty. He must be accompanied by personnel for testing water found, and must be able to apply the **Horrocks'** test himself (*see* Sec. **74**). He must be accompanied by a party with a supply of red, white, and blue flags, labels for indicating amount of chlorination required for drinking water, and a supply of tools.

On arrival at a suitable camping ground he first labels and marks with a white flag watering places allotted for men, and then carries out as much work as possible to improve conditions, as indicated in subsequent sections of this chapter.

5. Supply to troops on the march can only be from undamaged civil piped supplies, independent sources such as wells, springs, &c., or by transport from the rear (*see* Sec. **8**).

6. In countries in which surface supplies are abundant but grossly polluted, considerable use may be made of mobile purification equipment (*see* Chap. XVI) which would be specially provided for a campaign under such conditions.

7. When every drop of water has to be dug for, or lifted from deep wells, the problem is one of extreme difficulty, especially as regards animals.

The water distribution *unit* of equipment for animals may be regarded as :—

1 L. and F. pump, complete with hose.

1 trough, waterproof, 600 gallons (nominal, but really some 350 gallons under these conditions). (*See* para. 11.)

This unit, provided too great a duty is not put on the pump, can water with good management some 180 horses, or 54 camels, an hour. It should be noted that only 18 camels can use a trough at one and the same time, and each relay takes 20 minutes to water.

Each watering should be calculated as for 2 hours. Therefore, each brigade group requires a minimum of 5 units, and the divisional H.Q. group requires 9 units, where it is essential to water entirely from troughs. As the watering is very often widely distributed, and as sometimes the source of supply is insufficient for a unit supply, a division should carry no less than 36 units, or 12 per field company, of which some must be applied to men's water. Extra transport will be required in excess of normal establishment.

For the collection and chlorination of men's drinking water, the tank, waterproof, 2,300 gallons (nominal, but really about 1,500 gallons) is required ; about 10 are necessary for an infantry division, but the actual number depends on how many water-carts or other receptacles, in which chlorinating can be done equally well, are employed (*see* para. 10).

For storage while at rest, canvas tarpaulins, 30 feet by 30 feet, specially proofed and holding, when mounted on timber frames, or dug into ground, some 7,000 gallons, can be used.

It is not a practical proposition to expect a division to be watered the night of arrival at its destination, if water at a greater depth than 6 feet has to be dug for. For sandy soil it may be necessary to carry specially designed well linings of corrugated iron on timber framings, making a well of 6 feet by 6 feet.

Where the soil consists of coarse sand, perforated driving-heads, known sometimes as spear points, sunk by means of the Norton tube monkey, may be used in conjunction with the L. and F. pumps, but they are disappointing in fine sand, clay, or ordinary soil.

The Norton tube sets are especially valuable in such cases in testing the depth of the water. As a means of supply, their yield is only some 200 gallons an hour (*see* Chap. VII).

8. Where water is at a depth below the reach of a L. and F. pump, the following are the possible means of lifting, during operations, with great speed from open wells :—

Hand-power (*see* Chap. VI)
- (*a*) L. and F. pumps in series or stages. This method is placed out of court at once if the necessary stagings do not exist. (*See* Sec. **28.**)
- (*b*) Water bags, with valve in base. (*See* Sec. **28.**)

Power (*see* Chap. VIII)
- (*c*) Pumps of the *Band* or *Chaine Helice* pattern. (*See* Sec. **38.**)
- (*d*) Pumps of the *electric sinking* variety driven by generating sets at the top of the well. (*See* Sec. **38.**)

The yield of a deep well may be anything from 100 to 3,000 gallons an hour, or even more. A division must, however, with such sources of supply be considerably dispersed where yields are not great.

Where bore-holes are met with, it is often the case that the pump is either in working order or can be quickly repaired.

If native-owned engines and pumps are found, the owners may have removed the magneto and other essential parts.

Engines and pumps erected by the enemy cannot be relied upon as they are usually in a wrecked condition.

9. The canvas storage tanks and horse-troughs already alluded to in this chapter are the standard service stores for mobile purposes. The L. and F. pump is described in Chap. VI.

The storage tanks and troughs are described as :—

Tanks, waterproof, 2,300 gallons (actually 1,500).
Troughs, waterproof, 600 gallons (actually 350).

10. The 2,300-gallon waterproof tank consists of a double sheet of cotton with rubber between, fitted round the edges with brass eyelets, and strengthened at the edges with a small rope. Length, 16 feet 9 inches ; width, 16 feet 9 inches ; weight, 60 lbs.

The stores required are :—

16 posts, picket, 3 feet 6 inches.
16 rings, hook for posts, picket.
10 fathoms 3-inch white rope.
25 fathoms $\frac{3}{4}$-inch white rope.

The 16 posts must be driven well into the ground, equidistant from each other, and forming a square of $11'0'' \times 11'0''$; each post is fitted with a ring hook; the post is driven with the hook pointed inwards. The 3-inch rope is lashed round the edge by means of the $\frac{3}{4}$-inch rope which must be threaded through the brass eyelets and over and under the 3-inch rope.

The sheet can then be drawn into shape by means of the 3-inch rope, and supported by the latter resting in the hooks of the rings (Pl. **2**).

11. The 600-gallon trough consists of a double sheet of cotton with rubber between, fitted round the edge with brass eyelets, and strengthened at the edges with a small rope (Pl. **3**). Size, 36′ 0″ × 5′ 0″. Weight, 54 lbs.

The stores required are :—

4 posts, picket, 2 feet 6 inches.
1 tracing line.
4 lashings, 1½-inch, 30 feet.
10 standards (1 set).

The standards are set up at about every eighth eyelet hole in the length of the trough, the end standards opposite the third from each end. With the Mark I pattern, the iron props of the standards point towards the middle of the trough, and the standards, with the exception of the end ones, are hooked into the eyelets.

The tracing line is rove over and through the eyelets. At the corners of the trough the line passes through the third eyelet along both side and end; the overlap thus formed is folded round the end standard and laced to the side of the trough. With the Mark I standard, at each standard, except the end one, the line is not rove through the eyelet, but is passed with a round turn round the standard above the hook. With Mark II standard, the line will rest in the groove at the top of each upright (Pl. **3**).

The four pickets are driven about 6 feet from the trough in prolongation of the sides, two at each end; the top of the end standards are lashed to the foot of the pickets with the four 1½-inch lashings (Pl. **3**).

The trough itself and the tracing line are set up taut before water is admitted.

Units having these water-troughs and also the waterproof storage tanks on their establishment of stores should be frequently exercised in their erection, since a certain amount of skill is necessary.

12. **The water tank carts** forming part of the regimental transport will be of great use on the march, and must be properly looked after and cared for.

The latest pattern of water tank cart (*see* Pl. **4**) is known as the Mark VII. It consists principally of a galvanized iron cylindrical reservoir tank, together with filtering apparatus, two pumps, a box for small stores and spares, and a sterilizing kettle, the whole being mounted on a wood frame with cranked axle and a pair of wheels. A draught pole and two swingletrees are provided for pair-horse draught.

The tank is placed in a transverse position on the body frame to which it is secured by steel bands. It has a capacity of 110 gallons, and is fitted internally with partitions to prevent excessive surging of the water when travelling. At the top of the tank are provided two connections for the inlet hose, and an opening to facilitate cleaning out with a brush, the opening being closed by a lid with canvas cover. At the bottom of the tank is fitted a connection for a draw-off pipe and two drain-hole plugs. The draw-off pipe is furnished with four taps for the delivery of the pure water; it is placed in a transverse position, and provided with a stop plug at each end for cleaning out purposes. A short length of wire-embedded rubber tubing connects the draw-off pipe to the tank, a gun-metal stop-cock being provided to the elbow connection on the tank to enable the water to be kept clear of the draw-off pipe and prevent it becoming frozen in the latter during frosty weather.

The two filters are placed transversely on the body frame in front of the tank; they have each their own pump, and may be used either separately or simultaneously. Each filter consists of a steel cylinder in which is contained a cloth-covered steel reel and a chamber for the clarifying powder. The water enters the filters through hose passing along each side of the cart and connected to the top of the pumps; it then enters the tank in a clear statc through a second length of hose, coupled to the end of the filter.

The pumps are of the differential type, and are placed one on each side toward the rear of the cart, the suction hose from the source of supply being attached to the bottom of the pumps.

A wooden box with hinged front is mounted at the rear of the cart for carrying small stores and spares. A kettle, in which the cloth covers of the clarifying reels may be sterilized, is secured by straps and staples to the top of the box.

Galvanized iron drinking cups, secured against loss by a chain, are provided one on each side of the cart.

Additional water storage on water-carts can be arranged for as shown on Pl. **16**.

Instructions for working the purification apparatus of the cart are contained in Sec. **83**, para. 2. In good hands the regimental water-cart is capable of rendering safe a really bad water, but must be properly looked after and cared for. The personnel in charge must be thoroughly well instructed in *chlorination* duties, and in working and looking after the filtration apparatus on the cart. Water-carts must be regularly cleansed with a strong bleaching powder solution. A good method of cleansing a water-cart is to brush thoroughly the interior with a stiff brush. The cart should then be half-filled with water, and a handful of bleaching powder, which has been made up into a cream with water, added. The cart is then sent out on the road for an hour or so, and on return is rinsed out till its contents no longer taste of bleaching powder. The filter and pumps should also be regularly inspected and cleaned.

These instructions apply also to the cleaning of motor tank lorries.

6. *Water supply reconnaissance.*

(*See* Sec. **15**.)

1. Reconnaissance for water must always be included in the engineer reconnaissance undertaken by all engineer units. Under the conditions now contemplated it is not to be expected that much engineer work can be undertaken, and the reconnoitring officer must, therefore, concentrate his attention on those supplies which appear to be easiest of development.

2. When examining a well the following particulars should be recorded :—

- i. Nature and depth of steining. (*See* Sec. **26**.)
- ii. Diameter at top and bottom.
- iii. Depth from ground to water level.
- iv. Depth of water in well.

v. Any obstructions in the well which will hinder installation of means of raising water.

vi. Sample of water (*see* Sec. **74**), or result of test taken on the spot.

vii. Yield of well, determined either by test, enquiry of local inhabitants, or estimation.

viii. How supply can best be developed.

3. When prospecting for spots at which to sink shallow wells, the following rules hold to a greater or less extent according to the locality :—

i. Look where the grass is green or more verdant in one place than in another.

ii. In summer, insects hover over damp spots, and remain in columns above the site of springs.

iii. More dense vapours rise from those portions of the surface below which springs exist, especially in the early morning or in the evening.

iv. Springs are often to be found at the junction of valleys, especially at the junction of a long transverse valley with a principal one.

4. Considerable use can often be made by water reconnaissance parties of *Norton tube wells* (*see* Chap. VII).

7. *Protection of supplies.*

1. In a well or partially watered country, the sources of supply must necessarily be of an uncertain character. Elementary precautions, however, must and can be taken, especially as regards drinking water. **Chlorination must be made a matter of regimental routine throughout the force.**

2. Small collections of water, such as ponds and streams in inhabited places, are never fit for drinking purposes without purification, since any contamination which they contain is likely to be of recent origin and will be but little diluted.

Contamination by the troops themselves must be particularly guarded against, special care being taken that the drainage of latrines, urinals, washing places, trenches in which night soil or refuse is buried, and of animal lines does not flow into the source of supply.

If running water is not available, a rough barbed wire fence, or some other form of fencing, should be placed round the water supply to keep out animals, which should in this case be watered by bucket, nosebag, water-troughs, or trenches lined with puddled clay.

When ponds, tanks, or lakes are used as sources of water supply, the place selected for drawing drinking and cooking water should be where it is least likely to be contaminated, and where there is a good depth of water, so that mud will not be stirred up. Another spot will be set apart for watering animals. Bathing and washing of any description in the lake or pond must be prevented. Water for these purposes must be taken away in empty biscuit tins or other receptacles to selected places from which the drainage will not flow back to the source.

3. Rivers vary enormously in the purity of their water. This can best be judged by the character of the country through which they flow

and by their size. When it is necessary to use such water it will usually have to be clarified, **and must always be chlorinated.**

If water is obtained from a stream, horses will be watered below the place where troops obtain their drinking water, but above bathing and washing places. Patrolling by mounted men will often be necessary for some distance above the spot where the drinking water is drawn. The spot selected for drawing water for drinking and cooking purposes should be well above the camp. It should be at a place where the current is good and the depth considerable, and the same precautions should be adopted for safeguarding it as have already been described.

If the water is to be got out by dipping in buckets, &c., a barrel with holes in the side or a gabion with stones in the bottom should be sunk in a vertical position, so that the dipping may not stir up the mud. If the water near the bank is shallow, a wooden gangway should be made out to a part deep enough for dipping.

Where animals are to drink, a hard bottom of gravel or stone should be made, with water from 4 to 6 inches deep over it. If the sides are steep, a ramp by which the animals should approach should be made straight down to the water, and they should leave by ramps up to right and left, so as not to interfere with other animals coming to drink. If necessary a barrier should be erected to prevent the animals going out too far into the water.

If other troops are using the river lower down, special arrangements for washing and watering animals away from the river, similar to those described for ponds and lakes, are often necessary.

4. All wells should be protected by a fence enclosing an area not less than 25 yards in diameter; in the case of springs on a slope, protection need only be at the sides and above. The following steps should be taken to protect a well from contamination :—

(*a*) The mouth should be one or two feet above the level of the ground, and the ground round the mouth should be sloped outwards.

(*b*) If the well is a small one, the mouth should be closed with a tightly fitting cover with a manhole in it.

(*c*) The pump should be provided at the side, and not directly over the well, the water being pumped to tanks outside the fenced area, chlorinated, and drawn off by taps.

If there is no pump, one or more buckets must be set apart for drawing water, and no other vessels allowed to be put into the well.

Where more than one spring or well is to be used, the best should be set apart for drinking and cooking water. The remainder will be reserved for watering animals and for washing water. Washing must never be allowed at springs or wells used for drinking purposes.

5. Springs should be protected in a similar way to wells. The water from a spring should be conducted directly into a closed tank, chlorinated, and drawn off by taps. Failing this or some similar improvised arrangement, a spout, or spouts, should be arranged so as to obtain the water from the spring. In no case should it be collected in open vessels or in hollows scooped out of the ground, for, if this is done, the water is certain to be fouled either by drainage from above, or by persons who come to draw water washing in it or dipping infected vessels into it.

If, for want of time or for other reason, springs and wells cannot be adequately protected, a special water party should be detailed to fill the vessels, all other persons being kept at a distance.

8. *Transport of water.*

1. The circumstances under which this system will be used to supply advancing troops with the whole of their water will be either that a stretch of waterless country has to be crossed to reach a watered area, or that the advance over a considerable depth of dry country is to be made by stages, in order to allow time for pipe-lines to be brought up or fresh sources of water developed in readiness for the next advance.

Transport of water may be either by tank trucks on the railway, tanks mounted on motor lorries, pack transport (horses, camels, &c.), or transport by sea or canal.

The diagram on Pl. **5** shows generally how the supply of water for troops has been organized during operations in a desert. In this case the whole supply, except what could be obtained from local sources, was brought up by train to the rail-head, and thence distributed by camel convoys. At the same time the piped supply was extended forward to relieve the pressure on the railway.

2. The transport of water by rail requires special tank trucks. These can be improvised from ordinary flat trucks fitted with iron tanks of suitable capacity. **Initial railway water points** must be constructed so that tank trucks may be quickly filled from the initial source of supply. It is desirable that sufficient standpipes should be provided for a number of trucks to be filled at the same time, thus avoiding shunting (*see* Pl. **6**).

In some cases, a spur off the main line may be provided for engines and trucks to stand on while filling. If the tanks can be placed alongside the spur, the deliveries, which should be not less than 4 inches diameter, may come straight from the bottom of the tank; otherwise standpipes will have to be provided.

Pl. **27** shows an initial light railway water point.

Sites for initial railway water points must be chosen with reference to railway requirements, and must be in a position safe from hostile shell fire.

Spill tanks must be provided at rail-head to receive the water brought up by train, and the number of tanks provided should equal the number of trucks to be catered for at a time. The spill tanks must be situated alongside the railway, to permit of rapid emptying of the tank trucks. Suitable provision must be made for the further distribution of the water; this will probably be by pack transport or motor lorry. In any case arrangements must be made for filling tank lorries, &c. Time may not be available to erect overhead storage tanks with the regular pattern water point, so other means must be found. Small petrol-driven pumps can be used. The ideal solution is to site the spill tanks alongside the track at the top of an embankment; the water can then be siphoned to tank lorries, &c., below (*see* Pl. **7**).

The average load of a broad gauge water train would be about 20—2,000-gallon tank trucks, or say 40,000 gallons.

3. The arrangements for water-borne transport will be generally similar to those described for rail-borne water, special filling and emptying devices being constructed as found necessary.

It is especially important in the case of large quantities of water transported by ship or barge that efficient means of discharging the water ashore are provided. **High capacity power-driven pumps** and **considerable storage on shore** will always be necessary. If the ship has to lie off shore, plenty of piping or hose will be required. This can be supported perhaps on boats or specially constructed rafts. Piers may be required. Very efficient policing is necessary at the shore end of the pipe.

4. For the supply of fast moving troops through a waterless area in which roads are available, special **motor water columns** must be formed. These columns will be under the control of the C.E. or C.R.E. of the formation concerned. The supply of water under such circumstances is analogous to the supply of rations with this difference, that the water will probably be produced somewhere in the zone of operations and not brought up from the base.

Initial water points (I.W.Ps.) must be established in the first instance for the water columns to fill at. These I.W.Ps. will be constructed as far forward as practicable before the advance. Their general construction and lay-out will conform as nearly as time, labour, and material permit to the *water-cart and lorry points* described in Chap. III.

The most highly developed pattern, constructed before a deliberate advance, would permit of a continuous stream of lorries filling up throughout the day. The most rudimentary kind, established as the advance proceeds, may consist merely of a petrol or hand pump at a roadside spring.

It is essential that the forward and return journeys of the tank lorry columns from the I.W.P. should not be outside the capacity of the vehicles, otherwise the advance must be checked. The extent of this limiting distance cannot be accurately stated, since it depends entirely on road conditions.

Adequate arrangements for the reception of the lorry-borne water must be provided. These will usually take the form of waterproof spill tanks conveniently situated alongside the road. Such *forward water points* will normally be situated near ration dumps (also supplied from the rear). The forward water points must be arranged for quick emptying of the tank lorries, and, if possible, should be so situated that tank lorries and regimental water-carts do not use the same road. If the supply of water for animals is being made by tank lorry (though this is extremely difficult), water points for their use must be constructed in other locations. The troughs will usually be filled direct from the lorries.

The whole business of supplying advancing troops with water by lorry demands the most careful organization from start to finish. At $\frac{1}{2}$ gallon each man and 5 gallons each horse, an infantry division would require about *300 tons of water a day*.

According to the state of the roads, &c., this means from *150 to 300 lorries* employed; each lorry will probably only do one trip a day.

Specially constructed water-tank lorries are the best for this service, but tank lorries may be improvised from ordinary lorries by mounting iron cisterns on them, or by slinging waterproof tanks inside (*see* Pl. 8). In the former case, the cisterns must be provided with internal baffle plates, and must be securely anchored to the lorry floor (*see* Pl. 9).

5. The general principles of **transport by pack animals** are the same as for transport by lorry, and this system will be used only if no roads are available.

Water convoys must be formed, and the nature and composition of these will depend on circumstances. In Egypt an infantry division required 2,200 camels, each carrying two tanks of 12 gallons capacity each.

Owing to the large number of animals involved, very perfect arrangements are required at the I.W.Ps. In addition to filling the receptacles carried, the animals themselves must be watered. Pl. **10** shows an I.W.P. in a desert where ample room is available.

Pl. **11** shows an I.W.P. constructed in Egypt for filling tanks carried by camels. The following is a description :—

The water main supplied a line of six standpipes, each pipe being fitted with two hoses. From each standpipe a line of light rail ran out at right angles to the line of the water main. Full tanks were loaded on trucks on these rails and were carried from the trucks to sandbag platforms on either side.

Camels marched up in eight strings of 24 camels ; each string marched across the line of rails, and each camel was *barracked* between a line of platforms from which the tanks were loaded on its back. In this way 192 camels were accommodated at one time, and there was an average carry of only 15 feet from the line of rails to the loading platform.

The tank referred to above is an article of store, and is listed as *tank, camel*, &c. (*see* Pl. **12**).

Two-gallon petrol tins, fitted in wooden racks, have been used for carriage by pack mule (*see* Pl. **15**).

Skins and water bags may also be used for pack transport.

To prepare a skin, it should be removed from the animal, while still warm, without any cut except at the neck and feet ; it is then roughly tanned, and dressed with lard to make it water-tight, and the openings at the feet and vent closed.

Bags made of the best canvas, with double and close-stitched seams, leak when first made, but become nearly water-tight after a day or two ; the water in them keeps cool owing to slight evaporation through the canvas.

Bags made of waterproof sheeting, specially designed for transport on mules or camels, are articles of store.

CHAPTER III.

WATER SUPPLY DURING POSITION WARFARE AND THE DELIBERATE ATTACK.

9. *General conditions.*

1. The period of position warfare must be considered only as a preparatory period leading up to offensive operations. The water supply works required during the stationary period and those required for the

attack and their extension during the preparatory stages of the advance are so closely interwoven that it will be convenient to consider them all under one head.

2. An army area may be considered as consisting, from front to rear, of three zones :—

(*a*) The forward area.
(*b*) The concentration area.
(*c*) The back area.

3. Water supply during withdrawal to a line in rear will not occasion any additional work, unless the withdrawal is of such an extent as to shift the zone previously occupied by the army back on to an undeveloped region. If such an eventuality is anticipated, arrangements must be made beforehand, so that supplies can be quickly made available.

In a bore-hole country, holes will be sunk beforehand in suitable positions in readiness for operation when required. For this purpose the ***compressor lorry*** system is especially suitable (*see* Sec. **15**).

If a withdrawal is expected, adequate demolition arrangements must be made beforehand. These are explained in M.E., Vol. IV.

10. *Supply to the forward area.*

The conditions in this area will vary according to whether active operations are in progress and to the tactical situation at the time.

The limits of the forward area may be taken as the front line and the rear of the heavy battery zone. The supply of water in this area is usually confined to drinking water supplies for troops located in the area.

The possible methods of distribution are summarized as follows :—

i. Independent sources such as wells and springs.
ii. Horse-drawn water-carts or water-lorries filling at water points in rear.
iii. Distribution by tank trucks on the light railway.
iv. Pipe-line distribution to water points.
v. Hand carriage from the rear.

i. *Independent sources such as wells and springs.*

The extent to which wells can be dug or reclaimed, bore-holes sunk, or small purification plants installed in the forward area, depends on the labour available, the intensity of shell fire, and bombing from aircraft. Any such water points need only be developed for filling buckets and water-bottles, and should invariably be provided with adequate chlorinating arrangements. If safe water cannot be provided at these sources, it is better to carry it from a suitable source further in rear. Water taken from shell-holes, especially after gas shelling, is a fruitful source of sickness. Water tainted by gas shelling is not purified even by boiling.

Springs usually form excellent water points in the forward area. So far as possible, they should be protected against contamination, and provided with chlorinating tanks (fitted with bib-cocks for drawing off) and hand pumps. Fouling will occur if men are allowed to dip receptacles into the spring.

Existing wells may be used if not liable to excessive contamination. They should be provided with chlorinating arrangements as for springs. For shallow wells a hand lift and force pump may be used; for deeper wells a windlass and bucket or suitable pump can be installed. Both these forms of elevating gear must be unusually robust in their construction, and will require a good deal of maintenance.

Small purification sets, such as the coolie and mule pack filters described in Sec. **83**, may often be employed in the front line, since they are so compact as to be readily erected in forward dug-outs and shelters.

During long periods of position warfare and in suitable country, it will often be possible to dig wells or sink bore-holes in the trench system quite close up to the front line. Wells of this kind are preferably sunk at the bottom of a dug-out specially reserved for the purpose. Very special precautions must be taken against foul drainage finding its way into the well. Some form of elevating apparatus must be provided, either windlass or bucket, or hand or power pump, though the latter will not usually be necessary in such locations. Chlorinating arrangements must be provided.

In advanced positions, boring with a steam power-driven machine is usually impracticable, but on quiet sectors holes may be driven with small petrol or hand power-driven boring plants. The form of pump to be fitted will then be usually a hand-power tube well pump if the water is beyond suction reach or, if water is near the surface, an ordinary hand lift and force pump. All such installations must be protected against shell fire. Where the water level is within suction reach, bore-holes may be made with an *earth auger* (*see* Sec. **34**). These holes can be lined with light sheet-iron tubing should the character of the soil necessitate it.

ii. *Horse-drawn water-carts or water-lorries filling at water points in rear.*

Distribution by water-cart or lorry will be widely made use of, both while independent sources are being developed and also in addition to such sources. The horse-drawn water-carts are usually those on the establishment of units, and are filled at *water-cart points* situated in rear of the forward area, but as far forward as they can be maintained. Water-cart points will be referred to again under the heading of *supply in the concentration area* (*see* Sec. **11**).

The water delivered to the unit by its own water-cart may be stored in tanks of 100 gallons or so, and by so doing the cart can make several journeys in a day if the water point is not too far away. Tanks for domestic purposes can be of the galvanized iron pattern, but these are bulky for transport. Storage tanks should be part of the normal equipment of the unit, otherwise considerable numbers will be wasted. A convenient form of tank for storing water required by a unit consists of a waterproof bag suspended from the apex of a tripod standing on the ground. The slight exudation from the bag keeps the water cool (*see* Pl. **13**).

When water is delivered by lorry, an adequate amount of storage must be provided, in order to take advantage of the carrying capacity of the lorry. The water may be delivered direct to units, but this is unusual in the forward area. A more usual method is to deliver to *spill tanks*, from which units draw their supplies by cart or hand. Spill tanks must be constructed alongside roads used by water-lorries. They should be sunk in the ground to avoid damage from shell fire, and may profitably be provided with a corrugated iron cover to keep out earth and stones thrown up by shells. Types of sunk tanks are described in Chap. X. The 2,000-gallon capacity size is a good one for this work.

The arrangements by which consumers draw water from the spill tanks consist of hand pumps and *dixie fillers*. Waste of water must be prevented, so the arrangement is generally adopted of having two tanks with a pump to pump through a dixie filler from one to another, as shown on Pl. **14**. Spill tanks in the forward area should be small and scattered in order to obtain a good distribution of water and not to form too conspicuous a mark. A sheltered position should be selected whenever possible. Water-cart filling points, in particular, should not be in locations particularly liable to shell fire.

iii. *Distribution by tank trucks on the light railway.*

Distribution may sometimes be effected by light railway (L.R.). Tank trucks are employed which fill at *light railway water points*. The construction of these water points is described in Sec. **11**.

Tank trucks usually deliver to light railway spill tanks (Pl. **14**), from which water is drawn by consumers as required. Such tanks are constructed in the same way and with the same precautions as those supplied by water-lorries. If a site can be selected where the L.R. is on a bank, so much the better, since with a hose connection to the tank on the truck rapid emptying can be secured.

The tank trucks can in some cases deliver their water to individual units along the track. This can often be arranged for the heavy batteries, since in position warfare the L.R. generally delivers ammunition direct to the battery and can deliver water at the same time. Storage to receive the daily supply must be arranged.

In addition to water carried by the L.R., water for steam L.R. locomotives may have to be considered.

For work in forward areas, where a piped water supply may be impossible to arrange, locomotives may be fitted with a steam water-lifter of the injector type, enabling them to water from streams or ponds. This apparatus has obvious advantages, and can be used elsewhere than in forward areas, provided that traffic conditions are such as to allow of the delay caused by this method of watering, though its usefulness, of course, is limited by the fact that its delivery is considerably restricted if the lift exceeds about 15 feet.

It is probable, however, that in the future steam locomotives will be little used in the forward areas.

iv. *Pipe-line distribution to water points.*

In all shelled areas any pipe system requires a good deal of maintenance, and should not be undertaken when other forms of distribution can be more conveniently arranged. On an active front it will not generally be possible to maintain pipes within about 5,000 yards of the line.

On quiet fronts when the only sources of supply are in the rear, it will be advantageous to lay pipes up to a short distance of the line to supply water points within the trench system. Each situation, however, must be dealt with on its merits, but pipe systems in the forward area should not be embarked upon without the fullest justification. It must be remembered that the quantity of water consumed in this area will be comparatively small, and the relative amount of labour involved in pipe construction and maintenance consequently large.

The principles governing the lay-out of a pipe system installed in the forward area are essentially the same as for any other pipe system (*see* Chap. XI), but the general plan should be extremely simple, and as few branch lines taken off the main as possible. Complicated systems in the forward area give endless trouble in the location of breaks, and lead to waste and shortage of water. It is better to construct several radiating lines from the source rather than branches from a main trunk line. A pipe patrol can then follow up the pipe-line with a reasonable chance of locating a break quickly. The tendency to put in branch connections with several hundred feet of small pipe attached should be repressed. Any connection off the main should not be more than a few feet long, and should terminate in a storage tank.

Despite the work entailed in uncovering to repair breaks, all pipes should be buried with 3 feet of cover. In the past many pipe-lines in the forward area have been laid on the surface, it being contended that breaks are more easily seen and mended. This argument is true to a certain extent, but is discounted by damage by shrapnel and especially by damage by frost. In mountainous country and under certain exceptional circumstances when means for emptying pipes can be provided and time is all-important, pipes may be laid with only 1 foot of cover.

Protected shelters for pipe repair and maintenance parties, together with stocks of tools and specials, should be arranged along the pipe route. When pipes are mended in foul ground, the interior should be liberally dosed with bleaching powder before joining up.

The supply from the source should be by gravity whenever possible. Ample storage along the lines must be provided, since breaks will be frequent. The arrangement of water points consists generally of a series of small tanks (say 400-gallon) dug-in and fed direct from the mains. Water points may be arranged to serve an area or may be made for the individual supply of dressing stations, &c., but must be located to the best advantage having regard to the disposition of the troops. Each water point must have a *dixie filler,* which consists of a length of 4-inch or 2-inch pipe with ½-inch bib-cocks sweated in at 2-foot intervals, for filling *dixies* and water-bottles. It is important that the spout of the bib-cock should be small enough to enter the neck of a water-bottle.

Water points must be well drained, and provided with trench-boards for men to stand on while filling dixies, &c. All possible protection against shell fire must be given.

In view of the difficulty at individual water points, chlorination must be done at the source.

v. *Hand carriage from the rear.*

The last stage of travel of the water consumed by troops in the front line must be by hand. Such receptacles as petrol tins may be used, but every effort must be made to provide water as far forward as possible in order to minimize hand carriage to the utmost possible extent. Petrol tins filled with water for troops in the line may be carried to dumps within hand carriage reach on pack animals, horsed vehicles, and tramlines.

Pl. **15** shows a pack animal fitting for petrol tins, and Pl. **16** shows a similar arrangement for water-carts.

11. *Supply in the concentration area.*

1. The amount of water supplied in the concentration area will be considerable, and a large proportion of the water used in the forward area will be carted or pumped from sources in the concentration area.

The line of demarcation between the two areas is not usually well defined, but is generally about the rear of the heavy batteries. The problem of horse watering may become important in the concentration area and, when all water has to be lifted from below ground, transcends all others in its magnitude and difficulty.

Supplies in this area usually resolve themselves into three varieties ;—

i. Water-cart and lorry points—supplying an area.
ii. Horse water points—supplying an area.
iii. Camp, back area, and railway supplies.

To reduce expenditure of labour and material, the aim should be to secure an equable distribution of water over an area, having regard to the disposition of troops, even though consumers may have to travel some distance to draw water. Demands will be constantly received for water to be laid on to individual camps, &c., but such demands must be very strictly scrutinized or excessive expenditure of labour will be incurred. It will assist distribution considerably if adequate *dixie-filling points* are installed at all locations where a piped supply of safe water permits.

2. The methods of distribution in the concentration area will comprise those already summarized for the forward area, but will be on a much greater scale. The general scheme to be adopted depends chiefly on hydrological conditions. A comprehensive pipe system, while economizing plant and the skilled labour necessary for its erection and operation, involves an immense amount of labour in laying the pipes and their subsequent maintenance. The installation of a large number of individual pumping stations economizes in pipework, but necessitates a correspondingly large number of engine drivers. Unskilled men can, however, be trained to look after the small plants usually put down, so that it is generally best to avoid extended pipe systems whenever a system of independent sources can be more easily adopted. Another disturbing feature in connection with pipe systems is that the boundaries between armies, corps, and divisions are constantly altering, and it frequently happens that a pipe-line has to supply the areas of several formations. When water is short, the result is that, unless very careful methods of regulating the division of water are adopted, one formation will take water at the expense of its neighbour. The best way of regulating this is to post men under the independent control of a higher formation to take charge of the valves at determining pipe junctions. Thus, if a pipe-line supplied two or more corps areas, **army control stations** would be arranged at suitable points in order to control the flow of water into each corps area.

Similarly **corps control stations** would be arranged to control the supply between divisional areas. The personnel at these stations must be provided with a time-table showing times of opening and closing the various valves. They will require a shelter to live in, and must be in possession of reliable watches.

Controls must be connected to the telephone system.

3. Pipe-lines supplying an area will always be more satisfactory if worked on the *indirect system* of distribution (*see* Chap. XI), that is to say, when as much as possible of the system is under a constant gravity head. Whether or not this can be arranged depends on the character of the ground. The chief trouble encountered with pipe systems is invariably that of control, and this is easier on a gravity-fed system than on a pressure-fed system direct off the pump.

The various forms of water points at which water may be drawn in a concentration area will now be considered in detail.

4. **Water-cart and lorry points** are peculiar to field operations, and are rendered necessary owing to the shifting nature of the population to be supplied and the impossibility of laying water on to individual camps.

Whenever a large traffic is expected at a water point, separate turn-outs from the traffic road should be provided for water-lorries and horse-drawn water-carts, and it is better to establish the two kinds in different locations. The difficulty arises that, owing to the hurried conditions obtaining, lorries and water-carts will both collect at any point where water is available, and both classes of vehicles have to be catered for at the same spot. If, however, the traffic is liable to be heavy, separate filling points must be provided for horse-drawn and motor vehicles. The motor vehicles will not then be blocked by the slower moving horse-drawn carts.

In any case, each sort of water point should be constructed so as to be capable of filling any vehicle that may come along. The site for a water point of this character should be such that it is at the **centre of demand** of the area to be supplied. It should not be on a main road, since this leads to blockage of traffic, especially if the road is narrow. It may be possible to allot a by-road, not otherwise required, for water purposes, thus rendering the construction of a turn-out unnecessary. Due provision must be made for vehicles waiting their turn to fill, and this is simplified if a good flow of water is available and rapid filling ensured at the standpipes. A water point must always be sited with due regard to **traffic circuits** on local roads. The road on which the water point is placed must be one that will stand up to the traffic ; nothing is more disappointing than to have an otherwise good water point rendered inaccessible by a bad approach.

Every water-cart point must be provided with wardens who will require a shelter to live in. The duties of the wardens are to work the main valves (if any) supplying the water point, keep the place clean and in good order, and record the amount of water drawn by each unit.

The regulation of traffic, a very necessary matter at a busy water point, is carried out by the road traffic organization.

5. As regards the constructional details of vehicle water points :—

(*a*) *Storage.*—It will usually be advisable to provide as much independent storage at each water point as possible. When a water point has become known, consumers get into the habit of using a particular point, and if supply fails much extra fatigue is caused. Any of the type designs of tanks described in Chap. X may be used. The minimum storage to be aimed at is as follows :—

1 or 2 standpipes ...	...	...	9,000 gallons.
3 or 4 standpipes ...	...	...	18,000 gallons.

(*b*) *Standpipes.*—A standard arrangement of standpipes should be adopted, and these can be made up in H.Q. workshops and quickly erected when necessary.

Pls. **17** and **18** show a suitable design which has been found satisfactory. A horizontal pipe fixed in the crutches of vertical timber supports gives great longitudinal strength to the arrangement.

Any arrangement of standpipes adopted must be rigidly constructed. Standpipes can often be fixed to existing supports such as trees, walls of houses, &c., and advantage should be taken of such supports when possible. The distance between standpipes should be about 30 feet, as shown on the Plates, in order that several vehicles may fill at once. Not more than four standpipes should be fixed at one water point; a greater number leads to congestion of traffic. A minimum delivery of 100 gallons a minute should be provided at each standpipe when all are flowing, and a 2-inch standpipe generally meets the case. The connections, however, usually have to be 4-inch when more than one standpipe is in use.

The hoses for filling the vehicles are of rubber or canvas, and require looking after. They should hang vertically, and should be well clear of the ground when not in use. Individuals are certain to come to water-cart points for water, so that *dixie fillers*, as described in the preceding section, should be provided at all such points.

Pls. **19** and **20** show further designs for vehicle water points.

12. *Horse watering points.*

1. When large numbers of horses have to be watered at one spot, properly constructed water points for the purpose are essential.

Experience has shown, moreover, that there is a limit to the number of horses that should be watered at one point. It is a mistake to concentrate a large number of troughs on the same piece of ground, and more especially along a main traffic route. The results of this policy, if carried out, are that the vicinity of and approaches to the troughs rapidly churn up into an ever-widening and deepening sea of mud. If the water point is on a main road, traffic is held up by streams of horses crossing backwards and forwards to the troughs, and any road so crossed is destroyed almost at once in wet weather at the points of crossing.

In long-continued periods of stationary warfare, water can no doubt be laid on to the stables occupied by units, thus approaching the ordinary peace-time standard of perfection, but usually such practice is impossible, or at the best involves an excessive expenditure of labour and material.

As in the case of water-cart points, the consumer (the horse) must come from a distance for his water.

From what has been said, it will be apparent that it is best to establish numerous small watering points. The location of these must depend usually on the local conditions, and will, before all else, determine the position of stables, when such are to be built. It is very necessary that the positions chosen both for stables and for mounted unit bivouacs should be such as will accord with the water facilities either existing or to be provided. Stables can be built almost anywhere, but water cannot always be produced in any location. This point is very frequently overlooked, and is, therefore, insisted upon. Cases have, indeed, occurred of large masses of horses being concentrated at a moment's notice in areas entirely destitute of water, even though other and better watered areas were available.

2. If water is near the surface and plentiful, the watering problem is easily met by the use of hand-power lift and force pumps and troughs by each mounted unit. Even if water is not actually flowing in streams, &c., but can be found a few feet down in sufficient quantity, the same rule applies. In such cases units may be required to dig their own wells, if the engineers are required for other more urgent or skilled work. The policy of self-help must be encouraged.

3. Large ponds, especially if their bottoms are of an impervious nature, will often be of value for horse watering. Ponds usually collect the drainage from an area, and much can be done to extend the area drained, as for example, by cleaning out drainage channels, &c. If streams or watercourses are available in which water flows only after rain, ponds can be dug alongside and connected thereto. Sluices must be provided to hold the supply in the pond when the flow in the stream ceases. Water points with hand pumps should be provided in connection with such ponds, and the pond fenced off. Horses must not be walked *into* the pond.

If the bed of the stream be suitable, dams can be made at various points to hold up the water and thus provide storage. For the construction of temporary dams, *see* Chap. X.

4. To cope with an emergency concentration of horses lasting only for a few days, and when no surface supplies exist, it may be possible to fill up reserve storage tanks beforehand from some existing pipe system.

5. When water lies deep below the ground necessitating the use of pumping machinery, the problem becomes one of extreme difficulty when large numbers of horses have to be supplied.

In view of the necessity for economizing both plant and the skilled personnel available, it will be necessary to feed several groups of troughs from one pumping installation. No group should exceed 100 feet, or at most 150 feet, run of double watering trough, and each group should be erected along a by-road, *not* on a main road. Although horses can go to the troughs across the open in dry weather, experience has shown that they must be allowed to use the roads in wet weather.

All the groups of troughs must be fed from reservoirs by gravity, and, if watering is likely to go on for a prolonged period, the reservoir must hold one day's supply for the greatest number of horses likely to water at all the troughs supplied.

6. When troughs are to be used continuously, hard standings are necessary. Such standings must be fenced in. It is no good making a standing if, in wet weather, horses are to approach from every direction bringing mud and slime on to the standing. Nothing destroys a standing so quickly as mud. The fence should be rigid with a fair-weather opening, which is used only in dry weather when horses are allowed to come across country to the water point. The principle should be *keep the horse on a hard surface* (*i.e.*, road and standing) during wet weather.

7. Pls. **21** and **22** show a design of horse watering points. The construction of these water points depends on local supplies of material. In ruined brick villages, bricks from the ruins can well be utilized to form standings, while timber from the houses will supply all that is required for the construction of trough frames and fences. Under these circumstances water points, stables, and horse bivouacs can conveniently be placed in or near villages.

8. Pls. **23** and **24** show designs of horse-troughs of a semi-permanent nature. The standard 600-gallon canvas trough is referred to in Chap. II. As regards the scale on which to provide troughing, allow 4 feet frontage for each horse. All horses should be watered, if possible, in one hour, and are usually watered three times a day. Five minutes is the usual time allowed for horses to water. Hours should be laid down for each unit to water. It is sometimes necessary to provide special troughs for sick horses.

For good traffic regulation, in addition to substantial fencing around the water point, prominent notice boards are required. These should be lettered as follows :—

IN	**DISMOUNT, BITS OUT, & FILE RIGHT ALONG**

at the entrance, and

OUT

at the exit.

If traffic is heavy, special police must be posted.

13. *Camp, back area, and railway supply.*

1. There will be few camp supplies required in the concentration area, other than for casualty clearing stations or for hospitals. Most of the troops grouped in the concentration area will be fighting units or formations, who will be provided with their own water-carts and can draw from area water points.

C.C.Ss., however, require special attention, and, generally, water has to be laid on to standpipes near kitchens and ablution rooms, and to taps in operating theatres, &c. A C.C.S. of 1,000 beds will use, if water is piped on, about 9,000 gallons per day.

2. Water supply work in the back area approximates to that undertaken on the remainder of the L. of C., and little more need be said regarding the methods adopted, which will usually be of a semi-permanent nature.

The bulk of the work will consist of the provision of piped supplies to schools of instruction, reinforcement camps, depots, and similar establishments, though in some cases when water is scarce, the system of *area* water points will have to be employed.

The subject of camp supply is treated in Chap. XI.

3. No definite rule can be laid down for the **location of water supply points for railway purposes.** This is obviously governed to a large extent by the existence of a suitable source of supply. Watering facilities are always required at engine sheds, and should be provided if possible at sorting yards of such a size as to necessitate the continual attendance of shunting engines. Facilities for watering the engines of main line trains should be provided, for preference, at points at which the trains have to stop for traffic purposes, rather than at wayside stations where a special stop for water would be necessary.

The distance between points at which watering facilities for main line trains are provided naturally depends on the tank capacity of the locomotives in use; for main line tender engines of 4-foot $8\frac{1}{2}$-inch gauge this varies from 2,000 to 5,000 gallons. As a general rule, such facilities should be provided on a L. of C. every 15 to 20 miles.

In the sorting yards the water columns should be placed near the exit, but should be so located that shunting engines and engines of trains waiting to depart can water without obstructing the main lines.

Water standpipes for the use of trains on the main line should be so located that an engine can water without leaving its train, while the latter is stopped in a convenient position for traffic purposes.

4. It is hardly possible to lay down in advance a standard **design for railway watering points.** The essential factors to be borne in mind are that :—

(*a*) From a traffic point of view it is desirable that a train should not require to stop more than five minutes to water; of this time probably only three minutes would be available for the actual operation of filling the tender. If a train is drawn by two engines, a halt of 10 minutes is, however, permissible.

(*b*) On an average, 1,500 gallons will be taken by an engine during such a stop.

(*c*) A head of about 20 feet (above the top of the tender) is desirable; since the tender manhole is, as a rule, about 10 feet above the rail, the bottom of the storage tank should be at least 30 feet above rail level.

The elevated tanks may be placed close to the track, supported on timber trestles (*see* Pl. 27). When a number of water columns have to be supplied from one tank, it will often prove expedient to take advantage of rising ground, if such exists near the track, to provide the necessary head. Water columns are usually of 6-inch bore, and 6-inch piping or over from tank to column is desirable. Many water columns are so arranged that the stop-valve at the foot, when in the closed position, opens a small port to allow the water in the column itself to run off, in order to guard against freezing. For extended operations steel tanks and stagings, together with water columns, would be a standard supply.

A storage capacity of 6,000 gallons will allow two double-headed trains (one in each direction) to water in quick succession. The time available for refilling the storage tank depends, of course, on the interval between trains. A double line worked under intensive traffic conditions may carry as many as six trains an hour in either direction, but the density of traffic under military conditions is hardly likely to be so great as this.

14. *Preparations for an attack.*

1. Water supply preparations before and after an attack divide themselves into those for supplying troops and animals during the concentration period and those for making adequate arrangements for keeping up the supply to the troops as they advance.

During a period of transition from position warfare to a war of movement, there will always arrive a time when events move too rapidly for much engineering work to be done to open up supplies within reach of the advancing troops. When this moment arrives and if natural supplies are insufficient, the advance may have to stop until supplies have again been developed. In civilized countries, unless the region traversed has been completely devastated by the enemy, natural resources are usually sufficient during purely mobile warfare for the troops engaged, and formations are usually dispersed over a relatively wide area.

Under certain conditions, however, the natural resources of an area may be unequal, either in quality or quantity, to the demands of the troops, and special water supply work becomes necessary.

2. In changing from a period of stationary warfare to one of movement, the critical time is that immediately after the advance, when the troops are still fairly concentrated, but are situated in a region almost certainly denuded of its natural water resources.

The period of concentration for an attack has in the past often occupied several weeks, and during this time most extensive water supply preparations have been necessary for the purely temporary demands of the troops awaiting battle. Under such circumstances, water points have to be constructed or enlarged, hospitals, aerodromes, camps, &c., supplied, and existing water facilities generally improved.

The concentration of heavy batteries necessitates special arrangements for storage of water in battery positions, and storage tanks have to be installed and filled in or near the forward assembly trenches.

Work required during the concentration period is, therefore, an improvement of existing resources on the same lines as described for position warfare.

In the future the element of surprise in the attack is likely to be still further developed, and not only will time not be available for deliberate preparations, but such activity will not be permissible owing to enemy observation from the air.

The aim should, therefore, be during tranquil periods to develop supplies uniformly and extensively on all parts of the front where a concentration may be expected. Some of these supplies may never come into use, but will be designed to cope with a sudden influx of troops into the area prior to an attack.

The scheme on which these preparations are based must be definitely prepared in accordance with the intentions of the Higher Command as regards accommodation and disposition of troops.

3. The preparations for supply after the initial advance will vary in details according to the type of country that will be traversed and the consequent methods to be adopted for the supply of water.

Above all things, complete and accurate intelligence is required of the hydrographical features of the country ahead. This will entail assiduous efforts on the part of headquarter staffs, who may base their forecasts on information supplied from civil authorities belonging to the region in question, statements of refugees, aerial observation, geological reports, and various other sources.

Technical information should always be sought from managers of municipal waterworks and similar officials, who usually have extensive information regarding the hydrology of the country. Raids on the enemy's communications may supply much useful information.

The preparation of such information will have been undertaken in peace-time, but its amplification must be continuous throughout the campaign.

4. Broadly speaking, the scheme for supplying troops during the advance will fall under one or other of the following heads :—

i. Pipe-lines from sources in rear.
ii. Independent sources in the area occupied.
iii. Supply by transport ; or
iv. A combination of any of the above three methods.

The selection of the method to be adopted demands the fullest investigation by those responsible for framing the water supply policy of the army, and on its success or otherwise largely depends the whole conduct of operations. Everything depends on the conditions of the campaign, but, very generally speaking, the following axioms will be found to hold good :—

(*a*) It is useless, except in the very early stages of the advance, to endeavour to follow up an advancing army with pipe-lines.
(*b*) The transport of water from the rear places an almost unbearable strain on the transportation organization.
(*c*) Independent sources in the area occupied, if such can be found, will be the easiest method.

5. If the method of supply to be adopted is that of following up the advancing troops with **pipe-lines** from sources in rear, a sufficient number of pumping stations and forward pipe-lines must be initiated with a margin to cover those put out of action during the first few days of the battle.

Advanced dumps of piping and *specials* must be provided as far forward as possible in readiness for laying immediately the advance has started. Such dumps must not be too large or in conspicuous positions.

Very careful preliminary organization is necessary to ensure that carrying parties, pipe-laying squads, &c., are detailed to each particular job.

Additional transport will probably have to be allotted to supplement that on the establishment of units.

It is not generally possible to select the exact route for the pipe-line beforehand, but much can be done with the aid of a map and aerial observation. A pipe *objective* can at least be given to each officer in charge of the line, and he will be responsible for taking the line through on the most expeditious location. The ordinary rules as regards locating the whole line before laying will have to be disregarded, and the line laid as best found possible.

It is better, if labour permits, to arrange for certain *virgin* lines to be taken forward from selected pumping stations rather than to extend existing systems already supplying water points. There will be large numbers of troops coming up behind the foremost troops who must be supplied, and, if existing systems have to supply them in addition to the forward troops, the latter are liable to go short.

Pumping stations should be as far forward as they can be maintained with reasonable safety, and must be given protection. It is a mistake, however, to install pumping stations, which are to supply forward pipe-lines, too far forward, since *booster* stations can be quickly installed when the head becomes too much for the initial pumping station. Such booster stations can always be installed faster than, or at least as fast as, the intermediate pipe can be laid.

The forward pipe-lines should be taken as far forward as possible before the attack. This will depend on the amount of shelling expected, and cannot be accurately estimated. If a prolonged bombardment is to be carried out, hostile retaliation will result, and pipes within about 5,000 yards of the front line will be destroyed. If, on the other hand, the attack is to be entirely in the nature of a surprise, pipes may be taken very close up to the front line. Tactical conditions alone can decide.

It will be useless to attempt to pick up rear pumping stations and *leap-frog* them over those in front, at least in the first phases of the advance and until or unless the advance is checked. It generally takes longer to pick up a working plant and install it elsewhere than to draw from store and install a fresh one; that is, if the latter is in perfect working order and complete with fittings. Further, there is almost always a disinclination on the part of Staffs to agree to closing down a pumping station entirely. If a considerable advance is anticipated, and if stock of plant permits, it will be advisable to hand over the working of the greater part of the plant in the area of the field army to the L. of C. engineers before the attack, so as to set free personnel for the advance. If this is not practicable, detailed arrangements should at least be made to do so directly the attack has started and the advance is under way.

6. When the scheme for opening up supplies is that of **independent sources**, full and accurate intelligence reports are especially important. These reports will determine the supplies of plant and material to be sent up from the base. Adequate supplies of plant, &c., must be arranged before the advance, and careful organization is, as always, necessary.

15. *Water supply while the advance is gaining momentum.*

1. As the advance proceeds, **early and expert reconnaissance** for existing supplies in enemy territory becomes increasingly important.

Reconnaissance should be carried out by an officer of the water service; this officer must be conversant with the general water supply policy and resources. He must promptly submit **definite technical reports** as to what work can advantageously be carried out by the units of the water service. He should be provided with all available information regarding possible sources of supply, and must be in close liaison with the technical authority of the formation superior to his own. The most advanced engineers will not usually be equipped to carry out water work of any but the simplest kind. It is, therefore, of the greatest importance that accurate information is available as soon as possible. Reports must show all necessary particulars, to enable the required men and material to be sent on to the job and work to be started immediately.

Reconnaissance for water, however, must form part of the engineer reconnaissance undertaken by all engineer units.

2. Power plant will generally have to be installed on existing wells, springs, &c. Often damaged plant found can be repaired. The reconnoitring officer must know at sight whether this can be done, or whether it will be better to replace the plant by new, or whether the source is not capable of development in reasonable time.

When entering territory taken over from the enemy, the head gear and machinery over wells will probably be found to be demolished. This may or may not be capable of repair in reasonable time. Search should be made for *booby traps* on first examining a well and its machinery.

It sometimes happens that the engine driving the pump has been demolished, but that the latter can be quickly repaired. In such cases a fresh engine can often be installed in some other position to drive the pump. It is generally the case that it will be quicker to install a new standard plant and repair the old one at leisure.

Cleaning and restoring badly damaged wells involves heavy labour, and should not be undertaken if water can be produced more easily in any other way.

3. If it is anticipated that bore-holes will have to be sunk, the boring machines and crews will have been got ready before the advance, and supplies of casing, fuel, &c., arranged beforehand. Good locations can sometimes be selected beforehand from the map, and reconnoitring officers should report on these locations and on any others they may think desirable.

4. If the country to be traversed favours the use of airlifts in bore-holes, compressors may be mounted on lorries or other forms of transport as mobile units. *See* Chap. IX, Sec. **45**.

This system is of particular value under any of the following conditions:—

- (*a*) If the country has been occupied and provided with bore-holes piped for airlifts at some period prior to the advance.
- (*b*) If the country is known to be provided with bore-holes suitable for airlifts.
- (*c*) If holes can be quickly sunk by mobile drill units.

5. The working of the compressor lorry system is generally as follows, and these instructions apply also to the operation of a system of bore-holes during position warfare.

Each lorry will have a group of bore-holes allotted to it daily. The groups must be selected according to :—

(*a*) Distance to be travelled daily.
(*b*) Amount of water required from each bore-hole.
(*c*) Capacity of each bore-hole.
(*d*) Road and traffic regulations.

A lorry will visit each bore-hole of its group in turn at stated periods, and the storage at each bore-hole must, therefore, equal the maximum consumption between the visits of the lorry. Generally at least 9,000 gallons are required. The storage tank must be raised sufficiently to feed the water point allotted to it, and the airlift can generally discharge into the tank if not too high.

A standing should be made for the lorry while working, but this need not be close to the well-head. The compressor can blow through several hundred feet of pipe if necessary. A 1-inch flexible pressure hose connection must be carried on the lorry to connect up with the airpipe of the airlift. The latter must, of course, be carried up to the lorry standing, and guarded by a fence round it.

The whole site should be well drained to prevent pollution finding its way down the bore-hole.

Each compressor lorry can work up to, say, six bore-holes in a day under average conditions, but no definite figures can be given.

The lorry driver should be made responsible for working the compressor.

Pl. **25** shows diagrammatically the arrangement at the well-head, while Pl. **101** shows a *compressor lorry* ready for the road.

6. The constructional work carried out in the initial stages of the exploitation of the area for water can only be of a very limited kind. Work should be limited to the barest essentials, and it cannot be too strongly emphasized that at this period the object should be to **get water at the earliest possible moment.** Pl. **26** shows the type of hasty work required.

If the advance checks and large masses of troops bank up, thus forming a new concentration area, the hasty water points made in the initial stages must be consolidated to withstand the increased usage to which they will be subjected. This will necessitate construction of the ordinary pattern water points with hard standings, &c., and perhaps provision of plant of greater capacity than that first installed.

7. As the advance gains momentum, conditions will approach those of purely mobile warfare, and the methods indicated in Chap. II, will come into force.

8. The possibility of the advance checking and position warfare again occurring should not be neglected by those responsible for the provision of plant and material.

PART II.—TECHNICAL PRACTICE.

CHAPTER IV.

SOURCES OF SUPPLY.

16. *Hydrology.*

1. The type of works to be adopted for semi-permanent water supplies depends largely on two factors, (*a*) the existing supplies, and (*b*) the geological structure of the country.

When the developed supplies are small or non-existent, a knowledge of the geological structure of the area is of the first importance in deciding upon a plan of water supply.

The type and number of installations depend on several factors, such as the presence or absence of surface water suitable for horse watering or capable of purification for human consumption, and the possibility and ease with which water can be obtained from wells, bore-holes, &c. The latter can be answered best by a study of the geology of the district, together with a knowledge of the conditions of the rainfall.

2. The larger rivers naturally rise on the inland high ground, and collect smaller tributaries in their course to the sea.

The size and number of small streams which go to swell the main river vary considerably according to the permeability of the strata of the country which they drain, and also according to the rainfall and topography of the district.

Streams normally tend to flow at all times of the year in temperate countries where the rainfall is distributed more or less evenly over the whole year and where there is no marked *rainy season*. Naturally, however, the streams contain more water in winter, when evaporation is of little consequence and rains are rather more frequent.

3. In a general way, it may be said that in an area formed of hard slates, grits, granites, &c., small streams will be numerous, and the water clear. In clay country small streams are also numerous, but are liable to be muddy at all times of the year, and the flow to be reduced to a mere trickle in a dry season. Limestones, chalk, and loose sands are extremely pervious in mass, so that all rain falling on the surface immediately soaks into the ground with the result that small streams are scarce. The higher parts of the valleys are *dry*, and only contain water during heavy storms or in wet seasons. The water which soaks into the surface issues as springs on the low ground of the main valley or lower reaches of the tributary valleys. The water of these streams is clear and generally of good quality.

4. The three chief factors governing the subsequent history of water which falls as rain are :—

i. Amount of rainfall.
ii. Amount of run-off.
iii. Extent of evaporation.

In all types of country, even in heavy clay land, a certain proportion of the water falling on the surface soaks into the ground. In a clay or slate area only a small proportion of the rainfall penetrates down through the surface soil, which has been rendered pervious by the action of plants, &c., and a large proportion runs off the surface. In an area of pervious strata, such as sands, rubbly limestone, or chalk, a large percentage of the rainfall is absorbed into the ground, and only during heavy storms is there any run-off direct to the rivers.

It must not be assumed, however, that the difference between rainfall and run-off gives the measure of the water that goes to replenish the underground reservoir which feeds the springs and wells. A third factor to be taken into account is that of evaporation. In a country like northern France, from the months of May to September inclusive, practically all the water which falls as rain is disposed of either by evaporation or run-off. The chief result is that the subterranean reservoir is gradually depleted from the month of May onwards through the summer and autumn till some time in October or November. This depletion is shown not only in the falling off in the yield of springs, but also in the lowering of the water level in wells, bore-holes, &c.

The widespread occurrence of water in pervious layers of the earth's crust has given rise to the notion that it flows in great channels very much as do the rivers on the surface. There are a few cases in which this occurs, but in the majority of instances subsurface water occurs merely or principally as moisture saturating the rocks. The sands or gravels washed down from adjacent heights are particularly well adapted to hold moisture, and great volumes of water can be obtained from these formations.

The behaviour of water in such formations is not clearly understood, and is still a matter of enquiry. For instance, one leading question is: Is it stationary, or does it flow freely from place to place? It is probable that to a certain degree both these conditions apply. In a small valley entirely enclosed, the water accumulates in the beds until they are entirely saturated, and the moisture in the ground approaching the surface of the soil begins to be evaporated.

The matter then adjusts itself until a balance is reached between the water which flows in and the amount which is evaporated, the water rising until the loss is equal to inflow. If a well is made in this basin and the water drawn upon, the level of the water in the immediate vicinity of the well is at once lowered. The influence extends only with great slowness towards the edge of the basin, the water level not falling as a whole at once, as would be the case in drawing from a large open body; the place of the water removed is slowly occupied by gradual progression of moisture from the sides. Instead of a small basin, if one of indefinite size is considered, there is seen a condition of things similar to that which takes place in a broad extent of country. The moisture at the lower limit of a large plain, escaping either in springs or by evaporation, is gradually replaced by the slowly progressing water, which percolates at a rate varying with the porosity of the rock or sand beds. The amount of water which can be taken from underground sources is limited not so much by the total quantity in the area as by the rate at which it can flow through the water-bearing strata.

5. It may be generally stated that the course of the water falling as rain,

except that lost by evaporation, follows the lines of natural drainage. The rivers and streams, supplied by springs, in their turn contribute to supply the sea, which together supply the atmosphere by evaporation, and thus complete the circuit. A vast circulation is thus kept up by the radiating power of the sun.

6. Oceans and seas cover four-fifths of the earth's surface, and the principal evaporation takes place in those portions of the globe where the sun's rays act in a vertical or nearly vertical direction. A very large quantity of aqueous vapour is thus constantly being carried into the higher regions of the atmosphere, and is being borne from the equator to the poles, with certain modifications due to physical causes.

7. From these physical differences the rainfall varies in different places, being *nil* in the deserts of Asia, Africa, and parts of America, to 600 inches a year in certain parts of India. In England it varies from 20 inches in some of the eastern counties to 150 or 160 inches in Cumberland.

8. The circumstances in each locality render the application of hard and fast rules unreliable, but, if observations are carried out for a series of years, an average can be obtained which will give fairly accurate results for a similar series in future.

The method of estimating probable rainfall from known data is given in Chap. V.

9. Rain falling from the clouds may be collected directly in suitable vessels and used for drinking, &c. A simple calculation, however, will show that the amount that can be collected in this way is very small unless the collecting surface is large. Rain-water in its pure state, moreover, is not palatable for drinking, being deficient in aeration, and also flat and insipid due to the absence of dissolved salts. Attention, therefore, has to be directed to rain-water which subsequently appears in lakes.

10. The great effect of the geological structure on the question of water supply to troops in the field is well illustrated by a study of the areas occupied by the British Armies in France and Belgium during the War of 1914-19. In this area the meteorological conditions are sufficiently uniform to constitute only a very minor controlling factor.

A glance at the geological sketch map and section (Pls. **29** and **30**) shows that the area falls into two main divisions—recent and tertiary sands and clays to the north, and a great undulating chalk plateau in the south. The geological section from Ostend to the top of the Notre Dame de Lorette ridge and from thence to Peronne shows the general arrangement of the strata in the areas referred to.

The chief points to be noticed in the hydrology of the area may be taken in order, starting at the coastal plains of the North Sea at Ostend, Nieuport, &c. The coastal strip of the Polder plain, with the exception of its seaward margin of sand dunes, lies below or near high tide level. The Polder plain consists mainly of marine sands with thin clays and peat beds in certain places in the upper part. Water supply in this area presented great difficulties. Although the region is thickly intersected with waterways, these are all foul and in many cases brackish. Potable water was, therefore, obtained chiefly from sterilizing lorries and barges drawing from the canals and numerous waterways where these were not too saline. A certain amount of fresh water could also be obtained from shallow wells of large diameter sunk among the sand dunes along the coast, and the method shown on Pl. **34** was used with success. The town of Dunkerque, which lies in this area, is supplied by pipe from chalk springs near St. Omer.

A tough blue impervious clay called the Ypresian or Tertiary clay, which is of similar age to the London clay of England, is found beneath the marine beds of the Polder plain at a depth of about 100 feet on the coast. This clay is found near the surface round Ypres and over most of the plains of Flanders. The loamy clay surface layer overlying this Ypresian clay varies in thickness according to the contour of the ground, and the wells in this region contain only surface drainage water, which is almost invariably of bad quality. During most of the year the subsoil water level is but a few feet from the surface, and, particularly after rain, small and muddy streams abound. Water supply work was, therefore, directed chiefly to providing drinking water for troops. The two lakes, Zillebeke and Dickebusch, which supplied the town of Ypres before the War, offered a water which was quite satisfactory after sterilization, and water was pumped from these sources over a large part of the area. For the operations in 1917, purification plant was installed at Harenghe on the River Yser, the only river of any magnitude in the area. An extensive pipe system was laid in connection with these works.

The range of hills from Cassel, Mt. Noir to Kemmel, with their continuation the Messines-Wytschaete ridge, are relics of sands which naturally come above the Ypresian clay, but have been worn away by the action of weather from all the clay surface except on this isolated range of hills. There are numerous land springs in these hills, and, by damming across the re-entrant valleys, small impounding reservoirs were formed, which made valuable sources of supply.

The flat ground running from near Calais to St. Omer and Bethune, although mainly covered by recent alluvial deposits, is underlain by the sands and sandy clays which come below the blue Ypresian clay, and form a basal series to the tertiary strata (*see* Pls. **29** and **30**). These sands crop out at the surface near Bethune and St. Omer, and are found at a depth of 300 feet below sea level near Ypres, and about 520 feet below sea level at Ostend. The lower tertiary sands as obtained from bores near Ypres are extraordinarily fine, but become coarser towards the outcrop. They are water-bearing, but only near their outcrop can any considerable volume of water be obtained from them. In the plains of Flanders the usefulness of bores to the lower tertiary sands was limited not only by the small volume of water which could be obtained, but also by the extreme difficulty of dealing with the sand which came up in great quantities once the well was overpumped; this difficulty was later overcome by the use of an airlift in conjunction with an Ashford tube filter (*see* Pl. **86**), but even then the yield was only some 200 to 300 gallons an hour from a 6-inch well. In the Ypres area, as already stated, reliance was placed rather on the treatment of surface water than on subterranean supplies. Near the outcrop, however, the lower tertiary sands give good supplies, and in the basin of the River Lys, near St. Omer and Lillers, are found many artesian wells supplied from the chalk hills of Artois to the south.

Rising up from the plains of Flanders are the chalk hills of Artois and Picardy. The chalk must not be considered as a whole, because its character varies both vertically and horizontally. Thus, under the plains of Flanders the chalk is found to thin over an old submerged crest of slate rocks, and in this locality it is found to be a compact hard marly chalk with few or no fissures, and contains no water. Again, near Lille and round Bapaume and Peronne the upper beds of the chalk are porous and fissured, while the middle and lower beds are marly and impervious. The undulating plateau of Picardy to the south and the valley of the Somme are thus formed of white upper chalk overlying the marls of the middle and lower chalk. The structure, however, is not that of a uniform horizontal series of beds, but is a series of gentle folds as shown on the geological section (Pl. **30**). In this area springs are frequent at the level of the underground water reservoir ; but when troops were located above this level, often in considerable concentrations, much work was required to get the water to them. In the earlier stages, pipes were laid from the springs, and existing deep wells developed, but as the practice of deep boring was perfected it was possible to dispense with the pipes. The level of the water horizon varies from the surface to 300 feet according to the location, but bore-holes were often driven far deeper into the chalk marls in order to secure sufficient submergence for airlift working.

One of the most striking features of the area as a whole is the abrupt rise of the Notre Dame de Lorette and Vimy Ridge, which is explained when the geological structure of this area is studied. Running along the foot of these hills is a large fault with a throw of about 300 feet passing in places to a fold fault on the Vimy Ridge (*see* Pl. **30**). This great fault brings the lower marly chalks to the surface ; there is no water in these chalks, and consequently it was necessary to pump water into this area from springs situated in rear.

From the above short description, it will be seen that in the north the main source of supply was contaminated surface water, while in the south water of excellent quality could be obtained from the chalk. It resulted, therefore, that water supply practice was essentially different in Flanders to that obtaining in Picardy where chalk formed the whole country.

It is of the first importance, therefore, before deciding on the type of plant which will be necessary and the water supply policy to be pursued for a campaign, to have a sound knowledge of the geology of the district and of the behaviour of the underground water. This information must to a large extent be collected in peace-time, but should be amplified and extended during the progress of operations. In any large campaign, geologists will be included in the engineer staff of the army, and part of their duties will be the collection of hydrological information.

17. *Springs.*

1. A considerable portion of the water which passes into the soil not infrequently reappears on the surface in the form of springs. The water sinks through porous strata until it reaches—as it usually does at a greater or less depth—an impermeable stratum. Here it is upheld, forming an

underground reservoir, natural outlets of which are springs which occur where the impermeable stratum *crops out* on the earth's surface. Such springs are sometimes classified as land springs or main springs. *Land springs* are of limited capacity, the water in them being formed in superficial beds of sand or gravel overlying a stratum of clay, and they often cease to discharge when rainfall is delayed. *Main springs* are deep-seated outlets of geological formations, such as chalk, oolite, and sandstone, often fed by rain at great distances from the spring.

2. Water is thrown out as springs whenever a saturated water-bearing stratum rests on an impervious one, or when the valleys are cut down below the level of saturation if the whole country is formed of a rock-like chalk. The exact location of a spring will be influenced by local accidents, such as small original irregularities in the surface of the impervious underlying strata or by small faults. There are, however, more important considerations whenever the strata have been inclined to the horizontal by earth movements. In this case springs will be larger and more numerous on that side of the hill where the lowest point in the impervious underlying bed is found. In limestones, and probably to a less degree in chalk, the jointing of the rock has an important influence on the location of springs. The main joints become enlarged by solution, and the water flows more or less freely in these fissures and issues as large springs.

In limestone areas the surface streams frequently take a temporary underground course, and may be mistaken for springs on issuing to the light again. This must be guarded against, as the water may be highly contaminated with surface pollution although it appears clear and cool.

Springs are thus the natural outlet for the waters of the underground reservoir which is fed by the percolation of the rain-water down through the soil and subsoil into the pervious strata which form the reservoir and hold the water in a manner similar to a sponge. In mountainous country the upper regions may be waterless if there is no impervious stratum except at low levels.

3. As a rule (which is, however, by no means an invariable one), springs afford excellent water for drinking purposes, so that the supply from such sources is always sought after. The water in sinking through the ground absorbs some of the carbonic acid from the ground air, and then becomes capable of dissolving certain mineral constituents of the rocks over which it passes. Thus calcium carbonates and calcium sulphates are found in water issuing from chalk, oolite, and limestones; magnesium carbonates from dolomitic limestones; iron from green sands and iron stained sandstone; salts of sodium or potassium from some sandstone rocks and other strata. As a rule, the temperature is constant at all times, the aeration is good, and the salts in solution are sufficient to render it palatable. The supply, however, from ordinary springs is not generally more than would suffice for small peace-time communities, but they form valuable sources of supply in the field. The flow from a spring can often be increased by enlarging the point of outflow. To guard against the pollution of springs, it is desirable that the point of delivery should be walled in, and the water conducted to the surface by a pipe. It is important to remember that the water from springs is not invariably safe, especially in fissured formations in which pollution can enter at a distance.

18. *Shallow wells.*

1. Shallow wells obtain their water from the superficial deposits found either in the weathered surface beds of impervious strata or in recent gravels and alluvia of rivers, sand dunes, &c.

The water from shallow surface wells is open to much pollution, and, except when made in river gravels, such wells seldom yield large volumes of water. As a temporary source of supply they are often of great value, but for a large supply shallow wells are not individually of great value, except when in gravel beds.

2. The conditions of surface drainage materially affect the level of water in surface wells. This was markedly proved at Lucknow where an extensive scheme of surface drainage of the cantonments was carried out in 1877-81. The water supply obtained from surface wells was very sensibly reduced, the water level in the wells being everywhere lowered. This example is an excellent illustration of the dubious sources from which many shallow wells receive their supply.

3. Some simple rules for ascertaining a good site for a surface well are given in Sec. **6**, para. 3.

These rules apply only to surface wells, being neither sufficient nor applicable to deep wells for which geological knowledge is always necessary.

4. In Afghanistan and Persia where valleys of irregular contour occur between barren ranges of mountains, the natives utilize the subterranean water for irrigation purposes by sinking a series of wells, generally across the valleys, connecting the same at the water level by almost horizontal galleries leading to the natural surface of the ground where irregularities of contour permit. Such a system of wells is called a *Karez* (*see* Pl. **28**, Fig. 1), and the advantages of it are that the length of the horizontal gallery, tapping as it does a greater portion of the water-bearing stratum than a single shaft would do, stimulates the flow throughout that stratum, and the water is protected throughout its passage underground from evaporation.

5. In contradistinction to *shallow wells*, which are merely sunk into superficial porous beds overlying an impermeable stratum, those wells which are sunk through an impermeable to a permeable stratum are known as *deep wells*, and are described in the following Section.

19. *Deep wells and bore-holes.*

1. A deep well may be considered as a large diameter bore-hole, and the following remarks apply to both. Since these wells are only found in water-bearing strata where the water level is a great depth below the surface, the water will probably be of good quality, and, if the well has been sunk several feet below water level, with the aid of pumping machinery the yield may be considerable. The water level in wells with 10 feet or more of water may have considerable seasonable variation.

2. When the type of rock is suitable, deep wells and bore-holes offer a means of tapping the deeper waters.

Another great advantage in obtaining water by this means is that the superficial polluted waters are cased off, and also that the water can be drawn from a pervious stratum which is overlain by an impervious series of beds when they are of great thickness.

3. The conditions governing the supply of water from a bore-hole may be considered under two heads :—

(*a*) Nature of the strata.
(*b*) Geological structure and topography of the district.

4. The nature of the water-bearing beds which yield the water in a bore naturally exercises much influence on the amount and quality of the water which can be abstracted.

For instance, in water-bearing sands the volume of water obtainable for each foot of boring in the water-bearing strata is largely controlled by the rate at which water can flow through the sand.

In some cases where the sand is extremely fine, the volume which can be taken without drawing sand into the bore is very small. Various strainers have been devised to keep back the sand, but with the best obtainable it was found in the fine sands below the Ypresian clay in Flanders that a bore in about 50 feet of sand would not yield more than 300 gallons an hour.

In coarser sands or fine gravels very large volumes can be obtained, particularly if the water is under a certain degree of pressure.

From limestones the yield depends entirely on the number and size of the fissures intersected by the bore, and frequently two bores quite near each other may give different yields, and may strike water at different depths.

In chalk the conditions are rather different, as the mass is more or less permeable as a whole, and behaves more uniformly than a hard limestone.

5. Before being able to estimate the depth or yield of any bore-hole, the topography and geological structure of the area must be studied as well as the physical state of the water-bearing strata. By physical state is meant the coarseness or permeability of a sand or a sandstone, or the amount of fissuring which may be expected in a limestone at a depth, &c.

If the area be one of which the geology is fairly well-known, reasonably accurate estimates as to depth and yield can usually be given by an expert. The height to which water will rise in the bore can also frequently be estimated. This point is of particular importance in dealing with an *artesian basin.*

6. All strata with which the water engineer is concerned may be divided into permeable and impermeable strata; the former consisting of chalk, gravel, or sands through which the water will readily filter, or rocks broken up by fissures along which the water passes readily. The impermeable strata are either formed of layers of dense clays and marls, or close-grained compact rocks.

Now if all the strata on a given surface were *horizontal,* the water would sink through the permeable strata till it reached the impermeable upon which it would be borne up, and would ooze out at any outcrop caused by the irregularities of the surface, *e.g.*, on a hillside.

If the strata were *saucer shaped,* or synclinal, a reservoir would be formed, which would in course of time become filled and would overflow after heavy rain.

If the basin is filled with permeable material only, the water may rise to the surface of the ground anywhere. But if the permeable material is again covered with impermeable, so as to leave a ring only of the former material exposed, the water will rise to the surface only on the area of the ring itself, and, if a well is dug in this superstratum until the water-bearing stratum is tapped, the water will rise up the well towards the surface of the ground, or even overflow, forming what are known respectively as *sub-artesian* or *artesian wells*.

As a matter of actual fact, however, the surface of the earth is so irregular that the existence of a perfect basin, such as the one assumed, is most rare. In most of the impervious strata there are cracks and *faults*; and there are certain planes of bedding and joints all of which affect the question, and are of great importance.

7. As an illustration, Pl. **28**, Fig. 3, may be taken as a section of a typical basin. The water in all the strata, shown in the section, is derived from the rain which falls on those portions of the surface that are not covered by the London clay, and is upheld by clay beds of the gault. Thus it accumulates in the strata up to the horizontal line AB, at which it overflows by springs in valleys, *e.g.*, at C. Below this line all the chalk, &c., is filled with a permanent reservoir of water, except when faults or fissures allow it to escape into lower strata. Except where such escape occurs, the level of AB gives the line up to which water will rise in any well by hydrostatic pressure, when the superincumbent London clay is perforated. If the level at the ground surface be below the line AB, as at G or H, the water will rise in a perpetually flowing *artesian* fountain.

Artesian wells are deep wells of the nature above alluded to, where the surface of the ground is below the level of the water in the subterranean reservoir, and consequently the water flows at the top of the well without any pumping.

8. Faults in geological strata affect this question in various ways. The section on Pl. **28**, Fig. 2, represents a portion of a basin intersected by a fault HL filled with clay. A, B, C, D are porous strata, the remaining ground being impervious. It is quite clear that not only the rain-water which enters the outcrop at A, B, C, D of the inclined and porous strata, but also all that falls on the surface of the impervious strata between each will he held up by the fault. The rainfall on CD will flow down C, that between C and B will flow down B, and so on. A well sunk at E will yield water which will rise to a greater height and in greater volume as each successive layer is tapped.

In many limestone districts the faults become filled with clay, which acts as a dam, and forces the water out at the surface. The springs thus formed have frequently led to the discovery of the geological faults. On the other hand, faults may act as conduits, leading water down through impervious strata to others below.

As a general rule, the level of the water in the underground reservoirs does not remain constant, nor does it remain absolutely the same for all parts of the same stratum. If there is an outfall or spring, the level of the saturation is inclined towards that spring, and in every case the level varies with the season of the year and the rainfall, being least in October or November, and greatest in February or March in England.

9. The typical conditions for a constant water supply by means of wells are shown on Pl. **28**, Fig. 3, *i.e.*, where there is a broad extent of pervious strata overlying a band of impervious formation on a *synclinal* (*i.e.*, saucer-shaped) axis. The difficulties that practically present themselves are :—(*a*) To know whether the proposed site is on a synclinal or anticlinal axis. (*b*) To know whether any impervious band of clay underlies the permeable strata.

As regards the first of these two points, observation may be made of the sections of the earth's surface in quarries, cuttings, river embankments, &c. Any fossils which may be collected will furnish a means of identification as to the strata, reference being made to a geological museum for comparison. In observing the dip of strata, it will often be found that the strata do not follow the inclination of the ground surface.

Frequently synclinal axes are found at the tops of hills and anticlinal axes in valleys, due to the denudation of strata already strained by upheaval. Hence it does not follow that the best site for a deep well is in a valley. If the synclinal axis happens to correspond with the valley, it would, of course, be the most economical place to bore for water.

In all cases where boring for water is carried out, endeavour should be made to find where the outcrop of the water-bearing stratum is situated, so as to determine its thickness. The outcrop of other overlying strata should also be ascertained.

As regards the other difficulty, viz., the existence of impervious substrata, it may be stated, generally, that where oak trees flourish, and where the country is flat, clay is the chief ingredient of the soil. In the Weald of Kent, for instance, oak trees are abundant in the flat plain of clay, but they do not grow in the overlying chalk formation. Where pines grow, as in the Aldershot district, they are characteristic of sandy soil.

Gravel is generally a good water-bearer, and in a gravelly valley down which a river flows water may be obtained in shallow wells in any part by percolation from the river. Frequently in dry valleys water may be obtained by digging into the gravel which forms the bottom.

In deep wells sometimes boring is carried through an impervious stratum into a porous one below, so that instead of the yield being increased it is lost altogether. This danger must be guarded against by obtaining the best knowledge possible of the geological conditions of the site.

CHAPTER V.
REQUIREMENTS AS TO QUANTITY.

20. *Estimates of requirements.*

1. The water consumed by men and animals, for raising steam, and in the multitudinous other ways in which water is made use of, varies so much according to circumstances that it is impossible to lay down an exact figure for any particular case. In planning any water supply scheme, the

aim should be to provide as much water as can be made use of, provided that adequate arrangements can be made with regard to drainage. A copious supply of water promotes health, and is, therefore, to be encouraged. On the other hand, economy is to be sought after, not by limiting the amount of water used for legitimate purposes, but by the use of up-to-date plant, skilful planning of the necessary works, and by the elimination of waste in distribution. The use of inferior fittings is a fruitful source of waste.

2. Although accurate data regarding consumption of water cannot be given, the following tables show figures on which an approximate estimate may be based. The estimates thus arrived at must be modified according to local circumstances, especially in hot climates.

TABLE A.—*Daily consumption. Temperate climates.*

Man	Highly civilized communities	50 galls.	Includes water-borne sewage system.
	Semi-permanent cantonments	30 galls.	Includes water-borne sewage system.
Man	Standing camps	15 galls.	No water-borne sewage.
	Temporary camps	5 galls.	No water-borne sewage.
Man	Absolute minimum	1 gall.	At rest.
	Absolute minimum	½ gall.	On the march; periods not exceeding 3 days at a time.
Horse, mule, or ox	Normally	10 galls.	——
	Absolute minimum	3 galls.	It is possible for a horse to go 48 hours without water. It drinks 3 galls. at a watering, and takes 5 mins. to water.
Sheep or pig	——	1 gall.	——
Camel	——	10 galls.	Allow an extra 10 galls. every third day. A camel takes 20 mins. to water, and drinks in two bouts with an interval of 10 mins.

TABLE B.—*Miscellaneous consumption figures.*

Consumer.	*Daily consumption.*
Each slipper bath	200 gallons.
Each W.C.	40 ,,
Each lavatory basin	20 ,,
Each urinal	40 ,,
Each yard tap	40 ,,
Each vehicle washed	10 ,,

Boilers, steam-raising.

Locomotives, broad gauge, large ...	7,000 gallons a day, or allow 120 gallons each train mile (empty or loaded trains and one engine each train).
Locomotives, metre gauge, small ...	2,500 gallons a day.
Locomotives, 60 cm. gauge	1,800 gallons a day.
Horizontal stationary type—compound modern engine	2 gallons each h.p. hour.
Horizontal stationary type—non-condensing	4 gallons each h.p. hour.

Boilers, washing-out.

About 20 gallons each h.p. each washout under normal conditions, at a pressure of about 50 lbs./square inch.

Locomotives require about 3,000 gallons every 7 or 14 days: pressure about 50 lbs./square inch.

Condensing water.

At normal temperature and sent to waste	100 gallons each h.p. hour.

Petrol and oil engines, cooling.

Loss = $\frac{1}{4}$ to $\frac{1}{2}$ gallon each h.p. hour. Circulate at rate of 7 gallons each h.p. hour. Provide 35 gallons tank capacity each b.h.p.

3. The first thing to be done when selecting a source of supply is to ascertain whether the amount of water available is sufficient for the maximum possible demand. When, in the case of a pumped supply, the minimum yield of the source is equal or more than equal to the maximum rate of demand, requirements as to quantity are fulfilled. It often occurs, however, that the yield of the source is a fluctuating one, being at times less than the rate of demand, while at others it is much greater. In such cases, it is necessary to provide storage reservoirs at the source, in order that the periods of insufficient flow may be compensated for by those during which the flow is more than enough. Such reservoirs are in large works termed *impounding reservoirs.*

21. *Yield of a catchment area.*

1. The amount of water available as *run-off* from a given catchment area can be estimated if the following factors are known :—

(*a*) The average rainfall during the period.
(*b*) The extent of the area under consideration.
(*c*) The proportion of the rainfall absorbed by the ground, and how much of this is given back to the collecting area by springs.
(*d*) The amount of evaporation from sheets of water within the area, and from the surface of the ground itself.

2. The difficulty of making even a fairly accurate estimation of the first and two last factors renders it impossible to make an accurate forecast of the *run-off* from a given area. Where, however, comparatively

large quantities of water are involved, an estimate accurate enough for all practical purposes can be made, if the rainfall over a previous cycle of years is known. Rainfall forecasts really demand expert knowledge, and should, when possible, be entrusted to a meteorologist.

The accuracy of the forecasts as regards the probable rainfall during a period will vary directly with the length of the cycle of time for which records are available, with the number of observations during that time, with the number of stations at which observations have been taken, and with the accuracy of the observations. It will very often happen that no rainfall records whatever are available for the area under consideration. It may, however, be possible to forecast with some degree of accuracy the probable rainfall from the records of stations situated some distance from the area.

Owing to the fluctuations of rainfall during consecutive years, it is usual to take the *least annual rainfall* as the basis of calculation. When a large number of records are available, it may be possible to deduce an *average monthly rainfall* for any particular month of the year, but the results so obtained cannot always be relied upon. In any case, where the construction of an impounding reservoir or the adequacy of a naturally formed reservoir is in question, the least annual rainfall is the important factor, since winter rains are generally relied upon to make up the shortage in summer.

The following empirical rules deduced from records in various parts of the world have been found to hold good :—

i. In order to include a sequence of two or three periods of wet or dry years it is necessary to consider a cycle of about thirty-six years.

ii. Periods of three consecutive dry years may occur, the average rainfall in which is as low as 80 per cent. of the average for the longer cycle.

iii. Single dry years may occasionally occur in which the rainfall is as low as 60 per cent. of the average.

The usual practice is to consider as available no more than the average fall for three consecutive dry years, but, if the available storage is very small in proportion to the consumption, the least annual rainfall should be taken as not more than the lowest on record. When the records are scanty, even this should be reduced.

3. The actual *superficial area* likely to receive the rainfall can be arrived at from a contoured plan of the district, if one is available—otherwise a rough survey will be necessary.

4. Next to the rainfall factor, the *absorption factor* is probably the most serious source of inaccuracy in the computation of the available yield from the area.

Absorption may take place in several ways. If a part or the whole of the area is covered with a pervious stratum overlying an impervious stratum, a proportion of the rain will descend to the impervious stratum, and will there be held up. If conditions permit, the water will descend until it breaks out in springs, which may or may not be included in the total yield of the area, *i.e.*, the springs may break out below the dam on the down-stream side of the reservoir. It is important that the course of such subterranean flows should be taken into account. It may be impossible for the water to escape in such a way, and then the ground will become water-logged, and the ground water level will be lowered in periods of drought owing to evaporation.

In some cases, the conditions of the strata comprising the catchment area will permit of a considerable proportion of the precipitation escaping through subterranean channels.

Although a detailed study of the geological conditions will afford much information as to the proportion lost by absorption, a reasonably accurate estimation of the absorption factor can only be made by comparing the gaugings of streams at the down-stream end of the catchment area with the rainfall figures at various points within the area over a period of time. Observations over only a few weeks will give a fair idea of the ratio between precipitation and absorption. It is, however, to be noted that this ratio will vary according to the time of year, owing to the effects of ground storage and evaporation. A heavy downpour after a period of drought may afford no increase in the amount of water impounded, being entirely absorbed by the ground.

No definite or even approximate figures can be given here for the proportion of rainfall absorbed on a given area. It will generally be possible to take gaugings of the streams running away from the catchment area together with rain-gauge readings taken during the same period, and from these the necessary correction must be made, it being remembered that this figure includes that due to evaporation (*v. seq.*).

5. *Evaporation* can be measured in an evaporameter, which consists simply of a shallow pan provided with a gauge and exposed to the same conditions as the ground or water surface under consideration.

The determination of the evaporation is of little value so far as the total yield is concerned if the method outlined in the preceding paragraph is followed, since the evaporation figure is included in the result. It may, however, be necessary to determine the evaporation when calculating the net capacity of the reservoir, since the evaporation from the surface of a sheet of water is greater than that from an equal area of ground.

6. The foregoing observations apply more particularly to the selection of a watershed when the construction of large impounding works is in prospect, but cases may arise when it is desired to use an existing lake as a storage reservoir of which the adequacy or otherwise is in question. The general principles above formulated should enable an approximate determination to be made of the probable annual yield. This calculation may be necessary in determining the capacity of a natural reservoir to supply a large formation during an extended campaign.

22. *Gauging the flow of springs, streams, and rivers.*

1. To measure the yield of a spring, a point should be selected as near as possible to its overflow. The flow here can be determined either accurately by the *notch* method, or approximately by the method described below for taking the yield of a river. Care should be taken that the whole outflow from the spring passes along the measuring channel.

When the yield is very small, it is best measured by taking the time required to fill a vessel of known capacity.

2. The rough average yield of a spring or stream may be measured as follows :—

Select a straight length of 15 to 20 yards where the channel is fairly uniform, and there are no eddies. Measure the breadth and depth at three or four places, and from these obtain the average sectional area of the channel.

Drop in a chip of wood, and find the time it takes to travel a known distance in feet, say 30 feet. This gives the surface velocity of the stream in feet each second ; then,

if V = surface velocity of stream in feet a second,
A = sectional area of channel in feet, *i.e.*, $b \times d$ where b = average breadth of channel in feet, and d = average depth of channel in feet ;

$$\text{then } \frac{4}{5} V \times A = \text{yield in cubic feet each second,}$$

$$\text{or } \frac{4}{5} V \times A \times 6\tfrac{1}{4} \times 60 = \text{yield in gallons each minute.}$$

The most accurate method and the one most generally used by engineers is by measurement over a weir, as subsequently described.

3. **The rectangular notch method** is as follows :—Construct a dam in such a manner as to cause the stream to flow through a rectangular notch cut in the top of the dam (Pl. **31**, Figs. 1 and 2). This notch is called a weir, and is simply an opening of sufficient length and depth to allow all the stream to pass through it. For small streams the simplest form of dam is one made of planks. The notch is preferably cut out ot hin brass sheet.

The bottom of the notch should be bevelled on the down-stream side; the sides of the notch should also be bevelled on the same side, leaving the edge sharp.

The surface of the water below the dam should be from 10 to 12 inches below the bottom of the notch, so that the flow of water through the notch may not be impeded.

The sill of the weir *must be level*, and its length accurately known.

The dam should be of sufficient height to form a still pond above, so that the water will approach the weir without any perceptible velocity, since a larger quantity will pass if the water moves rapidly.

Care should be taken, when filling in the weir-dam, that the depth of water at the weir be not less than three times the depth of the notch or twice the head over the rectangular weir. The width of the pool should be at least equal to the total length of the weir, plus four times the maximum head over the rectangular weir. The weir-pool should be on a straight stretch of the stream. The ends of the dam should go deep and well into the bank on each side, so that there shall be no escape of water under or around them.

A stake should be driven several feet above the dam in *still water*, near the bank, for convenience in taking measurements. This should be far enough up-stream to be above the curvature of the surface of the water passing over the weir.

Cut a hole in a piece of board to prevent it floating away, and slip it over the stake.

Measure down from the top end of the stake to the top surface of the plank, just as the water has *filled the weir-pool level with the notch*; this should be done when the weir-pool is *first* filled.

When the pond has filled to its maximum height, take another measurement in the same manner. The difference between these two measurements is the depth of water flowing over the weir.

The Table below shows the number of cubic feet of water which passes a weir for each inch in breadth in each minute.

TABLE C (i).—*Rectangular weir discharges.*

Inches.	0	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$
		·006	·01	·03	·05	·07	·09	·11
1	·40	·43	·47	·51	·55	·60	·65	·70
2	1·14	1·19	1·24	1·30	1·36	1·41	1·47	1·52
3	2·09	2·16	2·23	2·29	2·36	2·43	2·50	2·57
4	3·22	3·29	3·37	3·44	3·52	3·60	3·68	3·75
5	4·50	4·58	4·67	4·75	4·84	4·92	5·01	5·10
6	5·90	6·00	6·09	6·18	6·28	6·37	6·47	6·56

Inches.	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$
	·14	·17	·20	·23	·26	·30	·33	·36
1	·74	·78	·83	·87	·93	·98	1·03	1·08
2	1·59	1·65	1·71	1·77	1·83	1·89	1·96	2·02
3	2·63	2·71	2·78	2·85	2·92	2·99	3·07	3·14
4	3·83	3·91	3·99	4·07	4·16	4·24	4·32	4·41
5	5·18	5·27	5·36	5·45	5·54	5·63	5·72	5·81
6	6·65	6·75	6·85	6·95	7·05	7·15	7·25	7·35

For instance, if the notch is 12 inches wide and the depth of water over the weir is $3\frac{5}{16}$ inches, the amount of water passing over the weir in a minute is found by multiplying the amount found in the horizontal line opposite to 3 and in the vertical column under $\frac{5}{16}$ inch by the width of the weir.

Thus, amount required is $2{\cdot}43 \times 12$ cubic feet a minute; or $2{\cdot}43 \times 12 \times 6{\cdot}25$ gallons a minute.

4. For smaller quantities the **triangular notch method** may be used. In this method, a triangular notch with its sides at 90° is cut in the sillboard, the notch being of sufficient size to allow the full volume of water to discharge through it (Pl. **31**, Fig. 3).

A series of V notches may be cut in the sillboard if the flow of water is great; these notches must be of equal size and not too close together;

it is important that the apices of the notches should be exactly in line, and that this line should be exactly horizontal.

The following Table shows the number of cubic feet which passes over a right-angled V notch 1 inch to 6 inches deep in each minute.

The Table is used the same way as that for the rectangular notch method.

TABLE C (ii).—*Triangular weir discharges.*

Inches.	0	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$
	Discharge (q) in cubic feet each minute.							
1	·300	·339	·403	·461	·522	·591	·665	·742
2	1·7	1·83	1·97	2·12	2·28	2·42	2·61	2·78
3	4·68	4·92	5·18	5·44	5·71	5·99	6·28	6·57
4	9·6	9·98	10·4	10·8	11·2	11·6	12·0	12·4
5	16·8	17·3	17·8	18·4	18·9	19·5	20·1	20·7
6	26·5	27·2	27·9	28·6	29·3	30·0	30·8	31·5

Inches.	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$
	Discharge (q) in cubic feet each minute.							
1	·827	·916	1·01	1·11	1·22	1·33	1·44	1·57
2	2·96	3·15	3·35	3·55	3·76	3·98	4·21	4·44
3	6·88	7·19	7·51	7·83	8·17	8·51	8·87	9·23
4	12·9	13·3	13·8	14·3	14·8	15·2	15·7	16·3
5	21·3	21·9	22·5	23·1	23·8	24·4	25·1	25·8
6	32·3	33·1	33·9	34·7	35·5	36·3	37·2	38·0

5. **Gauging the flow of larger streams and rivers.**—In the case of streams with a flow varying from a maximum in wet weather to a minimum in dry weather, a *combination weir* is convenient. This consists of a rectangular weir in the sill of which is formed a wide angled notch. The dry weather flow can then be measured in the notch with greater accuracy than would be possible with the large rectangular weir.

The following data will determine the dimensions of the notch :—

(i) The minimum flow should not be less than 3 inches. This determines the angle of the notch. Under ordinary circumstances the minimum flow will be about 0·05 *cusecs* (cubic feet a second) for each 1,000 acres of area drained by the stream.

(ii) The notch should be large enough to pass 5 cusecs for each 1,000 acres.

The maximum capacity of the weir for drainage areas up to 10,000 acres need not generally exceed 100 cusecs for each 1,000 acres.

The flow over a triangular notch is given by

$$Q = 2\cdot 48\, n\, H_{N}^{2\cdot 47},$$

where Q = discharge in cusecs,

n = tangent of half the included angle,

H = head in feet measured above the apex.

For rectangular weirs with end contractions

$$Q = 3 \cdot 10\, L^{1 \cdot 02}\, H_w^{1 \cdot 47},$$

where Q = discharge in cusecs,
L = length of weir in feet,
H_w = head in feet measured above the sill.

For a combination weir, while the flow is through the notch only, the first of the above two formulæ may be applied.

When the flow is over the horizontal portion of the weir as well, the following adapted formula may be used :—

$$Q = 3 \cdot 10\, L_w^{1 \cdot 02}\, H_w^{1 \cdot 47} + 3 \cdot 10\, L_N^{1 \cdot 02}\, (H_w + h)^{1 \cdot 47},$$

where Q and H_w are as before,
L_w = length in feet of horizontal portion of weir over which water flows,
L_N = length in feet of base of notch triangle
(whence $L_w + L_N = L$ = total width of weir),
and h = head in feet on a rectangular weir of length L_N which would give an equal delivery to that given by the notch flowing full. This can be found from formula $Q = 2 \cdot 48\, n\, H_N^{2 \cdot 47}$.

The following Tables may be used where applicable :—

TABLE D.—*Combination weirs.*

(*a*) FLOW THROUGH TRIANGULAR NOTCH.

Head ft.	Discharge in cusecs for n =					
	1.	2.	3.	4.	5.	6.
0·2	0·047	0·093	0·140	0·186	0·233	0·279
0·25	0·081	0·162	0·242	0·323	0·404	0·485
0·3	0·127	0·253	0·380	0·507	0·634	0·760
0·4	0·258	0·516	0·774	1·03	1·29	1·55
0·5	0·448	0·895	1·34	1·70	2·24	2·69
0·6	0·703	1·41	2·11	2·82	3·51	4·23
0·7	1·03	2·06	3·08	4·11	5·14	6·17
0·8	1·43	2·86	4·29	5·72	7·15	8·58
0·9	1·91	3·82	5·73	7·65	9·56	11·47
1·0	2·48	4·96	7·44	9·92	12·40	14·88
1·2	3·89	7·78	11·67	15·57	19·46	23·35
1·4	5·69	11·36	17·08	22·78	28·47	34·16
1·6	7·92	15·83	23·76	31·67	39·59	47·51
1·8	10·60	21·19	31·78	42·39	52·96	63·57
2·0	13·74	27·48	41·22	54·95	68·69	82·45
2·25	18·37	36·74	55·11	73·50	91·86	110·3
2·50	23·84	47·68	71·52	95·36	119·2	143·0
2·75	30·17	60·34	90·52	120·7	150·9	181·0
3·00	37·40	74·80	112·2	149·6	187·0	224·4

$Q = 2 \cdot 48\, n\, H^{2 \cdot 47}$ = cusecs.
n = tangent of half angle of notch.

To obtain million gallons a day multiply by 0·54.

(b) DISCHARGE IN CUSECS OF RECTANGULAR WEIRS WITH COMPLETE CONTRACTION.

Head ft.	Length in feet.									
	5	10	15	20	25	30	35	40	45	50
0·1	0·54	1·10	1·66	2·23	2·80	3·37	3·95	4·52	5·10	5·68
0·2	1·50	3·05	4·61	6·18	7·76	9·36	10·9	12·5	14·1	15·7
0·3	2·73	5·53	8·36	11·2	14·1	17·0	19·8	22·7	25·6	28·5
0·4	4·16	8·44	12·8	17·1	21·5	25·9	30·3	34·7	39·2	43·6
0·5	5·78	11·70	17·7	23·8	29·8	35·9	42·1	48·2	54·3	60·5
0·6	7·56	15·3	23·2	31·1	39·0	47·0	55·0	63·0	71·1	79·1
0·7	9·48	19·2	29·1	39·0	48·9	58·9	67·0	79·0	89·1	99·2
0·8	11·5	23·4	35·4	47·4	59·5	71·7	83·9	96·2	108	121
0·9	13·7	27·8	42·1	56·4	70·8	85·3	99·8	114	129	144
1·0	16·0	32·5	49·1	65·8	82·6	99·5	117	134	151	168
1·2	20·9	42·4	64·2	86·1	108	130	152	175	197	219
1·4	26·3	53·2	80·5	108	136	163	191	219	247	275
1·6	31·9	64·8	98·0	131	165	199	233	266	300	335
1·8	38·0	77·0	117	156	196	236	277	317	357	398
2·0	44·4	89·9	136	182	229	276	323	370	417	464
2·25	52·7	107	162	217	272	328	384	440	496	552
2·50	61·6	125	189	253	318	383	448	513	579	645
2·75	70·8	144	217	291	366	440	516	591	666	742
3·00	80·5	163	247	331	416	500	586	671	757	843
3·50	101	204	309	414	520	626	733	840	947	1055
4·00	123	249	377	505	634	764	895	1025	1155	1287
4·50	146	296	448	601	754	908	1063	1218	1373	1530
5·00	171	346	523	701	880	1060	1241	1422	1604	1786

$$Q = 3{\cdot}10\, L^{1\cdot02}\, H^{1\cdot47} = \text{cusecs.}$$

To obtain million gallons a day multiply by 0·54.

(c) DEPTH OF FLOW THROUGH RECTANGULAR WEIRS GIVING THE SAME DISCHARGE AS TRIANGULAR NOTCHES (FOR USE WITH COMPOUND WEIRS). THE LENGTH OF THE RECTANGULAR WEIR IS EQUAL TO THE WIDTH OF THE NOTCH.

Proportions of notch.			Depth for rectangular weir for depth of notch given in feet.				
			1·0	1·5	2·0	2·5	3·0
Included angle.	90°	n = 1	0·53	0·79	1·05	1·31	1·57
	126° 52′	2	0·53	0·79	1·04	1·30	1·56
	143° 8′	3	0·52	0·79	1·04	1·29	1·55
	151° 2′	4	0·52	0·78	1·03	1·29	1·54
	156° 56′	5	0·52	0·78	1·03	1·28	1·54
	160° 48′	6	0·52	0·77	1·03	1·28	1·53

EXAMPLE.—Triangular notch, depth 2 ft. and included angle 152° 2′ ($n = 4$). Depth over rectangular weir $2 \times 4 \times 2 = 16$ ft. long, to give same discharge as the notch running full = 1·05 ft.

23. *Yield of wells and bore-holes.*

1. The most practical method of gauging a well is to pump the water down to the desired level, and take the time of refilling to the former level. By noting the cross-sectional area of the well, the yield an hour can be determined.

It should be remembered that the yield is *not* directly proportional to the depth the water is lowered. Generally speaking the lower the water is lowered, the greater the delivery each hour.

2. The yield of a bore-hole can usually only be directly determined by pumping at the maximum possible rate into a receptacle of known volume or into a *weir box* (*see* Pl. **32**).

24. *The rain-gauge and water-meters.*

1. The **Rain-gauge** consists of a cylinder (*see* Pl. **33**, Fig. **1**) set so that the lip is about a foot above ground level. Inside the cylinder is a bottle which receives all the rain falling within the mouth of the gauge.

The rainfall during a certain time is measured by pouring the water collected into a measuring glass. This glass is calibrated to show the equivalent depth in inches of the fall on an area equal to that of the mouth of the gauge.

When a number of gauges are in use, they should all be set as far as possible under the same natural conditions. The gauge must be set level, on level ground, away from walls, bushes, &c., and on a clear site.

The gauge should be read at the same time each day or week, as the case may be. The unit of measurement is an inch, and the measurement should be taken to the nearest hundredth of an inch.

Gauges should be read immediately after heavy rains.

Snowfall can be measured by melting the snow caught in the gauge with a known amount of warm water.

2. **Meters** are instruments fixed in a run of piping to indicate the rate of flow of the water, thereby giving the consumption.

In permanent work, meters are generally fixed on all consumers' connections other than those for purely domestic purposes. This practice, though desirable, is not necessary in semi-permanent schemes, but it is often an advantage to have a meter on mains or on important branch connections.

There are two classes of meters in use :—

(*a*) The positive type. These meters measure directly the quantity of water passing through.

(*b*) The inferential type, in which the flow is inferred from the movement of a revolving disc.

The former are less likely to get out of order than the latter. If dirty water has to be measured, some means of depositing sediment must be provided before the water passes through the meter.

There are many varieties of each type on the market, and space is not available to describe any one in detail.

The size of a meter is defined by the size of its connection and its capacity. A $\frac{5}{8}$-inch meter is usually suitable for domestic supplies, but for larger consumers up to 4-inch or 8-inch may by required.

3. Above 8-inch, a **Venturi meter** is preferable to any mechanical type.

The Venturi meter will be described in some detail, since its simple construction permits of its manufacture locally when it cannot be obtained ready made.

The meter consists simply of a pipe (*see* Pl. **33**, Fig. 2) passing the whole quantity of water to be measured, and fitted with a portion BC uniformly converging to a parallel throat CD. At D the pipe again diverges to its full diameter at E.

The usual relative dimensions are shown on Pl. **33**, Fig. 2.

The principle on which the measurement is carried out is that of measuring the fall of pressure between the larger and the smaller diameters consequent on the increase of velocity.

It can be shown that the volume o water in cubic feet each second each square inch of larger diameter passing through is equal to $C\sqrt{h_A - h_a}$, where C is a constant, and h_A and h_a are pressures expressed as a head in feet of water at the larger and smaller diameters respectively.

When the ratios of the diameters are as 3 to 1, the constant C will be about 0·89, but in any case should be determined empirically for each instrument.

The permissible range of velocities is about a maximum of 16 times the minimum.

The Venturi meter is very accurate for large mains, but less so for smaller; it should not be fixed on mains under 2 inches diameter. It is not very suitable for mains supplied by a reciprocating pump owing to the uneven flow.

The differential tube, shown on Pl. **33**, Fig. 2, for measuring the pressure difference may contain mercury, or, when the difference of pressure is small, an inverted U-tube may be used, the upper part of the tube being kept supplied with compressed air. The difference is then measured direct in feet of water.

Venturi meters are often supplied with automatic recording devices.

4. In a town distribution, or a large camp supply, considerable waste often occurs through leaky mains or service pipes, or from taps being left running.

Cases may arise where the **Deacon waste-recording meter** may be profitably made use of, but it should be noted that, if it is intended to be used, suitable connections and valves must be provided in the pipe-work. The reader is referred to standard text-books for a description of this meter.

CHAPTER VI.

SUPPLY FROM SURFACE WELLS AND METHODS OF RAISING WATER BY HAND.

25. *Well-sinking.*

1. The digging by hand of large diameter wells to other than very moderate depths demands great expenditure of labour and time, and below about 15 feet is never an expeditious means of reaching underground supplies. When water lies more than about 15 feet from the surface, far better results can usually be achieved by the use of power-driven boring plant. The use of such plant will be described in the next chapter. The successful application of rapid methods of boring for water is of comparatively recent introduction, and accounts for the existence in many localities of hand-dug wells fitted with cumbersome pumping plant. Such wells would nowadays often be superseded by bore-holes with high duty bore-hole pumps or airlifts for raising the water.

2. There are, however, cases to be considered where boring plant is not available, or sufficient water cannot be obtained from a single bore-hole or even a battery of bore-holes. It is generally preferable to dig a well by hand when water lies in sufficient quantity within about 15 feet of the surface. Again, for small and individual supplies it may be undesirable to install any form of pumping plant which, even though of the hand-worked pattern, will require periodic attention; in such cases a simple windlass and bucket may prove to be the best water-raising gear, and for this a well of at least 4 feet diameter is required.

In view of the foregoing considerations it is proposed to review briefly the various methods of sinking wells to moderate depths for water supply purposes. The methods employed for sinking deep shafts of large diameters, though analogous to those used in ordinary well-sinking, will not be considered.

It should be pointed out that men of the *well-sinker* trade should be employed on any important job, since some experience in the work is desirable.

3. The sinking of a well by hand consists of three operations :—

(*a*) Excavation.
(*b*) *Steining* or lining the shaft.
(*c*) Keeping the water down by pumping when water is reached.

4. **Excavation** is done with pick and shovel, and there is generally room for one man only to work at the bottom of the shaft. Rock blasting is usually impracticable in semi-permanent work, and it will, therefore, not usually be possible to dig wells to any considerable depth by hand in rocky formations. The size and shape of the shaft depend on the amount of water to be obtained and the system of steining to be adopted.

A stout windlass and tub are required both for lowering the workmen and their tools and for removing the spoil.

Below about 130 feet air must be blown down the shaft for ventilating purposes. This can be done with a hand or power-driven fan and sheet metal pipe or flexible rubber hose of about 2 inches diameter. Light will be required at the bottom of the shaft. If the size of the work merits the outlay, a small electric set can be used to work the winch and blower, to provide light at the bottom of the shaft, and to work a sinking pump when water is reached.

The hydrological conditions may be such that, though water lies near the surface of the ground, a very large well is required to collect a sufficient quantity. Such conditions may be encountered among sand dunes where, in spite of their proximity to the sea, fresh water may sometimes be obtained.

The depth of wells in such locations may perhaps not exceed 10 to 15 feet, but a diameter of 15 or even 20 feet may be necessary.

26. *Steining.*

1. The form of **steining** to be adopted will depend on the character of the formation through which the well is dug, and whether water in the surrounding strata is to be admitted to the well or not.

When the diameter does not exceed, say, 8 feet, the steining may be made as on Pl. **34**. Timber and corrugated iron steining may perhaps be used for greater diameters, but cross-bracing will be necessary. For the larger diameters, brick is the more usual form of steining. Concrete may, however, be used.

In sinking this class of well in soft sand, it may be necessary to excavate a large area to the required depth, with the sand standing at its natural angle of repose, and, after placing the steining in position, to fill in the sand round it. This method naturally requires an enormous amount of labour.

It sometimes happens that surface or other undesirable water has to be excluded from the well, and in such cases the steining has to be water-tight.

The chief varieties of steinings in use are :—

(*a*) Brick or masonry.
(*b*) Timber.
(*c*) Steel tubbing.
(*d*) Reinforced concrete tubbing.

2. The oldest method of lining wells is with brick or masonry steining, but takes considerably longer than other methods. The material for masonry linings can, however, often be found on the site. $4\frac{1}{2}$-inch and 9-inch brick linings are shown in plan on Pl. **36**, Figs. 3, 4, and 5.

The thickness to be adopted depends on the diameter of the well and character of the soil. Small wells will usually be laid in $4\frac{1}{2}$-inch work and those above 4 feet in diameter in 9-inch work, but no definite rules can be given. Everything depends on the strata ; in solid rock no steining is required, while in running sand a brick steining may be impracticable.

If bricks are used they should be equal in quality, if possible, to *malm paviours* ; if stone is used the best in the locality should be selected.

Brickwork is usually laid dry for several courses, followed by three courses or so of bricks laid in cement.

When passing through soft strata which is liable to squeeze through interstices of the brickwork (where laid dry), or if the water is to be excluded, the space behind the brickwork may be puddled with clay, or the whole of the work may be laid in cement. The latter plan is necessary when springs have to be entirely excluded.

3. Brickwork steinings may be erected in three ways :—

(*a*) On a **curb**, which is an iron-shod timber ring. The additional courses are added at the top, and the curb sinks with the weight of the superincumbent brickwork, the earth being scooped out in the centre of the well and from under the curb (*see* Pl. **35**). The weight of the gradually increasing load forces the curb down, so the digging of the well below and the building of the steining above go on simultaneously. The great difficulty is to ensure the vertical sinking of the shaft. The centre can be accurately gauged by a heavy plumb-bob hung by a wire from the top of the well. If the friction of the earth becomes such as to hold up the steining, the latter may be forced down by weights or jack-power.

One method of using weights is as follows (*see* Pl. 36, Fig. 2)—

The well is fitted with an iron cap A, which has angle-iron flanges of a size that will admit four ring bolts aa, of large diameter, passing through them. These ring bolts are connected with a frame B, which is slung or suspended from a staging C resting in the ground on piles or other secure foundation. The frame B is connected with C by bolts b, and is heavily loaded with weights W. By turning the nuts d the weights can be transferred either to the staging C, or to the cap A. Thus the sinking of the cylinder can be adjusted with the greatest accuracy, and the actual weights applied need never be more than a few feet above ground, in case of accidents.

The foregoing method may be applied to any other form of steining stiff enough to take the thrust of the weights.

(*b*) By hanging up the steining from the top of the well by iron tie rods and successively building up from the bottom to meet the original work (*see* Pl. **37**).

As the well deepens, and if the brickwork is well bonded together, the friction of the mass of brickwork with the ground will be enough to hold it up, especially if the soil be such that it tends to swell round the brickwork.

(*c*) The third method is by underpinning :—

To construct a well by **underpinning**, a shaft is first constructed at full size to a depth that the soil will stand without support. A curb or flat ring of wood (usually oak or elm 3 or 4 inches thick, and of a width equal to the thickness of the steining) is laid at the bottom of the shaft, and the steining built upon it. This completes the first section of the work. In the centre of the pit thus completed another small shaft is dug to about the same depth as the first. A hard wood block is placed in the centre at the bottom of this pit, sometimes on a small wood platform, and raking props are inserted under the completed steining, butting against the central block. Sufficient earth is cut away to enable these props to pass from the central block to the steining. The curb, with its load of brickwork, is thus temporarily supported by the props, and it is possible to enlarge the pit to its full size. Another curb is then set, and the new brickwork built to form a permanent support to the first section. The props are then removed, and the operation repeated (*see* Pl. **36**, Fig. 1).

In some cases the soil is sufficiently stiff to enable the raking props to be dispensed with, and the well is excavated to the full internal diameter, so that the earth underneath the curb supports the brickwork above. When the soil is at all treacherous this is dangerous, because when the earth begins to give way it is likely to fall in a considerable mass, and injure the workmen below. By this method the work is more quickly carried out than with the raking props. An example of concrete steining for a large diameter well is shown on Pl. **40.**

4. **Timber** as a lining for wells is of the greatest value for semi-permanent purposes, and timber-lined wells are sunk in the same way as shafts used in mining operations in the field.

The methods of sinking timber-lined shafts are described in Military Engineering, Vol. IV.

4′ 0″ × 4′ 0″ is a convenient size for shallow wells; for depths over, say, 50 feet, at least 6′ 0″ × 6′ 0″ should be adopted, but here again the size selected must be determined by the nature of the soil and the amount of water required. Above 6′ 0″ × 6′ 0″ the well will require cross-bracing according to the thickness of the timbers used for casing. This should preferably be 3 inches and not less than 2 inches.

5. When **tubbing** can be obtained, it forms probably the most speedy and satisfactory method of sinking, especially in wet and treacherous soil.

An improvised form of tub for temporary use at shallow depths has already been referred to. This can be sunk to 15 feet in ordinary soils (Pl. **34**).

6. **Steel tubbing** (Pl. **38**). This form of steining is especially useful for sinking through loose loams and sands wherever it is anticipated that excessive side pressures will be encountered, and may conveniently be used for diameters up to about 6 feet.

The method of use for ordinary soils is as follows :—

An excavation is made on the site of the proposed well rather larger than the section of tubbing as made up (Pl. **38**, Fig. 1). The first section of tubbing is provided with an angle-iron cutting edge (Pl. **38**, Fig. 3). The earth is scooped out from the centre of the space inside the *tub* and then from underneath the cutting edge. Great care is necessary to ensure that the first few tubs sink evenly, otherwise the steining will eventually jam.

When the first tub is set, the next section is bolted on. The joint, if desired, can be made water-tight by caulking with red lead and spun yarn, lead wool, or other suitable material. (*See* Sec. **60**, para. 3.)

After the first one or two tubs are inserted they will no longer fall of their own weight, and must be forced down by weights applied at the top. The system described in connection with Pl. **36**, Fig. 2, may well be used for this purpose.

When strata of the nature of *running sands* are encountered, steel tubbing is practically the only method available for sinking. The special precautions necessary under these circumstances are described in Military Engineering, Vol. IV.

7. The use of reinforced concrete tubbing is a modification of the method described in para. 5 above, and is shown on Pl. **39.**

Both these methods can only be used in strata through which the tubs will either fall by their own weight or can be forced down by jacks or weights. The latter is a tedious and difficult operation.

27. *Finishing off the well.*

When the water-bearing stratum is reached, the well must be continued to such a depth that the water will come in at all seasons in the quantity desired. To deepen the well sufficiently some form of sinking pump is required. An electrically driven vertical centrifugal pump is by far the best. If such a pump is not available, it will be necessary either to rig up some other form of temporary pump or to install at once the pump intended for permanent use. These considerations must be borne in mind when the dimensions of the well are settled at the start, so that the seasonal variation of the water horizon may be allowed for. The well must be sunk amply deep enough to ensure sufficient supply.

After reaching water level and particularly in fissured formations, the yield may be sometimes increased by driving *adits* or galleries at right angles to the direction of the main underground water flow, so as to cut as many fissures as possible; it will be evident that a gallery at right angles to the direction of the ground flow will intercept a greater amount of water than would find its way into the well-shaft alone. When the strata are horizontal and there is no flow across, the galleries may radiate from the well-shaft all round. The size of such galleries is limited by the least dimensions in which men can work conveniently, and would for semi-permanent work be constructed in the same way as mine shaft galleries, as described in Military Engineering, Vol. IV. Pl. **41**, Figs. 1 and 2, show forms of adits as constructed in permanent work.

The top of the well must be secured against surface contamination by raising the brickwork above ground level and suitably enclosing the opening (*see* Pl. **41**, Fig. 3).

28. *Methods of raising water by hand.*

1. In this section will be considered only those forms of water-raising devices which are not *power-driven.*

These may be classified as follows :—

(*a*) Windlass and bucket.
(*b*) Service (or other pattern) lift and force pump.
(*c*) Water bag and mine shaft.
(*d*) Bucket chain.
(*e*) Hand-power deep well pumps.
(*f*) Chaine Helice.

The question as to the best hand-driven water elevator for deep wells depends on the labour available for maintenance. Any kind of pump requires a certain amount of skilled maintenance. If the demand for water is small, it can often be met by the ordinary windlass and bucket. If, on the other hand, the demand is heavy, it may justify the installation of a power pump. For intermediate cases hand-driven plunger pumps or water elevators can be used.

2. **Windlasses and buckets** are of common occurrence, and no detailed description is necessary. It should be noted, however, that for field use they should be unusually rigid in construction, and wire rope is better than cordage.

3. **Service pattern hand lift and force pumps** (Pls. 42 and 43). The Mark V (Pl. 43) lift and force pump, weight 84 lbs., can lift water through a suction hose-pipe from a depth of 20 to 28 feet, but depth for normal working is 15 to 18 feet. It can also force water up to a total height of 60 feet above its former level.

In the case of a well, &c., if the depth of the water level is greater than 15 to 18 feet, it will often be possible to lower the pump to a position where this lift will not be exceeded. Two men are required to work the pump, and they can lift and force water 60 feet, at the rate of about 12 gallons a minute, but six men would be required to keep up this rate for any considerable time.

The pump is made almost entirely of gun-metal; the crank lever CL, gudgeon screws, bolts, and locking pin are manganese bronze; the box hinges H, handle cross-head CH, and caps to inlets and outlets are sometimes made of malleable cast-iron and galvanized; the handle lever L is of mild steel, and the two handle bars HB are made of English ash.

The barrel B is single ($4\frac{1}{2}$-inch bore) and placed horizontally, the buckets BKS being connected together and operated by a crank lever with handle sockets HS. The stroke is 4 inches.

The suction SB and delivery DB branches are cast in one with the barrel, and are threaded 2-inch British standard pipe thread; gun-metal or cast-iron caps are provided to protect the branches in transit.

The suction valves SV are fitted at each end of the barrel, and are easily replaced by removing the end covers CVR.

The pump is mounted on an elm base, attached to which are two elm hinged flaps fitted with pins to keep them rigid when lowered, and two rope handles for carrying when closed.

The suction hose comprises four 12-foot lengths of prepared canvas hose wired internally and externally, fitted with male and female unions threaded 2-inch British standard pipe thread. Unions are secured in the hose by leather binders and tinned copper binding wire.

The strainer for attachment to suction hose, which is issued with the pump, is a perforated steel drum $9\frac{1}{2}'' \times 2\frac{7}{8}''$ fitted with a foot-valve and dome. The dome is fitted with a gun-metal female union threaded 2-inch B.S. pipe thread.

The delivery hose consists of one 30-foot length of canvas hose, 2-in bore, fitted with male and female unions threaded 2-inch B.S. pipe thread. Unions are secured in the hose by leather binders and tinned copper binding wire.

Three adapters, to enable hose unions threaded $3\frac{1}{4}$ old Metropolitan Fire Brigade thread to be used with hose unions threaded 2-inch B.S. pipe thread, and two hose wrenches are issued with each pump.

The floor space is $19'' \times 10\frac{3}{8}''$ when flaps are closed.
" " " " $43'' \times 10\frac{3}{8}''$ when flaps are lowered.
The height of pump is $12\frac{3}{16}''$.

These pumps require a considerable amount of maintenance, and when large numbers are in use adequate arrangements must be made for their repair. Units should not be allowed to carry spare parts, but should be made to return a faulty pump in exchange for a good one.

4. **Semi-rotary hand pumps** are very useful for dealing with small quantities of water. They are classified by the size of the suction pipe, and may be obtained from ½-inch up to 3-inch, the deliveries ranging from about 3 to 30 gallons a minute respectively. The Service Mark II pump is 2-inch. The height of delivery may reach 70 feet.

5. The **water bag** (*see* Pl. **44**) is an eastern device for raising water from wells and irrigation channels. It is simple and very effective.

The simplest variety of this method involves the use of a horizontal spar so adjusted that the weight of stone or clay at the shorter end readily lifts the bucket attached to the longer end when it is full of water. (*See* Pl. **46.**) The man working the apparatus therefore pulls the empty bucket down into the well instead of pulling up a full bucket. The full bucket also is lifted straight up instead of banging on the sides of the well, and is held in a convenient position while being emptied.

When conditions are suitable and other types of pumps are unobtainable, water may be directly hoisted by hand, animal, or other power into large tanks from wells or shafts. This method, largely used in mine shafts, is really an improvement on the ancient system just described. Permanent practice as regards this method need not be considered, but rough-and-ready apparatus can be improvised in the field from available materials, such as the bucket shown on Pl. **45.**

6. The **Persian wheel** (or Saqquia) elevator is a hand or animal-driven water lift of extreme antiquity, and is shown on Pl. **47.** It is suited for low lifts, where continuous delivery is required, as for irrigation purposes.

7. **Hand-power deep well plunger pumps** are seldom worth installing except for more or less permanent use in isolated locations. They are especially useful in small cantonments where the consumption is beyond the capacity of a windlass and bucket, but would not justify the installation of a power pump.

The following simple rule may be applied for a deep well :—

For a camp holding up to 50 men install windlass and bucket.

A camp holding over about 500 men will require a power pump. For intermediate cases some form of hand-driven mechanical pump is required.

Pl. **48** shows satisfactory forms of hand-driven deep-well bucket pumps.

8. The **Chaine Helice** for hand use is valuable if the chains can be properly looked after. (*See* Sec. **38**, para. 7, and Pl. **82.**)

CHAPTER VII.

WELL-BORING.

29. *Advantages of bored wells and general methods of boring.*

1. A decision as to whether boring will be a profitable means of getting water will depend on primary investigation by a geologist, followed by experiment.

Whether or not boring is worth while depends on :—

(*a*) Difficulty of drilling through overlying strata to reach the water-bearing beds.

(*b*) Quantity of water obtained once the water horizon has been reached.

Careful consideration of the above two factors is essential, since nothing is more wasteful than unprofitable drilling.

2. The *geological* difficulty of drilling may be governed by the hardness of the rock, presence of running sand or mud, liability of the hole to cave in, adhesive tendency of certain clays which cause the casing to *bind*, and many other factors.

What may be called the *mechanical* difficulties are chiefly due to faulty or absence of directional control over the work, unsuitability of the plant, or inefficient personnel.

3. **The point must be emphasized that drilling is a highly technical business, and must be in the hands of experts provided with suitable equipment.**

4. When the geological and hydrological conditions are suitable, drilling offers enormous advantages over other means of getting water. It is usually vastly quicker than well-sinking by hand, at any rate for depths over about 15 feet. Surface and polluted water can be entirely cased off, and when a strong underground supply is met there is no stagnant water ; further, the water can be drawn from any particular level desired. Bore-hole supplies are usually less subject to seasonal variations in yield than most surface supplies, and when obtained from a depth are generally *safe* and of excellent palatable quality.

When, therefore, conditions are favourable, drilling work should be exploited to the utmost possible extent, instead of other methods such as pipe-lines supplying from a distance.

5. For field operations time is the ruling factor. The time taken to sink a bore-hole will vary roughly with the hardness of the formation and the depth of the bore. For chalk and similar formations the experiences of the Great War have upset all preconceived notions so far as English practice was concerned. An average of 50 feet drilled each day has been obtained in chalk and chalk marl formations, while as much as 178 feet has been drilled by a drill crew working in two shifts of 8 hours each on a 6-inch diameter bore-hole. Such rates in similar formations mean that a 300-foot bore-hole can be completed in three or four days, and this

brings the system within the scope of the water engineers of an army in the field.

On the other hand, it is no use resorting to boring if the amount of water obtained from a hole is so small as to necessitate a number of holes out of all proportion to the plant and labour available, and if it is actually easier to provide water by other means.

6. The two factors, viz., *drilling difficulties* and *yield of the hole*, must be carefully balanced.

It may sometimes occur that boring is the only practicable method of obtaining a supply, and in order to obtain enough water a large number of holes of small yield are necessary. Such cases, however, are of infrequent occurrence.

7. At least of equal and generally of greater importance than the technical efficiency of plant and personnel, is the organization of the work. This will be considered in greater detail in a later section. The question generally resolves itself into that of ensuring an adequate supply of coal, casing, &c., for the machines at work, and the elimination of all unnecessary delay.

8. There are in general two distinct systems of boring :—

(*a*) The percussion method.
(*b*) Rotary methods.

The percussion system employs a heavy chisel bit with a vertical up and down motion, similar to the familiar *jumping bar* of mining and quarry practice.

In the rotary system, a circular cutter is revolved so as to cut out a core of rock, in the same way as a boring-bar and cutter are employed in a workshop drilling machine.

The percussion method will drill nearly every formation that can be drilled by the rotary method, and, moreover, is generally quicker and less subject to breakdown. There are, however, certain cases in which the rotary method has the advantage, and a few formations in which it is the only possible system. A fuller consideration of each system is given later on.

For nearly all semi-permanent work and almost invariably as regards work with a field army, the rotary method is too slow.

9. The most suitable plant for work with a Field Army has been found to be of the type described as the *portable American rig*. A representative machine is the *Keystone*, and this will be described in some detail; it must not be forgotten, however, that there are other machines, such as the *Columbia* and *Star*, which work on the same principle.

The **portable American rigs** are self-contained portable drilling plants capable of drilling up to 1,000 feet in depth. They have hinged derricks, so that when the drill is being moved from place to place the derrick lies in a horizontal position over the main body of the plant. When erected the crown pulley is about 30 feet above ground level. These rigs are either steam or oil driven, and can be of the self-propelled type, if so desired.

Four Keystone drills bored a total of 12,000 feet in three months, a total of 40 bore-holes with an average yield of 6,000 gallons an hour each bore-hole, in the cretaceous strata of the Somme Department, France, during the operations on this front in 1918. Not a single *fishing* operation took place.

During this period the total distance travelled by these drills in moving from one bore-hole site to another was 400 miles.

In addition it is a simple matter to employ the hydraulic flushing system on one of these rigs. This combination proved its value in the operations with the British Armies in France and Belgium during 1917 and 1918.

It is also easy to convert this rig into a rotary machine, should cores be required, in which case attachments embodying either the Diamond or Calyx systems may be adopted (*v. seq.*).

30. *The Keystone drill—construction and operation.*

1. A type of drill which was much used in the Great War was the Keystone No. 4 traction with cog hoist for 800 feet in depth. This is a portable drill mounted on four wheels (*see* Pl. **50**), and is self-propelled. When on the move the derrick is lowered back into a horizontal position, as on Pl. **51**.

The *boiler* A is 34 inches by 66 inches, has 61 vertical tubes, with close ash pan, and grate bars for either wood or coal.

The *engine* is 8 inches by 8 inches and 11 h.p. The belt pulley C is 8 inches face, 30 inches in diameter, and makes about 4 revolutions to one stroke of the drill.

Tracks and tractor gearing. The tread wheels D are 55 inches diameter, and have 12-inch wrought steel tyres with wrought cleats and mud dogs. The rear axle is made of $2\frac{3}{4}$-inch square iron, 6 feet 6 inches long. The front axle is made of 8-inch steel I girder with autotype knuckle steering joints 6 feet 8 inches overall. The steering wheels E, 30 inches diameter, have 7-inch tyres with cutter bands. The machine has two speeds of 2 and 5 miles per hour.

The *walking beam* J is actuated by a crank pin and arm, belt-driven from the engine.

The *derrick* F when erected is 34 feet high.

The crown pulley G is 22 inches diameter, and the two spudding sheaves H—H are 18 inches diameter.

The overall dimensions of the drill are—length 20 feet, width 6 feet 8 inches, and height 11 feet 2 inches.

The weight without tools is about 13,000 lbs., and with complete outfit of tools 22,000 lbs.

These machines were sent crated to France from America, and were entirely dismantled. The whole machine had to be erected, and practically every bolt inserted and tightened up. After assembling the first drill, it was found that this operation could be performed and the machine put on to the road in 24 hours.

The drill is driven on the road like any ordinary steam tractor. The driving belt for operating the drilling gear is, of course, taken off. A 400-gallon water-tank fixed on a framework and two wheels can be towed, and will supply water for a distance of 5 miles.

2. The three main points in the process of drilling, in which great care is required, are :—

i. Erecting the drill properly.
ii. Dressing the bits properly.
iii. Spudding and handling of the temper screw.

3. **Erecting the drill for work.**—On arrival at the site, the machine is set so that the crown pulley will come plumb over the spot where the bore is wanted. Wooden wedges which are provided with the machine are placed in the ends of the bolster to steady the forward end of the machine. Erecting the derrick can be done by steam if desired. The usual way when doing it by hand is to place brace poles on the pins at the top of the derrick with the lower legs to the rear (*see* Pl. **52**). A board is placed across the rear end of the walking beams upon which the drillers can stand when lifting. The derrick is then lifted until it can be pushed by the men at the rear ends of the brace poles. When erected it should lean a little forward, and the drilling tools should hang central.

4. **Starting the hole.**—A *string of tools* is made up consisting of a *rope socket*, *stem*, and *bit* (*see* Pl. **53**).

It is most important to see that the joints are properly tightened up; this is done by means of a special *tool wrench* and *floor circle* (*see* Pl. **54**). The cable is passed over the spudding pulleys, and the walking beam set in motion at a speed of about 40 strokes a minute. It will be seen from Pl. **50** that the vertical reciprocating movement, given to the *walking beam* **J** by the engine, results in a corresponding movement of the cable and string of tools. The operator holds the bit in his hands, and a man usually stands on the derrick and guides the stem. Great care must be observed not to pay out more cable than is necessary, or the tools will begin to sway at the top. A sharp blow is required. The bit must be turned regularly and constantly. When 3 or 4 feet have been drilled, it will be necessary to clean out the hole. To do this the walking beams are thrown out of gear, the cable reel is set in motion, and the tools withdrawn clear of the hole. The bailer or sand pump is then lowered by means of the sand reel and sand line. About 2 gallons of water for each foot drilled are required to be poured into the hole to mix with the cuttings, in order that they may be readily picked up with the sand pump or bailer (Pl. **55**, Fig. 5).

The foregoing shows the principle on which the drilling is carried out, that is to say, it is a process of successively churning up the rock or soil into a slurry, and then removing it with the bailer.

5. **Lining the hole.**—In boring through the upper formation it is usually necessary to line the hole. To do this steel drive-pipe must be used. The best type for well-boring is probably the socket coupling drive-pipe. The ends of the pipe meet or butt together in the centre of the coupling. The pipe is made very heavy, and will, therefore, stand heavy driving. It is advisable to use a drive-shoe on the bottom of the pipe.

Drive-pipe is made in lengths varying from 2 to 20 feet and more.

After drilling from 6 to 10 feet in the subsoil, a length of casing is inserted and driven down with the boring tools, a pair of heavy drive-clamps (Pl. **55**, Fig. 2) having been so fixed on the stem as to hit a sharp blow on the top of the pipe. A drive-head is used to protect the threads of the upper end of the pipe which is being driven. This process is continued until the required amount of lining is done.

6. **When a depth of about 50 feet is reached,** the *jars* are put on (*see* Pl. 53). The jars are made in two pieces like two links of a chain, and their action is such that on the upward motion of the drilling cable a sharp jerk is given to the bit. The object of this is to release the bit from any obstructions such as corners of flints, &c., which might have a tendency to jam the tool. The jars are put on between the stem and the bit.

As the drilling proceeds more drive-pipe must be inserted, and the bottom of the drive-pipe should be a few feet only above the bottom of the hole throughout the job.

7. **Care of the cutting edge of the bit.**—It is most important to keep the cutting edge of the bit correct as regards (*a*) cutting angle, and (*b*) diameter.

A steam blower is supplied with the drill for use on a smith's fire. A rough hearth is easily made, and any smith can readily sharpen and temper the bits. A circular bit gauge is used to get the correct form for the bit end, and the angle of taper is determined by the chargeman, softer rocks requiring a more acute angle than harder rocks (*see* Pl. **55**, Fig. 3).

It is advisable for the chargeman to check the dimensions of the bit each time it is withdrawn. If it is allowed to become undersized, which will easily occur if a hard rock is struck unexpectedly, there is likely to be trouble if a new bit is put on and lowered into the undersized hole. **More mishaps are caused by the non-observance of this important point than from any other cause.** Should the tools become fast in the hole, fishing operations (para. 10) will have to be undertaken, causing serious delay and sometimes leading to the abandonment of the bore-hole.

8. **When a depth of about 400 feet is reached,** it may be necessary to discontinue the *spudding action*, by which the vertical motion of the walking beam is transferred to the cable by means of the spudding wheels before the cable passes over the crown pulley, and resort to the *temper screw*.

By means of the temper screw a grip is taken on the cable directly from the ends of the walking beam over the hole, and the portion of the cable passing up over the crown pulley is slack while drilling. The temper screw is so constructed that a little cable can be paid out as drilling proceeds to follow the sinking of the hole, but to withdraw the string of tools the temper screw must be disconnected. For this reason drilling is slower when the temper screw is used, and it is only made use of when the weight of the cable due to the depth of hole makes it impossible to work it over the crown pulley. For work in the field the temper screw will rarely be necessary.

It sometimes happens that the drive-pipe fastens itself before arriving at the required depth. In this case it is necessary to insert pipe of less diameter. If this is likely to occur it is advisable to use *flush-joint* pipe, which will enable the bore-hole to be kept at its maximum diameter.

The amount and character of the lining to be put in entirely depends on the strata passed through. In very many formations drilled by the percussion system no lining whatever is required, save for the few feet of subsoil at the surface.

The rising of water in the hole may give warning of an underground flow, otherwise the time required to *bail out* must be relied upon as an indication of the strength and occurrence of the water sought for. When it is decided that the true water-bearing stratum has been met, it will be advisable to insert *perforated drive-pipe* for the bottom 50 feet or so of the hole. This should have been foreseen when the hole was started, and is dependent on the knowledge acquired.

9. Linings for bore-holes drilled with percussion drills.— Although cases may arise when it will be unnecessary to line bore-holes, this must not be counted upon. The object of lining bore-holes is to prevent soft formations falling in on the drill when at work, and to prevent loss of water on the completion of a successful boring, since much of the strata pierced may be of a pervious character, or there may be fissures and crevices through which artesian water might escape from the bore-hole.

The bore-hole should be commenced with as large a diameter as possible, since it has often to be decreased in diameter as the depth increases. This is due to the fact that on reaching a certain depth it may be impossible to drive the lining deeper. A boring tool of smaller dimensions will then be necessary to work inside this lining. If the same thing occurs again, lining of a size smaller will have to be inserted, and so on.

Tubing or lining for bore-holes probably constitutes the heaviest item of the plant. If it is necessary to economise weight, it should, therefore, be selected with the greatest care.

Drive-pipe is made in different thicknesses to suit varying conditions. To ensure strength, care should be paid to the form of joint supplied.

Barrel-shaped couplings are used for making the joints for socketed drive-pipe (Pl. **49**, Fig. 1), which is the most usual form of lining.

A heavy flush joint tube (Fig. 4) may be used under certain favourable conditions as a drive-pipe. The lining (Fig. 5) has a tapered screw and socket joint.

Drive-pipe is generally about $\frac{5}{16}$ inch thick for sizes of 8 inches diameter and under.

In America, the custom in quoting for tubing is to state the inside measurement; in England, the outside measurement. Socket thread protectors should invariably be specified when giving an order, as the threads are very liable to be damaged in transit. Wooden plugs are useless.

From 3 to 6 steel drive-shoes should be ordered for 1,000 feet of tubing, or drive-pipe. It is always advisable to put a *drive-shoe* on the first length of drive-pipe inserted, to prevent its being damaged (*see* Pl. **55**, Fig. 1).

For extensive boring operations **drive-pipe must be standardized.**

In bore-holes where the lining has been successfully inserted and artesian water encountered, it may be necessary to control the flow by a valve fixed to the tubing above the ground surface.

In unsuccessful bore-holes, as much as possible of the lining should be withdrawn. This can be done by jacks.

A reserve of jack-power is recommended, and for borings of 500 to 1,000 feet two 50-ton jacks should be included amongst the drilling stores. For shallow bores jacks of less power should suffice.

The wood plug method of withdrawing casing.—Another method of withdrawing casing is by means of an oval ball of wood slightly less in diameter than the inside of the casing. This is lowered into the casing by means of rods with screw joints; the bottom rod passes through the ball, and has a nut on the bottom end to secure the ball. When the required depth is reached, a few handfuls of coarse grit, sand, or gravel is dropped down the hole on to the top of the ball. This causes the plug to bite, and the casing can then be withdrawn.

This method was found to be particularly useful where long lengths of piping, such as the rising main of deep-well pumps or airlifts, had fallen into the bore-hole, and when all other attempts at recovery had failed.

Army Drill crews have recovered as much as 200 feet of 4-inch piping by this method from a depth of 400 feet.

10. **Fishing operations with the percussion system.**—The principal fishing tools are (*see* Pl. **56**) :—

Rope knife.
Rope spear.
Spud.
Horse-shoe rope knife.
Rope knife jars.
Combination socket.
Solid jar bumper.
Fishing jars. (Ordinary jars with long stroke of 18 inches.)

Fishing operations are the bugbear of well-boring, and can only be tackled by an expert.

The maximum time to be spent on a fishing operation will depend upon the following factors :—

i. The nature of the fishing job, and likelihood of a successful operation.
ii. The urgency of the boring. If water is urgently required it may be quicker to begin a new boring.
iii. The value of the tools lost. If drilling tools are scarce it may be imperative to recover the lost tools.

31. *Other percussion systems.*

1. There are several other variations of percussive drilling, the most important being :—

(*a*) The American oil field plant.
(*b*) Mather & Platt's system.
(*c*) The rod system, used with or without hydraulic flushing.

2. The **American oil field plant system** comprises a derrick from 70 to 80 feet high, steam engine, band wheel, walking beam, bull wheel, and sand pump reel.

A string of tools about 56 feet in length and weighing about 2,000 lbs. (suspended by a steel wire or manilla rope) is used to carry out the operation. About 60 blows a minute are struck, and the cuttings are brought up by means of a bailer or sand pump which is carried on a separate wire rope, or sand line, from the sand pump reel over a pulley at the top of the derrick.

The great advantage of this system is the speed with which holes can be drilled. On the other hand, the records of strata bored are not accurate, as only the cuttings are brought to the surface, and no core of the strata penetrated. It is used principally in the oil fields, where great depths have to be bored, and accurate records of strata are not absolutely essential.

The particular plant referred to, though similar in principle to the portable rig (*see* Sec. **30**), would not be very suitable for work with an army in the field owing to the difficulty of transport.

3. The special features of the **Mather & Platt system** are a flat rope and a special contrivance for rotating the cutting chisel. The cutting chisel consists of a number of separate chisels set at intervals around the circumference of a circle.

Cores may be cut and brought to the surface. As there is no twisting or turning of the rope, the cores are brought up in their true relative position showing the angle of dip of the strata.

From 20 to 40 blows per minute are struck, and holes from 20 inches to 45 inches diameter are bored.

It is specially adapted to bore-holes of large diameter, and is much slower in operation than the systems already described when used for holes of smaller diameter.

4. With the **Rod system** iron or wood rods are used, usually in 16-foot lengths screwed together. It is very slow in hard rock owing to the time taken in lowering or withdrawing the chisel.

When **hollow rods with hydraulic flushing** are used, it is much quicker.

A pump on the surface operated by steam, or whatever power is available, forces water down the interior of the rods through the hollow cutting chisel or bit. The water returns up the bore-hole on the outside of the boring rods, bringing with it the cuttings, and is directed into settling ponds excavated near the boring site, and when clear is taken up again by the pumps.

The quantity of water required to be circulated in this manner is between 2,000 and 3,000 gallons an hour. A pump of 3,000 gallons an hour capacity gives excellent results in 4-inch to 6-inch bore-holes.

This system is very efficient and expeditious when drilling through sand, clay, gravel, or soft rocks.

One hundred feet were drilled in eight hours by this method adapted to a Keystone rig in the blue clay near Ypres, Belgium, by an army drill crew in 1917.

5. In the **Raky rod system** hollow rods are used. These rods are Mannesman steel tubes 2 inches in diameter and 16 feet long, connected by loose collars and screw threads. The walking beam is supported on a bearing resting on a cross-beam with, between the two, 30 to 40 strong steel spiral springs. The rods are connected to the beam by a conical turned gland provided with a clamp and screws for fixing the rod in any position. Above this is a second clamp connected to the first by four studs projecting $\frac{3}{8}$ inch, and pushed outwards by spiral springs on the inside. At first the boring bit does not touch the bottom, but with the vibration the recoil increases until with 80 to 100 strokes per minute the bit strikes the rock each time, the stroke being only 3 or 4 inches.

The bottom of the hole is kept clear by means of a constant current of water which is brought down the hollow rods.

32. *Rotary systems*

1. The usual rotary systems are :—

(*a*) The Diamond. (*See* Pl. **57.**)
(*b*) The Davis Calyx. (*See* Pl. **58.**)

2. In the **Diamond system** the cutting tool or crown consists of a soft iron tube about 4 inches long, in the bottom of which *black diamonds* are set. Above the crown is a core trap or tube of the same diameter as the crown and about 20 feet long. A rotary motion is obtained by means of bevel gearing. The hollow boring rods are attached by screw thread to a strong hollow tube, which can slide by means of a keyway through the horizontal bevel wheel, which is immediately above the bore-hole. This hollow tube is about 6 feet long, and it will be seen that when 6 feet have been bored it will have to be disconnected from the hollow boring rods which are resting on the bottom of the hole, raised, and a 6-foot length of rod connected.

Accurate cores are brought up, and it is, therefore, very useful for prospecting. Its chief disadvantage is the costliness of the crowns.

It is also very slow and is useless in sand, gravels, and clays.

3. The **Davis Calyx system** is similar in operation to the *Diamond.* Instead of the crown being provided with diamonds, it is formed with saw-like teeth. It is useful in moderately hard rocks, and has the same advantage as the diamond with regard to producing a core.

It can be employed satisfactorily in clays and soft rocks.

4. **Linings for holes drilled on the rotary system.**—For lining, a rotary drill has an advantage over a drop drill, as it bores a cleaner hole, and consequently the tubing will go down of its own weight, or can be rotated down instead of driven, as may be necessary when a drop drill is employed.

Cressed and socketed drive-pipe (Pl. **49,** Fig. 2) has been designed for use with rotary drills, as it is flush outside. It should not be used with a drop drill, as the projections on the inside would be cut to pieces by the bit.

The lining tube (Pl. **49,** Fig. 3) has a swell and cressed joint, and is the pattern generally used with a rotary drill.

33. *Organization of boring operations.*

1. The officer commanding a Boring Section should have expert knowledge of boring work, and exercise as much personal supervision as possible. It is not necessary that he should be a water diviner, though some people associate this faculty with well-boring.

A boring expert will have a sound training in geology, and that, together with his practical experience and observation, will enable him to determine sites for boring and probable results with as much and possibly greater accuracy than any so-called water diviner.

2. **Selection of drilling machinery.**—When selecting drilling machinery, the following points should be considered in detail :—

(*a*) The lithological character and thickness of the strata.
(*b*) The transport available, and appliances for moving machinery about the country.
(*c*) The nature and quantity of water available for drilling purposes.
(*d*) The power to be used—hand, animal, steam or oil engines. (This consideration will depend largely on local fuel and transport conditions.)
(*e*) Personnel to work the drill.
(*f*) Probable depth of bore-holes.
(*g*) Dimensions and quantity of lining for bore-holes.
(*h*) Whether the supply is likely to be artesian or sub-artesian. If the former, no pumping machinery will be necessary ; if the latter, pumping machinery must be added to the plant required.

As regards (*a*) deep boring for water would not, as a rule, be attempted unless the geological conditions were shown to be favorable. Assuming this to be the case, the practical points on which information should be obtained are the composition of the individual strata to be pierced, *i.e.*, whether they are uniformly soft or uniformly hard, or of a mixed or conglomerate nature, and their respective thicknesses. If this information is not available and time permits, a competent geologist should be employed to report on the locality.

As regards (*b*) there are few countries where a light portable drill mounted on wheels could not be taken. These drills are so designed that they can be taken to pieces and carried by hand over places where wheeled transport could not go.

In localities where wheeled transport is impracticable and pack transport has to be used, a specially designed drilling plant might be necessary.

As regards (*c*) a portable drop drill would require, apart from water for the boiler, roughly 5 gallons each foot drilled. The water required for working a rotary drill varies very considerably according to the porosity of the strata. It would not be safe to calculate on a smaller expenditure than 1,000 gallons each working day of 12 hours, or about 70 gallons each foot drilled. In either case salt or briny water could be used. The above quantities are for drilling purposes only.

If steam engines are employed, to the above should be added about 5 gallons an hour for each nominal horse-power.

The water required for the consumption of the drilling party must also be added.

As regards (*d*) the nature of the power to be employed to work a drill is subject to local conditions, irrespective of the type of machine used. One of the secrets of success is to have a reserve of power.

The quickest and most practicable form of boring plant is, of course, the power-driven variety. Up to the present time steam has been the most popular prime-mover, but there is no reason why the internal combustion engine or electric motor should not take its place.

For work in a battle area by night or near the front line, steam is impracticable.

Boring is sometimes done by hand, but this is too slow for most military purposes. The *Norton tube well*, however, is useful for depths up to, say, 30 feet. A description of this apparatus will be found at the end of this chapter.

In any case it is of the first importance to select the most reliable *power* machine suited to the conditions of the locality.

Steam engines are in many cases the most suitable for the following reasons :—

In drilling work the load is a constantly varying one, and it is essential that, the driller, who stands at the drill and consequently some distance away from the engine, should have the latter under his complete control.

Steam engines are easily repaired and kept in order, and an intelligent labourer, either white or coloured, can in a short time be taught to look after them. They are not liable to get out of order in a country where sand and dust are constantly blowing about, and they stand rough travelling.

In countries where fuel and water are scarce, it will be necessary to use internal combustion engines. They have the great advantage of being light, and the fuel which they require is also easily carried.

Engines should invariably be of a standard design ; all parts liable to get out of order should be duplicated, and important bearings made dustproof.

As regards (*e*) drilling has to be regarded as a profession, and it would be idle to recommend deep-boring machinery without securing the services of trained expert drillers. *Well-borer* is now a Service trade, and A.F. B 161/15 shows qualifications required.

As regards (*f*) and (*g*) it is most important before selecting a drill to arrive at the probable depths of the bore-holes. Great discrimination is necessary, and a margin must be allowed for, as it is impossible to foresee the exact thickness of the strata.

Portable machines are divided into classes according to the depth of boring required.

With regard to (*h*) it would not be safe, when employed on pioneer work where an artesian system has not been thoroughly established by the practical test of boring, to count on the water rising to the surface.

3. **Organization of the work.**—The personnel of a Boring Section can best be arranged so as to provide a headquarter party and four complete drill crews. Each drill crew can conveniently consist of a N.C.O. in charge and nine men.

The work of the headquarter party includes repairs to machinery, &c., *i.e.*, jobs which the drill crews are unable to do owing to pressure of time and lack of the necessary workshop appliances. Work which requires more expert mechanical services and appliances must be done by an Electro-mechanical unit, R.E. If a Boring Section were supplied with a workshop lorry, there is no reason why they should not be able to carry out the greater part of their repairs, with the exception of castings. The provision of castings can be obviated to a great extent by always having in stock a reasonable quantity of spare parts.

All bore-hole lining and pipes for pumps, airlifts, &c., are stores kept at H.Q., and must be carefully examined and rethreaded if necessary before being sent out to the drills. The N.C.O. i/c stores will keep careful records of all stores sent out, particularly with regard to lengths of pipe and casing. This will check the drill N.C.Os.' reports, and save endless trouble. It is most important that the lengths of casing, pipes, &c., lowered into a bore-hole should be correctly ascertained and recorded for future reference.

A H.Q. store is required to stock spare parts of machinery, drilling tools, a complete set of fishing tools, drilling cable, sand line, pipe fittings, &c. (*See* Table F at end of this chapter.)

A small workshop, containing drilling machine, bench, vices, stocks and dies, and smith's forge, is required.

One clerk should be able to deal with all clerical work. It is very important that correct records of all bore-holes, showing depth of bore-holes, nature of strata bored, water levels, amount of casing used, particulars of pumps, airlifts installed, &c., should be kept up to date.

Weekly reports from each drill crew, signed by the N.C.O. in charge, showing daily progress, hours worked, &c., will be required.

It is advisable to ration the drill crews from H.Q., and not to depend on other units supplying these men. The work on the drills is of a very arduous nature, and, therefore, the men so employed need good rations and every attention to their personal comfort.

By giving the strictest attention to these matters, the output of work on the drills can be largely increased.

The **drill crew** is made up as follows :—

1 N.C.O. expert driller in charge.
4 well-borers.
2 engine drivers.
1 blacksmith.
1 cook.
1 night watchman and spare hand.

A drill crew made up as stated will constitute two working shifts each of eight hours' duration. If possible, it will be advisable to include a fitter in the crew, who is able to assist in drilling operations when not required to work at fitting.

The chargeman will keep careful records of strata, bored depths, &c., and will send to H.Q. a weekly report of all work carried out by his crew. He will be responsible for the discipline of his crew and for the whole of the work, including moving, erecting, and dismantling of the drill.

34. *Norton tube wells and earth augers.*

1. Norton tube wells are useful for prospecting purposes and for small camp supplies; this tube well and the apparatus for driving it by hand are articles of store.

The well consists of a tube with perforations at the lower end, driven from the surface to the water-bearing stratum. A pump can be fixed to the top of the tube, but is not, strictly speaking, a part of the well.

The tube being small is in itself capable of containing only a very small supply of water, which would be exhausted by a few strokes of the pump; the condition, therefore, upon which alone tube wells can be effective, is that there shall be a free flow of water from the outside through the apertures into the lower end of the tube. When the stratum in which the water is found is very porous, as in the case of gravel and some sorts of chalk, the water flows freely, and the yield may be as great and rapid as the pump can lift. In some other soils, such as sandy loam, the yield in itself may not be sufficiently rapid to supply the pump; in such cases the effect of constant pumping is to draw up with the water from the bottom a good deal of clay and sand, and so gradually to form a hollow around the foot of the tube, making a reservoir in which water accumulates when the pump is not in action. In dense clays, however, the well is not applicable, since the perforations near the bottom become sealed, and water will not enter the tube.

The tube well cannot itself be driven through rock or large stones, although the pump is frequently used for drawing water from a subjacent water-bearing stratum through a hole bored in the rock to receive it. It has, however, been driven through chalk and very hard beds of flint and gravel, breaking the larger flints after a few blows.

Besides being useful in the search for water, tube wells with their pumps may be used for raising water from ponds and rivers for the purpose of filling troughs, &c. This will prevent the bottom being fouled by animals entering the water and being disturbed by the dipping of pails, &c. For this purpose a well should be driven into the bank close to the water, till the perforations are below water level.

2. **Well and driving apparatus.**—The tubes forming the well (Pl. **59**) are of iron, and have an internal diameter of $1\frac{1}{4}$ inches, and an external diameter of $1\frac{11}{16}$ inches, and are threaded at the ends for a length of $1\frac{1}{4}$ inches.

Each tube is fitted at one end with a barrel-shaped *socket*, $2\frac{1}{8}$ inches long, tapped to fit the tubes. *Tongs* are provided for holding the tubes and sockets when screwing them together.

One length of the tube has a steel point welded into it, and a length of 1 foot 9 inches above the steel point is perforated with 320 holes, $\frac{1}{8}$ inch diameter, and covered with perforated brass sheathing to act as a strainer. The combined area of the perforations in the tube is three times the cross-sectional area of the tube.

For description of the pump, *see* para. 6.

The well is driven into the ground by blows delivered on either a driving cap (Pl. **60**, Fig. 11) or a driving clamp (Pl. **59**, Fig. 3); both are of steel. The cap should be used when the ground is sand or loam; the clamp when the ground is harder.

The *driving cap* is a single block of steel with a hole through the centre. The lower part of the hole is tapped to fit on to the well, while the upper part is only $1\frac{5}{16}$ inches in diameter, so that there is an internal shoulder which will rest on top of the tube when the cap is screwed home. The rim of the cap has two $\frac{3}{4}$-inch holes, into which the ends of the handles of the tongs fit, for screwing the cap on to the well.

The *driving clamp* consists of two halves which may be fixed to any part of the tube by two bolts squeezing the halves together. The inner surfaces of the clamp are serrated and hardened, so as to grip the tube firmly. A *spanner* is provided to fit the nuts which have $1\frac{1}{8}$-inch square heads.

The blow on the cap or clamp is delivered by a cast-iron *monkey* weighing 84 lbs., having a 1⅝-inch hole through the centre, so as to slide freely upon the tubes, and provided with two cotton *ropes* 9 feet long. The latter pass over two sheaves at the top of a *pulley bar*, which is a 4-foot 6-inch length of well tube with a solid bar, 1⅛ inches diameter welded in and projecting 12 inches at one end, and with a head carrying the sheaves screwed on at the other end (Pl. **59**, Fig. 4).

A description of cleaning apparatus is given in para. 5.

3. **Driving the well.**—The position for a well having been selected, a hole is made with a crow-bar, and the well tube inserted to a depth of about 2 feet. The clamp is then screwed firmly on to the tube about 2 feet from the ground, each bolt being tightened equally, so as not to indent the tube; or, if the ground is fairly soft, the cap is screwed on to the tube as far as it can be made to go. The monkey is then placed upon the clamp or cap, and the pulley bar inserted in the tube. The ropes are made fast to the monkey, and passed over the sheaves of the pulley bar.

The monkey is raised by two men pulling the ropes at the same angle (the nearer to the vertical the better); they should stand exactly opposite each other, and work together and very steadily, so as to keep the tube perfectly vertical and prevent it from swaying about while being driven. Only short blows should be given to begin with, and the tube must be held vertically until deep enough to retain its upright position. If the tube shows an inclination to slope towards one side, guy ropes should be fastened to the top of the pulley bar, each held by a man, to keep it vertical. When the men have raised the monkey, they lift their hands suddenly, thus slackening the ropes and allowing the monkey to descend with its full weight on to the clamp. The monkey is steadied by a man who also assists to force it down at each descent (Pl. **59**, Fig. 1).

When the clamp is used, particular attention must be paid to see that it does not move on the tube; the bolts must be tightened after the first blow, again after two more blows, and again after four more blows, and subsequently after every dozen blows, both bolts being tightened up equally.

When the clamp has been driven down to the ground, the monkey is raised off it, the screws of the clamp are slackened, and it is again screwed to the tube about 2 or 3 feet from the ground. To prevent the monkey slipping while this is being done, the pulley men will take a hitch with the running parts of their ropes round the pulley bar below the monkey. When the clamp has been screwed on again, the driving is resumed as before.

When the tube has been driven so far into the ground that there is not sufficient drop for the monkey, the monkey and pulley bar are removed, and a fresh length of tube is screwed, by means of its socket, on to the tube in the ground. The two tubes *must butt* against one another, otherwise the screw-thread may be injured when driving is resumed. A little red lead should be placed on the threads of the socket before screwing up, to make the joint air-tight.

Driving can then be resumed, but after a few blows the upper length should be turned round a little with the tongs to tighten the joints, which have a tendency to become loose from the jarring of the monkey.

Care must be taken after getting into a water-bearing stratum not to drive through it, owing to anxiety to get a larger supply. From time to time and always before screwing on an additional length of tube, the well should be sounded (by means of a small lead attached to a line), to ascertain the depth of water, if any, and the character of the earth which has penetrated through the holes perforated in the lower part of the well tube.

Five men are required for driving a well quickly, allowing two men in two reliefs for working the monkey, while the fifth steadies the monkey, attends to the clamp to see that it does not slip on the tube, and alters its position as required. The two men not working the monkey prepare the additional lengths of tube, and fix them on.

Tube wells can be driven at the rate of 12 feet an hour in flinty chalk, and 20 feet in soft soil, and they can be withdrawn much more quickly.

4. **Drawing the well.**—The tube well, when required no longer, can be withdrawn by any of the following methods :—

(*a*) In very soft ground the well may be drawn by simply turning it round with the tongs, right-handed so as not to unscrew the joints, at the same time lifting it upwards.

(*b*) A short chain is passed twice round the tube, close to the ground, and one end passed through a large ring in the other end (Pl. **59**, Fig. 7). The end of the chain is then put through a movable *stoppering link* (Pl. **59**, Fig. 6) which can be made to grip any link desired. A lever or handspike is next inserted into the stoppering link, and borne down on some convenient fulcrum, and the tube well lifted. When the pressure is taken off the lever, the chain will generally slip down by itself, and a fresh pressure will lift the well still higher.

(*c*) The monkey is placed on the tube with its lower end upwards, and the clamp screwed on (face downwards) about 1 foot above it. The monkey is then raised sharply, and by striking the clamp gradually starts the well ; the position of the clamp is lowered from time to time as required. The pulley bar is, of course, not used in this process (Pl. **59**, Fig. 5). This method has always been found to succeed, but is not so rapid a process as the foregoing ; it must never be attempted with the cap, as the threads of the screw holding the cap will probably be spoilt.

5. **Cleaning apparatus.**—As soon as the well has been driven far enough, the pump is screwed on the top, with a little red lead in the joint, and an attempt is made to pump the water up.

When sinking in certain soils, however, the bottom of the tube is liable to become filled up by material penetrating through the holes, and, before a supply of water can be obtained, this accumulation must be removed by the *cleaning tubes* (Pl. **60**, Fig. 5).

The cleaning tubes are $\frac{1}{2}$ inch internal diameter and $\frac{13}{16}$ inch external diameter ; the lengths are connected together in the same way as the well tubes, viz., by sockets screwed on over the adjoining ends of two tubes.

To clear the well, one cleaning tube after another is lowered into the well, until the lowest one touches the accumulation ; the tubes must be held carefully, for if one were to drop into the well it would be difficult to withdraw it, without drawing the well. A *funnel* (Fig. 5) is screwed on the top of the well, and a pump is then attached to the cleaning tube by means of a *reducing socket* (Fig. 6).

The cleaning tube is then raised and held about one inch above the accumulation by a *clip* (Fig. 7). Water is next poured into the funnel and runs down the well outside the cleaning tube, and, being pumped up through it, brings up with it the upper portion of the accumulation. The cleaning tube is gradually lowered, and the pumping continued until the whole of the accumulation inside the well tube is removed. The pump is then unscrewed from the cleaning tube, which is withdrawn piece by piece, and finally the pump is attached to the upper end of the tube well itself.

It is advisable, when several wells have to be sunk, to keep one pump specially for the purpose of cleaning out the wells, as the grit, &c., at first pumped up is liable to damage the valves. When all the wells have been sunk, the valves of this pump should be examined and, if necessary, repaired, when it may be used for a well if required.

6. **Tube well pump.**—The water in a tube well can be extracted by a tripod pump fitted with a reducing socket; this is a special pump which should be screwed direct on to the top of the well, with some red lead in the joint. It is especially necessary to make this particular joint air-tight; if it is not so, air will be heard to pass in by it when the handle is worked, and it must be taken off and supplied with more red lead. To start the pump it is necessary to pour some water into the top, and to pump for a few minutes to exhaust the air which is in the tube, and, when this is done, in all ordinary cases the water will follow.

The principle of the tube well pump is the same as that of the tripod pump, with the addition of what is called the *tilting action*. The pump itself consists of a barrel with a bucket or piston working in it. At the bottom of the barrel and in the bucket, there are valves capable of opening upwards only. If the handle is depressed, it raises the bucket, and makes a partial vacuum under it, so the lower valve opens and some air enters the barrel from below; as soon as the bucket stops moving, the lower valve falls and shuts again. Then when the bucket is lowered, the enclosed air can escape only by pushing open the upper valve. Every time the bucket is raised air is taken into the barrel, and the water rises to take its place, and after a few strokes the water will enter the barrel itself and flow out by the spout.

The tilting action can be applied at will, and the object of it is to open both valves at the same time, so that any water which has been pumped up in the well will rush down again, force its way violently out through the holes at the bottom of the well, and disturb the mud and fine particles in the immediate vicinity of the holes. On pumping again, some of this mud will be brought up with the water, and by repeating the process several times all the finer particles near the holes will be removed. Only the larger stones and grit will be left, and in the interstices between them water will collect, when the pump is not being worked, ready to be pumped out when required (Pl. **60**, Fig. 4). If at first water only comes with great difficulty, it must not be concluded that no supply can be obtained; on the contrary, in many or most cases by a free use of the tilting action the compact earth will be broken up and loosened, so that after half an hour, or it may be one or two hours' pumping, it will produce a perfectly free yield.

The means by which the *tilting action* is brought into play are as follows (Pl. **60**). The valve (Fig. 2) in the pump bucket is a metal one, which opens by lifting up, something like the plug of a basin. The valve (Fig. 3), at the bottom of the barrel of the pump, is an india-rubber *clack* opening like a hinge. An iron *cover plate* is screwed to the clack, and has a projecting *lug* and a *button* at the top. The bucket itself has a leather packing to make it water-tight, and a packing ring secured by three screws, which project downwards; when the handle of the pump is in a certain position, the screw head presses down on the projecting lug opening the lower valve, and this causes the button to press up against the upper valve, which is, therefore, opened too.

When it is not desired to use the tilting action, the bucket must be turned round horizontally, so that the screw head will not strike the lug when the bucket is lowered, and the lower valve will consequently not be opened. To arrange for this, the fulcrum of the handle is fixed to an adjusting ring, held to the top of the pump by three bolts passing through slots in the ring, which allow of its being moved circumferentially (Pl. **60**, Fig. 1).

When the pump is first fixed on the well, the handle and ring should be adjusted to bring the tilting action into use, and after pumping for a short time the handle should be raised as high as possible for a second or two, till the water has just run out of the pump into the well. A few more strokes will recover this water, and the action should be repeated several times, after which the whole contents of the well should be pumped out, and the tilting repeated, as before, until it is found that the supply cannot be made to come any faster, or until the water remains clear after tilting. The adjusting ring should then be turned to prevent the accidental use of the tilting action when pumping, and screwed down tightly.

The barrel of the pump is 3 inches in diameter, and the bucket has a stroke of 6 inches.

The tube well fitted with a suction pump, in good condition, can suck up water from a depth of 20 feet to 28 feet, at the rate of 10 gallons a minute.

This apparatus is described in the specification as:—

Well, tube, 1½-inch.
Apparatus, driving.
Implements, chest of.

Table **E** shows what is included under each heading.

TABLE E.—*Equipment for Norton tube wells.*

Part.	No.	Weight. Each. lbs.	Weight. Each. oz.	Weight. Total. lbs.	Weight. Total. oz.	Remarks.
WELL, TUBE, 1½-INCH.						
Tubing, steel, 1½-inch, length of 3 feet	1	8	10	8	10	28 feet of tubing.
Tubing, steel, 1½-inch, length of 5 feet	5	14	6	71	14	28 feet of tubing.
Tubing, steel, 1½-inch, length of 5 feet	1	15	1	15	1	with point and strainer.
Sockets, 1½-inch tube	7	0	12½	5	5	
Pump, 3-inch	1	33	0	33	0	with handle.
Total	—	—		133	14	

TABLE E.—*continued.*

Part.	No.	Weight. Each. lbs.	oz.	Weight. Total. lbs.	oz.	Remarks.
APPARATUS, DRIVING.						
Pulley bar	1	25	8	25	8	
Monkey	1	84	0	84	0	
Set of cleaning-out tubes, viz. :—	1					
½-in. tubes 6 ft. long	6	5	14	35	4	42 feet of tubes, weighing 42½ lbs.
„ 3 ft. „	1	2	15	2	15	
„ 1 ft. 6 ins. long	2	1	7½	2	15	
sockets, ½-inch tube	9	0	2½	1	7	
Total	—	—		152	1	
IMPLEMENTS, CHEST OF.						
Clamp, driving, steel	1	26	2	26	2	with 2 bolts and nuts.
Bolts and nuts for ditto	6	2	1	12	6	spare.
Cap, driving	1	5	12	5	12	
Cap for well tube	1	0	11	0	11	
Tongs, ½-inch, ¾-inch, 1¼-inch, 1½-inch, 1 of each	4	—		22	2	
Spanner for clamp bolts	1	4	9	4	9	
„ screw	1	1	3	1	3	
Red oxide, tin of	1	1	3	1	3	
Oil can, filled	1	0	6	0	6	
Cotton waste.... .... lbs.	1	1	0	1	0	
Ropes, cotton .... pairs	2	1	6	2	12	1 pair for guys.
Line plumb, 40 feet, with winder	1	0	6	0	6	
File with handle	1	0	6	0	6	
Stocks and dies, tap, and tube-cutter combined set	1	12	13	12	13	
Cutters, tube....	1	0	1	0	1	spare.
Funnel, cast-iron	1	5	11	5	11	
Clip for cleaning-out tubes	1	1	14	1	14	
Socket, reducing, 1½-inch to ½-inch	1	0	14	0	14	
Leathers, bucket, for pump	10	0	12	7	8	spare.
Clacks, india-rubber, for pump	10	1	0	10	0	spare.
Link, withdrawing, and chain	1	2	14	2	14	
Instructions, copy of	1					
Total	—	—		120	9	

7. **Deep tube wells.**—Though the stores for deep tube wells on Norton's principle are not articles of store, it is useful to know how to apply these wells to situations when water is too deep to be raised by the ordinary lift pump.

The *deep wells* are usually made with pumps and tubes of larger diameters, and the driving is executed in precisely the same manner as for smaller wells.

As soon as the first or pointed length has been driven, a *working barrel* (Pl. **60**, Fig. 10), which consists of a short length of well tube lined with brass, is added to the well tube by placing the valve seat A (Fig. 15) into the working barrel (which is engraved in section, in Fig. 10, in order to show the position of the lower valve seat and ring), and then screwing the working barrel on the well tube in the usual manner, with the socket which has been taken off the well tube, until it fairly butts upon the well tube.

The ring B (Fig. 12), with its broad part downwards, is next laid on top of the working barrel, as shown in Fig. 10, on to which the next length of tube is screwed in the ordinary way until it is firmly butted on to the working barrel, after which process driving is continued in the ordinary manner until water is reached. When water is reached and there stands several feet of water in the tube, the lower valve and its seating C (Fig. 14) is lowered into its seating by means of a small hook provided for that purpose, which can be coupled to the pump rods.

The lower valve, having been carefully wound round with tow and a little tallow, is hung on to the hook above mentioned, and thus lowered down the tube until it reaches into the valve seat A, as shown in Fig. 10; the hook is then disengaged from the valve and drawn up.

The bucket D (Fig. 13) is then screwed on to one of the iron rods provided for the pump, and lowered down the tube well by adding as many of the rods as are necessary, until it reaches into the working barrel, as shown in Fig. 9, and by allowing it to rap very slightly on to the lower valve C, it will embed the lower valve seating firmly into its place.

The rods that have been thus lowered have now to be coupled to the short length connected with the pump handle and passing through the barrel. The best way to do this is to remove the pump handle, when the short rod leading from it can be screwed into the coupling, and made secure like the rest of the joints by split joints; the pump head can then be screwed or bolted on to the tube well (Fig. 8).

8. **Boring by hand with the earth auger.**—In certain locations water may be obtained from shallow holes of 6 to 8 inches diameter.

The following extracts show the type of bore-hole that was used for forward drinking water supply in Flanders during the Great War:—

"Galleries were driven 60 to 64 feet long, in deep dug-out systems at about 50-metre contour. Bore-holes were spaced approximately 6 feet apart, with 10 bore-holes per gallery.

"Borings were made with an ordinary 8-inch earth auger (*see* Pl. **61**), the bit being expanded to make a 9-inch hole.

"The tubing consisted of 8-inch piping made of sheet iron riveted in 3-foot lengths. Lowest length consisted of a filter 8 inches diameter, 3 feet long, made of expanded metal, covered with rot-proof canvas with circular reinforcing bands 3 inches wide, with four vertical reinforcing rods.

"The most satisfactory way of drawing the water was found to be with a bucket dipper with rubber flap-valve on the bottom. A lift and force pump drew in too much sand.

"Six-foot centres for bore-holes were found to be too small, as one bore-hole robbed the adjacent one.

"Most efficient spacing will be governed by the nature of the soil.

"Depth of bore-holes on Observatory Ridge varied between 8 and 12 feet. Each set of 10 bore-holes gave a yield of about 1,000 gallons a day. One set gave 1,300, another 1,100, another 750."

The earth auger (Pl. **61**) consists of two iron scoops set slightly eccentrically. They are connected together at their upper ends by an adjustable distance-piece. One of the scoops is fixed and slightly longer than the other, which is so hinged to the distance-piece that it can be moved outwards through about 45°. To the centre of the distance-piece is fixed an iron rod 2 feet 6 inches long; the head of this rod is fitted with a screwed collar to receive the "T" handle or a lengthening rod.

On the tool being rotated clockwise about its vertical axis, it screws into the earth, and the scoops auger out the hole. When the scoops are full of earth the tool is withdrawn, the hinged scoop turned on its pivot, and the earth scraped out. The procedure is then as before. Lengthening rods, which are usually 2 feet 6 inches long, are screwed on as the hole is deepened.

The sizes of earth auger commonly used are the 4½-inch and the 6-inch. The smaller tool will make holes between 4½ inches and 6 inches in diameter; the larger tool holes between 6 inches and 8 inches in diameter. The range in diameter is obtained by varying the length of the adjustable distance-piece. This is done by unscrewing the wing nut which clamps together the two pieces of which the distance-piece is made.

In ordinary clay, sand, or earth, the auger is suitable for making holes up to 25 feet deep, and in exceptionally soft soils up to 30 feet deep. In dry or hard clay the addition of a little water in the hole will often assist progress. The earth auger cannot be used in stony soils.

TABLE F.—*Type table of stores required by a well-boring section, R.E. (using percussion drilling plant).*

DESCRIPTION OF STORES.		DESCRIPTION OF STORES.	
WEEDON SECTION A.		SECTION No. 1A—*continued.*	
Rifles, short, M.L.E.	*	Web equipment, sets complete (for officer)	2
Sword-bayonets	*	Belts, waist	*
Scabbards, sword-bayonet	*	Braces, with buckle	‡
Bottles, oil	*	Carriers, cartridge—	
Pull-throughs, Mark IV	*	75 rounds, left	*
Covers, breech	*	75 rounds, right	*
SECTION No. 1A.		Carriers, water-bottle	*
Bags, ration, Mark II	†	Covers, mess-tin	*
Bottles, water, enamelled	*	Frogs	*
Slings, rifle, web	*	Haversacks	*
Tins, mess, dismounted service	*	Packs	*
Whistles, infantry	2	Straps, supporting	‡

* 1 each for all N.C.Os. and men. † 1 each for all officers, N.C.Os., and men.
‡ 2 each for all N.C.Os. and men.

TABLE F.—*continued.*

DESCRIPTION OF STORES.	
SECTION No. 2A.	
Axes, felling, curved helve	5
Boxes, stationery, field	1
Helves, maul, $34\frac{1}{2}$-in.	5
Hooks, bill	5
Kettles, camp, oval, 12 qts.	12
Mauls, G.S., heads	5
Sheets, ground	*
Stove, Soyer, complete	1
Tents, circular, single	6
SECTION No. 2B.	
Axes, pick, heads	5
Axes, pick, helves, 36-in.	5
Crowbars, 5-ft.	10
Spades, Mark III	5
SECTION No. 6B.	
Basils, brown, unstrained	2
SECTION No. 7.	
Grindstone, with own handle, F.S., 14-in.	1
Chests, tool, filled—	
Smiths', No. 11, G.S.	5
Carpenters', No. 3, G.S.	1
Anvils, 1-cwt.	5
Augers, $\frac{1}{4}$-in., $\frac{3}{8}$-in., $\frac{1}{2}$-in., $\frac{5}{8}$-in., $\frac{3}{4}$-in. of each	5
Augers, handles, 12-in.	10
Axes, hand, 3-lb.	5
Bars, pinching, 2-ft. 10-in.	5
Blocks, anvil, 1-cwt.	5
Chisels, $1\frac{1}{2}$-in., firmer	5
Handles, file, middling	6
Pipe-cutters, 3-wheel—	
$\frac{1}{4}$-in. to 1-in., $1\frac{1}{4}$-in. to 2-in. sets of each	1
$2\frac{1}{2}$-in. to 3-in., $3\frac{1}{2}$-in. to 4-in. sets of each	1
Pipe-cutters, 8-wheel—	
2-in. to 6-in., sets	1
Saws, hand, 26-in.	5
Screwdrivers, G.S., 12-in.	5
Spanners, double-ended—	
$1\frac{1}{2}$-in. and $1\frac{3}{8}$-in.....	5
$1\frac{1}{4}$-in. and $1\frac{1}{8}$-in.....	5
1-in. and $\frac{7}{8}$-in.	5
$\frac{3}{4}$-in. and $\frac{5}{8}$-in.	5
$\frac{1}{2}$-in. and $\frac{3}{8}$-in.	5
Spanners, McMahon, 15-in.	5
Spanners, McMahon, 12-in.	5
Spanners. McMahon, 9-in.	5

DESCRIPTION OF STORES.	
SECTION No. 7—*continued.*	
Tools, screw-cutting, bolt and nut—	
Chest "B," filled	1
Chest "C," filled	1
Chest "D," filled	1
Tools, screw-cutting, iron and steel tube—	
$\frac{1}{4}$-in. to $1\frac{1}{2}$-in. chest, filled, Mark II	1
$1\frac{3}{4}$-in. to 3-in. chest, filled, Mark II	1
$3\frac{1}{2}$-in. to 4-in. chest, filled, Mark II	1
Vices, bench, parallel, 45-lb.	5
Vices, hand, 20-oz.	5
Wrenches, pipe, flat, link—	
$\frac{1}{4}$-in. to $2\frac{1}{2}$-in.	10
1-in. to 6-in.	10
Forges, field, G.S., Mark II	5
Hammers, smiths', up-hand....	5
SECTION No. 7, N.I.V.	
Screw-cutting gear, 6-in. sets	1
SECTION No. 8D.	
Bottles, ink, surveying	1
Instruments, drawing, R.E., Mark II, sets	1
Protractors, circular, celluloid, 9-in.	2
Protractors, rectangular, 6-in., wood, "A"	1
Set squares, celluloid, 6-in., 60°, 45° .... of each	1
Tapes, measuring—	
Metallic woven, 100-ft.	5
Steel woven, 100-ft.	5
Steel woven, 25-ft.	5
Watches	1
SECTION No. 9A.	
Dubbing .... lbs.	2
Grease, lubricating, yellow .... lbs.	14
Oil, lubricating, G.S. .... pints	4
Oil, lubricating, motor cycle pints	16
Soap, yellow .... bars	10
SECTION No. 9B.	
Bottles, tin, oil, 1-pint	5
Tins, oil, with screw tap, $\frac{1}{2}$-pint	†

* 1 each for all officers, N.C.Os., and men. † 1 each for all N.C.Os. and men.

TABLE F.—*continued.*

DESCRIPTION OF STORES.		
SECTION No. 10A.		
Nails—		
Wire, iron, grooved, 6-in.	lbs.	14
Wire, iron, grooved, 5-in.	lbs.	7
Wire, iron, grooved, 4-in.	lbs.	7
Wire, iron, grooved, 3-in.	lbs.	7
Wire, iron, grooved, 2-in.	lbs.	7
SECTION No. 10B.		
Covers, sailcloth, waterproof, 30 ft. × 30 ft.		5
Covers, waterproof, green, 20 ft. × 15 ft.....		5
SECTION No. 11.		
Brooms, bass		6
Handles, broom		3
Lamps, hurricane		6
SECTION No. 12.		
Implements, butchers'—		
Cases, wood, filled		1
SECTION No. 13A.		
Blankets, G.S.		*
SECTION No. 13C.		
Flannelette	yards	20
SECTION No. 20.		
Jacks, lifting, G.S., 5-ton		10
SECTION No. 27.		
Cartridge, small-arm, ball	rounds	100†
Pistol, Webley	„	20‡

DESCRIPTION OF STORES.		
SECTION No. 29B.		
Pumps—		
Lift and force, complete with hose		5
Hose, delivery, spare lengths		10
Spare parts	sets	5
PIMLICO SECTION No. 30.		
Dressings, field		*
N.I.V.		
Machines, drilling, steam tractor, *Keystone* type, complete with boiler, engine, derrick, for 800 ft., and tools		4
Cable, drilling, and sand line.		
Cable, drilling, hawser-laid manilla, 1,000-ft. lengths		5
Rope, flexible, steel, 1½-in., 1,000-ft. lengths		5
Tools, fishing.		
Jars, fishing, 18-in. stroke	sets	1
Bumpers, solid jar		5
Foot, crows		1
Jars, rope knife	sets	1
Knife, rope, horse-shoe		1
Spud		1
Socket, horn		1
Socket, slip		1
Socket, combination		1

* 1 each for all officers, N.C.Os., and men. † Each rifle. ‡ Each pistol.

CHAPTER VIII.

PUMPING MACHINERY.

35. *Requirements to be fulfilled by plant.*

1. Pumping machinery would demand a large volume to itself to be adequately treated; it is, therefore, impossible to do more than indicate the types of plant which are specially suitable for semi-permanent work, and the ways in which they are connected to the pipe distribution system.

It is not, therefore, proposed to consider the details of the various types of pumps and prime-movers in use, and, moreover, such considerations come within the expert purview of a mechanical engineer.

2. The requirements of a plant designed for semi-permanent work, beyond the obvious one of being capable of the required delivery of water at the necessary head, are :—

(*a*) Ease of transport. This will vary according to the purpose to which the pump is to be put.
(*b*) Freedom from breakdown. This is especially important when facilities for carrying out repairs are limited.
(*c*) Economy in fuel. Increased economy in fuel may be sacrificed in favour of (*a*) or (*b*) according to circumstances.
(*d*) Standardization so far as practicable. This is very necessary when large numbers of plants are in use. By careful consideration before ordering plant, types can be standardized to a great extent; the supply of spare parts will thereby be simplified, and repairs more quickly executed owing to the personnel becoming more familiar with the various patterns of plant in use.

So far as possible plant should be standardized on the *interchangeable* system, and, if parts are numbered, it will not be necessary to strip down a machine before the dimensions and detail of any broken part can be obtained for ordering replacements.

As regards spares, the principle should be adopted of sending a limited number of spares boxed up with each machine, and keeping a number of those less frequently required at base and other electro-mechanical depots. The former are termed " A " spares, and the latter " B " spares. A complete set of spanners should be supplied with each machine. Suction and delivery connections must be standardized.

If one, or at the most two, standard belt speeds can be arranged for all belt-driven pumps and for the engines used in driving them, much time will be saved in making up belt-driven sets from stock. It is probable, however, that belt-driven sets will be, for standard plant, superseded by direct or gear-driven sets.

It is not possible to give detailed particulars of any standard power pumping sets, since no sealed patterns are yet approved.

3. Pumps may be worked by hand, animal, steam, I.C., electric, hydraulic, or wind power.

For field purposes the last two methods may be neglected.

Of the remaining methods electric power will only be feasible when an extensive system of power distribution is undertaken by the electro-mechanical service of an army in the field, when civil supplies are available, or in other special circumstances. For locations of a more or less permanent nature and not too much exposed to shell fire or aerial attack, electric motors form an ideal method of driving pumps.

For most purposes, however, high-speed internal combustion engines will be used, and are satisfactory if properly connected to the pump and operated by competent personnel. These engines, in the present state of their development, require a good deal of maintenance, and, if it is desired to use low-grade operating labour, slow and medium-speed oil engines may be found best. The latter are, however, cumbersome compared to petrol engines.

Steam, as a prime-mover, will probably find no place in the future power pumping plant equipment of a field army, but may be encountered among civil installations.

The secret of successful operation of pumping plant is to have an ample reserve of power. Thus petrol engines to drive field pumping plant should be of twice the power theoretically required.

The technical descriptions of types of prime-movers will be found in Military Engineering, Vol. VIII.

4. Pumping plant will usually be supplied from home as a *set* complete with engine or motor, and in most cases will be made up for direct or gear drive, the whole plant being mounted on a rigid base. It is important that these sets are not made up so as to exceed limiting transportation dimensions, either as regards space or weight. By the use of high-speed petrol engines direct or gear coupled to turbine or centrifugal pumps, these requirements can usually be fulfilled for any plant likely to be required by an army in the field.

A pumping set will consist of :—

i. Prime-mover—direct, gear, or belt coupled to
ii. Pump, fitted with—

(*a*) Stop-valve ... ... (*b*) Reflux-valve ... ... (*c*) Pressure gauge ... ... (*d*) Release-valve ... ... (*e*) Bye-pass for priming pump	on delivery side.
(*f*) Suction piping, foot-valve, and strainer (*g*) Suction pressure gauge.	on suction side.

Valves must be provided for releasing air from pump and suction prior to priming, and for charging air chambers while running.

The set must be supplied with any fuel and water-tanks or starting gear required for the engine or motor, also a set of spanners and a box of "A" spares.

The plant should be wholly or partially boxed up for transit, and suspension chains and lifting ring should be provided so that the case may be easily slung for crane lift.

5. The classes of pumping plant employed in field water supply work are as follows :—

(*a*) Surface or normal suction pumps.
(*b*) Deep-well pumps.
(*c*) Bore-hole pumps.
(*d*) Water elevators for wells.
(*e*) Airlift pumps—described in Chap. IX.

A résumé of the elementary hydraulics of pumping plant will be found in Chap. XIII; this chapter will be limited to a general description of the types of pumps likely to be of use in the field.

Detailed descriptions, specifications, and part lists for power pumps are not included in this volume, since there are no sealed patterns of these stores; but Table G gives a list of pumps which will be of general application.

TABLE G.—*List of pumps.*

No.	Type.	Typical makes.	Gallons an hour delivered at head in feet.	Remarks.
1	Portable petrol ram set (on wheels)	Guy and Mital (self-contained)	1,000 × 60′ 2-in. connections	For delivering to horse-troughs, tanks, &c., near the source of supply. *See* Pls. 69, 70, and 72.
2	Portable petrol rotoplunge	Lister-Rotoplunge (self-contained)	3,000 × 80′ 2-in. connections	
3	Portable steam	Merryweather I .... Merryweather II	3,000 × 100′ 7,200 × 250′	
4	Surface 3-ram, oil engine driven	Pearn pump with Blackstone engine 7 h.p.	2,500 × 350′ 4-in. connections	For deliberate installation on pipe-lines. *See* Pl. 71.
5	Surface 2-ram double acting on girder frame with petrol engine	Hayward Tyler with Day 8 h.p. engine (self-contained)	2,500 × 350′ 4-in. connections	For hasty installations on pipe lines.
6	Steam surface, Duplex type with vertical boiler	Hayward Tyler pump	4,000 × 350′ 4-in. connections	For deliberate installation on long pipe-lines. *See* Pl. 73.
7	Petrol turbo direct-coupled	Dennis-Mather and Platt, 7-stage (self-contained)	7,200 × 600′ 4-in. connections	For use on long pipe-lines. *See* Pl. 63.
8	Petrol turbo direct-coupled	Aster-Gwynnes', 4-stage (self-contained)	6,000 × 250′ 4-in. connections	For hasty installation in connection with pipe-line. *See* Pl. 64.
9	Tube well pump	Duke & Ockenden, and 7 h.p. Blackstone oil engine	1,000 × 250′ for 4-in. rising main	Takes time to install. Plants may be made portable.
10	Tube well pump	Duke & Ockenden	3,000 × 250′ for 6-in. rising main	For deliberate installation.
11	Air compressors	Aster engine and Broom & Wade compressor	69 / 150 cub. ft. free air × 100 lbs. pressure a minute	For use on lorry. / For use on semi-stationary work. *See* Pl. 99.
12	Belt pump	Day (self-contained)	2,000 × 200′	Hasty work with existing wells. *See* Pl. 81.

36. *Rotary pumps.*

1. Until quite recently rotary pumps of small size were so uneconomical in operation that the more positive ram variety was preferred for peace-time purposes. In the future, however, it is probable that the turbine,

centrifugal, or rotoplunge type pump will predominate, and that these types will be found to be by far the most suitable for use in the field. The hydraulic theory of turbine and centrifugal pumps is briefly described in Chap. XIII.

2. **High-speed rotary pumps** possess the advantages of compactness and small weight as compared to ram pumps of equal capacity, but require higher grade labour for their maintenance. The high rotational speed of centrifugal and turbine pumps permits of their being coupled direct to multi-cylinder vertical petrol engines. Centrifugal and turbine pumps are also particularly well suited for direct coupling to electric motors. This arrangement is to be preferred when electrical power is available. In general, it may be said that turbine pumps direct-coupled to the prime-mover are the most up-to-date proposition, and before long will be universally employed.

3. In all semi-permanent work and particularly during military operations, the plant used must be easily transported to site and quickly erected. These conditions are best met by this class of pump.

Pl. **62** shows a Gwynnes' turbine pump (duty 100 gals./min./250 ft.), direct-coupled to an Aster high-speed petrol engine.

Pl. **63** shows a petrol-turbo pumping set of the same type (Dennis engine—Mather & Platt pump). This type of set has proved very suitable for installation in a confined space.

Pl. **64** shows a smaller, but similar, set (Aster engine—Gwynnes' pump) mounted on wheels for transport. The duty of this set is 100 gals./min./250 ft.

Pl. **65** shows a Gwynnes' pump direct-coupled to an electric motor, a very convenient arrangement where power exists.

Pl. **66** shows a small centrifugal pump connected to a single-cylinder petrol engine (duty about 40 gals./min./50 ft.). This set can be carried by two men, and was originally designed for unflooding trenches.

Pl. **67** shows a high capacity, low-lift centrifugal pump, coupled to a six-cylinder petrol engine.

All the foregoing pumps can, of course, be driven by belt or gearing.

Pl. **68** shows two belt-driven turbine pump sets.

4. **The Rotoplunge pump.** (*See* Pl. **69**.) This pump has no valves, and possesses the advantage of a simple positive action, and can be obtained for deliveries up to 40 gals./min. against 100 ft. head.

The action of the pump is as follows (*see* Pl. **69**) :—

Supposing the pump to be rotating in the direction indicated by the arrow, then, owing to the eccentricity of the pin G, any one of the four plungers when passing the upper shoe must be in its extreme outward position. As this temporarily top plunger moves down the suction side l, its movement in its cylinder is inward until, on the completion of the half revolution, it reaches the bottom shoe, when it is at its extreme inward position, and the water drawn in is trapped by the shoe. During the second half revolution, while the same plunger is passing up the discharge side m, the movement is outwards, and the water trapped when passing the lower shoe is expelled, the plunger again reaching the extreme outward position as it comes to the upper shoe on completion of the revolution.

The standard pumps are made mostly in cast-iron, but can be supplied in gun-metal to suit special requirements.

The pumps automatically and efficiently lubricate themselves throughout with the liquid they are pumping, but to prolong life and reduce wear and tear the larger pumps are now drilled for grease lubrication throughout.

Pl. **70** shows a convenient arrangement of small sizes of this pump, which is of great value for field use.

37. *Ram pumps, steam pumps, and pulsometers.*

1. Ram or plunger pumps can be driven direct or by belt, and usually through a countershaft.

One or more rams are used, usually not more than three.

Pl. **71** shows a treble ram pump, with driving pinion direct-coupled to the shaft of a slow-speed oil engine. This type of pump is useful for continuous running with semi-skilled labour.

Three-throw pumps with a duty of 2,500 gallons an hour against 350 feet head are convenient for supplying water through pipe-lines from independent sources to camps, hospitals, &c. They can be best driven by oil engines or electric motors, and such installations require only a moderate amount of maintenance.

When in good condition, a suction lift of 25 feet can be obtained with a ram pump, but it is safer to rely on 20 feet as a maximum. Ram pumps are particularly useful installed on stagings down wells in which the water level is between 20 and 40 feet from the surface, and driven by an inclined belt from an oil engine at the surface.

2. Direct-action steam pumps come under this head, but will not in the future be of extended application in the field, owing to the large and cumbersome boilers usually required.

3. An exception, however, must be made in the case of the **Merryweather** steam fire pumps, which are particularly useful when petrol is difficult to get, or labour for operating petrol engines is scarce. In oil-producing countries, the boilers of these sets may be conveniently equipped with oil-firing gear.

The general appearance of the pump is shown on **Pl. 72.**

This pump was largely used during the Great War for all kinds of water supply and pumping operations, and upwards of a thousand were supplied by the makers (Messrs. Merryweather & Sons, of Greenwich) to the British and American Governments for service in the field. They were used for a very great variety of work, including fire protection, water supply, washing-out locomotive boilers, and many other pumping duties.

Lightness and portability are essential features of this pump, and it can readily be taken into confined spaces where larger pumps are inadmissible. The pump and boiler are mounted on a two-wheeled detachable hand carriage, on which it can be readily moved about by one or two men. If necessary, the machine can be removed from the carriage and carried on men's shoulders by means of poles. It is made in three sizes, but the No. 1 and No. 2 sizes are usually adopted, and these have a capacity of 50 to 100 and 100 to 200 gallons a minute respectively according to head. The smaller machine weighs $6\frac{1}{2}$ cwt. and the larger 11 cwt., and considering their comparatively light weights, the power they are capable of producing is remarkable. The boiler can be arranged for burning wood, coal, or oil fuel.

4. Pl. **73** shows a pair of steam-driven pumps with portable loco-type boilers (duty each 66 gals./min./350 ft.).

It is unlikely that such plant will be supplied in the future for use in the field, but, since similar civil installations abound and may have to be operated or repaired, personnel must be trained in its use.

Pl. **74** shows the general construction of this class of pump, but of a larger type than Pl. **73.**

5. A source of steam must be available to work a **pulsometer** (*see* Pl. **75**), and thus this type is not of much use for field operations. Pulsometers are particularly useful when the pump has to be constantly shifted vertically or horizontally a short distance at a time, as in unflooding foundations, but the large steam consumption (about 500 lbs. each pump h.p. hour) is a disadvantage.

The action of the pulsometer is as follows :—

Referring to Pl. **75**, there are two side chambers A to receive the water alternately. E is suction-valve, and D delivery-valve. These valves are duplicated on the other side of the pump. To start the pump, it is filled with water through a hole (not shown), the water resting on the foot-valve provided in the suction pipe. The ball B being compelled to lie on one or other of the seats in connection with chambers AA, steam is admitted at C, and, entering, say, the right hand passage, displaces the water through D *without agitation* until the level falls to the upper edge of the orifice. Steam then blows through with some violence, and an *instantaneous condensation* occurs, causing a partial vacuum in A. The ball being now drawn to the right hand seat, water enters the right chamber ready for the next stroke, steam enters the left chamber, and the action is continuously repeated.

6. There are not many situations in which **hydraulic rams** would be installed during operations, but they are sometimes useful for small semi-permanent camp supplies.

The water working the ram is supplied through the *drive-pipe* (Pl. **76**, Fig. 1), and escapes through the mushroom valve W, until it has gained a velocity sufficient to raise the valve or ball V, which suddenly stops the current and causes excessive pressure in the body of the ram. The water is forced into the *air vessel*, and finally through the delivery pipe to its destination. When equilibrium of pressure is restored, the ball V falls, and the operation is repeated.

The length of the supply pipe should not be less than five times the height of the fall.

In ordinary cases the hydraulic ram returns about 50 per cent. of the natural effect, that is, the quantity of water $Q \times H$, the height of the delivery above the ram, will be about 50 per cent. of the quantity of water, q working the ram, multiplied by the head of the fall h in the same unit of time, or $QH = 0{\cdot}5\,qh$.

38. *Pumps for deep wells.*

1. The term *deep-well pump* generally implies a pump fixed in a well of considerable diameter as opposed to a *bore-hole pump*. The ordinary pattern of *deep-well pump* is shown on Pl. **77**.

The working barrels, of which there are usually three, are placed in the well within suction reach of the water, and the pump rods are constrained in position by guides fixed in the sides of the well.

Owing to seasonal variations of the water level, the pumps are in many cases submerged and sometimes remain so throughout the year owing to permanent changes of the water level. Under these conditions repairs to the pump barrels are difficult to carry out, and usually involve pumping out the well with an independent pump. Deep-well pumps are thus troublesome to maintain. This type of pump, moreover, takes a long time to install, especially in the larger sizes. Deep-well pumps slung from metal rods in order to be adjustable for varying water levels are sometimes met with.

2. When the well is of but moderate depth, a normal suction pump may be fixed on a staging near water level, and belt-driven by an engine at ground level.

3. When no other plant is available, a steam pump may be fixed down the well, and connected to the boiler at the top. Installations have been constructed in the field, in which the boiler was sunk below ground level for security against shell fire. This method involves an enormous amount of work, and is not recommended; also, steam consumption is excessive owing to condensation in the pipe.

4. There are several better ways of getting water out of a deep well, other than by the installation of pumps such as just described.

For moderate quantities bore-hole pumps or water elevators as described in subsequent sections may be used, but their use is limited.

For larger quantities probably the best plant is the **electric centrifugal** variety. This may be arranged in two ways. The pump and motor may be fixed on supports across the well or in a chamber cut in the side of the well within suction reach of the water, and the rising main brought up the side of the well from the pump. In this case care must be taken that the motor does not get submerged owing to rise of water level. (*See* Pl. **78**.)

If there is a considerable fall of water level when pumping, the motor may be arranged at the top of the well in a vertical position, so as to drive a turbine pump at the bottom by means of a long vertical shaft. In this system the shaft usually works within the rising main from the pump. This type of pump, which is more especially suitable for dealing with larger quantities of water than can be dealt with by a bore-hole pump, is more generally applicable to permanent practice.

5. The arrangement that would be most convenient in the field would be to use such a pump as shown on Pl. **79**. This pump is slung from the top of the well by a wire rope tackle. The current would be furnished by either a petrol electric lorry or a small petrol generating set. For a campaign in suitable country these sets should be standardized. Sufficient flexible hose connections would be required for each set.

6. The **canvas belt water elevator,** or band pump, is shown on Pl. **81**. This machine can be very rapidly installed over a deep well, and, provided there are no obstructions in the well, water can be made available within a very short time of starting the work of installation. **It is thus particularly suitable for military operations.**

The principle of operation is that of a canvas belt made to revolve on a pulley at the top of the well, while the bottom loop is immersed in the water. The water is thrown off by centrifugal force as the belt reaches the top.

Its chief disadvantage is that the belts last but a short time, but the manufacture of such belts will probably be improved, and a durable belt will eventually be made.

A quickly made and satisfactory belt pump designed for an output of 1,000—2,000 gallons an hour is shown on Pl. **80**, and a similar pump for mounting on a G.S. wagon is shown on Pl. **81**.

The following conclusions have been drawn from experiments carried out with this pump in wells of varying depths.

The diameter of belt drum was 1 foot 3 inches, and it had a camber of 1/24.

The belt used was 8 inches broad, and weighed ·346 lb. a yard run.

Slip is best guarded against by tacking a strip of canvas 4 inches wide round the middle of the pulley.

Immersion.—The best results are obtained with a belt of such a length that its lowest point is six inches from the bottom of the well when the pump is not working.

Depth from ground to water.—As the depth from ground to water decreases, the belt has less chance of becoming steady before reaching the drum ; also there is less weight on the drum and more tendency to slip, and, therefore, more tendency for the belt to wear. This is overcome by using two or more belts superimposed.

Generally speaking, the deeper the well, the greater may the speed be. If the speed is too great for any particular depth of well, the belt will *hunt* from side to side of the drum, and rapid wear will result owing to the edges of the belt rubbing against the sides of the notches.

Table **H** shows the maximum output and belt speed for wells of various depths, the bottom of the belt being, in each case, 10 feet under water when the pump is not working. Below these speeds, the output will be in direct proportion to the speeds.

In this table the maximum quantity of water that can be obtained with this pump and a 5 h.p. Petter Junior engine is shown, but if these deliveries are required, the belt will wear out very quickly.

No form of bottom pulley has been found to give satisfactory results.

The **Carnelle** type of elevator is a variation of the above, and is marketed by Messrs. Boulton and Paul, of Norwich. In this machine, a multi-cellular band of sheet-metal is riveted to a canvas or leather belt or to a steel chain, according to the depth of the well. This type of elevator is made for hand-working to deliver up to 900 gallons an hour, and, if power be employed, considerably larger quantities may be lifted.

7. The **Chaine Helice pump.**—The head gear of the Chaine Helice pump is shown on Pl. **82**. There is an endless chain passing over the pulley

shown in the illustration, and this chain is surrounded by coils of wire which move with the chain, being fixed to the latter at frequent intervals. The spiral chain is suspended from a grooved pulley, by means of which motion may be imparted to the chain, and the lower end dips into the water of the well about 2 feet. When the grooved pulley is turned by hand or power, the suspended spiral chain, which is kept taut by a counterweight grooved pulley hanging freely in the loop at the bottom, ascends filled with water on one side, the water being held in the chain by capillary attraction. As the spiral passes over the grooved pulley at the top, it opens out slightly, and centrifugal force causes the water to be thrown off. The water is caught in a tank, and cannot run back through the hole by means of which the chain entered this tank, owing to the hole being surrounded by a sleeve.

The quantities lifted vary with the size of the chain; the largest single chain used at the present time delivers 2,500 gallons an hour, and requires mechanical driving power; whilst the smallest will deliver 150 gallons an hour. The greatest depth from which water can be lifted at present is 300 feet, but the same principles are applicable to even greater depths.

Although the Chaine Helice is not a force pump, and will only lift water to its own level, this limitation may be overcome by placing the machine on a staging if only a small head is required, or by an arrangement by which a small positive force pump is directly coupled to the Chaine Helice, and supplied with water from the same tank.

By doubling, tripling, &c., the number of chains in the heavier types of elevator, a proportionally increased supply of water is obtainable, and the h.p. will, of course, be increased pro rata.

This type of pump was extensively used during the Great War, but considerable trouble was experienced from chains breaking. The manufacture of the Chaine Helice pump has now been taken over by a British firm, and it is stated that the material, &c., has been so improved that breaking of chains is quite unknown.

The Chaine Helice pump is similar to the Belt pump in that it can be rapidly installed, and is thus of great value for military work.

TABLE H.—*Characteristics of belt pumps.*

Depth from pump drum to water.	Total length of belting under water.	Belt speed.	Output g.p.h.	Belt used.	Maximum delivery obtainable.	Maximum belt speed.	Remarks.
Feet.	Feet.						
197	20	1,600 1,300*	2,000 1,500	Single	—	—	—
155 155	20 20	1,320 1,120*	2,000 1,500	Single	2,400	1,520	Limit of power of 5 h.p. Petter engine.
110 110	20 20	1,120 920*	2,000 1,500	Single	2,700	1,400	Belt slips after this speed.
66	20	960	2,000	Double	—	—	—
43	20	800 640*	2,000 1,700	Treble	3,200	1,160	Belt slips after this and output goes down.

* Best speed.

39. *Bore-hole pumps.*

1. The amount of water that can be lifted by a bore-hole pump is governed by the diameter of the hole and the stroke.

With a 6-inch bore-hole, a 4-inch rising main and 3⅝-inch pump barrel can be used, giving 1,000 gallons an hour. With a 6-inch rising main and 5⅝-inch barrel, 3,000 gallons an hour can be obtained.

The pump rods are actuated usually by a crank working in a frame (*see* Pls. **83** and **84**), but there are varieties of steam bore-hole pumps in which the pump rod is a continuation of the piston rod of the steam cylinder.

2. It often happens with a heavy draught on a bore-hole that it is difficult to keep sand or grit out of the pump barrel with the ordinary pattern suction strainers shown on Pl. **85**. The Ashford tube strainer (*see* Pl. **86**) has proved useful in excluding fine sand.

3. Bore-hole pumps can, of course, be used, and are of great value for ordinary deep wells. The method of suspending the rising main is the same as in bore-holes, *i.e.*, by clamps or a flange resting on transoms across the well mouth. For wells over about 100 feet deep it may be necessary to cross-strut the rising main from the sides of the well to prevent excessive vibration.

The valves of all bore-hole pumps supplied for Service use should be balls of solid brass to avoid stoppages; the buckets should be fitted with several leathers to give long service without renewing.

For moderate ease of installation, 250 feet is the maximum depth of pump barrel below surface.

4. Where hydrological conditions permit, the airlift is by far the best means of raising water from a bore-hole, at any rate in semi-permanent work. Permanent practice condemns the airlift on account of its low efficiency, but in the smaller sizes it is doubtful whether there is much to choose in point of efficiency between the airlift and the ordinary bore-hole pump. The main features of the airlift are stated in Chap. IX.

40. *Pump-houses, foundations, and connections to the pump.*

1. For semi-permanent purposes pump-houses are generally built of corrugated iron on wood framing, or any other suitable materials which may be available, while in the forward area pumps will have to be installed in dug-outs. A concrete floor, though not essential, is very desirable. When time presses, nearly all plant of sizes likely to be used in the field can be put down on girder or timber framing, and concreted in afterwards.

The pump-house should be sufficiently large for the plant to be properly operated and opened for inspection. Walls should be 3 feet clear from all machinery. Accommodation may be required for the engine attendants, and a small store with a bench and vice should be provided. A fuel store will be necessary, but should be built away from the pump-house (*see* Pl. **129**).

Underground engine rooms must be efficiently ventilated. Special care must be taken against danger of poisoning by exhaust fumes. Fire fighting appliances must be provided in all engine rooms, and these will usually take the form of *buckets* of sand and fire extinguishers, but carbon tetrachloride extinguishers must *not* be used in underground engine rooms.

2. Under field conditions and with the types of pumps that will be employed, elaborate foundations are unnecessary. In most cases, if time presses, concrete can be dispensed with, and the machine firmly bedded down on sufficiently substantial timber baulks. Coach screws can often be used for the latter purpose instead of bolts. For belt-driven sets, the framing must be such that the pump is not pulled bodily towards the engine by the tension on the belt. It is best, in such cases, when a timber foundation is used, to have two continuous longitudinal bearers supporting both pump and engine, and well braced together.

3. The height a pump will lift water depends on the type and construction of the pump, but is rarely more than 25 feet. Centrifugal and turbine pumps are worse in this respect than ram pumps; they may be given a suction head of 15 feet, but this must not be exceeded, and, whenever possible, such pumps should be run flooded. The suction lift should always be as small as possible.

The suction pipe joints must be well made so as to exclude air; this is particularly important with centrifugal and turbine pumps.

Bends should be avoided if possible, and the suction pipe should be all of one diameter. For making flanged joints in a suction, india-rubber or canvas rings are best. These should be a little larger than the bore of the pipe. The rings should be steeped for a few moments in warm water, or held to the fire, to soften before being used. Screwed joints must be made with the greatest care, since the least air-hole or leak will stop the action of the pump. The suction main should be laid with a gentle rise from the source to the pump, so that no pockets are left for the accumulation of air. This last instruction only applies to installations where the pump draws its supply from a level lower than that at which it is placed.

There should, if possible, be no valves on the suction pipe, except in the case of a turbine pump which runs *flooded*. The suction pipe should be at least as large as the suction connection on the pump. With long suction pipe-lines the diameter should be larger, and can be calculated according to the ordinary rules for pipe friction.

It is often forgotten that suction pipes require protection against frost. The weight of suction pipes should be taken by supports; they should not be *hung* from the suction flange of the pump.

Foot-valves are desirable on all suctions, and almost essential on suctions of centrifugal and turbine pumps. Efficient strainers should be fitted to keep pebbles and mud out of the pump. Strainers in front of intake chambers should be in duplicate for cleaning purposes.

The total area of holes in a suction strainer for a ram pump should be twice, and in a centrifugal pump three times, the sectional area of the suction pipe.

A type of straining chamber is shown on Pl. **87**.

4. It may sometimes happen that the seasonal variation of water level is such as either to cause the water to fall below suction reach at one time, or at another to submerge the pump. This may happen in the case of a river subject to flood. The following courses are open:—

(i) To install the pump in a water-tight chamber at such a level as to suit the lowest water level anticipated.

(ii) To install the pump at a convenient level, and move it when the flood season occurs. A temporary lifting gantry might be made on the same principle as the Weldon trestle.

(iii) To run the pump submerged. This is only possible with specially designed pumps.

(iv) If the river flows between banks, a tunnel might be driven through the bank, and the pump placed so as to draw from a sump supplied from a regulating sluice in the tunnel.

Similar precautions must be taken regarding the suction pipe and foot-valve, &c., so that the latter does not get immersed in silt. The suction pipe can be made in short lengths (3 feet or so) so that it can be shortened, or a flexible joint can be introduced and lifting arrangements provided.

In the case of a shallow stream or pond with muddy bottom and varying water level, it may be advisable to install a floating suction. This is best effected by a flexible pipe of appropriate diameter floated on empty oil drums, which are kept in correct position by hinged iron radius rods attached to the suction flange or metal portion of the suction pipe.

5. A main stop-valve of the *sluice* or *full-way* type is generally fitted on the rising main side of the pump, so that the pump can be isolated from the main, but a reflux-valve answers the same purpose. In both cases a small bye-pass should be provided for flooding the pump from the rising main in the event of a leaky foot-valve.

A pressure gauge is a necessary adjunct to all pumps; plunger and piston pumps will each require a pressure relief-valve.

41. *Personnel and maintenance.*

1. Ordinary mechanical engineering practice is involved in the installation, operation, and maintenance of pumping plant in the field, and this may be the responsibility of the electro-mechanical service, or may be carried out by other engineer units with their mechanical personnel. In common with other mechanical work, the following grades of labour will be required :—

(*a*) Expert supervisors.
(*b*) Expert mechanics (for repairs and installation).
(*c*) Semi-skilled labour (for actually driving the engines).
(*d*) Unskilled labour (for moving machinery).

2. The work required in connection with pumping machinery may be classified as follows :—

(*a*) Overhaul and repair work in H.Q. workshops and testing of plant on first arrival.
(*b*) Installation work.
(*c*) Operation.

3. The personnel employed must be organized in accordance with the above to get the best results with the available man-power. Untrained men can usually be trained to operate small standard pumping sets, but expert mechanics are required for repair and overhaul purposes. Installation gangs must have a proportion of skilled mechanics, while the remainder can be semi-skilled or unskilled men trained to the work. All men employed, however, must belong to the unit; the practice of *temporarily attaching* men from other units is disastrous, and wastes the energies of officers in unnecessary administrative details.

4. The maintenance of a number of pumping stations scattered over an area demands careful consideration. It will generally involve the establishment of a central workshop with outside installation and repair gangs.

5. For small plant, it is often quicker and more economical to replace a broken-down set by a similar set than to repair it on the spot. The faulty set is then returned to the shops for repair. An adequate supply of spare parts, and especially of such parts as valves, packings, &c., will do much to ensure efficient maintenance.

6. Proper records must be kept of pumping stations, each of which should be given a number or distinguishing name. For control purposes, records of quantities of water pumped, oil used, pressure pumped against, &c., must be kept in the form of engine log sheets. A suitable form of log sheet is as follows :—

To be rendered every week for each Station.

Weekly Machinery Report.

Name of station............ Army No............. Map reference...............

Nature of installation (pumping station, E.L. station, workshops, or other)...

Army reference No. of prime-mover ....

" " other machines.......................

Unit or Officer in technical charge.......................

Log.

Date.	Hours worked.	Shifts worked.	Pressure.		For Pumps only.			Remarks.
			Max.	Min.	Gallons pumped.	Water level from ground.		
						Before.	After.	
Total								
Average per day								

Nature of fuel—

	Date.	Coal.	Petrol.	Fuel Oil.
Balance brought forward.				
Received				
"				
"				
Total fuel consumed				
Balance in hand				

Crew.			
Unit.	No.	Name.	Rationed by.

....

Engine Driver in charge.

Date.........................

CHAPTER IX.

THE AIRLIFT PUMP.

42. *General principles.*

1. The airlift as a means of raising water from a bore-hole is of such great value in the field that a separate chapter is devoted to its consideration. Some information is also included to enable approximate designs to be worked out. The determination of the most *efficient* design for any particular purpose is a matter for extended test, for which time is not available in the field.

In a country of fairly uniform hydrological characteristics, some degree of standardization of airlift piping arrangement and types and sizes of compressor plant may be arrived at.

2. The airlift is a device for raising water from a depth by means of compressed air. The method of operation is such that a column of water unmixed with air is opposed to a column of air and water mixed. A mixture of air and water has a lower specific gravity than that of plain water, depending on the relative volumes of air and water in the mixture. When the difference between the weights of the two columns is in favour of that of plain water, the column of mixture is set in motion, and under favourable circumstances the air and water are discharged above ground level. When the columns balance one another, no motion ensues.

3. Pl. **88** shows an airlift installation in diagram form. This system is known as the **central air pipe system.** Other systems are in use, identical in principle and only differing in the arrangement of the piping.

It is evident from the diagram that the pressure of the air admitted to the water must at least be equal to the head of unmixed water above the point of entry of the air; in other words, the air pressure depends on the degree of submergence of the air pipe, and *not*, as is commonly supposed, on the height to which the water is lifted, although a certain degree of submergence is necessary to set the column in motion.

4. In practice the working air pressure will slightly exceed that equivalent to the external column of unmixed water, by an amount corresponding to the frictional resistance encountered during the passage of the air through the air pipe.

The *starting pressure* is almost always greater than the *working pressure,* for two reasons: (*a*) because the standing water level is usually lowered when pumping is in progress; (*b*) on account of the extra energy required to set the column in motion.

In some cases (owing to low submergence ratio) difficulty is found in overcoming the initial inertia of the system, and air connections have to be arranged so that air pressure can alternately be put on to and taken off the surface of the free water column, thus getting up a kind of *bounce* in the system. This necessitates sealing the top of the well between the casing and the rising main, so that a pressure can be exerted in the space above the free surface of the water. Some authorities maintain that this should always be done, it being claimed that a few pounds pressure on the surface of the water while the lift is in operation tends to prevent surging of the two columns and to produce a more even flow. It is doubtful, however, if any appreciable increase of efficiency results.

In a well liable to become sand-choked, and where the water is drawn in through perforated casing, it is of great advantage if the well is capped and air connections arranged as just described. If a pressure is built up periodically in the space above the rising main, the water will be forced back into the feeding strata or fissures, and the sand washed away from around the casing.

5. The advantages of the airlift in semi-permanent work over other forms of pumps for raising water from a depth may be summarized as follows :—

(*a*) All the moving parts and machinery are on the surface of the ground, and are open to inspection and proper maintenance. The delay occasioned by a breakdown is one of the most serious objections to the ordinary pattern of deep-well pump, when several hundred feet of rods have to be lifted from a well. Compressor plant can be more quickly installed than bore-hole pumps of equivalent capacity.

(*b*) More water can be lifted from a bore-hole by an airlift than by a bore-hole pump, provided the water is there.

(*c*) The pumping station can be located in any desired position, regardless of the position of the well. Thus compressors can be located in safe dug-outs at a distance from the well. Existing sources of power situated some distance from the well can often be utilized for driving the compressor.

(*d*) The airlift is the only pumping system which permits of a stand-by plant being provided for working a bore-hole.

(*e*) Several wells can be driven from one plant.

(*f*) The water is often sensibly purified by the aeration to which it is subjected.

(*g*) The yield of the well is often increased.

(*h*) Sandy or gritty water can be pumped without detriment to the plant. This is one of the most fruitful causes of breakdown of deep-well and bore-hole pumps.

(*i*) It is not affected hy frost.

The disadvantages of the system are :—

(*a*) Low efficiency.

(*b*) The well must be roughly twice as deep as the working lift for moderate lifts, and about one and a half times as deep for high lifts. This is the only objection from a military point of view.

43. *The airlift in practice.*

1. The usual methods of arranging the air pipe and rising main are as follows (*see* Pl. 89) :—

i. Air pipe suspended centrally within rising main.
ii. Air pipe outside and separate from rising main.
iii. Rising main suspended within air pipe.

Method i. is the handiest for practical purposes, since the air pipe can readily be withdrawn or altered, and will normally be used for field installations.

Method ii. possesses the advantage of leaving an uninterrupted passage for the mixture and reducing friction losses.

Method iii. requires, other things being equal, a larger bore-hole than either of the first two methods.

2. There are innumerable patterns of patent air pipe footpieces on the market, most of which merely serve as an obstruction to the water flow without materially increasing the efficiency.

With the central air pipe system, the type of footpiece shown on Pl. **90** is recommended. It will be noted that a length of plain pipe is attached below the point of admission of the air. If this pipe is omitted, it is found that the air is apt to blow straight through the open end instead of passing through the holes in fine streams.

The length of plain pipe, while permitting scale and dirt to escape from the air pipe through the open end, secures a resisting head of water, and the air taking the line of least resistance passes through the small holes.

The end of the air pipe should not be plugged as is sometimes done, since the scale and dirt from the inside of the air pipe will eventually block up the small holes.

The point of entry of the air to the water should be several feet above the bottom of the rising main to avoid any danger of the air blowing up between the rising main and the casing or, where the casing is used as a rising main, between the casing and the side of the hole.

The total area of the small holes should be at least one and a half times that of the interior of the air pipe.

A further development of the principle of splitting up the air into fine streams is to drill a number of relatively large holes, say $\frac{3}{8}$ inch diameter, in the air pipe and cover these with fine wire gauze.

3. The arrangement of making the pipe separate from the rising main, with a footpiece, as shown on Pl. **91**, is probably the most efficient yet devised.

4. There are several methods of dealing with the **discharge**, three of which are shown on Pls. **92**, **93**, and **94**.

In any case, the discharge pipe conveying the air and water mixture should be as short as possible in order to reduce friction.

A long discharge pipe carrying a mixture of air and water very greatly reduces the flow of water.

Circumstances may, however, render it necessary to put in a long discharge pipe even at the expense of a considerable loss in efficiency. In one experiment a 4-inch pipe was used to convey the air and water mixture over half a mile, but the flow which was about 8,000 gallons at the bore-hole (without the half mile of rising main) was reduced to 3,000 gallons per hour at the end of the discharge pipe when the latter was connected up.

A method which may be employed in certain circumstances and which will result in an increased efficiency is that shown on Pl. **93**. Here the standpipe admits of the escape of the air, while sufficient head is given to allow of the air-free water flowing down the discharge main at the required velocity.

A further development of this principle is found in the so-called **Booster** pump, in which the standpipe shown on Pl. **93** takes the form of a receiver, as shown on Pl. **95**. The air valve is replaced by an air-escape valve which can be set to blow off at any desired pressure. The pressure remaining in the air on its arrival at the top of the rising main is made use of to force the water along the discharge pipe. A sketch of this apparatus is shown on Pl. **93**.

Where, however, any considerable height or length of discharge is to be encountered after the water leaves the well-head, some form of surface pump should be employed to boost the water on.

The airlift at best is of low efficiency, and it is desirable to keep the working lift, both static and frictional, as low as possible.

5. Every geological formation has its yield independent of all calculations of the usual formulæ for airlift. The formulæ subsequently given for airlift work can only be accepted as guides of the probable dimensions, &c., required, on the assumption that perfect conditions as regards yield are present, namely, unlimited flow of water.

Local conditions vary so much that the ultimate degree of efficiency possible can only be obtained after successive tests on the plant installed.

6. A preliminary design, however, can be based on the following information :—

(*a*) *Velocity of air in air pipe* should not exceed 30 feet a second, but whenever possible should be kept below 20 feet a second.

(*b*) *Admission of air to water* should be in fine streams, and can conveniently be through small holes not more than $\frac{1}{8}$ inch diameter. The total area of the holes should be at least $1\frac{1}{2}$ times that of the main air passage.

(*c*) *Position of point of entry of air with reference to bottom of rising main*, 10 to 20 feet above foot of rising main.

(*d*) *Ratio of volume of air to water raised.*—From formula—

$$Va = \frac{h}{C \log \frac{H + 34}{34}}$$

Where Va = Cubic feet of free air a minute (piston displacement) each gallon of water.

h = Working lift in feet (*see* Pl. **88**).

C = Constant.

H = Submergence in feet.

Values of " C " for various lifts are :—

10 to 60 feet	245
61 to 200 feet	233
201 to 500 feet	216
501 to 650 feet	185
651 to 750 feet	156

(*e*) *Submergence ratio.*—*See* curve on Pl. **96**. (This gives *working* submergence ratio.)

(*f*) *Velocity of mixture.*—Not less than 6 f.s. nor more than 25 f.s. It may be necessary to enlarge the rising main from bottom upwards.

(*g*) *Fall of water level while pumping.*—This can only be found by test. The difference between the starting and running pressures, after correction for air friction in air pipe, gives the drop in water level.

7. An **example** will show the application of the foregoing data.

Well.—Six-inch bore-hole in chalk—350 feet deep ; cased 100 feet.

Water level stands 100 feet from surface.

Plant available.—Compressor giving 60 cubic feet/minute (piston displacement) of free air at 100 lbs./ sq. in.

It is desired to work the compressor off the shafting of a factory situated $\frac{3}{4}$ mile from the well. Ample power is available.

Delivery from bore-hole.—The factory works 10 hours a day, and a maximum supply of 50,000 gallons a day is required.

A reservoir can be built near the bore-hole which will command a gravity supply over area to be supplied, and under these circumstances the delivery pipe from the well-head would be 250 feet long with a rise of 5 feet.

The following are the calculations required :—

Air volume.—In order to operate the compressor at its rated speed, the economical delivery of water can be found from the formula

$$Va = \frac{h}{C \log. \frac{H + 34}{34}}.$$

From examination of wells in the neighbourhood the fall in water level while pumping is assumed to be about 10 feet.

Assuming lift above ground to be (with friction over 250 feet of horizontal pipe) about 10 feet, total h is 120 feet.

From Pl. **96**, a 64 per cent. submergence should be adopted. The running submergence in feet will then be 213 feet.

$$\therefore Va = \frac{120}{233 \log. \frac{213 + 34}{34}}$$

$= 0{\cdot}597$ cub. ft. free air a minute each gallon of water.

Then economical delivery of water is about $\frac{60}{0{\cdot}597}$, or about 100 gals./ minute. This amount will be sufficient.

Air pressures.—The maximum total pressure will be air pressure equivalent to 223 feet of water (starting submergence) + pressure due to air friction in air pipe in well + pressure due to air friction in air pipe between factory and well.

At a velocity of 20 f.s. and delivery of 60 cub. ft./minute of free air compressed to about 100 lbs./sq. in., the smallest pipe that should be used is a little over 1 inch diameter.

Assume 1-inch air pipe in well, and $1\frac{1}{2}$-inch air pipe between compressor and well.

Between compressor and well (distance 3960 feet)

$$P_1^2 - P_2^2 = (114 \cdot 7)^2 - P_2^2 = 30 \cdot 48 \times 39 \cdot 6 \text{ (see Table I)}$$
$$= 1208$$
$$\therefore P_2^2 = 13120 - 1208 = 11912$$
$$\therefore P_2 = 109 \cdot 1 \text{ lbs./sq. in. abs. or } 94 \cdot 4 \text{ lbs./sq. in. gauge pressure.}$$

Then the air friction between compressor and well will be

5·6 lbs./sq. in.

For the loss in 323 feet of 1-inch piping—

$$P_1^2 - P_2^2 = (109 \cdot 1)^2 - P_2^2 = 224 \times 3 \cdot 23 \text{ (see Table I)},$$
$$\therefore P_2^2 = 11912 - 723$$
$$= 11189$$
$$\therefore P_2 = 105 \cdot 7 \text{ lbs./sq. in. abs. or } 91 \cdot 0 \text{ lbs./sq. in. gauge pressure.}$$

A submergence (starting) of 223 feet is equivalent to a pressure of 96·5 lbs./sq. in., and a running submergence of 213 feet is equivalent to 92·2 lbs./sq. in. With pipe sizes as stated this means running the compressor at pressures of respectively 5·5 lbs./sq. in. (approximately), (plus pressure due to starting inertia which will be small) and 1·2 lbs./sq. in. (approximately) above the rated figure for starting purposes and while running.

As, however, it is assumed that the water level is at its highest point having regard to seasonal variations, the slight overburden on the compressor can be accepted.

The compressor may now be put down, and the pipe-line to the well laid.

Size of rising main.—Equivalent volume of 60 cub. ft./minute free air (92·2 + 14·7) = 106·9 lbs./sq. in. absolute pressure—

$$= \frac{14 \cdot 7}{106 \cdot 9} \times 60 \text{ cub. ft./minute or } \frac{14 \cdot 7}{106 \cdot 9} = 0 \cdot 137 \text{ cub. ft./second.}$$

$$\text{Volume of water per second} = \frac{100}{60 \times 6 \cdot 25}$$
$$= 0 \cdot 267 \text{ cub. ft./second.}$$

Then total volume of mixture

$$= 0 \cdot 137 + 0 \cdot 267 = 0 \cdot 404 \text{ cub. ft./second at bottom of rising main.}$$

Assuming an initial velocity of 9 feet/second—

$$\text{Area required} = \frac{0 \cdot 404}{9} \text{ sq. ft.}$$
$$= \frac{0 \cdot 404 \times 144}{9} \text{ sq. ins.}$$
$$= 6 \cdot 46 \text{ sq. ins.}$$

Assuming that the central air pipe system is employed, the outside area of a 1-inch pipe is 1·33 sq. ins.

Then inside area of rising main

$$= 1 \cdot 33 + 6 \cdot 46 = 7 \cdot 79 \text{ sq. ins.}$$

The diameter of pipe to give this is between 3 and $3\frac{1}{4}$ inches.

Assuming a rising main of 3-inch uniform inside diameter be employed, this has an area of 7·068 sq. ins., and the velocity at the bottom is consequently increased to

$$\frac{0{\cdot}404 \times 144}{7{\cdot}068 - 1{\cdot}33} = \frac{0{\cdot}404 \times 144}{5{\cdot}738}$$

$$= 10{\cdot}1 \text{ feet/second.}$$

For the velocity at the top, the total volume is now

$$\frac{60}{60} + 0{\cdot}267 \quad = 1{\cdot}267 \text{ cub. ft./second;}$$

and velocity

$$= \frac{1{\cdot}267 \times 144}{5{\cdot}738}$$

$$= 31{\cdot}8 \text{ feet/second.}$$

This velocity is rather on the high side, so it will be advisable to enlarge slightly the rising main towards the top.

Taking the next larger size of pipe, viz. $3\frac{1}{2}$ inches, this would give a velocity of

$$\frac{1{\cdot}267 \times 144}{9{\cdot}621 - 1{\cdot}33} = \frac{1{\cdot}267 \times 144}{8{\cdot}291}$$

$$= 22 \text{ feet/second.}$$

This is within the limit, so a $3\frac{1}{2}$-inch rising main will be adopted for a certain proportion of the depth. The next point is to determine what proportion of the length should be $3\frac{1}{2}$ inches and what proportion should be 3 inches.

Pl. **97** shows velocity curves drawn by calculating velocities at various points for 3-inch and $3\frac{1}{2}$-inch rising mains. The most favourable point to make the change appears to be 188 feet from the bottom. The curve drawn in firm line is the resulting velocity curve.

The step-down in velocity where the change in section occurs will be a source of loss, and to lessen this the difference in pipe sizes should certainly not be more than $\frac{1}{2}$ inch. Nothing would probably be gained by inserting a tapered junction-piece.

The well can now be piped up, the bottom of the air pipe, &c., being arranged as on Pl. **90**, and final adjustment of submergence made when the actual drop of water level has been ascertained.

Discharge from well.—Some arrangement, similar to that shown on Pl. **93**, can be adopted to lead the water to the reservoir.

For the height of the standpipe—

Assume a 4-inch surface line, with no elbows :—

Friction head	=	3·61
$\frac{V^2}{2g}$	=	0.14
Static head	=	5·00
Total		8·75
Allow for air space at top	=	3·25
Height of standpipe	=	12·00 feet

8. In designing an airlift installation for a well the qualities of which are unknown, the most difficult quantities to estimate are :—

(*a*) The economical capacity of the well.
(*b*) The drop in water level when pumping.

Both the above particulars can only be ascertained with certainty by test, but when there are other wells of the same nature in the locality a fairly near estimation can be made.

If the drop in water level is plotted together with the delivery of water, it will usually be found that the resulting curve is a straight line up to a certain point, which denotes the economical capacity of the well, and after this point the curve is irregular. It will usually be advisable to work the well at its economical capacity, but it will generally be the case in the field that it is desired to obtain the maximum quantity of water possible from the well.

The drop in water level should be determined for the delivery at which it is intended to pump the well before the final arrangement of piping is made, since this figure affects the submergence ratio. In some cases the drop of water level is so great as to render it impracticable to work in a single lift.

If conditions permit a *compound lift* may be employed.

A two-stage lift is shown diagrammatically on Pl. **98.**

44. *The compressor and air mains.*

1. It is not intended here to enter into a detailed description of the many types of compressors on the market.

Information on this subject can be found in Military Engineering, Vol. VIII.

Compressors may be one or multi-stage, and it is generally considered economical to adopt single-stage compression up to about 80 lbs./ square inch and multi-stage after that point.

2. Instances of unsatisfactory operation of air compressor plant and disastrous explosions in receivers and air lines usually result from improper installation or negligence on the part of the attendant.

Location.—A clean and cool place should be selected with room to walk round and inspect the plant.

Foundation.—Should be designed with a view to absorbing the shocks to which a compressor is subject.

Receiver.—The functions of a receiver are :—

i. To act as a cushion.
ii. To serve as a storage of power.
iii. To cool the air, and precipitate any oil or moisture carried in entrainment.
iv. To reduce friction losses by cooling the air before it reaches the pipe-line.

The receiver should be located near the compressor and in a cool spot.

The receiver should be provided with pressure gauge, safety-valve, and blow-off cock.

Air-inlet piping.—The piping or conduit should have double the cross-sectional area of the compressor inlet opening, and be arranged so as to draw air as cool as possible and free from dust or grit. The point of entry of air should be outside the engine house and at least 6 feet from the ground. The inlet piping should have as few bends as possible.

Discharge piping.—The pipe connecting compressor and receiver should be at least of the diameter of the discharge opening of the cylinder, and should contain as few bends as possible.

No stop-valve should be placed between compressor and receiver.

Lubrication.—The same attention should be paid to the lubrication of the wearing parts as in the case of any other machine.

The lubrication of the air cylinder requires special oil, with an ignition-point depending on the degree of compression attained.

A compressor working at 70 lbs./ square inch will discharge air at a temperature of about 350° F. The ignition-point of common lubricating oil is about 295° F., and of common cylinder oil about 400° F.

The necessity for an oil of high ignition-point is thus apparent.

A scored piston or cylinder may allow air at discharge temperature to escape back to the suction side of the piston. On the compression stroke the temperature may be raised to an abnormal and dangerous degree.

All this shows the necessity of using a suitable compressor oil, and of supplying air as clean and cool as possible to the compressor.

A fusible alarm plug can be obtained for insertion in any pipe-line.

The amount of oil required for the cylinder may be gauged as follows :—

Cylinders 6 to 10-inch stroke	...	1 drop in 1 minute.
„ 12 to 16-inch „	...	3 drops „ 2 minutes.
„ 18 to 24-inch „	...	2 „ „ 1 minute.
Larger cylinders	...	3 to 5 drops in 1 minute.

Circulating water.—The object of circulating water is to facilitate lubrication of the air cylinder.

Care should be taken when installing the compressor that the circulation is satisfactory.

It is of advantage if the water outlet is in plain view of the operator. The circulating water should be clean, and its pressure should not exceed 50 to 60 lbs./square inch.

Water jackets should be drained after shutting down, if there is danger of frost.

Inspection and cleaning.—The compressor should be thoroughly inspected at stated intervals.

The points requiring special attention are the air-valves, ports, and passages. These should be slightly oily, and free from carbonaceous deposits.

The inside of the air cylinder may be cleaned effectively by filling the lubricator with a strong solution of soap and water, and feeding liberally throughout a day's run. At the end of the run, the lubricator should be filled with oil, and the compressor operated for a while.

Paraffin should never be used for cleaning the cylinder, on account of its low flash point.

The following instructions might well be posted in every compressor room :—

Every morning.

(*a*) Drain the receiver.
(*b*) Note the height of lubricating oil in the crank-case (or in oil cups), and replenish, if necessary.
(*c*) Adjust lubricator for proper amount of oil feed.
(*d*) Start circulating water.

Every week.

(*e*) Remove crank-case oil and filter.
(*f*) Remove and examine suction and discharge valves. If worn or cut, they should be ground to a tight fit.
(*g*) Test safety-valve by raising air pressure to point of blow-off.
(*h*) Take up lost motion in pins and bearings.

Every month.

(*i*) Renew crank-case oil, and thoroughly cleanse the inside of crank-case.
(*j*) Thoroughly inspect all parts, including air and water passages.

3. **Air friction and air mains.**—Most of the published tables giving air friction figures are incorrect, generally because the air is assumed to travel with uniform velocity through a pipe of uniform cross-sectional area.

The following table gives figures for moderate air deliveries which may be taken as reasonably accurate (*Pumping by compressed air.*—Iven's).

TABLE I.—*Air friction losses.*

Equivalent volume in cubic feet of free air a minute passing through pipe.	Size of pipe in inches.							
	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4
	$P_1^2 - P_2^2$ = difference in squares of initial and final absolute pressure, each 100 feet of pipe.							
50	150	49·2	20	4·8	—	—	—	—
75	335	98·5	46·2	10·5	—	—	—	—
100	600	197	79	18·8	6·15	—	—	—
150	1,350	443	178	42·2	13·8	5·5	—	—
200	2,400	788	316	75	24·6	9·9	2·0	2·4
250	3,750	1,230	494	117	38·5	15·4	7·1	3·6
300	5,400	1,770	711	168	55·4	22·2	10·3	5·3
400	9,600	3,150	1,263	300	98·3	39·5	18·2	9·4
500	15,000	4,920	1,978	470	154	62	28·5	14·6

As an **example**, suppose the following to be the data given :—

Volume of free air—100 cubic feet/minute.
Length of air main—2 miles.
Compressor working pressure—100 lbs./square inch.
Terminal working pressure—90 lbs./square inch.

It is required to find the size of the air main necessary.

$$\begin{aligned} P_1^2 - P_2^2 &= (114\cdot7)^2 - (104\cdot7)^2 \\ &= 2194 \text{ for } (2 \times 5280) \text{ feet.} \end{aligned}$$

Then

$$P_1^2 - P_2^2 \text{ per 100 f.r.} = \frac{2194 \times 100}{2 \times 5280} = 20\cdot75.$$

From the table it will be seen that a 2-inch pipe will be a suitable size. It does not follow, of course, that this is the most *economical* size to install for permanent work.

Transmission of power by compressed air offers many advantages in bore-hole work, since a range of bore-holes can be worked from a centrally situated compressor station. In this system, either of two methods of operation may be adopted.

In the first method, each well is worked separately for a certain period each day, and the compressor furnishes only sufficient air to work one well. The wells may be connected to the compressor by independent air mains, or may be teed off a common main with a valve at each well.

In the second method, all the wells are worked simultaneously, and the compressor furnishes enough air for the purpose. In this case, the delivery to each well is usually teed off a common main of suitable size to carry the requisite volume of air for the wells supplied.

The first method possesses the advantage that it is easily operated, and does not require adjustment of pressure at each well to take care of variations of water level (and consequently variations of submergence and working pressure).

Where, however, several wells are worked in order to obtain the united delivery of water from them all, the second method must be employed. It is rarely possible to adjust the submergences so as to obtain an equal working pressure at each well, so some form of pressure regulating valve on each air delivery must be provided.

It is desirable to insert a second cock, so that the well may be shut off without disturbing the setting of the regulating valve.

As regards laying air mains, it is most necessary that good joints should be made. Ordinary screw joint water pipe is quite suitable for moderate pressures.

The sealing compound should be applied to the male end of the joint, otherwise it is liable to be squeezed inside the pipe.

The pipe used should be clean, and care taken that dirt is not introduced during laying. In pronounced dips in the line a blow-out cock should be inserted to release any water that may collect, but this is only necessary in long lines.

A similar cock should be provided at the end of the line.

When the line is complete, it should be filled with air rather above working pressure, and examined for leaks—these are a fruitful source of loss of power. It is a good plan then to hammer the pipe well all along, and suddenly release the pressure. This will loosen and remove any scale remaining in the pipe.

Surface lines should have some provision for expansion. The best plan is to lay in a curve on supports that will not resist a slight movement. Expansion joints generally leak.

45. *Portable sets for use in the field.*

For work in the field, compressors may be made up in *sets* with engines, in the same way as pumping plant.

Pl. **99** shows a direct-coupled set specially designed for mounting on a lorry for use with the *compressor lorry system* (*see* Pl. **25**). Pl. **100** shows a less mobile set.

Pl. **101** shows a *compressor lorry* fitted up. If these lorries were specially designed for the purpose, the compressor would, of course, be driven electrically or mechanically from the lorry engine. The secret of successful working is to have an ample reserve of engine power.

CHAPTER X.

STORAGE.

46. *Choice of design.*

1. In nearly all semi-permanent schemes considerable storage of water is required. The main considerations affecting size and location of storage tanks are discussed in Chap. XI; in this chapter will be described the types and construction of the various tanks and reservoirs adopted in semi-permanent work.

2. The choice of type must be decided by labour and time available for construction.

In field operations there is usually plenty of unskilled labour, but little skilled labour available, and time is short. The centralized dug-in type of reservoir placed high up the slope of the hill is under such circumstances often the quickest, and involves little skilled labour. When time is of secondary importance, it may be better to subdivide the storage, and construct tanks on high stagings.

3. The following classes of storage are of application in the field :—

(*a*) Large capacity. Dammed reservoirs.
(*b*) do. do. Dug reservoirs.
(*c*) Medium capacity. Framed wooden tanks lined with canvas.
(*d*) Small capacity. Small tanks and cisterns.

47. *Dams.*

1. Dams of small size may often be of use in connection with semi-permanent water supply. In a suitable location, a considerable volume of water may be impounded with perhaps only a small amount of labour. Streams and rivers may often be dammed in order to conserve water in long reaches for use during dry periods. This system is particularly useful when the stream flows between high banks and is subject to periods of low water flow.

Dams built of masonry and concrete are outside the scope of semi-permanent work; timber and earth are the only materials that can conveniently be used. Timber dams are most suitable for use as weir-dams, that is, those over the crests of which water flows. Earth dams, on the other hand, will surely fail if any water whatever flows over them, unless specially constructed spillways are used.

2. **Timber dams** must be regarded as temporary structures only, and are seldom very water-tight.

For large timber dams, if the bottom is hard, cribs are weighted with stone and sunk directly on it; but if soft, loose stone should be placed over the bottom at the site of the dam, and allowed to settle as far as possible. This foundation should extend for some distance above and below the dam, and when levelled off the cribs are sunk upon it. The timbers should be as large as can be conveniently employed.

For small timber dams, such as would be feasible in semi-permanent work, the actual design must depend on the conditions of the case, but, in order to indicate the general methods employed, Pls. **102** and **103** should be studied.

3. An **Earthen dam** must never be used as a weir-dam, but a spillway must be constructed in connection with it. To be safe, an earthen dam must be so compact that no water can pass through it as a stream, however fine; further, there must be no continuous smooth surface, such as that of a pipe along which the water may flow.

Earthen dams have been built more than 100 feet high, but of course this scale of construction would not be necessary or possible in the field. Dams of heights up to about 20 feet in short lengths might, however, be built.

The inside slope of the bank should be 1 in 2, and the outside not more than 1 in 3 or 4. These slopes may have to be flatter if the soil is sandy in nature.

The top of the embankment should be at least 3 to 4 feet wide up to 10 feet high, and 6 to 8 feet wide up to 20 feet high.

The top of the embankment should be carried to 3 feet higher than the high-water level of the reservoir. On the outside slope drainage should not be neglected, and, if necessary, gutters must be constructed to carry it out. Pl. **104** shows typical sections of earthen dams as constructed in permanent practice.

4. The embankment can be made water-tight in three ways:—

(*a*) Ensuring that the embankment is of a sufficiently homogeneous material to prevent seepage through.

(*b*) The use of a core wall.

(c) Lining the interior face with water-tight material, such as puddle or concrete.

While the decision as to which method to adopt must be guided by materials and resources available, method (a) is generally the easiest, and for small reservoirs quite suitable, if good material can be obtained.

5. The first operation in the formation of the embankment will be to remove all surface vegetable soil, as well as any other material of a peaty, slippery, or compressible nature, and also any silt or earth which, when acted on by water, is liable to become quicksand. The ground on which the dam is built should be dug or ploughed up, so that old and new material may unite. The outer part of the embankment should rest on ground that is thoroughly drained, so that it may not be liable to saturation from moisture. Subsoil drainage is of great importance.

The following are the main essentials of the embankment :—

(a) Puddle or core wall (if used).
(b) Filling in of selected material.
(c) Filling in of the main body of the embankment.
(d) Turfing the exposed slopes and sides,
and in permanent work—
(e) Stone pitching on the inner face.

The core wall will not often be required in embankments of the heights contemplated in semi-permanent work. When it is thought that the material to be used for the body of the embankment is not good enough alone, the use of a timber or sheet-steel piling wall should be considered. If this is impracticable and a wall is really required, puddle may be used. The width of the puddle core at the bottom should be about one-third of the depth of the water it has to sustain.

There should be no sudden change from one kind of material to another; hence the puddle wall should be supported on either side by clay backing, well rammed, trodden, and watered. About 5 feet of this is required. Next the clay is selected earth of as uniform a consistency as possible, and of a clayey and retentive nature. Outside this selected earth, the harder, rougher, and less water-tight material is laid, all slippery clay, &c., being excluded from it, so that the outside slopes of the embankment may preserve their original inclination.

The whole of the embankment should be constructed in layers of 9 to 24 inches in thickness, or as thin as possible. No high tips must be allowed. Each layer must be continuous. It should dip towards the centre on each side, and as each layer is laid it should be consolidated by rolling.

The best material is a sandy loam with a small amount of clay intermixed, and the worst is micaceous clay. Clay alone is a bad material for embankments. Gravel, consisting of stones, sand, and loam, and capable of being puddled, makes an excellent embankment material.

The following mixture is recommended :—

Coarse gravel	$\frac{3}{4}$	cubic yard.
Fine gravel or coarse sand	$\frac{1}{4}$	,,
Fine sand	$\frac{1}{8}$	,,
Clay or loam	$\frac{1}{8}$	,,

The materials should be thoroughly mixed, the clay being cross cut into fine pieces, slightly damped, spread in 6 to 9-inch layers, and thoroughly rammed. Water should be used with discretion, the aggregate usually containing sufficient.

The bond between each successive layer of earth as put on should be thorough.

6. Circumstances alone can decide whether a core wall is necessary or not, but an earth embankment must never be placed on rock without a core wall.

Core walls may be made of puddle, masonry, or concrete, and in the case of very low banks, say up to 10 feet, of timber. The object of a core wall is merely to provide a water-tight partition; the core wall is not relied upon for the stability of the structure. The core wall must be well tied into not only the base of the dam, but also into the slopes at either end. This principle applies also when there is no core wall; not only the bottom but also the ends of a dam must make an impervious union with the natural soil. If there be no core wall, the ends of the dam should be extended into the sides of the valley for a distance equal to, say, 10 feet plus half its height. If impervious material be found, this distance may be reduced.

To prevent the percolation of water beneath the embankment, the puddle core is carried down vertically to an impervious stratum below, sometimes to great depths. The excavation for this is called the *puddle trench*. This must extend on both sides of the valley to a point above top water level, where it should tie into some water-tight stratum.

In older rocks, all the depth necessary will be to carry the trench below surface fissures into the compact rock below. In such cases it is well to remember to protect the flanks of the trench, so as to obviate the chance of water finding its way round. In stratified rocks, greater care must be taken, owing to the existence in many formations of water-bearing fissures. In all cases, while care must be observed to guard against all possible contingencies, the depth must be in proportion to the work required.

In the construction of a puddle trench, the bottom should not be stepped longitudinally, because the sudden unequal strains at the steps cause vertical cracks in the puddle. Hence the better practice is to avoid abrupt changes of depth in the long slopes by gradually changing the depth.

During the excavation of the puddle trench, springs may be tapped, and difficulty caused by water flowing into the trench down the sides. To obviate this special pumping arrangements must be made.

If a flood down the valley is anticipated, it is well to stop pumping, let the trench partly fill with water, and then, if the flood-water does overflow the top, it will fall on a water cushion, and do comparatively little damage. It can be pumped out afterwards.

It is very necessary that, where deep puddle trenches are constructed, very careful arrangements should be made for shoring.

7. **Puddle** is used for a variety of purposes in waterworks construction, the chief being the construction of heart or core walls for earth embankments. Puddle is also used for lining reservoirs, &c.

The essential condition for puddle is that it must be impervious to water; the important requisite for good puddle is that the original formation should be broken up, and a new arrangement of particles formed with the addition of water to fill up every pore. Tempering clay to form puddle is greatly facilitated by exposing it to the atmosphere, especially since climatic changes disintegrate the clay more thoroughly than even grinding it in a pug mill, and the labour of working it into puddle is much reduced.

The important requisites of clay for making good puddle are:—

(*a*) Tenacity or cohesion.
(*b*) Power of retaining water.

The tenacity of a clay for puddle may be tested by working up a small quantity with water into a thoroughly plastic condition, and forming it by hand into a roll about 1 to $1\frac{1}{2}$ inches in diameter by 10 to 12 inches in length. If such a roll is sufficiently cohesive not to break on being suspended by one end when wet, the tenacity of the material is ample. To test the power of retaining water, 1 to 2 cubic yards of clay should be worked with water, by the usual methods, to a compact homogeneous plastic condition; a hollow should then be formed in the centre of the mass capable of holding four or five gallons of water. After filling the hollow with water, it should be covered over to prevent evaporation and left for about two hours, when its capability of retaining water would indicate its suitability or otherwise for making puddle. No water should be lost in 2 hours if the puddle is good.

The operation of laying the puddle is as important as its composition. The workman should be provided with a spade curved like a cheese scoop. With this he should keep chopping the puddling stuff, giving it a lunging move every time he withdraws it, so as to let the water in and permeate throughout. If more water is required, another man supplies this as the puddler moves on. He goes on chopping and trampling over every inch of the ground till he gets to the end, when he returns and repeats the operation till the stuff is worked thoroughly up. When the spade passes with equal ease through every part of the stuff, which it will not do if there are hard dry lumps, the work is sufficiently done.

A proper supply of water is essential to this work, and it may be necessary to make special arrangements both for bringing water in ample quantity to the site of the work, and for draining off any surplus.

When the first course of 10 inches has become fairly solid, the second course of stuff (not thicker than 10 inches) may be laid on. Water is then applied, and the puddling recommenced, care being taken that the spade at every cut sinks through the upper to the lower layer, so as to bond them together. As puddle is apt to contract if exposed to the heat of the sun, it must be protected. Whenever possible men with previous experience in this class of work should be employed. The danger of using too much water, and thus producing a mass of semi-fluid mud, must be guarded against.

8. For **lining reservoirs and facing the up-stream sides of dams,** concrete is best, but the time required to lay large areas of concrete will probably not permit of the adoption of this system for semi-permanent work. From 4 to 8 inches of concrete would be used, and this may conveniently be reinforced with expanded metal to limit the tendency to crack. It must be noted, however, that the concrete is intended only as

a lining, the pressure of water being taken by the earth backing behind. Concrete dams and retaining walls are quite outside the scope of field operations.

Clay puddle can be used as a lining, but is not very satisfactory. The proportions for the puddle are as recommended in para. 5.

This should be put on in 4-inch layers and well tamped, the total thickness being 1 to 3 feet according to the depth of water. When possible, the clay lining should be protected from injury.

Bitumen can be used when obtainable, being placed either on concrete or puddle, or directly on the earth. The elastic and easily repairable qualities of asphalt make it a very suitable lining when it can be obtained.

The first coat should be liquid bitumen which will take root in the foundation soil. The object of this coating is to secure adhesion with the ground, but it cannot stand the heat of the sun. The second, or sunproof coat, should consist of hard rock asphalt heated up to 300° Fah. and applied hot.

The exact method of applying the bitumen depends on the particular grade used, and should for each case be made the subject of local experiment.

A mixture of stone and pitch might profitably be employed as a lining, if available.

9. The outlets from reservoirs made in the field, of heights up to, say, 15 feet, may most conveniently be made with a C.I. or W.I. pipe of sufficient diameter, laid in a trench round and several feet away from the end of the embankment. The pipe should not be laid through the embankment, or leakage will be certain to occur. This pipe should be laid in as narrow a trench as can conveniently be made, and the trench should be filled with good puddle well packed round the pipe. If the pipe can be provided with flanges every 3 or 4 feet, so much the better, in order to prevent leakage.

An alternative way to arrange the outlet is to construct a siphon over the top of the dam, but siphons are apt to give trouble unless some arrangement is made to remove air, and this introduces complications.

10. Some form of **waste weir** is absolutely essential. For temporary dams these can best be made of timber. The object of a waste weir is, of course, to relieve the reservoir of abnormal quantities of water, which would otherwise flow over the top, and, if the latter is made of earth, wash it away with disastrous results. Masonry dams are sometimes made in permanent practice, to provide for the flood-water being got rid of in this way. In semi-permanent dams, this method is only possible in the smallest sizes, such as dams of 4 or 5 feet high and a few feet only in width. Even in this case, if the dam is of earth, the down-stream face of the dam should be protected with iron or timber sheathing.

The normal water level being known, the approximate rate of discharge of flood-water must be ascertained. Using the tables for the flow through a rectangular notch, given in Sec. 22, the approximate dimensions for the waste weir outlet can be determined. It will not usually be possible to estimate the flood discharge very accurately, so the waste weir must be made amply large enough to take any possible flood. Calculation will, however, give some idea of the dimensions required, which can be increased according to the accuracy of the data.

The waste weir is best made of timber for temporary purposes and rectangular in section. It must be provided with external flanges at about 3 feet centres to prevent leakage past it, and must be well bedded in puddle. A means of regulating the flow is required, and can be made easily with boards fitting in vertical slots. These boards, in the larger sizes, are apt to stick, and some mechanical arrangement is necessary to lift them if there is a head of water on one side. An adequate arrangement can be rigged up with some iron and a long steel screw.

11. When the construction of dams more than about 15 feet in height is in question, expert advice should be obtained, and the standard text-books on the subject consulted.

For purely temporary purposes and when a river or stream is required to be dammed in a hurry, dams may be constructed of sandbags filled with earth. A large amount of labour will be required, and the working parties must be carefully organized.

A footbridge to carry two single files of men walking in opposite directions should first be constructed along the centre-line of the dam.

If bags can be filled on both sides of the river, four parties should be detailed, viz.:—One party filling bags, and one party carrying and depositing the bags on each side of the river. The carrying parties each receive their bags from alternate sides of the river. With ample labour, a river can be quickly dammed in this manner. A timber sluice-way must be provided at the top of the dam to provide for overflow of the water, **which must not flow over the top of the sandbags.**

For small streams, a sandbag dam, revetted both sides with corrugated iron and pickets wired together, may be useful, as shown on Pl. **102**, Fig. 2.

48. *Dug reservoirs.*

1. If the soil is suitable, dug reservoirs can be unlined; otherwise they must be lined with puddle or other material, as already described. If used for drinking water, it is always preferable to line reservoirs in some way. By far the quickest form of lining is with tarred canvas, as described for framed tanks (*see* Sec. **49**). The same remarks made therein apply to the lining of dug tanks except that they can be made deeper; properly tarred sailcloth sheets with an earth backing will stand a head of five feet of water for months without leakage.

Pls. **105, 106,** and **107** show various constructions and arrangements of reservoirs. It will be noticed that the sides are made with a slope, which will depend on the natural angle of repose of the soil; those shown are for ordinary loam soil. The bottom of the tanks should be made with a fall to a washout connection in the form of a bowl-shaped depression.

2. A more durable lining can be made of reinforced concrete 4 to 6 inches thick. This pattern is, moreover, unaffected by frost, a disadvantage from which the canvas-lined variety suffers. Concrete linings, however, unless very carefully made and well backed up behind, are apt to crack and let the water through. A good clay puddle behind the concrete, say, 12 inches thick, will assist in preventing leakage.

3. Instead of canvas or concrete, the reservoir can be lined with locally available bricks laid in lime mortar and covered with bitumen. If

bricks are scarce, the face of the excavation can be plastered with mud, and, when this has dried, covered with bitumen. A backing of clay puddle will, as in the previous case, assist in keeping the reservoir water-tight.

4. It is especially to be noted in the descriptions given in preceding sections of various ways of lining reservoirs that the lining is intended only as a water-tight medium for transmitting the water pressure to the earth backing.

Reinforced concrete or masonry reservoirs, in which the strain due to water pressure is taken up by the strength of the material, are usually outside the scope of the field water engineer, and, if constructed, must be designed according to the rules of permanent practice.

5. Special arrangements may be necessary for climates in which exceptional frost occurs, or for use above the snow line in mountainous country.

Pl. **108** shows a type of tank that has been constructed for this purpose.

49. *Ground level and raised tanks.*

1. **Sectional pressed-steel tanks** are made up in sections and bolted together, with a strip of lead or some other jointing material in the joints.

The cast-iron patterns are much heavier than the pressed-steel type, and their utility is not to be compared with the latter for semi-permanent purposes.

The **Piggott** pressed-steel tank is shown on Pl. **109.**

These tanks take some time to assemble (say, two man days each 1,000 gallons of capacity), but are suitable where a good lasting job is required.

Pressed-steel tanks can be mounted on stagings with greater facility than other types.

A typical structural steel-work staging is shown on Pl. **110.**

For any extensive and organized semi-permanent water supply operations, provision should be made for a standard supply of these tanks and steel stagings in vertical bays of about 10 feet.

Typical improvised stagings for pressed-steel tanks are shown on Pls. **111** and **112.**

2. For **framed wooden tanks** a waterproof lining must be provided of tarred canvas or tarpaulins. This construction is of very useful application in the field. If the sheets are tarred properly they may be expected to last up to two years; their replacement is a simple matter. The chief advantage of their use is the rapidity with which considerable storage can be obtained. Tarpaulins will usually be supplied ready tarred, but if this has to be done on the spot the following is the way it should be carried out:—

(*a*) Sheets should be tarred under cover.
(*b*) The sheet should be spread on a hard surface, and brushed over to remove dirt before applying the tar.
(*c*) The tar can be spread on the sheet most conveniently by means of a tar-spraying machine. When this is not available, a long-handled tar brush should be used.

(*d*) The tar must then be rubbed into the sheet by means of a hand scrubbing brush.

As little tar as possible should be applied in each coat.

The object is to get the tar well into the pores of the material, and not to give the sheet a skin of tar.

The tar must be used boiling.

(*e*) When the sheet has been tarred one side, it must be hung up to dry under cover.

It must be quite dry before the next coat is applied.

(*f*) The process is repeated until each side of the sheet has been tarred three times.

Common mistakes are :—

(*a*) The tar used is not boiling, and thus adheres only in patches.
(*b*) A tar brush with hardly any bristles is used.
(*c*) Men walk about in muddy boots on the sheet while tarring it.
(*d*) The sheet is tarred in the open, and rain falls in the middle of the process.
(*e*) The second coat is applied before the first is properly dry, and the result is a slimy coating of partially dried tar which never dries at all.
(*f*) Sometimes in order to save the trouble of tarring the sheet properly, the sheet is fixed in the tank and then tarred all over inside, and the water leaks under the folds.
(*g*) Sheets are filled with water before properly dry, and, even if the sheets are dry, the first filling of water is run into the supply mains instead of to waste, resulting in complaints of the taste of the water.

3. Pl. **113** shows method of construction for raised canvas tanks. The construction depends, of course, on the sizes of the sheets and materials available. It is not generally advisable to make the tank more than about 3 feet deep. It is important that the canvas be quite slack, and it must not bear on any sharp edge or nails. The sides of the tank must be well strutted, and there should be a light footboard all round for cleaning purposes. Raised tanks as shown should always have a washout connection fitted and a light cover to keep out dust and flies.

4. Ground level framed tanks can be made as shown on Pl. **114**. Convenient sizes are :—

(*a*) 8,000 gallons—using a 30′ × 30′ tarpaulin ; and
(*b*) 2,000 gallons—using a 2,300-gallon waterproof tank.

5. When **bricks** are plentiful sunk tanks may be constructed as shown on Pl. **115**. A light roof of timber framework supporting a rabbit wire and hessian canvas covering should be provided. The canvas should be tarred to keep dust from working through, and a manhole fitted to allow access for cleaning.

It is possible to build a tank of this type in seven days.

The materials required for the tank shown are :—

Cement	Tons, 1½.
Bricks	Number, 2,000.
Rabbit wire	Square feet, 1,150.
Canvas	” ” 750.
Timber, 4″ × 2″	F.r., 220.

50. *Small tanks, cisterns, and fitments.*

1. The **Service pattern waterproof tanks** (*see* Chap. II and Pl. **2**) are made of canvas impregnated with rubber. They are made in two sizes, nominally 2,300 and 1,500 gallons, but in practice only storages of 1,500 and 1,000 respectively can be obtained. This pattern of tank does not require tarring, but if it is to last must be carefully erected, no strain being thrown on the canvas. A solid and level floor is desirable, and care must be taken in cleaning. These tanks are most suitable for hasty and temporary purposes, as shown on the plate. They are not suitable for use in the tropics owing to the rubber in the fabric quickly perishing.

2. All tanks and reservoirs, whenever possible, should be provided with connections for washout and overflow, and dust-proof covers.

Indicators for showing the level of water in the tank are useful; when tanks are supplied from a pump-house some distance away, an electrical indicator can be placed in the latter to show the progress of filling the tank.

3. The galvanized steel tank of commerce is a useful article for small amounts of storage. Where the expenditure is likely to be heavy, as in field operations, the tanks can be painted instead of galvanized (for cheapness). A coat of cement wash inside is an improvement.

Several of these tanks, up to, say, four, may be grouped and connected with pipes, as a single storage, but above this number it is simpler to construct some other form of single tank.

Pl. **116** shows suitable dimensions and particulars of mild steel cisterns. For sizes below 150 gallons, these cisterns are often made round and of corrugated iron. The same type of construction is often adopted for larger sizes.

The French army water service use standard tanks of 1,000 and 500 gallons capacity, made circular and of riveted steel. These form very handy tanks.

4. Small cisterns for storage and transport of water can be made locally of green Willesden canvas stretched over *rabbit netting* inside a wooden frame of 3″ × 2″ timber; 50 and 100 gallons capacities are useful sizes. Water can be drawn off from the bottom by a long canvas pipe, the end of which during movement is fastened to the top of the casing. Alternatively, bib-cocks can be fitted.

Various ways of making the framework will suggest themselves. One variety has been made cylindrical of wooden slats fastened together by piano wires run through them.

CHAPTER XI.

DISTRIBUTION SYSTEMS.

51. *General principles.*

1. In this chapter will be considered the general arrangement of the system by which the water is delivered to the consumer. The fundamental principles involved are the same, whether the system supplies a small camp or a large town.

2. Any distribution system may consist of the following :—

(*a*) The source.
(*b*) Means of conveying and distributing the water.
(*c*) Storage.

and where (*a*) is insufficiently elevated

(*d*) A pump or pumps.

3. The functions of storage, apart from storage considered as an integral part of the arrangements at the source of supply, are as follows :—

(*a*) To provide against a breakdown of the pumping machinery.
(*b*) To ensure a constant static head on all parts of the distribution system.

4. When the source of supply is not high enough above the area of consumption to ensure a sufficient supply by gravity, an artificial head must be produced by pumping.

5. The combination of the above four components may, in general, be effected by one of three distinct systems given below, or by a combination of them all.

The three distinct systems of distribution are :—

(*a*) The **direct system.**
(*b*) The **indirect system.**
(*c*) The **direct-indirect system.**

The three methods are shown diagrammatically on Pls. **117, 118, 119,** and **120.**

6. In the **direct system of distribution** the water either gravitates into the distribution system from a sufficiently elevated source, or is pumped direct into the mains by means of a pump. The amount of storage in this case amounts solely to that provided at the source. With a gravity supply, if the distributing channels follow the hydraulic gradient, they can be open, as, for example, an irrigation system; for ordinary purposes they will be pipes under pressure.

When a pump is used with this system, immediately the pump stops work the pressure falls to zero or to that due to the head of water remaining in the pipes above the point under consideration. A duplicate pump must, therefore, always be provided to ensure a constant supply.

In some cases it is difficult to keep the pump pressure constant while it is working, and in others it is difficult to keep the delivery proportionate to the number of draw-offs which are open at the time. Unless careful governing of the prime-mover is ensured, it may result that when a large draw-off near the pump is open the pump tends to race. Again, it may happen that all draw-offs are shut except a small one far from the pump, when excessive pressures may ensue. The results of these occurrences, the likelihood of which has been alluded to in general terms, are that a variable pressure is set up within the system leading to the troubles incidental to *water hammer*, and that adequate control of the amount of water passing through a draw-off becomes difficult. These difficulties tend to increase, generally speaking, in the inverse ratio to the size of the system.

As the design of rotary pumps becomes more perfected, however, it will probably be possible to combine this class of pump with variable speed prime-movers in such a way that a variable delivery can be obtained at a constant pressure and, moreover, at a constant efficiency. Speed regulation could be obtained by an automatic pressure regulator from the delivery side of the pump. The variation in delivery might be obtained by parallelling two or more pressure chambers as required.

At the present time, however, such plants are not of general application for semi-permanent purposes, and, except in large systems, the practice of pumping direct into the mains must be considered as a makeshift and unsatisfactory arrangement.

7. The **indirect system of distribution** is the one generally employed in both permanent and semi-permanent work. Essentially it consists of a pump and a *virgin* rising main from the pump with an overfeed into a raised reservoir at such an elevation that it will feed by gravity, at the desired rate, the whole area under supply.

The rising main has generally no draw-offs, although, of course, the system may be extended by using the same rising main to supply several reservoirs. In this case suitable means of control must be arranged to ensure that each reservoir gets its share of the supply. Such means of control may be automatic, but in semi-permanent work will generally have to be manual.

8. In the **direct-indirect system** the rising main to the reservoir is used also as a distributory main, and distribution connections are taken off it. The rising main is connected to the bottom of the reservoir, which thus acts as a kind of water cushion and to some extent as a pressure regulator. When the rate of draw-off from the system exceeds the delivery of the pump, the water in the reservoir supplies the deficiency. Conversely, the water level in the reservoir is raised.

9. The selection of the best system to adopt in any particular case must be determined by the local conditions. Generally speaking, the direct system is adopted only for purely gravity supplies, or, if pumping has to be resorted to, when the system is of considerable size. It is almost always safe to say that in semi-permanent work a direct pumping system should never be employed.

The choice between the indirect and the direct-indirect systems will be chiefly determined by whether high ground exists in a suitable position for adopting the indirect system. The indirect system is certainly the most satisfactory, since it ensures a constant head on the system. Where, however, the area to be supplied lies between the pump and the high ground, the direct-indirect system is generally preferable in order to eliminate the return gravity main.

When the area covered by the distribution system is small and fairly flat, the system may be indirect in character, but consisting of several reservoirs on built stagings fed from the same rising main, with either a separate distribution from each or with the distribution from each mutually interconnected.

There are innumerable ways of planning a distribution system, and the plan can really only be settled on the merits of each case and by actual inspection of the site.

10. Where the supply at the source is adequate, the expense of a large reservoir can often be saved by the use of a standpipe situated either at the pumping station or on high ground. The function of a standpipe of relatively small cross-section is thus solely to give constant head to the system, and the other function of storage, viz., that of guarding against breakdown of plant, must be provided for by providing sufficient stand-by plant. The latter procedure, especially with up-to-date plant, will in extensive systems be much easier than the provision of a large reservoir; the standpipe method in such cases often fulfils excellently the required conditions. (*See* Pl. **120.**)

A development of the standpipe system is to replace the standpipe at the pumping station by an air vessel or an accumulator with an automatic controlling device on the prime-mover. Such plants are not yet, however, in a sufficiently advanced state of development to justify their adoption for work in the field. (*See* Pl. **118.**)

52. *Conduits and mains.*

1. The three ways, other than by transportation, by which water can be delivered from place to place are:—

For relatively large quantities—
- (*a*) Closed conduit.
- (*b*) Open conduit.

For relatively small quantities—
- (*c*) Pipes under pressure.

2. Closed conduits of masonry or concrete will not be feasible in semi-permanent practice on account of the time required for construction.

3. Open conduits might sometimes be constructed where considerable volumes of water have to be dealt with. Open conduits must follow the hydraulic gradient (*see* Sec. **66**), and this fact may limit their use unless it is possible to carry out the necessary earthwork or take them over valleys on piers.

If the general longitudinal grade is steeper than that permissible for the conduit, an occasional drop can be made in the latter, the necessary *falls* being constructed to allow of this.

The simplest form of open conduit is a dug canal. The chief objection is loss by seepage, which will vary according to the nature of the ground. The methods adopted in permanent work to check this, such as puddling or lining the canal with masonry, &c., will not be possible in semi-permanent work. It may occur, however, when labour is plentiful and the initial supply of water sufficient, that dug canals will afford the best means of conveying the water to the required spot.

The velocity of flow should not exceed :—

2 feet a sec. in sandy soil ;
3 ,, ,, in firm loam or clay ; or
5 ,, ,, in brickwork, wood or sheet-metal flumes.

The banks must be 12 to 18 inches higher than the highest water level.

In calculating the cross-sectional area, allowance must be made for evaporation and seepage, and the final flow must equal the maximum rate of consumption unless an impounding reservoir is provided.

The shape of the cross-section of a dug canal varies according to the nature of the soil, but in ordinary soil the side slopes are generally $1\frac{1}{2}$ in 1 with a flat bottom.

Where an open conduit takes the form of a wooden flume, the construction is similar to that shown on Pl. **121** or **122**, the size of scantlings being in accordance with the size of the flume. Flumes should not, if possible, be supported on made ground, and the sills should be raised above ground and supported on solid stone, brick, or concrete foot blocks; or for more temporary work timber piles, trestles, or cradles may be used.

4. The third class of conduit comprises pipes under pressure, and this is by far the most usual method of conveying water. The different classes of pipe are dealt with in Chap. **XII**.

53. *A small temporary camp supply.*

1. In the case of a small force of, say, 400 men, camped on the banks of a stream for one or two nights, the water supply arrangements must be given the same attention as in more comprehensive schemes, although, of course, the same amount of work will not be possible. Piping will be out of the question, unless the camp is occupied by successive parties when it becomes a staging camp ; the case of a staging camp is similar to that of a standing camp (*v. seq.*).

2. Pls. **123** and **124** are intended to show the guiding principles in arranging a scheme of water supply for a small force encamped on the banks of a stream. In both cases a force of 400 men and 300 horses is assumed. Pl. **126** represents more complete arrangements, water being raised from the stream by a lift and force pump and stored in 108-gallon barrels and in tanks.

Service horse-troughs, 33 feet long, are available for watering horses.

The water required by the force would probably be for one day :—

Men's drinking and cooking	400	gallons.
Men's washing	1,200	,,
Horses' drinking	2,400	,,
	4,000	,,

3. In the temporary camp (Pl. **123**), the men's drinking and cooking water can be pumped up and stored in the water-carts by means of the lift and force pumps. **The water must be chlorinated.**

Horses will have to drink from the stream, in which case adequate arrangements must be made.

Men must bathe or wash in the stream below the horses' watering place, but there will be no objection to men filling buckets and biscuit tins from the stream above the horses' watering place.

Pl. **124** shows a case in which rough-and-ready means of distributing the water are adopted. Improvised camp water supply accessories, including sand filters for clarifying water before chlorinating, wooden shoots, and a field siphon, are shown on Pl. **125.**

4. With means of storage available it will be necessary to consider at what times of the day the various supplies of water will be required. A suitable arrangement for the scheme shown on Pl. **126** would be as follows:—

		Gallons.
Early morning	all men's drinking and cooking water ...	400
	$\frac{1}{2}$ men's washing water	600
	$\frac{1}{3}$ horses' drinking water	800
		1,800
Midday... ...	$\frac{1}{3}$ horses' drinking water	800
Evening	$\frac{1}{2}$ men's washing water	600
	$\frac{1}{3}$ horses' drinking water	800
		1,400

It will be seen from Pl. **126** that storage is provided for 400 gallons of drinking and cooking water by means of four 108-gallon casks; two more 108-gallon casks are provided to store the chlorinated water.

Two small iron tanks, each capable of holding about 300 gallons, are placed near the men's washing places from which men can fill their basins.

One lift and force pump will supply the 600 gallons required in under one hour.

Allowing 4 feet frontage each horse and 5 minutes each horse to drink, 400 horses will require $\frac{400}{12} \times 4 = 133$ feet run of trough or four 33-foot service troughs, if one hour is allowed for the watering, and watering is done from one side only.

If horses are watered from both sides at once, troughs will best be at right angles to the bank. In this case two troughs will suffice to water the horses in one hour, and with four troughs watering could be done in half an hour. Barriers will have to be arranged to mark the entrances and exits.

The troughs easily hold the water required, and two pumps working for three-quarters of an hour will easily supply 800 gallons, so that there is no necessity to replenish the supply during watering.

Suitable fatigue parties for the camp under consideration, allowing 4 men to each lift and force pump, would be as follows :—

Overnight or early morning, 16 men for one hour, to pump up men's drinking and cooking water, horses' drinking water, and men's washing water into storage.

Midday, 8 men for one hour, to pump up horses' drinking water.

Evening, 12 men for one hour, to pump up horses' drinking water and washing water.

54. *Standing camps.*

1. More extensive engineering work is required for a standing camp than for a temporary camp, but the water supply for a standing camp in the field is probably one of the easiest problems that the field water engineer is likely to encounter. The existence of a satisfactory source of water supply is a *sine qua non* in settling the site of a camp, but is, indeed, sometimes forgotten.

2. The scale on which a piped water supply is provided depends on the permanence or otherwise of the camp and available labour and material. The actual practice involved is dealt with in other chapters.

It is a mistake, unless it is known that the camp is to be relatively fairly permanent, to embark at the outset on too lavish a scheme. On the other hand, the dimensions of pipes and plant should be on the large scale, so that extensions or extra connections may be easily made. When the indirect system of distribution is selected, storage should be ample, at least one day's supply being provided. It is best in this case to provide one suitably placed storage tank rather than a number of small ones. In very large camps, however, this will not usually be possible. A site for a storage tank should be sought for on rising ground, if such exists ; it is easier to lay a reasonable amount of extra pipe than to build tank stagings. Similarly, it may be feasible to sink a bore-hole on elevated ground discharging direct into the tank, rather than site the bore-hole in a valley and pump up. This entirely depends on the circumstances.

3. In the more permanent camps, water will be piped on to all cook-houses, ablution rooms, bath-houses, &c., and in addition L. of C. camps may require water-borne sewage and fire supply. It must be remembered that all water supplied must be got rid of in some way, involving some form of drainage system. Drainage considerations are dealt with in Military Engineering, Vol. VII.

For comparatively temporary camps a few standpipes are all that can be provided. For a 1,000-bed casualty clearing station (under canvas with the exception of a few huts), a 9,000-gallon canvas tank raised 15 feet and supplying a 2-inch ring main will be found satisfactory ; standpipes would be placed in the vicinity of officers', nurses', and men's cookhouses and ablution benches, and water piped into the operating theatre.

4. For fire protection much larger mains are necessary than are required for ordinary domestic supply, and in nearly all semi-permanent schemes, when hydrants are to be supplied, the extra pressure required for fire fighting purposes must be supplied by pump power rather than by gravity.

Each hydrant to be in use simultaneously requires a delivery of 120 gallons per minute, and the ordinary War Department standard practice is to cover each building by two hydrants.

In case of a large Base Park it might be necessary to allow for as many as six hydrants to be in use.

Where pressure is sufficient to allow a residual head at the jet sufficient to cover all buildings and stores, no fire engines are necessary; where this cannot be arranged, the supply for fire engines has to be considered, and this may require from 120 gallons a minute for a manual engine up to 1,000 gallons a minute for a large motor engine.

Frequently a supply from a canal or pond may be used to save a large outlay on fire mains.

55. *A large permanent camp scheme.*

1. The scheme illustrated on Pls. **127, 128, 129, 130,** and **131** is an example of one actually carried out, and shows the scale on which such work may be required.

2. The camp was for 10,000 men, and an estimated consumption of 15 gallons a head each day gives 150,000 gallons a day as maximum estimated requirements.

3. There was no source of pure water within reach, and a small and muddy stream running through the camp was the only supply. This was dammed above the camp, as shown on Pl. **127.**

No mechanical filtration plant being available, direct sedimentation by alum followed by chlorination was resorted to.

Two sedimentation tanks of 50,000 gallons capacity each allowed for an output of 150,000 gallons of clean water a day, the sedimentation period being about 8 hours including time required for filling.

Two similar pumps of capacity each 120 gallons/minute/500 feet were provided, and their pipe connections arranged so that either could pump crude water into the sedimentation tanks or from the chlorinating tank along the up main into the high level reservoir. Emptying the sedimentation tanks into the chlorinating sump was effected by gravity, and the water fell over splash boards for aeration purposes.

4. The high level reservoir was a dug-in canvas-lined one of 50,000 gallons capacity, and could have been enlarged if necessary.

The distribution system was, as shown on the plates, a variety of the direct-indirect system.

The method of calculating pipe sizes for similar schemes is given in Chap. XIII.

CHAPTER XII.

PIPEWORK AND FITTINGS.

56. *Nature of pipes suitable.*

1. For most purposes W.I. screwed and socketed piping will be suitable, and **their threads must be British Standard.**

Pipes may be of wrought iron (W.I.), cast-iron (C.I.), or lead. On account of their weight and the time required for jointing, the two latter are not suitable for work in the field, but small bore lead pipe is useful for interior work. A description of the standard C.I. pipes, &c., will be given since W.I. pipes may not always be available. For notes on lead pipe *see* Sec. **60**.

In permanent practice pipe-lines are classified as *mains* and *service connections*. In semi-permanent work the pipe has often to partake of the character of both classes. In English permanent practice W.I. mains are seldom laid in sizes larger than 2 inches diameter, because 3-inch C.I. pipe is cheaper than 2-inch W.I. pipe and suffers less from corrosion. American and semi-permanent practice may use W.I. welded mains up to 12-inch diameter.

Riveted steel and reinforced concrete mains up to 5 feet diameter and wood stave pipes are used for large quantities of water, but such cases are outside the scope of semi-permanent work.

When steel or W.I. pipes are to remain any time in the ground, investigation should be made as to the chances of excessive external corrosion.

For military work abroad or in the field and for all kinds of temporary work, the weight and rapidity with which a pipe-line can be laid are the ruling factors in the selection of the class of pipe and nature of joint to be used.

For work in the field it is desirable to limit the numbers of sizes of pipes and fittings held in stock, and the sizes found by experience to cover most requirements are 1-inch, 2-inch, 4-inch, and 6-inch.

2. **Wrought iron pipes** are known in the trade as *tubes*, and, as a rule, are formed by welding. They are obtainable in three qualities, graded by strength, for use with *steam*, *water*, and *gas* respectively. They can be had black (*i.e.*, with the iron uncoated), galvanized, or coated with Angus Smith's solution, though this last is rarely used except on cast-iron pipes. (*See* Sec. **61**, para. 9.)

Pipes are made of the following internal diameters :—$\frac{1}{8}$-inch, $\frac{1}{4}$-inch, $\frac{3}{8}$-inch, $\frac{1}{2}$-inch, $\frac{3}{4}$-inch, 1-inch, $1\frac{1}{4}$-inch, $1\frac{1}{2}$-inch, $1\frac{3}{4}$-inch, 2-inch, $2\frac{1}{4}$-inch, $2\frac{1}{2}$-inch, $2\frac{3}{4}$-inch, 3-inch, $3\frac{1}{2}$-inch, 4-inch, $4\frac{1}{2}$-inch, 5-inch, $5\frac{1}{2}$-inch, 6-inch, and larger.

Certain sizes are more generally used than others. The makers' catalogues comprise the items listed below, which are illustrated on Pl. **132**. All these are in common use. They are divided into *tubes* and *fittings*. Tables **J(i)** and **J(ii)** give properties of British standard W.I. pipes for water.

3. The following are made from straight lengths :—

(*a*) *Tubes.*—Straight pieces in various lengths from 2 to 14 feet. Screwed at each end, the joints being completed by sockets with female screws.

(*b*) *Pieces.*—Straights under 2 feet long.

(*c*) *Long screws.*—Straight pieces with extra long screws so that the socket can be run right back to clear the end of the pipe. These connectors are put in at intervals in a long run of piping so as to avoid unscrewing a long length of pipe if later connections have to be made. They are also used for repairs.

A backnut is usually fixed with these.

(*d*) *Bends* are ready made to certain radii (about 20 sizes varying from $1\frac{1}{2}$-inch to 20-inch internal radius, and 4 inches to 40 inches long). If a bend is made with rather an angular turn instead of a curve, it is called a *spring*.

Slight bends can be made on the site by cold-bending a tube. Hot-bending can be used for bigger bends, but heat spoils galvanizing.

4. The following are special fittings :—

(a) *Unions.*—Sockets or pipe.
(b) *Elbows.*—Square or round.
(c) *Tees.*—All three pipes can be of one diameter, or with the stem of different diameter from the cross-piece.
(d) *Crosses*, with all four pipes of one diameter, or with two pairs of different diameter.
(e) *Sockets.*—Plain and diminishing.
(f) *Caps* for closing a pipe-end.
(g) *Plugs* for closing a socket-end.
(h) *Backnuts* are used with long screws to prevent back movement of the socket and leakage.
(i) *Nipples* for making junctions when a hole is tapped in a main for a branch pipe.
(j) *Flanges* for connections to tanks, &c.

5. Water pipes able to withstand a hydraulic test up to 300 lbs. sq. inch (= 690 feet head) will be approximately of the weights given in Table **J(ii)**. They should not be used for heads higher than 300 feet. As gas piping is often mixed with water piping in storing, the weights of gas piping are given for comparison. Gas piping is only tested to 50 lbs. sq. inch (= 115 feet head).

There is not yet a British standard specification for wrought iron tubes and fittings. There are, however, British standard specifications for the threads on the pipe-ends and also for pipe flanges.

Tables **J(i)** and **K** give particulars of these quantities, and this subject is again referred to.

6. **Screw-threads.**—Definitions.—*Gauge diameter.*—The gauge diameter is the full diameter of the standard male parallel screw gauge which the parallel coupler, to be used with a pipe of that size, is required to fit.

The following definitions of the elements of a screw-thread, shown on Pl. **133**, Figs. 1 and 2, apply equally to parallel pipe threads :—

Effective diameter of a screw.—The effective diameter of a screw, having a single thread, is the length of a line drawn through the axis and at right angles to it, measured between the points where the line cuts the slopes of the thread (Pl. **133**, Fig. 1).

Core diameter.—The core diameter is twice the minimum radius of a screw, measured at right angles to the axis (Pl. **133**, Fig. 1).

NOTE.—From Pl. **133**, Fig. 1, it will be seen that the core diameter of the male thread is measured between the roots of the thread; it should be borne in mind, however, that the core diameter of the female thread, being approximately the same dimension, is measured between the crests of the thread.

Full diameter.—The full diameter is twice the maximum radius of a screw measured at right angles to the axis (Pl. **133**, Fig. 1).

Crest.—The crest is the prominent part of the thread, whether of the male screw or of the female screw (Pl. **133**, Fig. 2).

Root.—The root is the bottom of the groove of the thread, whether of the male screw or of the female screw (Pl. **133**, Fig. 2).

Slope of thread.—The slope of the thread is the straight part of the thread which connects the crest and root (Pl. **133**, Fig. 2).

Angle of thread.—The angle of the thread is the angle between the slopes, measured in the axial plane (Pl. **133**, Fig. 2).

Pitch.—The pitch is the distance in inches measured along a line parallel to the axis of the screw between the point where it cuts any thread of the screw and the point at which it next meets the corresponding part of the same thread (Pl. **133**, Fig. 2). The *reciprocal of the pitch* measures the number of turns per inch.

The Whitworth form of thread is adopted for all iron and steel tubes manufactured in accordance with Table **K.**

In the Whitworth form of thread the angle between the slopes, measured in the axial plane, is 55°; the threads are rounded equally at crests and roots, leaving a depth of thread approximately equal to 0·64 of the pitch.

For simplicity, the depth so derived has been approximated in Table **K,** and the depths there given are to be regarded as the standard depths.

All threads for iron or steel pipes and tubes, purporting to be of British standard dimensions, have the gauge diameters, core diameters, and number of threads per inch given in Table **K,** and all threads of Class I (*see* below) have correct positions of gauge diameters as defined in Columns 9, 10, and 11 of that table.

Nominal sizes of bores for iron or steel tubes are contained in the first column of Table **K.** All iron or steel tubes, purporting to be of British standard dimensions, have approximately the outside diameters given in Column 2 of the table.

Couplers and fittings for the tubes are manufactured to the *gauge diameter, form and length of thread* shown, and each coupler or fitting should be capable of being screwed by hand to a standard male screw shop gauge, and when screwed thereon should have no perceptible shake: the standards laid down with regard to the threads in couplers apply equally to elbows, tees, fourways, valves, &c.

Two classes of *screwed connections* between tubes and couplers are recognized, viz.:—

Class I.—The taper screw.
Class II.—The parallel screw.

In Class I the screw at the pipe-end is conical, being coned one-sixteenth of an inch ($\frac{1}{16}$ inch), measured on the diameter, per inch of length.

The screw in the coupler may be either parallel or conical, as required. The common form of coupler has a parallel thread, and is screwed on to a conical pipe-end; conical couplers are sometimes employed where exceptionally good fits are required.

In order to ensure that the pipe-ends shall not butt against each other within the coupler, and that a sufficient *length of thread* is comprised in each joint:—

(*a*) The length of thread within the couplers is not less than twice the length of thread on the pipe-ends, *i.e.*, not less than the values given in the table (Column 8).

(*b*) The length of thread within the screwed portion at the end of any fitting (other than flanges) is not less than the minimum length of thread on the corresponding pipe-end (Column 7).

The *length of thread* on the pipe-end in Class I and Class II is given in Column 7 of Table **K.**

In Class II the screws at the pipe-end and in the coupler are both parallel to the axis of the pipe throughout the whole length of the thread.

All iron and steel pipes and tubes made in accordance with the sizes given in Table **K** are known as *British standard iron or steel pipes and tubes*, and the screws on the pipes and tubes and in the couplers as *British standard pipe threads for iron or steel pipes and tubes* (*B.S.P.*).

Gauges.—For the purposes of manufacture two classes of male and female screw gauges are used, viz. :—

Class A.—Reference gauges.
Class B.—Shop gauges.

The male reference gauges are copies of the standard male screw gauges deposited with the National Physical Laboratory, and are intended for use by manufacturers and others when checking their own shop gauges (Class B).

The shop gauges, both male and female, are used by manufacturers to determine the accuracy of the work itself.

Gauge diameter (*taper screw, Class I*).—In order to ensure correct gauging, it is necessary to define the position of the gauge diameter on the pipe-end and in the coupler. The position of the gauge diameter on the pipe-end is shown on Pl. **133,** Fig. 3, and is defined by Columns 9, 10, and 11 of Table **K,** while the position of the gauge diameter in the coupler or fitting is at the outer end of the thread either for parallel or conically screwed couplers or fittings.

Gauging the pipe-end (*taper screw, Class I*).—For shop purposes gauges of the type shown on Pl. **133,** Fig. 4, are used.

The width of the gauge is ·9L, where L is the length of the thread on the pipe-end as given in Column 7 of Table **K.**

The distance apart of the surfaces A and B for any given size is the difference between the values of the figures in Columns 10 and 11 of Table **K,** and is approximately one-third of the standard distance of the gauge diameter from the end of the tube (Column 9).

This gauge, having a plain internal conical surface, is slipped over the pipe-end, and, when pressed home by hand, the pipe-end must protrude beyond the surface A but not beyond the surface B.

For checking the accuracy of the pitch and form of thread, a comb gauge should be employed.

Gauging the pipe-end (*parallel screw, Class II*).—*Go* and *Not go* plain cylindrical ring gauges should be employed, bearing on the full diameter of the screw.

For checking the accuracy of the pitch and form of thread, a comb gauge should be employed.

Gauging the couplers and fittings (*parallel screw, Class II*).—For gauging the gauge diameter in the coupler or fitting, *Go* and *Not go* threaded gauges should be employed, having a sufficiently acute angle of thread to bear only on the roots of the thread in the coupler.

Gauging the couplers and fittings (*taper screw, Class I*).—For gauging couplers and fittings having taper screws, a threaded plug gauge of the type shown on Pl. **133**, Fig. 5, should be employed, having a sufficiently acute angle of thread to bear only on the roots of the thread in the coupler.

The width of the gauge is ·9L, where L is the length given in Column 7 of Table **K**. The distance apart of the surfaces C and D is the difference between the values of the figures in Columns 10 and 11 of the Table, and is approximately one-third of the standard distance of the gauge diameter from the end of the tube (Column 9). When the gauge is screwed home by hand, the surface C must pass inside the coupler, while the surface D must remain outside.

The foregoing information has been given in some detail in view of the absolute necessity for pipe threads of standard and correct dimensions.

TABLE **J(i)**.—*Dimensions of British standard pipe flanges for working steam pressures up to 55 lbs. a square inch and for water pressures up to 200 lbs. a square inch.*

This Table does not apply to boiler feed pipes, or other water pipes subject to exceptional shocks.

1	2	3	4	5	6	7	8	9
Internal diameter of pipe.	Diameter of flange.	Diameter of bolt circle.	No. of bolts.	Diameter of bolts.	Thickness of flanges.			Internal diameter of pipe.
					Cast-iron, with steel or iron welded on.	Cast-steel and bronze	Stamped or forged wrought iron or steel.	
ins.	ins.	ins.		ins.	ins.	ins.	ins.	ins.
½	3¾	2⅝	4	½	½	⅜	3/16	½
¾	4	2⅞	4	½	½	⅜	3/16	¾
1	4½	3¼	4	½	½	⅜	3/16	1
1¼	4¾	3 7/16	4	½	⅝	½	¼	1¼
1½	5¼	3⅞	4	½	⅝	½	¼	1½
*1¾	5½	4½	4	½	⅝	½	¼	*1¾
2	6	4½	4	⅝	¾	9/16	5/16	2
2½	6½	5	4	⅝	¾	9/16	5/16	2½
3	7¼	5¾	4	⅝	¾	9/16	⅜	3
3½	8	6½	4	⅝	¾	9/16	⅜	3½
4	8½	7	4	⅝	⅞	11/16	⅜	4
*4½	9	7½	8	⅝	⅞	11/16	7/16	*4½
5	10	8¼	8	⅝	⅞	11/16	½	5
6	11	9¼	8	⅝	⅞	11/16	½	6
7	12	10¼	8	⅝	1	¾	½	7

* These sizes are not generally used.

TABLE J(i)—*continued.*

1	2	3	4	5	6	7	8	9
Internal diameter of pipe.	Diameter of flange.	Diameter of bolt circle.	No. of bolts.	Diameter of bolts.	Thickness of flanges.			Internal diameter of pipe.
					Cast-iron with steel or iron welded on.	Cast-steel and bronze.	Stamped or forged wrought iron or steel.	
ins.	ins.	ins.		ins.	ins.	ins.	ins.	ins.
8	13¼	11½	8	⅝	1	¾	½	8
9	14½	12¾	8	⅝	1	¾	⅝	9
10	16	14	8	¾	1	¾	⅝	10
*11	17	15	8	¾	1⅛	⅞	⅝	*11
12	18	16	12	¾	1⅛	⅞	⅝	12
*13	19¼	17¼	12	¾	1⅛	⅞	¾	*13
14	20¾	18½	12	⅞	1¼	1	¾	14
15	21¾	19½	12	⅞	1¼	1	¾	15
16	22¾	20½	12	⅞	1¼	1	¾	16
*17	24	21¾	12	⅞	1⅜	1⅛	⅞	*17
18	25¼	23	12	⅞	1⅜	1⅛	⅞	18
*19	26½	24	12	⅞	1⅜	1⅛	⅞	*19
20	27¾	25¼	16	⅞	1½	1¼	1	20
21	29	26½	16	⅞	1½	1¼	1	21
*22	30	27½	16	1	1½	1¼	1	*22
*23	31	28½	16	1	1⅝	1⅜	1⅛	*23
24	32½	29¾	16	1	1⅝	1⅜	1⅛	24

* These sizes are not generally used.

Bolt holes—For ⅝-inch and ¾-inch bolts the diameters of the holes to be $\frac{1}{16}$ inch larger than the diameters of the bolts, and for larger sizes of bolts ⅛ inch. Bolt holes to be drilled off centre-lines.

TABLE J(ii).—*Weights of W.I. water and gas piping.*

	½-in.	¾-in.	1-in.	1¼-in.	1½-in.	2-in.	
Water pipe..	·896	1·268	1·833	2·598	3·237	4·128	lbs. a ft. run ungalvanized.
Gas pipe	·818	1·165	1·653	2·367	2·973	3·786	
Water pipe....	2,430	1,730	1,240	850	680	540	ft. to the ton.
Gas pipe	2,660	1,900	1,330	910	730	—	

TABLE K.—*British standard pipe threads.*
Schedule of sizes.

1	2	3	4	5	6	7	8	9	10	11
Nominal bore of tube.	Approximate outside diameter of black tube.	Gauge diameter (*see* definition.)	Depth of thread.	Core diameter, measured at same distance from end of pipe as the gauge diameter.	Number of threads per inch.	Length of thread. On pipe-end. Min.	Length of thread. In coupler. Min.	Distance of gauge diameter from pipe-end. (Class I. taper screw.) Standard.	Distance of gauge diameter from pipe-end. (Class I. taper screw.) Max.	Distance of gauge diameter from pipe-end. (Class I. taper screw.) Min.
ins.	ins.	ins.	in.	ins.		ins.	ins.	ins.	ins.	ins.
1/8	13/32	0·383	0·0230	0·337	28	3/8	3/4	5/32 (0·1563)	0·18	0·13
1/4	17/32	0·518	0·0335	0·451	19	7/16	7/8	3/16 (0·1875)	0·22	0·16
3/8	11/16	0·656	0·0335	0·589	19	1/2	1	1/4 (0·2500)	0·29	0·21
1/2	27/32	0·825	0·0455	0·734	14	5/8	1 1/4	1/4 (0·2500)	0·29	0·21
5/8	15/16	0·902	0·0455	0·811	14	5/8	1 1/4	1/4 (0·2500)	0·29	0·21
3/4	1 1/16	1·041	0·0455	0·950	14	3/4	1 3/8	3/8 (0·3750)	0·44	0·31
7/8	1 7/32	1·189	0·0455	1·098	14	3/4	1 1/2	3/8 (0·3750)	0·44	0·31
1	1 11/32	1·309	0·0580	1·193	11	7/8	1 3/4	3/8 (0·3750)	0·44	0·31
1 1/4	1 11/16	1·650	0·0580	1·534	11	1	2	1/2 (0·5000)	0·58	0·42
1 1/2	1 29/32	1·882	0·0580	1·766	11	1	2	1/2 (0·5000)	0·58	0·42
1 3/4	2 5/32	2·116	0·0580	2·000	11	1 1/8	2 1/4	5/8 (0·6250)	0·73	0·52
2	2 3/8	2·347	0·0580	2·231	11	1 1/8	2 1/4	5/8 (0·6250)	0·73	0·52
2 1/4	2 5/8	2·587	0·0580	2·471	11	1 1/4	2 3/8	11/16 (0·6875)	0·80	0·57
2 1/2	3	2·960	0·0580	2·844	11	1 1/4	2 1/2	11/16 (0·6875)	0·80	0·57
2 3/4	3 1/4	3·210	0·0580	3·094	11	1 3/8	2 3/4	13/16 (0·8125)	0·95	0·68
3	3 1/2	3·460	0·0580	3·344	11	1 3/8	2 3/4	13/16 (0·8125)	0·95	0·68
3 1/4	3 3/4	3·700	0·0580	3·584	11	1 1/2	3	7/8 (0·8750)	1·02	0·73
3 1/2	4	3·950	0·0580	3·834	11	1 1/2	3	7/8 (0·8750)	1·02	0·73
3 3/4	4 1/4	4·200	0·0580	4·084	11	1 1/2	3	7/8 (0·8750)	1·02	0·73
4	4 1/2	4·450	0·0580	4·334	11	1 5/8	3 1/4	1 (1·0000)	1·17	0·83
4 1/2	5	4·950	0·0580	4·834	11	1 5/8	3 1/4	1 (1·0000)	1·17	0·83
5	5 1/2	5·450	0·0580	5·334	11	1 3/4	3 1/2	1 1/8 (1·1250)	1·31	0·94
5 1/2	6	5·950	0·0580	5·834	11	1 7/8	3 3/4	1 1/4 (1·2500)	1·46	1·04
6	6 1/2	6·450	0·0580	6·334	11	2	4	1 3/8 (1·3750)	1·60	1·15
7	7 1/2	7·450	0·0640	7·322	10	2 1/8	4 1/4	1 3/8 (1·3750)	1·60	1·15
8	8 1/2	8·450	0·0640	8·322	10	2 1/4	4 1/2	1 1/2 (1·5000)	1·75	1·25
9	9 1/2	9·450	0·0640	9·322	10	2 1/4	4 1/2	1 1/2 (1·5000)	1·75	1·25
10	10 1/2	10·450	0·0640	10·322	10	2 3/8	4 3/4	1 5/8 (1·6250)	1·90	1·35
11	11 1/2	11·450	0·0800	11·290	8	2 1/2	5	1 5/8 (1·6250)	1·90	1·35
12	12 1/2	12·450	0·0800	12·290	8	2 1/2	5	1 5/8 (1·6250)	1·90	1·35
13	13 3/4	13·680	0·0800	13·520	8	2 5/8	5 1/4	1 5/8 (1·6250)	1·90	1·35
14	14 3/4	14·680	0·0800	14·520	8	2 3/4	5 1/2	1 3/4 (1·7500)	2·04	1·46
15	15 3/4	15·680	0·0800	15·520	8	2 3/4	5 1/2	1 3/4 (1·7500)	2·04	1·46
16	16 3/4	16·680	0·0800	16·520	8	2 7/8	5 3/4	1 7/8 (1·8750)	2·19	1·56
17	17 3/4	17·680	0·0800	17·520	8	3	6	2 (2·0000)	2·33	1·67
18	18 3/4	18·680	0·0800	18·520	8	3	6	2 (2·0000)	2·33	1·67

7. Though **cast-iron pipes** are not likely to be used in most temporary water supplies owing to their weight and the difficulty of jointing them, particulars are given below for reference if required.

Cast-iron pipes are of three kinds :—

(*a*) Straight spigot and socket pipes and special castings (bends, tees, &c.) with plain sockets. The joints must be run with lead or lead wool to complete them.

(*b*) Straight spigot and socket pipes with half-turned spigots and bored sockets. The joints are a tight fit and need no lead.

(*c*) Straight flanged pipes.

The first kind are much the most common in all work, and the second kind need never be used in temporary work. Flanged pipes might be used for the immediate connections to pumps, &c., but not in the mains generally. They would usually be supplied with the pumps. Only the first kind are dealt with here.

There is a British standard specification for cast-iron pipe. Pipes already in existence will not necessarily conform to this, but are likely to do so fairly closely. In future most English pipes are extremely likely to be in accordance with this specification. The tables that follow are based on it, but they only refer to pipes up to 10 inches. C.I. pipes are made up to 48 inches. Fuller details are available in the pamphlet published by the British Engineering Standards Association.

There are four thicknesses of pipe made, and the pipe is classed as A, B, C, or D accordingly. The external diameters are kept constant so as to make jointing easy between different thicknesses, therefore the nominal internal diameters actually vary slightly.

Classes A, B, C, and D are tested for 200, 400, 600, and 800 feet head of water respectively. Class A is designed for gas work only, the others for water or sewage. **Working pressures should not exceed half the test pressures.** Water and sewage pipes will always be coated internally and externally with Angus Smith's composition—a black bituminous covering. Gas pipes are coated externally only.

Pipes made to this specification will have a special mark, as shown on Pl. **134**, cast on them. This gives the class letter, then, in a rectangle, the standard specification brand and maker's name, and lastly the year of manufacture. On special castings, usually termed *specials*, there will be further marks cast on :—on bends, the nominal internal diameter and angle ; on tees and branches, the nominal internal diameter of the main body and of the branch ; on tapers, the nominal internal diameter at each end ; on collars, the nominal internal diameter of the pipe for which they are intended.

Weights will usually be marked in oil paint on the inside of the sockets. The permissible deviation usually allowed in pipes up to 12 inches diameter is about 4 per cent.

TABLE L (i).—*Cast-iron pipes. Straight spigot and socket, with plain sockets.*

Nominal internal diameter, inches.	3	4	5	6	7	8	9	10
External diameter, inches	3·76	4·80	5·90	6·98	8·06	9·14	10·20	11·26
Thickness (ins.), gas pipe, Class A	0·38	0·39	0·41	0·43	0·45	0·47	0·49	0·52
Thickness (ins.), water and sewage, Class B	0·38	0·39	0·41	0·43	0·45	0·47	0·49	0·52
Thickness (ins.), water and sewage, Class C	0·38	0·40	0·45	0·49	0·53	0·57	0·60	0·63
Thickness (ins.), water and sewage, Class D	0·40	0·46	0·52	0·57	0·61	0·65	0·69	0·73
Depth of socket, ins.	3	3	3½	3½	3½	4	4	4
Weight (lbs.); length 9 ft., exclusive of depth of socket, gas pipe, Class A	129	172	228	286	345	416	485	566
Water and sewage pipe—								
Class B	129	172	228	286	345	416	485	566
Class C	129	175	246	318	395	488	574	666
Class D	134	196	276	359	444	544	644	753
Weight (lbs.); length 12 ft., exclusive of depth of socket—								
Class A	—	222	294	368	446	536	625	730
Class B	—	222	294	368	446	536	625	730
Class C	—	227	318	411	512	631	743	863
Class D	—	255	359	467	577	706	837	979

The above thicknesses and external diameters apply also to standard flange pipes. The weights above apply to both plain socket and to turned spigot and bored sockets, but flanged pipes of similar lengths (but in their case *measured over the flanges*) are slightly lighter.

TABLE L (ii).—*Cast-iron pipes. Standard bends.* (*See* Pl. **134**.)

Nominal internal diameter. Inches.	90°			45°		22½°		11¼°	
	Dimensions.			Dimensions.		Dimensions.		Dimensions.	
	A.	C.	R.	F.	R.	F.	R.	F.	R.
	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.
3	1 0	0 6	0 9	2 4	2 0	2 4	4 0	2 4	8 0
4	1 3	0 6	1 0	2 4	2 0	2 4	4 0	2 4	8 0
5	1 3½	0 6	1 0	2 7	2 3	2 7	4 6	2 7	9 0
6	1 6½	0 6	1 3	2 7	2 3	2 7	4 6	2 7	9 0
7	1 6½	0 7	1 3	2 9	2 6	2 9	5 0	2 9	10 0
8	1 10	0 8	1 6	2 10	2 6	2 10	5 0	2 10	10 0
9	1 10	0 9	1 6	3 0	2 9	3 0	5 6	3 0	11 0
10	2 1	0 10	1 9	3 0	2 9	3 0	5 6	3 0	11 0

TABLE L (iii).—*Cast iron pipes. Tees—branches—tapers.* (*See* Pl. 134.)

Nominal internal diameter.		Standard tees.		Standard 45° branches.			Tapers.
		Dimensions.		Dimensions.			Dimensions.
D1.	D2.	E.	G.	E.	F.	G.	E.
ins.	ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ins.
3	3	3 0	0 5	3 0	0 10	0 10	—
4	3	3 0	0 6	3 0	0 11	0 11	6
—	4	3 0	0 6	3 0	1 0	1 0	—
5	3	3 0	0 6	3 0	1 0	1 0	6
—	4	3 0	0 6	3 0	1 0	1 0	6
—	5	3 0	0 7	3 0	1 1	1 1	—
6	3	3 0	0 7	3 6	1 0	1 1	6
—	4	3 0	0 7	3 6	1 1	1 1	6
—	5	3 0	0 7	3 6	1 2	1 2	6
—	6	3 0	0 7	3 6	1 3	1 3	—
7	3	3 0	0 7	3 6	1 1	1 1	—
—	4	3 0	0 8	3 6	1 2	1 2	6
—	5	3 0	0 8	3 6	1 2	1 3	—
—	6	3 0	0 8	3 6	1 3	1 3	6
—	7	3 0	0 8	3 6	1 4	1 4	—
8	3	3 6	0 8	3 6	1 1	1 2	—
—	4	3 6	0 8	3 6	1 2	1 3	—
—	5	3 6	0 8	3 6	1 3	1 3	—
—	6	3 6	0 8	3 6	1 4	1 4	6
—	7	3 6	0 8	3 6	1 5	1 5	6
—	8	3 6	0 8	3 6	1 5	1 5	—
9	3	3 6	0 8	3 6	1 2	1 3	—
—	4	3 6	0 9	3 6	1 3	1 4	—
—	5	3 6	0 9	3 6	1 4	1 4	—
—	6	3 6	0 9	3 6	1 4	1 5	6
—	7	3 6	0 9	3 6	1 5	1 5	—
—	8	3 6	0 9	3 6	1 6	1 6	6
—	9	3 6	0 9	3 6	1 7	1 7	—
10	3	3 6	0 9	4 0	1 3	1 4	—
—	4	3 6	0 9	4 0	1 3	1 4	—
—	5	3 6	0 9	4 0	1 4	1 5	—
—	6	3 6	0 9	4 0	1 5	1 6	—
—	7	3 6	0 9	4 0	1 6	1 6	—
—	8	3 6	0 9	4 0	1 6	1 7	6
—	9	3 6	0 10	4 0	1 7	1 7	6
—	10	3 6	0 10	4 0	1 8	1 8	—

Table L (iv).—*Cast-iron pipes. Standard collars.* (*See* Pl. **134**.)

Nominal internal diameter of pipe.	Dimensions.		
	H.	P. Classes A and B.	P. Classes C and D.
ins.	ins.	ins.	ins.
3	9	$4\frac{5}{8}$	$4\frac{5}{8}$
4	9	$5\frac{11}{16}$	$5\frac{11}{16}$
5	$10\frac{1}{2}$	$6\frac{13}{16}$	$6\frac{13}{16}$
6	$10\frac{1}{2}$	$7\frac{7}{8}$	$7\frac{7}{8}$
7	$10\frac{1}{2}$	$8\frac{15}{16}$	$8\frac{13}{16}$
8	12	10	10
9	12	$11\frac{1}{16}$	$11\frac{1}{16}$
10	12	$12\frac{1}{8}$	$12\frac{1}{8}$

8. **Fittings.**—It should be noted that it is very false economy, even in a temporary installation, to use unreliable and bad quality fittings. The leakage through bad fittings can be very considerable ; in a small scheme the waste from a few fittings may mean a large proportion of the legitimate consumption. The water lost through leakage costs just as much per gallon as the water otherwise consumed, and being continuous soon runs away with much more money than good fittings would cost.

The principal fittings required to regulate the water come under the headings :—*stop-cocks* (or *stop-valves*), *bib-cocks* (or *taps*), and *ball-cocks*.

An important point about all these fittings is that they should not be capable of shutting off the flow very suddenly. The sudden closing of the waterway, causing what is called *water hammer*, may result in a momentary increase of pressure in the pipe to three or four times the ordinary residual head, and burst pipes or strained fittings may be the consequence. The connections for fittings are made in two different forms to fit lead or iron pipes respectively.

Cocks and valves are fitted with two kinds of turning arrangement : the familiar T-shaped handle, or the nut-ended spindle for use with a spanner or key when it is not desirable that anyone but an authorised person should use the cock.

A *stop-cock* or *stop-valve* is one placed in the course of a main or branch main to stop or regulate the flow. The old type was a *plug-cock* in which a quarter-turn of the plug, containing the port through which the water passed, could completely shut off the flow. This was objectionable for the reasons stated above. Another defect was that particles of grit in the water inevitably caused wear in the plug, and led to poor fit between the plug and its seating. When that occurred, the cock leaked continuously. Plug-cocks are still obtainable, but should never be used.

The modern types are usually something of the kind illustrated on Pl. **135**. The water passes through a horizontal orifice, and, though this means that there is not a clear run through, the loss of head at the bend is insignificant. The main points are that the disc which closes the opening is screwed down on to it gradually, and that the disc is given a little horizontal play on its spindle, so that uneven wear tends to adjust itself. Stop-cocks should be so fitted that the flow of water is *upwards* through the horizontal orifice.

Stop-cocks outside buildings, being 3 feet or so underground, need some kind of housing to make them accessible and to protect them. This is done in permanent practice by building a small pit with half-brick or concrete walls, the top being closed in with a cast-iron surface box, or plain lid. A piece of 6-inch or 9-inch diameter stoneware pipe makes an efficient pit, if its edge is suitably supported at the base. To prevent tampering with the flow, these stop-cocks are usually fitted with a nut-headed spindle and are turned by a long spanner-ended turnkey. Inside buildings the cock usually has the handle head. In temporary work a wooden valve box is used.

For the larger pipes, full-way stop-valves can be obtained. They can be fitted with wheel-handle or nut-head.

Bib-cocks, taps, or draw-offs are the fittings through which water is drawn. Except that there is a curved spout, their general features are the same as those of stop-cocks. Two or three types are illustrated. It is an additional advantage if the tap can be unscrewed for renewing the valve packing without having to turn off the water at the main. In Guest and Chrimes tap only the upper valve disc can be removed; the water pressure on the other closes the orifice while repairs are being made. In Lord Kelvin's tap a non-corrodable spring prevents the screw being tightened up too forcibly, and a loose disc ensures uniform wear and tight meeting surfaces.

Push-taps are a special form of bib-cock often found in lavatories, &c. In theory they remain open only when the finger is pressed against the button, the idea being to prevent the tap being left running. In practice the spring very often works imperfectly, and then there is continual dripping. The advantage claimed for this type that it checks waste is, therefore, very doubtful, and they stop the flow somewhat suddenly, which is a disadvantage.

Ball-cocks are used for automatically regulating the flow into cisterns. The floating ball working on a lever arm closes the tap when the cistern is full. They are extremely liable to stick as the closing force is slight at the top of the rise. A large proportion of ball-cocks, therefore, are always wasting water, and they should only be used sparingly. Ball-cocks are supplied up to about 2-inch. Above this size automatic water-level valves working on the same principle can be obtained.

The number of slightly different designs in all the above fittings is legion. Most of the variations in design are of minor importance. The main point is to see that the taps used are simple in action, close gradually, and are well and solidly made of good brass or gun-metal.

Reflux-valves, or flap-valves, automatically close when a break in the main occurs, and the flow reverses its direction. They are usually necessary on a long pumping main.

Air-valves are necessary at the summit of all long undulations in a pipe-line, if there are no other taps where air can escape. A collection of air in vertical bends is inevitable after a time, as water is always aerated to a certain extent. The air collected considerably impedes the flow of water. Special automatic air-valves are made for large mains. A short vertical branch with a cock at its lower end and screw-plugged at the other does quite well for small mains.

Sluice-valves.—These fittings are of the same design as stop-valves. The name sluice-valve is used in large schemes for those valves at the lower ends of mains for the purpose of completely emptying them if necessary. In small mains a stop-cock, or even a plug, will suffice. All long mains should have them in the valleys to enable silt to be cleared out. A combined stop-cock and sluice-valve is frequently used for buildings.

9. **Hose** is generally made either for suction *or* delivery, but varieties may be obtained which can be used for either.

Hose is made of various materials, such as canvas, rubber, leather, impregnated canvas, &c. When obtaining hose for any particular purpose, the points to ensure are :—

(*a*) It must be strong enough for pressure anticipated.
(*b*) If for suction purposes, it must be constructed so as not to collapse under external atmospheric pressure.
(*c*) The material must be suitable for character and temperature of liquid handled.
(*d*) Couplings must agree with connections with which used, and for field purposes would be screwed *British standard pipe thread.*

Canvas hose is liable to deteriorate if coiled up wet, and should, therefore, be dried before coiling. The most useful sizes are 2 inches and 4 inches. Delivery hose should generally be *armoured* in some way.

Flexible bends are particularly useful for rapid connections to pumps, &c., to save pipe fitting. Flanged or screwed connections can be used. Flexible bends should be provided of diameters to agree with standard sizes of mains.

57. *Laying and jointing W.I. screwed pipe.*

1. The following is a general specification for laying and jointing W.I. screwed pipe :—

(*a*) *Location of trenches for mains.*—All trenches must be dug as far as possible in straight lines, the angles being formed with square or easy bends. If pipe is laid in a curve, the curve must be regular and of large radius. The curve must be such that the pipe does not require the application of undue force to adapt it to the curve.

Where pipe is laid over shell-holed or rough ground, cover must be obtained by an alternation of cut and fill.

The bottom of the trench must be smoothly graded. It is best to avoid level stretches as these collect air.

(*b*) *Protection of formation.*—If there is any chance of the formation (where the pipe is banked over) being used as a track, barbed wire or other obstacles should be erected over the covering at intervals.

(*c*) *Anchorages.*—Substantial anchorages must be placed on all slopes over 1 in 10 for pipes over 4 inches diameter.

(*d*) *Frost protection* (*temperate climates*).—A minimum of 3 feet cover of earth is to be given to water pipes, and 1 foot to pressure air mains. When filling in, the smaller stuff should be selected for filling in immediately round the pipes.

All exposed water piping is to be lapped to a thickness of 3 inches round the pipe with straw or sawdust. The whole will then be covered with canvas, well bound with wire, and tarred.

Valve boxes will be filled with sawdust to a minimum depth of 12 inches above the pipe, but the wheels of stop-valves will be left exposed.

Where pipes are exposed at ditch crossings, the pipe must be enclosed in a water-tight box with 6 inches of manure all round the pipe, and the level of the pipe so adjusted that the ditch flow can pass underneath the pipe.

Where a pipe crosses a marshy place or a place likely to be flooded it must be raised on trestles and lapped as described above.

The rising main of an airlift after it leaves the well need not be lapped, providing that it is self-emptying.

(e) *Jointing.*—Pipes are to be screwed right home in the socket; red lead and oil, or *graphite compound*, are to be used on all joints. An equal amount of thread must be caught by the socket on the two pipes.

The protection rings supplied on the ends of new pipes must be saved for protecting the ends of salved pipes.

Whenever a pipe-end is left open while laying, it must be plugged.

Care must be taken that no dirt is allowed to remain in any pipes laid.

(*f*) *Valve chambers.*—All valves and fittings requiring inspection will be enclosed in properly constructed valve chambers.

(*g*) *Marking.*—Runs of mains must be indicated by plates lettered as necessary, attached to iron posts in the ground above the mains. (*See* Pl. **136**.)

Valves and fittings will be located in the same way.

Wooden pickets must not be used for marking purposes.

(*h*) *Testing.*—No pipes are to be covered or lapped until every joint has been examined for leakage under a pressure of at least 10 per cent. in excess of the working pressure of the system.

(*i*) *Isolating valves.*—On long lines the main is to be broken into sections, each about 1 mile long. The valves at the junctions may be stop or reflux-valves, according to the shape of the ground.

(*j*) *Washouts.*—At the bottom of all valleys a tee is to be put in with a branch leading to a drain-away. The branch is to be plugged.

When a reflux-valve is fixed in a similar position, a tee must be fixed on either side of it, with plugged branches leading to suitable drains.

(*k*) *Road and track crossings.*—Where pipes cross under roads, sufficient protection must be given against damage by heavy traffic above. The pipe must be boxed in, and the road filling carefully packed round the box before filling up the trench. Special crossings may have to be provided for *tanks*.

(*l*) *Repairs to W.I. pipe-lines.*—Leaks in W.I. pipes at the joints necessitate remaking the joint. Sometimes pipes split, and then the faulty part must be cut out and renewed. A rapid way of doing this is by the use of a sleeve (*see* Pl. **137**), which obviates screwing. The joint for the sleeve, shown in Fig. 3, can be made either with run lead or lead wool; the latter is, of course, the quicker (*see* Sec. **60**). A substitute for the special

C.I. sleeve shown on Pl. **137** can be made from a piece of steel or W.I. tubing about $\frac{3}{4}$ inch larger in diameter than the piping to be repaired. W.I. bands should be shrunk over the ends of the tube to stiffen it against the caulking necessary to make the joint.

2. **Cutting, threading, and jointing of pipes.** *Cutting.*—Steel or wrought iron pipe can be satisfactorily cut by holding it in a vice and using a pipe-cutter. For small pipes, say up to 2 inches, the three-wheel pattern (Pl. **138**) is most suitable, but for larger sizes up to 8 inches or 12 inches the multiple wheel chain pattern will be found the most satisfactory (Pl. **138**). For the method of use *see* Pl. **140**. Spare cutting wheels are essential for both types.

Threading.—Several types of screwing dies suitable for pipes are now on the market, the most satisfactory being the *Beaver* type, which is a type used in the Service. With this type one man can screw all sizes of pipe up to 6 inches, owing to the minimum of friction obtained by the aid of the narrow cutting dies. It is strongly made, light, and portable (*see* Pls. **141** and **142**). In screwing pipes of small diameter where no collets (or guides) are fitted to the stock holding the dies, it is advisable to use a fitter's square in order to ensure that the thread is cut truly central to and parallel with the axis of the pipe. An ample supply of lubricant is required. Table **K** shows properties of B.S. threads for W.I. pipes.

Jointing.—Pipe-ends are screwed for a distance equal to half the length of the socket which is to join them together; the thread is slightly tapered. Sockets are screwed in a lathe or special machine, and should be a fairly good fit on the pipe. A few strands of oakum smeared with red lead or *graphite compound* are carefully wound round the thread of the pipe, the socket then being screwed on for half its length. The socket is then held by means of a pipe wrench of which there are many patterns in use, examples of which are shown on Pls. **138** and **139**. The *Footprint* is used for small pipes, and a *chain pipe wrench* for larger ones. Another length of pipe similarly treated to the first is screwed into the socket. This process, if carefully carried out, will ensure a perfectly water-tight joint.

For confined spaces or where bends are fitted and there is not room to turn the bend to screw it into the socket, a *running* joint is made (Pl. **145**). This means the ends of the pipes to be joined being screwed slightly longer than the length of the socket to admit of the use of nuts, by which the joint is made doubly secure. The joint is then made as follows :—The nuts (called backnuts) are first screwed on pipes as far as the latter are threaded, and the socket is then screwed on for its entire length. The bend or length of pipe to be joined is then placed in line, and the socket screwed back on to it for half its length. The backnuts are then screwed up to the ends of the socket, and the joint made by a spun yarn grummet inserted between the end of the socket and the nut, and the whole screwed up tight.

Screwing machines.—Where a large amount of screwing has to be done under workshop conditions, screwing machines may be advantageously used. Pl. **143** shows a power-driven screwing machine for pipes of diameter up to 4 inches. This machine can also be worked by hand through a back gear, but this is usually no quicker than the Beaver tool.

These machines can also be provided with cutting-off tools, and when power is available the operation of both cutting off and screwing is cleaner and quicker than by hand.

When extensive pipe screwing operations are contemplated, ample supplies of spare dies must be provided, but consumption of dies will be minimized if all worn dies are sent to Base workshops for re-grinding.

This is only practicable if designs of screwing tackle are standardized.

58. *Organization of labour for pipe-laying.*

1. When rapid pipe-laying is desired, as in field operations, the labour employed must be very carefully organized.

The following instructions show how the various parties should be arranged, and the duties of each.

2. **Lining-out squad.**—Lining-out must always be done by an officer or responsible N.C.O. The selection of location will be largely guided by natural conditions. The location to be followed must be selected before any excavation is made, and clearly marked with pegs. Unless the work is properly organized it will happen that portions of the trench are dug, and then the location has to be changed because of unforeseen difficulties in the ground. Location must be selected well ahead of pipe-head.

Mains should normally be laid in straight lengths connected with square or easy bends.

The position of any air-valves, reflux-valves, stop-valves, bends, tees, &c., must be clearly marked **on the ground** with iron notice boards. *See* Pl. **136.**

The line will be marked out with iron *mile-posts*; half miles should be marked with smaller red-painted iron posts. The minimum curves and grades are determined by the section of pipe used. With heavy section pipe, considerable cutting and banking may be required in rough country. When possible, it will be advantageous to locate the line near roads, railways, or canals, for ease in distributing the pipes along the location.

3. **Formation party.**—This party digs the trench and makes any cuttings and embankments required. All the earth excavated must be put *on one side only* of the trench.

4. **Carrying party.**—The pipes are then laid out along, but clear of, the selected locations, and the special fittings placed alongside the notice boards denoting their positions.

This may proceed concurrently with the excavation. Pipes, &c., must be laid on the opposite side of the trench to that on which the spoil is deposited.

The distribution of pipes along the track requires careful organization. Usually pipes will be off-loaded into convenient heaps at intervals along a road, railway, or canal, and thence distributed along location by hand. If the location is far from the road, &c., further transport in horsed vehicles may be necessary. In some cases motor tractors can be used to distribute the pipes along the location.

5. **Screwing parties.**—Two of these parties start screwing at the ½-mile posts, and, working away from each other, meet similar parties which have started at other points 1 mile away. Thus every mile length

can be screwed up continuously from the centre, and the work of screwing up can be carried out simultaneously over any convenient distance.

When plans have been made, the N.C.O. in charge of each screwing party should have a copy of the plan referring to his length.

6. **Making-good party.**—A party will work independently of the screwing parties for work at the fittings, provision of proper frost protection to the pipe where it crosses roads and ditches, and insertion of valve boxes. At road and track crossings the main must be boxed in to prevent damage by heavy traffic above.

When the pipe-laying approaches the position of any fitting, it is stopped one or two lengths short of the fitting, and is recommenced on the forward side of the fitting, the fitting being connected to the first length laid. The connection between the rearward part of the main and the fitting is made by the making-good party, using a connector of the required length.

The making-good party also couples up the various 1-mile lengths, inserting isolating valves, &c., as may be necessary.

The making-good party must include competent pipe fitters, and be provided with transport for their tools and fittings.

7. **Filling-in party.**—When the main has been tested, the trench is filled in, care being taken that sufficient covering against frost is secured throughout its length. Banking over must be resorted to if necessary. Surplus pipes and fittings will then be collected, and the runs of mains and positions of fittings marked with iron marking posts.

In hot climates it may be necessary to cover the pipe as soon as it is laid to protect it from sharp changes of temperature which, by expanding and contracting the steel, would break the joints. The joints may, however, be left uncovered for inspection on test.

When sand is used for banking, some means must be found to prevent the sand from being blown away. *Camel scrub* has been used for this purpose in the desert. In all cases the local vegetation should be induced to grow on the newly formed bank.

8. It is very difficult to give accurate figures as to the speed at which pipe can be laid, as so much depends on local conditions, weather, labour available, &c.

The following tables are, however, given as an approximate guide (for W.I. screwed pipes):—

TABLE M.—*Pipe screwing.*

Diameter.	Pipe fitters.	Labourers.	Tongs.	Approximate footage each shift of 8 hours.
ins.				
6	2	15	5	800
4	2	10	4	1,000
3	2	8	4	1,200
2 and under	2	6	2	1,800

Table N.—*Pipe carrying.*

A	6-inch pipe	requires	6	men	to carry it.
A	4 ,,	,,	4	,,	,,
A	3 ,,	,,	3	,,	,,
A	2 ,,	,,	2	,,	,,

In dry weather on ordinary ground, one man carries one 6-inch pipe $\frac{3}{8}$ mile per day.

Table O.—*Pipe trenching.*

i. In average ground—free from shell-holes—average weather—

	Each man each day
4-inch to 6-inch pipe	15 feet run
Under 4-inch pipe	18 ,,

In shell-holed ground, halve above figures.

ii. Normal trench sections are—

3 feet 6 inches in depth by 2 feet wide for 4-inch pipe.
3 feet 6 inches in depth by $1\frac{1}{2}$ feet wide for 2-inch pipe.

59. *Pipe-laying cradle.*

1. Various devices have been tried for speeding up pipe-laying, one of which is by means of a cradle, shown on Pl. **144**. Its chief use appears in night work when swinging the pipes by eye is very difficult; also with a very little practice pipes can be laid at a greater rate during the daytime, and the liability to cross threads and do careless work is reduced.

A maximum rate of 18 4-inch pipes an hour and a good average of 15 an hour can be reached. A gang of six men is required for these rates, three of whom should have had previous experience with the cradle.

2. To use the cradle successfully, especially at night, it is very important that it should be *packed* properly when crossing uneven ground, as otherwise it is liable to distortion under the load of the pipes.

To do this proceed as follows (*see* Pl. **144**)—

The last length of piping is laid in the rests D, C, the end of the pipe coming between C and B.

The cradle should now be packed before laying the new length of piping on it.

i. If the pipe takes a bearing at D and not at C, pack up underneath A until a bearing is just obtained at C

ii. If, however, the pipe bears on C and not on D. *do not* pack underneath D, as this will tend to distort the cradle out of vertical alignment. In this case always pack up underneath C in order that the support may come directly under the load.

When a bearing has been obtained under D and C, find out whether the cradle has a bearing on the ground underneath A; if not, support on packing pieces here also.

The new length of pipe has its point of balance very near A, and hence the cradle will not be distorted by weight of this pipe if the above instructions are carried out.

In laying over ground covered with shell-holes, it is often necessary to have packing that will support the cradle to a height of 2 feet or so.

The adjustments necessary for the successful use of the cradle are quickly carried out, once the men clearly understand their respective duties.

60. *Laying and jointing C.I. pipe and lead pipe.*

1. Practically the only difference between the method of laying C.I. and lead pipes, and that of W.I. pipes lies in the way the joints are made.

Joints in C.I. pipes can be made either with—

(*a*) Lead melted and run in } afterwards caulked
or
(*b*) Lead wool }

The former is the more usual, and will be first described.

The work is done by a pipe joiner, but can be undertaken by a competent plumber.

2. **Jointing C.I. pipes with lead.**—The operation consists of filling the space between the spigot and socket with lead, and then caulking the latter up tight. In order to run the lead a clay jointing roll wrapped round the pipe must be used. The following are some of the points to be noted in connection with jointing :—

(*a*) The pipe must be central in the socket at the start ; this is ensured by an initial joint of yarn (not tarred), which is well caulked.

(*b*) See that the clay used in the jointing roll is well kneaded and has a rope core.

(*c*) For lead melting up to 10-inch pipe, one man can manage the ladle ; 12-inch or over, two.

(*d*) The whole quantity of lead should be poured in at one running. It should be at least three times set up with proper caulking tools (*see* Pl. **153**, Fig. 2). Light sledge hammers should be used for the larger sizes.

(*e*) Each caulker should be required to stamp every joint made by him with a particular mark for reference when the pipe is tested. In caulking begin at the bottom.

(*f*) The sockets should be well dried before running the lead.

(*g*) See that there are no obstructions or dirt in the pipes as laid.

(*h*) After jointing, the lead fringe must be pared off and left flush. Save all loose lead.

(*i*) When using lead wool, especial care must be taken over the caulking. *See* para. 3.

(*j*) The pipes should be laid with their sockets in the direction of the flow of the water, except when descending a hill when the sockets should be reversed, otherwise the lead cannot be poured freely into the socket, and an air space will be left.

(*k*) When digging the trench, joint holes must be left in the approximate positions to enable the jointer to handle his tools.

3. **Lead wool** for jointing C.I. pipes is of special value for work in the field on the rare occasions that lead joints are required, since no melting is required. It can also be used for caulking iron tanks and similar purposes.

Lead wool consists of fine threads of pure lead, rolled together in the form of a rope, and done up in skeins. A skein weighs about 17 lbs., and they are usually packed in 1-cwt. sacks.

The method of use is much the same as for a run lead joint. The joint is first partially filled with the usual hemp yarn (not tarred) which is well caulked. A strand of lead wool is then taken and twisted till it becomes a fairly stiff rope. It is then thoroughly caulked into the space between the spigot and socket. This caulking is repeated with each turn until the socket is full to within $\frac{1}{8}$ inch, and the joint finally faced up with a finishing tool.

4. **Lead pipe.**—The chief objection to lead pipe for field use is its weight. Lead pipe up to about 1 inch in diameter is, however, particularly useful for work inside buildings, owing to the ease with which it can be bent to follow an irregular line, and there may be a large amount of plumbing work in existing permanent buildings at bases and L. of C. depots.

Lead pipes should not be used with plumbo-erosive or plumbo-solvent water, nor where high pressures or water hammer occur.

Although lead pipe is easy to bend, this must be done with discretion, or damage will result. The pipe is secured to walls, &c., with *pipe hooks*, or is buried in the ground in the same way as W.I. or C.I. pipes.

As regards jointing lead pipe, it may be required to make a joint either between a lead pipe and a W.I. pipe, or between two lead pipes. In the former case a special connection is used. First, a ferrule and collar are slipped over the end of the lead pipe, and the end of the latter bell-mouthed out. The collar is screwed internally to take a coned connection which fits the iron pipe. By tightening up the collar against the ferrule, the cone is forced into the bell-mouth of the lead pipe, forming a water-tight joint. The joint is similar to the familiar cone-and-socket joint used on copper, petrol, and lubricating oil pipes.

To joint two lead pipes, the usual method is the plumber's *wiped joint.* One pipe is bell-mouthed, whilst the other is thinned at the end to fit, and the two are held together. The outer surface of each pipe is scraped bright for a length equal to about 3 times the diameter from the end. Plumber's solder is then melted in a ladle, and *wiped* round and into the joint so as to form a *swell*. This is done by hand with a piece of moleskin, and requires a certain degree of skill. A pipe may be jointed into the side of another at any angle by this method.

Lead pipes can also be straight-jointed with ferrules and collars as described for lead to W.I. pipes.

61. *General notes on pipe work.*

1. **Laying water mains under water** may be necessary at river crossings, but it is always preferable to take the main over an existing bridge, or, if the labour be not too heavy, to construct a separate structure.

The usual practice when pipes have to be laid under water is that of jointing up and lowering the pipe-line from a raft or series of trestles. W.I. pipes are the best form of pipe to use, since they stand best the slight bending inseparable from the operation. Even so, if the depth at which the pipes are laid is considerable, care must be taken that they are not unduly sprung, and are well supported by slings till they reach the river bed.

When possible, information should be obtained as to the nature and profile of the bed on which the pipe is to lay. If the bed is not soft enough to give the pipe a good bearing, a channel may perhaps be cut by pressure water jets. On completion the pipe must be tested hydraulically for leakage.

The methods adopted for laying submerged pipes of diameters greater than those obtainable in ordinary screw-jointed W.I. pipe are outside the scope of this volume.

2. **Specials.**—When careful drawings have been made, the number of specials required can be taken therefrom. Preliminary drawings are usually sketchy, and it is well to estimate well on the high side as regards specials.

Table **P** shows the basis on which specials should be demanded when large consignments are required for stocking engineer parks, &c., but this provides a considerable margin for wastage.

3. **Main tapping.**—It is often required to take a 1-inch or ¾-inch pipe off a main under pressure. To do this without emptying the main or releasing the pressure special machines are necessary. One of these is shown on Pl. **146**. The operation consists in drilling and tapping a hole in the main, and afterwards inserting a ferrule within a water-tight box. The operator must be specially instructed according to the type of apparatus used. Whenever possible, mains should be tapped at the side and not at the top.

4. **High-pressure pipes.**—In operations in a mountainous country extra high heads may be required, and special pipe must be provided. During the operations of the British Army in Italy during the Great War, pumps working against heads of 2,000 and 4,000 feet were used. Pipes for such services must be of the *hydraulic* type (*see* Pl. **147**), and, of course, special care must be given to the joints.

The greater ease and rapidity with which 2-inch mains can be laid in mountainous country as compared to 4-inch is to be noted, and the use of the smaller pipe is often possible for gravity mains when the head available is as great as it usually is in the mountains. For long gravity mains under heavy pressures, *break-pressure* tanks must be provided. These can be made with 400-gallon tanks and, say, 2-inch ball-valves. If the latter are of the ordinary pattern, the arms will probably require strengthening, and the washers modification to withstand the high pressure.

5. **Expansion.**—In long pipe-lines, especially when left uncovered, trouble may be experienced by reason of expansion due to an excessive temperature range. This effect is naturally more serious in hot climates. Pipes laid in the daytime, exposed to the sun, contract at night time or when filled with water. For expansion, allow 0·8 inch each 100 feet of pipe each 100° F. difference in temperature.

Pipes of standard thickness can usually take up the stresses occasioned by such variations in length. If, however, different thicknesses of pipes are used and consequently threads are not fully engaged, or if threads are so damaged in transit as to prevent their being screwed right home, failure may occur.

Expansion joints may be used, if desired, and should be placed at the higher points on the line. It is difficult, however, to avoid leakage at expansion joints.

6. **Maintenance.**—On active service much more labour must be expended on maintenance of pipe systems than is usual in peace-time practice. This fact is often lost sight of. Long pipe-lines will require regularly organized *pipe patrols*. These patrols consist of a couple of men, mounted if necessary, who are made responsible for patrolling a certain length of line every day. They must be kept regularly at the same work, so that they may know their particular length, and take an interest in their work.

All the stores necessary for repairing the line should be kept at selected points, so that there may be no delay in repairing any burst or leaking pipe. It is also necessary that a telephone system should be organized for extensive pipe systems.

7. **Salvage.**—Pipes and fittings may be salved by unskilled labour after a little training. The protecting sockets fitted on the unsocketed end of new W.I. pipes should be saved for replacement on salvage.

Old pipes may be cleaned internally by the *sand-jet*. The method is shown on Pl. **148.**

8. **Hydraulic thrust boring** is at the present time comparatively unknown, but will probably revolutionize existing methods of pipe-laying.

Small pits are dug every 150 feet or so, and linked up by pipes pushed through the earth by hydraulic pressure.

The system has not been sufficiently developed to give further details in this volume.

9. **Dr. Angus Smith's solution** is applied as follows :—The pipes should be thoroughly scraped and brushed free from sand, scale, and rust,

and receive a coat of linseed oil to protect them while awaiting the dipping process. They are then immersed in a bath of coal-tar pitch prepared in the following manner, viz., the tar must be boiled until the naphtha is entirely removed and it attains about the consistency of wax, after which five or six per cent. of mineral oil (coal-tar or pitch oil) is added. This composition is to be carefully heated in a suitable vessel to a temperature of not less than 400° F., and so maintained during the dipping of the pipes, which must also attain the same temperature at least ten minutes before their removal from the bath. When the process is complete, the pipes should be carefully lifted vertically out of the bath, so that the surplus composition may run off, leaving a thin uniform coat (about $\frac{1}{100}$ inch in thickness) on all surfaces of the iron. The pipes are then left to dry on skids. When the pipes are cold, the coating should be tough and adhere firmly to the iron. The efficacy of the process may be tested by immersing a pipe in clear water for 24 hours, when the coating should be perfect and the water uncontaminated by the tar.

62. *Hot water supply to temporary bath-houses.*

1. Pl. **150(A)** shows an improvised arrangement that has proved successful. Forty shower baths are provided, sufficient for 800 men a day. There are hot and cold water tanks, each 400 gallons, open, and on the same level. They and all piping are lagged with tarred roofing felt. The heater consists of four parallel 2-inch pipes joined together with tees at both ends, and laid in a trench, similar to that of a field kitchen, at a slope of 1/22. Brick baffle walls are built to direct the fire up and down over the pipes. The fuel is either wood or coal, about 1½ to 2 cwts. being used daily.

2. The circulation system consists of primary and secondary circuits, the draw-offs being connected only to the latter. The cold water enters the system in the primary return, and a siphon is arranged between the cold water tank and the primary return to prevent hot water reaching the cold tank.

3. An important feature is the non-return valve close to the hot water tank on the primary return. This is to prevent the hot water tank being flooded with cold water if there is a sudden large draw-off for baths. It is very easily made with materials that are likely to be obtainable almost anywhere. In its normal position it is open, as shown in the drawing, but when hot water is drawn off the rush of cold water into the pipe close at hand closes the valve and keeps it shut until the system is balanced again. In practice it has proved very sensitive and efficient.

4. The baths are fitted with showers which, if of the pattern drawn, are easily made by tinsmiths. The drawings show two alternative methods for fixing the hot and cold water for each group of five showers. The method shown on the right is recommended, as it enables a man to mix hot and cold water to his liking. In the other, the cold water introduced serves five showers. Pl. **149** shows constructional details of the bath-house itself.

5. The arrangement illustrated on Pl. **150(B)** shows a small bath-house for officers or one company. Either pipes bent hot in a coil, or a combination of bends and sockets (as illustrated), or even a single length of 1-inch or 1½-inch pipe, can be used for the boiler. The coils can be laid either vertically or horizontally. The circuits will be on the same principle as in the larger system.

6. For extensive operations, standardized portable hot water heaters should be provided from home for field bath-houses.

7. Adjacent steam boilers used for driving power plant can sometimes be made use of for supplying hot water.

TABLE P.—*Unit of tube*

	¼ Bends.	⅛ Bends.	$\frac{1}{16}$ Bends.	Elbows.	Tees, equal.	Tees, red. to 2-in.	Tees, red. to 1½-in.	Tees, red. to 1-in.	Sockets.	Sockets, dim. to 2-in.	Sockets, dim. to 1½-in.
6-in.	50	50	50	50	75	100	63	75	75	50	38
4-in.	100	100	100	100	150	200	125	150	150	100	75
3-in.	100	100	100	100	150	200	125	150	150	100	75
2-in.	400	—	200	500	300	—	75	—	200	—	75
1½-in.	400	—	200	500	300	—	—	100	200	—	—
1-in.	400	—	300	750	400	—	—	200 (red. to ¾-in.)	250	—	—
¾-in.	400	—	300	750	400	—	—	200	250	—	—
										For us	*e with*
¾-in.	—	—	—	—	—	—	—	—	—	—	—

6-in. sluice-valves.	6-in. air-valves.	6-in. reflux-valves.	4-in. sluice-valves.	4-in. air-valves.	4-in. reflux-valves.	3-in. sluice-valves.	3-in. air-valves.	3-in. reflux-valves.	2-in. stop-valves.
25	25	25	50	50	50	50	50	50	300

Pipe-cutting and

Stocks and dies.	Pipe-cutters.
6-in. sets, 40	No. 100
4-in. „ 40	„ 100
3-in. „ 40	„ 100
2-in. „ 80	„ 200
1½-in. „ 80	„ 200
1-in. „ 80	„ 200
¾-in. „ 80	„ 200

...tings for 10 miles of tubing

Sockets, dim. to 1-in.	Connectors, long.	Connectors, short.	¼ junction pipes (with long screws, 2 sockets and 2 backnuts) 4′ 6″ long.	¼ junction pipes (with long screws, 2 sockets and 2 backnuts) 9′ 0″ long.	Cross pieces.	Plugs.	Caps.	Nipples.	Backnuts.	Screwed flanges.	45° branch pipes, right and left (half of each).
38	125	125	50	50	38	38	38	100	150	63	50
75	125	125	100	100	75	75	75	200	300	125	50
75	125	125	100	100	75	75	75	200	300	125	50
75	125	125	—	—	50	100	50	250	500	300	50
400	125	125	—	—	100	100	50	250	500	300	—
500 (dim. to ¾-in.)	150	150	—	—	50	200	75	300	750	300	—
--	150	150	—	—	50	200	75	300	750	300	—
...-in. bib-cocks.											
—	250	250	—	—	—	—	—	—	500	200	—

2-in. ball-valves.	2-in. reflux-valves.	1½-in. stop-cocks.	1½-in. ball-valves.	1-in. stop-cocks.	1-in. ball-valves.	1-in. bib-cocks.	¾-in. bib-cocks.	½-in. bib-cocks.	Notice boards for pipe-lines.
10	50	300	40	300	60	500	100	100	50

...rewing tackle.

Pipe-vices.	Pipe-wrenches.	Backnut spanners.
150	400	200
150	400	200
150	400	200
200	500	250
200	500	250
200	500	250
200	500	250

CHAPTER XIII.

HYDRAULICS.

63. *Static pressure.*

1. The average pressure intensity over any area A equals the total pressure P on the area divided by the area, or $\frac{P}{A}$.

The unit of pressure intensity is the pound a square inch, or a square foot.

In a liquid at rest, the pressure intensity is everywhere the same at the same depth below the surface, and is the same in all directions. If a pressure be applied to the surface of a liquid, this pressure is transmitted equally to all parts of the liquid. This is the principle of the hydraulic press, or *Bramah's press.*

Strictly speaking, the pressure at a depth of water should include that due to the atmosphere, but for practical calculations the latter is omitted. Pressure intensities are measured either by the ordinary pressure gauges, or by *manometer tubes* (*see* Pl. **152**, Fig. 1).

2. The most common case in considering the resultant pressure on a submerged area is that of a plane surface either partially or wholly submerged

The total pressure on a single face of a submerged area is equal to the area multiplied by the depth of the centre of gravity of the area below the free surface and by the intrinsic weight of the fluid.

The following example will show the method of calculating the pressure on an immersed surface. The pressure, of course, acts at right angles to the surface immersed.

Pl. **151**, Fig. 1, shows a dock gate with water on both sides of it. The width of gate being 20 feet, the depth of the centroid of the submerged portion on the right hand side is 5 feet, and on the left hand side 2 feet. The areas of these submerged surfaces are 200 and 80 feet respectively, so that the total pressures and also the resultant pressures on the two surfaces are $5 \times 200 \times 62 \cdot 4 = 62{,}400$ lbs. and $2 \times 80 \times 62 \cdot 4 = 10{,}000$ lbs. The resultant of the two pressures will then be a single force of $62{,}400 - 10{,}000 = 52{,}400$ lbs., acting from right to left. The magnitude of the resultant pressure intensity and of its distribution over the gate are indicated in the diagram; the pressure intensity at any depth is indicated by the horizontal distance between the surface of the gate and the straight lines AC and FG. The resultant pressure at any depth is then to the left, and is represented by the horizontal width of the shaded area. Evidently at all points below the lower surface level the resultant pressure intensity will be constant, since the pressure intensity increases at equal rates on both sides of the gate. The resultant force to the left each foot run of the gate is represented by the shaded area ABDE.

3. The centre of pressure, or point of application of the total resultant pressure on a submerged face, can be found by methods given in any text-book on hydrostatics.

Pl. **151**, Fig. 2, gives the position of the centre of pressure in some cases of frequent occurrence in practice.

64. *Strength of pipes and cylinders.*

1. Generally, for steel or W.I. pipes

$$t = \frac{pr}{f},$$

where p = internal pressure in lbs./sq. in.,
t = thickness of metal in inches,
r = pipe radius in inches,
f = stress per square inch,

$$\left.\begin{array}{l} = 8{,}000 \text{ lbs./sq. in. for W.I.,} \\ \text{or } 12{,}000 \text{ lbs./sq. in. for steel,} \\ \text{or } 3{,}000 \text{ lbs./sq.in. for cast-iron,} \end{array}\right\} \text{(working values).}$$

For riveted pipes, take efficiency of joint as 55 per cent. for single and 70 per cent. for double riveting.

2. Most W.I. pipes are tested to a pressure of 300 or 400 lbs./sq. in., but should not be used above two-thirds of that amount.

Pipe fittings such as bib-cocks, &c., should not be subjected to more than a static head of 200 feet of water.

65. *Flow of water in pipes.*

1. There is little scope for detailed hydraulic calculation in laying out semi-permanent pipe systems. This is due, firstly, to inadequacy of data with which to work, and secondly, to the fact that standard pipes generally have to be used.

There are, however, certain fundamental principles which must be observed, and these will be briefly indicated.

2. **Bernoulli's theorem** expresses the fact that the total energy of a fluid (such as water) a lb. in a *stream tube* is constant.

The energy of a stream tube is the sum of :—

(*a*) Pressure energy possessed by virtue of the elasticity of the water.
(*b*) Kinetic energy possessed by virtue of its motion.
(*c*) Potential energy possessed by virtue of its height above an assumed datum.

The case of hydraulic water-pressure mains (such as are used for working presses, &c.) illustrates the possession of energy in the form of pressure energy in a far greater degree than in the other two forms, which in this particular case are generally low.

The conversion of potential energy into kinetic energy in the nozzle of a Pelton wheel should be considered in illustration of (*b*) and (*c*).

Most pipe-supply problems resolve themselves into ensuring that the water will reach the point at which it is required with sufficient velocity to give the quantity required.

The passage of water through pipes, in common with other similar physical operations, demands the expenditure of energy in overcoming frictional resistances and in the formation of the eddy currents inseparable from pipe flow.

For water to flow through a pipe-line, a difference of head between two ends of a pipe-line must be available for :—

(*a*) Overcoming frictional and eddy resistances in the pipe.
(*b*) Imparting sufficient velocity to the water to induce flow.

Bernoulli's theorem (for proof of which see any standard work on hydraulics) states that

$$\frac{p}{w}+\frac{V^2}{2g}+h=\text{constant}$$

where the first term expresses the pressure energy a lb. of fluid, the second the kinetic energy a lb., and the third the potential energy a lb.

If the suffixes t and b indicate the top and bottom of a pipe-line,

then $\frac{p_t}{w}+\frac{V_t^2}{2g}+h_t=\frac{p_b}{w}+\frac{V_b^2}{2g}+h_b$.

Now $p_t=p_b=$ atmospheric pressure (for all practical purposes).

$Vt=0$ (in most cases).

Then $h_t-h_b=\frac{V_b^2}{2g}$ = difference of level between top and bottom of pipe.

This expresses the fact that, if there is no pipe friction or eddy loss and if the pipe is connected at the top to a pond of infinite area, the velocity at the bottom is given by $V=\sqrt{2gh}$ where h is the difference of level. Practically, the discharge from an orifice in a thin plate is given very approximately by $V=0{\cdot}6\sqrt{2gh}$.

3. For flow in pipes this result is modified in several ways. Bernoulli's theorem involves the idea of a perfect *stream tube* in which no energy is lost either in friction or eddy disturbances—the motion is assumed to be perfectly regular and uniform.

In practice these conditions never obtain, and in any pipe-line energy is lost as follows :—

(*a*) Loss due to friction and eddy formation at the entrance to the pipe.
(*b*) Losses at valves, &c.
(*c*) Losses at elbows, bends, &c.
(*d*) Losses at sudden enlargements or contractions.
(*e*) Loss of kinetic energy at exit.
(*f*) Loss due to friction in the pipe itself.

Of the above, (*a*) to (*e*) can in general be neglected or covered by an overall allowance—they are small in comparison to (*f*).

4. The loss due to friction in the pipe by analogy with other forms of friction varies directly with the wetted surface and with the velocity raised to some power.

Thus, if p_1-p_2 is fall of static pressure in lbs. each square foot over length l feet of pipe, and

V = velocity in feet a second,
A = area of pipe in square feet,
P = length of perimeter of pipe in feet,

then $(p_1-p_2)A=fPlV^n$

where f is a coefficient,

or $p_1-p_2=f\frac{P}{A}lV^n$.

$\frac{A}{P}$ is called the *hydraulic mean depth*, and may be denoted by m.

If $p_1 - p_2 = 62{\cdot}4 \times h$ where h is difference in level in feet,

then $h = \frac{f\,lV^n}{62{\cdot}4m} = \frac{f'lV^n}{d}$ for a circular pipe running full where d is diameter of pipe in feet.

If G is gallons a minute discharged,

$$G = V\,\pi\,d^2 \times 6{\cdot}25 \times 60,$$

and $$V = \frac{G}{\pi \times 6{\cdot}25 \times 60 \times d^2},$$

then $$h = \frac{f'lV^n}{d} = \frac{f''lG^n}{d^{2n+1}},$$

where f'' is a new constant.

For practical purposes the formula

$$h = \frac{f\,lG^2}{d^5 \times 5{\cdot}5767},$$

which is of the same form as above ($n = 2$), may be taken.

As before :—h = head lost in feet owing to friction.
G = number of gallons a minute discharged.
l = length of pipe in feet.
d = internal diameter of pipe in *inches*.
f = constant (as given below).

Diameter of pipe.	*Value of f.*	
½″	0·016	Calculated as *foul*.
¾″	0·0155	
1″	0·015	
1¼″	0·01475	
1½″	0·0145	
2″	0·014	
2½″	0·0135	
3″	0·00862	Calculated *slightly tuberculated*,
3½″	0·008435	
4″	0·00825	
5″	0·007925	
6″	0·00772	
7″	0·00752	
8″	0·00733	
9″	0·00719	
10″	0·00706	
12″	0·00680	
15″	0·00646	

For pipes over 15 inches diameter the formula

$$h = \frac{G^2 \times l}{(3d)^5}$$

may be taken, symbols as before.

Table **R** has been worked out from above constants, but it should be noted that for *new smooth pipes* the value of h found from the table may be reduced by 50 per cent. for pipes up to 2 inches, and by about 30 per cent. for pipes above that size shown in the table.

It should be noted from the formula

$$h = \frac{flG^2}{d^5 \times 5 \cdot 5767}$$

that the discharge from a pipe-line of given length and head varies as $d^2 \sqrt{d}$, or, in other words, the quantity of water flowing in two pipe-lines of the same length and under the same head will vary as their respective diameters raised to the power $2\frac{1}{2}$.

As a practical illustration of this :—

One 12-inch pipe is equivalent to two 9-inch.
One 9-inch ,, ,, three 6-inch.
One 12-inch ,, ,, six 6-inch.

A comparatively slight enlargement in diameter thus results in a greatly increased delivery of water.

5. Since the friction losses are generally so much greater than all the rest combined, it is usually sufficient to calculate the friction loss for the required rate of flow, the known length of main, and an assumed size of pipe, and to see whether this is covered by the difference of head between the two ends of the pipe-line. The difference between static head and friction head is called *residual head*. If V is the velocity of exit, the residual head would be given theoretically and approximately by $\frac{V^2}{2g}$.

It is generally stated that the residual head at an ordinary tap outlet should be at least about 5 feet.

The velocity of flow would then be about $\sqrt{2gh} = \sqrt{64 \times 5} = 18$ f.s.

$$\text{This equals } 18 \times \frac{0 \cdot 785}{144} \times 60 = 5 \cdot 89 \text{ cub. ft./minute}$$
$$= 36 \cdot 8 \text{ gallons/minute}$$

for a 1-inch pipe, but would be rather less owing to other losses.

It will be seen, therefore, that the residual head need only be quite small. The selection of an otherwise convenient sized pipe may indeed result in a *negative* residual head for an assumed rate of flow. This, if small, need not alter the size of pipe used—the only result will be a slightly diminished flow.

6. **Flow in open channels.**—The general formula already given,

$$h = \frac{flV^n}{62 \cdot 4m},$$

may be taken for flow in open channels, and n may again be taken as 2. This formula may then be expressed as—

$$V = C\sqrt{mi},$$

where $i = \frac{h}{l} =$ slope of channel,

$V =$ velocity of flow in feet a sec.

$m =$ hydraulic mean depth of channel $= \frac{\text{area}}{\text{perimeter}}$,

$C =$ constant.

A selection of values of C for various conditions is given below—

Character of surface.	Value of C.		
	$m = 0 \cdot 5$	$m = 1 \cdot 0$	$m = 2 \cdot 0$
Smooth cement, or planed timber	136	141	145
Unplaned timber, or well laid brickwork	110	120	125
Brickwork in bad condition—fine gravel well rammed	72	86	98
Canals with earth-beds in good condition	50	62	74
Canals with earth-beds in bad condition—weeds on bottom	35	46	56

66. *Hydraulic gradient* (Pl. **153**).

1. The hydraulic gradient is a curve whose ordinates (measured above the pipe-line) give the residual head at any point in the pipe-line. For pipes of uniform diameter, the hydraulic gradient can be shown to be a straight line.

2. Suppose *bc* (Pl. **153**) to be any portion of a water main of uniform diameter supplied by a head *h* at *b*. Suppose also that the frictional head between *b* and *c* is *f*. Then the residual head at *c* is obviously *cd*, and the hydraulic gradient is the line *ad*, since *ab* and *cd* represent the residual heads at *b* and *c* and the gradient is a straight line.

It will be seen that the residual head at *c* is in no way affected by the pipe rising or falling above or below the line *bc*, *unless the pipe-line runs over a hill crest and rises above the hydraulic gradient ad* (*e.g.*, the dotted pipe-line cutting *ad* at x and x^1). If this is the case there will be negative residual heads between the points of intersection of the pipe-line and the hydraulic gradient, water will only flow by siphonage and, at the best, the full discharge will not be obtained.

3. This difficulty can be overcome in three ways :—

(*a*) By sinking the pipe in a trench through the hill between x and x^1. This would not be possible in some cases.

(*b*) By finding another position for the pipe-line.

(*c*) By altering the sizes of the pipe, and so changing the form of the hydraulic gradient.

4. The third method is usually the most practicable, and may be illustrated as follows :—

By a judicious selection of pipes the hydraulic gradient must be made to assume the form *ald*. This means that the frictional head between *b* and *m* must be *ap*, and between *m* and *c* it must be *lq*. From Table **R** the size of the pipes *bm* and *mc* can therefore be calculated.

5. When calculations show that the residual head at the end of a pipe is sufficient, the pipe is not likely to be above the hydraulic gradient if the ground slope is fairly uniform. *But in the case where a pipe runs first over flattish ground and then down a steeper slope, it is important to see*

that it is not above the hydraulic gradient. This is a case that can frequently occur, since a reservoir is very often placed just back from the brow of a hill. Where this happens, the obvious remedy is to use a pipe of larger diameter on the flat part than on the steep slope. There is then only small frictional loss before the crest is passed, and the hydraulic gradient is consequently flatter than the slope of the pipe. Sometimes it is not convenient to provide the two different sizes of pipe. In such a case it is much more important to test the residual head at the brow of the hill than at the point of delivery.

6. In some cases a **siphon** may be necessary, as when a pipe-line is to be laid to connect two reservoirs over ground which is higher than either water level, and the methods indicated in the preceding section cannot be applied.

In its simplest form the siphon consists of an inverted U-tube, as on Pl. **152**, Fig. **2**, and it can be shown that the head producing flow is theoretically $h_A - h_C$.

Actually, frictional losses in the pipe and losses at entry and exit reduce this quantity, and the presence of air collecting at B tends to stop the flow ; also the legs must run full.

The hydraulic gradient for a gravity pipe-line, as on Pl. **153**, may be raised by a height equal to barometric pressure, or 34 feet. If the contour *blc* rises above this new hydraulic gradient, water will cease to flow at all.

In practice, siphons should be avoided, since they always give trouble unless arrangements are made for exhausting the air periodically from the top of the siphon. This may be done with a pump, but is an unsatisfactory proceeding for semi-permanent work.

67. *Calculations for pipe systems.*

1. Elaborate calculations to determine the necessary sizes of the pipes required to make up a pipe system should be undertaken with due discretion, since so much of the preliminary data is of necessity pure guesswork.

The chief fault to be avoided is that of putting in pipes too small. Larger pipes cost little more, and, since in semi-permanent work they are usually salved when no longer required, the increase of capital cost is not of much account.

In nearly all semi-permanent work extensions to the system are certain to occur, and if the pipes used are too small to start with, it will involve laying additional ones, or relaying altogether. Further, the multiplication of reducing specials means the handling of many different sized pipes.

This doctrine, however, can be applied only so far as the conditions of the case permit. Especially where rising mains are concerned, transport and other considerations may preclude the use of pipes above a certain size. In such cases it may be better to put down pumps to work at a pressure greater than would be employed in permanent work, in order to take care of the increased frictional head.

2. In the following paras. the main lines of a water supply scheme for a semi-permanent cantonment for two battalions will be worked out, as shown on Pls. **154** and **155.** It would be unpractical to go into much detail when the ground is known only on paper, but what is given here will be sufficient to show how to undertake any similar scheme. Calculations are given at some length, but after a little experience they can be much reduced.

3. Since it is a paper scheme, some assumptions as to the conditions must be made. These will be as follows :—

The cantonment is a semi-permanent one. The main points about the cantonment and its water supply are that it should be put together quickly at a small first cost, and that it should remain in workable condition for a few years. Since the occupants will be living under ordinary barrack conditions, a fairly liberal supply of water should be given. It is reasonable in a case of this description to assume that an ample supply of water for domestic services will be expected, and it will therefore be allowed. As all the occupants are subject to discipline, it should be quite easy to prevent avoidable waste, and the cost of a satisfactory supply for legitimate purposes is warranted. It might also be assumed that, if a few fire hydrants and a sufficient flow for them can be provided without much extra expense, they will be advisable, since the huts are built of wood.

As speed in construction and economy in first cost will be necessary, the piping will be confined entirely to wrought iron screw-jointed pipes, which are light and easily put down.

4. *The scheme, for purposes of comparison, will be worked out for two different assumed sources of supply.* In one will be adopted a **ring main** with cross connections supplied from an elevated tank; in the other a **central main** with subsidiary rings supplied from a town main with water in it at 34 lbs. a square inch pressure equivalent to a head of 80 feet. A small pump installation would probably be associated with the former, but that mechanical question is not dealt with here.

5. The **quantity of water required each day** can be calculated on the assumption that the following quantities will be used daily at the places mentioned :—

Fittings :—	Gallons.
Basins or taps, at each	20
Baths	200
W.Cs.	40
Urinals...	40
Water-troughs, each horse	10

Buildings, in addition to allowance for known fittings therein :—

	Gallons.
Cookhouses, one battalion	1,500
Messes, serjeants' or officers'	20 each member.
Stables (for cleaning)	5 each horse.
Wagon sheds	10 each vehicle.
Officers' quarters...	30 each officer.
Institute and dining-room	1,000 each battalion.

There is no need for meticulous accuracy as to numbers in applying these figures. Using them the following quantities are obtained :—

Daily supply of one battalion.

Building No.	Occupants or fittings.	Supply in gallons.
2, 3, 4	6 taps, say	120
5	15 vehicles	150
7	66 horses	330
8	30 officers, 6 baths, 3 other taps	2,160
9	30 officers, 3 taps	660
10, 11, 12, 13	Cookhouses, 1,500 ; institute, 1,000	2,500
14	54 members	1,080
15, 15, 15, 15	30 basins (12 per cent.), 15 w.cs. (6 per cent.), 15 urinals (6 per cent.), per block	7,200
17	40 baths	8,000
18	66 horses	660
	Total	22,860
	Add for miscellaneous uses, say	1,000
	Unavoidable waste in leaks, &c.	1,000
	Total gallons daily	24,860

This, it will be noticed, is about 25 gallons a head. Experience has shown that under similar conditions this would be a reasonable allowance. Details have been worked out here to give some idea how the water is likely to be distributed, but in practice it is just as accurate to take straight away so many gallons a head. It may be remarked that it is extremely difficult without constant supervision and some inconvenience to reduce the quantity used daily for all purposes below 20 gallons a head. It is difficult to restrict consumption below this figure, as there are certain habits and customs which it is hard to stop.

6. In the first scheme, the reservoir for two battalions should contain at least one day's supply, say 50,000 gallons ; the reservoir should be preferably in two compartments so as to allow periodical cleaning without interruption to the supply.

7. In the second scheme, where the cantonment is supplied from the town supply, the main that is tapped probably has a large town reserve behind it, so no cantonment reservoir is required.

8. If the figures above be considered in connection with the plans, it will be evident how the main pipes should run. The main ring in Scheme A, or the subsidiary rings in Scheme B, should run close to every building where a considerable supply may be required within a short time. Since the battalion site plans are nearly symmetrical, a fairly symmetrical pipe plan will be the natural result, but, generally speaking, it is a mistake to let symmetry for its own sake have too much weight, as it leads to waste of piping. A symmetrical lay-out looks best on paper, but since pipes are buried this is no real advantage, except in so far as it makes the arrangements less complicated. The number of bends that cannot be

made with the usual specials, such as right-angled bends, tees, &c., should be kept down, but all big corners should be cut to save piping.

9. The piping for the alternative schemes will now be considered in detail. In these pipe calculations it will be assumed that frictional losses of head are only 80 per cent. of those given in the frictional loss table, which is equivalent to assuming almost new pipes. In all probability new clean pipes would be used, but they would be considerably encrusted after a year or two of use, and any margin on the right side that the following calculations show would certainly disappear in that time. If, therefore, the pipes are not new, or lengthy occupation is likely, the full frictional losses given by this or similar tables should be used.

10. **Pipe calculations—Scheme A.**

Main a—b.

Length 1,000 feet. Assume two 4-inch pipes (if 4-inch is the largest size to be allowed). Some likely conditions must be assumed as to demand for water; say heavy demand in one battalion while there is light demand in the other. Heavy demands in both are unlikely to coincide.

The maximum flow would be, therefore, say :—

	Galls. a min.
Right battalion.	
All ablution rooms in use, *i.e.*, 120 basins = 60 taps ...	120
Subsidiary ring (10 gallons at c and 10 at d)	20
Miscellaneous (of which say 10 are flowing in bath-house)...	20
Left battalion.	
One ablution room in use	30
Officers' quarters	30
Miscellaneous	20
	240

This maximum demand is much greater than one commonly assumed, viz., at the rate of the whole day's supply in 8 hours, equal in this case to $\frac{2 \times 24860}{8 \times 60}$ = say 100 gallons a minute. This latter assumption is fairly true where a considerable population with varying pursuits is concerned, but in small cantonments of this kind where all are employed on the same kind of work, there is much more likely to be an exceptional demand at certain periods on most days. As there is nothing unreasonable in the calculation given above, it is much better to go by it than by any general formula.

Each 4-inch pipe takes, therefore, 120 gallons a minute. From the tables, frictional loss $= 10 \times 2 \times 0{\cdot}8 = 16$ feet.

(Note that the factor $0{\cdot}8$ is the reduction already mentioned.)

The difference in ground level being about $170 - 134 = 36$, the residual head at b is 20 feet, which shows that the assumed flow will be obtained.

Main b—c.

Length 500 feet.

With say 120 gallons flow the frictional loss will be $5 \times 2 \times 0{\cdot}8 = 8$ feet, and the residual head at c will be 20 (res. head at b) + (134 − 124) − 8 = 22 feet.

Main c—d—e.

From c to 1st No. 15 block: length 500 feet, flow say 110 gallons.
Frictional loss $= 5 \times 0{\cdot}8 \times 1{\cdot}7 = 6{\cdot}8$ feet.
From 1st No. 15 block to d: length 150 feet, flow 80 gallons.
Frictional loss $= 1{\cdot}5 \times 0{\cdot}8 \times {\cdot}9 = 1{\cdot}08$ feet.
From d to bath-house: length 200 feet, flow 40 gallons.
Frictional loss $= 2 \times 0{\cdot}8 \times 0{\cdot}2 = {\cdot}32$ feet.
From bath-house to e: length 150 feet, flow 30 gallons.
Frictional loss $= 1{\cdot}5 \times 0{\cdot}8 \times 0{\cdot}1 = {\cdot}12$ feet.
Total frictional loss $= 8{\cdot}32$ feet: say 9 feet.
Residual head at e will be :—
22 (res. head at c) + (124 − 111) − 9 = 26 feet.

At no time will the head exceed about 70 feet. (That is, the difference in statical head between the tank and e, minus a very small frictional loss when the flow is very small).

For this main quite a sufficiently accurate result could be obtained by briefer calculations, thus :—

Assume that the flow is 100 gallons a minute right through from c to e (1,000 feet). Then frictional loss $= 10 \times 0{\cdot}8 \times 1{\cdot}4 = 11$ feet: and the residual head at e works out to 22 + (124 − 111) − 11 = 24 feet, which is approximately what was obtained before, the error being on the right side.

It would be just possible to use a 2½-inch pipe from d onwards. The margin would, however, be small, and incrustation would soon occur in the smaller pipe; also it breaks the complete 4-inch ring, and is, therefore, not to be recommended.

Main b—f—e.

Obviously its conditions are very similar to those of b—d—e, and therefore no calculations are necessary.

Main c—g—h—i—d.

Length 1,600 feet.

Assuming a heavy demand elsewhere, the head at c will be 22 feet and 28 feet at d. The flow required into it under these conditions may be taken as 10 gallons at c, and 10 at d.

Frictional loss (10 gallons a minute in 800 feet of 2½-inch pipe) will be $8 \times 0{\cdot}8 \times 0{\cdot}2 = 1{\cdot}28$ feet; therefore the residual head, though it is difficult to calculate accurately, will be over 20 feet at any rate, which is sufficient.

Assuming a small demand elsewhere and heads of over 35 feet at c and d, and also a flow of 25 gallons a minute (to supply 6 baths) into the pipe at c and d, the frictional loss $= 8 \times 0{\cdot}8 \times 1{\cdot}5 = 9{\cdot}6$ feet. The residual head will again exceed 20 feet and be sufficient. Calculation will show that a 2-inch main is too small.

Main j—k.

A good supply for washing-up is required. A $1\frac{1}{2}$-inch pipe will suffice.

Main l—m.

Length 300 feet.

The head at l will vary usually between 18 and 30 feet. Flow required in all the blocks is about 40 gallons a minute, or say an average of 30 up to point m.

Frictional loss (30 gallons a minute in 300 feet of 2-inch pipe) will be $3 \times 0{\cdot}8 \times 7{\cdot}1 = 17{\cdot}0$ feet.

Therefore a 2-inch pipe will do.

The connections to all ablution blocks will be 2-inch; to serjeants' messes $1\frac{1}{2}$-inch; to bath-houses $2\frac{1}{2}$-inch (these can be smaller if there are large cisterns to deal with sudden heavy demands); to water-troughs 1-inch; to officers' messes or quarters containing baths $1\frac{1}{2}$-inch; and to washing-up rooms, cookhouses, &c., 1-inch. Reference to the frictional loss table will show that pipes of these sizes will give the required supplies without the loss exceeding a few feet in any case.

The house connections in a town are usually smaller than those just mentioned, but it must be remembered that in this scheme the head in the mains is comparatively low (being on the average only about 60 feet) while in a town it is commonly 80 — 200 feet. It is a common fault in low-pressure temporary schemes to have the service branches too small.

Much cannot be expected in the way of fire protection from a low-pressure water system of this kind, and reliance is placed very often on other methods. Provided there is sufficient reserve of water, fire protection is worth considering in many cases, for, if the domestic uses require mains 3 inches and upwards, these can serve hydrants too. The hydrants should be placed actually on short 3-inch branches of their own. The range of a hydrant is taken usually as 100 yards, and preferably every important building should be within range of two. A 4-inch main cannot be expected to keep more than two hydrants going simultaneously, for each uses over 120 gallons a minute.

11. **Pipe calculations—Scheme B.**—This consists of a central main (double 4-inch pipes) and subsidiary rings. It should be noted that these subsidiary rings use no more piping than would a tree-like arrangement, but they give a much better supply.

There is no necessity to give the calculations in as full detail as in Scheme A. Making similar assumptions to Scheme A as to the flow, the residual heads will work out approximately as follows :—

Pipe a—c (4-inch)	flow 120 g.p.m.	Residual head at	c = 46 feet.
,, c—d (4-inch)	,, 100 ,,	,, ,,	d = 22 feet.
,, d—e ($2\frac{1}{2}$-inch)	,, 50 ,,	,, ,,	e = 15 feet.
,, e—f (2-inch)	,, 10 ,,	,, ,,	f = 5 feet.

&c.

The short branches would be the same sizes as those given for Scheme A.

12. **Comparison of the schemes.**—The following table shows the lengths of mains (1-inch diameter and over) used in each scheme; also very approximately their cost, including jointing and laying.

Pipe.	Scheme A.		Scheme B.	
	Length.	Cost.	Length.	Cost.
	Feet.	£	Feet.	£
4-in.	5,000	2,080	2,700	1,130
$2\frac{1}{2}$-in.	1,600	400	3,500	880
2-in.	650	120	1,900	360
$1\frac{1}{2}$-in.	350	50	300	40
1-in.	300	30	100	10
		2,680		2,420

To make a just comparison of the costs of the ring and central main arrangements, the cost of the main between **a** and **b** in Scheme A should be deducted. This amounts to £500, which deducted from £2,680 leaves £2,180. In this case, therefore, there is not much to choose as regards cost between ring and central main lay-outs. The former is much better adapted for supplying hydrants.

68. *Pump hydraulics.*

1. The types of pumps likely to be of use in the field have already been described in Chaps. VIII and IX; the elementary theoretical considerations involved, together with a brief description of their working, will now be dealt with.

2. **Bucket pump** (*see* Pl. **156**, Fig. 1). On the upstroke of the plunger a partial vacuum is produced below the bucket, and the water is forced up the suction pipe by atmospheric pressure.

If h_s = suction head in feet of water for any given position of the bucket, and Atm = atmospheric pressure (in feet of water), then pressure head on the under side of bucket = $Atm - h_s$ feet of water.

When an absolute vacuum is produced, $Atm - h_s = 0$, or $h_s = Atm$: and maximum-lift is thus Atm or 34 feet approximately.

Owing to friction, &c., the suction lift is limited in practice to something over 20 feet.

If h_d = delivery head on bucket, *i.e.*, height between bucket and outlet, then the pressure head on upper side of bucket

$$= Atm + h_d \text{ feet,}$$

and net head on bucket $= Atm + h_d - (Atm - h_s)$

$$= h_d + h_s = H \text{ feet.}$$

This explains why, in calculating the static head on a pump, the suction lift must be added to the lift from the pump cylinder to delivery level.

The above takes no account of frictional resistances, &c., which must be added to H.

3. **Single-acting force pump.**—By the addition of a closed top fitted with a stuffing box through which the bucket rod works, the machine becomes a force pump for delivering water under pressure (*see* Pl. **156**, Fig. 2).

4. **Single-acting and double-acting plunger pump.**—For higher pressures buckets with their valves are unsatisfactory, and either a piston or plunger of uniform section may be employed (*see* Pl. **156**, Fig. 3).

So far, each type considered has suffered from the disadvantage that it only delivers water on alternate strokes. In the *bucket and plunger pump* illustrated on Pl. **156**, Fig. 4, equal delivery is made on both up and down strokes, if the cross-sectional area of the bucket is made twice that of the plunger.

A modification of this type in which the bucket valves are omitted is shown on Pl. **156**, Fig. 5.

Suction and delivery valves are usually duplicated at each end of the barrel, each end becoming in effect a separate displacement pump. Such pumps are known as *double-acting pumps*.

When gritty water is to be dealt with by this class of pump, pistons working in barrels are unsatisfactory, and *outside-packed plunger* pumps are better.

5. **Pump valves.**—The velocity of water through the valve should not exceed 4 feet/second. For low pressures rubber or composition discs working against perforated grids, as on Pl. **157**, Figs. 1 and 2, are used.

For high pressures metallic valves, spring or weight loaded, are used (*see* Pl. **157**, Fig. 3).

Pl. **157**, Figs. 4 and 5, show the **Gutermuth** valve, which consists of a single sheet of special bronze.

Modern practice favours increasing the number of valves as the best means of providing the necessary valve area, the diameter and lift of each being limited to 3 inches and $\frac{3}{4}$ inch respectively.

High-speed reciprocating pumps with piston speeds up to 600 feet/minute must have mechanically operated valves, but the development of such pumps is likely to receive less attention in the future, owing to the progress of rotary pump design. The best valves for bore-hole pumps are brass balls which pulverise any foreign matter that would put pumps with other types of valve out of action.

6. The **discharge coefficient** is the ratio $\frac{\text{actual}}{\text{theoretical}}$ discharge, and with ram pumps of good design and in good order lies between 0·94 and 0·99.

The type of pump has a great bearing on the evenness or otherwise of the delivery.

The following table gives the average range of velocities for various types of pumps :—

TABLE Q.—*Range of velocities—Reciprocating pumps.*

Type of pump.	Ratio of maximum to mean velocity in discharge pipes.
Single-cylinder, single-acting	3·24
Two single-acting cylinders, cranks at 90° ...	2·17
Single-cylinder, double-acting	1·62
Two double-acting cylinders, cranks at 90° ...	1·11
Three-throw pumps, crank at 120°—	
Single-acting	1·09
Double-acting	1·05

7. In a reciprocating pump, if the piston moves faster than the following column of water in the suction pipe, *cavitation* or *separation* occurs. The water, however, will overtake the piston when the latter retards near the end of its stroke, and *water hammer* then ensues. To obviate this, an **air vessel** is used on the suction side, the action of which is as follows :—

During the first part of the stroke the pressure behind the piston is reduced, and water flows out of the air vessel. The flow along the suction pipe is thus reduced, as is the acceleration of the whole mass of water. This reduces the frictional resistance in the suction pipe, while the pressure behind the piston is increased both on this account and because of the reduced acceleration. At the same time, tendency to separation and to water hammer at the end of the stroke is almost eliminated, and the discharge coefficient becomes unity, or slightly less than unity.

The suction air vessel is made from 1·0 to 3·0 times the displacement of the pump each revolution, and should be placed in a direct line with the suction pipe without any bends or elbows. The pump speeds laid down by makers for reciprocating pumps should not be exceeded, or cavitation may result.

8. **An air vessel is placed on the delivery side** for the same reasons as already outlined for the suction side. Delivery air vessels must be made much larger both on account of the increased head and to the fact that water at high pressure dissolves an increased amount of air. They are usually from six to nine times the pump displacement each revolution.

Large reciprocating pumps will have small air compressors for maintaining the supply of air in the delivery air vessel.

9. Good reciprocating pumps will show **efficiencies** up to about 90 per cent. on the test bed, but less, of course, in practice. This efficiency falls off rapidly as the working head is reduced, so that below about 100 feet head rotary pumps are the more efficient. The piston pump, however, has the advantage of being positive in action, is not so liable as the centrifugal pump to lose its water, and has an efficiency which to a larger extent than in the case of the latter type is independent of speed.

The following detail shows approximate efficiencies to be expected in practice :—

Pump h.p.	*Efficiency percentage.*
Below 5	50
5 to 10	60
10 to 25	65
25 to 100	70
Above 100	75

10. **Rotary pumps.**—The simplest form of *centrifugal pump* consists of an impeller fitted with curved vanes, and mounted on a spindle within the casing, as on Pl. **158**, Fig. 1. The water to be pumped is supplied at the centre of the impeller, and, when the latter is made to revolve by some outside power, the water is thrown off the tips of the vanes by the action of centrifugal force. The considerable kinetic energy, now possessed by the water has to be turned into pressure energy, in order that the water may be forced up the discharge pipe against the static head.

The transformation of the kinetic energy into pressure energy is effected in the casing, the form of which is as shown on Pl. **158**, Figs. 1 or 2.

In Fig. 2, the casing is made of volute form to allow for the gradually increasing quantity of water flowing from A to B. A cutwater with a generous amount of clearance is placed at C, to ensure the whole flow being at once discharged from the casing.

On Pl. **158**, Fig. 3, the casing is designed by superimposing a volute chamber of uniformly increasing area upon a circular chamber concentric with and of considerably larger diameter than the impeller, but there is no division between the two. The object of this arrangement is to interpose a free vortex, in which the pressure increases radially from the centre, between the impeller and the volute chamber, and thus decreases the shock and eddy losses which occur with the form of casing shown on Pl. **158**, Fig. 2. The latter losses are, however, still considerable, even with the form shown on Pl. **158**, Fig. 3, which is the general form of a *centrifugal* pump.

11. Pl. **159**, Fig. 1, shows a pump having a single impeller with open vanes, and discharging directly into a volute casing or vortex chamber. There is an axial inlet on one side only of the impeller, and provision must be made for balancing the end thrust. The end thrust may be perfectly balanced by having the vanes open on both sides and suction inlet on both sides of the wheel, as on Pl. **159**, Fig. 3.

In order to reduce slip or leakage of water between the pump casing and impeller blades, the latter may be enclosed at the sides by discs or shroudings. This type is to be preferred, and may be made with either single or double-suction inlet, as on Pl. **159**, Fig. 2, P. It is suitable for heads up to about 80 feet, and, as thus constructed, efficiencies up to 80 per cent. may be obtained.

12. For heads higher than about 80 feet, even with a combination of vortex and volute chambers, there would be considerable shock and eddy loss. To overcome this, guide vanes may be fixed around the impeller, as shown on Pl. **158**, Fig. 4, having angles so designed as to receive the water without shock on leaving the wheel, and to direct it by gradually diverging passages either into a vortex chamber or directly into the

collecting volute, from which it is taken by the discharge pipe. In the latter case the pressure changes take place entirely in the guide passages themselves.

The pump thus fitted becomes in every essential a *reversed water turbine,* and is commonly known as a **turbine** pump. The ring of guide vanes in such a pump is called the *diffuser ring,* and must be designed according to the discharge at which maximum efficiency is desired.

Turbine pumps are usually made for heads higher than 100 feet, and to effect this are constructed in *stages, i.e.*, a series of impellers are mounted on the same shaft, each discharging into the inlet of the next.

For efficiency, well-designed volute chambers or diffuser rings on the discharge side of each impeller are essential. The general type of construction is shown on Pl. **160**. Double impellers may be used in order to balance end thrust, but this involves tortuous and complicated passages, and an even number of stages must be used. If single impellers are used, the construction is simpler, but special arrangements for balancing the considerable end thrust are necessary, and are incorporated in the design of the pump.

Turbine pumps should show efficiencies up to 85 per cent., and are constructed up to heads of 4,000 feet, in stages of about 100 to 200 feet each.

Leakage from stage to stage of a high-lift pump is prevented by brass packing rings surrounding the shaft between each pair of chambers. These may require attention when overhauling the pump.

Admission of air on the suction side of a turbine pump is to be guarded against with the greatest care.

13. The design of impeller vanes and diffusion passages has a great bearing on the duty and efficiency of the pump. For a detailed consideration of the factors influencing design, the reader must refer to the standard text-books on the subject.

It is most important to have a large margin of power in the prime-mover driving a turbine pump, since the power absorbed, at *constant lift,* varies as the cube of the speed. Unless this reserve is available, trouble will ensue whenever the turbine pump has to be slightly speeded up, and for this reason the prime-mover must be designed for a specified continuous overload.

A further cause of overload results from a reduction in the lift at constant speed. In many pumping schemes a variation in the lift is bound to occur, either from alteration in pipe friction owing to varying quantities of water being drawn off the distributing pipes, or because the pump has to deliver to service reservoirs at different levels. It is a well-known characteristic of the turbine pump that *at constant speed* as the lift is reduced the power increases in much greater proportion to the reduction in lift, thus seriously overloading the prime-mover. If, in the case of an I.C. engine, an attempt is made to take up the overload by increasing engine speed, the former effect comes into play, and the overload is accentuated. There are two ways of overcoming the difficulty, either by reducing the speed to suit the lift, or by designing the pump for self-regulation. The former requires that the prime-mover is capable of developing enough power at the reduced speed, and necessitates constant supervision and hand operation. Moreover, plants driven by A.C. motors are tied to a constant speed.

Overload at constant speed is, therefore, usually prevented by throttling the water in the diffusion vanes: that is, the areas of the openings through the diffusion vanes are designed so that the best effect is obtained at normal load, and as the head is reduced the pump is unable to force a large quantity through the diffusion vanes owing to the high velocity of the water. For small variations in lift this method is quite effective, but where variations in lift occur of 40, 50, or even more per cent., this throttling in the diffusion vanes becomes extremely inefficient. In extreme cases it may be necessary to add to the throttling effect by partially closing the stop-valve on the delivery side of the pump.

Self-regulation is effected in the Rees-Roturbo pump by means of a revolving pressure drum from which the water issues in a rearward direction to that of the rotation, thus producing a reactive turbine effect similar to that in a Barker Mill. If, therefore, the lift is reduced and the pump is running at constant speed, proportionally more water is delivered from the pressure drum, and the turbine effect is increased and assists the prime-mover to take the load.

14. Turbine pumps ordered for a definite service, in permanent practice, will be made up by the makers from standard designs in the best way possible to fulfil that service, or may be specially designed. Pumps for use in the field must be capable of employment over a fairly wide range of conditions. For any standard make of pump there will be *characteristic curves* available from the makers. Examples of these characteristics are given on Pl. **161**, Figs. 1 and 2.

Examination of these characteristics will show that pumps of this class can be used for a certain range of conditions as regards head and delivery on either side of those corresponding to maximum efficiency. Guaranteed characteristic curves should be supplied before such pumps are adopted for use in the field.

15. The actual **working efficiency of the pump** is the ratio of the energy contained in the water delivered by the pump to the work done on the pump shaft each lb. of water.

If H_m be the total head on the pump, Q the volume a minute in cubic feet, and B.H.P. the power put into the pump shaft, the efficiency will be

$$E = \frac{Q \times 62\cdot5 \times H_m}{\text{B.H.P.}},$$

The total head on the pump, H_m

$$= H + H_f + \frac{V^2}{2g} \text{ feet},$$

where H = height from supply tank level to discharge tank level (feet),

H_f = total friction head (feet) in suction and delivery main,

V = velocity of discharge.

H can be easily determined, while H_f and $\frac{V^2}{2g}$ (kinetic energy rejected) can be calculated. For ordinary purposes $\frac{V^2}{2g}$ can be neglected, but should be taken into account when the lift is small.

TABLE R.—*Showing in feet the head of water consumed by friction in each 100-foot length of pipe.*

Delivery gallons a minute.	Internal diameter of pipes in inches.													
	½	¾	1	1¼	1½	2	2½	3	3½	4	5	6	7	8
1	9·181	1·171	0·269	0·087	0·034	0·008								
2	36·724	4·684	1·076	0·347	0·137	0·031								
3	82·629	10·541	2·421	0·780	0·308	0·071								
4	146·896	18·719	4·304	1·387	0·548	0·125								
5	229·525	29·281	6·724	2·217	0·856	0·196	0·062							
6		42·165	9·683	3·120	1·233	0·282	0·089							
7		57·391	13·180	4·247	1·678	0·384	0·121							
8		74·959	17·214	5·547	2·191	0·502	0·159							
9		94·870	21·787	7·020	2·773	0·635	0·201							
10		117·124	26·898	8·667	3·424	0·784	0·248	0·064						
11			32·546	10·487	4·143	0·949	0·300	0·077						
12			38·732	12·480	4·930	1·130	0·357	0·092						
13			45·457	14·647	5·786	1·326	0·419	0·107						
14			52·719	16·987	6·711	1·538	0·486	0·125						
15			60·520	19·500	7·704	1·765	0·558	0·143	0·065					
16			68·858	22·187	8·765	2·008	0·635	0·163	0·074					
18			87·148	28·081	11·094	2·542	0·803	0·206	0·093					
20			107·590	34·668	13·696	3·138	0·992	0·254	0·115	0·058				
22				41·948	16·572	3·797	1·200	0·308	0·139	0·070				
24				49·921	19·722	4·519	1·428	0·366	0·166	0·083				
26				58·588	23·146	5·303	1·676	0·430	0·195	0·098				
28				67·948	26·844	6·150	1·943	0·499	0·226	0·113				
30				78·002	30·816	7·060	2·231	0·572	0·259	0·130	0·041			
35				106·169	41·944	9·610	3·037	0·779	0·353	0·176	0·056			
40					54·784	12·552	3·965	1·018	0·461	0·231	0·073			
45					69·336	15·886	5·020	1·288	0·583	0·293	0·093			
50					85·599	19·613	6·197	1·590	0·720	0·361	0·114	0·044		

60						28·242	8·924	2·290	1·037	0·520	0·165	0·064		
70						38·441	12·147	3·117	1·411	0·708	0·224	0·087		
80						50·209	15·865	4·071	1·843	0·927	0·293	0·114		
90						63·545	20·097	5·152	2·333	1·170	0·371	0·144		
100						78·451	24·789	6·361	2·880	1·445	0·458	0·178	0·080	
110							29·994	7·697	3·485	1·748	0·554	0·215	0·097	
120							35·696	9·160	4·147	2·080	0·660	0·256	0·115	
130							41·893	10·750	4·867	2·442	0·774	0·301	0·136	
140							48·586	12·467	5·644	2·832	0·898	0·349	0·157	
150							55·775	14·312	6·480	3·251	1·031	0·401	0·180	0·090
160								16·284	7·372	3·698	1·173	0·456	0·205	0·103
170								18·383	8·323	4·175	1·324	0·514	0·231	0·116
180								20·610	9·331	4·681	1·485	0·577	0·260	0·130
190								22·963	10·396	5·215	1·654	0·643	0·290	0·145

N.B.—When new smooth pipe is used, the value of h found from the above table may be reduced by 50 per cent. for pipes up to 2 inches, and by about 30 per cent. for pipes above that size shown above.

TABLE R—(*continued*).

Delivery gallons a minute.	Internal diameter of pipes in inches.										
	3	3½	4	5	6	7	8	9	10	12	15
200	25·444	11·519	5·779	1·833	0·712	0·321	0·160	0·087			
210	28·052	12·700	6·371	2·021	0·785	0·354	0·177	0·096			
220	30·787	13·938	6·992	2·218	0·862	0·388	0·194	0·106			
230	33·649	15·234	7·642	2·424	0·942	0·424	0·212	0·115			
240	36·639	16·588	8·321	2·639	1·025	0·462	0·231	0·126			
250	39·756	17·999	9·029	2·864	1·113	0·501	0·251	0·136	0·079		
260	43·000	19·468	9·766	3·097	1·203	0·542	0·271	0·148	0·086		
270	46·371	20·994	10·532	3·340	1·298	0·585	0·292	0·159	0·092		
280	49·870	22·578	11·326	3·592	1·396	0·629	0·314	0·171	0·099		
290	53·495	24·219	12·150	3·853	1·497	0·675	0·337	0·184	0·106		
300	57·248	25·918	13·002	4·124	1·602	0·722	0·361	0·196	0·114		
320		29·489	14·794	4·692	1·823	0·822	0·411	0·224	0·130		
340		33·291	16·701	5·297	2·058	0·927	0·464	0·252	0·146		
360		37·322	18·723	5·938	2·307	1·040	0·520	0·283	0·164		
380		41·585	20·861	6·616	2·571	1·159	0·579	0·315	0·183		
400		46·077	23·115	7·331	2·848	1·284	0·642	0·349	0·203	0·078	
420		50·800	25·484	8·082	3·140	1·415	0·707	0·385	0·223	0·086	
440		55·753	27·969	8·871	3·447	1·553	0·776	0·423	0·245	0·095	
460			30·570	9·695	3·767	1·698	0·849	0·462	0·268	0·104	
480			33·286	10·557	4·102	1·848	0·924	0·503	0·292	0·112	
500			36·117	11·455	4·451	2·006	1·003	0·546	0·316	0·122	
520			39·064	12·389	4·814	2·169	1·084	0·590	0·342	0·132	
540			42·127	13·361	5·191	2·339	1·170	0·637	0·369	0·143	
560			45·305	14·369	5·583	2·516	1·258	0·685	0·397	0·154	
580			49·599	15·413	5·989	2·699	1·349	0·734	0·426	0·165	
600			52·009	16·495	6·409	2·888	1·444	0·786	0·456	0·176	0·055
620				17·613	6·843	3·084	1·542	0·839	0·487	0·188	0·059

640				18·767	7·292	3·286	1·643	0·894	0·518	0·201	0·062
660				19·959	7·755	3·495	1·747	0·951	0·551	0·213	0·066
680				21·187	8·232	3·710	1·855	1·010	0·585	0·227	0·070
700				22·451	8·723	3·931	1·965	1·070	0·620	0·240	0·075
720				23·753	9·229	4·160	2·079	1·132	0·656	0·254	0·079
740				25·091	9·749	4·393	2·196	1·196	0·693	0·268	0·083
760				26·465	10·283	4·634	2·317	1·261	0·731	0·283	0·088
780				27·876	10·831	4·881	2·440	1·328	0·770	0·298	0·093
800				29·324	11·394	5·135	2·567	1·397	0·810	0·314	0·098
820				30·809	11·970	5·395	2·697	1·468	0·851	0·329	0·103
840				32·333	12·561	5·661	2·830	1·541	0·893	0·346	0·108
860				33·888	13·167	5·934	2·967	1·615	0·936	0·362	0·113
880				35·482	13·786	6·213	3·106	1·691	0·980	0·379	0·118
900				37·113	14·420	6·499	3·249	1·768	1·025	0·397	0·123
920				38·781	15·068	6·790	3·395	1·848	1·071	0·415	0·129
940				40·486	15·730	7·089	3·544	1·929	1·119	0·433	0·134
960				42·227	16·407	7·394	3·696	2·012	1·167	0·452	0·140
980				44·005	17·097	7·705	3·852	2·097	1·216	0·471	0·146
1000				45·819	17·803	8·023	4·011	2·183	1·266	0·490	0·152

N.B.—When new smooth pipe is used, the value of h found from the above table may be reduced by 50 per cent. for pipes up to 2 inches, and by about 30 per cent. for pipes above that size shown above.

PART III.—WATER PURIFICATION.

CHAPTER XIV.

REQUIREMENTS AS TO QUALITY.

69. *General considerations.*

1. The methods and apparatus by means of which water is rendered safe for human consumption are among the most important considerations of the field water engineer. In peace-time, the attention given to analysis of the crude water is so meticulous, the systems of purification are so diverse, and the whole subject generally has been so highly developed, that it might well be thought impossible to adapt the modern science of water purification to the haphazard conditions of active service.

In order to gain a clear idea of the requirements of a safe water, the latter may be summarized as follows :—

A safe water should—

(*a*) As far as possible be free from colour, taste, or odour.
(*b*) Contain no appreciable amount of mineral or organic suspended matter.
(*c*) Be neither too hard nor too soft.
(*d*) Not contain large quantities of common salt or of alkaline carbonates.

The above provisions are what may be termed *desirable*, and may be modified to a greater or less extent in each case.

The following requirements are absolutely positive, and cannot be modified in any way :—

(*a*) **The water must not contain pathogenic, *i.e.*, disease-producing organisms of any kind.**

(*b*) **The water must be free from poisonous substances, either organic or inorganic.**

2. The only natural waters which satisfy these requirements are upland surface waters (the catchment areas of which do not include dwellings or cultivated lands), deep wells, bores, artesian wells, some springs, and rain-water collected with suitable precautions in country districts. Even in such cases, before the water is used as a drinking water supply without purification treatment, the area should be carefully examined to ensure that no pollution of the supply is possible, and a careful examination of the water, chemical and bacteriological, should be made, if possible, after a spell of dry weather and also after heavy rain. Practically all other sources are liable to contamination with sewage or surface drainage, and some form of purification is necessary before the water is safe to use for drinking.

3. War experience has shown that few waters are so foul that they cannot be converted into a safe drinking water by suitable means (*see* Sec. **73**), but it is only reasonable that the best sources should be chosen, and that contamination of the source should be reduced to a minimum.

4. In both permanent and semi-permanent purification plants, suspended matter can be removed by filtration and sedimentation, the hardness and reaction (acid or alkaline) can be adjusted by chemical means, and colour, taste, and odour can often be removed by suitable treatment with coagulants. On the other hand, bacteria are removed either by filtration through sand, by prolonged storage, by treatment with oxidizing substances such as bleaching powder, chlorine, or ozone, by the excess lime process, or by the action of ultra-violet light. In semi-permanent installations the first two methods are, in general, inadmissible, since the construction of extensive sand filters or of large impounding reservoirs is not generally possible.

5. Before extensive purification operations are undertaken, the officer in charge will be responsible that all the necessary tests of the proposed water are made by experts, so that the suitability or otherwise of the water can be judged, and that suggestions may be made as to the best way of dealing with its purification. In this manner expenditure of labour and material upon an unsuitable plant or the exploitation of an unsuitable source can be avoided.

It must be remembered also that the crude water of many semi-permanent systems will be contaminated and dangerous, and that, in consequence, any failure of the sterilizing system may be attended with results disastrous to the health of the users of the water; hence it is important that intelligent men with a certain amount of education be employed to carry out the normal processes involved in the purification of water. The practice of entrusting this important work to unskilled labour cannot be too severely condemned, as it is apt to result in a complete breakdown of the whole purification system at a critical moment or at any time when the conditions change, such as when a fairly clear stream becomes turbid through the influx of storm water.

6. The removal or destruction of bacteria is by far the most important part of the purification process. It is essential to avoid pollution of the crude water as far as possible, and to ensure a satisfactory degree of sterilization. The aim must be to obtain an effluent as palatable as possible and of good appearance, for men will reject a safe water if it has an unpleasant taste, is turbid or coloured, and instead will drink an untreated water which may be highly contaminated and dangerous, though clear, sparkling, and palatable.

7. *Water for horses* is not usually submitted to any preliminary treatment. Grossly polluted water and water containing large quantities of suspended matter must be avoided, and metallic salts must be absent, but almost any fairly clear river or pond water may be used in the crude state.

8. To estimate the suitability of a given source of drinking water requires (*a*) a careful examination of the source and its neighbourhood, (*b*) a chemical examination of a sample of the water, (*c*) a bacteriological

examination. None of these three alone will be sufficient to enable one to pronounce a water safe for use, although any one of them may give sufficient evidence to condemn the source. Thus, (*a*) the discovery of a cesspool overflowing into a well, (*b*) the detection of lead or of an inordinate amount of salt in a water, or (*c*) the presence of *B. coli.* in 1 c.c. of the water, would be sufficient to condemn the water; while a chemical analysis *alone* might lead to no suspicion of bacterial contamination, and examination of the source *alone* would not reveal harmful substances in solution.

9. For field purposes the process of purification is reduced, generally speaking, to :—

(*a*) Removal of suspended matter.
(*b*) Destruction of pathogenic bacteria.

The main difference between peace-time and field purification practice is that in the field some form of chemical sterilization to destroy pathogenic bacteria is *invariably* employed. The chemical sterilizer normally employed will be **chlorine,** either contained in bleaching powder (chloride of lime), or as a gas ; this process is known under the term of **chlorination.**

It is important to remember that the elaboration of practice in peace-time, both of analysis and treatment, is mainly due either to the retention of plant installed prior to the comparatively recent introduction of efficient sterilizing agents, or in some cases to a sentimental objection to the use of chemical sterilizers. In war, military discipline enables a rigorous and universal system of chemical sterilization to be enforced.

So far as is at present known, the action of chlorine on water, during a sufficient contact period, results in the destruction of all pathogenic bacteria. It follows, therefore, that water in which a trace of free or *available* chlorine persists may be regarded as safe for human consumption. **The process of sterilization in the field consists in the addition of sufficient chlorine to enable a certain amount of available chlorine to persist in the water after the remainder has been used up in the destruction of bacteria and in other ways.** The amount of available chlorine left in the water should not exceed in general 1 part per 1,000,000 ; anything more than this will render the water unpalatable.

10. The success of all purification schemes depends on careful analysis of the crude water both prior to the installation of the plant and at frequent intervals throughout its operation.

Analysis for field purposes may be classified as under :—

(*a*) Preliminary analysis.
(*b*) Complete analysis.

A *preliminary analysis* determines generally how much chlorine must be added to render the water safe, and whether harmful poisons are present (*see* Sec. **74**, para. 3). A *complete analysis* shows the exact state of the water (*see* Sec. **74**, para. 9). A preliminary analysis can be undertaken by anyone with elementary scientific knowledge, whereas a complete analysis can only be made by an expert. It is difficult to lay down the exactitude and frequency with which analyses must be made. No unknown water should be made use of without a preliminary analysis, and, moreover, time will often not be available for a complete analysis before the supply is developed. In any field purification plant the available chlorine in the finished water should be checked at least twice a day.

In waterworks of any size a complete analysis, both of the crude and finished waters, should be made regularly, and in some cases analysis may be required daily for specific purposes.

All engineer officers and selected subordinate personnel engaged on water supply work must be able to carry out a preliminary analysis. It will usually be possible to obtain a complete analysis from the mobile laboratories maintained by the R.A.M.C.

In the case of extended water supply operations, special water analysis laboratories might have to be set up under engineer control in addition to those provided by the R.A.M.C., though the last word as to the suitability of a supply for human consumption must rest with the R.A.M.C.

11. A general view of the modern systems of purification and the principles involved is given in Chap. XV, since it is essential to have a clear idea of the objects aimed at and the various ways in which they are achieved. Chap. XVI contains descriptions of the particular types of purification apparatus which have been found adaptable to active service conditions.

70. *Quality of water from various sources.*

1. *Rain-water.*—This, if collected from roofs in such a way as to avoid the first runnings which may be contaminated with dust and excreta of birds, forms a satisfactory, if not very palatable, drinking water. Owing to the absence of dissolved salts, it is flat and insipid to the taste. Rain-water is soft, and is liable to contain minute quantities of mineral acids derived from the air ; it is, in consequence, not always suitable for raising steam, and should not be stored in lead cisterns or used with lead pipes as explained later.

2. *Upland surface water.*—The quantities of dissolved solids in these waters are generally small, and the water is fairly soft and very suitable as a drinking water supply. Some upland waters are plumbo-solvent or plumbo-erosive. The main difficulty is the avoidance of pollution. Drainage from cultivated lands and from farm houses are the main causes of fouling, and the catchment area should be closely examined with the view to detecting and, if possible, avoiding contamination of this kind. If the water is derived from a peaty district, it will contain acids which are conveniently grouped under the name of *humic acids* ; these are the cause of the action on lead.

3. *Surface wells.*—Water derived from surface wells will contain, in general, a larger proportion of mineral constituents than purely surface drainage, as the water has been in intimate contact with the surface soil and the rocks underlying it for a considerable time. This water is very liable to contamination from drains, cesspools, middens, and even from streams in the neighbourhood of the well. No such source of contamination should be allowed within at least 100 feet of the well, the distance varying according to the nature of the ground ; moreover, such pollution is more likely to occur when the well is below the contaminated source in

the direction of the flow of the underground water. No water should gain access to the well except at the bottom, when the water will have undergone filtration through the surface strata. Thus the well should not be in a place liable to floods ; the top should be efficiently protected by a wall or coping and a cover, and the pump should be at such a distance from the well that no dirty water can flow back into the well. Unfortunately these conditions rarely hold, and, in consequence, wherever possible, well water is avoided as a drinking water supply unless it can be sterilized.

4. *Surface springs.*—The conditions under which contamination can take place are similar to those noted in the case of surface wells.

5. *Rivers and streams.*—The quality of the water in rivers and streams is very variable. In steady reaches and in dry weather sedimentation takes place, and the beneficial effects of storage in causing a diminution in the numbers of bacteria may also be noticed, so that the water may become clear and bright, and the percentage of dissolved matter increases. River water is more liable than most other natural waters to change of character and composition ; thus after rain, owing to the influx of surface drainage, the water becomes turbid, and the proportion of organic matter increases, while that of mineral matter in solution decreases. In time of flood or after heavy rain, the water may become thick and muddy, and reaches, which in dry weather are steady, may in a small river become swollen and rapid. Rain following a long spell of dry weather is particularly liable to induce pollution of river water, since ditches which have been accumulating filth or drainage from farms and manured land all contribute their share of organic and bacterial contamination, while the organic matter is further increased through the stirring up of the muddy bottom in times of flood.

Rivers still receive sewage effluents, and in country places it is common to see the untreated drainage and storm water from the roads conducted directly into the stream. In view of these facts some kind of treatment is imperative if river water is to be used as a source of drinking water. In most cases the volume of polluted water which gains access to a river is small in comparison with the flow of the river, so that a great deal of the organic matter becomes oxidized on dilution with the large volume of aerated river water.

6. *Lakes.*—Lakes are practically storage reservoirs of river water. The water gradually deposits its suspended matter, aeration takes place, and the harmful bacteria tend to die out. Lakes in mountain districts form excellent sources of drinking water. Water should be taken from the lake as far as practicable from the inlet of the lake, so as to take advantage of the sedimentation and storage of the water in the lake.

7. *Ponds.*—Quite small and dirty ponds, containing a large amount of organic matter, have been used as sources of drinking water when no better supply was available (*see* Sec. **73**). In such cases contamination is obvious, rigorous methods of purification are necessary, and a careful supervision of the effluent is essential.

It is advisable, where possible, to fence in the sources of supply, to prevent bathing and washing in the water, and to take steps to reduce or to avoid altogether sources of contamination.

8. *Deep wells, bores, and artesian wells.*—If properly constructed, there should be no contamination in the water from these wells. The water is generally clear, and contains little or no organic matter, while the quantity of dissolved solids is comparatively large. If the well passes through an upper water-bearing stratum the lining should be impervious so as to avoid mixing with the less satisfactory water of this stratum. Occasionally the water from deep wells varies in quality, and it may at times be seriously contaminated owing to fissures in the rocks which admit surface water. Should it be necessary to find out whether a stream or other water is a source of pollution or not, this may be done by adding to the suspected water a quantity of common salt, of a lithium salt, or of fluorescein. The main water supply is then tested frequently, and the appearance of excess of chlorides, or of lithium (which can be detected in extremely minute quantity by the spectroscope), or of the dye in the water supply is proof that the supply receives water from the contaminated source. It does not follow, however, that the supply receives bacterial contamination from this source, as it is conceivable that, while the salts or the dye can pass through the strata from one point to the other, bacteria may be filtered off. A more definite proof can be obtained by infecting the suspected source of pollution with a culture of a hardy, prolific, and harmless organism such as *B. prodigiosus*, which can readily be detected (producing a bright red coloration). One disadvantage of this method is that the microbe may be difficult to get rid of when once introduced into a water supply.

71. *Nature of impurities found in water.*

1. Since practically all substances are soluble to a greater or less extent in water, pure water does not occur in nature. Thus, *pure drinking water* means a water which, though containing perhaps considerable quantities of suspended matter and some bacteria, is not unpleasant to taste or smell, is not unduly coloured, and which can be drunk continuously without affecting the health. It follows that the word *impurities* may be misleading unless everything which is not H_2O is regarded as an impurity—and this would include oxygen, carbon dioxide, calcium bicarbonate, and many other things which are either harmless or even actually beneficial—or unless impurities are divided into *harmless* and *harmful* impurities—and this would need to be further modified, as substances such as common salt, calcium sulphate, and others are quite harmless in small quantities, while in larger quantities they render the water unfit for drinking. It is better, therefore, to speak of a *safe* rather than of a *pure* drinking water, and to divide the foreign substances in water into the four classes :—(*a*) **dissolved substances**, (*b*) **colloidal matter**, (*c*) **suspended matter**, (*d*) **micro-organisms**.

2. **Dissolved substances.**—The chief gases in the air are oxygen, nitrogen, and carbon dioxide. Of these, nitrogen is present in the largest proportion, but its solubility is only 2 per cent. in water, and it has no effect upon the taste or other properties of the water or upon its potability. Oxygen is more soluble, and is usually present in natural waters unless pollution with sewage or decomposing organic matter has occurred, or unless reducing agents such as ferrous salts are present. Carbon dioxide, although present in the atmosphere only to the extent of about 0·04

per cent., being more soluble than the other constituents, is generally present in water in the free or combined state, or in both conditions. Water without dissolved gases, for example, boiled or distilled water, is flat and insipid to the taste, and steps are generally taken to aerate such water before it reaches the service reservoir. Some natural waters contain considerable quantities of carbon dioxide, and, if rising from some depth, the water may be slightly effervescent. In manufacturing districts sulphur dioxide and oxides of nitrogen are present in the air, and the last may be present in the air over the country or the sea, especially after a thunderstorm. These gases are dissolved by the rain, which then contains traces of sulphurous, sulphuric, and nitric acids. The acids are not present in quantities sufficient to render the water harmful for drinking, but their prolonged action on the metals of boilers, tanks, and service pipes may give trouble. Some waters contain variable quantities of sulphuretted hydrogen arising from the decomposition of organic matter containing sulphur or from the action of certain bacteria such as the fungus (regarded by some authorities as a bacterium) *Beggiatoa alba* and some species of *Chara* (a cellular aquatic cryptogam). This gas gives the water an unpleasant odour (rotten eggs) and a sweetish taste, and, while it may be of service medicinally, such water is unfit for drinking purposes. Small quantities of the gas may be removed from water by oxidation, as described later.

The quantity of solids which may be present in solution in natural waters varies in freshly collected rain-water from the merest trace to several hundred parts in 100,000. As the materials of all rocks and soils are soluble to a slight extent in water, the quantity and character of the dissolved salts will depend upon the geological formation from which the water is derived, upon the time that the water has been in contact with the materials, and upon several other factors. Thus river water, which often contains considerable amounts of surface drainage, will, in general, have a lower content of dissolved salts than the water of wells and springs in the same district; similarly, after rain a river water will contain a smaller proportion of dissolved matter than after dry weather. Wells near the sea often contain very large quantities of dissolved salts owing to the infiltration of sea water.

3. The salts most commonly occurring in natural waters are carbonates, sulphates and chlorides of calcium, magnesium, and sodium; silica is sparingly soluble in water and, being a constituent of nearly all rocks and soils, is generally present to the extent of about 1 or 2 parts in 100,000. Salts of calcium and magnesium render the water hard, and waters containing much of these salts cause waste of soap when used for washing; they also give trouble when the water is used in steam boilers. A certain quantity of these salts is an advantage in drinking water, rendering it more palatable, but very hard waters are said to cause constipation, especially to people who are unaccustomed to their use.

4. Over 100 parts of *calcium sulphate* in 100,000 have been found in certain waters, but the quantity is usually below 10 parts.

Magnesium sulphate is a less frequent constituent, and rarely exceeds 3 or 4 parts in 100,000, except in medicinal springs such as those at Epsom.

Calcium and magnesium chlorides rarely exceed 5 parts in 100,000, and are frequently absent.

Calcium carbonate is almost insoluble in water, and *magnesium carbonate* is only very slightly so, but water containing carbon dioxide dissolves these substances fairly readily, forming soluble bicarbonates, so that these last may be present to the extent of 50 or more parts in 100,000, and are rarely entirely absent even in surface waters.

Sodium salts are generally present in natural waters, and may be derived from rocks or soil; the chloride in addition is sometimes derived from sea spray, which may be blown many miles inland, by infiltration of sea water, or from sewage.

Sodium bicarbonate is found in considerable quantities in some deep wells and bores, notably in Flanders, and is supposed to be due to the interaction of sea water with chalk.

Sodium nitrate is present in most waters in very minute quantity.

Sodium salts have no harmful effects when present in drinking water; they do not render the water hard, and they do not affect steam-boilers, but water containing much carbonate or sulphate of sodium may have a saline taste and may exert a purging action, while about 50 parts of common salt in 100,000 renders water perceptibly brackish. The only known method of removing sodium salts when present in excess is by distillation, and this is generally too costly an expedient except at sea (*see* Sec. **88**).

5. *Salts of iron* occasionally occur, usually in the ferrous state as ferrous sulphate or carbonate. It is generally advisable to take steps to remove iron when present, as it gives trouble by producing a brown coloration or precipitate on oxidation, and also encourages the growth of certain organisms which give an unpleasant colour and odour to the water, and which may lead to blocking of service pipes. The removal of iron by oxidation and filtration is referred to in Sec. **80**, para. 5. *Crenothrix* can multiply rapidly in waters containing only very small quantities of iron salts. The iron is secreted in the cells, is there oxidized, and the filaments of the organism, with the contained precipitated ferric hydroxide, give a brown colour to the water and render it turbid. The threads attach themselves to the interior of the pipes, die and become hard, and so gradually reduce the bore of the pipes. The only certain method of getting rid of such organisms is to free the water from iron compounds.

6. *Ammonia.—Free* or *saline ammonia* is almost always present in natural waters; it is derived partly from the decomposition of organic matter containing nitrogen. It is rarely present in greater quantities than 0·2 parts in 100,000. Certain bacteria in the soil convert ammonia into nitrates, and the reverse action can occur when water comes into contact with reducing agents.

Albuminoid ammonia.—Other nitrogen-containing organic substances in water are reckoned as albuminoid ammonias; some of them may actually be substituted ammonias, but all substances (except salts of the base ammonium) which yield ammonia when distilled with alkaline permanganate solution are included in the term. These substances result from the decomposition of organic matter, hence sewage contains relatively large quantities of albuminoid ammonias; it does not follow, however, that water containing much ammonia is contaminated with sewage. The quantity generally found in water is below 0·1 part in 100,000.

7. *Nitrates.*—The source of nitrates in water is probably animal refuse, ammonia being first formed by the decomposition of animal matter, and this is then oxidized to nitrates by the agency of nitrifying organisms.

Nitrites.—One source of nitrites in water is undoubtedly sewage, but nitrites may arise as an intermediate product of the oxidation of ammonia to nitrates or of the reduction of nitrates to ammonia. The quantity of nitrite present seldom exceeds a trace.

8. *Potassium salts* are sometimes found; these are, like sodium salts, quite harmless except in unusually large quantities.

9. *Salts of the heavy metals.*—Small quantities of zinc, copper, lead, and other metallic salts occur occasionally in water; such water should not be used for drinking. Methods are available for removing poisonous metals from drinking water, but it will seldom, if ever, be necessary to make use of them, since such waters will usually be rejected in favour of uncontaminated water.

10. **Colloidal matter.**—Between solutions proper and suspensions lies the class of so-called *colloidal solutions*. Colloidal solutions pass unchanged through ordinary filtering media, but the dissolved substance is unable to pass through parchment membranes. The dissolved substance in a true solution is separated into particles of molecular dimensions, while in a colloidal solution the particles are aggregates of molecules. In suspensions the particles are of sensible size, can be distinguished with the naked eye or with microscopes of low power, and can be filtered off by ordinary filtering media. Certain organic substances with extraordinarily large and complex molecules do not form true solutions, but mix with water and other liquids, forming colloidal solutions; such are gelatin and albumen, and probably certain decomposition products of animal and vegetable substances. Thus, a water which has been polluted with sewage or with drainage from farms may contain colloidal organic matter. Very finely divided clay also forms a colloidal solution with water, so that muddy streams in clayey country may prove unfilterable.

Under certain conditions the particles of a colloidal solution coalesce, and the colloid is precipitated, often in a finely divided state. Colloidal substances give colour and an earthy unpleasant taste to water, and it is to remove these substances that coagulants such as aluminium hydroxide are used. The action of coagulants is partly mechanical, capturing and dragging down the fine suspended particles, and partly physical. Colloidal precipitates, like aluminium hydroxide, are able to absorb dissolved substances, hence the colouring matter of the water and compounds giving an unpleasant taste are removed by the use of a coagulant.

11. **Suspended matter.**—The suspended matter in water consists of fine mineral particles, vegetable and animal débris, living plants such as algæ, diatoms and so forth, and water animalculæ. None of these is desirable in a water supply, and they can be removed by sedimentation and filtration.

12. **Micro-organisms.**—Bacteria, protozoa, and other microscopic forms of life, animal and vegetable, can flourish and multiply in water

containing dissolved salts and organic matter, consequently it is rare to find natural water entirely free from them. River and pond waters often contain many thousands of bacteria each cubic centimetre. Some bacteria are, as far as is known, harmless in drinking water, while others multiply in the blood and other fluids of the body and produce disease. The chief water-borne diseases are various forms of diarrhœa, dysentery, enteric or typhoid fever, and cholera. The transfer of the germs of disease from one person to another can, of course, take place in many ways; water-borne diseases are conveyed through the contamination of the water supply by the excreta of persons either actually suffering from the disease, or who, though infected by the bacteria, have obtained immunity from the disease; such persons are called *carriers* of the disease. On this account water which is contaminated, however little, with sewage is to be regarded as potentially dangerous, as the bacteria are capable of surviving in water for considerable periods, and any healthy person drinking such water is liable to contract the disease.

Bacillus coli is an invariable constituent of the flora of the human intestine, and, fortunately, this bacillus is fairly easily detected. Also *B. coli* appears to be more robust than the water-borne bacteria which cause disease. Hence if a given water is shown to be free from *B. coli*, it is fairly safe to assume that the water is uncontaminated with sewage and with intestinal organisms.

The eggs and embryos of certain parasitic worms existing in some waters may also cause disease. It does not necessarily follow that a process that will destroy bacteria will also destroy these organisms, and in tropical countries the matter should be given special attention.

13. **Hardness.**—Hardness due to chlorides and sulphates of calcium and magnesium cannot be removed by boiling, and is termed *permanent hardness*.

Calcium and magnesium carbonates are dissolved by water containing free carbon dioxide according to the equation

$$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2.$$

The calcium (or magnesium) bicarbonate produced is soluble in water. On boiling, the reverse action takes place, and chalk (or magnesium carbonate) is precipitated. In the case of magnesium carbonate the salt is partially hydrolysed, and a basic carbonate is formed and precipitated. Thus hardness due to these salts is removed by boiling, and is termed *temporary hardness*.

Hard water reacts with soap (sodium stearate or oleate), giving an insoluble calcium or magnesium soap (calcium or magnesium stearate or oleate) which forms a scum on the top of the water,

e.g., calcium sulphate + sodium stearate = calcium stearate (scum) + sodium sulphate.

Thus, before a lather can be formed a certain amount of soap is used up to precipitate the calcium and magnesium salts in the water.

14. *Steam boilers.*—(*a*) Magnesium chloride, and to a certain extent calcium chloride, is hydrolysed by hot water, giving free hydrochloric acid as shown by the equation—

$$MgCl_2 + 2H_2O = Mg(OH)_2 + 2HCl.$$

The acid so formed corrodes the boiler plates, the action being electrolytic. The metal of the plates and that of the rivets being in different physical states act as the poles of an electrolytic cell, and one or other goes into solution; thus corrosion is produced. Similarly, though to a less extent, acid waters from peat are unsuitable for use in boilers unless the acid be first neutralized.

(*b*) Calcium sulphate is much less soluble in hot water than in cold, and at any temperature above boiling point is almost insoluble. Thus, waters containing calcium sulphate deposit this salt on the inside of a boiler, and, in time, a thick adherent coating is formed which acts as a non-conductor of heat and which is hard and difficult to remove.

(*c*) The bicarbonates of calcium and magnesium, as shown above, are decomposed on heating, but the precipitated carbonates do not, in general, form an adherent scale, and the particles are more easily removed than the calcium sulphate scale.

The water for use in steam-boilers should be softened if hard, and neutralized if acid.

Sodium chloride does not cause corrosion of boilers, but if much be present brass fittings are corroded, and a green deposit forms on them.

15. **Plumbo-solvency and plumbo-erosion.**—Peaty water contains the so-called *humic* acids produced by certain bacteria which flourish in the soil. Such water dissolves lead, and, as lead is a cumulative poison, it is necessary to take steps either to avoid lead service pipes with such water or to remove the acids by neutralization. Dr. Houston found that variation in the speed of flow of water in lead pipes made little difference in the amount of lead dissolved. Hard water, unless containing a large excess of carbon dioxide, does not dissolve lead, but forms a protective coating of basic lead carbonate on the inside of the pipes, similar to that produced by the action of the air on the outside. This protection is also formed by the action of hard waters containing excess of carbon dioxide after a time: their power of acting upon lead then ceases. The basic lead carbonate would be removed by the action of any acids in the water, so that water which has passed over certain minerals such as pyrites, and the water from coal workings, is plumbo-solvent in consequence of the mineral acids present in such water. Plumbo-solvency is removable by mixing the acid water with suitable quantities of hard water or by neutralizing the acids with sodium carbonate or with lime.

The term *plumbo-erosive* is applied to waters which form scales of a hydrated oxide of lead on clean lead. The scales are not soluble in water, but neither are they adherent, so that the compound is carried on by the stream of water, and the surface of the lead is further eroded. Since the compound is insoluble it is probably not a cause of lead poisoning, but the damage to pipes caused by such waters is considerable. The action appears to be due to dissolved oxygen, so that any water which is not capable of producing a protective coating on the lead may be plumbo-erosive. Such are rain-water and soft waters in general. A protective coating is produced by waters containing common salt, ammonium carbonate, chalk, calcium or magnesium carbonates, or alkaline salts. Some waters which contain only small quantities of plumbo-protective substances may become erosive as they pass along the pipes, and the erosion, once started, continues. Again, a water which is normally without action on lead may become dangerous through a change in the relative volumes of some of the feeders of the supply.

Both forms of activity may occur in the same water, but, fortunately, both forms can be remedied by the same treatment. Filtering through chalk tends to neutralize the acids and to induce a certain amount of temporary hardness, and, if this be followed by the addition of sodium carbonate, the formation of a protective coating on the lead is ensured.

The action of a water on lead is tested as follows :—A strip of sheet lead is scraped to expose a bright surface, another strip is left covered with the film of basic carbonate formed by the previous action of moist air on the lead. The strips are allowed to stand for 24 hours or more in separate beakers of the water to be tested. If the surfaces of the strips are altered, plumbo-solvency or plumbo-erosion is to be suspected. Erosion will be indicated by the presence of white basic lead carbonate (insoluble) in the water, and solvency can be confirmed by removing the strips and adding to the water a solution of sulphuretted hydrogen when a darkening of colour shows the presence of lead.

72. *Chemical treatment to destroy bacteria.*

1. In all semi-permanent water supply schemes it is necessary to employ some form of chemical sterilization ; the only alternatives, storage of the water until the bacteria have had time to die out, or slow filtration through a film of bacterial or algal origin, are not generally possible. Bacteria may to some extent be removed by filtration of the water through an artificial film formed on the sand of a pressure filter, but with a plant of this character it is advisable to make doubly certain by the use of chemical sterilization.

2. This being so, it is obvious that sources may be used which are far more contaminated than would be admissible if chemical sterilization were not employed. Whilst every care should be taken to avoid unnecessary pollution of the supply, it is a mistake to undertake a costly piece of work to escape some small but unavoidable fouling, the evil effects of which will be easily and efficiently removed by the chemical treatment (*see* Sec. 73).

3. In the case of wells and streams from which men can obtain their own supplies of drinking water under fortuitous conditions, the source should invariably be put out of bounds as a source of drinking water, or it should be placed under a warden whose duties should include the addition of a given proportion of bleaching powder or other suitable substance to all water taken from the source.

4. In examining a well or spring it must be remembered that the source may be considered as liable to pollution from any cesspools, drains, dunghills, and so forth situated within a range of 100 feet or more, especially if these are above the well or spring in the direction in which the underground water flows. Pollution from flood water should not be possible, and the access of dust, small animals, and surface water should be prevented by the construction of a satisfactory wall or coping and by covering the

well. Where the strata overlying the water-bearing strata are liable to fissures, contamination from points at a considerable distance is possible.

In the case of rivers and streams unavoidable pollution, such as sewage outfalls and storm water from roadways, should be diverted, if necessary, so as to enter the stream below the intake of the waterworks.

73. *Examples of safe use of foul water after sterilization.*

1. Immediately after the advance on the Somme in 1916, a sterilizing lorry was set to work in a marsh. The stream used drained a valley in which there had been dug-outs and horse lines, so that the water was highly unsatisfactory in the crude state. It was treated with alum and bleaching powder, and a clear and palatable drinking water was obtained and formed the main supply of the district for two or three miles round. It was only when the weather became warm that a dead horse was discovered partly buried in the mud of the marsh directly above the intake of the sterilizer and not twenty yards away. This did not interfere with the production of potable water. Had it been considered necessary to avoid this source of contamination, either it would have resulted in the abandonment of the water point, or great expense would have been incurred in making a road across the marsh, and this would have involved great delay at a time when every hour was of importance. One dead horse would have been avoided probably only to incur pollution through greater proximity to several others.

2. A sample of the water from a well in the Somme area after the retirement of the enemy pointed to a very serious organic pollution. As water was scarce, the well was further examined, and the body of a calf in a fairly advanced stage of decomposition was recovered. The well was dosed with a strong solution of bleaching powder and partially emptied two or three times; the water was finally used, without ill effects, for drinking, chlorination before use, of course, being insisted upon.

3. A very foul stream was used immediately after the battle of Messines. This was almost an open sewer, receiving drainage from camps and horse lines and surface drainage from foul ground which had for a long time been just behind our lines. A potable though not palatable water was obtained by alum sedimentation, followed by filtration and chlorination, and no cases of water-borne disease were reported.

4. Upon several occasions, particularly in the summer of 1918, ponds in fields, flax-retting pits, and even *moats* surrounding farmhouses into which most of the drainage of the house could percolate were used in conjunction with alum sedimentation, filtration, and chlorination. In one case the pond water was extremely foul and greenish brown in colour, yet a potable and safe water was prepared. The possibility of making use of foul ponds and also streams was undoubtedly of great military importance.

5. The foregoing examples are quoted in order to emphasize the possibility of using, **with adequate treatment**, sources which in peace-time would be utterly condemned.

74. *Water analysis.*

1. Some of the tests which are to be found in books upon water analysis are of little interest to those concerned with semi-permanent water supplies; such tests are estimation of the colour, turbidity, specific gravity, and electrical conductivity. These tests, if regularly carried out, give warning of the change of character of the crude water which is very valuable when slow sand filtration is employed. The first two, also, when carried out on both crude and finished water, form an interesting record which looks well on paper, and which appears to the uninitiated to indicate the degree of purification attained. Tests of more value are those for acidity or alkalinity, chlorine absorption, hardness, chlorides, ammonia, nitrates, nitrites, solids (total, suspended, and dissolved), iron, other metals, and perhaps gases. The tests are not of equal value, and the relative values attached to the different tests by different authorities are not the same. A check upon the purification process and such information as will assist in the choice of a suitable method of treatment is all that is required in the installations contemplated, and an elaborate analysis is not necessary.

2. **Sampling.**—In taking a sample, if only a *chemical examination* is intended, it is sufficient to use a clean bottle of about two litres capacity (*e.g.*, a Winchester quart), with a well-fitting stopper or a clean unbroken cork. Before filling, the bottle is rinsed out two or three times with the water to be sampled. The bottles should be labelled, and notes of the character of the source and its surroundings should accompany the sample.

In sampling a well, the bottle should be weighted at the bottom and should be supported in a cradle of string or wire, the weights being attached to the cradle. The bottle is then lowered until the neck is three or four inches below the surface of the water. It is an advantage to attach the stopper or cork to a separate string, so that the bottle can be opened below the surface of the water.

In sampling a stream or pond, the bottle should be held well below the neck, and the neck should be three or four inches below the surface of the water. When the bottle is full a small quantity of water is poured out, so that there is an airspace below the stopper. The stopper can be secured by stretching a piece of clean calico, linen, or rubber sheet over it and tying it down below the flange of the neck with string or fine wire.

If the sample is required for *bacteriological examination*, besides the above precautions, the clean bottles should be sterilized by heating in a steam sterilizer or in an autoclave, and after sterilization stoppers should be secured as described. Corks must not be used. In taking a sample care must be exercised to avoid touching the neck of the bottle or the stopper with the fingers, and the water must not flow over the hand into the bottle. Before removing the stopper, and after filling, the neck of the bottle should be *flamed*. A convenient way of doing this is by means of a torch consisting of a piece of cotton wool about the size of a hazel nut supported at the end of a short wire. The other end of the wire may be passed through the cork of a small bottle containing methylated spirit, when the torch will always be ready for use. Care should be taken not to heat the neck of the bottle too strongly, a temperature of just over 100° C. being quite sufficient.

When the sample has been taken, the stopper can be secured again with a clean piece of material or rubber as described.

Before taking a sample from a pump or tap, the water should be allowed to run to waste for a short time.

Samples, whether for chemical or bacteriological examination, should be tested as soon as possible, as otherwise the bacteriological content found may be very different from that of the original water; also the relative quantities of ammonia, nitrates, and nitrites are subject to change.

3. **Preliminary analysis.**—The preliminary analysis may be regarded as the first safeguard against the presence of harmful impurities in the water under examination; it will when necessary be followed by a *complete analysis.*

A preliminary analysis should consist of :—

(*a*) Examination of physical characteristics. (para. 4).
(*b*) Determination of the *alkalinity.* (para. 5).
(*c*) Determination of amount of chlorine required to leave available chlorine in the water, *i.e.*, the chlorine absorption figure. (para. 6).
(*d*) The available chlorine present in the chlorinated water. (para. 7).
(*e*) Tests for poisons. (para. 8).

4. **Physical characteristics.**—The *turbidity*, or its reciprocal *visibility*, of different waters can be compared by noting the depth at which a short piece of platinum wire can just be seen with the naked eye in a good light, not direct sunlight.

The *colour* can be judged by looking at a white surface through a column of water contained in a tall glass cylinder with a clear glass bottom.

Odour is best observed after slightly heating the water in a test tube. A faint smell is more easily detected by closing the test tube with the thumb after warming, and by shaking.

5. To test the **alkalinity** of a water so that the suitability of the water for alum treatment can be gauged, the following apparatus can easily be provided for those in charge of small purification plant. The test given is such as needs to be part of the ordinary routine work of the installation. The necessary solution can be made up in any water testing laboratory.

i. A graduated pipette fitted with a rubber tube, a stopper, and a jet. By squeezing the tubing, the liquid can flow past the stopper.
ii. A stand for the pipette. This can easily be made of wood with an elastic band.
iii. Horrocks' cup.
iv. Glass rod.
v. Methyl orange indicator.
vi. Decinormal acid.

Measure 50 c.c. of the water in a Horrocks' cup, also *one drop* of methyl orange solution, and run decinormal acid from the pipette until the colour has just changed to red. The number of c.c. of decinormal acid used $\times 10$ gives directly the alkalinity of the water (as parts of $CaCO_3$ in 100,000).

6. The **chlorine absorption figure** may be determined with the *Case, water testing, sterilization.* This test is sometimes called the **Horrocks'** test, and enables the chlorine absorption to be determined within the nearest 1 part in 1,000,000, and what is important for field use, the number of *scoops* of bleaching powder of average strength that should be added to the service water-cart of 110 gallons.

Cups and scoops are used of such sizes that one scoopful of bleaching powder of average strength when added to 110 gallons of water adds one part of available chlorine per million.

The following instructions refer more particularly to the chlorination of a small volume of water, such as is contained in the service water-cart, but the same test can be applied to water treated in larger plants.

Description of test apparatus (*see* Pl. **162**).

The test apparatus consists of a box containing the following :—

i. (*a*) Six conical cups enamelled *white* inside, to be filled within a quarter of an inch of the brim with the water to be tested.
   (*b*) One cup enamelled *black* inside, to be used for making chloride of lime solution.

ii. Two tin scoops, each holding 2 gms. when filled with bleaching powder level with the brim (the same amount as the measure contained in the quarter-pound tins, when filled in the same manner).

iii. A test solution (zinc iodide and starch) in glass bottles, three drops of which give a definite blue colour with water containing one part in a million of free chlorine.

iv. Six pipettes, each of such a bore that one drop from the chloride of lime solution i. (*b*) added to the water to be tested in the white enamelled cups filled as directed under i. (*a*) gives a dilution of chlorine of one part in a million.

v. Handkerchief. A handkerchief of thin material is provided ; one fold of this placed over the finger covering the end of the pipette enables a novice to add uniform drops to the water.

vi. Stirrers. Four glass rods are provided for this purpose.

Methods of using the apparatus.

A. *When the water is not immediately required* for use, it is best to clarify it in the evening, and as soon as the chlorinating tank is filled with water—

i. Fill the cup enamelled *black* up to the mark on the inside with clarified water, then add one level scoopful (or one level measure from the quarter-pound tin) of chloride of lime, and mix thoroughly. Place the cup on the top of the box.

ii. Place the cups enamelled *white* in a row, as shown on Pl. **162.** Fill each cup with clarified water to within a quarter of an inch of the top.

iii. By means of a pipette held vertically, add to each of the cups 1, 2, 3, 4, 5, and 6 drops respectively of the chloride of lime solution made as directed in A i. Mix thoroughly and allow to stand for half an hour.

iv. To each of the cups then add three drops of the test solution contained in the glass bottle. Stir vigorously.

v. Some of the six *white* cups will show no colour, some will show a blue colour. Then add for every 100 gallons of the water in the chlorinating tank one measure of the bleaching powder, made into a paste with clarified water, for every drop of the solution from the *black* enamelled cup, contained in the *weakest* strength which has maintained a blue colour for 30 minutes. Say that the blue colour had disappeared from the cups containing 1, 2, and 3 drops, but was maintained in the cup containing 4 drops, then four measures of bleaching powder should be made into a paste with clarified water placed in the black enamelled cup, previously emptied and washed out, and added to the water contained in the chlorinating tank, and the water thoroughly stirred up with a stick previously washed with clarified water. If the tank is divided into compartments by means of baffle plates, then the paste should be divided equally between the compartments.

vi. Allow the chlorinated water to remain in the tank until the following morning. The water will then be quite free from the germs causing water-borne disease, if the requisite amount of bleaching powder has been added as instructed.

NOTE.—If the blue colour disappears in half an hour from *all* the cups, the test must be made again, adding to the water in the cups 7, 8, 9, 10, 11, and 12 drops respectively of the solution made as described under i.

This second test will rarely be required.

B. *When the water is required within an hour*—

i. Pump clarified water into the chlorinating tank, and, as soon as the bottom is covered with water, make the stock solution of chloride of lime as described under A i.

ii. Fill the white enamelled cups with clarified water, and proceed as described under A ii, iii, and iv.

iii. At the end of one minute, note which of the cups still have a blue colour, then add to the water in the tank the number of measures of bleaching powder corresponding to the *weakest* strength which still maintains a blue colour (*see* A v).

iv. Continue filling the tank with water, and watch the colour in the cups until the tank is filled. If the colour in the cup next in the series disappears before the tank is filled, add at once one measure of chloride of lime made into a paste, and so on until half an hour has elapsed. The water will then be fit for use, but it is better to allow the chlorine to act as long as possible.

NOTE.—If the test has been satisfactorily carried out, water drawn from the body of the tank at the end of the half hour and placed in one of the cups, previously washed out, should give a blue or violet colour when three drops of the test solution are added to the water.

The water in the tank should always be examined in this manner, irrespective whether the directions under A or B are being carried out.

Use of the Horrocks' test in connection with regimental water-carts.

These carts are provided with a special clarifying apparatus, which should remove all suspended matter from the water. In these circumstances it is usually found that one part in a million of free chlorine will destroy in half an hour the bacteria causing water-borne disease. To make sure that free chlorine is present as soon as the cart is filled the clarified water from the body should be placed in one of the cups, and three drops of the test solution (zinc iodide and starch) added. If a blue or violet colour is produced, the chlorination may be considered satisfactory. If the water remains colourless, then the procedure described in A i, ii, iii, iv, and v should be followed, the water being allowed to stand as long as possible after chlorination.

Table S may be used for the determination of the amount of chlorine in lbs. an hour, when the Horrocks' test is used in connection with chlorine gas dosing apparatus.

TABLE S.—*Conversion table.*

Showing lb. of chlorine an hour.

Parts in a million.	Gallons of water an hour.										
	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400
1	0·004	0·005	0·006	0·007	0·008	0·009	0·01	0·011	0·012	0·013	0·014
2	0·008	0·01	0·012	0·014	0·016	0·018	0·02	0·022	0·024	0·026	0·028
3	0·012	0·015	0·018	0·021	0·024	0·027	0·03	0·033	0·036	0·039	0·042
4	0·016	0·02	0·024	0·028	0·032	0·036	0·04	0·044	0·048	0·052	0·056
5	0·02	0·025	0·03	0·035	0·04	0·045	0·05	0·055	0·06	0·065	0·07
6	0·024	0·03	0·036	0·042	0·048	0·054	0·06	0·066	0·072	0·078	0·084
7	0·028	0·035	0·042	0·049	0·056	0·063	0·07	0·077	0·084	0·091	0·098
8	0·032	0·04	0·048	0·056	0·064	0·072	0·08	0·088	0·096	0·104	0·112
9	0·036	0·045	0·054	0·063	0·072	0·081	0·09	0·099	0·108	0·117	0·126
10	0·04	0·05	0·06	0·07	0·08	0·09	0·1	0·11	0·12	0·13	0·14

7. To estimate the amount of **available chlorine** present in water, the apparatus mentioned in para. 5 is used, with the addition of :—

i. Standard solution of sodium thiosulphate of such strength that 1 c.c. is equivalent to 1 part of free chlorine in a million when titrated with 50 c.c. of water. This solution should be renewed at least once a week.

ii. Glass cylinder, 50 c.c.

iii. Starch-iodide solution.

Measure 50 c.c. of water in a Horrocks' cup, add three drops of starch-iodide solution, and run in the thiosulphate solution from the pipette until the blue colour is just discharged. Add a further drop or two of the starch-iodide solution, and, if a further blue colour is produced, titrate further. The number of c.c. of thiosulphate used is the number of parts of free chlorine in a million in the water.

8. The presence of the more **common poisons** may be detected with the *Case, water testing, poisons.*

The contents of this case are :—

Acid, hydrochloric, in 2 bottles ...	Oz.	6
Caustic soda, sol., 0·5 per cent., in bottle ...	„	2
Ferrous sulphate, sol., 25 per cent., in bottle ...	„	2
Sodium sulphide, 20 per cent., sol. ...	„	4
Zinc gran. arsenic free ...	Bottle	1
Corks and wick-holder ...	Pkt.	1
Corks and porcelain tile on tin stand ...	No.	1
Lamp, spirit, copper ...	„	1
Spare arsenic tubes ...	Box	1
Stand, test tube ...	No.	1
Tubes, test ...	„	9

Instructions for the use of the case are as follows :—

Biological test.—Wherever possible, note the effects of the water on fish.

Chemical tests. (A).—Half fill a test tube with the water to be examined. Add sodium sulphide solution (free from persulphide) in an amount occupying ½ inch length of the test tube. A brown colour indicates the probable presence of a metal, but the absence of a colour does not indicate the absence of arsenic. Now add to the same test tube an amount of hydrochloric acid to occupy one inch length of the tube :—

(*a*) If the colour remains still brown or black, *lead, copper*, or *mercury* is present.

(*b*) If a canary-yellow milky colour develops, *arsenic* is present.

NOTE.—Slight milkiness may be ignored.

Confirmation of the above indication of the presence of arsenic must be obtained as follows :—

i. Place in the test tube five pellets of granulated zinc, and add one inch of hydrochloric acid.

ii. Now place the test tube flat in the lid of the box, with the open end raised. Allow precisely half a minute to elapse, and then light the gas escaping from the end of the fine glass tube. Place the porcelain tile vertical in its holder, and move the tube so that the flame just touches the tile. A black stain, insoluble in dilute hydrochloric acid, on the tile indicates the presence of *arsenic* or *antimony*.

No stain should appear, thus proving the zinc and acid are arsenic free.

iii. Add two inches of the water to be examined, and proceed exactly as described under ii. above.

NOTE.—A fresh cork and fine glass tube must be used for every test.

(B.)—Separate test for the detection of *cyanide*. Half fill the test tube with the sample. Add ½ inch depth of caustic soda solution and five drops of ferrous sulphate solution. Boil very thoroughly. Add hydrochloric acid until the contents of the test tube are clear. A blue colour indicates the presence of *cyanide*. This colour is more pronounced if the test tube is allowed to stand for thirty minutes.

NOTE.—The water cannot be certainly regarded as free from poisons until the above tests have been repeated with negative results in two consecutive examinations.

All test tubes used must be most carefully washed and rinsed in clean water before being returned to the box.

9. **Complete analysis.**—The complete analysis is the work of experts and specialists who carry out the work in properly equipped laboratories.

A description, therefore, in detail of the various steps of a complete analysis is not included in this volume.

It is the duty of engineer officers employed on all semi-permanent and permanent water supply work to ensure that all water for which they are responsible is completely analysed by those experts whose duty it is to make such an analysis.

A complete analysis should generally include the following information :—

Physical. (a) *Physical characteristics, i.e.,* turbidity, colour, and odour, as determined by para. 4.

Chemical.
(b) *Chlorine absorption*—parts in 1,000,000.
(c) *Reaction* (acid or alkaline)—alkalinity is stated in parts of $CaCO_3$ in 100,000.
(d) *Suspended solids*—parts in 100,000.
(e) *Total dissolved solids*—do. do.
(f) *Organic solids*—do. do.
(g) *Ammonia*—do. do.
(h) *Albuminoid ammonia*—do. do.
(i) *Nitrates and nitrites*—expressed as parts of nitrogen in 100,000.
(j) *Chlorides*—parts of chlorine or sodium chloride in 100,000.
(k) *Oxygen absorption*—parts in 100,000.
(l) *Hardness*—(temporary and permanent)—parts of $CaCO_3$ in 100,000.
(m) *Iron*—parts in 100,000.
(n) *Presence of poisonous substances.*

Bacteriological. (o) *Bacterial content*—Smallest quantity of water giving positive results with MacConkey's broth in 72 hours at 37° C.

75. *Interpretation of results.*

1. An analysis may be taken of the water in its crude state or after treatment. Analysis of the finished water will usually be limited, in the field, to an examination of the physical characteristics such as colour, &c., and to an estimation of the available chlorine present, thereby testing the efficacy of the purification process. This may, and should when possible, be checked by making sure that lactose fractors are not present in 50 c.c.

The interpretation of the complete analysis of a crude water is a matter of some difficulty, and requires the services of a hygiene expert, who will also require to make a very careful examination of the source. It is essential to consider in conjunction with one another the results of chemical and bacteriological analysis, together with a thorough examination of the source.

The general significance of certain chemical determinations are given below.

2. **Total solids.**—Water containing suspended matter should be filtered or allowed to settle, but considerable quantities of dissolved solids may be present without rendering the water unfit for drinking, provided that the salts themselves are not harmful and have no pronounced physiological action. Thus, although as previously pointed out hard water is said to cause constipation, calcium bicarbonate and sulphate may be present to the extent of 10 or even more parts in 100,000, but magnesium salts and calcium chloride should only be present, if at all, in very small quantities.

3. **Chlorides.**—When a water contains more chlorides than the average for waters in the same district, some form of contamination is to be suspected. Urine contains 500 to 600 parts of chlorine in 100,000, while 20 per cent. of sewage in the water may raise the chlorine content only by 1 part in 100,000. Similarly the content of chlorine may be reduced owing to the influx of rain-water, which may mean that surface drainage is entering the well or other water source. Common salt may be present up to about 100 parts in 100,000 in drinking water without serious harm, but 50 parts render the water distinctly brackish; such quantities of calcium or magnesium chlorides, besides rendering the water hard, would be objectionable physiologically. In Egypt it was found that men could use water containing as much as 200 parts of common salt in 100,000, while horses and camels could, if necessary, be safely supplied with water containing respectively 500 and 700 parts of salt in 100,000.

4. **Ammonia.**—This is generally of animal origin, though not invariably, and is often regarded as an indication of recent pollution. At the same time, nearly all natural waters contain ammonia, and rain-water contains much more than the 0·005 parts in 100,000 which is sometimes regarded as the maximum allowable in potable water. Thus, if excess of ammonia is found, the source and its surroundings should be examined before the water is condemned. Ammonia may result from the reduction of nitrates by metals, in which case the organic source of the ammonia may be very remote. Spring and deep-well water should contain very little ammonia, as the nitrifying organisms present in the soil will have converted most of the ammonia originally present into nitrates, whereas upland surface waters and rain-water may contain considerable quantities and be free from contamination. River water should not contain more than 0·005 parts in 100,000.

5. **Albuminoid ammonia.**—The compounds included under this term may arise from either vegetable or animal sources, but sewage-polluted water will contain more saline than albuminoid ammonia. In general, more than 0·008 parts of albuminoid ammonia in 100,000 should render the water liable to suspicion, and the source should be carefully examined.

6. **Nitrites and nitrates.**—These are also mainly due to the presence of matter of animal origin in the water. Ammonia is readily oxidized to

nitrites and then to nitrates by bacteria. The reduction of nitrates to nitrites and ammonia also takes place as the result of bacterial action, hence the presence of nitrites in deep-well water is not so indicative of pollution as their presence in upland surface waters. Again, if much organic matter is present, the presence of nitrites in upland waters does not necessarily indicate recent pollution. In cultivated districts there will be more nitrate and nitrite in the water than in upland or deep-well water.

7. **Oxygen absorption.**—This, in the absence of inorganic reducing agents, may vary from less than 0·05 to more than 0·4 parts in 100,000, and may be due to either animal or vegetable organic matter.

CHAPTER XV.

PRINCIPLES OF WATER PURIFICATION.

76. *Storage and sedimentation.*

1. Purification involves mainly the removal of suspended matter, the destruction of bacteria, and the improvement of the appearance and taste of the water. At the same time, it is necessary in the case of certain waters to adjust the hardness, a very hard water being unsuitable for boilers, in laundries, and in certain manufactures, while, if too soft, a water is liable to act upon lead. Again, the removal of small quantities of iron salts or of other soluble substances is occasionally required, and all processes of this kind are conveniently grouped under the title of *purification*.

The chief methods available for improving a water supply are the following:—Storage, sedimentation with or without coagulants, filtration, aeration, addition of chalk to a soft water or of lime to a hard water, and chemical treatment to destroy bacteria, algæ, and so forth.

2. The effects of **storage** all tend towards the improvement of the water, suspended matter is gradually deposited, colloidal matter becomes coagulated to a certain extent and settles to the bottom, organic compounds become oxidized either directly or by bacterial action, and the bacteria themselves become reduced in numbers as the organic matter upon which they live is used up. Prolonged storage thus improves the colour and taste of a water, pathogenic organisms disappear, the bacterial content is reduced to small proportions, and the stored water is almost free from suspended solids. Lakes and steady reaches of rivers form in many cases excellent natural storage reservoirs, but their suitability for this purpose will depend a good deal on the nature of the bottom. If the bottom consists of fine mud, there will tend to be much animal and vegetable life, which at certain periods of the year may increase to such an extent as to render the water after storage even worse than before. An ordinary stagnant pond is an extreme example of this. A bottom of stones, gravel, or sand is more generally satisfactory. By constructing a small

dam in a river or stream, a useful natural reservoir of this kind can readily be formed ; this may, by deepening the stream above the dam, avoid rapid flow of the water, and so enable sedimentation to take place, besides offering the obvious advantage of maintaining a supply of water in dry weather. (*See* Appendix I to this chapter.)

3. In making such a reservoir all organic matter and, as far as possible, all mud should be removed before the reservoir is allowed to fill ; if the reservoir is entirely artificial, a suitable floor of concrete, gravel, or stones will, of course, be made. Overhanging trees should be avoided, and steps should be taken to prevent the fouling of the water by drains from houses or farms ; bathing and washing should be prohibited. If the reservoirs are to be used as a means of removing bacteria, they should be capable of holding at least one month's supply. This, except under very special circumstances, is not practicable in semi-permanent water supplies, but, at the same time, it may be a great advantage to be able to store the water, even if only for a day or two, as, although the bacterial content may not be affected appreciably, suspended matter will have diminished in the water, and a certain amount of improvement will result from the aeration and from the action of light. This is particularly the case with streams which become much swollen after rain, and which in consequence bring down large quantities of mud and sand. The entrance to the reservoir should be screened to prevent floating débris from collecting, and the waterworks intake should be near the outflow of the reservoir and a few inches below the surface of the water. This intake should also be screened to prevent leaves, fish, and other undesirable objects from entering the works. A bye-pass should be constructed, especially in country liable to sudden floods after rain, so that the stored water is not stirred up more than is unavoidable.

4. At certain periods of the year stored water is very liable to become infested with algæ. These are of many different kinds ; they may render the water turbid, green, or brown, or they may give an unpleasant earthy or fishy taste and odour. As will be seen later, a small amount of algal growth is sometimes an advantage, but if it becomes excessive it chokes the filters as well as causing the difficulties mentioned above. The algæ can be killed or their growth prevented by treating the water with a solution of bleaching powder or copper sulphate. About one part of either in a million may safely be used, and copper sulphate is to be preferred, as the effect is more lasting than that of bleaching powder. (Appendix II.)

In large waterworks a bag containing the requisite amount of copper sulphate is towed behind a boat, but the main object to be attained is as uniform an admixture of the salt with the water as possible, and the method employed will depend on the circumstances.

5. **Sedimentation with coagulants.**—In semi-permanent water supplies only such storage before treatment is possible, if any, as will allow the coarser sandy particles to settle. Clay is often so finely divided that it takes several days to settle, and, moreover, a well-puddled clay appears to form a *colloidal solution* with water, and in such cases complete subsidence may be a matter of months. A certain amount of organic detritus is often present also ; this settles only very slowly, and organic

matter may be present in actual solution or as a colloid. In these cases, too, several weeks or even months may be necessary to render the water clear, colourless, and of good quality.

This object can, however, be attained in a few hours by the use of coagulants, the action of which is partly chemical and partly physical. The chief coagulant used in water purification is aluminium hydroxide $Al(OH)_3$. The most convenient source is aluminium sulphate; an impure aluminium sulphate containing a little iron, and known commercially as *alumino-ferric* or *ferric alumina*, can be used. This substance must not be confused with iron alum, which is a much more costly salt of very different properties; it does not contain aluminium, and is practically useless as a coagulant. Ordinary potash alum can be used; it is not only much more expensive than aluminium sulphate, but it is also necessary to use a much larger quantity to produce the same effect.

When aluminium sulphate is mixed with a water containing a small quantity of alkali, a precipitate of aluminium hydroxide is formed. This is a gelatinous precipitate, and is denser than water; it falls to the bottom and entangles the minute particles of suspended matter, and so clears the water. The addition of alum also causes the coagulation of the colloidal matter, which also subsides.

There is a further action. The aluminium hydroxide precipitate is capable of absorbing a certain amount of organic matter from the water, and this results in the removal of much of the colour, odour, and taste. The reaction giving the precipitate of aluminium hydroxide in natural water is one of hydrolysis, and only takes place satisfactorily in the presence of a certain amount of an alkaline salt. Most natural waters contain bicarbonates of calcium and magnesium, and these salts are alkaline to methyl orange, even in the presence of weak acids like carbonic acid and the organic acids of the soil, and are capable, moreover, of giving a precipitate of aluminium hydroxide with aluminium sulphate. The reaction may be represented as follows :—

$$3Ca\,(HCO_3)_2 + Al_2\,(SO_4)_3 = 2Al\,(OH)_3 + 6CO_2 + 3CaSO_4.$$

If the alkalinity, calculated as parts of $CaCO_3$ in 100,000, is less than 12, it is advisable to add lime or sodium carbonate as well as alumino-ferric; otherwise the precipitation will tend to be incomplete and will be delayed, and this may result in the after-precipitation of the hydroxide in the sedimented and filtered water, which then becomes opalescent or turbid. The amount of alumino-ferric required depends very much upon the character of the crude water and upon the amount of purification expected. Thus in civil practice it is rare to use more than two or three grains of alumino-ferric each gallon of water to be treated. On the other hand, where it is desired to treat a water which would, under normal conditions, be rejected as quite unsuitable, it is often necessary to use 10 or 15 and in extreme cases even up to 30 grains a gallon. Still larger quantities were used with the water of the Sweet Water Canal (Suez); thus at Moascar 31 grains a gallon were employed. Again, if mere precipitation of the suspended matter is all that is required and a coloured effluent with an earthy taste will pass, it may be possible to make two or three grains a gallon suffice, while the same water, if treated with 10 grains a gallon, may be capable of giving a clear and palatable water.

It is possible to make the sedimentation continuous by using a long sedimentation tank, and allowing the crude water to flow in at one end together with a suitable amount of alum solution. The tank must be of such a size that it takes the water at least eight hours to flow from one to the other. Baffle walls should be arranged, and stirring of the sludge should be avoided. In waterworks dealing with the Sweet Water Canal circular concentric waterways of reinforced concrete were used of 32,000 gallons capacity.

6. The following description deals with waters containing finely divided and colloidal clay which do not respond to treatment with small quantities of alum, and which either clog sand filters so rapidly as to render their use very uneconomical, or else pass through the filters with little improvement. Such waters are of frequent occurrence, and the following notes deal with methods which have been proved to be efficacious in dealing with them. Attempts have been made to employ more orthodox quantities of alum, such as one or two grains a gallon, but it was found that the precipitate formed often failed to settle even after twenty-four hours or more, and the water was hardly improved in quality by the sedimentation.

For field purposes sedimentation should be complete in from twelve to twenty-four hours, but this period for sedimentation may be reduced to from eight to twelve hours, or even less, by carefully observing the following two conditions :—(*a*) The solution of alumino-ferric of suitable strength should be run into the sedimentation reservoir together with the crude water regularly; that is, each gallon of the water should receive its proper share of the alumino-ferric as it flows into the reservoir. The reason for this would seem to be that it is essential for the precipitate to be formed in contact with the colloidal and suspended matter, as it were, in order to obtain the maximum coagulant effect; to mix a quantity of preformed precipitate with the water can easily be shown to be much less satisfactory. (*b*) The water should be kept, as far as possible, in constant motion while the reservoir is filling. This has the effect of causing the precipitate to coagulate much more rapidly, and to form larger flocks which are more quickly deposited, the action being similar to that of shaking a test-tube in which a precipitate is being formed. If it is necessary to add an alkaline solution, this should be either well mixed with the water before the alumino-ferric is added, or should be added, from a separate tank, with that solution and with the same precautions as to regular addition.

These conditions can be fulfilled by running the crude water into the reservoir down a slightly sloping trough arranged from one corner along one side of the sedimentation reservoir, and leading the solution into the stream in the trough. Knowing the rate of flow and the concentrations of the solutions, it is easy to adjust the speed of flow of the solutions so that the water gets its proper dose. (*See* Pl **164**).

Theoretically, a water having an alkalinity of 10 can receive a dose of 13·3 grains a gallon of alumino-ferric without any unchanged alum remaining after sedimentation, but it is not wise to add as much aluminium salt as this, because the reaction is not instantaneous and is not necessarily complete. One experiment showed that 19·2 grains a gallon gave a clear water after eight hours, with no subsequent precipitation on adding an alkali (ammonia), while 25·3 grains a gallon, the theoretical equivalent, showed evidence of incomplete precipitation. At Amara in Mesopotamia alumino-ferric was added in quantity equivalent to 1·1 times the alkalinity (in terms of $CaCO_3$ in 100,000), but sedimentation for 18 to 24 hours followed.

7. **Coagulation with ferric hydroxide. The Anderson system.**—A horizontal rotating cylinder, provided with curved baffle plates attached radially to the inside circumference, is charged with scrap iron. The baffles lift the broken scrap iron, and allow it to fall through the water, which is caused to flow through the cylinder. The top part of the cylinder contains air. The water is in contact with the iron and air for about three and a half minutes, and dissolves from $\frac{1}{10}$ to $\frac{1}{8}$ grain of iron a gallon. Ferric hydroxide is formed, and this acts in the same way as aluminium hydroxide, carrying down with it the finely divided particles of suspended matter and the colloidal matter.

8. After the addition of the coagulant, three methods of procedure are available :—(*a*) The water may be allowed to stand until the sedimentation is complete and the water is quite clear, when it may be pumped into the rising main or otherwise used. (*b*) The water may be passed, after a short sedimentation, through a mechanical or pressure sand filter. It is not desirable that too great a quantity of precipitate should enter the pressure filter, which is in such case rapidly choked and needs frequent back-flushing, consequently it should be possible to allow a short time for the greater portion of the precipitate and the accompanying suspended matter to settle. (*c*) The water may be allowed to settle until practically clear, and then passed through an ordinary sand filter. In every case, and more particularly in the last, care must be taken that the sediment is not mixed with the clear water or carried over into the pump or in the outflow. A small amount of the precipitate is an advantage and even necessary in the case of the mechanical filter, but even a very small quantity, if introduced continually on the slow sand filters, causes rapid choking and involves frequent cleaning with consequent loss of time. Again, the precipitate carries down an appreciable proportion of the bacteria of the water, and so its presence in the finished water is to be avoided. At the same time, if the water is treated with a bactericidal agent after sedimentation, as is usually the case, the presence of a small quantity of the precipitate in the finished water does not affect the safety of the water, as it is without physiological action, although it spoils the appearance, rendering the water turbid or opalescent.

77. *Sand filtration.*

1. Filtration through sand is generally employed in permanent plant, whether preliminary sedimentation, with or without coagulants, is used or not, but experience has shown that this is not invariably necessary in semi-permanent water supplies. In almost all permanent plant the function of the sand filter is twofold :—(*a*) the removal of visible suspended matter, (*b*) the removal of bacteria. Slow sand filtration necessitates an area of filter bed in use sufficient to give 1 square foot of surface to each

75 gallons treated in 24 hours. In more temporary plant it is not convenient to make the filters so extensive, and, for other reasons also, the removal of bacteria in the filters is not practicable in all cases. In consequence of this some method of chemical sterilization is always necessary, and the work of the filters is confined rather to the removal of the suspended matter. Sand filters may be divided into four types for convenience :—(a) slow-gravity filters of fine sand, the oldest type and sometimes known as the English type; (b) rapid non-submerged filters of fine sand; (c) successive filtration through coarse gravel, fine gravel, coarse sand, and finally fine sand—the Puech-Chabal type; (d) mechanical or pressure filters.

2. The action of a sand filter of the conventional type is not merely that of a strainer, for an efficient filter will remove practically all the bacteria from the water, although it is obvious that these organisms could pass with the utmost ease through the spaces between even the finest sand particles. Each grain of sand becomes coated with a very thin layer of slimy material, probably of bacterial or of algal origin, and this layer attracts and retains particles of very minute size, including bacteria; the bacterial film also acts as an absorbent of certain dissolved substances in the water, and, in fact, acts very much in the same way as the precipitate of aluminium hydroxide described above. It is clear, therefore, that the filter needs a certain time to *ripen*, and that its power of removing bacteria will be very small at first but will gradually increase. The filter is then useful until it becomes so choked with silt and slime that the filtration is slowed down to an uneconomical rate. The filter must then be cleaned, after which the water passing through is rejected until the filter has ripened, unless chemical sterilization is used. In a mechanical filter the film of slime is replaced by an artificial film of aluminium hydroxide, and in this case the filtered water can be used a few minutes after the sand has been cleaned.

The principle of the coarse filters is similar, except that the film is probably formed on all the sand particles throughout the filter instead of on the particles only in the top inch or two as in the fine sand filters.

3. **Slow sand filters** are constructed on a foundation of perforated bricks or drain-pipes, above these is a layer of broken stone or shingle about 6 inches thick, then about 9 inches of graded gravel, and above about 30 inches of fine sand. The formation of the filtering film or the ripening of the filter takes time, the length of time varying according to the character of the water and the time of the year. The film is also liable to break if the speed of filtration is not kept uniform, or as the result of the activities of insect larvæ. The formation of bubbles of gas in hot weather may result in the detachment of portions of the film from the sand. Thus slow filters are not generally suitable for semi-permanent water supplies, unless they are regarded merely as strainers and the destruction of bacteria is carried out, after filtration, by chemical means. The rate of filtration gradually diminishes, and it becomes necessary to clean the filter by paring off the top two or three inches of sand and replacing it with clean sand. If chemical sterilization is employed, the first water passing through a clean filter may be used, and it is not necessary to wait until the filter has ripened. Under these conditions a small sand filter

may be very useful, and many of the precautions which are essential when the filter is used as a bacterial filter may be neglected. Thus it is possible to disregard the breaking of the film, and the speed of filtration may be hastened almost to the limit of the *head* available, provided that this does not result in a turbid filtrate; also it may be varied to suit the requirements of the works. Filters should be duplicated, since the cleaning requires several hours during which no water is available. If the crude water is highly charged with suspended matter or with colloidal clay, preliminary sedimentation with or without coagulants is necessary, otherwise the filters become choked very rapidly, and the supply is apt to be insufficient and irregular (Appendix III).

4. **Non-submerged filters.**—The water is distributed over the surface of a fine sand filter in fine jets at the speed at which the water will percolate through the sand. In this way the sand is not submerged, and the water is well aerated. The filter ripens slowly, and after a month or so is capable of reducing the bacterial content of the water to negligible proportions. It appears that the filtering film forms a few inches below the top of the sand. Such filters are not suitable for waters containing much matter in suspension, unless preliminary sedimentation is carried out.

5. **Puech-Chabal system.**—In this system there is a series of *roughing filters,* the first having particles about the size of walnuts and the last about the size of peas; the depth of filtering material and the superficial area of the filter increases as the size of the particles diminishes. The water is passed through these roughing filters in succession and then through one or two pre-filters constructed much in the same way as an ordinary sand filter, the top layer of sand passing through a sieve with eight meshes to the linear inch. Finally a finishing filter, much larger than the pre-filter, of fine sand is used, the water passing through this at a much slower rate. This type of filter is also capable of removing bacteria, and has the advantage that the roughing and pre-filters perform most of the purification, so that the finishing filter only needs cleaning at long intervals. While a complete Puech-Chabal plant is too large and too costly for semi-permanent work, a modification comprising one or two roughing filters and a fine sand filter can sometimes be used with advantage, the water after filtration being treated with a chemical sterilizing agent as usual.

78. *Purification by mechanical filtration.*

Mechanical filters are of many types, but the principle on which they act is, roughly, the same in all. Water is forced under pressure through a layer of sand, and an artificial film of aluminium hydroxide is formed on the sand. This, if carefully treated, acts as a bacterial filter, but it is advisable to employ chemical sterilization after filtration. The sand is washed by reversing the stream of water for a few minutes, the back-flushing being assisted in some cases by mechanical stirring of the top layer of sand, or by forcing air through the whole of the sand. For all water supply schemes of a semi-permanent nature, the mechanical filter is the most practicable and convenient, and it is possible to design quite simple plants on a small scale which can be readily transported and which serve very well as a temporary water supply.

79. *Methods of sterilization.*

1. While bacteria can be removed almost completely by efficient sand filters, either of the *gravity* or of the mechanical type, yet all kinds are liable to allow considerable bacterial contamination to pass through at times, particularly if they are not under the most careful supervision. Other more temporary methods of water treatment are not in the least likely to give bacteria-free water, so that in the installations under consideration it is imperative that some kind of process should be employed which will aim at the destruction of bacteria remaining after the preliminary treatment has removed suspended matter, colour, taste, and as large a proportion of the bacteria as possible. The methods available are :—(*a*) the use of hypochlorites such as bleaching powder, eau de Javelle, and eau de Labarraque ; (*b*) the use of chlorine gas ; (*c*) the use of ozone ; (*d*) the excess lime method ; (*e*) the use of ultra-violet light.

2. **Bleaching powder,** or **chloride of lime,** when dissolved in water behaves as a solution of calcium hypochlorite, and the *available chlorine* is able to act on organic matter and to destroy life. It must be remembered that the *Horrocks'* test, which shows how much bleaching powder must be added so that a slight excess may remain, is not a measure of the bacterial contamination of a water, as a number of other things which may be present in water can absorb the available chlorine from bleaching powder. The test shows what quantity must be added so that a sufficient excess may remain in proof of the fact that all bacteria are destroyed.

Bleaching powder is not a single substance, and always contains free slaked lime, which is not very soluble in water ; consequently it is not possible to obtain a clear solution of suitable concentration. This is not important, however, as the calcium hypochlorite readily passes into solution, so that a cream of bleaching powder, if carefully made, will deposit mainly slaked lime on standing, and the clear supernatant fluid will act as a solution of calcium hypochlorite. In making the solution care must be taken to break up all lumps, and the best method is to grind the powder with a little water in a mortar to a thick cream ; this is then diluted with water and allowed to settle, the liquid is poured off, and the residue is ground with more water ; this is continued until the whole of the powder has been transferred, when the suspension is diluted to a suitable concentration. The solution should only be prepared in such quantities as will be used up in about 12 hours, as the strength is liable to variation owing to the decomposition of the hypochlorite.

The solution is added to the filtered water in such quantity as will ensure that at least $\frac{1}{2}$ part in a million of available chlorine will persist in the water after the lapse of about three-quarters of an hour. If the water has to be transported for any distance, a larger quantity of available chlorine should be left, as the chlorine is absorbed in the pipe lines ; also the hypochlorite appears to react with water, especially in the presence of light, and the chlorine disappears. Moreover, it has been found that $\frac{1}{2}$ part in a million is only effective as a bactericide after about five hours' contact. A much safer method, which should be adopted when possible, is to add a considerable excess of free or available chlorine, say 2 parts in a million, and then, after about half an hour's contact, to remove the excess by the addition of some kind of reducing agent, such as sodium sulphite or sulphur dioxide. When the water has to traverse a pipe-line, it is found that 2 parts of chlorine in the rising main is reduced to $\frac{1}{2}$ part or even less after flowing through a mile or so of pipe. After a few days the quantity of chlorine in the rising main may be reduced, and chlorine still appears at the other end of the pipe-line. If there be no pipe-line the excess can be removed as already mentioned. Two parts of available chlorine in a million is effective as a bactericide in half an hour. There is no doubt that under active service conditions free or available chlorine should always be present in the service water, as the taps, the vessels in which the water is taken, and many other causes are likely to introduce contamination in an otherwise satisfactory water.

This excess of chlorine in pipe-lines has been proved repeatedly to be the most convenient method of preventing waters containing iron from developing *rustiness*. It has already been pointed out that this discoloration and turbidity is often due to the presence of crenothrix or of other iron bacteria. It follows that, if the bacteria be present in the pipe-lines, and the water contains iron, no amount of flushing will ensure a water free from rustiness. If, however, the whole pipe-line be treated with water containing a considerable excess of available chlorine, the bacteria will be destroyed. The service water subsequently, being chlorinated, will not re-infect the pipes, and the water supply will become and will remain clear. It is usually possible to carry out this cleansing of the pipe-line at a time when the water is not needed for use. Thus a strongly chlorinated water can be pumped into the line the last thing at night. After a few hours standing in the pipes this can be run-off. Six or even ten parts of chlorine in a million may be necessary in the water as it leaves the waterworks, as the quantity of chlorine diminishes as the water proceeds along the pipe, and, if an insufficient amount leaves the pumping station, the more remote parts of the pipe-line will not be sufficiently chlorinated. (Appendix IV.)

3. Solutions of sodium or potassium hypochlorite are known as *eau de Javelle*, although the sodium salt was originally called *eau de Labarraque*. This solution is more convenient to use than bleaching powder as the alkali salts are more soluble, and a more concentrated solution which is also free from undissolved solid can be used.

4. Many kinds of apparatus have been designed to apply the hypochlorite solution to the water, some of which aim at regulating the dose automatically as the speed of delivery changes. Some introduce the solution on the suction side, and some on the delivery side of the pump. Most of the types of such apparatus depend on the passage of the solution through a fine jet, and, even if great care be taken to allow the solution to settle for some hours before use, there is still danger that the jet may become choked, especially when bleaching powder is used. The fact that the apparatus is supposed to be automatic is apt to lead to a false sense of security, and it is advisable to watch the addition of the hypochlorite from time to time, or a considerable quantity of water may escape treatment. This being so, it is simpler, and on the whole more satisfactory, to add the hypochlorite solution to the water as it flows into a special reservoir or sump, which serves not only as a supply to the pump, but, what is of great importance, also serves as a contact tank in which the

necessary contact of the chlorine with the water can take place. In any case it is necessary to test the service water at regular intervals for free or available chlorine, and it is a simple matter for the attendant to adjust the flow of the hypochlorite solution so that a satisfactory amount of chlorine remains in the water. The following method was employed for many months with every satisfaction for different supplies varying from less than 100 gallons an hour to over 10,000 gallons an hour. Two vessels were used for the bleaching powder solution. In the case of the smaller supplies these were barrels of about 60 gallons capacity, and for the big supply they were galvanized iron tanks of about 400 gallons capacity. A suspension of bleaching powder was made in one of the vessels, with the precautions mentioned above, of such strength that the whole should just suffice for a day's run. This was allowed to settle for a few hours. The vessels were provided with taps a few inches from the bottom, so that the sediment was avoided and only the clear supernatant liquid was used. Knowing the rate at which the filtered water entered the reservoir or sump, it was easy to calculate the volume of solution that should be added in a given number of seconds. After one or two trials it was found quite easy to obtain the correct rate, using a measuring cylinder to test the speed of flow. If at any time the rate of flow of the filtered water changed, it was a simple matter to adjust the flow of the solution. This method does not take much more time than the automatic method, and gives less trouble as the apparatus is so much more simple. It must be remembered that the automatic method needs constant watching and testing.

Some automatic methods of applying bleaching powder solution and *eau de Javelle* are given in Chap. XVI.

5. **Sterilization with chlorine gas.**—This presents many advantages over sterilization by means of hypochlorites. (*a*) Liquid chlorine in cylinders is more convenient, and does not involve the necessity of making a solution daily. (*b*) A larger excess of available chlorine as gas than as hypochlorites may be present in the water without causing an unpleasant taste. (*c*) Given a satisfactory apparatus for applying the gas to the water, a more delicate adjustment of quantities is possible than in the case of hypochlorite solutions. On the other hand, the apparatus required is costly and delicate, and needs expert supervision. Even then, impurities in the chlorine may give much trouble, and may put the apparatus out of action for some hours at a time.

6. **Sterilization with ozone.**—Ozone is an active form of oxygen. The molecule of ozone contains three atoms of oxygen, and is unstable, breaking up readily on heating or in contact with oxidizable substances into a molecule of ordinary oxygen (consisting of two atoms) and a single atom of so-called nascent oxygen. It is this nascent oxygen which is responsible for the oxidation. Ozone is so unstable that it is not possible, at ordinary temperatures, to obtain more than 1·75 per cent. of ozone in air. To produce this amount, however, is very uneconomical, requiring four times the electrical energy necessary to obtain half the concentration.

Ozonized air, containing 1·6 to 1·8 gms. of ozone a cubic metre, or rather less than 0·14 per cent., is generally used. The ozonized air is produced by passing a silent electric discharge through air. For economical working the following points must receive attention :—(*a*) Sparking must be avoided, as this results in a diminished yield of ozone. (*b*) The air must be dry, as water vapour hinders the formation of ozone, and also, to a limited extent, decomposes ozone, forming hydrogen peroxide, which is not quite so satisfactory a sterilizing agent as ozone itself. The air is dried either by passing over calcium chloride or, more usually, by cooling strongly. (*c*) A high voltage must be used; the yield of ozone rises rapidly with increase of voltage, especially above 25,000 volts. (*d*) The temperature should be kept low. (*e*) Since about 73 per cent. of the ozone is used directly in oxidizing organic matter in the water and 7 per cent. remains dissolved, 20 per cent. passes on with the air; hence the air should be used again to avoid the loss of this 20 per cent., being mixed with a small quantity of fresh air and returned to the ozonizer. (*f*) Water containing much suspended matter should be allowed to deposit this, or should be filtered, so that the ozone is not used up unnecessarily.

The ozonized air is injected into the raw water at the bottom of a tower in the form of fine bubbles to ensure thorough admixture with the water. It has been found that 1·3 to 4 gms. of ozone a cubic metre of water, *i.e.*, 1·3 to 4 parts in a million, is effective according to the character of the water. Excess of ozone in the water is shown by the starch-potassium iodide test, a blue colour indicating that ozone is present (in the absence of free chlorine, hypochlorites, and oxides of nitrogen, &c.).

This method of purification is noteworthy in that nothing remains in the water as a result of the addition of the ozone, any excess of ozone disappearing in a short time. The hardness is unaffected. Oxides of nitrogen are not produced. The organic matter is reduced by nearly 50 per cent. There is no corrosion or solution of the metallic parts of the apparatus. The appearance, colour, and taste of the water are greatly improved. The treatment destroys all bacteria except the more resistant spores; all intestinal organisms disappear.

7. Sterilization by the excess lime method.—It was pointed out in Chap. XIV, Sec. **71**, that nearly all waters contain bicarbonate of calcium (and sometimes of magnesium) in solution, and that this renders the water *temporarily* hard—a hardness which can be removed by boiling. This hardness can also be removed by adding sufficient lime to react with the bicarbonate when the normal carbonate is precipitated, and can be removed by sedimentation or filtration. This is known as Clark's process, and was introduced in 1841. Subsequently, by Dr. P. Frankland (1885 and 1894), by some Continental authorities, and in the United States it was shown experimentally and practically on a large scale that an excess of caustic lime is a valuable bactericide.

The process was more fully studied by Dr. (now Sir) A. C. Houston, and a method of applying it was worked out and was described by him in the eighth report on research work published by the Metropolitan Water Board in 1912.

To ensure the destruction of pathogenic bacteria, Houston found that an excess of lime amounting to even less than 0·007 per cent. (as CaO) is effective in from five to twenty-four hours; but he recommended about 0·007 per cent. should be used to leave a margin of security.

It is not desirable to leave free caustic lime in the water supplied to consumers, hence the excess must be removed after a suitable contact period of, say, twenty-four hours. This can be effected in two ways :—(i) The treated water can be thoroughly aerated when the lime will absorb carbon dioxide from the air—or it can be treated directly with carbon dioxide, the product, carefully washed, of coke ovens ; chalk is formed and may be precipitated, part remaining in solution as bicarbonate. (ii) A quantity of un-limed water, which has been rendered safe by efficient storage or by the action of chlorine, hypochlorites, or ozone, can be added, when the excess of lime in the treated water will react with the bicarbonate in the water added, as in Clark's process. The reactions are as follows :—

$$Ca\,(HCO_3)_2 + Ca\,(OH)_2 = 2CaCO_3 + 2H_2O.$$

Action of carbon dioxide on the excess of lime—

$$Ca\,(OH)_2 + CO_2 = CaCO_3 + H_2O \text{ (chalk precipitated).}$$
$$Ca\,(OH)_2 + 2CO_2 = Ca\,(HCO_3)_2 \text{ (bicarbonate—in solution).}$$

Thus in the case of a hard water :—

A. Sufficient lime is added to

(*a*) precipitate all the dissolved calcium bicarbonate ;
(*b*) react with all the free carbon dioxide in the water ;
(*c*) leave at least 0·007 per cent. lime (as CaO) in excess.

B. Sufficient raw water, rendered safe by storage or other treatment, is mixed with the lime-treated water to ensure a suitable degree of hardness in the mixed water.

In the case of a soft water the treatment is :—

A. As above.
B. Complete aeration or treatment with carbon dioxide.

The precipitated chalk is allowed to settle or is filtered off. A hard water is thus softened to any desired extent by this treatment, while a soft water is given a suitable degree of hardness (0·007 per cent. of CaO is equivalent to 12·5 parts of $CaCO_3$ in 100,000).

The greater the temporary hardness of the crude water, the less unlimed water will need to be added to produce a given degree of hardness in the finished water, and *vice versa*.

Houston (*loc. cit.*) recommends the following procedure :—

". . . . a treatment in three stages, using (1) enough lime to combine with the temporary hardness in the whole of the water, but adding it to such portion of the whole as would leave an excess of about 0·007 per cent. of CaO in that portion ; and (2) sterilizing with chlorine or ozone the remaining portion ; and then (3) mixing the two together and removing the inert carbonate of lime by rapid filtration." He further states that :—"Speaking generally, the bactericidal dose with hard waters would seem to be about 1 to 5,000, and with very soft waters about 1 to 50,000."

The following table from Sir A. C. Houston's 8th report (above quoted) still further illustrates the method.

Average of eight experiments with eight different samples of raw Thames water (hardness 21·63).

Lime-treated (1 in 5,000) (Average excess CaO, 0·0066 per cent.)	Not treated.	Hardness of mixture (soap test).
60 mixed with	40	9·01
65 ,, ...	35	8·14
70 ,, ...	30	7·48
75 ,, ...	25	7·51
80 ,, ...	20	8·06

If chlorine be used for the sterilization of the water which is mixed with the lime-treated water, a moderate overdose of chlorine is of little moment, as it will be diluted considerably by the limed water, and the excess will rapidly disappear by acting upon the organic matter in the latter part.

The method results in a safe and palatable water which contains nothing that was not present in the water previously. It is applicable to flood water, and, by hardening soft water, renders it unable to act upon lead. It is relatively inexpensive.

8. **Sterilization by ultra-violet light.**—The chemical rays of the spectrum destroy bacteria rapidly. The water is made to circulate in such a way that it passes within a few inches of a Cooper-Hewitt mercury vapour lamp several times. The water must not be appreciably coloured, and should be free from suspended matter. An air space has been found necessary between the lamp and the water, otherwise the outside of the lamp becomes covered with a deposit of carbonates which absorb the rays ; the air space should be as small as possible, and the container of the mercury lamp should be of silica, as both air and ordinary glass absorb the ultra-violet rays.

9. **Sterilization by boiling.**—The disadvantages, that boiled water lacks aeration and is consequently flat and insipid to the taste, and also needs cooling, have been overcome in certain types of apparatus. Units can be constructed to deal with up to 25,000 gallons an hour. Boiling destroys pathogenic bacteria, but many spores resist the boiling temperature for some time.

Condensers were used to purify Nile water. In one case 22,000 gallons were distilled each day, with an expenditure of a ton of coal for 2,240 gallons.

10. **Other sterilizing agents.**—Many other substances have been suggested for the destruction of bacteria in water. Some are quite useful, but are not suitable for use with semi-permanent installations.

Tablets of *sodium bisulphate* are an article of supply, and 15 grains to a pint of water is the proportion used. These are useful for issue to men on detached duties; they can be used directly in the water-bottle.

Copper sulphate, though useful as an algicide, is too uncertain to use for sterilizing water.

Hydrogen peroxide, either added directly or indirectly by using peroxides of sodium, calcium, or magnesium, is an efficient sterilizer for water. Its action is slow, and a concentration of about 1 part in 1,000 of water is necessary with hydrogen peroxide itself; the peroxides of sodium, calcium, and magnesium are rather more efficient. Magnesium peroxide is used for sterilizing bottled mineral waters.

Potassium permanganate oxidizes organic matter, and a brown hydrated peroxide of manganese is formed which serves as a coagulant, but is less efficient for this purpose than the hydroxides of iron and aluminium. Potassium permanganate is used as a part of the process employed in the purification of the water of the Scheldt for the town of Ghent. It is too costly for use as a sterilizing agent alone.

Eusol.—Solution A.—6 oz. of boric acid in 2 gallons of water, which must be clear and boiled.

Solution B.—Bleaching powder solution containing 1·3 to 1·35 per cent. of available chlorine.

For use, 1 part of B is mixed with 2 parts of A.

Dakins' solution.—Solution A.—4·4 oz. of anhydrous sodium carbonate (or 12·6 oz. of washing soda, or 3·6 oz. of sodium bicarbonate) in 2 gallons of water.

Solution B.—As for Eusol.

Two parts of A and one part of B are mixed and filtered through double paper after standing half an hour.

80. *Removal of poisons.*

1. If any of the poisons enumerated in Sec. **74** be found in the raw water, it will, in general, be rejected as a source of drinking water; but since circumstances may arise under which only poisoned water is available, the following methods of poison removal are given. These methods have been tested and proved to be satisfactory, except in the case of organic compounds containing arsenic, such as may arise as the result of bombardment with poison shells. These compounds would probably be decomposed by the method described below, but careful experiment would be necessary before such water could be safely used.

It should be remembered that, setting aside questions of morality and humanity, it is doubtful whether it would be possible to poison the whole of the water supplies of a district with any known kind of poison; and that, should this be done, it would probably be easier and cheaper, and would certainly be safer, to transport the necessary drinking water by rail, road, or pipe, even for a considerable distance, than to attempt to render the poisoned water innocuous.

Obvious poisons, such as cresol, dead bodies, farmyard manure, excreta, &c., and substances such as common salt, Epsom salts, and other non-poisonous bodies present in great excess, cannot be removed by practicable processes; but, in general, a well contaminated with such substances can be rendered usable in a few days by cleaning out and continuous pumping, and, in the case of organic compounds, by the addition of large quantities of bleaching powder to the well followed by pumping out after a period of rest. (Appendix V.)

2. **Copper, lead, mercury, and zinc** can be removed by adding alum as a coagulant, then a slight excess of sodium sulphide. This precipitates the heavy metals as sulphides, which can be filtered off under pressure, using a tightly packed filter of wood wool. About ¼ lb. of alum each 1,000 gallons is added and sodium sulphide as a 7 per cent. solution of the moist salt. The excess of sodium sulphide is removed by oxidation in the subsequent treatment with bleaching powder. The following table gives the quantities of $Na_2S.9H_2O$ required to treat 1,000 gallons of water containing 1 gram a litre of the salts :—

TABLE T.—*Removal of copper, lead, mercury, and zinc.*

Salt.	$CuSO_4.5H_2O$.	$Pb(NO_3)_2$.	$HgCl_2$.	$ZnSO_4.7H_2O$.
$Na_2S.9H_2O$ lbs.	9·5	7·2	8·8	8·6

3. **Arsenic** (*see* Appendix VI).—The whole of the arsenic is first converted, if necessary, into sodium arsenate by the use of excess of bleaching powder, and is then precipitated as a basic ferric arsenate by the addition of iron alum. If more than 0·1 gram of arsenic (calculated as As_2O_3) be present in a litre, caustic soda must also be added. The following table shows the quantities of reagents found necessary to treat 1,000 gallons of water. The bleaching powder is assumed to contain 25 per cent. *available* chlorine.

TABLE U(i).—*Removal of arsenic.*

As_2O_3 grams a litre.	Bleaching powder. lbs.	NaOH. lbs.	Iron alum. lbs.
0·02	0·7	none	3·2
0·05	1·6	,,	7
0·1	3·1	,,	9
0·15	4·8	3·75	14
0·2	6·2	5	18
0·3	9·2	7·5	27
0·4	12·3	10	35
0·5	15·4	12·5	43

If the arsenic is already oxidized, the following table gives the quantities of iron alum to be used for 1,000 gallons of water, and the quantities of caustic soda to be added separately afterwards.

TABLE U(ii).—*Removal of arsenic.*

As_2O_5. grams a litre.	Iron alum. lbs.	NaOH. lbs.
0·02 to 0·1	11·75	1·25
0·15	17·5	1·9
0·2	23·5	2·5
0·3	35	3·75
0·4	46·75	5
0·5	58·5	6·25

4. **Cyanides.**—Cyanides can be completely precipitated as potassium ferrous ferrocyanide in alkaline solution :—

$$6KCN + 2FeSO_4 = K_2FeFe''(CN)_6 + 2K_2SO_4.$$

Excess of ferrous sulphate is added to react with the alkali so that the precipitate contains ferric hydroxide. If the alkali be in excess, the filtrate will be yellow owing to the presence of potassium ferrocyanide, and prussian blue will probably be formed. The precipitate also tends to become oxidized in a sand filter, giving ferrocyanide, so that the sand must be washed frequently. 0·005 gram a litre of potassium cyanide may be left in the water; this gives a lethal dose in about 14 gallons. The following table gives the amount of $FeSO_4.7H_2O$ to be used to treat 1,000 gallons of water. 2¼ lbs. of NaOH each 1,000 gallons must first be added.

TABLE V.—*Removal of cyanides.*

KCN grams a litre	0·01	0·02	0·05	0·1	0·2	0·3	0·4	0·5
$FeSO_4.7H_2O$ lbs.	5·8	6	6·7	8	10·5	13	15·2	17·4

5. **Removal of iron and manganese.**—Iron in water is generally present in the ferrous state. It can be removed :—(*a*) By oxidation thorough aeration, by cascade or passage through a perforated plate, or by the use of an oxidizing agent such as bleaching powder or chlorine, the iron being precipitated as hydroxide, which acts as a coagulant. (*b*) By the use of a permutit containing the higher oxides of manganese and regenerated by treating with potassium permanganate. Manganese can be removed similarly.

81. *Water softening.*

1. Although it is not, in general, necessary in semi-permanent water engineering to incur the expense of softening the water required for drinking, yet in some cases, where the crude water is unusually hard, it may be advisable to do so. Where a very hard water is to be used for steam raising, for laundry work, or for certain manufacturing processes, it is desirable that it should be first softened.

The distinction between temporary and permanent hardness was pointed out in Chap. XIV, Sec. **71**, and the treatment of temporary hardness with lime is dealt with in this chapter under the heading of the *excess lime* method of sterilization.

2. **Temporary hardness.**– Clark's method removes all the calcium carbonate, except about 2 grains a gallon which remain dissolved, but does not remove magnesium carbonate unless an excess of lime is employed, when the magnesium is precipitated as hydroxide. As already stated, it is undesirable to supply the consumer with water containing free lime, so that, if excess of lime is used for any reason, it is necessary to remove it by thorough aeration or by treatment with carbon dioxide.

The precipitate formed in Clark's process does not settle very rapidly, and is generally removed by filtration, using cloth filters. The lime used should be of good quality and free from stones; it is slaked, dissolved, and added to the water in the form of lime water. This is best made up frequently, and kept in slate tanks out of contact with the air as far as possible.

3. **Permanent hardness.**—This is removed by the use of sodium hydroxide (caustic soda) or sodium carbonate. The reactions are probably as follows :—

$$Na_2CO_3 + CaSO_4 = Na_2SO_4 + CaCO_3 \qquad \text{(i)}$$
$$2NaOH + Ca(HCO_3)_2 = CaCO_3 + Na_2CO_3 + 2H_2O \qquad \text{(ii)}$$

From equation (ii) it is seen that, if caustic soda is added equivalent to the permanent hardness, the sodium carbonate formed will remove (equation (i)) an amount of temporary hardness equivalent to the permanent hardness. To soften the water it is now necessary to add lime equivalent to the difference between the temporary and permanent hardness. This method is therefore applicable when the temporary hardness exceeds the permanent. If the temporary hardness is less than the permanent, it is necessary to add sodium carbonate equivalent to the permanent hardness, and then lime equivalent to the temporary hardness.

Owing to the solubility of magnesium carbonate, 1 in 2,500, the removal of magnesium salts is more difficult. The addition of excess of lime precipitates magnesium hydroxide, but this increases the quantity of calcium sulphate or chloride, both of which are troublesome in boilers. Sodium phosphate, Na_3PO_4 (*Tripsa*), and a double phosphate and fluoride, $Na_3PO_4.NaF.12H_2O$, precipitate the magnesium almost completely as phosphate and fluoride.

4. **Softening with Permutit.**—Permutit is an artificial silicate similar to the natural zeolites, formed by fusing together felspar, kaolin, and sodium carbonate, and subsequently treating the mass with water. The product is called *sodium permutit*, and is a double silicate of sodium and aluminium, $NaAl\,(SiO_3)_2.2H_2O$. The sodium is replaceable by calcium, magnesium, potassium, or other bases. The reaction is a *mass* action; thus sodium permutit treated with a solution of a calcium salt is converted into calcium permutit; this, treated with a solution of a sodium salt, such as common salt, is reconverted into sodium permutit, and so on.

The hard water is passed through granular sodium permutit contained in a cylinder, the calcium and magnesium salts are removed, and are replaced by sodium salts. The permutit is regenerated by leaving it overnight in contact with a 10 per cent. salt solution. Next morning the brine, containing the chlorides of calcium and magnesium, is run off, and the regenerated sodium permutit is washed and is ready for use again. The hard water is passed through at the rate of about 3 or 4 metres an hour. Free carbon dioxide decomposes permutit slowly, so that the bed is generally covered with a layer of broken marble or limestone.

Appendix I.

The advantage of small "natural" storage reservoirs.

1. A dam constructed in the Yser near Haringhe on the Franco-Belgian frontier resulted in the formation of a steady reach about 2 miles long, and it was found that, except after heavy rain when the river rose as much as a foot in a few hours, the water impounded was comparatively clear after standing for about a fortnight. The normal condition of the river was very turbid and muddy.

2. Two installations were placed on the banks of the Peenebeck, one at Arneke, in a situation where the stream is fairly rapid and almost invariably extremely turbid, and the other near Wormhoudt, where the stream is very slow. At the latter point the water is quite clear in dry weather, although after rain, when the stream is swollen and rapid, it is very thick and muddy; the storage here was small, but was sufficient to allow of quite good sedimentation.

Appendix II.

Algæ in reservoirs.

At Zuytpeene, on the Peenebeck, about a million gallons of water were impounded in an old moat. An attempt was made to clean out the moat before allowing it to fill, but, as there was a layer of black mud and slime 2 or 3 feet thick and as the time was short and the need for water urgent, the cleaning was not completed. In consequence, the water soon became green, and extensive algal growth appeared. About two parts in a million of *available* chlorine as bleaching powder was added from a boat and mixed as well as possible with the water, but this gave very little improvement. One part in a million of copper sulphate was accordingly added similarly, and this resulted in an immediate improvement in the water, and algal troubles did not recur during that summer.

During the two or three days that were necessary to free the reservoir water from algæ it was still essential to send the daily supply of water up the pipe-lines. It was found that, by treating the water with alum before filtering—a mechanical filter was used—and chlorinating after, a perfectly clear water flowed into the contact tanks. Within less than half an hour, however, the water became turbid, a yellowish green scum appeared in the tanks, and the water developed an unpleasant, somewhat fishy, taste. This unexpected result was taken to be due to the sand of the mechanical filter forming a breeding-ground for the algæ. The water was not examined microscopically, but it was presumed that the clear water leaving the filter was teeming with algæ which developed rapidly in the contact tank in the summer weather, in spite of the presence of *available* chlorine. The filter was accordingly filled with a strong chlorine solution (about 20 parts in a million), and left overnight. Improvement was noticeable next day, but the trouble soon returned ; apparently the filter rapidly became re-inoculated with the algæ. It was then decided to chlorinate the water before filtration instead of after, and this resulted in great improvement. It would seem that this treatment prevents the formation of algæ on the filter ; it involves the use of more chlorine, but it gives a ready means of avoiding algal growth in the finished water when it is not practicable to treat the crude water with copper sulphate.

Appendix III.

Choking of filters

It was necessary to supply about 250,000 gallons of treated water a day from the Yser at Haringhe, and the matter was extremely urgent. Consequently, crude river water, which at that time was very turbid and muddy, coloured, and contained colloidal clay, was passed directly, after preliminary straining through gravel in the pre-filters, through the fine sand filters. The filters became choked in three or four days, and, had there not been a duplicate set, it would have been impossible to keep up the supply of treated water. Sedimentation tanks were installed, and it was then common to run the filters for three weeks or a month without cleaning, and this in spite of the fact that, as 250,000 gallons a day were being delivered from a plant designed for 200,000 gallons a day, it was not always possible to allow the water to settle until quite clear, and, in consequence, a certain amount of aluminium hydroxide sludge found its way on to the filters. The sedimentation tanks constructed are shown on Pls. **106** and **107**.

Appendix IV.

Rusty pipes.

Upon many occasions during the Great War it was found that a perfectly clear water pumped into a pipe-line appeared reddish, turbid, and *rusty* at the other end. It was generally supposed that this was due to new or dirty pipes—*salved* pipes were often used—and many thousands of gallons of good water were pumped to waste in the attempt to clean them. It was found frequently that the water immediately recovered its rusty character when the pipes were used for the normal supply, even after repeated flushings extending over several hours each time. In no case did this happen when the pipes were treated with excess of chlorine as described in Sec. **79**, para. 2.

Appendix V.

The treatment of wells badly contaminated by the enemy.

A well near Bapaume, one of the main civil supplies of the town, had been extensively fouled by the enemy with excrement. The well was cleaned out as carefully as possible, and 3 lbs. of bleaching powder were put in and left for some hours. Water was then pumped out vigorously for some time, and the treatment was repeated, with the result that, after about four days, the water obtained from the well was of good quality, and gave negative results with MacConkey medium, *i.e.*, lactose factors were absent.

Appendix VI.

Arsenic in well waters.

Two wells in the Somme area were found, some days after they had been in use, to develop small quantities of arsenic of the order of $\frac{1}{10}$ to $\frac{1}{5}$ milligram of As_2O_3 a litre, quantities quite harmless in themselves but disquieting on account of the fact that another well a few miles away had developed salinity rather rapidly. It was supposed that the salt arose from the gradual solution of a supply put into the well by the enemy before he left. This may or may not have been the explanation, but there was the possibility of arsenic having been thrown into the wells, and a kind of *delayed action*, similar to that of the mines, at once suggested itself as the explanation. It was observed, however, that both the wells affected were served with *Chaine Helice* pumps, and the arsenic was traced to the zinc of the galvanized iron of the *Chaine Helice*. The quantity of zinc and arsenic which can go into solution under these circumstances is very minute, and could cause no dangerous symptoms. In the cases in point the quantity of arsenic did not increase beyond the traces mentioned above.

It is noteworthy that the various *arsenic scares* of the Great War proved to be unfounded. In one case, certainly, a considerable quantity of arsenic was found in a well at Messines. The well had been badly shelled —was, in fact, merely *vestigial*—and the arsenic was most likely due to arsenic-containing poison shells, which were at that time almost unknown.

CHAPTER XVI.

METHODS OF PURIFICATION SUITABLE FOR USE IN THE FIELD.

82. *Chlorination of well water.*

1. When a village is first taken from, or evacuated by, the enemy, it is sometimes found that one or two wells have escaped destruction, and in some cases it is very desirable that the water of such wells should be usable for a few days at least, until a more suitable supply can be made available by boring, by transport, or by means of a pipe-line.

Even if water is free from gross contamination, it is necessary to chlorinate, especially under the circumstances being considered, as the well is likely to be drawn upon almost continuously all day long. This involves muddy ground round the top, muddy buckets used for drawing water, splashing of the water with mud on its way from the well to the cook-houses, and innumerable other sources of contamination; it also involves very great difficulty in regulating the traffic around the well and the drawing of the water, especially when, as is frequently the case, the locality is very liable to be shelled.

2. Two methods of chlorination are available if the well is not provided with a pump, and water has to be drawn in a bucket :—

(*a*) A bleach solution is made up of a strength suitable for the water. If the Horrocks' test indicates that *n* parts of chlorine in a million are required, *n* scoops (2 grams each) of bleaching powder are dissolved as previously described, and the milky solution is made up to 2 gallons—a petrol can is useful for this purpose. Each gallon of the water then receives 3 fluid ounces of the solution before leaving the well, and each pint 3 teaspoonfuls. Measures can easily be made from empty cans; the warden in charge is instructed to add one of the large measures of solution to each petrol can, and one of the small ones to each mess tin full of water.

This method suffers from the disadvantage that each well so treated needs a water warden to be constantly on duty at the well, and this is not always possible in shelled areas; also, there is a tendency for the warden to put in a little extra for safety, or to omit the addition altogether in some cases for popularity.

(*b*) Direct chlorination of the well itself. This method has been tested with satisfactory results under active service conditions.

A cylindrical jam tin is weighted outside at the bottom by attaching strips of sheet lead or other dense material, so that it sinks in water when empty. It is supported by three strings, tied together about 6 inches above the top of the tin, one of them being a little longer than the other two so that the tin is tilted slightly. A siphon tube of glass, lead, or composition reaches to the bottom of the tin inside and to about an inch below the bottom outside. The knot of the strings is then attached to a long string, knotted at intervals of, say, 3 feet, by which it can be lowered into the well.

The apparatus is lowered until it touches the water, then further until it reaches the bottom; by noting the length of the string paid out in each case the depth of the water in the well can be determined. The diameter of the well is measured; it must be noted whether the diameter is the same lower down as at the top or not. Then the amount of water in the well is given by :—

$22/7 \times (\text{radius})^2 \times$ depth of water $\times 6{\cdot}25$ gallons, the measurements being given in feet.

If the Horrocks' test on the water indicates *n scoops* for every 110 gallons, a paste of $n + 1$ scoops of bleaching powder for every 100 gallons of water in the well is made and poured into the tin, which is then nearly filled up with water. The apparatus is lowered gently until it is just below the surface of the water. On raising it just above the water the siphon comes into play, and the whole of the contents are siphoned out into the water. The tin is next lowered into the water and emptied once or twice to wash out all the bleaching powder, and then lowered to the bottom of the well and raised to the top of the water rapidly several times to assist the mixing of the solution with the water.

This should be done at night. If no *free* chlorine remains in the morning, one scoop per 100 gallons should be added in the same way. If the well is used much, the water should be tested hourly. and if the *free* chlorine falls below ½ part in a million, another ½ scoop of bleaching powder for each 100 gallons should be applied. The advantages of this method are that one intelligent warden can easily attend to three or four wells, provided that they are not too far apart, and, as the water is always chlorinated, supervision of the drawing of the water is not so important.

3. When the water can be pumped from the well, two tanks, each provided with bib-cocks, should be set up to receive the discharge. These two tanks are used alternately, one in use and the other freshly filled and chlorinated allowing the necessary *contact period* for chlorination to take effect.

83. *Small and improvised purification plants.*

1. In this section will be considered such apparatus as can be readily improvised and operated without power-driven pumps. Capacities of over about 10,000 gallons a day will usually require the installation of plant, as described in the subsequent section under the heading of *Mechanical filters.*

2. **Cart, water, tank, Mark VII (L) (regimental water-cart).**—The apparatus supplied with this cart consists of two hand pumps and two cylinders, each containing a cloth filter. (*See* Pl. **4.**)

The filter consists essentially of a metal framework, round which is wrapped several layers of special cloth. The requisite quantity of alum is put into a small box attached to the head of the cylinder containing the filter, and water is pumped in by means of the hand pump. The precipitate caused by the alum settles on the cloth in the form of a film. Since the water has to pass this film, the suspended matters are stopped by it, and the water when clear is pumped into the tank of the cart. The tank holds 110 gallons. The requisite number of scoops of bleaching powder mixed into a thin cream with water are added to the tank when the bottom is covered with clear water, and the pumping is continued until the cart is filled. The water is fit for drinking purposes at the end of 30 minutes. It takes 20 to 30 minutes to fill the cart, so that 110 gallons of water are available at the end of one hour.

Instructions for operating the clarification arrangement are as under; the bleaching powder is added as stated above (*see* also Sec. **74**) :—

(*a*) Attach the hose to the bottom of the pumps, and place the strainers in the source of supply.

(*b*) Remove the cap from the back of each clarifying cylinder by unscrewing the wing nuts; open the box attached to the cap by reversing the bayonet catch. Remove the two circular pieces of wire gauze from the box, and place four measures of the clarifying powder (alum and soda) between them, then drop them into the bottom of the box, leaving a clear space at the sides. Insert the lid, and fasten by means of the bayonet catch.

(*c*) Remove the clarifying reel, and wrap round with three layers of the cloth; tie off the cloth at each end of the reel and also at three intermediate places. In all cases the cloth must extend to each end of the reel and must be wrapped smoothly; there must be no creases. If the cloth shrinks after repeated washing, put on two cloths and allow them to overlap in the centre of the reel.

(*d*) Insert the wrapped reel into the cylinder, and push the spigot well home so that the rubber ring comes in contact with the end of the cylinder. If the rubber ring becomes flattened out by repeated use, put on a new one. It is essential that a water-tight joint should be made.

(*e*) Insert the cap, and screw up the winged nuts. The pressure of the cap on the reel makes the spigot end form a water-tight joint if the rubber ring is not flattened out.

(*f*) Remove the plug from the exit pipe of the cylinder.

(*g*) Pump slowly. The first water which issues will not be quite clear; but after a few seconds, when a deposit has formed on the cloth, the water will become perfectly clear. The plug in the exit pipe should then be screwed home, and the water pumped directly into the cart.

(*h*) When water flows from the relief valves, the cloths of the clarifying reels are to be removed and replaced by clean ones.

NOTE.—After use the cloth should be removed from the reel, thoroughly cleansed with water, and boiled in a sterilizing kettle. Spare reels and cloths are carried, which can be used if the cart has to be again filled before the cloths have been cleansed.

The box must be recharged with clarifying powder for each 100 gallons pumped into the cart. When the day's work is over, the box must be thoroughly cleansed whenever dirt or deposit renders this necessary. Drain-plugs are provided underneath the tank for emptying after cleaning.

The leathers of the pumps may become dry from disuse, and cause the pumps to leak. A few sharp strokes will generally put this right. It will occasionally be necessary to dismantle the pumps, and apply dubbing to the washers or to renew them. A special spanner is provided for this purpose.

3. **Mule pack filter**.—*Principle.*—Crude water is treated with bleaching powder and alum solution, and filtered through crushed flint (silex) (*see* Pl. **163**, Fig. 2). The capacity of this apparatus is up to about 50 gallons an hour.

Description.—The apparatus consists of two cylindrical tanks mounted one over the other on a collapsible stand. The upper cylindrical tank is divided into two vertical compartments, each having a capacity of 27·5 litres (six gallons). These two compartments serve to hold the crude water, and are connected at the bottom by a three-way tap so arranged that while the water from one compartment is passing to the silex in the lower cylindrical tank, the other compartment can be filled with crude water and treated with aluminium sulphate and bleaching powder. By reversing the direction of the tap, when one compartment is emptied, the water in the other compartment passes to the silex, and a continuous method of working can be carried out.

A gauze strainer is fitted to the filling hole of each compartment. The lower cylindrical tank is divided horizontally into two portions—the upper portion containing the special filtering material, silex or crushed flint, and the lower portion fitted with taps serving as a distributor and container for purified water. This lower cylinder is constructed so that it is pivoted on axles and can be rotated so as to cause the purified water from the bottom of this cylinder to retrace its path and backwash the silex, and thus remove the material which has been filtered from the water. A small pump is attached for pumping water to the upper cylinder.

Method of use.—The stand is joined together by bolting, as indicated on Pl. **163**. The top cylinder is bolted to the frame; the lower cylinder is placed on its supports, and the silex levelled. The top of the lower cylinder is bolted in position, and the three-way tap between the two cylinders, connected to the brass pipe of the lower cylinder, is closed so as to shut both compartments of the upper tank. The apparatus is now ready for use.

One compartment of the top tank is then filled, and during the filling 50 c.c. of alum solution (30 grammes a litre) and the requisite quantity of bleaching powder solution, as shown by the case, water testing (5 c.c. of the black cup solution in the compartment of six gallons equals one part in a million of free chlorine), is added. After standing 10 minutes, the three-way tap is opened, and the water passes into a gauze box, which distributes the water evenly over the surface of the silex. The water passes through the silex, which is placed upon a gauze grid, through this grid, and then up through the outer of the two concentric tubes, and finally down the centre tube into the bottom portion of the lower cylinder.

It will be observed that the filter works under very little pressure, actually about 2-inch head of water, and the three-way tap may require a little adjustment on opening at first, in order to prevent more water entering the top of the silex than can be filtered. Water coming out of the top of the lower cylindrical tank indicates this, and it is necessary to close the three-way tap a little until water just ceases to come out of the top. It takes about four minutes for water to pass through the filter at commencement.

Whilst the first compartment is filtering, the other compartment is filled with water and treated as above. When the first compartment is empty, by changing the tap the water in the other compartment may be allowed to filter, whilst the first is again refilling. The filter thus works nearly continuously.

It will be found that after some hours continuous use the rate of filtration will be much slower, especially if the water to be filtered is very dirty. The filter is not so efficient when this is the case, and it becomes necessary to wash the silex. This is best done by removing the top of the lower cylinder and adding clean water from time to time, thoroughly stirring up the silex, and pouring away the dirty water. This must be repeated until no further dirt can be removed. When completed, bolt on the lid of the cylinder, connect the tap, and commence as before.

After this flushing, it will always take a little time before the filtered water is quite clear. For average working, the filter will deliver two gallons in from two to three minutes, and, if the time is greater than six minutes, it is generally an indication that the silex requires washing. With water containing about 25 to 30 parts per 100,000 of suspended matter, the plant can be run continuously for about six to eight hours, sterilizing and filtering.

4. **Coolie pack filter.**—A smaller type of apparatus, similar to the above, can be carried on a man's back. The filter consists of a canvas reservoir, which is suspended above a silex filter (Pl. **163**, Fig. 1), similar to the one in the mule pack filter. The reservoir is filled with water, and the requisite amount of alum and bleaching powder added. The whole is stirred up and allowed to stand for 10, or preferably 20, minutes. The filter tap is then turned on, and the water passes through the filter and is ready for use.

The capacity of this apparatus is about 20 gallons an hour.

5. For **larger quantities of water** than can be handled by the apparatus already described, plant can be improvised with material easily obtained. In this type of plant, clarification is carried out solely by the use of alum, and sterilization is effected by bleaching powder in the usual way.

Pl. **164** shows diagrammatically a typical plant.

This apparatus was designed to supply up to about 6,000 gallons of treated water a day from very unsatisfactory sources, such as muddy streams, ponds, or canals. The whole equipment can be carried on a G.S. wagon as far as road transit is possible, it can then be man-handled to its destination, and can be set up in a few hours. It is not costly, and the parts can be cheaply and rapidly replaced in case of destruction. The relative permanence of the apparatus varies very much with the nature of the situation, the requirements, and the material available. Thus, in a quiet situation where timber can be obtained, the tanks can be firmly set up in wooden frames, an overhead tank can be erected for filling water-carts, and a relatively permanent water point can be constructed, while in a dangerous situation the tanks can be sunk in the ground, covered, and rendered inconspicuous.

This apparatus was used extensively during the last phases of the Great War, and proved satisfactory and convenient.

The following apparatus is required :—

(*a*) Two tanks (canvas), approximately 1,800 gallons each.
(*b*) Three 5-gallon oil drums, two of them fitted with taps as near to the bottom as possible, with wooden covers.
(*c*) Two troughs about 4 feet long, V shaped or rectangular.
(*d*) Pump, with necessary hose-pipes. (Petrol or hand-driven.)
(*e*) 1 foot india-rubber tubing, ⅜ inch internal diameter.
(*f*) Alumino-ferric.
(*g*) Bleaching powder, or *Eau de Javelle.*
(*h*) Horrocks' testing cabinet.
(*i*) 50 c.c. glass Nessler cylinder.

(*j*) Improvised burette, standard solution of sodium thiosulphate N/10 acid, methyl orange.

If possible, the tanks should be erected so that the top of one is below the bottom of the other. The engine and pump should be placed as near as possible to the surface of the water in the stream or pond, and the lower end of the suction pipe should be suspended about 6 inches below the surface of the water by means of an empty petrol can, or should be otherwise prevented from approaching the bottom of the water; in general, a rose should be used. The upper tank B is for alum sedimentation. The trough should be fixed at one corner, parallel to one side, and sloping downwards into the tank with a fall of about 1 in 6. The delivery hose of the pump is supported in the trough with the end about 2 feet from the upper end of the trough. The oil drum A should stand on the upper end of the trough, so that the alum solution can be delivered from the wooden tap into the stream of water issuing from the hose-pipe. A short length of india-rubber tubing can be used to prevent the stream of alum solution from being blown away in windy weather. The arrangement of the trough and oil drum D, for the addition of the bleaching powder solution above the lower or clear water tank C, is similar.

A solution of alumino-ferric is made, if possible some time before it is needed in order that it may have time to settle. If the lumps are crushed (enclose in a sandbag and hammer with a piece of wood), solution in cold weather is fairly easy with stirring. The method of making the bleaching powder solution has been described in Sec. **79.** Knowing the capacity of the sedimentation tank B, it will be easy to calculate roughly how long it will take to fill, by finding the time taken to fill a 2-gallon petrol can or a 5-gallon oil drum. The flow of alum solution is set so that the solution is exhausted in this period. It is essential that the rate of flow should be as nearly as possible uniform throughout, and the water in the tank must be kept in motion continually during the filling. If a hand pump is used, it is advisable to assist the circulation of the water occasionally with a wooden paddle. Eight hours should be sufficient for sedimentation, the water should then be quite clear and practically free from colour and taste. The clear water is then pumped, or better siphoned, into the clear water tank C, and the bleaching powder solution is added fairly uniformly. If the *alkalinity* of the crude water be less than 12 (parts of $CaCO_3$ in 100,000), it will be necessary to add an alkali (lime, soda ash, or washing soda), in suitable quantity from a second drum, at the same time as the alum and with the same precautions. The lime and alum solutions must on no account mix until they come together in the stream of water. Water from the clear water tank C can be pumped after an interval of half an hour into the storage tank E, which should be fitted with bib-cocks.

Calculations and quantities.—The quantity of alum needed varies from 5 to 15 grains a gallon. With an unknown water it is advisable to commence with 10 grains a gallon. If this causes rapid and perfect sedimentation, the quantity can be reduced in subsequent fillings, unless such reduction is found to result in poor sedimentation or a coloured or tasting water.

The following table gives the quantities of alum that should be dissolved in 5 gallons of water in the oil drum, assuming that the tank can deliver 1,600 gallons of sedimented water. The first time that a tank is filled after cleaning, allowance must be made for the extra, say, 200 gallons that ordinarily remain in the tank with the sludge.

Grains each gallon...	5	7·5	10	12·5	15
Pounds of alum ...	1·25	2	2·5	3·25	3·75

A Maconochie M. & V. ration tin just holds a pound of alum in lumps about the size of a walnut. If the alum is powdered, 1 pound about fills three-quarters of the tin. A white Horrocks' cup contains 5 ounces, and, if the sedimentation tank requires 40 minutes to fill, the alum solution should be run at such a speed that a white Horrocks' cup fills in 17 seconds. The sedimentation tank needs cleaning out after about 14 fillings.

Every thousand gallons requires half an ounce (7 scoops) of bleaching powder for every part of available chlorine in a million (scoop of bleaching powder each water-cart) that it is required to add. If the size of the tank or the rate of filling differs from the above, it is easy to make the necessary adjustment of the figures.

6. A design of a somewhat more permanent character is shown on Pl. **165**; in this case the overhead tank containing the clean and chlorinated water is connected to a water-cart point of the usual type. The method of operating this plant is as follows :—

The settling tank is filled with crude water, valves A and E being open, and valves B, C, and D shut. At the same time as the pump is discharging water into the trough, an appropriate amount of alum solution is let in from the alum tank. The connection from this tank is provided with two cocks, one for regulating the supply and the other for shutting it off when required. The amount of alum required must be determined daily by experiment, and must be made up into a solution. It may be necessary to add a lime solution as well.

After about 8 hours' precipitation, valves A, E, and D are closed, valves B and C, to the drain, are opened. Enough clean water is pumped through to clean the pump, and valve D is opened and valve C closed. The clean water is then pumped up into the elevated tank. A bleaching powder solution is added to the discharge of clean water in the same way as the alum solution is added to the crude water.

It will be necessary from time to time to clear out the sludge from the settling tank. For this purpose a sump is formed at one end, and the sludge can easily be removed with a lift and force pump and a little water.

The methods of handling the chlorine and alum solutions are as explained in the preceding section.

84. *Mechanical filters.*

1. Mechanical filters are of two kinds :—*Gravity filters* in which the filter is open and filtration depends upon *head* of water within the filter, and *Pressure filters* which consist of closed cylinders in which the water is forced through the sand by pressure derived from pumps or from *head* of water above the filter. In gravity filters the down-stream pressure is that

of the atmosphere, while in pressure filters the pressures before and after filtration may both be considerable: the difference of pressure, however, should not be, in general, greater than about 10 lbs. a square inch. The filtering film in both cases is artificial, and is obtained by adding *alum* as a solution of *alumino-ferric* to the crude water. The water may be allowed to deposit a greater portion of the precipitate and accompanying silt before filtration, and this is the course to be recommended in most cases, especially when the crude water contains much suspended or colloidal matter, or it may be filtered immediately after the addition of the coagulant. In any case, for field purposes, the water must invariably be treated with some kind of chemical sterilizer after—in exceptional cases before—filtration.

Cleansing of mechanical filters is necessary at frequent intervals, as the quantity of water passed through the sand is considerable, with the result that filters soon become clogged, and a greater pressure is necessary to keep up the supply of filtered water. The different types of closed pressure filters differ mainly in the methods used to effect the cleansing of the sand. In all cases a fairly complicated system of valves and pipes is required to enable the direction of flow to be reversed for cleaning, to run the wash water to waste, and so on.

All mechanical filters should be provided with taps conveniently placed, so that samples of the crude water, filtered water, chlorinated water, wash water, and dechlorinated water (in cases where dechlorination is practised), may be taken easily at any time. Pressure gauges are attached so that the difference of pressure between the raw and filtered water, which decides the time for back-flushing, can be readily seen.

Pressure filters can be inserted in water mains, that is, the water from the filter can be delivered directly into the pipe-line, but, where possible, a contact tank should be provided, as this gives a margin of safety should the sterilizing arrangements go wrong for a time.

A single mechanical filter has usually an output of about 2,000 gallons an hour; for larger yields, batteries of several filters in parallel are used. Filters of much smaller capacity are also used.

In most closed filters there is an air release pipe in the dome, and in starting and after back-flushing it has been found advisable to fill the filter from the bottom leaving the valve on this pipe open until water flows through it, when the stream is reversed and filtration proceeds. This is most important in the small lorry plants.

2. **The Jewell gravity filter.** (*See* Pl. **166.**)—This may be taken as an example of the open type of filter. It consists of a double-walled cylinder; the incoming water is led into the space between the walls from which it flows over the sand, which is contained in the central part of the cylinder and is from 3 to 4 feet deep. As filtration proceeds, the head of the water above the sand increases, the output of the filter being kept constant by an automatic controller. The sand rests on a bed of gravel a few inches thick, and this on concrete in which the outlet pipes are embedded. The main outlet pipe has numerous branches, which are provided with holes covered with brass gauze and arranged so as to be spread over the whole of the base of the filter. When the filter becomes choked, it is washed by admitting water through these outlets, and the

cleaning is assisted by agitating the sand with a series of vertical rods attached to four radial arms rotated by a vertical shaft. Cleaning takes about 5 minutes, and uses from 2½ to 5 per cent. of the filtered water. The rate of filtration is nearly 14 feet an hour; this is a great increase upon the 4 or 5 feet an hour of the ordinary slow sand filters.

3. **The Jewell pressure filter.** (*See* Pl. **167.**)—This is one of the simplest of closed pressure filters, consisting, practically, of a closed cylinder filled to within a foot or so of the top with sand resting on gravel, rubble, or stones. The water passes downwards through the sand, and is collected below; the orifices of the collecting pipes are provided with special nozzles which prevent the wash water from interfering with the grading of the sand when the current of water is reversed for cleaning.

4. **The Bell filter.** (*See* Pl. **168.**)—The principle is similar to that of the Jewell pressure filter, but, in cleaning, the sand is stirred by rotating arms bearing hollow spikes through which the water is forced to assist the washing of the sand. At the same time, water is passed upwards through the sand.

5. **The Paterson filter.** (*See* Pl. **169.**)—The principle is similar to the above, but the mechanical cleansing is assisted by a current of air from a blower. The air is distributed by a large number of nozzles at the bottom of the sand, and this gives a more uniform stirring of the sand than by rakes, as, in the latter case, the sand near the axis is liable to remain undisturbed while that near the circumference is subjected to excessive agitation. The air blast is turned on for about half a minute before the current of water is reversed. This loosens the dirt, which is then washed away with a much smaller expenditure of wash water than is otherwise necessary.

6. **The Turn-over filter.** (*See* Pl. **174.**)—This is a horizontal cylinder supported on trunnions and rollers and half-filled with sand. During back-flushing, the cylinder is rotated, and the dirty water is siphoned off. Small units which can be turned by hand are made, and also larger ones, 12 feet long and 8 feet in diameter. The cylinder is divided into three compartments which can be washed separately if desired.

7. **The Candy compound filter.** (*See* Pl. **175.**)—In this filter there are two separate layers, one above the other, the upper one a coarse pre-filter and the lower a finishing filter of fine sand. In the space between the two, and above the pre-filter, are rotating arms bearing powerful jets which, during back-flushing, force the washing water into the filtering beds. The lower bed is at the same time washed by the upward flow of water through the sand. The dirty wash water leaves the filter from the space between the two beds. The pre-filter can also be washed from below, if desired, but this is not generally necessary.

8. **The Ransome continuous filter.** (*See* Pl. **176.**)—The principle of this filter is somewhat different from that of the preceding filters, and avoids the necessity of periodically stopping filtration in order to cleanse the sand. The filtering medium is a moving layer of sand over a larger fixed body of sand. The conical part is double-walled, and the sand rests on a perforated plate supported by the inner wall of the cone. Sand flows between the conical walls, and is carried by the incoming stream of

water to the top of the filter, where it is distributed over the remainder of the sand. Thus the sand at the sides is continually moving downwards and being replaced above, while the central mass of sand remains stationary. Under these conditions there is no opportunity for a film to form on the sand, as it is continually being washed by the incoming water; the sand does not become clogged, and back-flushing is only necessary about once in six weeks.

9. Chemical feed apparatus.—If preliminary sedimentation is employed, the method described in Sec. **76** is simple and convenient.

In the case of alumino-ferric, a tank of slate or cement—or of iron, well tarred or with a good wash of cement—of sufficient size to contain a day's supply of solution of suitable strength is used. To facilitate solution, if water under good pressure is available, a water supply pipe is fixed round the inside of the tank about 6 inches from the bottom with holes drilled at intervals, so that numerous jets of water can be projected downwards. The alum, broken into small lumps, is placed on the bottom of the tank, and the water is turned on. With stirring, the alum should be dissolved by the time the tank is full.

Another method, which involves the use of two tanks, is to put the alum on a perforated tray near the top of the tank, and to spray the water on it until the tank is full. It is then left for a few hours, if necessary, to complete solution and diffusion, and to allow the solution to settle.

Given the rate of flow of the crude water, it is easy to calculate the volume of chemical solution that should be used in, say, one minute, and the tap can be adjusted to give this quantity. To avoid the necessity of readjusting the flow as it diminishes through loss of head in the chemical tank, a box can be inserted between the chemical tank and the mixing trough, and supply adjusted by a ball-valve. This is quite satisfactory as long as the ball-valve is in order, but with chemical solutions this method is apt to be unreliable. A modified ball-valve can be made, using corks as floats and a wooden tap, but this would need continual repair, especially with alum solution.

When the solution is led into the suction pipe of the pump, it should enter at as great a distance from the pump as practicable, so that the solution may be well mixed with the water before entering the filter. In this case the feed will vary with the rate of pumping; this is obviously desirable. To gauge the rate of flow of the solution, the time taken for the level of the solution to fall in the tank (or better in the feed box, the ball-valve being closed while making the test) is the best indication.

10. Turbine feed. (*See* Pl. **177.**)—A small turbine, driven by the stream of water, is fixed near and after a right-angled bend of the pipe. The shaft of the turbine passes out of the pipe at the bend, and works a small feed pump by worm gearing. The pump forces the solution into the pipe just before the bend, and the turbine assists the mixing of the solution with the water. It is evident that the rate at which the pump is driven by the turbine will vary with the rate of the stream of water.

11. Mannock and Sibley's patent injector.—In this, the difference of pressure at the two ends of a Venturi tube is employed. The greater pressure at the up-stream end is caused to force the solution, by means of a piston, into the water at the down-stream end of the tube. By an ingenious arrangement of automatic valves, as soon as the cylinder is empty, it is filled by gravity from the solution supply tank, and, when full, the valves are again reversed, and the solution is injected. By using two cylinders one can be filling while the other is injecting, and the supply of solution is continuous. The amount of chemical solution added evidently varies with the rate of flow of the water.

12. **Improvised sand filters.**—Owing to the large amount of constructional work that is necessary in the slow sand filtration processes, it is not proposed to give any detailed account of them here. Quick sand filters of coarse sand have been improvised in the field, but, although the bacterial content was in some cases somewhat reduced, the water was not always appreciably improved either in appearance or taste, and the quantity of organic matter was sometimes hardly altered. Such filters can be regarded as strainers only for the crude water, and the filtration must always be followed by chemical treatment for the destruction of bacteria. A satisfactory alum sedimentation plant, giving really good results, can be erected at less cost and in less time. The filters used were of several types, two of which are here outlined.

(*a*) Cubical boxes, about $6' \times 6' \times 6'$, were filled with very coarse sand. The crude water was caused to flow from numerous jets on to the top of the sand; it percolated through rapidly at 10 to 16 gallons a square foot an hour, the sand not being submerged. The water from a battery of these was collected in a trough by which it flowed after chlorination into the reservoir. The filters could be washed by forcing water through in the reverse direction when required.

(*b*) Cubical boxes filled with coarse sand or fine gravel were constructed below the level of the water in a pond or stream the water from which flowed through the sand from below, and thence into a similar empty box in which it was chlorinated, and from which it was pumped into the storage tanks.

It is possible that a combination of this system with the Puech-Chabal system would prove satisfactory in a small plant.

85. *Automatic chlorination.*

1. The method of chlorination described in Sec. 79 is to be recommended, automatic methods being generally less reliable and more troublesome; certain automatic methods, however, have been used with some success.

2. **Addition on the suction side of the pump.**—The methods used for the addition of alum and other solutions described in Sec. **84** can be employed for bleaching powder solution.

A solution of bleaching powder or Eau de Javelle of suitable strength is made, and allowed to become quite clear by settling. It is then placed in a reservoir, the size of which depends upon the output of the station. Two such containers should be provided, so that a supply of solution sufficient for a 12-hour run can be made up and allowed 12 hours to settle before use. The delivery tube, fitted with a stop-cock, should leave the reservoir about 2 inches above the bottom so that the sediment is not drawn into the tube, and a drainage tube for the removal of the sediment must be provided. The lower end of the delivery tube is let into the suction pipe of the pump. The delivery tube is in two parts connected vertically through a jet as follows:—The tube from the bleach tank is connected by a piece of india-rubber tubing with a jet made by drawing off a piece of glass tubing. A piece of wide glass tubing (gauge glass), about 6 inches long, is drawn off slightly at each end to a width somewhat greater than that of the delivery tubing (⅜-inch copper pipe is very suitable for this), so that the metal tube can just enter the glass tubing. A somewhat similar arrangement is shown on Pl. **178**, Fig. **2**, in which it is assumed that the diameter of the glass tubing used is the same as that of the metal tubing. The wide glass tube is then connected with the delivery tube at both ends by means of india-rubber tubing; the jet should then be visible at about the middle of the gauge glass. The metal tubing should be fastened above and below the gauge glass to a board, for safety, by clamps. The clamps should be easily and quickly removable to facilitate cleaning. Given the volume of water passing through the pump in a given time, and the quantity of chlorine it is desirable to add, the bleach solution can sometimes be made up of such a strength that the stream of solution giving the correct dose takes the form of separate drops which can be counted. Failing this, the stop-cock on the delivery tube must be set so that the level of solution in the reservoir falls by a calculated amount in a given time. This apparatus gives good results with careful use, and the dose of sterilizing solution probably varies regularly with the speed of pumping, but it is necessary to watch the apparatus, as the jet is liable to become choked; also, unless the method of counting the drops is applicable, the regulation of the dose is not so easy as in the case where the stream of solution can be measured directly. If the jet chokes, either the whole plant must be stopped while the apparatus is taken down and put together again, or some water must be allowed to pass unchlorinated.

3. **Addition on the delivery side of the pump.** (*See* Pl. **178**, Fig. 1.) The principle of the laboratory filter pump can be employed to draw the sterilizing—or other chemical—solution into the stream; the amount thus added will depend upon the reduction of pressure produced by the filter pump, and this in turn will depend upon the speed of the stream of water. The figure is self-explanatory. If the stop-cock A is set so that with a given delivery of the pump the correct quantity of sterilizing solution is used, it should only be necessary to keep the reservoir supplied with clear solution of the right strength, and to turn on stop-cock B when the pump is started and off when the pump stops. Filter pumps of the type figured can be obtained in metal (copper should be avoided), and, if all the connections are made in metal, the apparatus is fairly strong and should not easily get out of order.

4. The chief difficulty that is found in chlorinating direct from the bleach tank, as described in Sec. **79**, is due to the fact that the rate of flow from the tank diminishes as the level of solution in the tank falls; consequently, occasionally—say every hour or so—it is necessary to adjust the rate of bleach. A ball-cock arrangement in a feed box was extensively used during the Great War to circumvent this difficulty, and, to avoid

possible corrosion, metal was avoided. An extensive experience of metal containers and taps in connection with bleaching powder solution, however, shows that this precaution is not necessary, and, although the principle of the ball-cock is not to be recommended, an excellent constant-level apparatus can be made using iron tanks and stop-cocks and employing the principle of the *chicken feed* as follows :—

An enclosed iron tank of suitable capacity is provided with a 2 or 3-inch hole at the top which can be closed by a plug which can be screwed down on a rubber seating. The bleaching powder (made into a cream with the usual precautions), or Eau de Javelle, is poured into the tank through this aperture, the tank is then filled with water, and the mixture is allowed to settle for a few minutes before use. A 1-inch delivery pipe about 2 inches from the bottom leads into an open sheet-iron box, and is provided with a stop-cock. A ½-inch air tube leads from the top of the tank to about 2 inches below the top of the box, and is cut off obliquely at the bottom. A 1-inch pipe provided with two stop-cocks leads from the box to the mixing box (where the bleach solution mixes with the water as it enters the contact tank). Now it is evident that, when the level of the bleach solution in the box falls below the open end of the air pipe, air passes up this into the tank and allows more solution to flow into the box until the air pipe is again sealed, thus the level of the bleach solution is kept constant within about 2 inches. To adjust the flow, a measuring cylinder is used (50 c.c.), and the time necessary for 50 c.c. to flow in order to give the correct dose of bleach to the water is calculated. One of the taps from the feed box is adjusted to this calculated flow, and, if the character and rate of flow of the water does not change, this tap may be left untouched, and the bleach can be turned on and off by the other tap. The tank should be provided with a sludge-cock, and should be cleaned out regularly to prevent the sediment from caking. As the delivery pipes are relatively large, it is not so important that the sediment, consisting mainly of lime and chalk, shall be settled completely, but there must, of course, be no lumps, since these not only would choke the pipes but are also a proof that the bleaching powder solution has been made up carelessly. A glass—or, better, a celluloid—window in the side of the bleach tank is very useful to indicate the amount of bleach solution remaining.

86. *Sterilization with chlorine gas.*

1. Chlorination by means of chlorine gas is particularly well suited for work in the field, and was extensively applied in the later stages of the Great War. There are at present two types of apparatus for chlorine dosage on the market—the *Paterson*, which is of British manufacture, and the *Wallace-Tiernan*, which is of American origin.

The sole objection to the use of gaseous chlorine dosage is the intricacy and delicacy of the necessary apparatus. These two factors are likely to be considerably improved in the future, and, in order to give a general idea of the working of the method, the Wallace-Tiernan system will first be described. Liquid chlorine apparatus should be installed in a well ventilated room or cabinet.

Table **S** may be of use in connection with chlorine gas apparatus.

2. The following is a description of the *Wallace-Tiernan direct-feed chlorinator* (*see* Pls. **170**, **171**, and **172**).

The apparatus is essentially one which meters chlorine gas and which at the same time delivers the gas at a constant pressure. Chlorine is stored in steel cylinders as a liquid, and the pressure within such a cylinder will depend upon the temperature at which the cylinder happens to be. The pressure of liquid chlorine at 0° C. is 54 lbs. a square inch, and at 50° C. (122° F.) it is 216 lbs. a square inch. The pressure registered within a cylinder of liquid chlorine is the pressure which the vapour of liquid chlorine, that is chlorine gas, exerts while in contact with liquid chlorine at the temperature of the cylinder and its contents. A rise in temperature will produce a rise in pressure, and *vice versa*.

If gaseous chlorine is allowed to escape by opening a valve on a cylinder of liquid chlorine, some of the liquid must evaporate to account for this escape. This will affect the pressure of the gas in the cylinder, for liquid chlorine is a bad conductor of heat, and consequently most of the latent heat required to evaporate it will be obtained first from the liquid chlorine itself and not from the surrounding atmosphere, and as a result the temperature of the liquid chlorine inside the cylinder will fall, and thus produce a fall in pressure. The density of chlorine will also increase with a fall of temperature, and consequently the volume of chlorine gas that may leave a cylinder is not a direct measure of its mass.

The Wallace-Tiernan chlorinator is actually a reducing valve and meter combined, and consists of three main portions :—

i. The Compensator, in which alterations of pressure in the cylinder are compensated, Pl. **171**.

ii. The Metering or flow-measuring apparatus combined in the orifice, scale, and manometer, Pl. **172**, Fig. 1.

iii. The Check-valve—or back-pressure valve—and diffusor, Pl. **172**, Fig. 2.

Compensator :—Explanation of working, Pl. **170**.—Under normal conditions when the instrument is started, the valve on the cylinder A and the auxiliary tank valve B, control valve E, blow-off valve K, and auxiliary valve on check-valve L are shut. The auxiliary valve L fitted to check-valve M and main tank valve A are opened, the control valve E being kept closed. The auxiliary tank valve B is opened slowly. Chlorine now enters the compensator C through the small needle valve (1, Pl. **171**), passes down the two holes (2), and fills the space between the front portion of the compensator and the silver diaphragm (6, Pl. **171**). The pressure in this space increases, and forces back the silver diaphragm (6) and the strengthening disc (5) against the spring (4), and at the same time allows the spring (3) to close the needle valve (1).

The pressure of the chlorine in the cylinder is indicated by the tank pressure gauge F, Pl. **170**. If the control valve E is slowly opened, chlorine will pass through this valve and slowly build up a pressure which is registered on the back-pressure gauge G. This pressure will be exerted on the back of the silver diaphragm (6, Pl. **171**), as there is a small hole (7) drilled through the apparatus for this purpose. During this operation the control valve E is only opened sufficiently to cause the liquid in the manometer tube H (Pl. **172**, Fig. 1) to rise in the small inner tube (9) and remain in sight. If opened too much, the liquid in the manometer tube will be driven up into the space at the top, and it may get into the compensator or orifice cap T and orifice I.

As chlorine passes through the control valve E, the pressure on the front side of the diaphragm (6) will fall, consequently the pressure on the back side of this diaphragm—due to a spring (4) and the back pressure—will cause the diaphragm (6) to press on the needle valve (1), and thus allow more chlorine to enter. As soon as the back and front pressures are equal, a state of equilibrium is maintained in the compensator. Any chlorine passing out of the compensator will tend to increase the pressure on the check-valve M (Pl. **172**, Fig. 2), and more chlorine will consequently pass through the needle valve (1) due to the slight breathing movement of the silver diaphragm, the chlorine entering the compensator from the main cylinder at the same rate as it passes through the check-valve to the diffusor. Thus a steady flow of chlorine is maintained, the chlorine leaving the apparatus at a constant pressure set up by the check-valve M.

Manometer, orifice, and scale (Pl. **172**, Fig. 1).—The outer glass tube of the manometer H is connected by means of the small tube (10) to the orifice I, which is made of glass and which varies in size according to the amount of gas that the instrument is required to pass, and by the small tube (9) to the orifice cap T. As chlorine flows from the compensator, it meets the orifice and is necessarily checked in its flow, and subsequently a pressure is set up before the gas passes through the orifice. The difference in the pressure of the chlorine before and after it has passed through the orifice is proportional to the flow of the gas, as in a Venturi water-meter. Since the back pressure set up by the check-valve is constant, the chlorine will be passing from the orifice at a steady pressure, and will therefore be unaffected by any change of pressure to which the chlorine may be subjected. The pressure set up by the flow of the chlorine through the orifice is indicated by the height of the liquid in the manometer tube, and this height is read by means of an adjustable scale which has been graduated, experimentally, for the orifice in question in pounds of chlorine an hour. Any desired quantity of chlorine can be allowed to pass from the instrument, within the range that the orifice can pass, by opening or closing the control valve E, Pl. **171**, on the compensator C.

Check-valve (Pl. **172**, Fig. 2).—The check-valve consists of a silver-plated brass or copper stem N through which runs a silver tube (12). To the open end of this tube is attached the diffusor O, which consists of a porcelain ring into which two discs of alundum are cemented. The other end is attached to a perforated silver hemisphere (14) which fits inside the main portion of the valve, and is fitted with a needle valve (15) which is kept open by a spring (16). Closing this hemisphere is a silver corrugated disc (17) with a similar strengthening disc of copper (18) on the top of it. Acting on this is a spring (8) to which is fitted an adjusting screw (20). This spring acts on a segmented disc (19) which in turn acts on the two diaphragms and closes the needle valve. No chlorine can pass out of the check-valve until the pressure within is sufficient to overcome the pressure of the spring (8) and so lift the needle valve. This pressure is the back pressure and is usually set at 25 lbs. a square inch, and the pressure of water at the point at which the gas is introduced must not exceed this.

By means of the apparatus the chlorine enters the compensator at any pressure, and, after passing through it to the orifice, it is metered and leaves the apparatus at a constant pressure and is forced into the water through the diffusor, which breaks up the gas into very small bubbles. The amount of chlorine passing through the apparatus is regulated by means of the control valve E (Pl. **170**), and, when once set, will continue to deliver chlorine at the set rate until the cylinder is empty. For a temporary stoppage, it is only necessary to close the auxiliary tank valve B and, on re-starting, to open this valve. The apparatus can be emptied of chlorine by means of the blow-off valve K.

It is absolutely essential that moisture should be kept from getting inside the apparatus, as, although dry chlorine has no effect, moist chlorine will rapidly corrode the metal parts of the apparatus. It is also necessary to keep the cylinder of chlorine at about the same temperature as the chlorinator, as at low temperatures chlorine under pressure very easily liquefies, and, if the instrument is colder than the cylinder, liquid chlorine will collect in it and render the flow of chlorine unsteady. For field purposes spare parts should be kept close at hand, especially several of the porcelain diffusers.

3. **The Paterson Chloronome.**—The Chloronome is the registered name of the Paterson Engineering Company's device for regulating, measuring, and administering chlorine gas to water supplies. Pl. **173** shows a typical arrangement of the apparatus capable of sterilizing up to 3,000,000 gallons daily. The following description of the Chloronome and its method of working is taken from the pamphlet issued by the Company :—

The liquid chlorine is contained in steel cylinders, each holding about 70 lbs., the pressure at 32° F. being 54 lbs. a square inch, or at 120° F. 215 lbs. a square inch. It passes into the gaseous form on evaporation by the heat abstracted from the atmosphere through the walls of the cylinders.

The steel cylinders are usually placed on a weighbridge to check the amount of chlorine used during long periods, and to indicate when the cylinders are nearly exhausted. A coil connecting tube is coupled up to the valve on the cylinder head. The chlorine gas is led through a flexible connecting coil of copper tube to the filter, which removes any slight deposit which may be carried by the gas from the exposed coil tubes or the cylinder fittings. As it is important that the pressure of gas be kept constant on the regulating valve, two pressure-reducing valves are arranged in series. The chlorine gas, at a pressure varying from 80 to 120 lbs. (depending upon the temperature of the surrounding atmosphere), passes through the first reducing valve, which breaks down the pressure to 20 lbs. a square inch, then through the second reducing valve, which maintains a constant pressure of 10 lbs. a square inch on the regulating valve. Should this pressure, as indicated by the gauge, show a tendency to drop, the attendant knows it is time to switch on the second cylinder. By the application of artificial heat it can be assured that the first cylinder is completely exhausted before being replaced by another to be put into commission at a later date, when the second is practically exhausted. The chlorine gas passes the regulating valve, and flows from the meter (detailed reference to which is made later) through a central pipe down to nearly the bottom of the absorption tower. This glazed earthenware tower is fitted at the top with a water-distributing tray and packed with pumice. A small trickle of water is uniformly distributed over the pumice, and in its downward flow absorbs the measured quantity of chlorine gas. The chlorinated water flows from the bottom of the tower through a chlorine-resisting rubber or earthenware pipe, and is uniformly distributed through the main body of the water to be disinfected.

Many water supplies can be chlorinated by the addition of a quarter part in a million, *i.e.*, 2·5 lbs. of chlorine in a million gallons of water purified, so that an installation purifying 1,000,000 gallons a day may only require to administer 1·66 ounces of chlorine an hour. Even with plant of this moderate capacity it is desirable to have a positive volumetric measurement of the gas administered, and absolutely essential when dealing with smaller plant of, say, 1,000 gallons hourly requiring ·041 ounces of chlorine.

Dry chlorine gas at normal temperatures has no appreciable corrosive effect on metals, but immediately it comes into contact with the moist atmosphere most virulent corrosion takes place. The special feature of the Paterson *Chloronome* is the interposition, between the instrument and the absorbing water supply, of an isolating column of liquid which is unaffected either by the gas or the water absorbing it, and acts as a volumetric meter. Tests were carried out with various liquid seals, and ultimately sulphuric acid was selected as the most effective. The sulphuric acid is contained in a "U"-shaped sealing tube. The flow of gas depresses the column of sulphuric acid until it unseals a small vent pipe, which then permits the passage of the measured quantity of gas from the inlet to the outlet limb. This establishes equilibrium, and permits the return of the column of sulphuric acid until it again seals the vent pipe, when the cycle of movement is completed and another downward stroke commences. The gas is maintained at 10 lbs. pressure on the regulating valve, but is measured by the volumetric meter at atmospheric pressure. The rate of pulsation and known volume of the stroke gives the weight of chlorine added. Prolonged tests have shown that when the regulating valve is once set, the meter continues to pulse for months at the same rate. By means of the stop valve below the pressure gauge, the attendant can stop and start the apparatus when required without readjusting the regulating valve.

87. *Sterilizing plants on lorries, barges, and railway trucks.*

1. To fix a filtering and sterilizing apparatus on a lorry appears at first to be an obvious means of obtaining rapidly a supply of potable water at any place where water exists; for example, in a country just taken from the enemy, in which case probably no suitable source of suitable water will be left intact, and where water will be urgently needed at once. In some cases, however, a number of circumstances arise which strongly favour a simple and portable apparatus, such as that described at the beginning of this chapter, in preference to so cumbrous a thing as a lorry.

Thus :—(i) The lorries in use weigh something in the neighbourhood of 8 tons, so that a very substantial standing must be provided before the apparatus can be put in position. A standing which appears to be satisfactory at first may give way under the weight after the ground has been soaked with the continual, and almost unavoidable, drip from various pipes and hoses. (ii) After an advance the roads are very liable to be cut up by shell fire, or, even if not, they will be damaged by the unusual traffic, and unsuitable for any but the lightest motor traffic; an attempt to take such heavy lorries over the road may result in *ditching* them, and in holding up the already over-congested traffic. (iii) The most suitable position for a sterilizing lorry is at or near the roadside, near a bridge, or where a stream approaches the road, and this position is bad from the point of view of traffic regulation, as, even if the lorry is parked off the road, the crowding of men and vehicles taking water adds complication to the traffic difficulties of such a time. (iv) A lorry is not easily hidden from enemy observation, it is very costly, and could be put out of action permanently by shell fire, while simpler plant can be replaced quickly, either wholly or in part, in case of damage at a comparatively little cost. (v) The output is small in comparison with the cost and size of the plant. A larger daily yield of equally good water can be obtained by the use of a few sedimentation tanks and portable pumps in situations quite impossible for lorries, and at much lower cost. (vi) Where the crude water is very bad, alum sedimentation must be arranged for before the water is treated by the lorry plant, and in such cases the lorry is almost superfluous.

2. The previous remarks are not, however, intended to detract from the value of lorries, &c., fitted with sterilizing plant, for mobile warfare and under suitable conditions. Sterilizing lorries have rendered the greatest service in the past, and will inevitably be required in future operations. A wise discrimination must nevertheless be made between their use and the installation of plant of the type referred to in Sec. **83**, which is sometimes more convenient.

3. There is not yet a sealed pattern of sterilizing lorry, but the three types used during the Great War may be referred to as embodying the general characteristics of this type of plant.

The plant was of three types :—

(*a*) The Old Type sterilizing lorry.
(*b*) The Depoisoning lorry.
(*c*) The New Type sterilizing lorry.

4. **The Old Type sterilizing lorry.**—Two filter chambers were provided, of which one was originally filled with granulated *manganese permutit*, which removed the excess of a *dechlor* consisting of ferrous sulphate and sodium bisulphite, and which needed to be regenerated with the rather costly salt potassium permanganate. This was very soon abandoned, and both chambers were filled with sand, and the principle of issuing water with a slight excess of chlorine was adopted. A 1¼ horse-power Lister engine, having a rotoplunge pump at each end of the shaft, is mounted on the lorry. One pump raises the water from the pond, stream, or sedimentation tank, and forces it through the first filter into the contact tank, where it meets with a stream of bleaching powder solution. The tank is provided with baffle plates, so that the water gets 45 minutes contact with the bleach, at 400 gallons an hour, and, in the last compartment of the tank, it gets a dose of *dechlor* and alum. After 15 minutes

contact with the alum, during which the precipitate becomes coagulated, the second pump forces the water through the second sand filter, through a small storage tank of 60 gallons capacity, into an overhead storage tank, into water-carts, or into tanks at ground level. Valves and bye-passes are arranged for back-flushing the filters, and for cleaning out the tanks. In 1918 some of the plants were modified, so that the filters worked in parallel instead of in series. Each pump forced water raised from the stream through one filter, and the combined streams were led into the contact tank and chlorinated. Alum solution was added in the suction pipe of each pump. The water from the contact tank passed direct to service, another pump being used if it was required to store the clean water in an overhead tank. Time of contact was lost, as the machine worked at about 1,200 to 1,600 gallons an hour, so that it was necessary to add more chlorine or to cut out the dechlorination altogether, as was done in many purification schemes during the war. In spite of the single filtration and the increased yield, the results, even with very bad water, were highly satisfactory, thus confirming the view that the existing machines in use were capable of great simplification and reduction of weight. The plant, modified in this way, was used on the lorries, and, after removal from the lorries, as small waterworks plant in several places during 1918 and 1919.

5. **The Depoisoning lorry.**—This plant was designed for the removal of metallic poisons and cyanides from possible drinking waters, and served this purpose well in official tests ; a considerable personnel was trained in the work, but it was not called upon for the work of depoisoning in practice. The plant was used extensively as a sterilizer. The crude water is pumped directly into a contact tank, where it receives a dose of bleaching powder solution. After contact, it is forced through a sand filter into an external service reservoir. A large portion of the contact tank can be used as a wood wool filter, and this enabled the plant to be used in some cases in which alum sedimentation was very necessary, but was impracticable owing to lack of space. In such cases it was found that either a turbid and unpleasant effluent had to suffice, or so much alum had to be added that the sand filter very rapidly choked, and there was a tendency for alum to be precipitated in the filtered water. By using a well-packed wood wool filter it is possible to add sufficient alum to ensure satisfactory clarification of the water, and, as the wood wool filter removed most of the precipitate, the sand filter did not become choked more rapidly than usual.

6. **The New Type sterilizing lorry.**—This is capable of delivering 1,200, or even 1,500, gallons an hour, but is perhaps less suitable than the other types for a foul supply. Alum sedimentation should be used as a preliminary, unless the crude water is relatively clean. Pls. **179** and **180** show the general construction of this plant. The plant may be divided into five sections :—

i. Pumping unit.
ii. Mechanical sand filter.
iii. Wallace-Tiernan patent chlorine gas administrator.
iv. Contact tank.
v. Dechlorinating apparatus.

Referring to Pl. **179**, the water, which is picked up from the crude source by a plunger pump P direct-coupled to a vertical petrol engine, is driven through the mechanical sand filter SF into the chlorine diffusion tube, where it receives the necessary dose of chlorine by means of the patent chlorine gas apparatus WT, after which the water passes in at the bottom of the contact tank CT, and rises until it leaves at the top and into the bottom of the dechlorinating tube, and thence to the sterile water delivery pipes. Provision is made in the dissolver D for making up a solution of alumina sulphate. This is sucked into the main pump by means of a small connection being made in the inlet to pump, and mixes with the water in the pump.

Taking each section in the plant separately :—

i. *Engine and pumps.*—General working instructions for the petrol engine will be found in the book provided by the makers. A by-pass valve is arranged on the delivery from the pump by means of which control of the rate of filtration can be effected.

ii. *Sand filter.*—This filter has four valves, by means of which back-flushing can be effected when the filter becomes clogged. For normal filtering when the plant is at work, valve No. SF1 is open, No. SF2 is shut, No. SF3 is open, and No. SF4 is shut. By this means the water passes into the top of the filter through valve No. SF1, down through the sand, and out through bottom valve No. SF3, whence it flows forward through the water meter into the chlorine diffusion tube.

A pressure gauge is fitted to the top of the sand filter, and when on gently tapping the gauge a pressure of 15 lbs. is registered, it is an indication that such accumulation of filtered material exists on the top of the sand bed as to call for back-flushing.

Back-flushing is effected in the following manner :—Open valve No. SF2, close valve No. SF3, open valve No. SF4, and close valve No. SF1. It is important that these valves should be operated in the order stated. This having been done, the water will now flow in through valve No. SF4, travel upwards through the sand from below, and out through valve No. SF2 and waste pipe connected to it, carrying away deposited suspended matter from the top of the sand bed. During this operation the by-pass valve on the pump should be closed so as to obtain a good flow of water. The water should be left flowing in this manner until it is fairly clear coming away from the open end of the waste pipe connected to valve No. SF2, when these four valves should again be operated as follows :—Open drain valve SFD and valve No. SF1, close valves Nos. SF2 and SF4. The water is now flowing in at the top and out at the bottom to waste. This should be continued for about five minutes, after which time open valve No. SF3 and close valve SFD. Again, care should be taken that this operation is carried out in exactly the order mentioned.

iii. *Chlorine gas control apparatus.*—The water, having been delivered from the sand filter into the top of the chlorine diffusion tube and flowing in a downward direction, is met by a constant dose of chlorine gas, which is controlled by the Wallace-Tiernan patent chlorine gas administrator WT, and fed into the diffuser tube by means of a copper tube.

Full working instructions will be found in the book supplied with the apparatus.

iv. *Contact tank.*—After chlorination, the water passes from the chlorine diffusion tube into the bottom of the contact tank CT, which is provided with baffles to prevent the water short circuiting to the outlet at the top, from whence it is delivered into the dechlorinating diffusion tube.

v. *Dechlorinating.*—In the dechlorinating tube, provision is made for administering sulphur-dioxide which neutralizes any excess chlorine which may be remaining in the water after the necessary contact period is passed.

The dose of SO_2 gas will be regulated by trial and error through the starch-iodide test, so as to effect sufficient dechlorination without leaving undue excess of SO_2 gas in solution in the water.

General instructions for starting plant to work.—The plant will arrive at any working site with all tanks empty.

i. Close every valve on the plant.
ii. Make up solution of alum.
iii. Open the following valves : AV, SF1, SF3.
iv. Start engine running with suction hose in water source.
The engine cooling water is regulated by either valve CW1 or CW2, according to whether the closed or open circuit is in use.
v. Open valve AV1 slightly.
vi. As soon as water flows from the open end of the air vent pipe on to the sand filter, close down valve on this pipe until water just trickles.
vii. Open all chlorine apparatus, in accordance with the special instructions relating to this portion of the plant.
viii. Take readings of water-meter, and adjust to required flow by means of by-pass valve on pump.
ix. As soon as water flows from delivery hose, open the SO_2 regulating valve sufficient to neutralize any excess chlorine which may be left in the water.

The plant is now in full work, and nothing remains to be done so long as rate of flow of water, the dose of chlorine, and SO_2 are desired to remain as adjusted.

Drains are provided to each unit which all flow into a common pipe and away to the back of the lorry.

General hints for the running of the plant.—An important part of the plant is the sand filter SF ; this will not properly fulfil its function unless it is maintained full of water right to the top, as otherwise the incoming water will fall down on the top of the filter bed and prevent proper filtration. In order to assure that the filter is absolutely solid with water, the outlet valve SF3 should be slightly checked from the *full open,* the amount of restriction of this valve to be carried only to the point where water commences trickling out of the open end of the air vent.

This slight trickle of water from the outlet indicates that the filter is solid with water to the top, and, if at any time it is observed that no water is coming from the air vent, the outlet valve SF3 should be slightly closed still further.

A little care will be necessary to prevent the checking of the outlet valve SF3 being carried to excess, as otherwise the relief valve on the pump will open, and water will be wasted.

Should the water-meter at any time cease to register, it will probably be due to a little sand or grit having lodged in the wheels ; this can generally be removed by disconnecting the meter and running water through in the reverse direction.

The chlorine gas control apparatus is a delicate instrument, and great care should be taken to follow out minutely the instructions given in the booklet supplied with the apparatus.

Care should be taken that the operation of the valves on the plant is carried out in the order laid down in the instructions.

7. **Sterilizing barges and railway trucks.**—A sterilizing plant capable of treating 4,000 gallons or more of canal or river water an hour can be built into a canal barge, and, in a country where navigable waterways are common and convenient, these barges serve a very useful purpose as semi-permanent water supplies. The principles of purification and filtration are the same as in the case of the sterilizing lorries. Ransome's, Bell's, or other types of filter can be used, and a unit would include, besides a sterilizing barge, a store barge and a reservoir barge for purified water together with accommodation for personnel. In the same way plants of considerable capacity can be mounted on railway trucks.

88. *Evaporators.*

Fresh water may be produced from salt or impure water by distillation. The apparatus consists of a boiler supplying high-pressure steam to an evaporator, and a condenser for condensing and cooling the low-pressure vapour produced.

Pl. **181** shows the character of the plant employed.

Evaporators will seldom be practicable forms of plant in the field, both on account of the cumbersome nature of the plant and the necessity for a large expenditure of fuel for a comparatively small amount of water produced.

Evaporators may have to be supplied for installation on sea shores ; or they may be mounted on railway trucks together with their boilers, &c. for operations in areas where only salt water is available.

When inland waterways are used of which the water is salt, evaporating plant might be fitted in barges.

When a steam-boiler can be obtained, an improvised distilling plant can be arranged by passing steam through coils of piping immersed in tanks through which a supply of cold water is passed, the whole arrangement being similar to a laboratory distilling apparatus, but the quantity of water produced is small.

Evaporating plant, however, is unsuitable for field use more particularly on account of its weight. The total weight of plant required is about 1½ tons for each 200 gallons of fresh water produced in a day of 24 hours, with an expenditure of 1 ton of coal for each 2,000 gallons of water distilled.

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CONVENTIONAL SIGNS TO BE USED ARE AS FOLLOWS :-

Potable water supplies to be shown __BLUE.__
Non-potable water supplies to be shown __RED.__
Air lines to be shown __GREEN.__

Pipe-lines (& size)	4"
Stop-valves	4"
Reflux-valves	4" R.V.
Air-valves	4" A.V.
Connectors	4" CON.
Tees (& size)	4" T. 4"×2"×4"
Pumphouse (& No.)	201
Tanks & reservoirs (& capacity)	1/9000 GALS OR 3/2500 GALS.
Dixie Fillers (& No. of taps)	D.F. (4.T)
Water-cart point (& No. of standpipes)	W.C.P. (4. S.P.)
Horsetroughs (total feet run)	(100 FT.)
Initial light railway water point	I.L.R.W.P.
Light railway spill tank	L.R.S.T.
Wells	W.
Bore-holes	BORE

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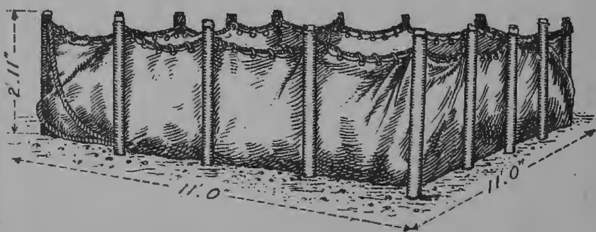
Plate 1.

Plate 2.

USE OF WATERPROOF SHEETS FOR STORAGE.

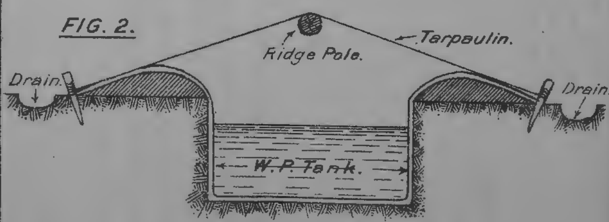
2,300—GALLON TANK.

FIG. 1.



SUNKEN TANK WITH COVER.

FIG. 2.



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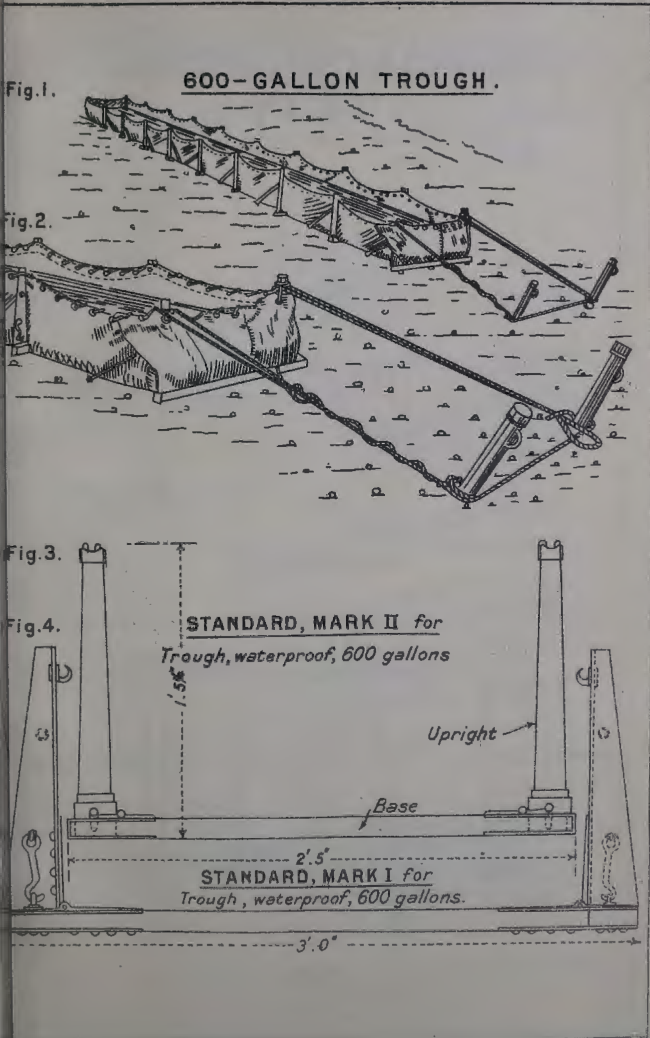

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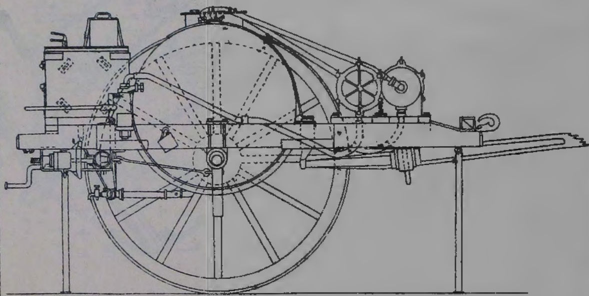
Plate 4.

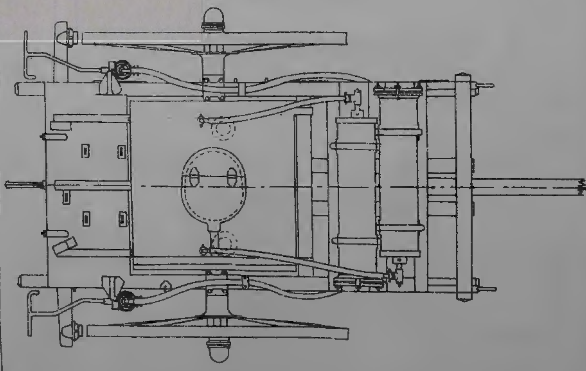
CART, WATER, TANK, MARK VII. (L).

Scale of Feet.

1 0. 1 2 3 Feet



SIDE ELEVATION.



PLAN.

10083

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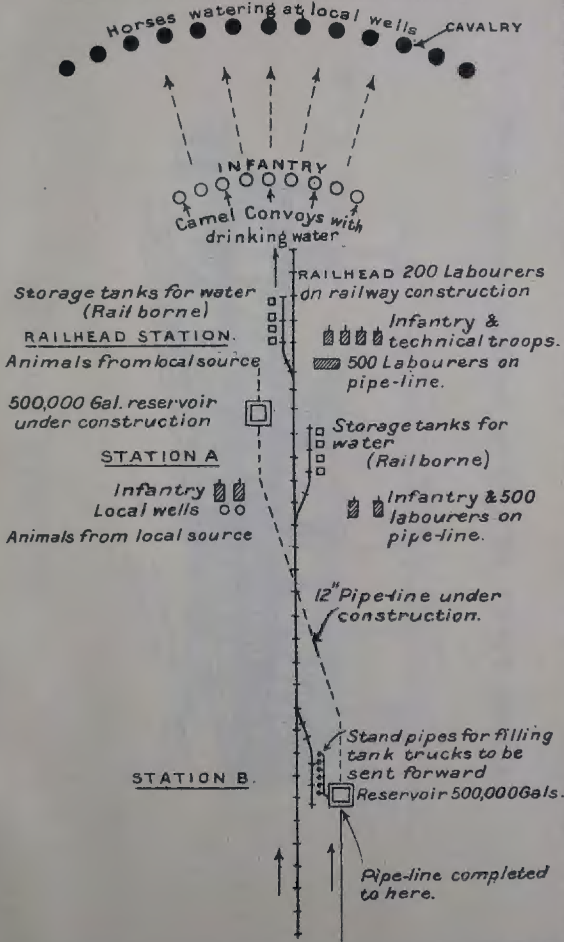
DIAGRAM ILLUSTRATING METHOD OF SUPPLYING WATER TO TROOPS.



10088.
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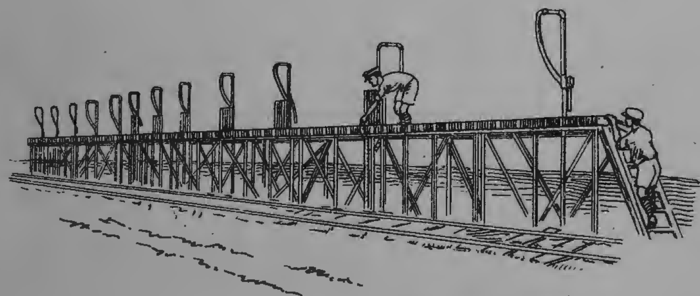
Plate 6.

STAND PIPES AT INITIAL RAILWAY WATER POINT.



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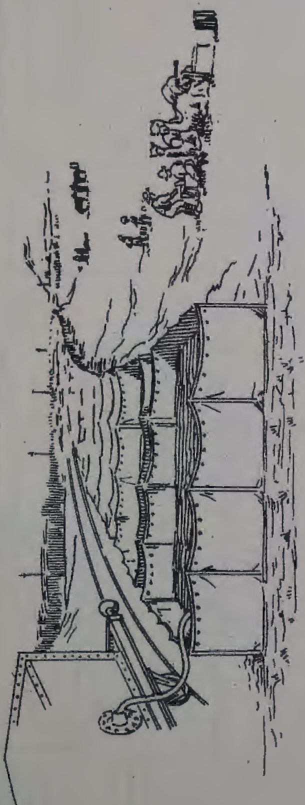
RAILHEAD STORAGE.



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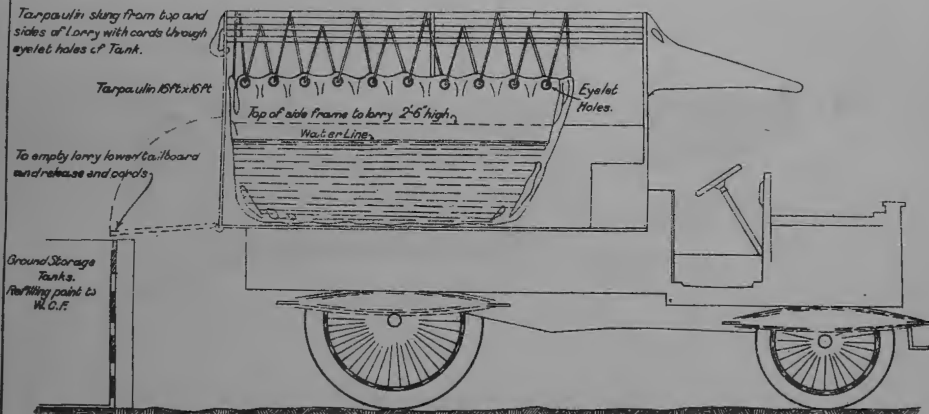
10083.

METHOD OF USING TARPAULIN ON LORRY FOR WATER TRANSPORT.



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IMPROVISED WATER-LORRY.

3-Ton Lorry with sides & ends removed & fitted with Two 300-Gallon Tanks.

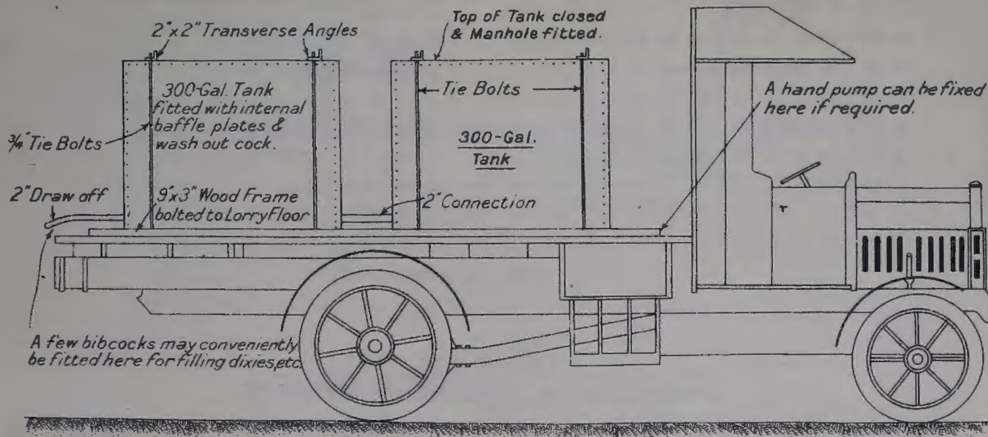

Plate 9

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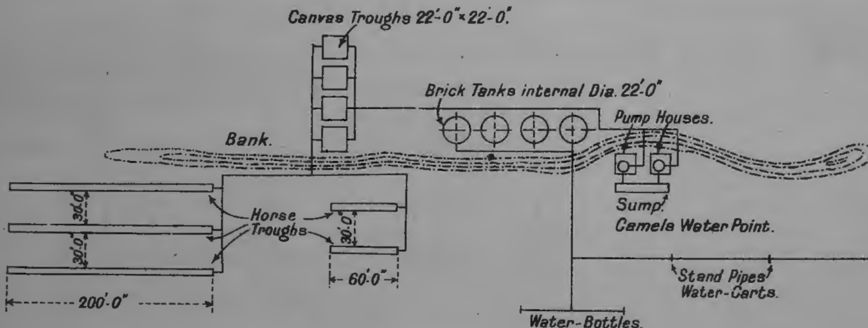
Plate 10.

10093.

DIAGRAM OF INITIAL WATER POINT.

IN A DESERT.



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INITIAL WATER POINT FOR CAMEL WATER CONVOYS.

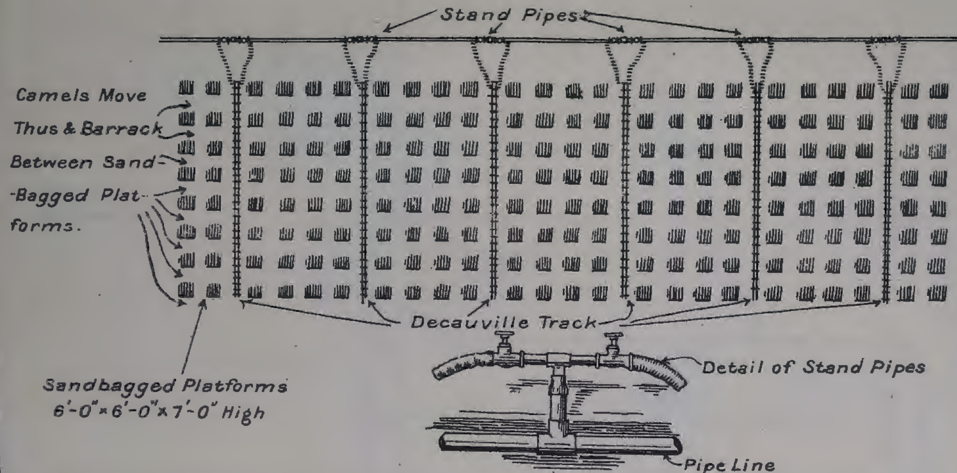

Plate II.

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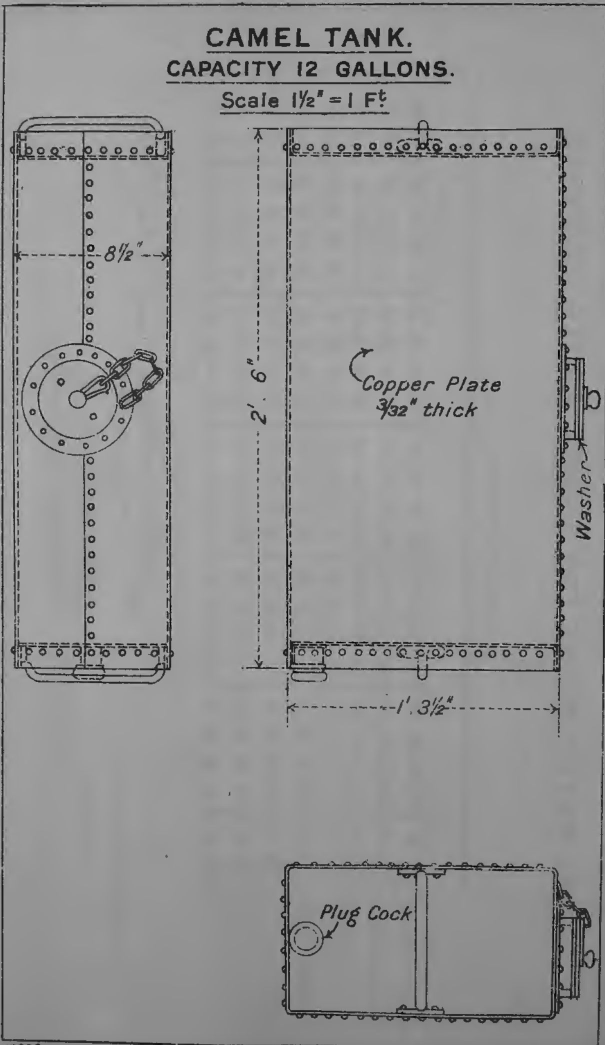
Plate 12.



10083.

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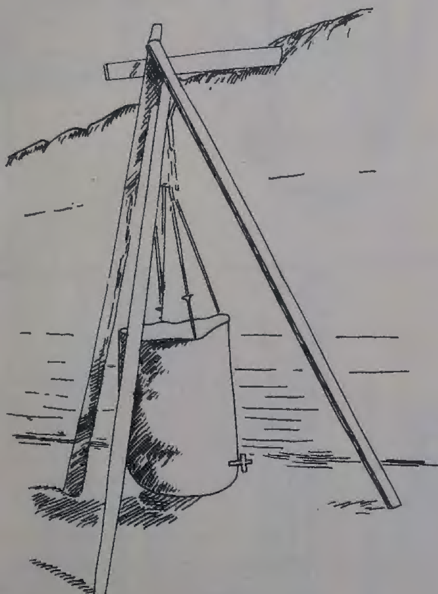
LISTER WATERPROOF BAG.



1093 - 18640/4812/217

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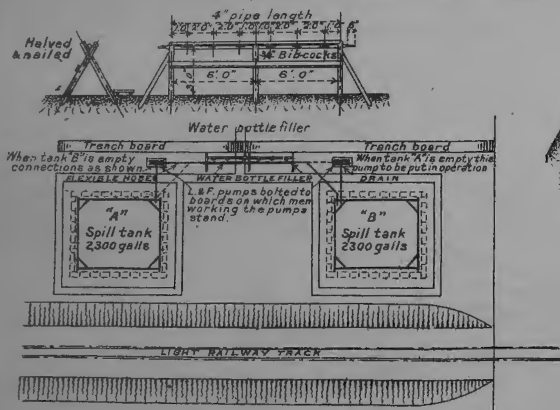
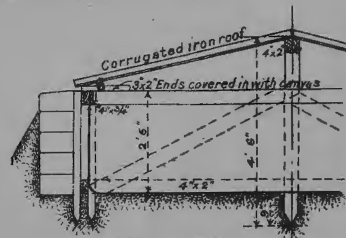
Plate 14.

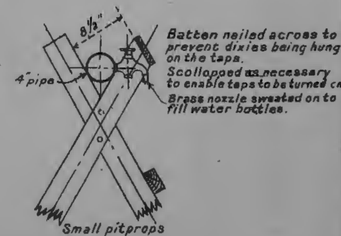
LIGHT RAILWAY SPILL TANK, DIXIE & WATER-BOTTLE FILLER.



PLAN.



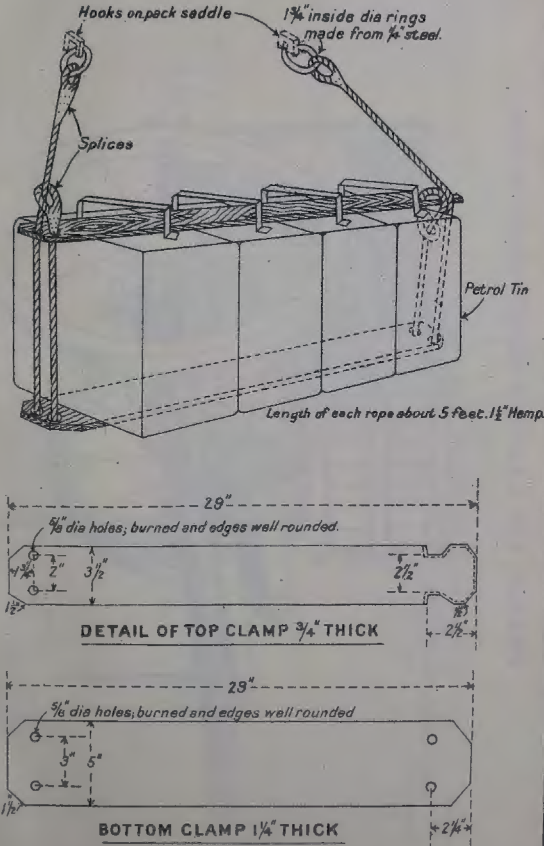
DETAIL OF TANK.



DETAIL OF BIB-COCK.

SECTION THROUGH TANK.

PETROL-TIN WATER CARRIER
FOR PACK MULES.



DETAIL OF TOP CLAMP ¾" THICK

BOTTOM CLAMP 1¼" THICK

10083

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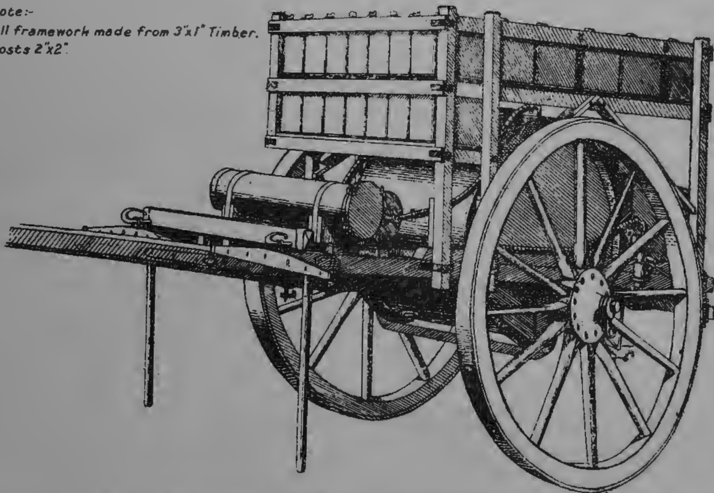
10093 [illegible] 11/12/17.

Plate 16.

PETROL TIN CARRIER FOR WATER-CARTS.

Note:-
All framework made from 3"x1" Timber.
Posts 2"x2".



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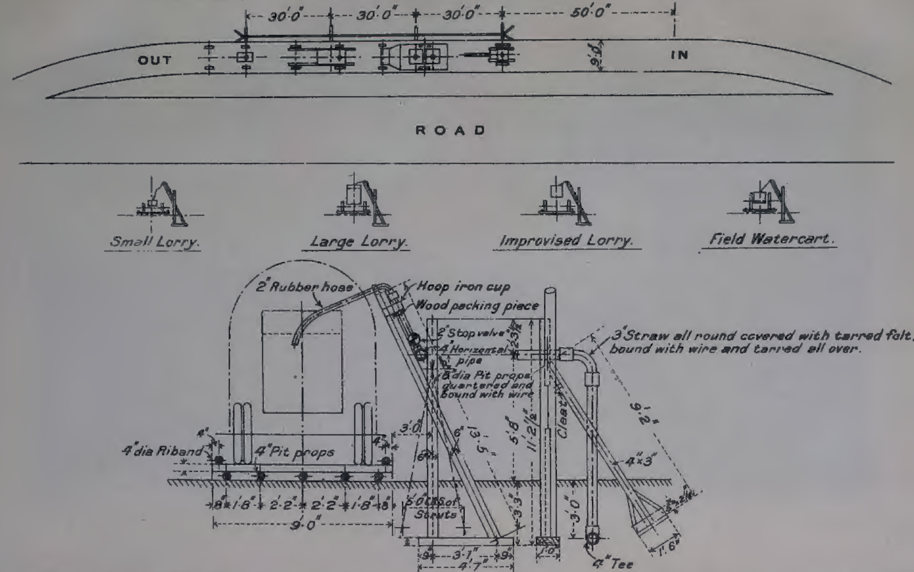
STANDARD WATERCART FILLING POINT.



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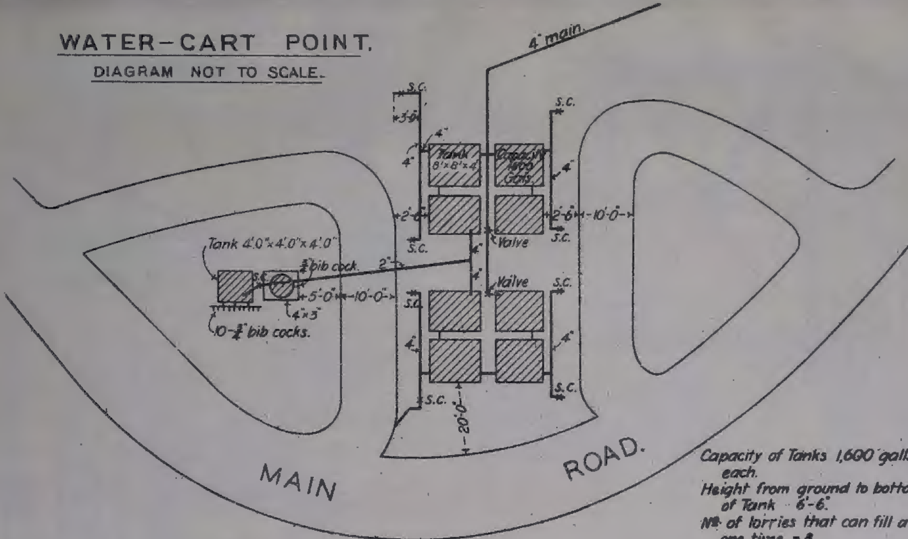
STANDARD WATER-CART FILLING POINT IN USE.

Plate 18.

WATER–CART POINT.

DIAGRAM NOT TO SCALE.



Capacity of Tanks 1,600 galls. each.

Height from ground to bottom of Tank 6'-6".

No. of lorries that can fill at one time = 8

Average No. of lorries that usually fill in one day = 80.

Plate 19.

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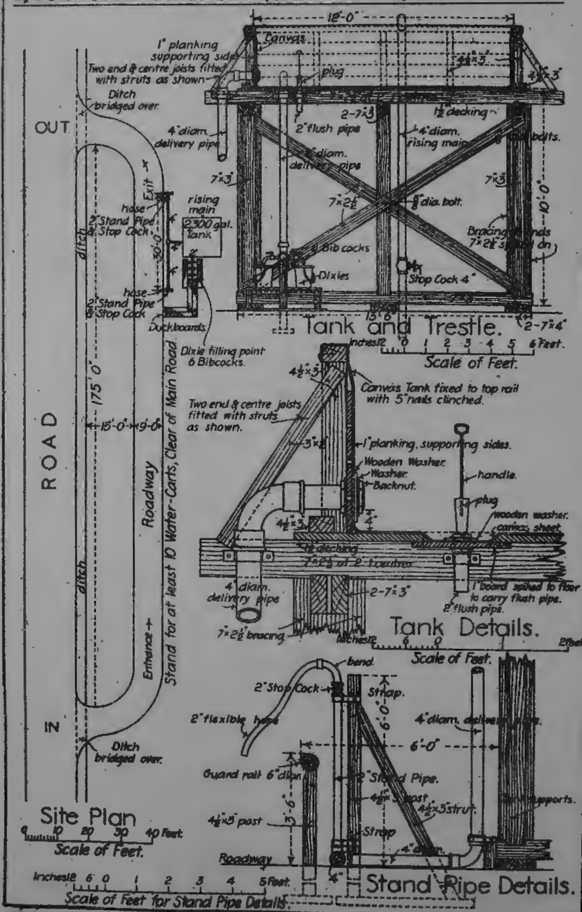
Plate 20.

FILLING POINT—WATER—CARTS & DIXIES
2,300-GAL TANK—1,500 GALS. NET STORAGE



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STANDARD HORSE WATER POINT.

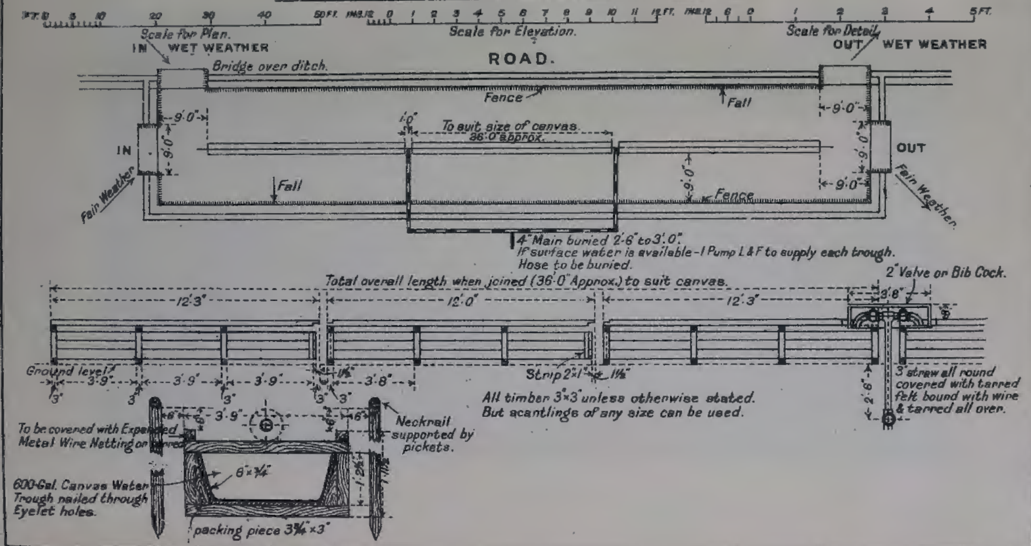

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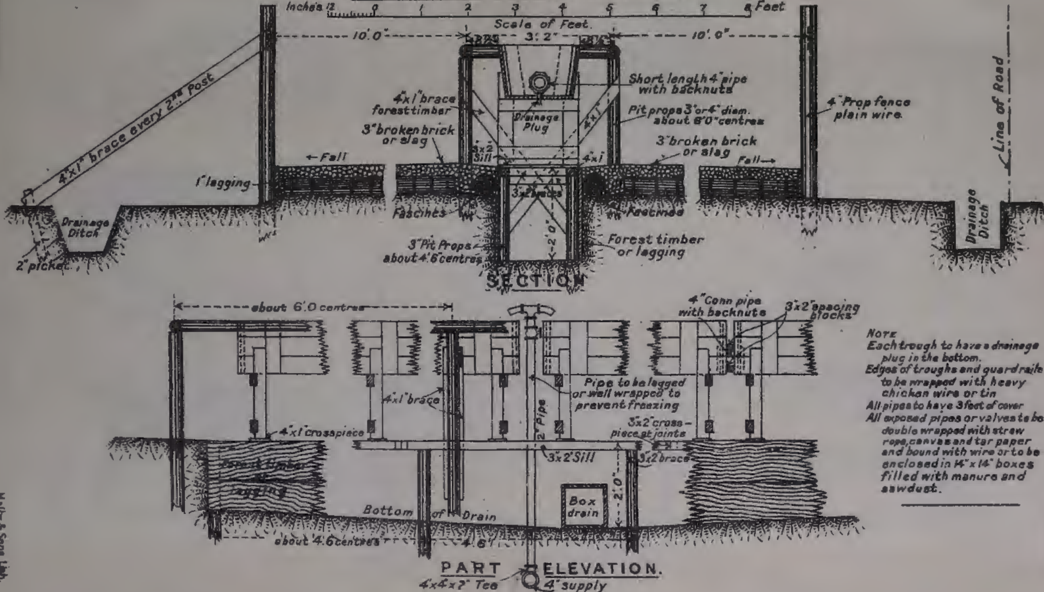
Plate 21.

STANDARD HORSE WATER POINT IN USE.

Plate 22.

TIMBER HORSE TROUGH.



NOTE

Each trough to have a drainage plug in the bottom.

Edges of troughs and guard rails to be wrapped with heavy chicken wire or tin

All pipes to have 3 feet of cover

All exposed pipes or valves to be double wrapped with straw rope, canvas and tar paper and bound with wire or to be enclosed in 14" x 14" boxes filled with manure and sawdust.

Plate 23.

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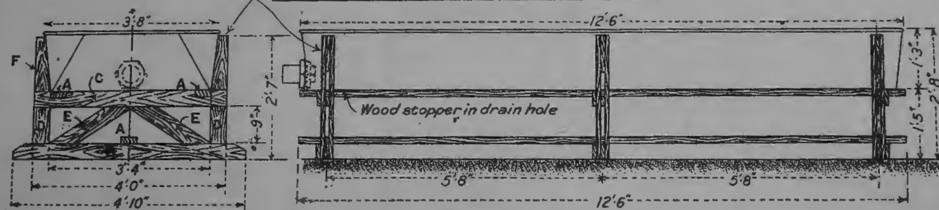
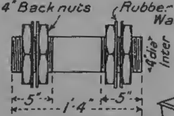
SHEET-IRON HORSE TROUGH.



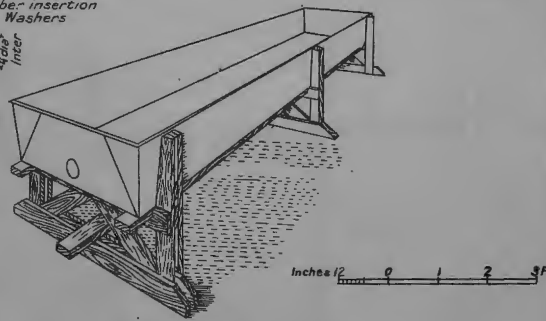
Material for 3 Troughs

No. of	Description		Mark
9	4"x1½"	12'.6" Long	A
18	4"x1"	4'.10" "	B
18	4"x1"	4'.0" "	C
36	4"x1"	2'.7" "	D
18	4"x1"	2'.3" "	E
18	4"x1"	9" "	F
3	Sheet iron troughs 18 Gauge		
2	Pipe connections complete		
3	Wood Stoppers.		



Detail of Pipe Connections

Key plan of three troughs forming one set arranged with pipe connections.



Perspective View

10083 18640/4812/217

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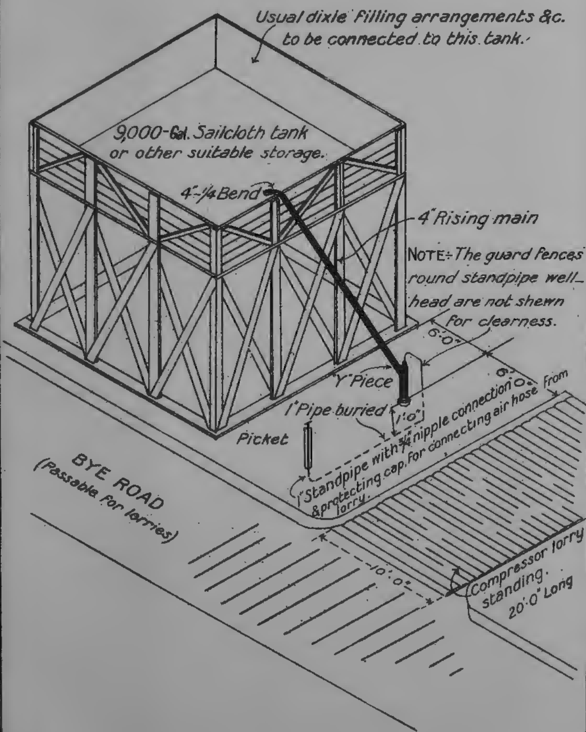
BORE-HOLE & TANK ARRANGED FOR WORKING BY COMPRESSOR LORRY.



Malby & Sons. Lith.

TUBE WELL PUMP AND PORTABLE ENGINE INSTALLED UNDER SEMI-MOBILE CONDITIONS OF WARFARE.

Plate 26.

Plate 27.

WATER POINT FOR LIGHT RAILWAY.

HYDROLOGY.

FIG. 1. KAREZ

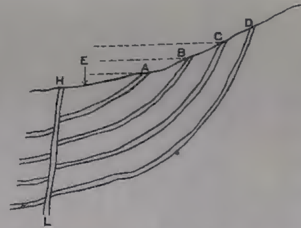


FIG. 2. FAULT IN BASIN.

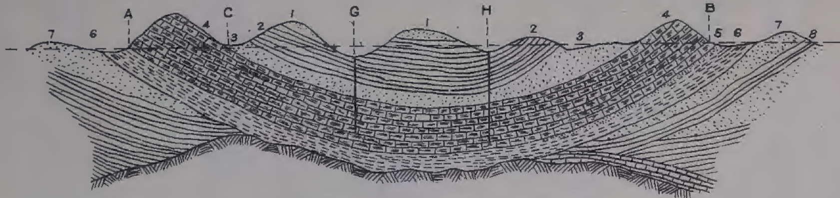


FIG. 3. SECTION OF TYPICAL BASIN.

1. Bagshot Sands. 2. London Clay. 3. Woolwich & Reading Beds & Thanet Sands. 4. Chalk. 5. Upper Green Sand. 6. Gault. 7. Lower Green Sand. 8. Weald Clay.

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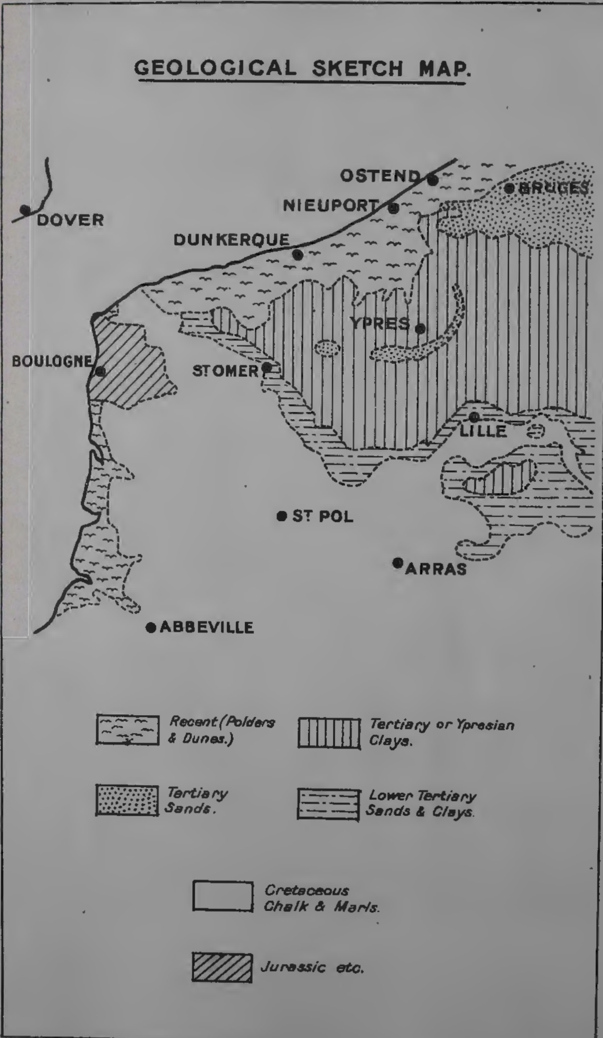
Plate 28.

Plate 28.



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Malby & Sons Lith.

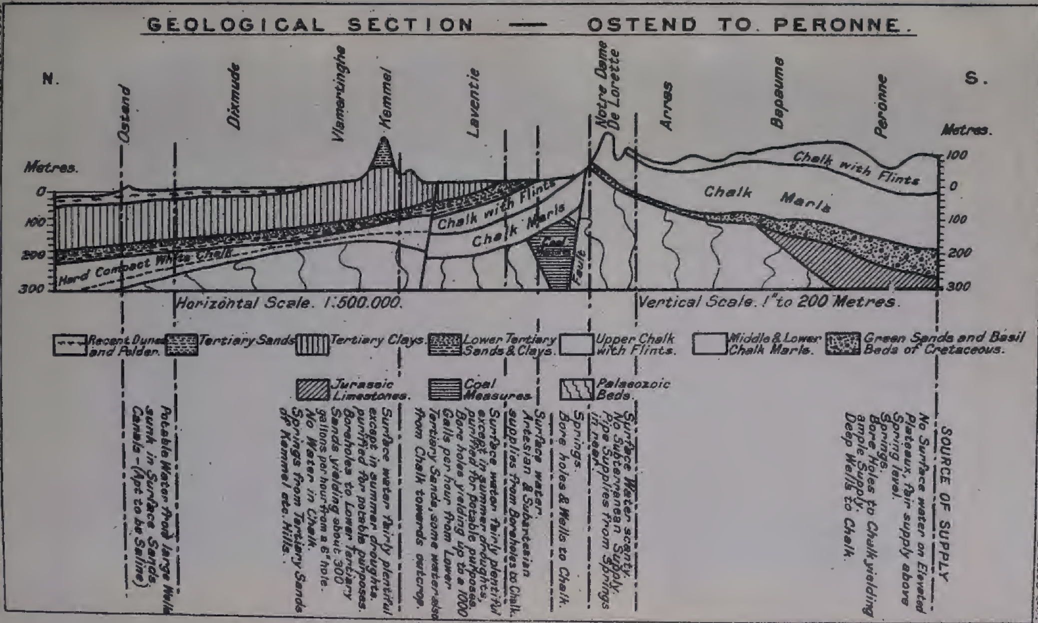

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Plate 31.

GAUGING SUPPLY OF A STREAM.

FIG. 1. RECTANGULAR NOTCH METHOD.

FIG. 2. LONGITUDINAL SECTION OF STREAM.

FIG. 3. TRIANGULAR NOTCH METHOD.

10093.18640.4812/217.

Plate 32.

Weir-Box.

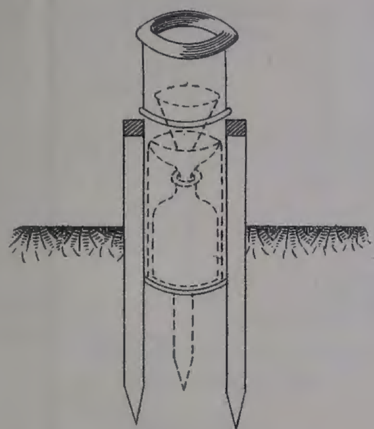
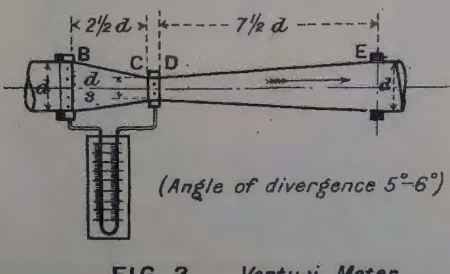


FIG. I. Rain-Gauge.



(Angle of divergence 5°-6°)

FIG. 2. Venturi Meter.

10023. 18640/4812/217.
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Fig. 2. Reproduced from Gibson's "Hydraulics".

Plate 34.

TUBBING FOR SINKING SHALLOW WELLS.

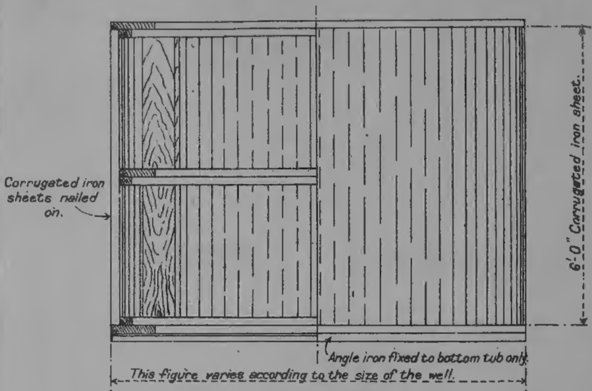

FIG. 1. ELEVATION.

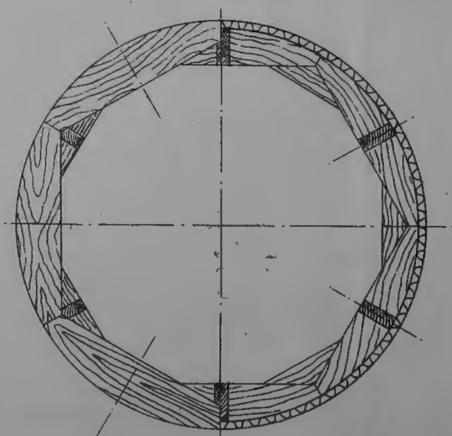

FIG. 2. PLAN.

Method of Operation.

The tub is placed in an excavation. Two rails are placed across the top and the ends weighted with sandbags. The earth is then excavated inside round the cutting edge & the tub falls by its own weight & that of the sandbags.

When the tub is flush with the ground, another tub is bolted on top and the process continued to the required depth. The frames & studs are made with timber of available scantlings.

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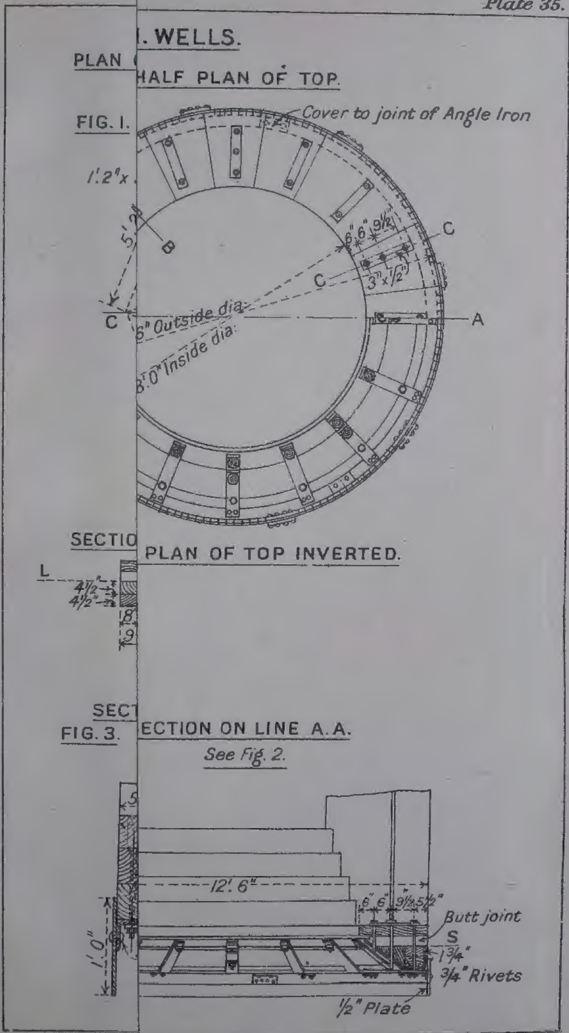
Plate 35.



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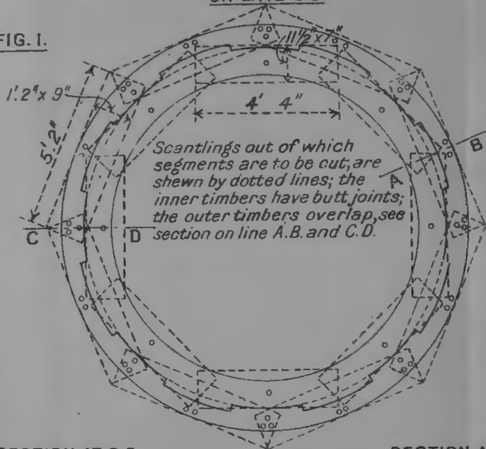
COMBINED IRON AND TIMBER

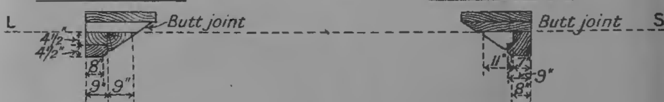
PLAN OF UPPER SIDE OF LOWER SEGMENTS OF TIMBER ON LINE L.S.

FIG. I.



SECTION AT C.D.

SECTION AT A.B.

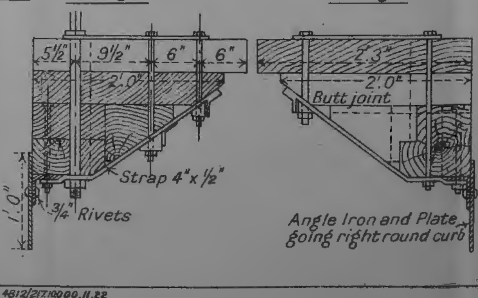


SECTION ON LINE B.B.

FIG. 3. See Fig. 2.

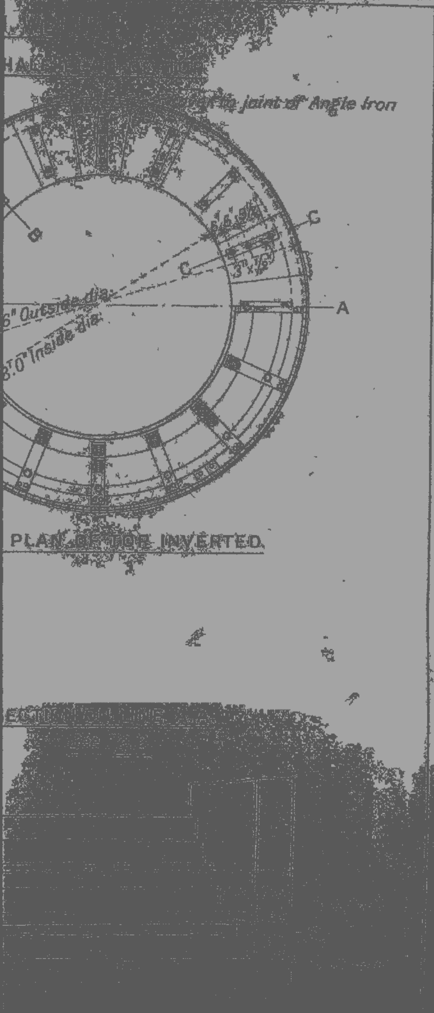
SECTION ON LINE C.C.

See Fig. 2.



10093. 18640. 4812/217.10000.11.22

Plate 35.


joint of Angle Iron
B
C
C
A
3" x 1/2"
Outside dia.
8' 0" Inside dia.
PLAN OF TOP INVERTED.

WELLS - No. 1.

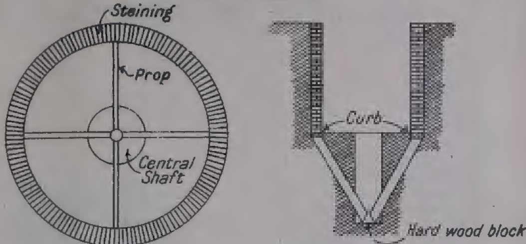


FIG. 1. CONSTRUCTION BY UNDERPINNING.

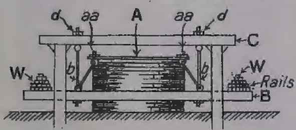


FIG. 2. FORCING DOWN THE STEINING.

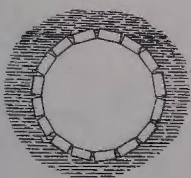


FIG. 3.

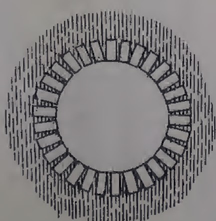


FIG. 4.

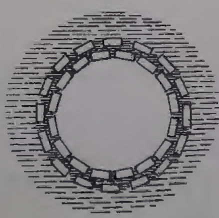


FIG. 5.

18640. [illegible]

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Plate 37.

HANGING UP THE STEINING.

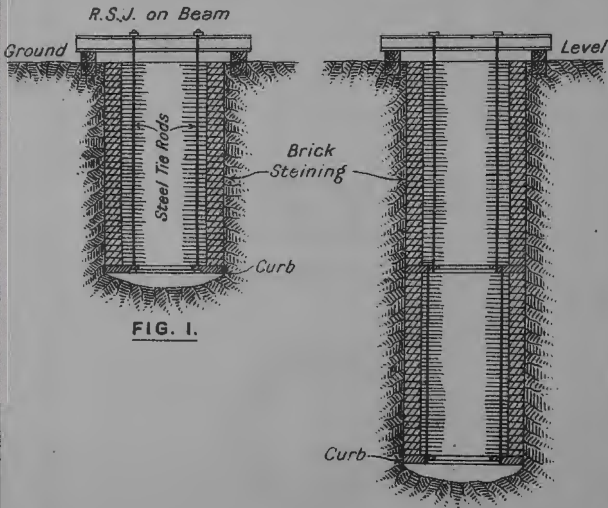

FIG. I.

FIG. 2.

The Brickwork is laid in cement in Sections of depths according to nature of Strata, & on a wood or iron curb; when the curb has sunk as far as it can, it is hung from the top as shewn in Fig. I.
Sinking then proceeds with another curb and the next vertical section is hung from the first curb as shewn in Fig. 2. and so on.

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STEEL TUBBING.

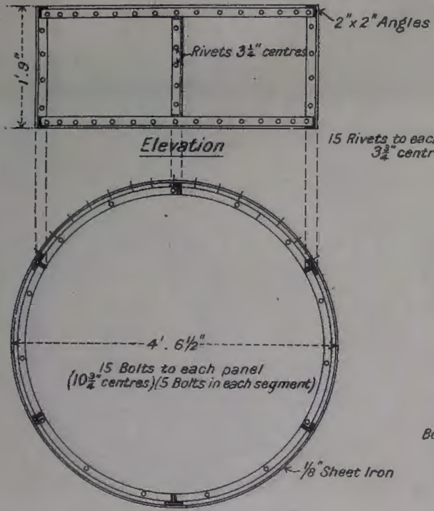

FIG. 1. *Plan*

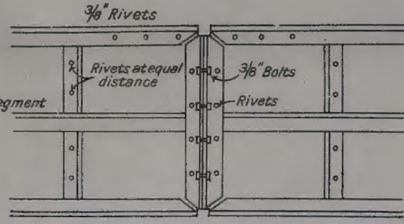

FIG. 2. *Detail of Panel Joints*

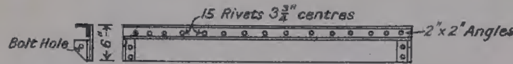

FIG. 3. *Detail of Cutting edge*

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Plate 38.

Plate 39.

REINFORCED CONCRETE TUBBING.

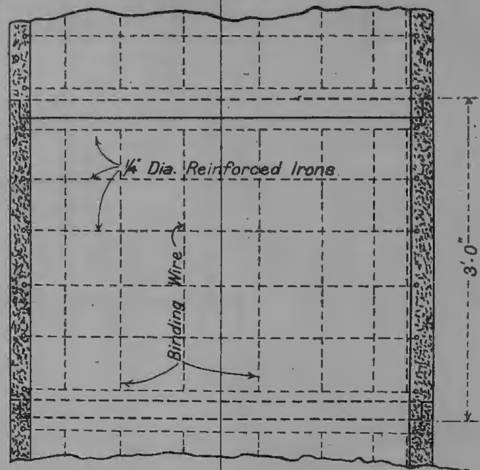

FIG. I.

SECTION.

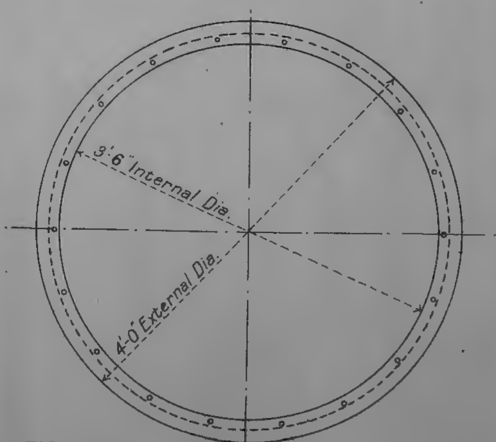

FIG. 2.

PLAN.

10098 - 18860 - 4812/217

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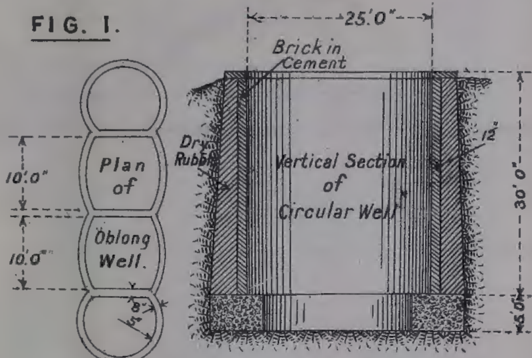
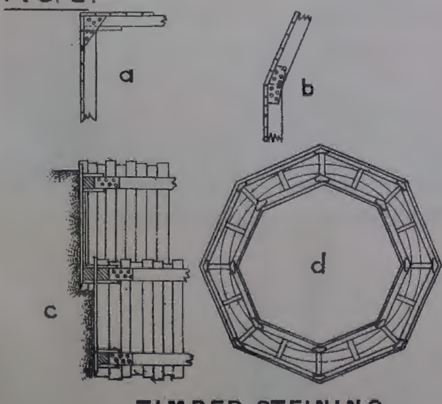
STEINING FOR LARGE WELLS.

FIG. I.



CONCRETE STEINING.

FIG. 2.



TIMBER STEINING.

18993. 18640/4812/217.
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Reproduced from Folwell's "Water Supply, 1912."

Plate 41.

WELLS-No. 2.

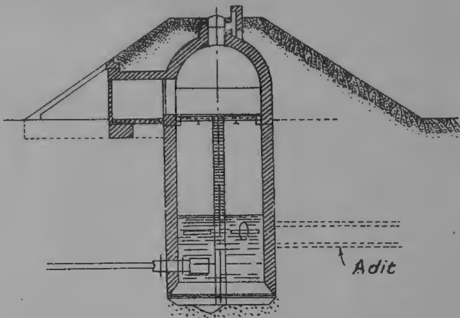

Fig. 1

ADIT

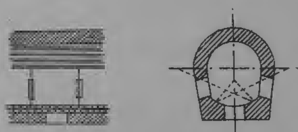

Fig. 2.

DETAIL OF ADIT

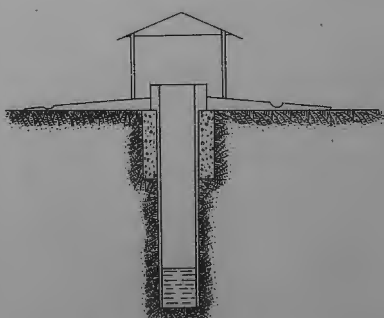

Fig. 3

SECURING WELL AGAINST CONTAMINATION.

10093.18640/4812/217

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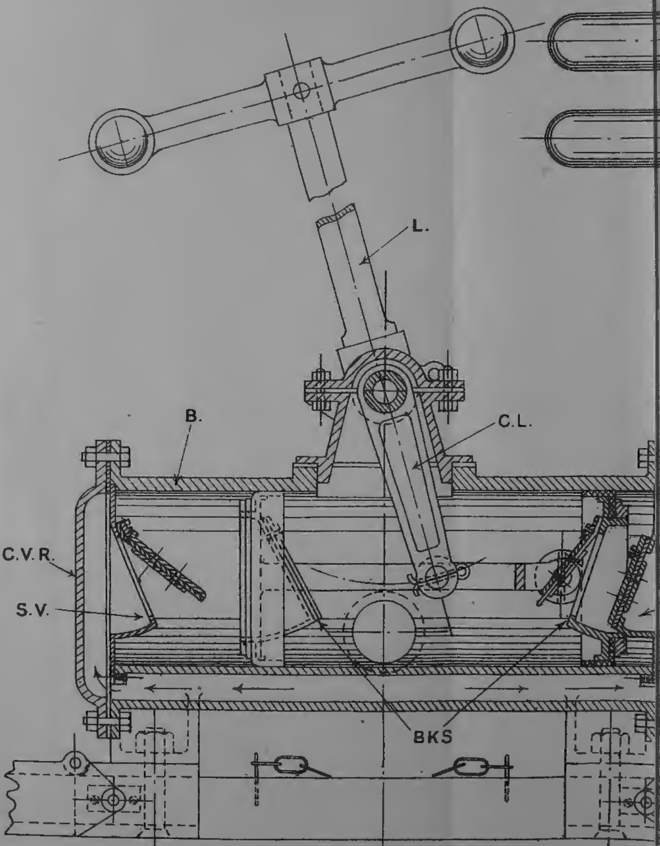
Lift and Force Pump in Use.

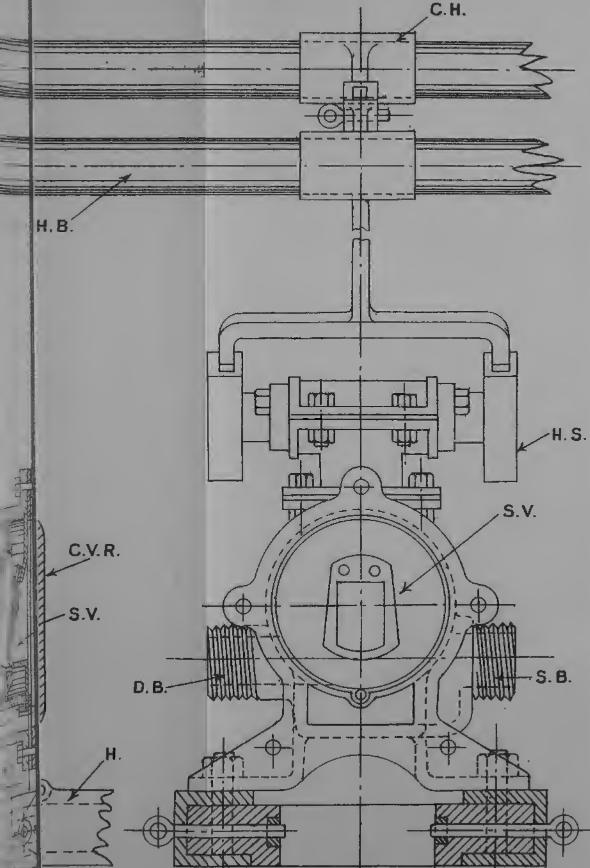
LIFT AND FORCE PU



LONGITUDINAL SECTIONAL ELEVATION.

1093. 18640. 4812/217.

RCE UMP, MARK V – DIAGRAM.



END ELEVATION WITH COVER REMOVED.

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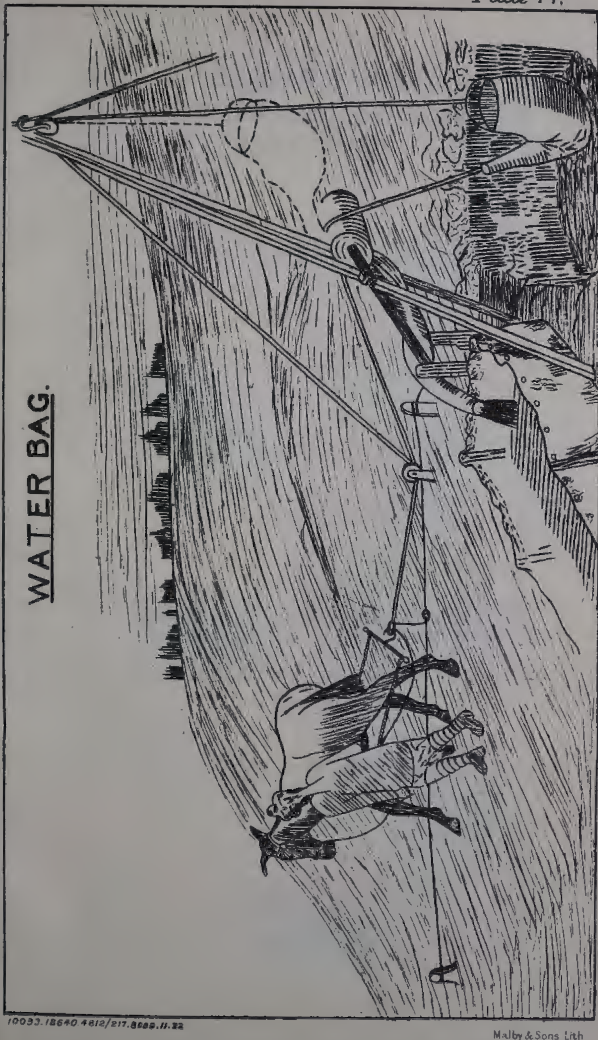

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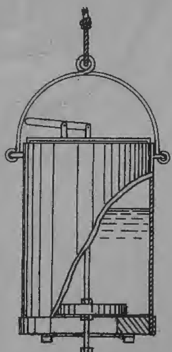
Malby & Sons Lith

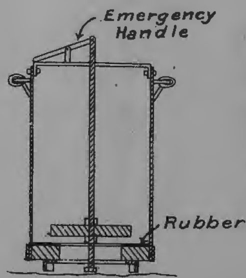
Plate 45.

WELL BUCKET

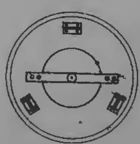
FITTED WITH VALVE FOR RAPID EMPTYING.



VALVE CLOSED



VALVE OPEN



10083-18640/4812/217.
Malby & Sons Lith

BUCKET AND LEVER.

10883. 19840 4918/217.

Malby & Sons. Lith

Plate 47.

PERSIAN WHEEL.

10093. 18640. 4812/217

Malby & Sons Lith.

PUMPS FOR WELLS & BOREHOLES.

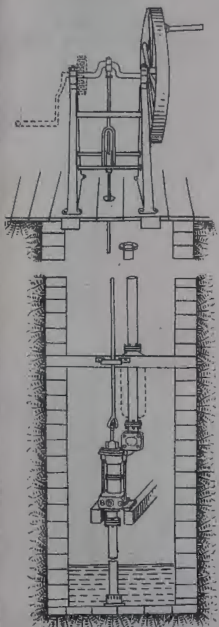


FIG. I.

Cast iron well frame, having wrought iron or steel single-throw crank, fly-wheel and handle and single-barrelled pump with doors for access to valves.

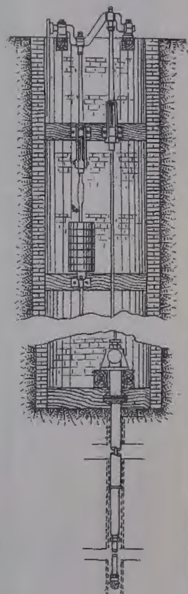


FIG. 2.

Bore-hole pump with gear for power driving.

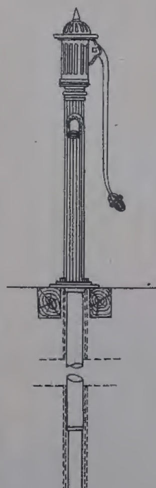


FIG. 3.

Hand power bore-hole lift pump suitable for depth up to 80 feet.

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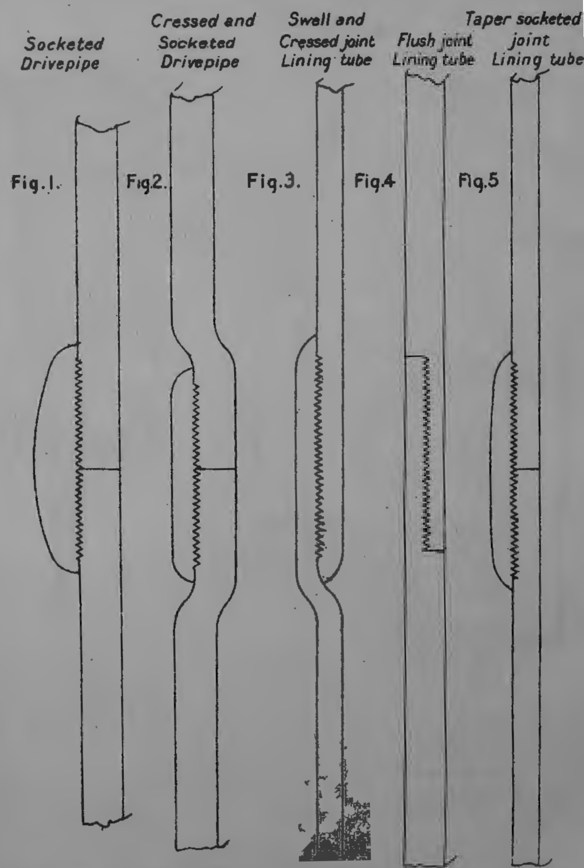
Plate 49.

TYPES OF TUBE WELL LININGS.



10093.18640.48640.4812/217

Malby&Sons.

KEYSTONE DRILL.

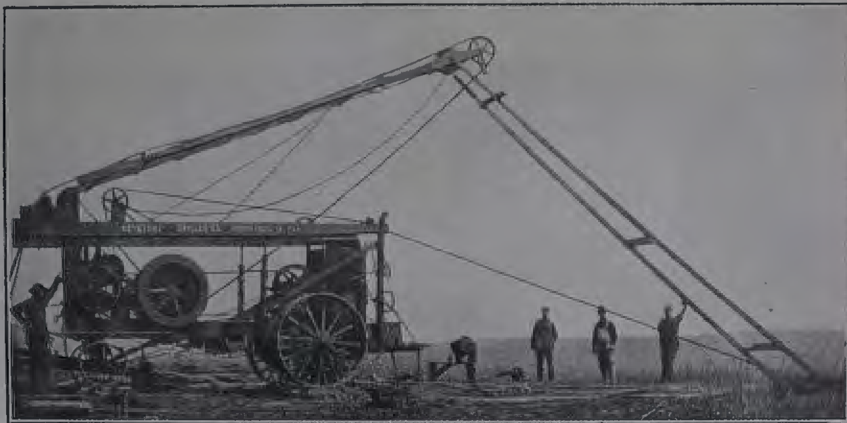
Reproduced from Keystone Driller Coy.'s Catalogue.

Plate 51.

KEYSTONE DRILL USED AS A TRACTOR.

Reproduced from Keystone Driller Coy.'s Catalogue.

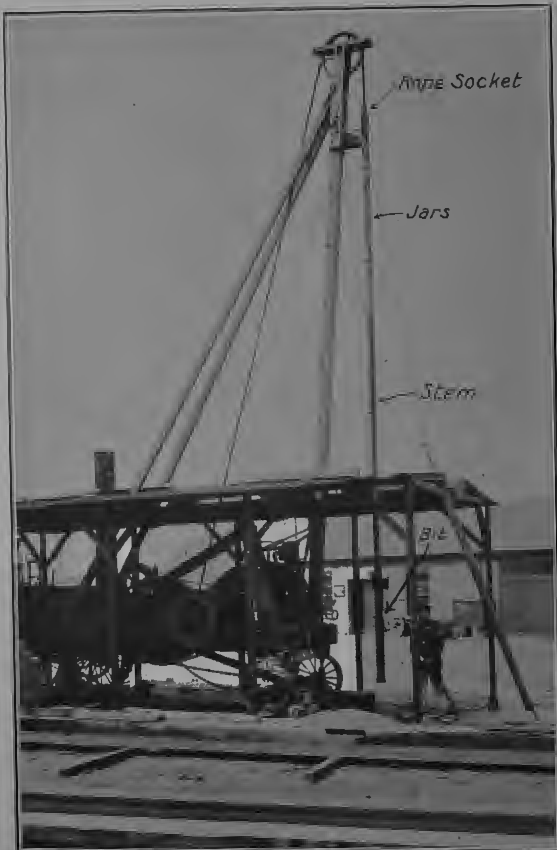
METHOD OF HOISTING DERRICK OF NO. 5 KEYSTONE DRILL.



Reproduced from Keystone Driller Coy.'s Catalogue.

Plate 52.

KEYSTONE DRILL. STRING OF TOOLS READY FOR SPUDDING.



KEYSTONE DRILL. TIGHTENING UP TOOL JOINTS WITH FLOOR CIRCLE.

Plate 55.

DRILLING ACCESSORIES.

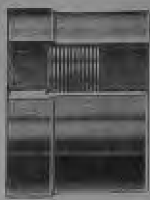


FIG. 1. *Driving shoe.*

FIG. 2. *Driving clamp.*

FIG. 3. *Bit gauge.*

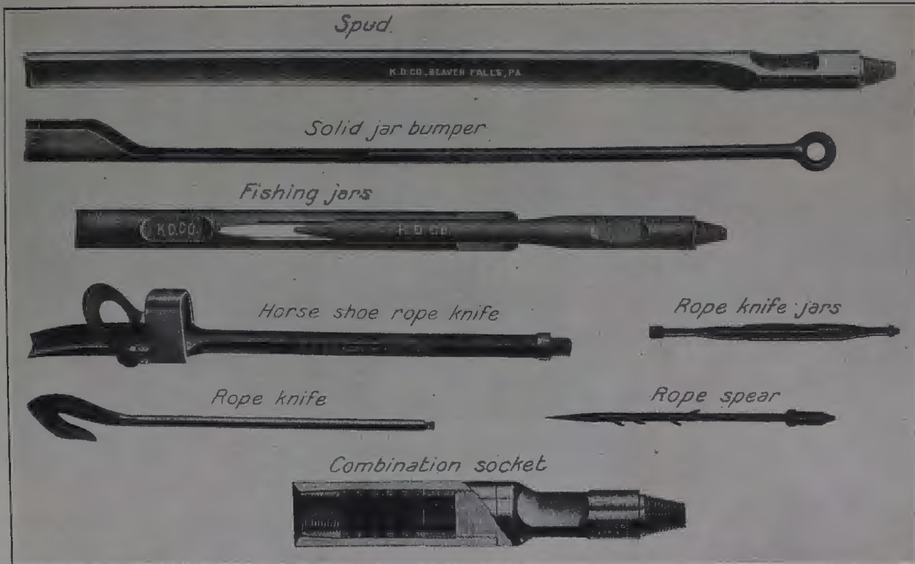
FIG. 4. *Bailer.*

FIG. 5. *Flat valve.* (*with steel hinges*)

FIG. 6. *Dart valve.*

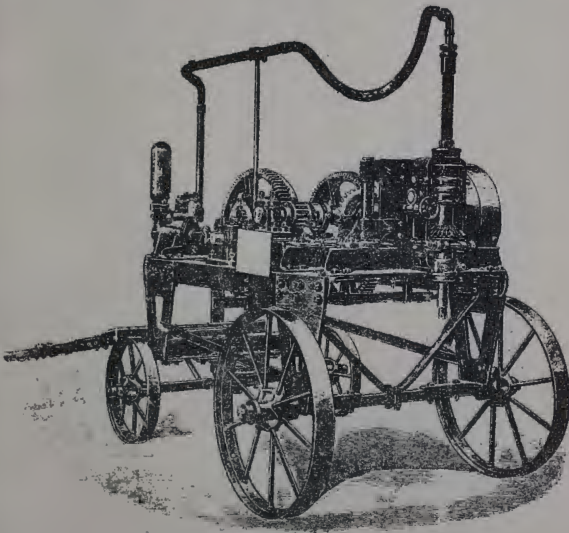
Reproduced from Keystone Driller Coy.'s Catalogue.

FISHING TOOLS.



Reproduced from Keystone Driller Coy.'s Catalogue.

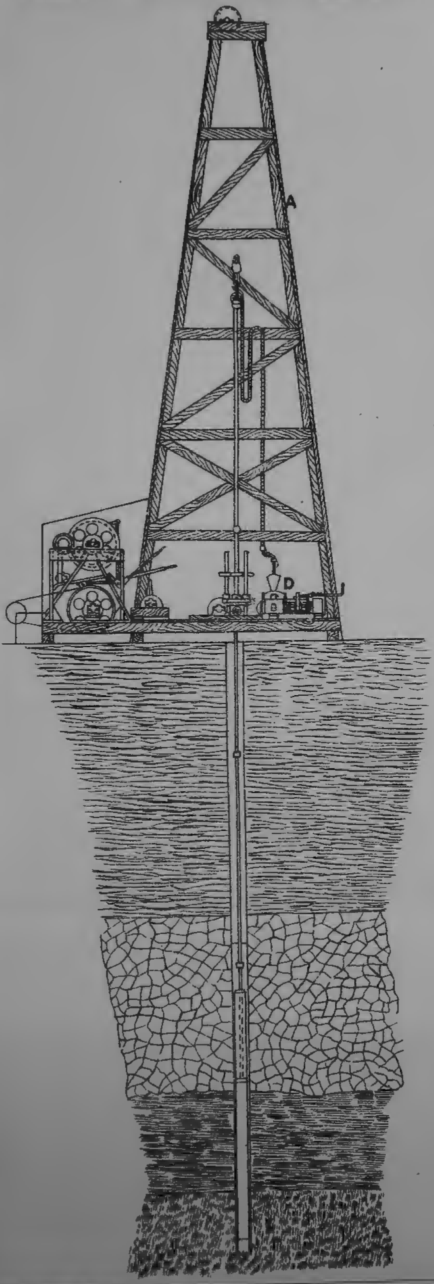
PORTABLE DIAMOND DRILL.
AQUEOUS C^o.Y



PORTABLE DIAMOND ROCK-BORING MACHINE,
recommended for depths of 300 to 500 feet.

CALYX DRILL, CLASS B.

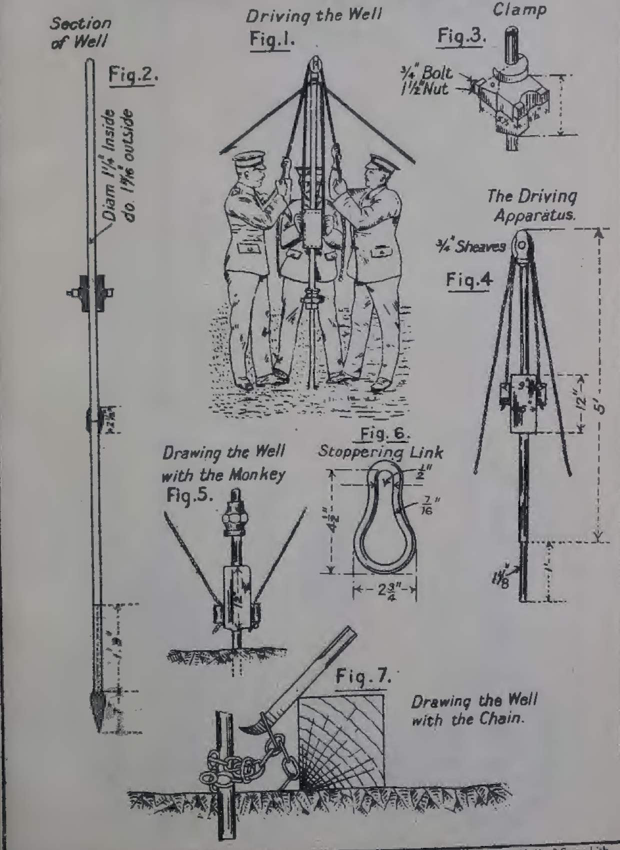
DRILL FOR DEPTHS OF 600 TO 1000 FEET.



Malby & Sons Lith.

NORTON TUBE WELLS - No. 1.

DRIVING APPARATUS



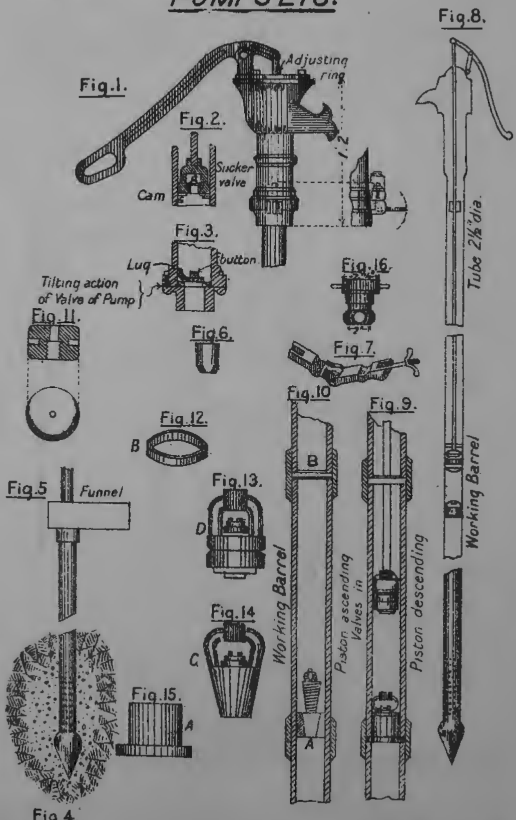
10093. 18640. 4812/217.

Malby & Sons. Lith.

Plate 60.

NORTON TUBE WELLS—No. 2.

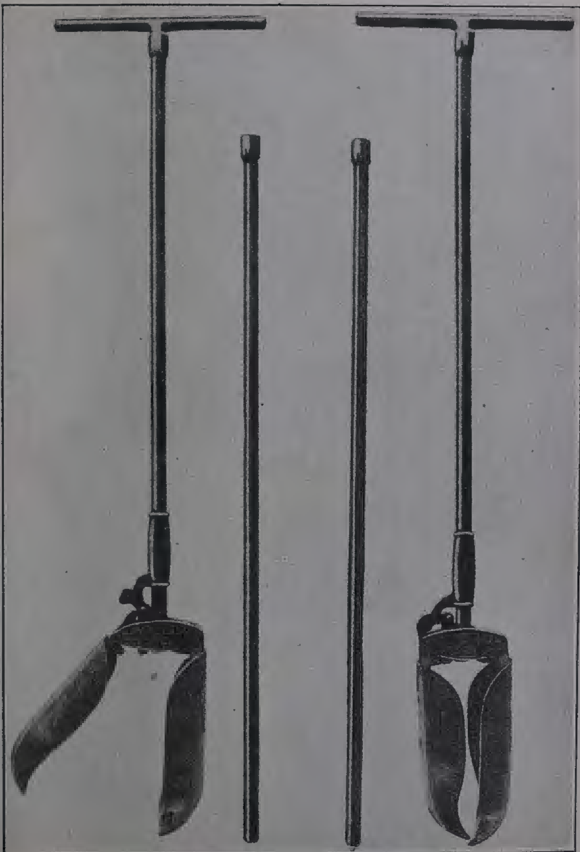
PUMPS ETC.



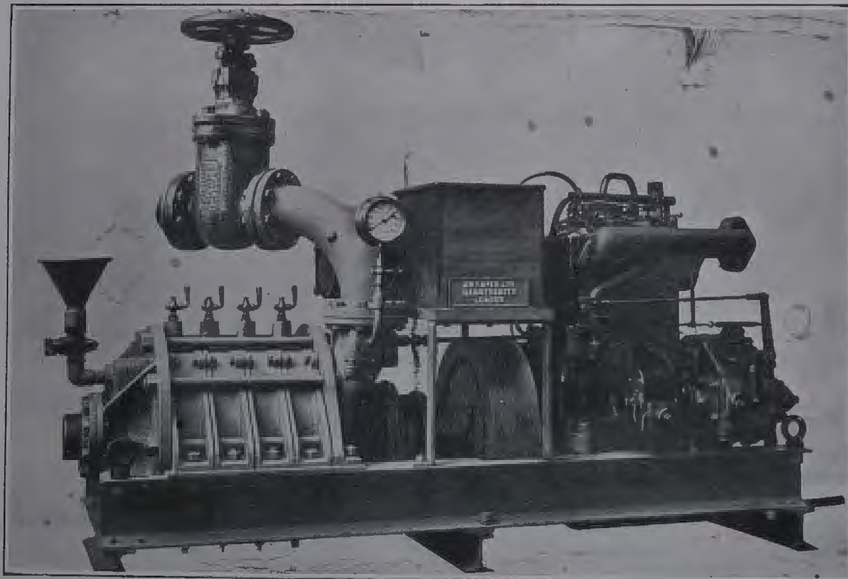
10093.18640.4812/217.

Malby & Sons, Lith.

EARTH AUGER.



GWYNNES' PORTABLE PUMPING SET. CAPACITY, 6,000 GALS./HR./250 FT.



Reproduced by permission of Messrs. Gwynnes', Ltd., Hammersmith.

DENNIS ENGINE COUPLED TO A MATHER & PLATT PUMP. CAPACITY, 7,200 GALS./HR./600 FT.

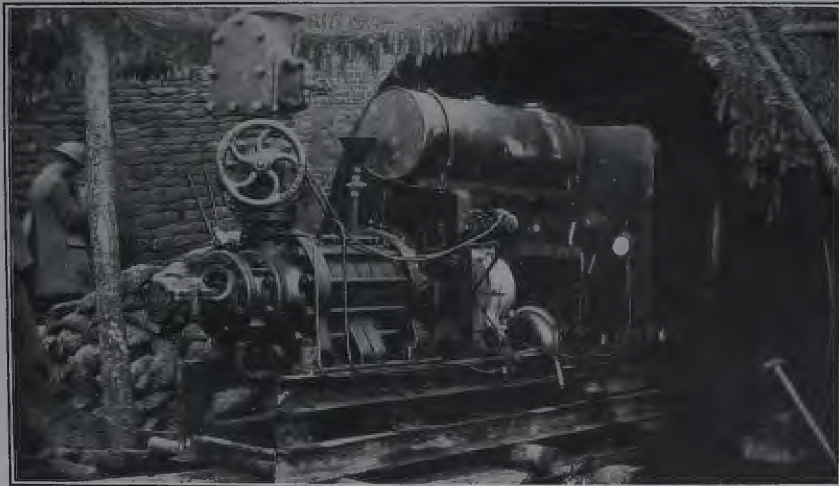
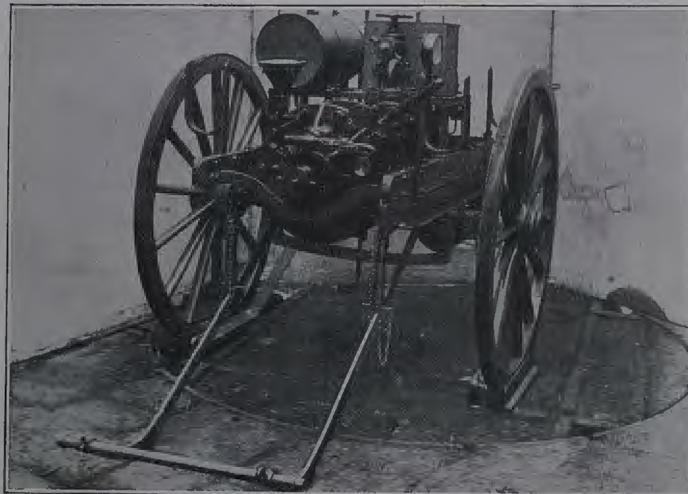


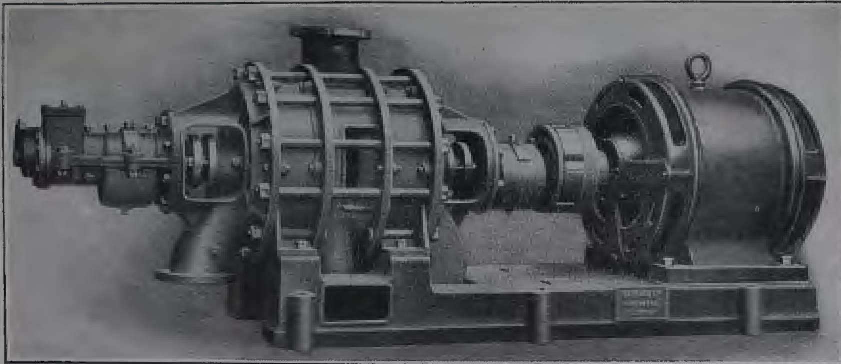
Plate 64.

Aster-Gwynnes' Pumping Set Mounted on Wheels.



Reproduced by permission of Messrs. Gwynnes', Ltd., Hammersmith.

"INVINCIBLE" DIRECT-COUPLED CENTRIFUGAL PRESSURE PUMP.

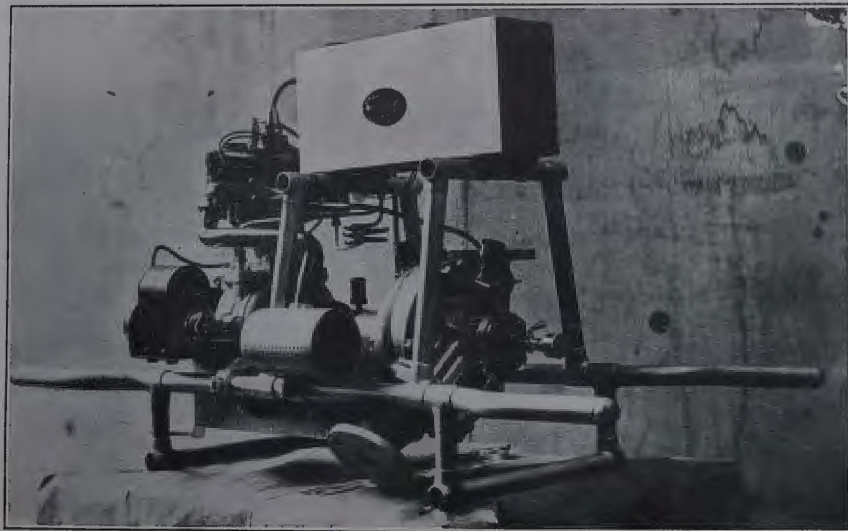


Reproduced by permission of Messrs. Gwynnes', Ltd., Hammersmith.

Plate 65.

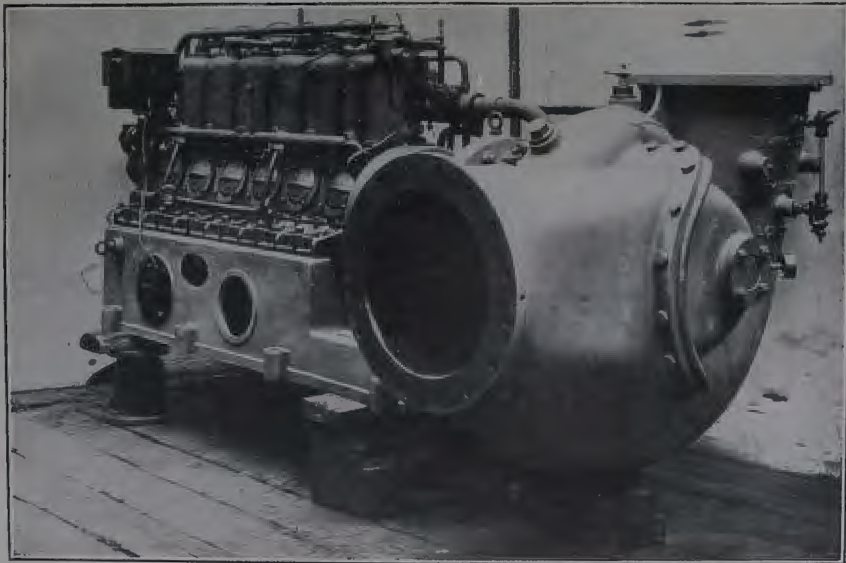
Plate 66.

GWYNNES' TRENCH PUMP.



Reproduced by permission of Messrs. Gwynnes', Ltd., Hammersmith.

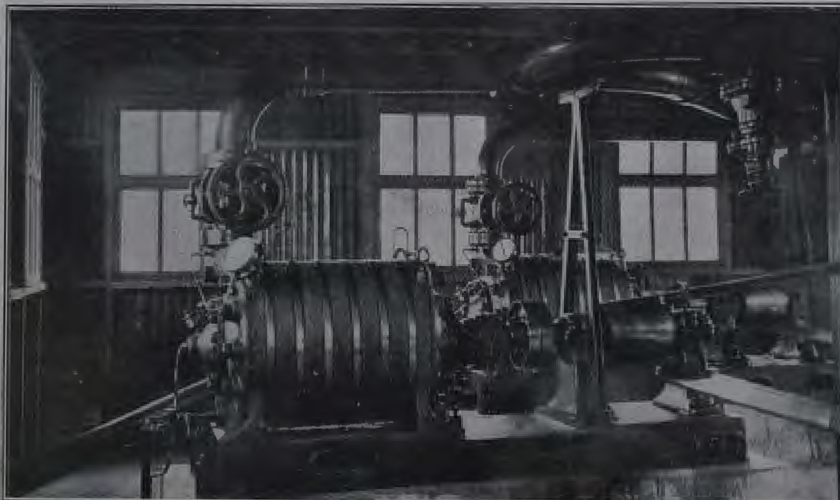
GWYNNES' LOW LIFT HIGH CAPACITY CENTRIFUGAL PUMP COUPLED DIRECT TO PETROL ENGINE.



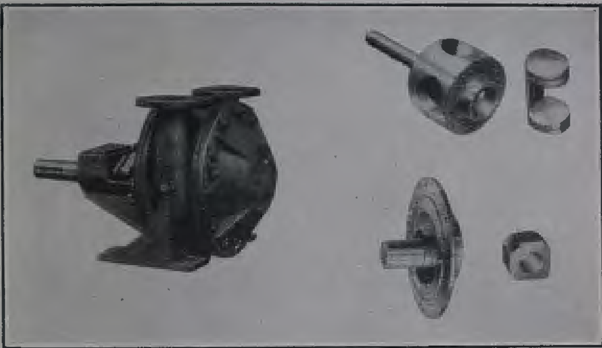
Reproduced by permission of Messrs. Gwynnes', Ltd., Hammersmith.

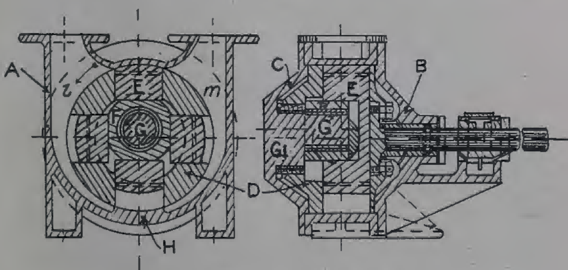
Plate 67.

Pair of Holden & Brooke's Pumps. Capacity, 1,200 gals./hr./600 ft. Each.



Rotoplunge Pump.





CONSTRUCTION DETAILS

The Pump consists of

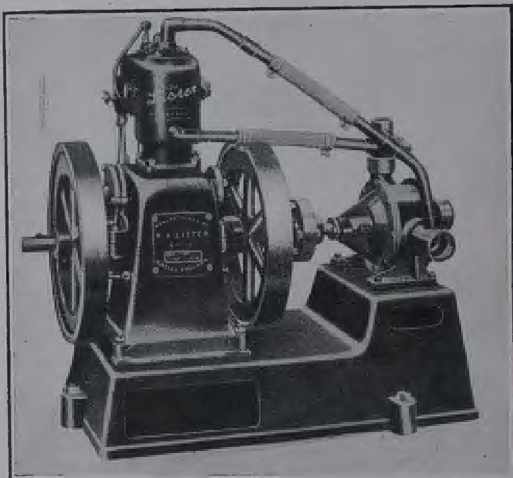
Seven Parts only.

A. The body, or casing, with shoes H.
B. Back cover.
C. Front cover (with boss for rotor bearing, G 1).
D. Rotor.
E. Plunger working in rotor.
F. Block working on eccentric pin, G. In the larger sizes the eccentric pin is bolted through the front cover, and in the smaller sizes is cast with the cover.

Reproduced by permission of The New Rotoplunge Pump Co., Ltd., Westminster, London, S.W. 1.

Plate 70.

ROTOPLUNGE PUMP AND LISTER PETROL ENGINE.

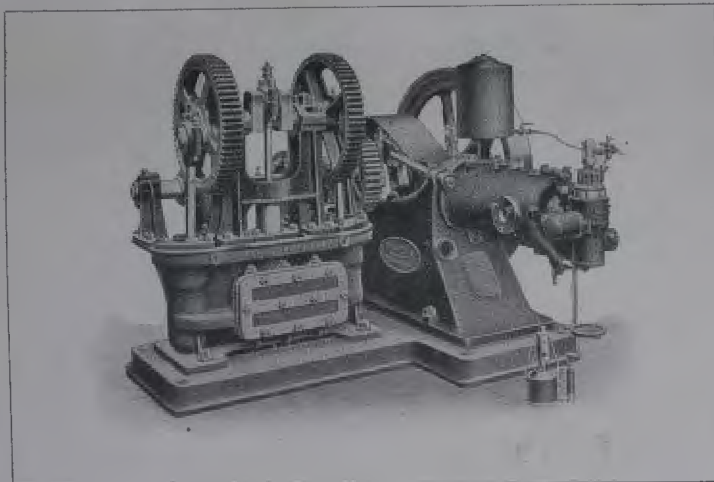


The above illustration shows an extremely compact unit, comprising a No. 5 pump directly coupled to a $1\frac{1}{2}$ H.P. Lister Petrol Engine, which will give a capacity of 1,000 gallons per hour and deliver to a head of 80 feet.

Suitable sets can be supplied covering all sizes of these pumps, and in each instance they can be direct coupled through flexible coupling, the normal speeds of pump and engine being practically identical.

Reproduced by permission of Messrs. R. A. Lister & Co., Ltd., Dursley, Glos.

TANGYE'S TREBLE-RAM PUMP GEAR-COUPLED TO OIL ENGINE.

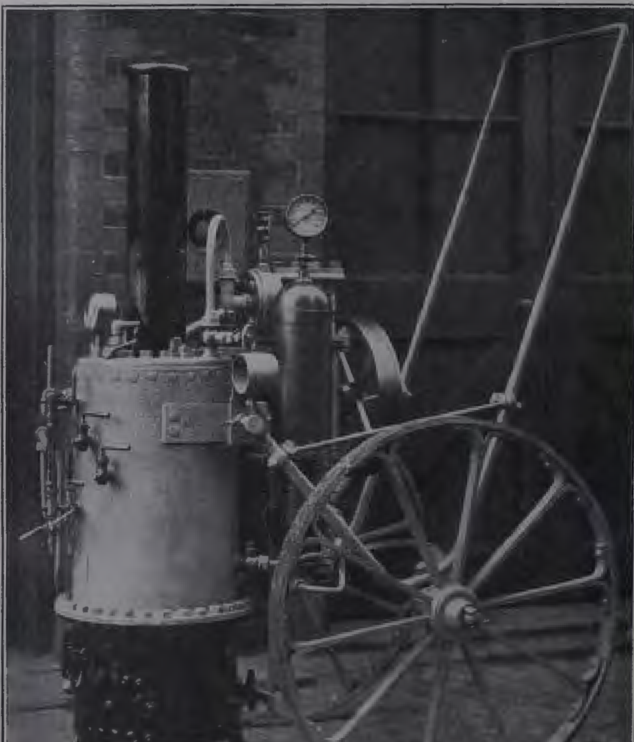


Reproduced by permission of Messrs. Tangyes, Ltd., Birmingham.

Plate 71.

Plate 72.

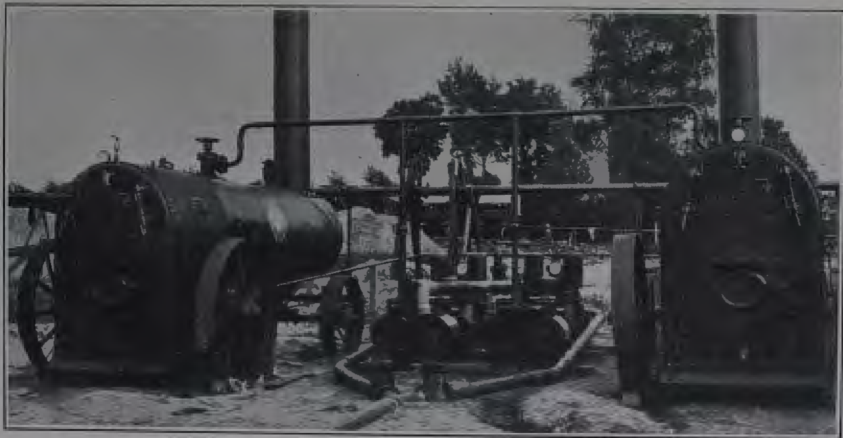
MERRYWEATHER STEAM PUMP.

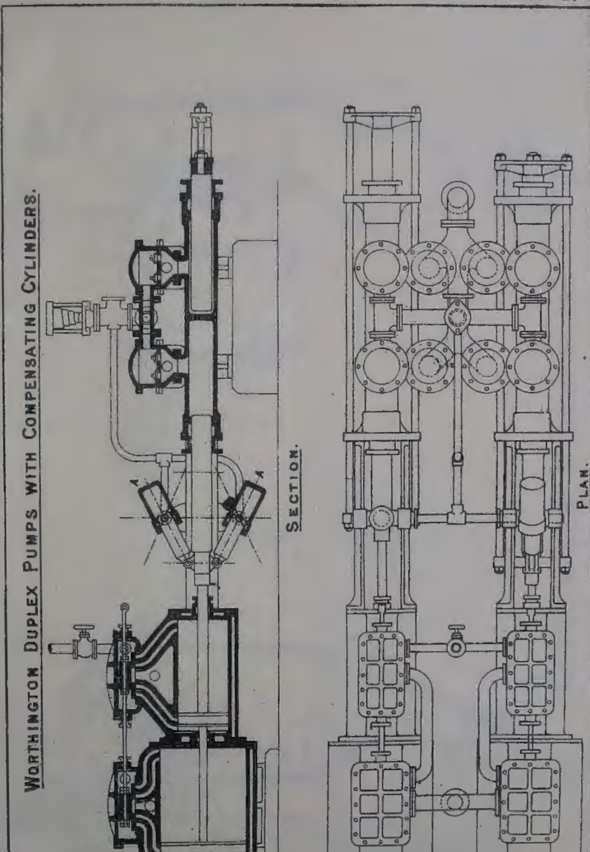


Reproduced by permission of Messrs. Merryweather and Sons, Ltd.

Plate 73.

Two Duplex Steam Pumps and Portable Boilers.

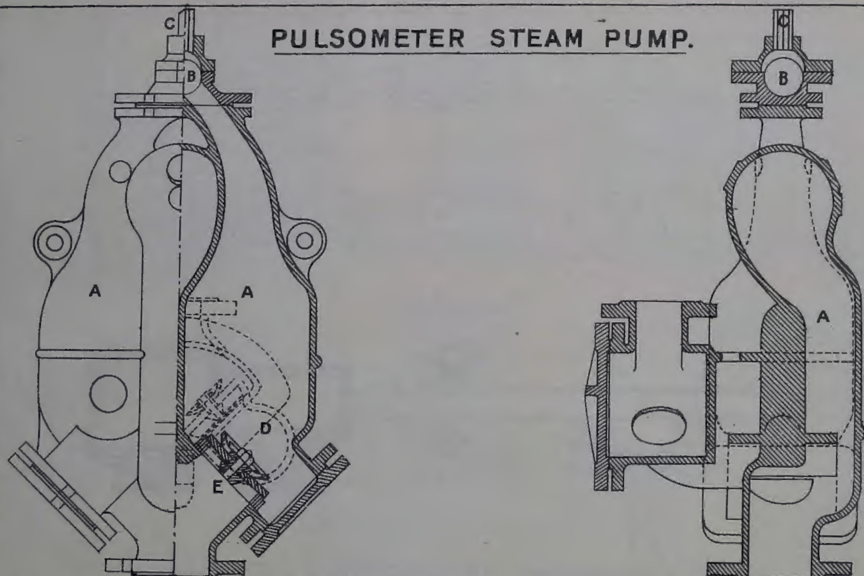




10033.

Malby & Sons, Lith.

PULSOMETER STEAM PUMP.



HALF ELEVATION HALF SECTION

SECTION

10083. 18840/4612/217

Malby & Sons, Lith.

HYDRAULIC RAM.

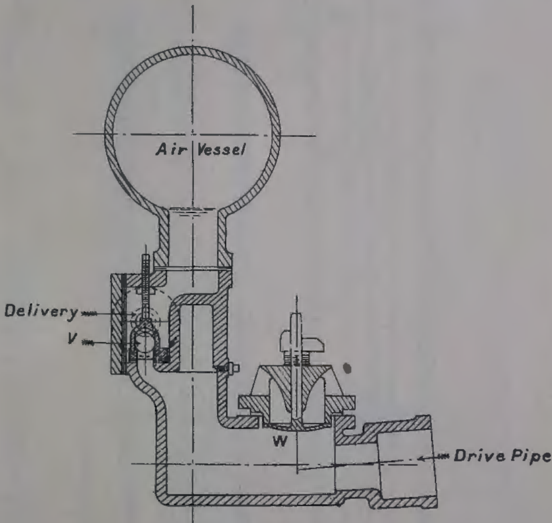


FIG. 1.

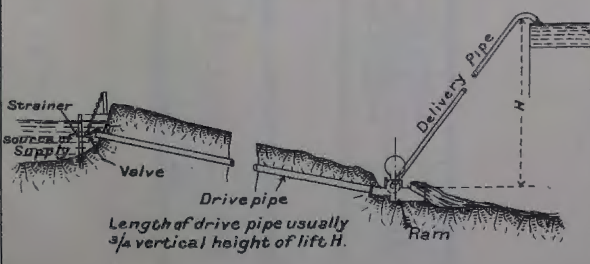
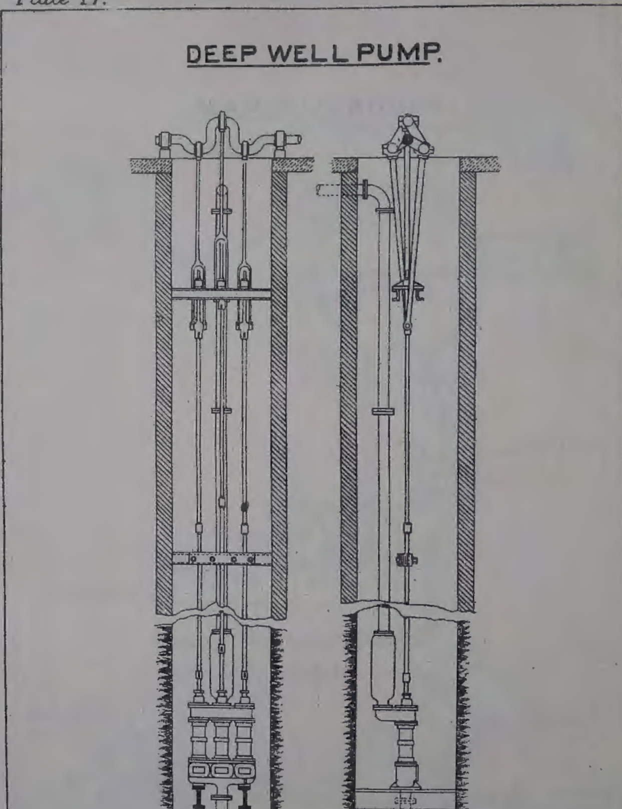


FIG. 2

Plate 77.

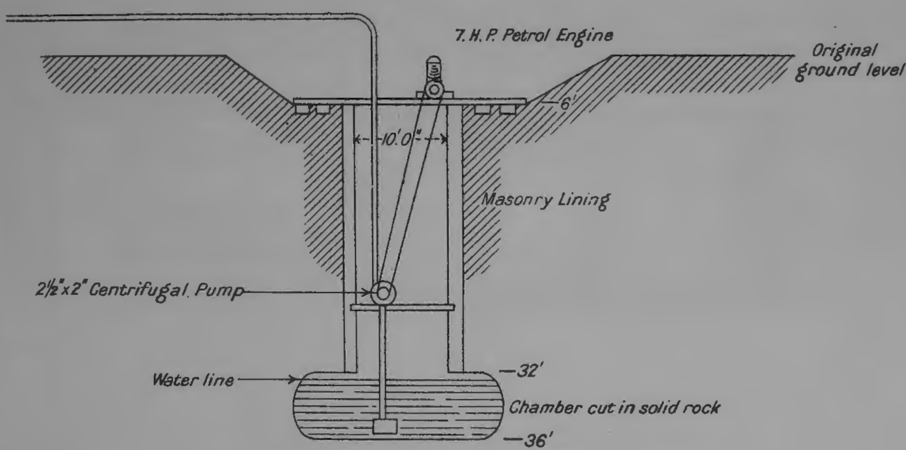


10093 18840 4812/217.

Malby & Sons.Lith.

10083.

METHOD OF INSTALLING CENTRIFUGAL PUMP IN A WELL.



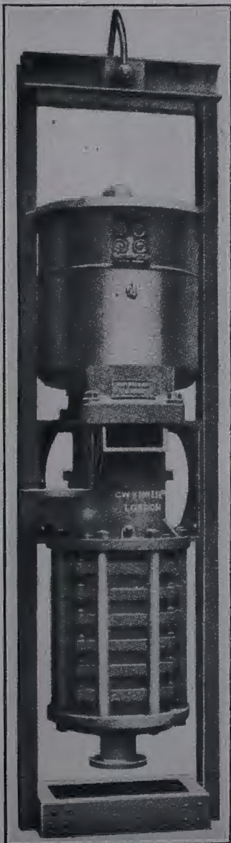
Malby & Sons. Lith

Plate 78.

Plate 79.

SINKING PUMP

(GWYNNES').

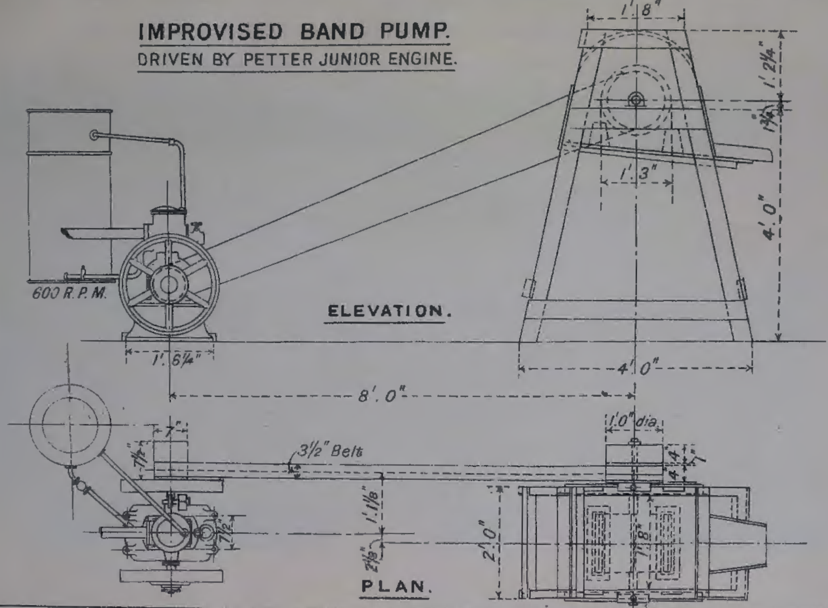


Reproduced by permission of Messrs. Gwynnes', Ltd., Hammersmith.

CAPACITY,
150 GALS. PER MIN.
AND 400 FT. HEAD.
R.P.M., 700.

IMPROVISED BAND PUMP.

DRIVEN BY PETTER JUNIOR ENGINE.



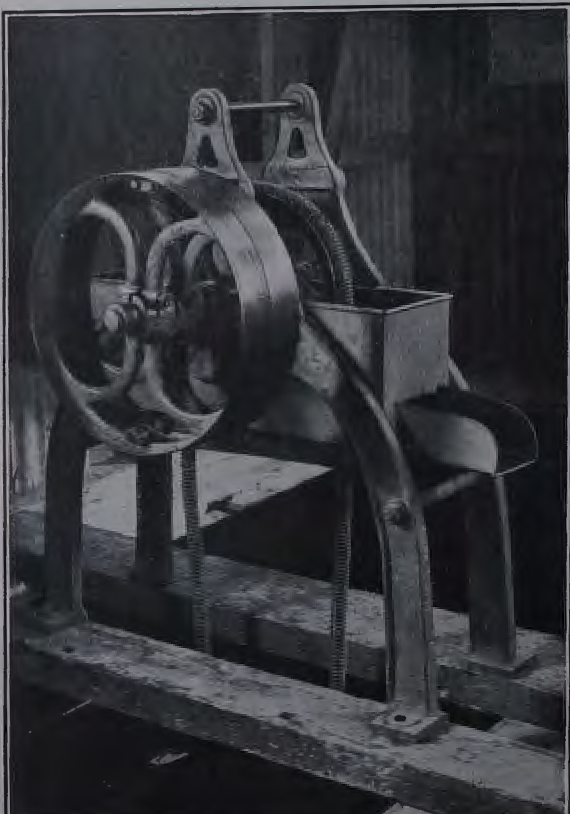
Malby & Sons Lith

Belt Pump mounted on a G.S. Wagon in Position over a Well.

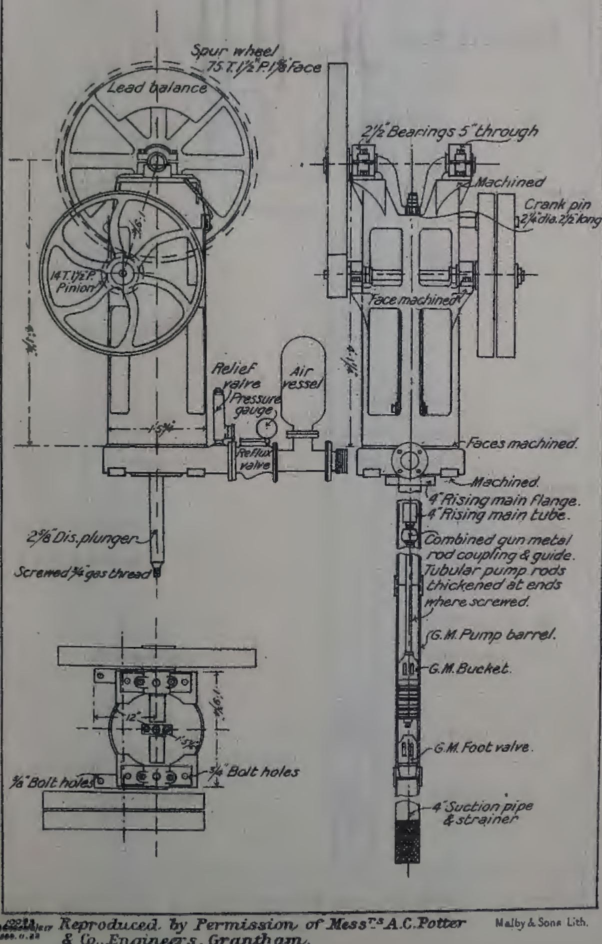
Plate 81.

Plate 82.

CHAINE HELICE.
(Cover removed.)



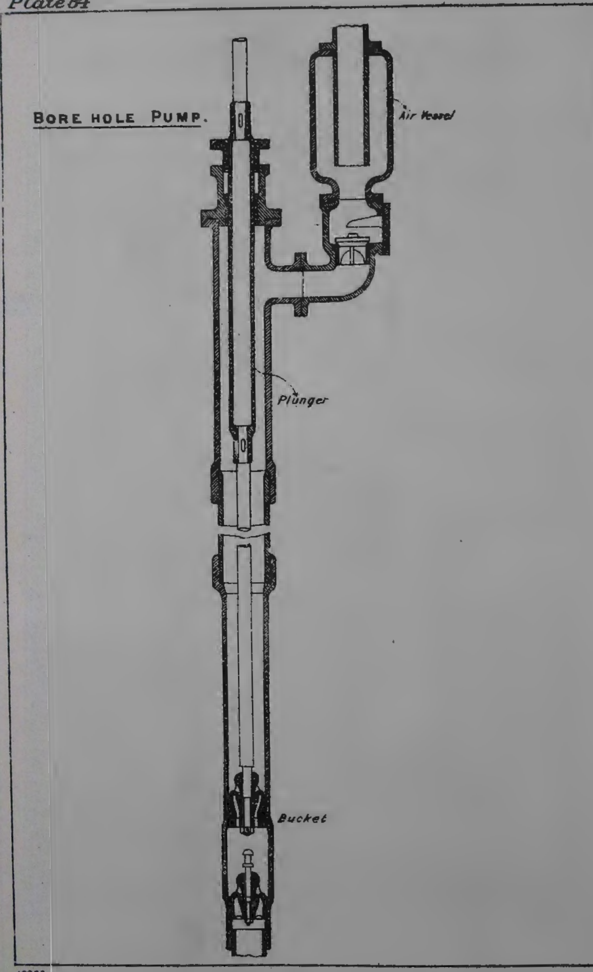
BELT-DRIVEN TUBE WELL PUMP.



Reproduced by Permission of Messrs. A.C. Potter & Co., Engineers, Grantham.

Malby & Sons Lith.

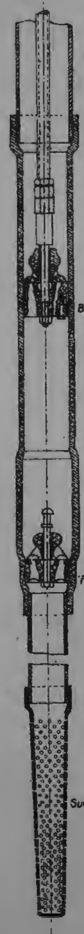
Plate 84

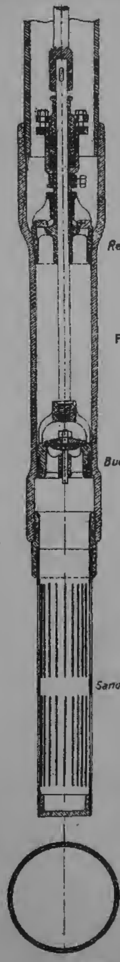


10093

Malby & Sons, Lith.

SUCTION STRAINERS FOR BOREHOLE PUMPS.





10093 16640.4812/217.

Malby & Sons. Lith

5" DIA. ASHFORD TUBE FILTER FOR 6" WELL.

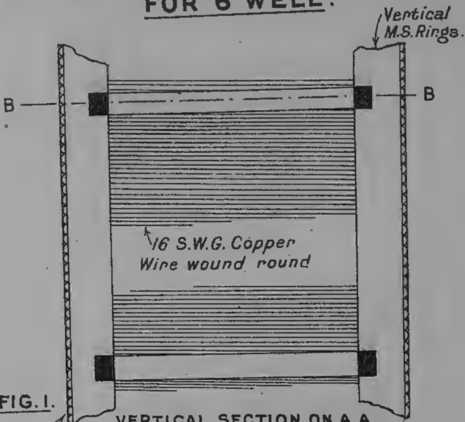


FIG. 1.

VERTICAL SECTION ON A.A.

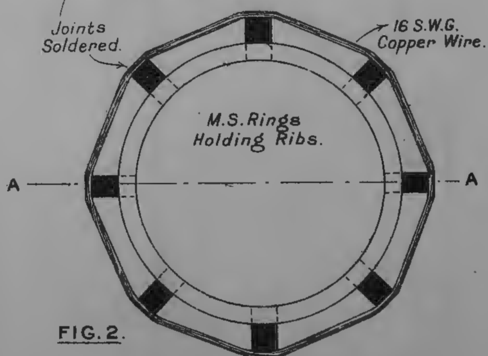
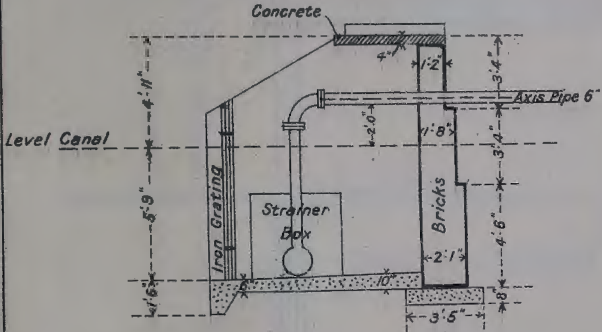


FIG. 2.

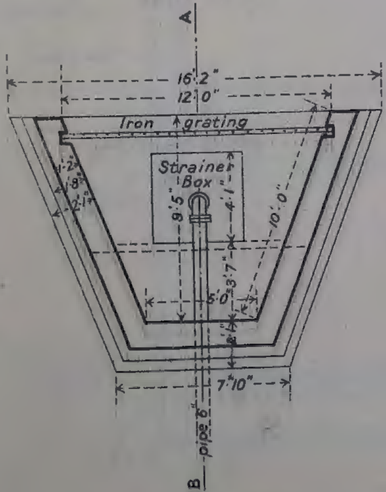
SECTIONAL PLAN ON B.B.

Above Views are approximately ½ size.
This Filter is made in lengths of about 6'.0" with special joint to each.
Water enters through small spaces between wires.

SEMI-PERMANENT STRAINING CHAMBER FOR SUCTION PIPE.



SECTION A.B.



PLAN

10083-18840/1612/2/17

Malby & Sons. Lith.

Plate 88.

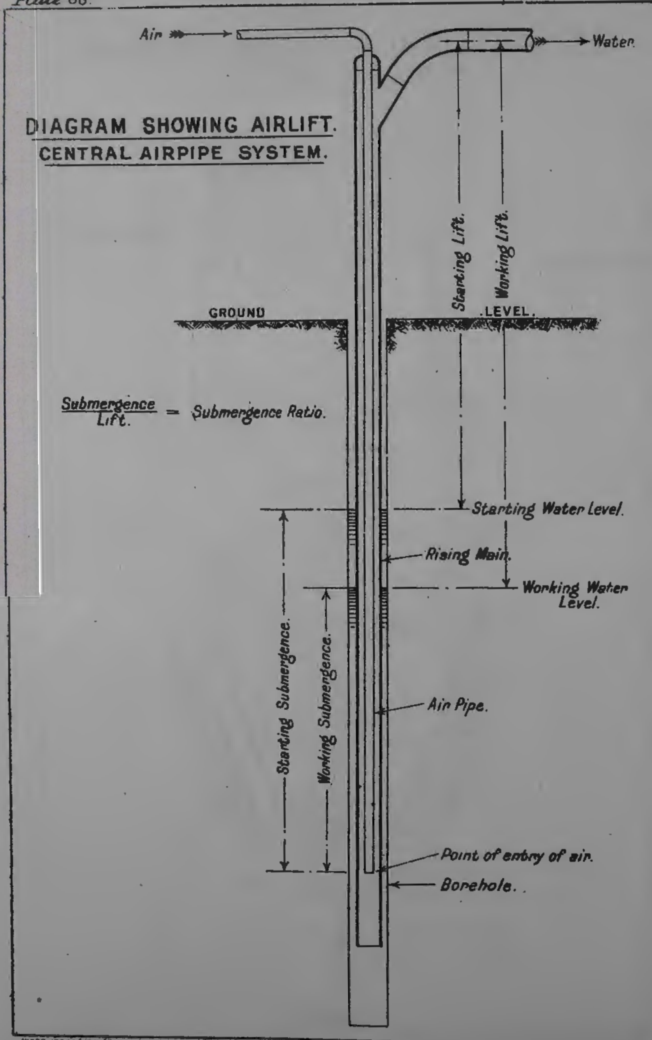
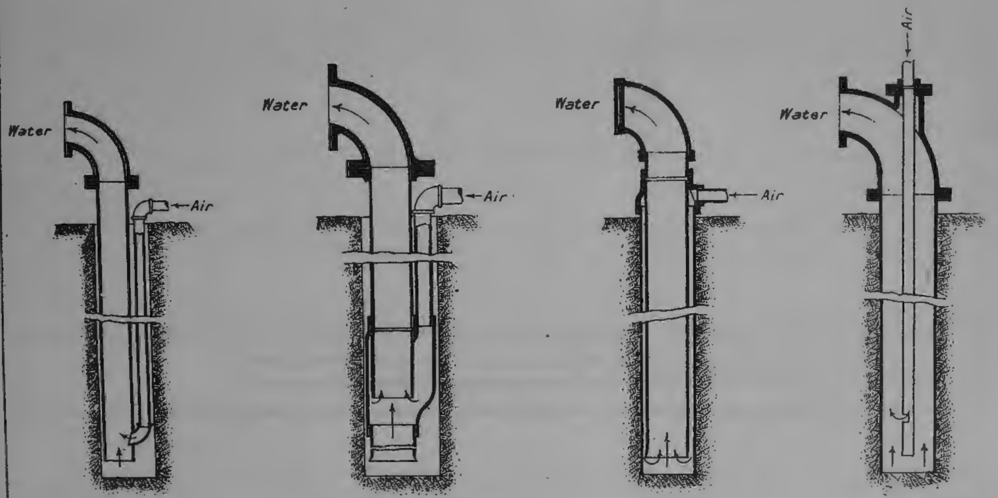


DIAGRAM SHOWING AIRLIFT.
CENTRAL AIRPIPE SYSTEM.
Air
Water.
Starting Lift.
Working Lift.
GROUND
LEVEL.
Submergence / Lift. = Submergence Ratio.
Starting Water Level.
Rising Main.
Working Water Level.
Starting Submergence.
Working Submergence.
Air Pipe.
Point of entry of air.
Borehole.

10093.

METHODS OF PIPING WELLS.



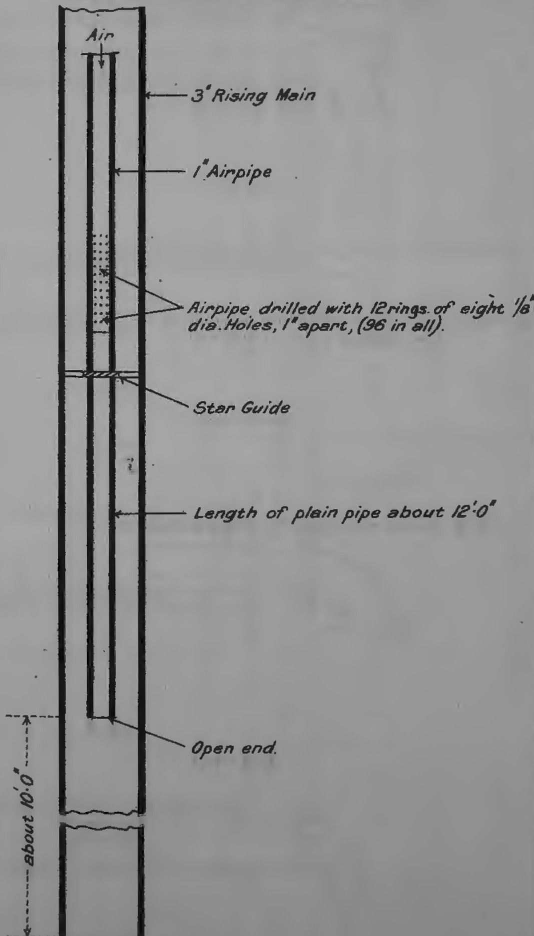
Malby & Sons, Lith.

Plate 89.

From Diagrams contained in Ingersoll-Rand Coy's Catalogue No 76.

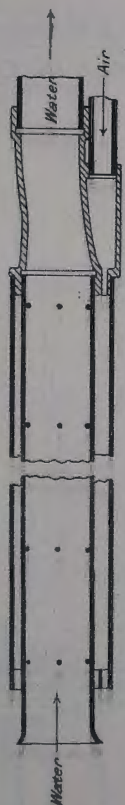
Plate 90.

FOOTPIECE FOR AIRPIPE
CENTRAL AIRPIPE SYSTEM.



10093-18640/4812/217.

THE "HARRIS" AIRLIFT PUMP.



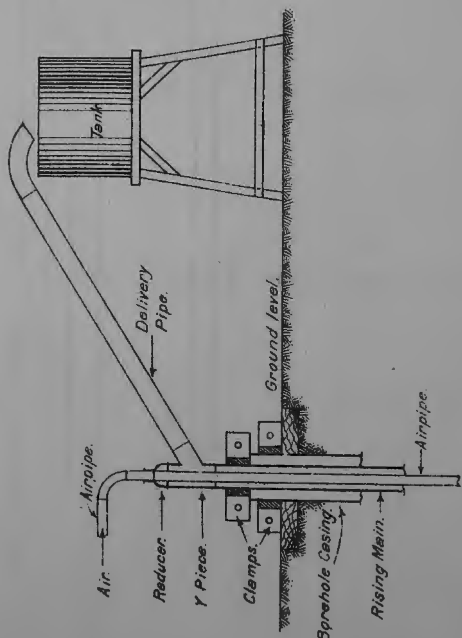
19083-14640/48/2/17

From Diagram contained in Ingersoll-Rand Co's Catalogue No. 76.

Malby & Sons, Lith

Plate 92.

METHOD OF LEADING DISCHARGE INTO AN ELEVATED TANK.



10283.

Malby & Sons, Lith.

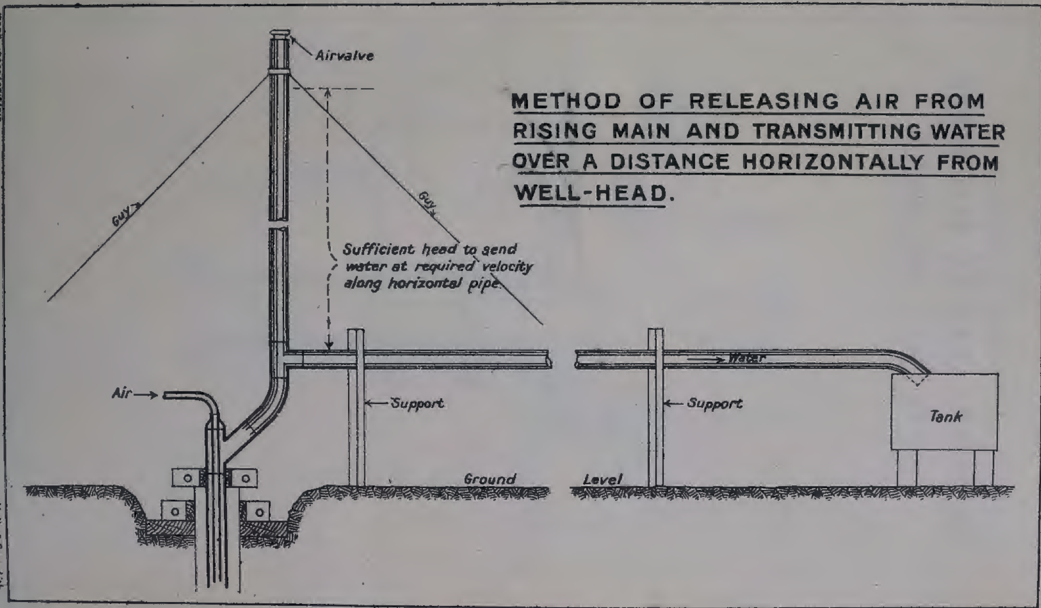
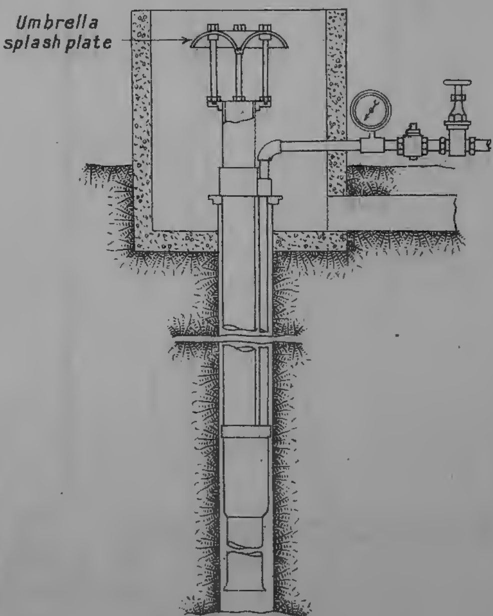


Plate 93.

Malby & Sons, Lith.

Plate 94.

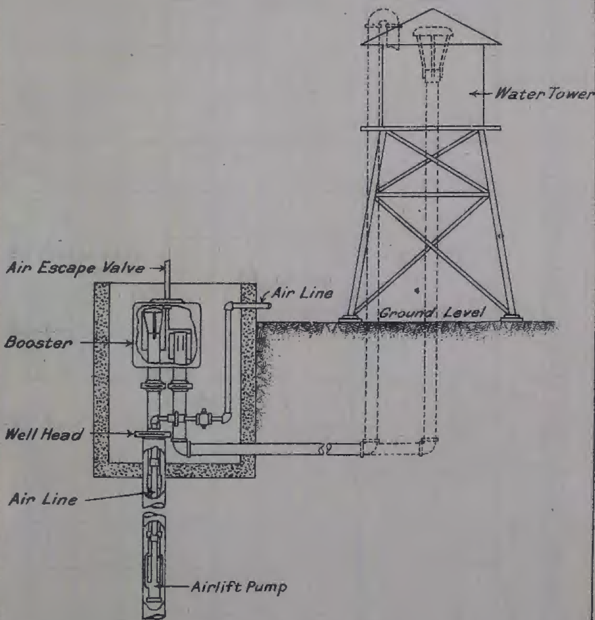
METHOD OF LEADING DISCHARGE AWAY FROM WELL-HEAD.



10093

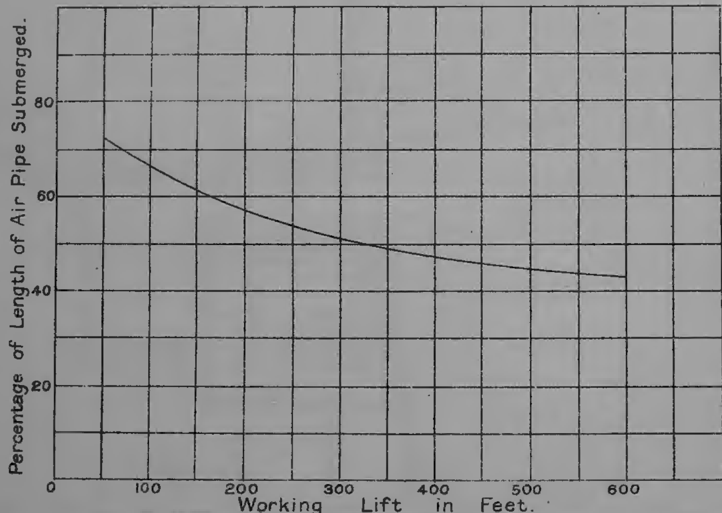
From Diagram contained in Ingersoll-Rand Co's catalogue No 76.

THE "HARRIS" BOOSTER PUMP.



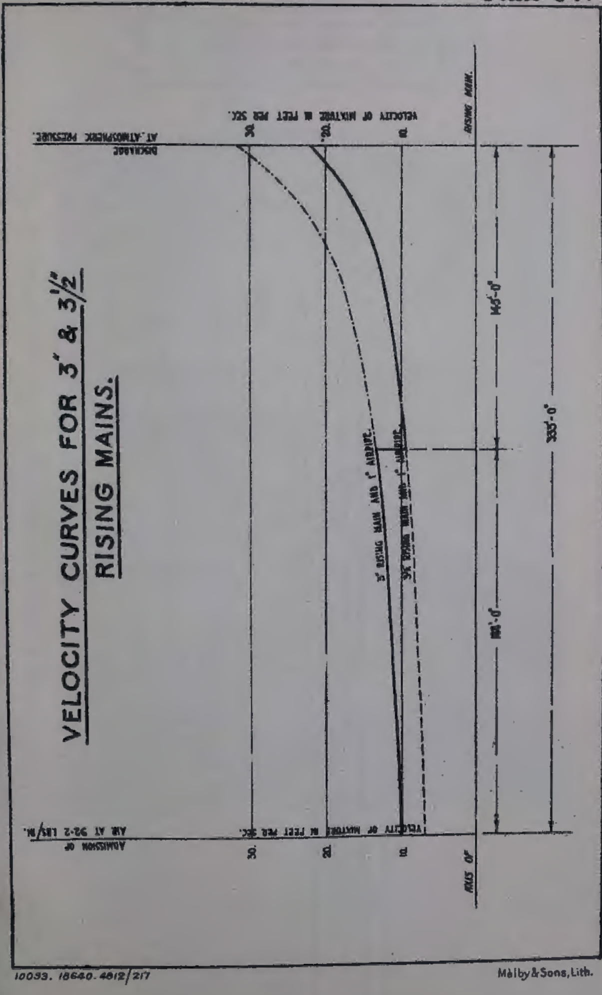
10093-18640/4812/217. *From Diagram contained in Ingersoll-Rand Coy's Catalogue No. 76.* Malby & Sons Lith

CURVE GIVING MOST EFFICIENT SUBMERGENCE FOR VARIOUS LIFTS.



From "Ivens' Pumping by Compressed Air."

Malby & Sons, Lith.



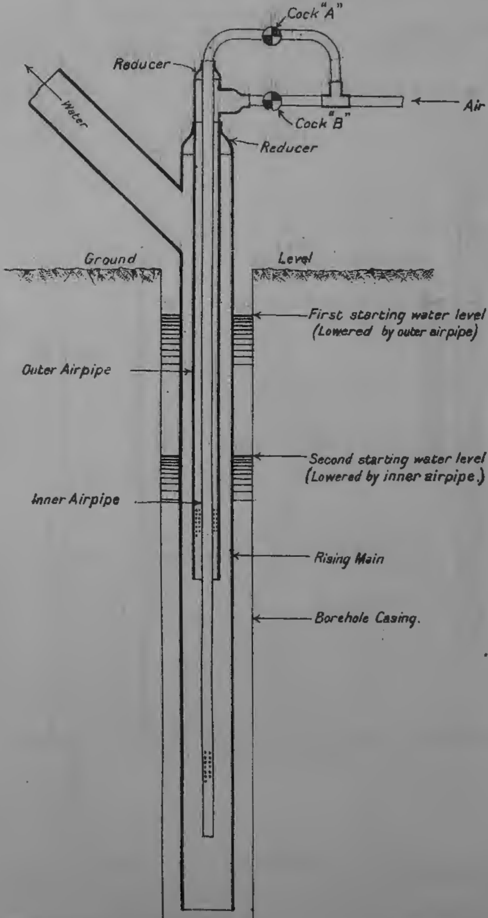
10033. 18640. 4812/217

Malby & Sons, Lith.

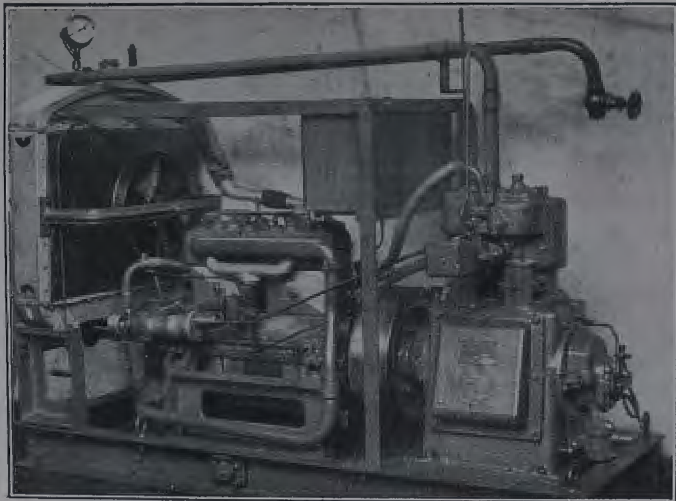
Plate 98.

COMPOUND AIRLIFT.

Cock "A" is kept shut and Cock "B" Open until water level is sufficiently lowered. "A" is then opened and "B" shut, and the airlift operated by means of the Inner Airpipe.



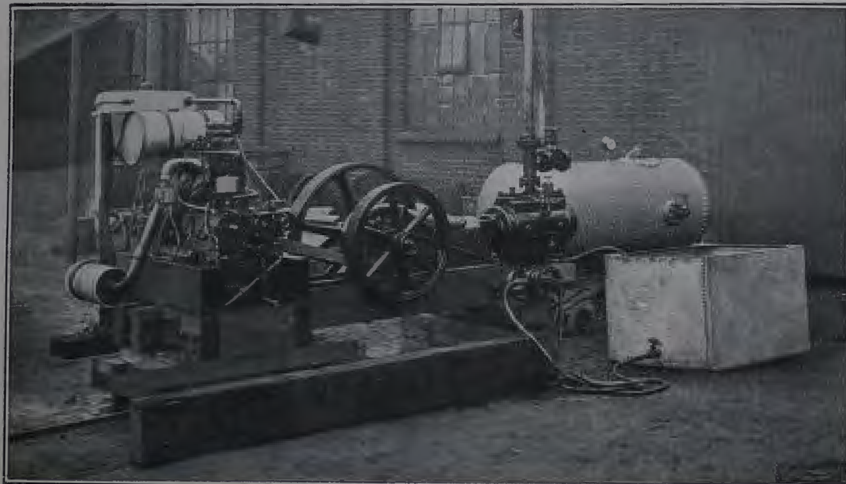
Two-Cyldr. Broom and Wade Compressor with Coventry Simplex Engine.
Duty, 120 cub. ft. of free air per min. at 100 lbs./sq. in.



Reproduced by permission of Messrs. Broom and Wade, High Wycombe.

Plate 99.

Ingersoll-Rand Compressor Driven by Petrol Engine.
Duty, 100 cub. ft. free air per min. at 100 lbs./sq. in.



Reproduced by permission of Ingersoll-Rand Company.

Compressor Lorry Ready for the Road.

Plate 101.

Dam in Ypres Canal.

The above dam was made by replacing damaged lock gates with 9″ × 3″ sheeting.

Plate 103.

SECTIONS OF EARTH DAMS.

FIG. 1.

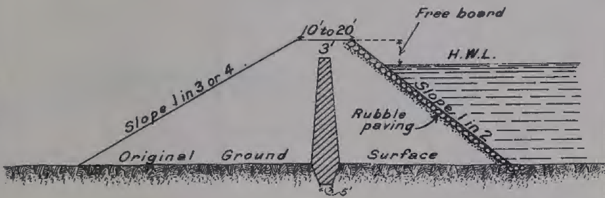


FIG. 2.

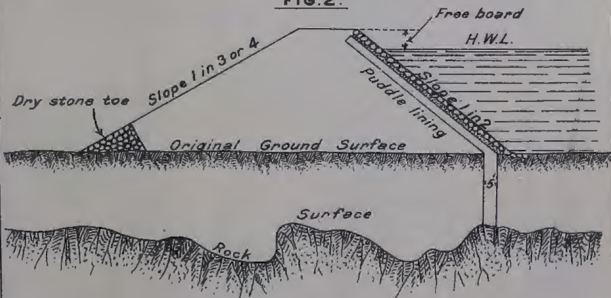
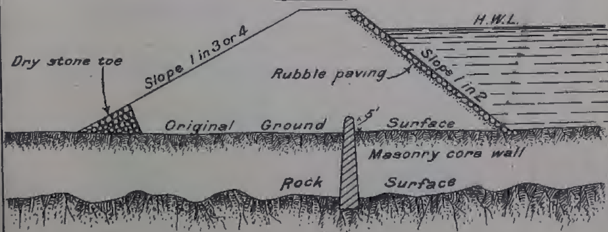


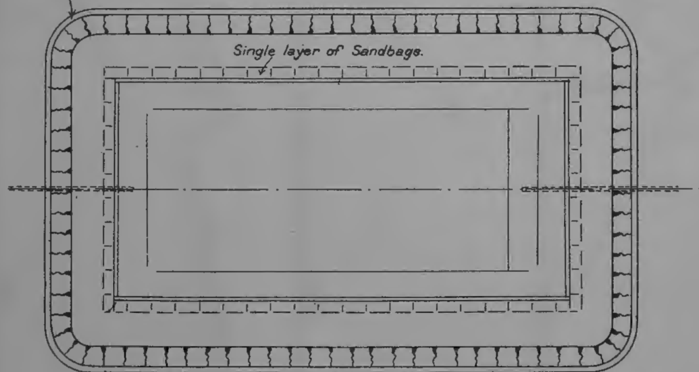
FIG. 3.



10093 18840. 4612/217
Malby & Sons. Lith

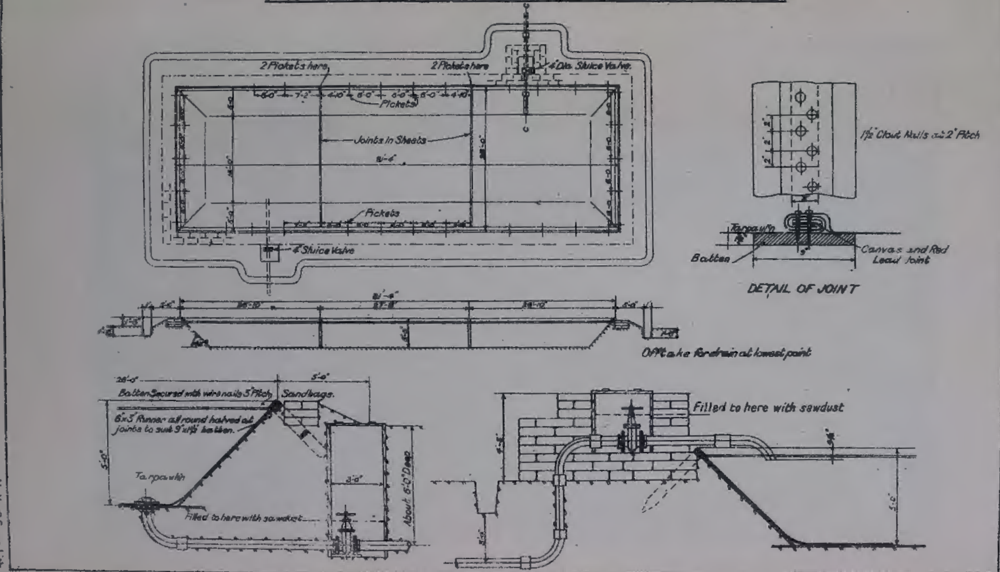
40′ x 20′ SAILCLOTH SHEET STORAGE RESERVOIR.

SECTION.



PLAN.

50,000-GALLON THREE-SHEET RESERVOIR.



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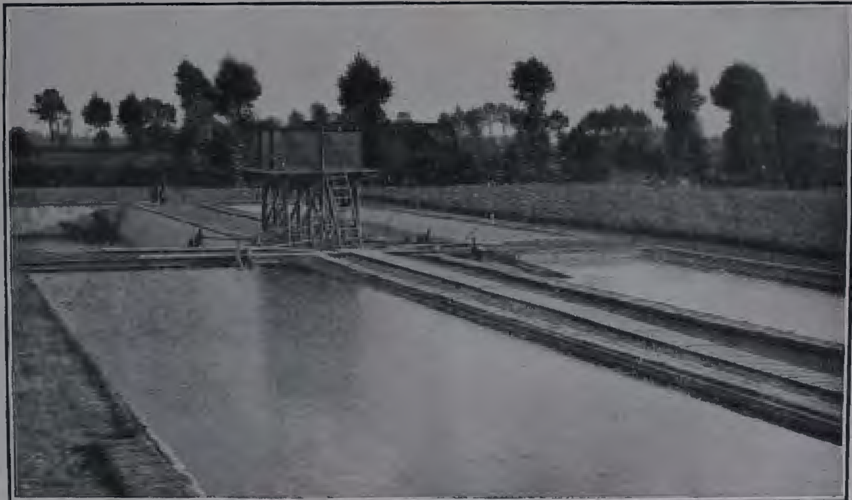
Group of Four 50,000-gallon Dug Reservoirs.



Above reservoirs were constructed according to Pl. **106.**

Plate 107.

FROST-PROOF TANK
FOR MOUNTAIN LOCATIONS.

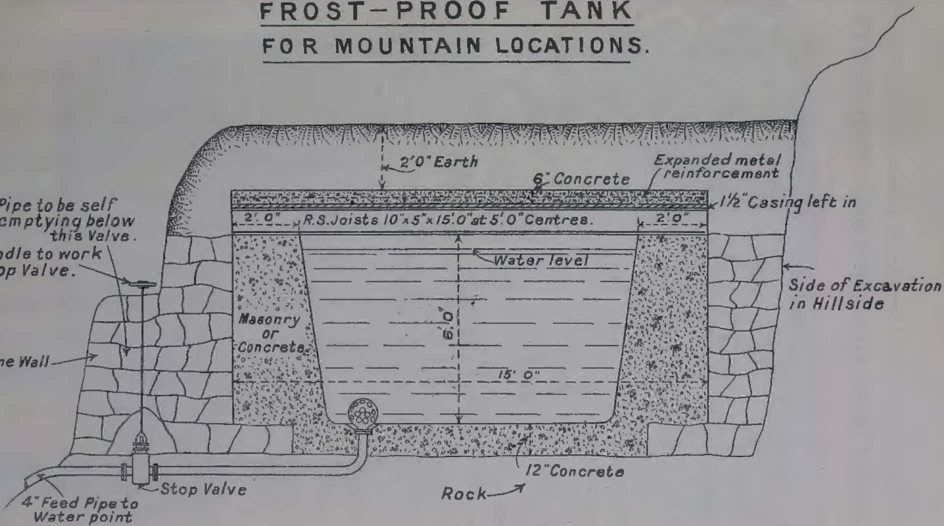


Plate 108.

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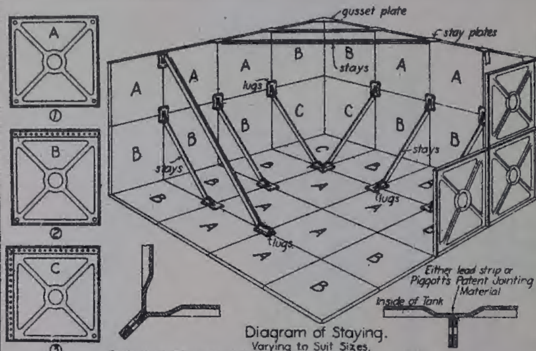
Plate 109.

PIGGOTT'S PATENT PRESSED STEEL TANKS.



Plates. Detail of Corner Joints. Diagram of Staying. Varying to Suit Sizes. Detail of Joint.

Capacities, Sizes and Weights.

Nominal Capacities in Gallons.	Length.	Width.	Depth.	Number of Plates.	Total Weight.	
					I. Tons.	O. Cwts.
800	8-ft.	4-ft.	4-ft	8	1	8
1,200	12	4	4	11	1	16
1,600	16	4	4	14	1	16
1,600	8	8	4	12	1	11
2,400	12	8	4	16	2	2
3,200	8	8	8	20	2	12
3,200	16	8	4	20	2	13
3,600	12	12	4	21	2	15
4,000	20	8	4	24	3	4
4,800	12	8	8	26	3	8
4,800	16	12	4	26	3	9
6,000	20	12	4	31	4	2
6,400	16	8	8	32	4	5
6,400	16	16	4	32	4	5
7,200	12	12	8	33	4	8
7,200	24	12	4	36	4	15
8,000	20	16	4	38	5	0
8,000	20	8	8	38	5	1
9,600	16	12	8	40	5	8
9,600	24	16	4	44	5	18
10,000	20	20	4	45	5	19
12,000	20	12	8	47	6	7
12,000	24	20	4	52	6	17
12,800	16	16	8	48	6	10
14,400	24	12	8	54	7	7
14,400	24	24	4	60	7	18
16,000	20	16	8	56	7	12
16,800	28	24	4	68	8	19
19,200	24	16	8	64	8	15
19,200	32	24	4	76	10	0
20,000	20	20	8	65	8	17
24,000	24	20	8	74	10	2
28,800	24	24	8	84	11	9
33,600	28	24	8	94	12	16
38,400	32	24	8	104	14	4

100.93

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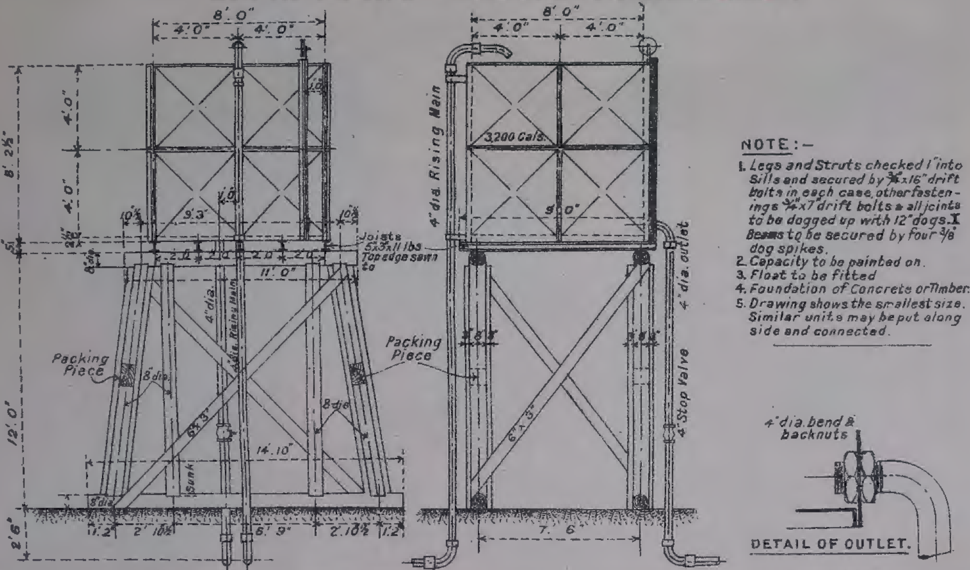
ELEVATED TANK (PRESSED STEEL) ON STEEL TOWER

PRESSED STEEL TANK ON LOW TIMBER STAGING.



NOTE:—

1. Legs and Struts checked 1" into Sills and secured by ¾"x16" drift bolts in each case, other fastenings ¾"x7" drift bolts & all joints to be dogged up with 12" dogs. I Beams to be secured by four ⅜" dog spikes.
2. Capacity to be painted on.
3. Float to be fitted
4. Foundation of Concrete or Timber.
5. Drawing shows the smallest size. Similar units may be put along side and connected.

Plate III.

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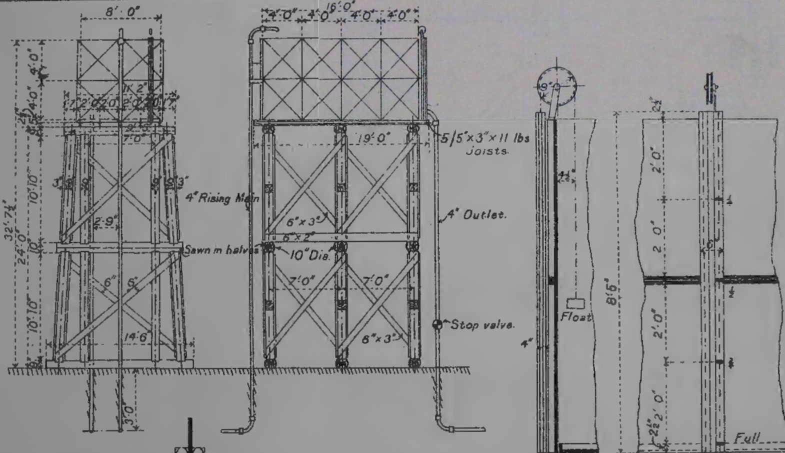
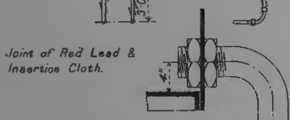
PRESSED STEEL TANK ON HIGH TIMBER STAGING.





Detail of Outlet.

NOTE :– 1. Legs & studs checked 1" into sills & secured by ¾"×16" drift bolts in each case. Other fastenings ¾"×7" drift bolts. Joints dogged with 12" dogs I beams secured by four ⅜ dog spikes.
2. Capacity to be painted on.
3. Float to be fitted.
4. Foundations of rough concrete.
5. Similar units may be put alongside & connected up.
All timber 9" dia. & 6"×3" unless shown otherwise.

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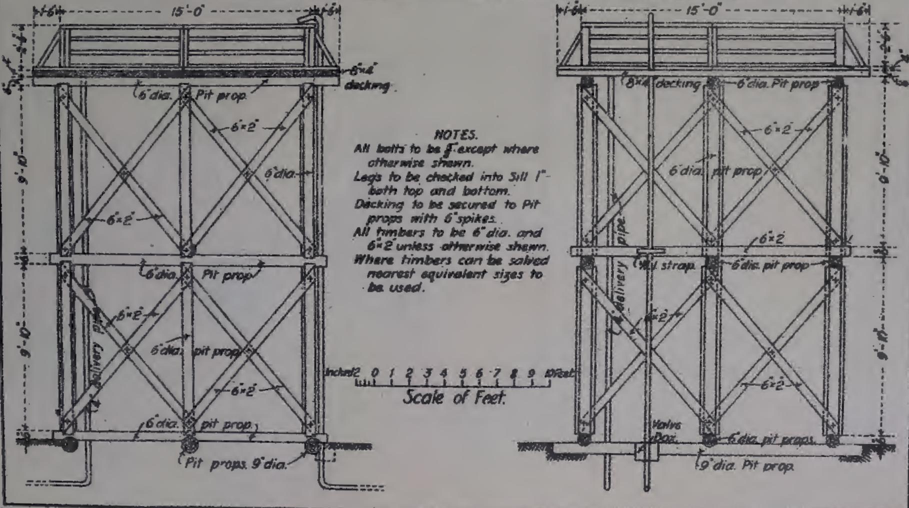
10093

FRAMED CANVAS TANK ON WOODEN TOWER.

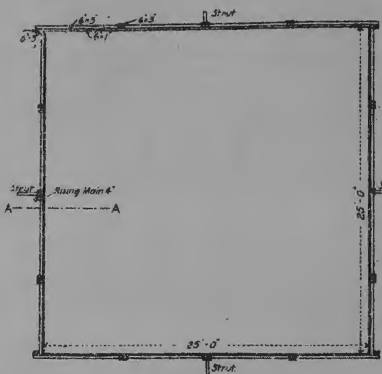


Malby & Sons Lith.

Plate 113.

Plate 114.

GROUND LEVEL FRAMED 8,000-GALLON CANVAS TANK.

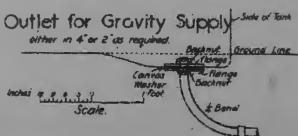


Plan.

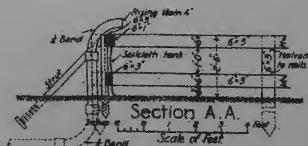
Scale of Feet

Outlet for Gravity Supply

either in 4" or 2" as required.



Scale.



Section A.A.

Methods of framing for 30'-0"x 30'-0" sail cloth covers supplied by the R.A.O.D. to form 8,000 gallon tanks to serve as Reservoirs.

A rough canvas ridge roof should be provided.

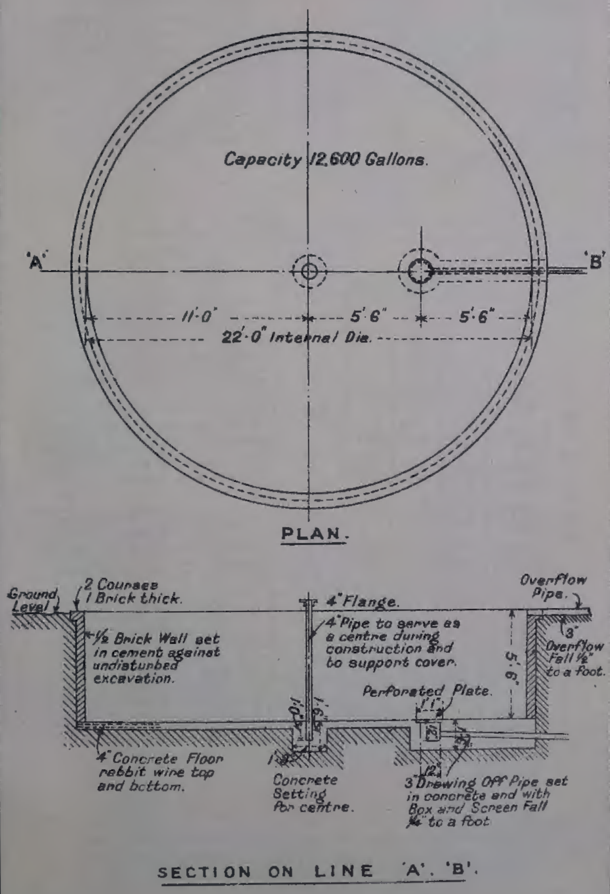
Commence erection by levelling tops of corner posts to give tank an average depth of 2'-6". Moderately sloping grourd with even surface need not be levelled to take tank floor.

Green canvas covers should be tarred before use.

10083.18640 4812/817

Malby & Sons Lith.

BRICK TANK.

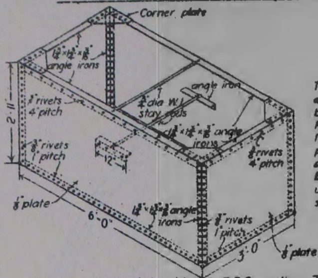


16688. 16640/46/5/217.

Malby & Sons, Lith

Plate 116.

GALVANIZED MILD STEEL CISTERNS.



Isometric View. 300-gallon Tank.

General Specification

The cisterns to be of mild steel, properly squared and flattened; each side, end and bottom to be in one piece, strongly and neatly riveted to flanged plates at angles with $\frac{3}{8}$" rivets, 1" pitch, and with angle iron and corner plates at top, riveted with $\frac{3}{8}$" rivets, 4" pitch, and to be galvanized in one piece after being riveted up. Pure spelter only to be used, and all galvanizing to be free from stains, blisters, and defects of any kind.

Description.					Weight exclusive of galvanizing	Specification
Gallons.		Length.	Width.	Depth.	lbs.	
150	deep	3'-7"	2'-5"	3'-1"	228	To be of 12 gauge plate with $1\frac{1}{2}" \times 1\frac{1}{2}" \times \frac{1}{4}"$ angle irons at top, $\frac{1}{8}"$ corner plates and two $\frac{3}{4}"$ diameter galvanized wrought iron stay rods, one riveted to angle iron framing at top, and the other riveted to angle iron, 12" long, riveted to sides of cistern. Nº 12 gauge = ·109 inches.
	shallow	3'-7"	2'-10"	2'-8"		
200	deep	4'-0"	2'-8"	3'-5"	270	
	shallow	4'-0"	3'-0"	2'-11"		
250	deep	5'-0"	2'-8"	3'-3"	380	To be of $\frac{1}{8}"$ plate with $1\frac{3}{4}" \times 1\frac{3}{4}" \times \frac{5}{16}"$ angle irons at top, and two $\frac{3}{4}"$ diameter galvanized wrought iron stay rods, one riveted to angle iron framing at top, and the other riveted to angle iron 12" long, riveted to sides of cistern.
	shallow	5'-0"	3'-0"	2'-11"		
300	deep	6'-0"	2'-8"	3'-5"	434	
	shallow	6'-0"	3'-0"	2'-11"		
350	deep	6'-6"	2'-8"	3'-6"	482	
	shallow	6'-6"	3'-3"	2'-11"		
400	deep	4'-0"	4'-0"	4'-5"	508	To be of $\frac{3}{16}"$ plate with $1\frac{3}{4}" \times 1\frac{3}{4}" \times \frac{5}{16}"$ angle irons at top, and three $\frac{3}{4}"$ diameter galvanized wrought iron stay rods, one riveted to angle iron framing at top and two in the body of the cistern.
	shallow	7'-3"	3'-6"	2'-11"		
500	deep	5'-0"	4'-0"	4'-3"	583	
	shallow	8'-0"	3'-9"	2'-11"		
600	deep	6'-0"	4'-0"	4'-3"	821	To be of 8 gauge plate, with $2" \times 2" \times \frac{1}{4}"$ angle irons at top, and three $\frac{3}{4}"$ diameter galvanized wrought iron stay rods, one riveted to angle iron framing at top and two in the body of the cistern. Nº 8 gauge = ·165 inches.
	shallow	8'-0"	4'-0"	3'-3"		
700	deep	7'-0"	4'-0"	4'-3"	908	
	shallow	8'-0"	4'-0"	3'-9"		
800	deep	8'-0"	4'-0"	4'-3"	1,152	To be of $\frac{3}{16}"$ plate, with $2" \times 2" \times \frac{1}{4}"$ angle irons at top, and four $\frac{3}{4}"$ diameter galvanized wrought iron stay rods, one riveted to angle iron framing at top and three in the body of the cistern.
	shallow	8'-0"	4'-6"	3'-10"		
1,000	deep	10'-0"	4'-0"	4'-3"	1,363	
	shallow	9'-6"	5'-0"	3'-10"		

NOTE :- All tanks should have (1). A 2" Screwed connection (blanked off) in Bottom. (2). A 1" Screwed connection (blanked off) 2" above bottom of tank in each side.

Malby & Sons Lith

DIRECT DISTRIBUTION SYSTEM - 1.

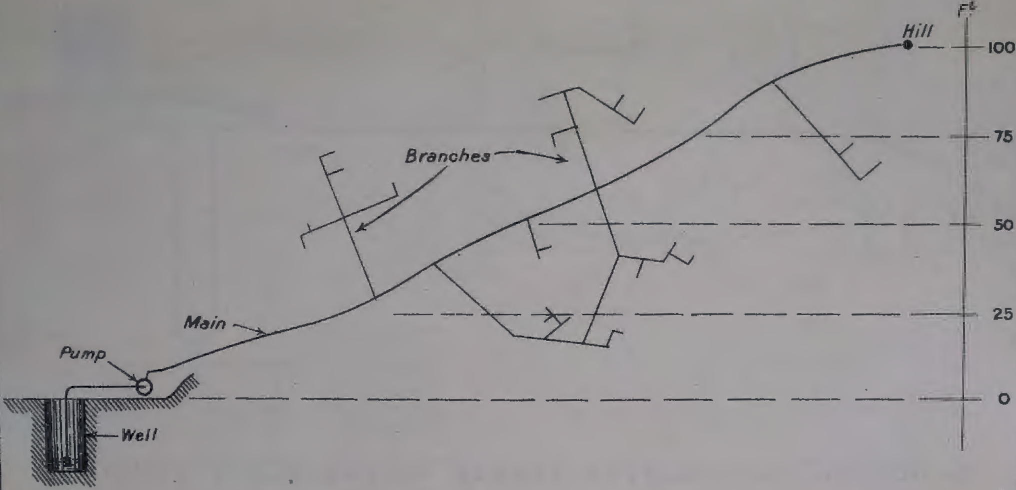


Plate 117.

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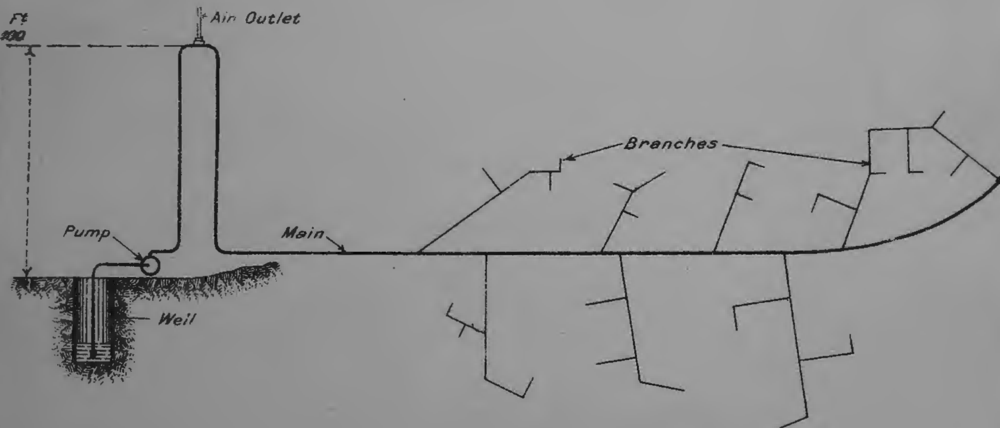
Plate 118.

DIRECT DISTRIBUTION SYSTEM—ALTERNATIVE METHOD—2.



10093. 18646/4612/217.

Malby & Sons.

INDIRECT DISTRIBUTION SYSTEM-3.

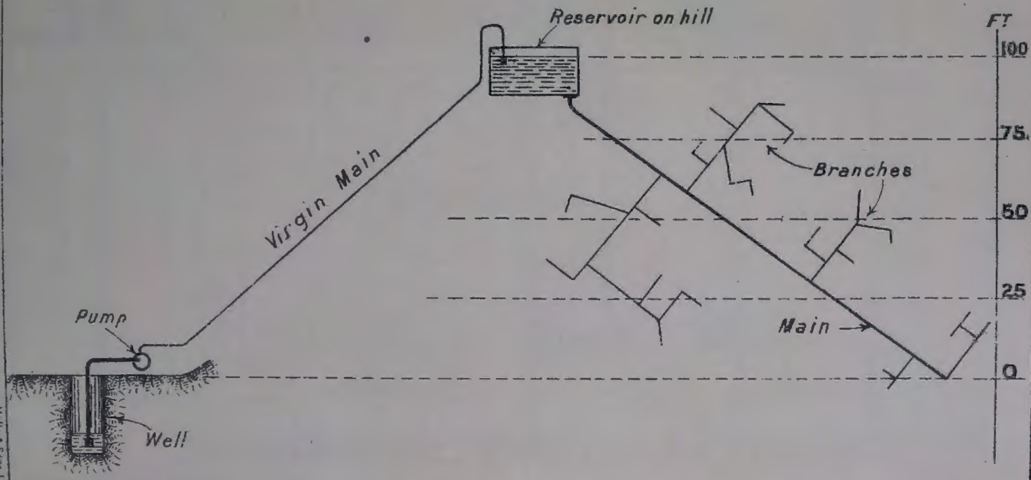


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Plate 119.

DIRECT-INDIRECT DISTRIBUTION SYSTEM-4.

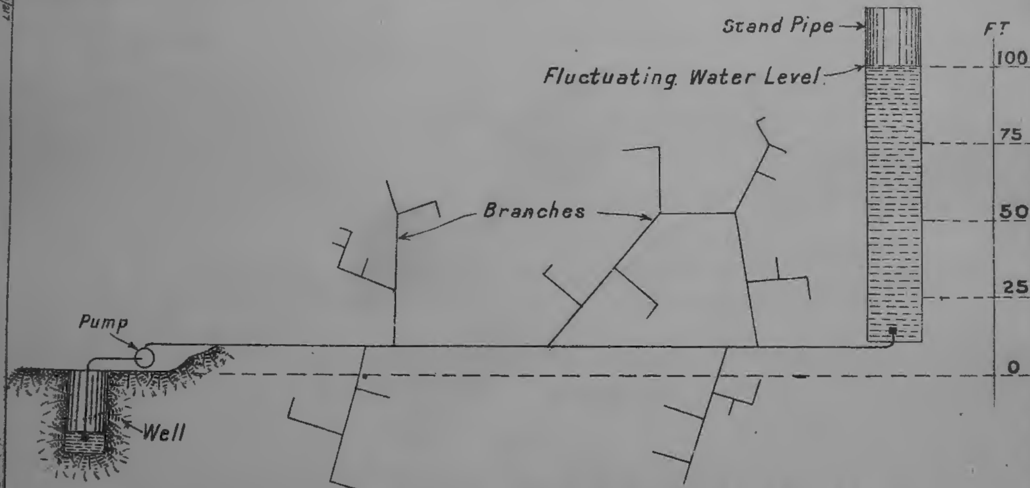
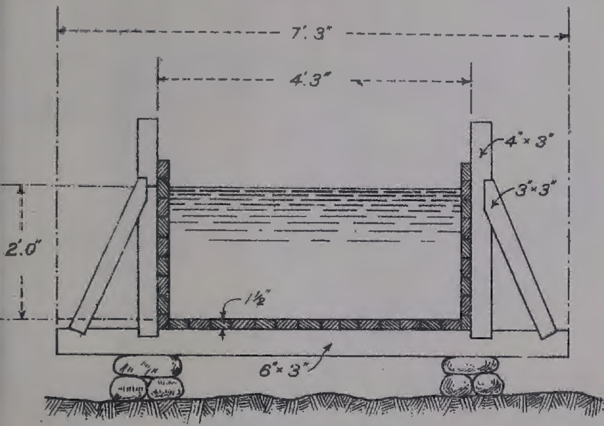
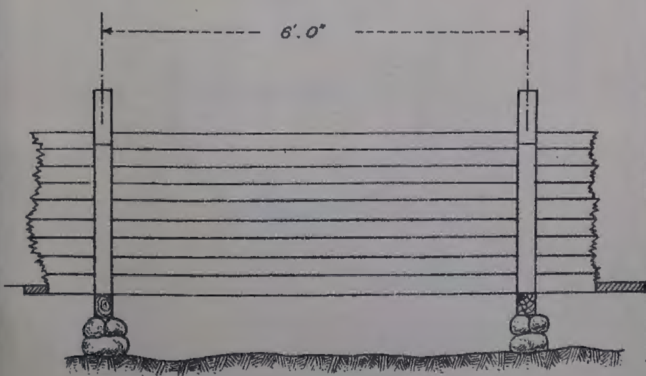


Plate 120.

BOX FLUME—RECTANGULAR SECTION.



SECTION.



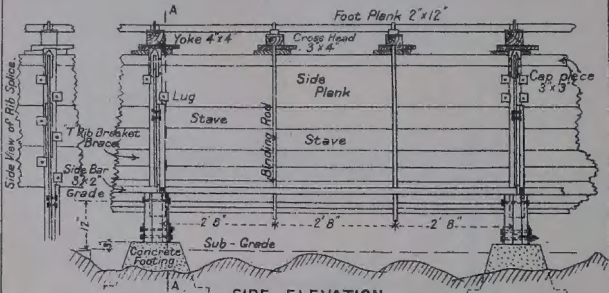
SIDE ELEVATION.

Reproduced from Folwell's "Water Supply, 1912"

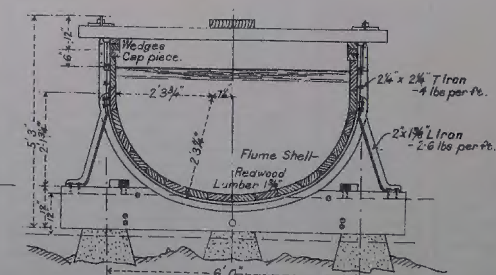
Malby & Sons, Lith.

Plate 122.

BOX FLUME - SEMI CIRCULAR SECTION.



SIDE ELEVATION.



SECTION AA.

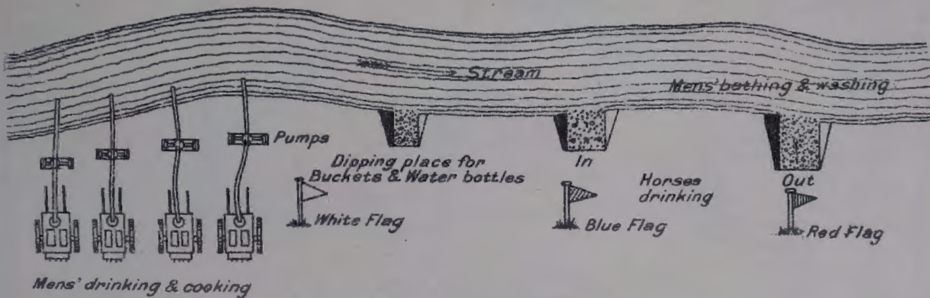
10033-18640-4812/817

Reproduced from Folwell's "Water Supply, 1912".

Malby & Sons Lith

10083-18640/4812/217.

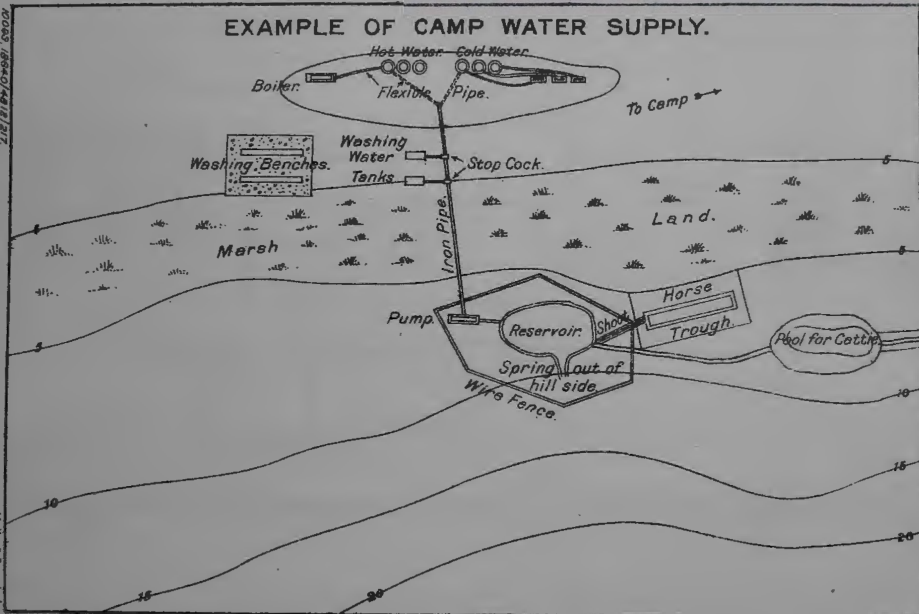
WATER SUPPLY—TEMPORARY CAMP FOR ONE OR TWO NIGHTS.



Mens' drinking and cooking. Pump into water carts and chlorinate.

Malby & Sons. Lith.

Plate 124.



100as. 18640/48/12/217.
Malby & Sons. Lith.

IMPROVISED CAMP WATER SUPPLY ACCESSORIES.

Clarifying Filters.

FIG. I.

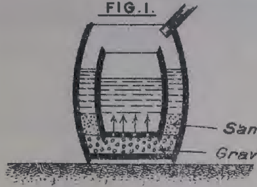


FIG. 2.

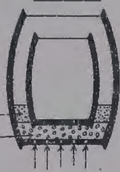
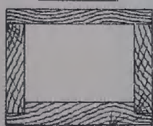
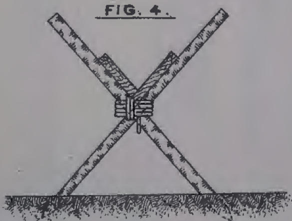


FIG. 3.



Wooden Shoots.

FIG. 4.



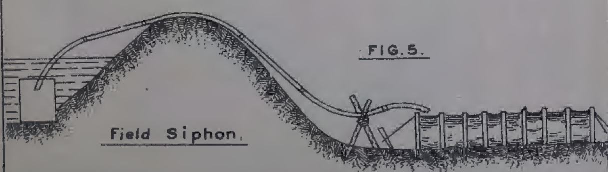


FIG. 5.

Field Siphon.

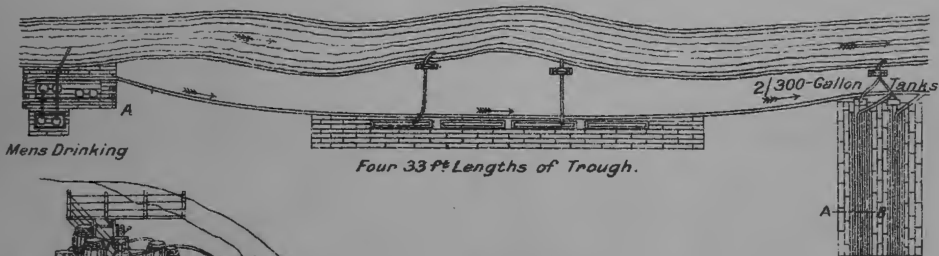
10098 10640 1912/217.

Malby & Sons. Lith.

WATER SUPPLY SCHEME FOR A STANDING CAMP.

Storage ÷ Barrels, Canvas Troughs, Iron Tanks.

FIG. 1.



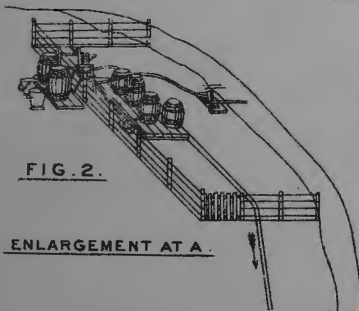
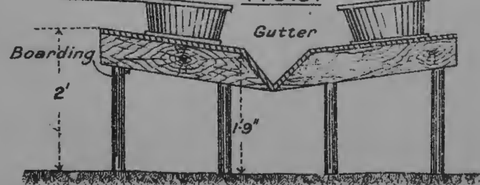


FIG. 2.

ENLARGEMENT AT A.

SECTION ON A—B.

FIG. 3.



10093-16640/4812/e17.

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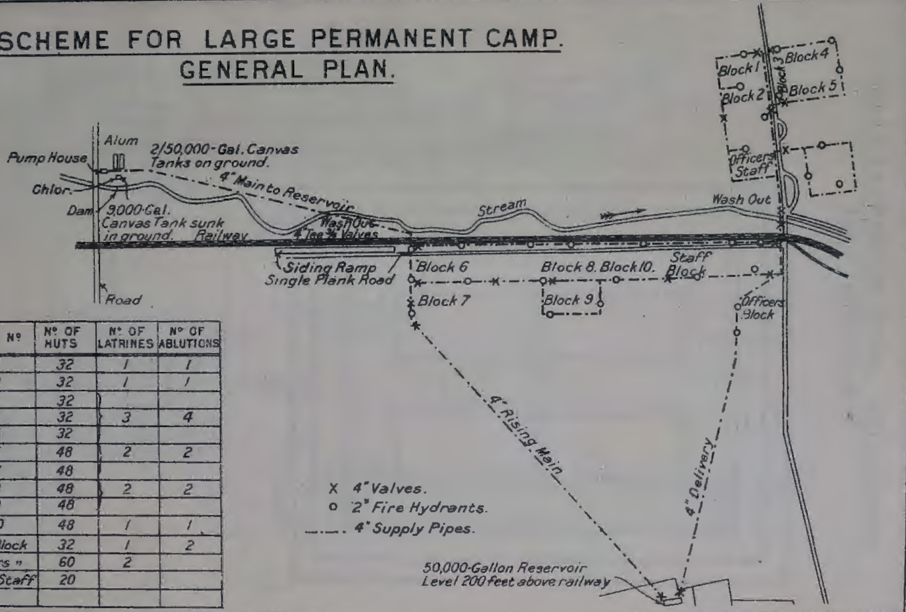
SCHEME FOR LARGE PERMANENT CAMP.
GENERAL PLAN.



BLOCK Nº	Nº OF HUTS	Nº OF LATRINES	Nº OF ABLUTIONS
1	32	1	1
2	32	1	1
3	32		
4	32	3	4
5	32		
6	48	2	2
7	48		
8	48	2	2
9	48		
10	48	1	1
Staff Block	32	1	2
Officers "	60	2	
" Staff	20		

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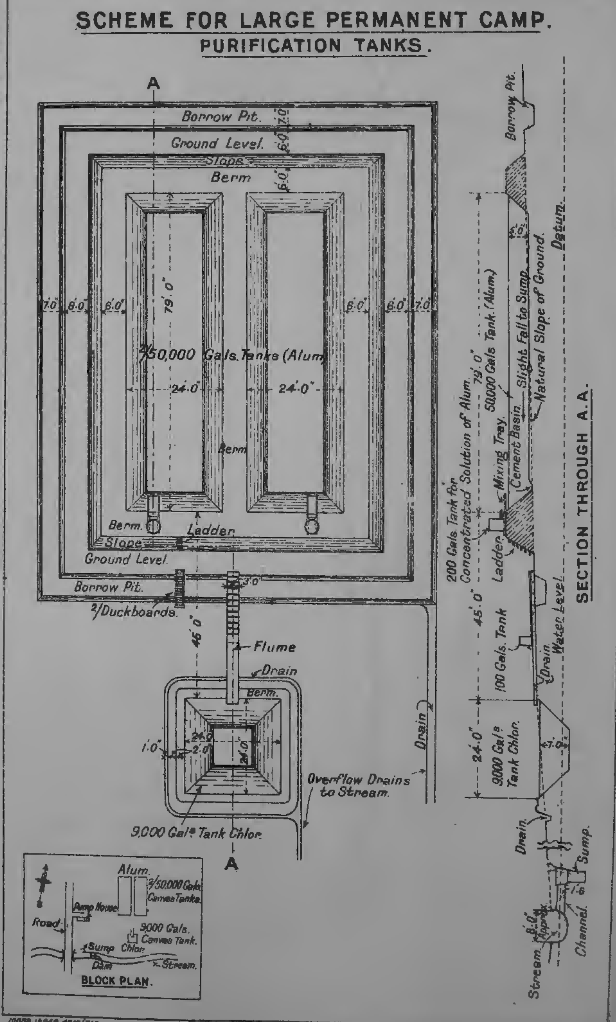
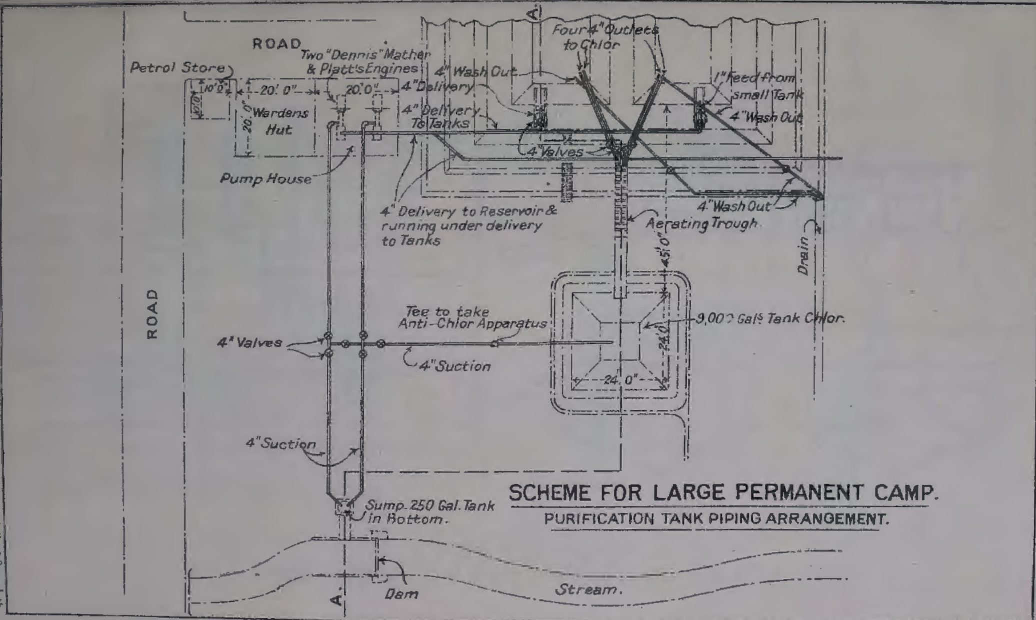
Plate 127.



Malby & Sons Lith



SCHEME FOR LARGE PERMANENT CAMP.

PURIFICATION TANK PIPING ARRANGEMENT.

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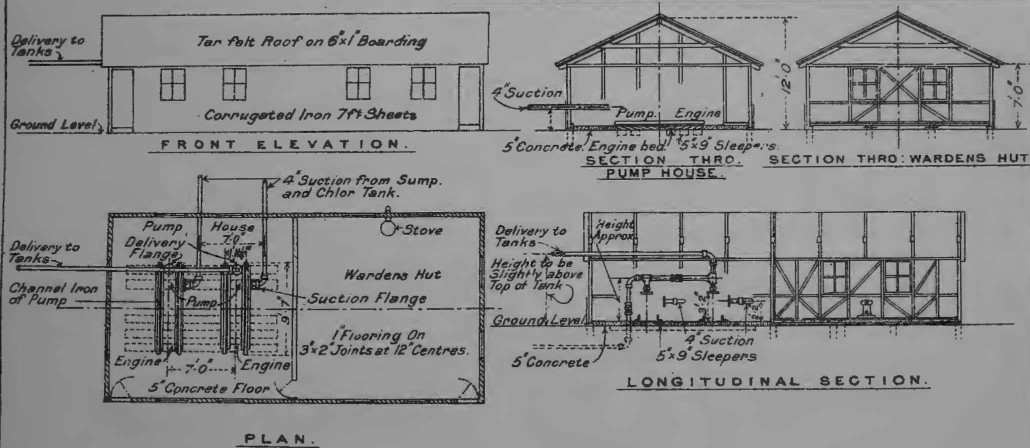
Plate 129.

Plate 130.

SCHEME FOR LARGE PERMANENT CAMP.
PUMP HOUSE.



Malby & Sons Lith.

SCHEME FOR LARGE PERMANENT CAMP.

WATER SUPPLY DETAILS.

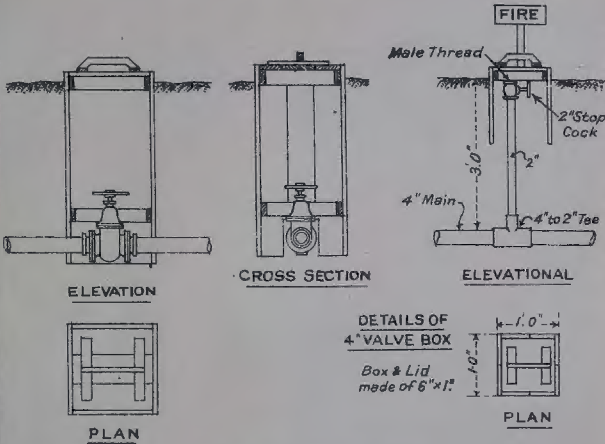


FIG. I. VALVE BOXES.

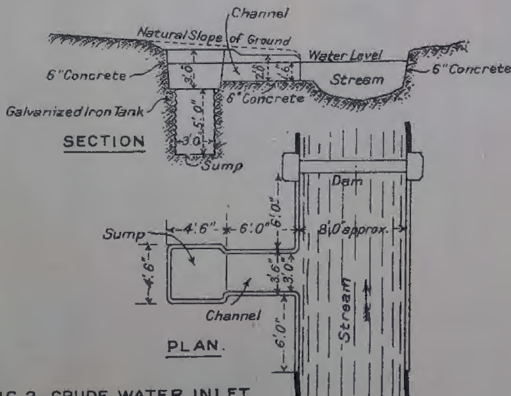


FIG. 2. CRUDE WATER INLET

10093. 18640. 4812/217.

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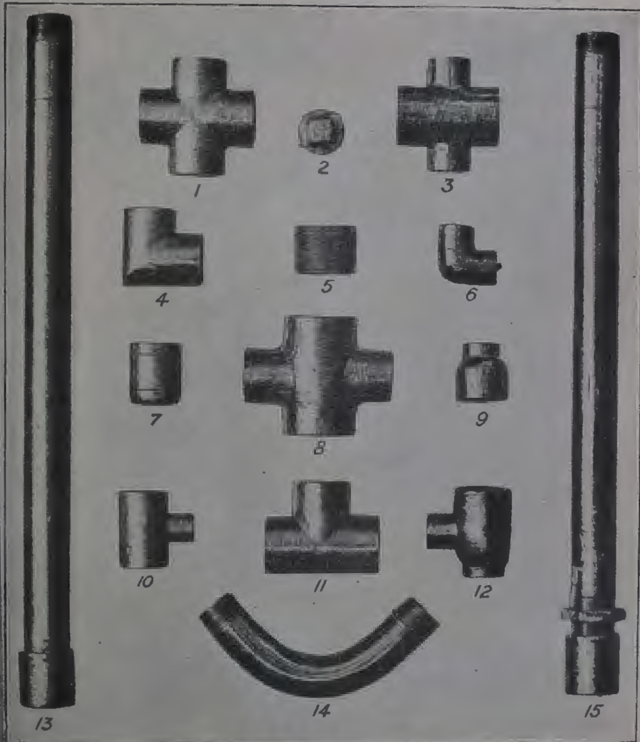
WROUGHT IRON PIPES AND FITTINGS.



REFERENCES.

1. Cross. (Equal arms.)
2. Plug.
3. Cross. (Unequal arms.)
4. Elbow. (Square.)
5. Nipple.
6. Elbow. (Round.)
7. Cap.
8. Cross. (Unequal arms.)
9. Diminishing socket.
10. Tee. (Unequal arms.)
11. Tee. (Equal arms.)
12. Tee, with diminishing socket.
13. Tube.
14. Bend.
15. Tube, long screw or connector.

BRITISH STANDARD SCREW-THREADS FOR PIPES.

FIG.1.

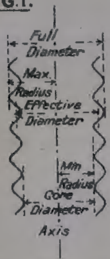


FIG.2.

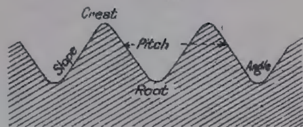


FIG.3.

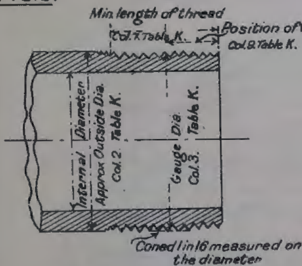


FIG.4.

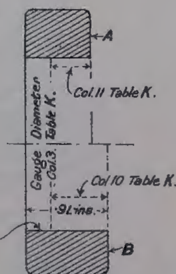
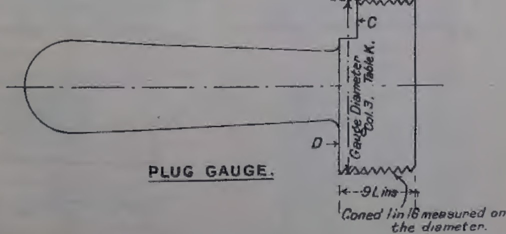


FIG.5.



PLUG GAUGE.

The above Diagrams are extracted by Permission of the British Engineering Standards Association from their Report No. 21, 1909, British Standards Pipe Threads. Official copies can be obtained from the Secretary of the B.E.S.A., 28, Victoria Street, S.W. 1, price 1/2 d. post free.

10039

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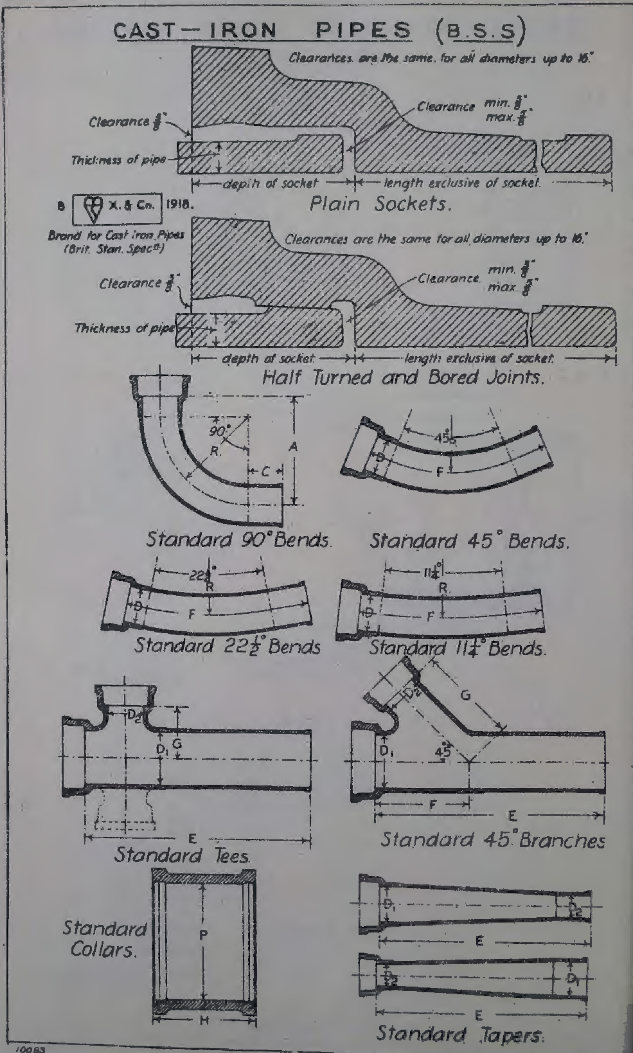
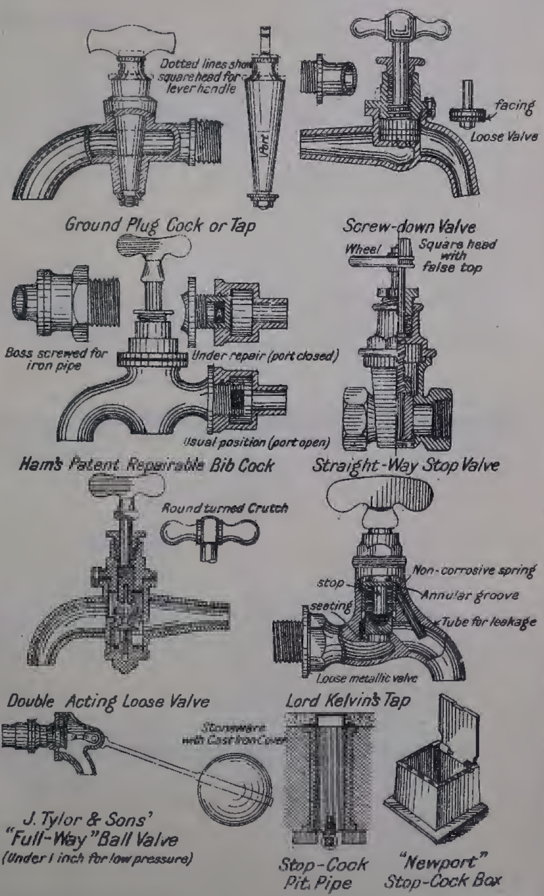
Plate 134.

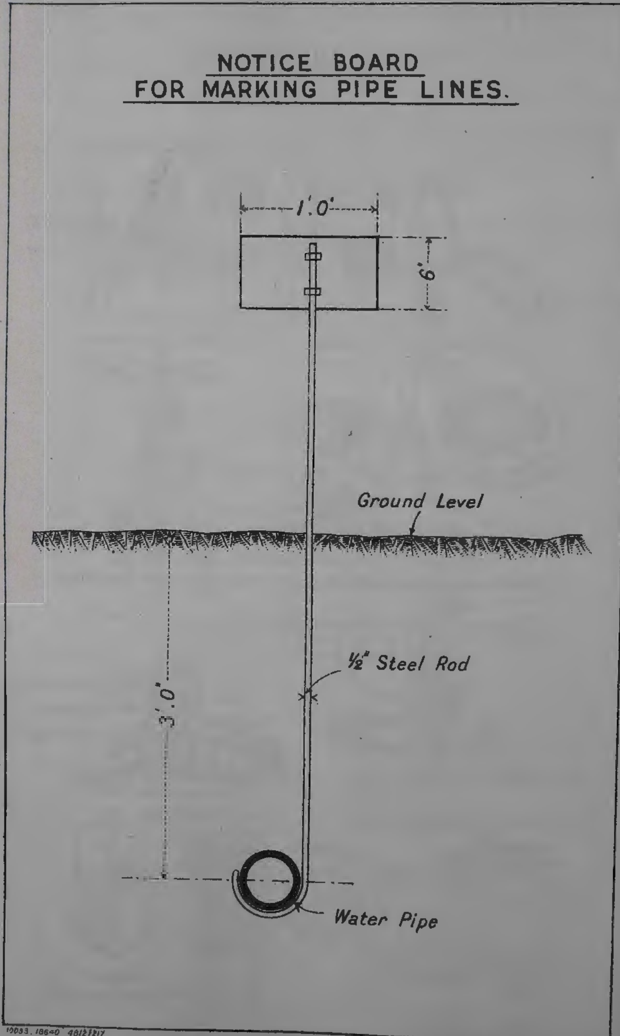


10083

COCKS AND VALVES.



Malby & Sons, Lith



10033. 18640 4812/217
Malby & Sons Lith

SLEEVES FOR REPAIR OF W. I PIPES.

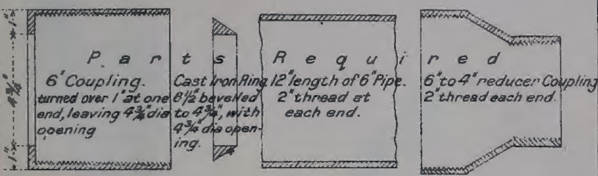
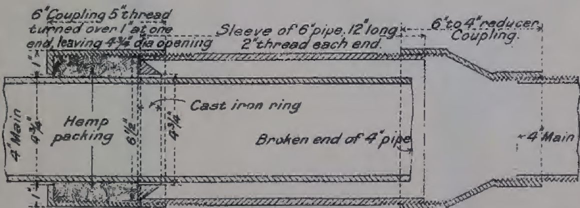


FIG. I.



LONGITUDINAL SECTION.

FIG. 2.

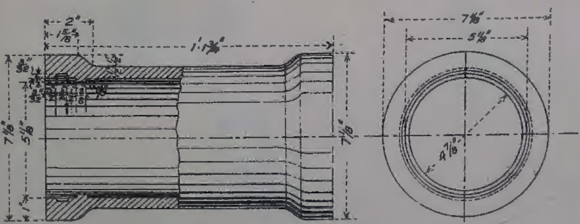


FIG. 3.

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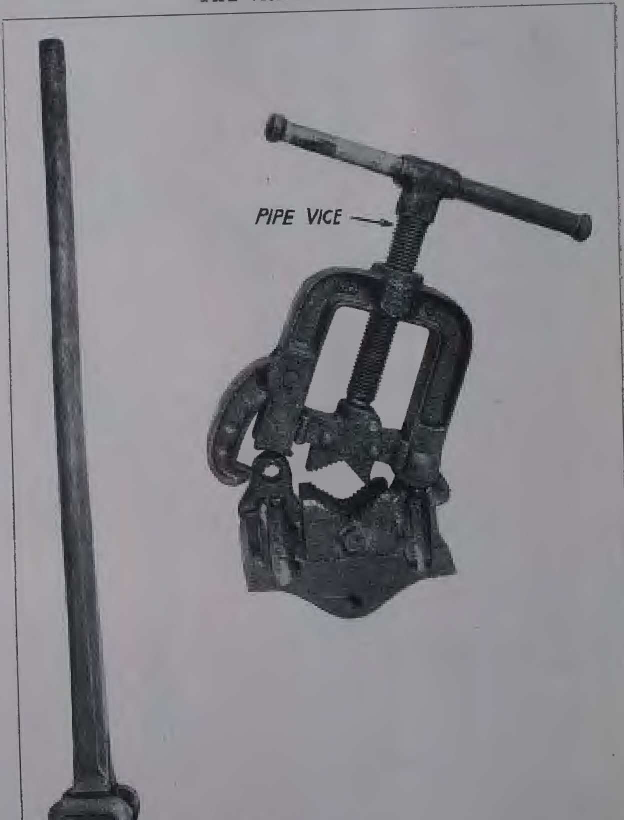
Plate 139.

PIPE VICE AND WRENCH.

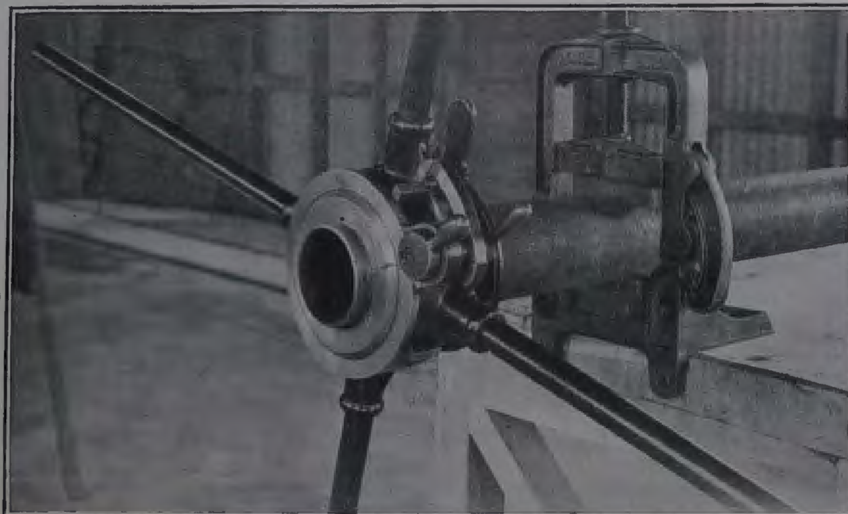


CUTTING 4-INCH PIPE BY HAND.

Plate 140.

Plate 141

Screwing 4-inch Pipe by Hand.



Beaver Type Screwing Tackle.

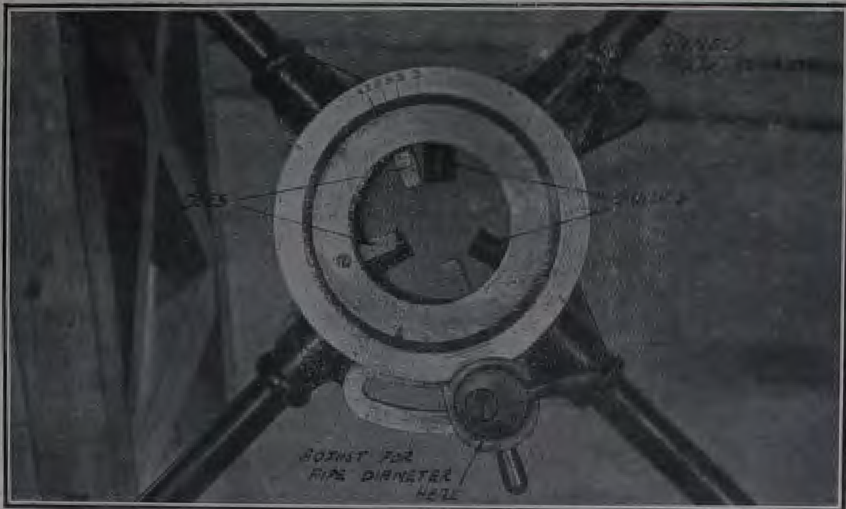
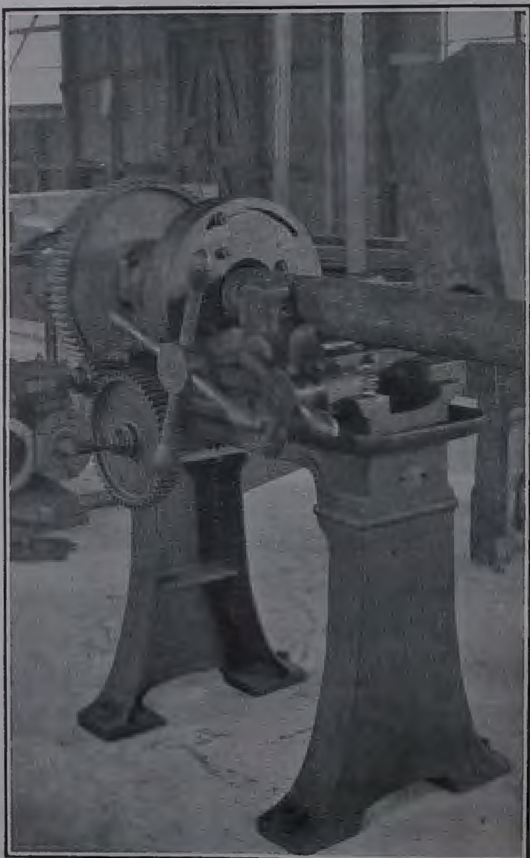


Plate 142.

Plate 143.

Screwing 4-inch Pipe in the Machine.



PIPE-LAYING CRADLE FOR 4" PIPES.

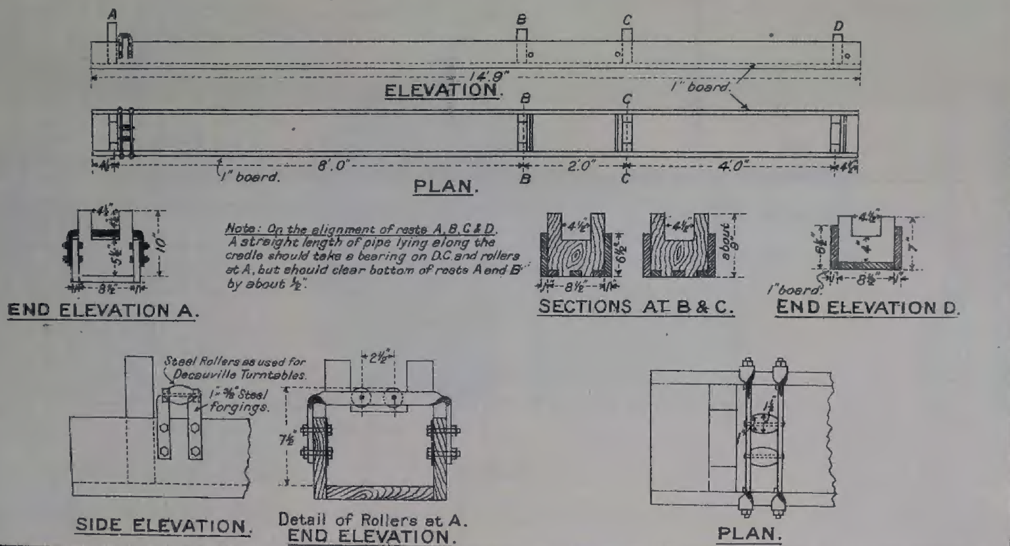


Plate 144.

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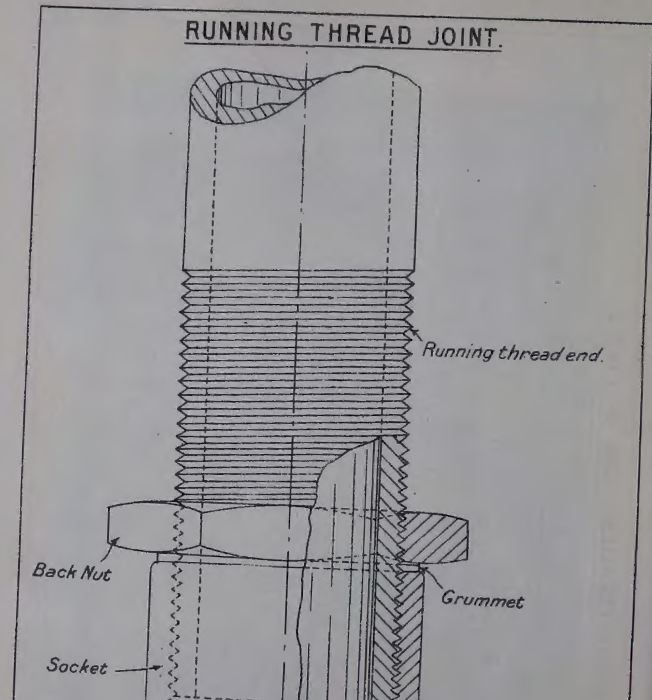
18000.12660/4.818/977

Plate 145.



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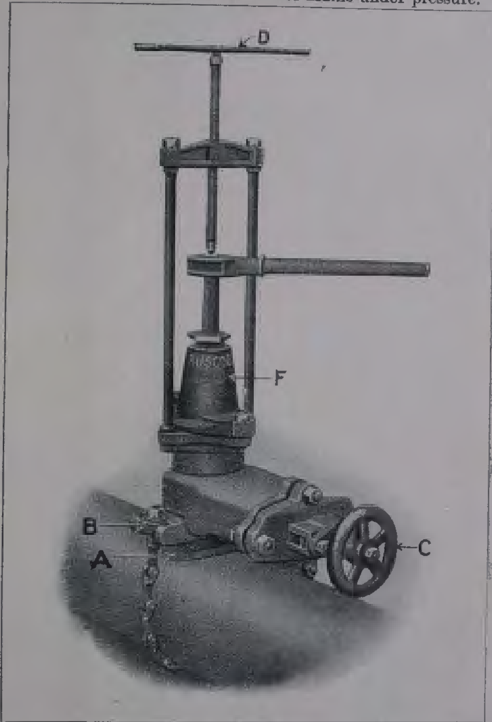
MAIN-TAPPING MACHINE

For Service connections on Water Mains under pressure.



Briefly described, the operation of inserting ferrules, &c., in water mains is as follows :—Having selected and placed in position the right size of loose saddle A, to which is attached a rubber ring for making the joint, pass chain round the pipe and screw up by adjusting filboe B. Fit twist drill and tap in spindle, then tighten up. Open sluice valve C, apply feed D, and commence drilling. Having drilled and tapped the hole, release feed screw D, reverse the ratchet, unscrew until tap is withdrawn, when the pressure of water will force it to the top of cone F. Close sluice valve C, swing off cone F, remove the drill, and replace with ferrule and driver. Screw up cone F again, open sluice valve and insert ferrule. As everything is now ready for running the service, the machine may be removed.

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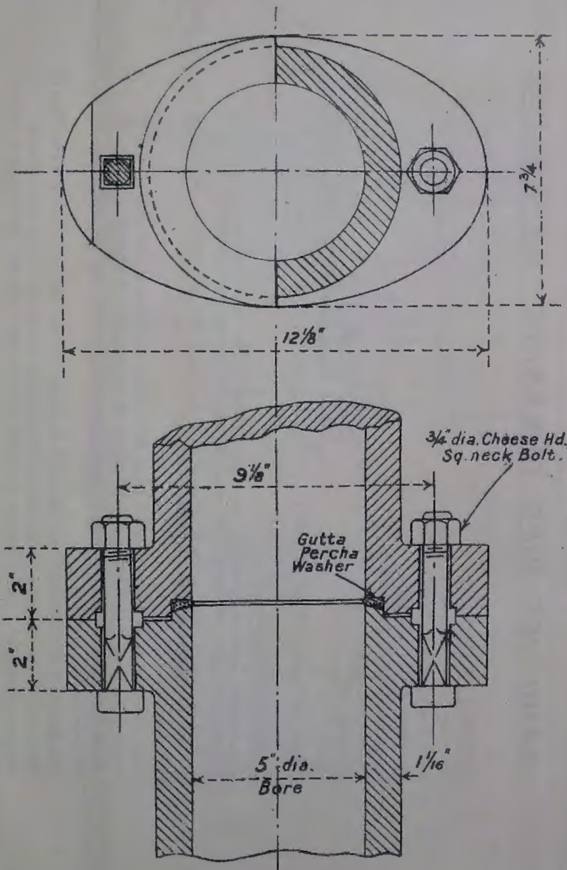
HYDRAULIC JOINT FOR 900 LBS./□" PRESSURE.



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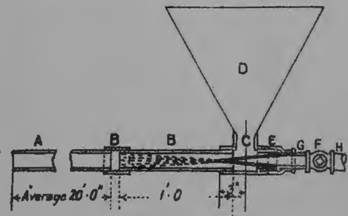
10093. 18640/14812/2177.

SAND-JET PIPE CLEANING APPARATUS.

1. INDEX TO PARTS.

A. *Foul Pipe*
B. *Socket 2" with Length of 2" Pipe 1'.0" Long.*
C. *Tee Pieces 2" × 1".*
D. *Funnel for Sand 15" Deep × 18" Dia.*
E. *Reducing Socket & Nipple 2" × 3/4" with Lock Nut.*
F. *Stop Cock 3/4".*
G. *Nozzle 3/4" to 1/8"*
H. *Flexible connection for Air or Steam.*



2. METHOD OF USE.

(a) *Secure the apparatus firmly in an ordinary vice by the Tee-Piece* G.
(b) *Screw the piece of Piping to be cleaned into the Socket* B.
(c) *Turn on the air blast through Stop Cock* F.
(d) *Feed sand gradually into Funnel* D.
(e) *Remove Pipe.*

The Air should be at a pressure of from 80 - 100 lbs. per Square Inch
About one G.S. Shovel full of sand will clean a 20 foot length of 4" Piping
To clean different sizes of piping a reducing Socket for the required size may be connected to socket B.

The best place for the end of the Nozzle G *is about 3" from the centre of the Tee-Piece* C.
This distance can be adjusted by means of the long screw thd. on the cone Nozzle.
It is essential that a short length of piping be fitted between the Tee-Piece & Socket B *in order to allow the blast to spread.*

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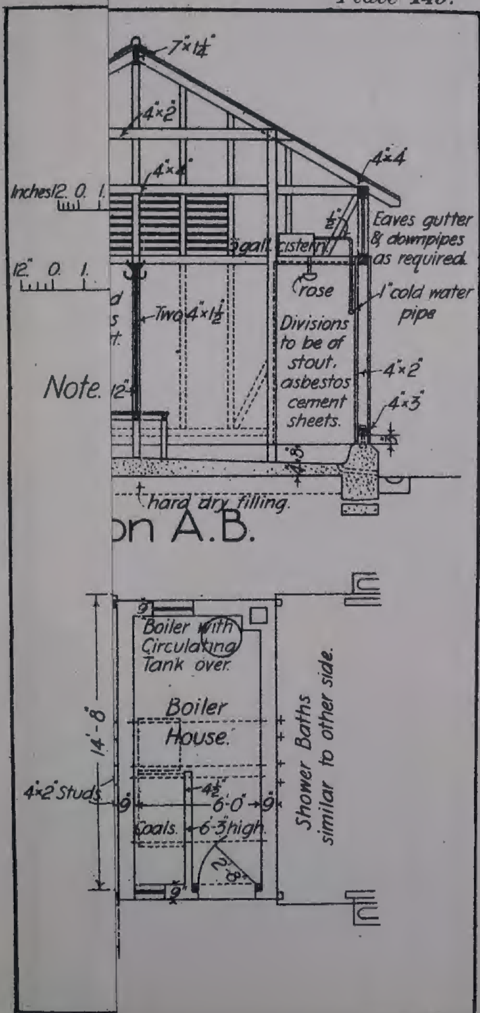


10083 18640 4812/
Malby & Sons, Lith.

BATH HOUSE.

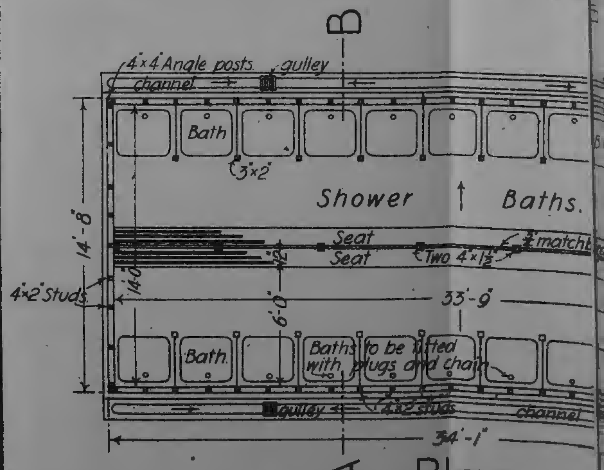
Inches 12. 0. 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. Feet.

Scale for Plan.

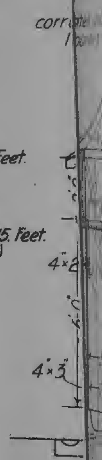
12" 0. 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. Feet.

Scale for Section.

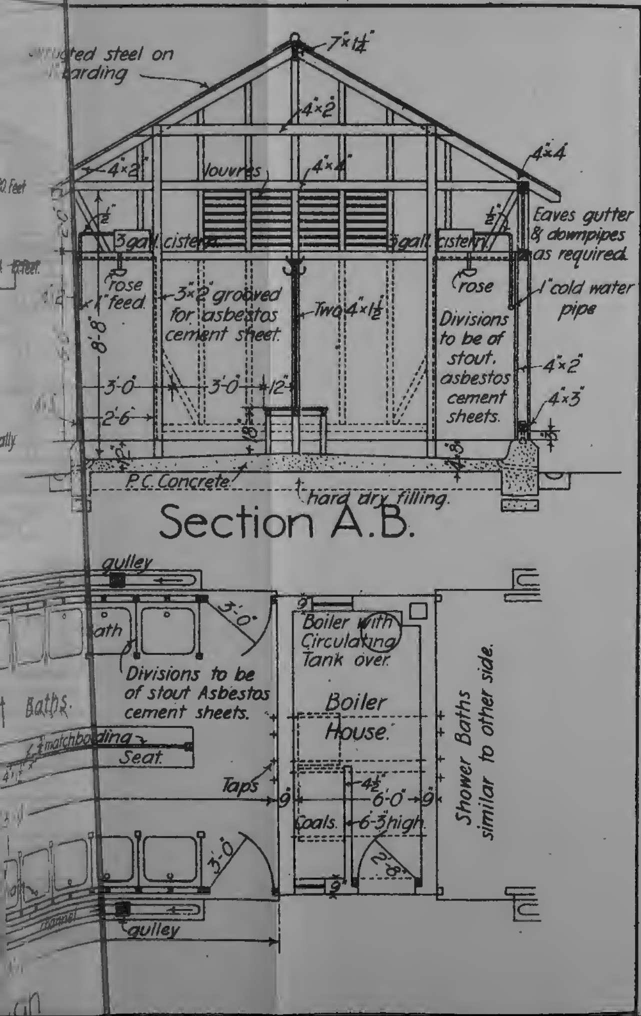
Note. Widths and depths of foundations to be determined locally.
Walls of shower baths to be covered externally and internally with asbestos-cement sheets 6'-0" high as shown.



Plan.



10093 18640 4812/317



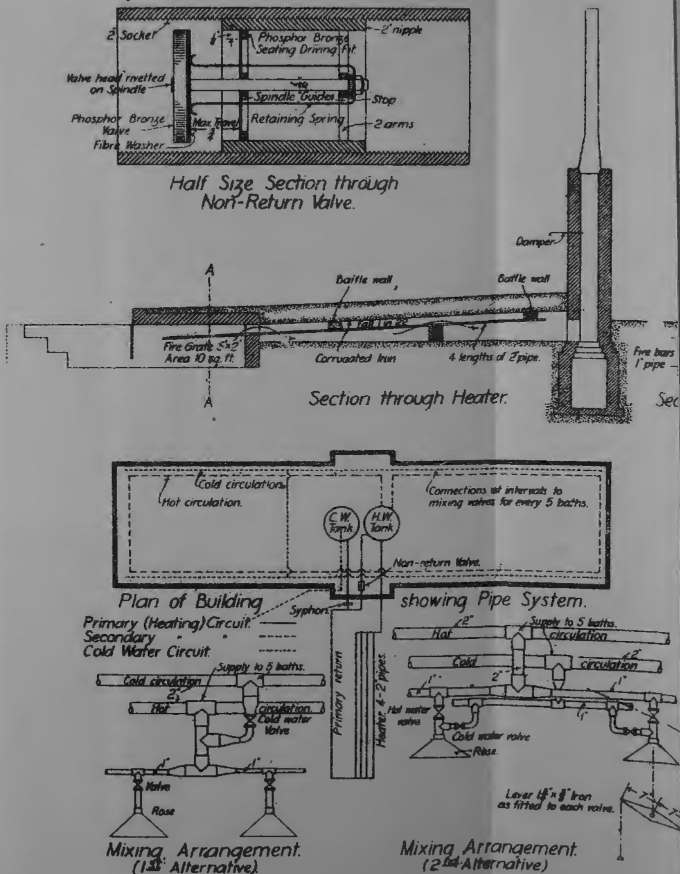
arding
7"×1¼"
4"×2"
4"×2"
louvres
4"×4"
4"×4
3 gall. cistern
3 gall. cistern
Eaves gutter & downpipes as required.
rose
1" feed
3"×2" grooved for asbestos cement sheet.
Two 4"×1½"
rose
1" cold water pipe
Divisions to be of stout, asbestos cement sheets.
4"×2"
4"×3"
8'-8"
3'-0"
3'-0"
12"
2'-6"
18"
P.C. Concrete.
hard dry filling.
Section A.B.
gulley
Bath
3'-0"
Boiler with Circulating Tank over.
Divisions to be of stout Asbestos cement sheets.
Baths.
Boiler House.
Shower Baths similar to other side.
Seat.
Taps
4½"
9"
6'-0"
9"
Coals.
6'-3" high.
2'-8"
3'-0"
9"
gulley

TEMPORARY B[...]

Hot and Cold [...]

A

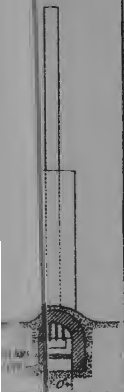
Large Bath House. (40 Shower Baths.)



10093 18640 4812/217

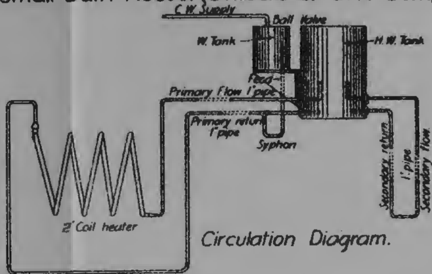
B TH HOUSES.

ld /ater Supply.

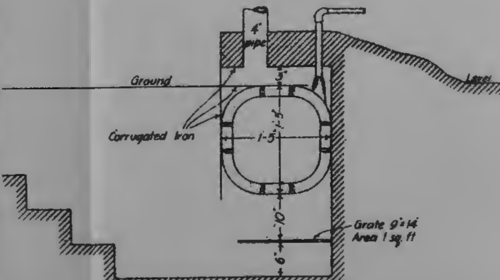


B

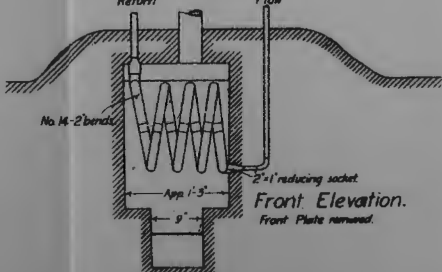
Small Bath House. (Officers or One Company)



Circulation Diagram.



Section through Heater.



Front Elevation.
Front Plate removed.

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HYDRAULICS — I.

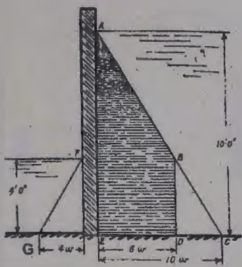

FIG. 1. *Pressure on submerged surface.*

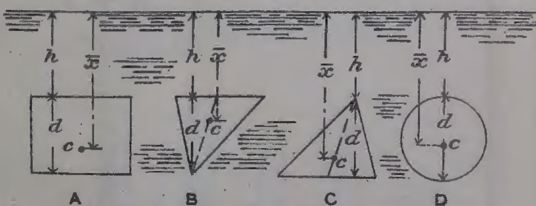

Figure.	A	B	C	D
$\bar{x}$	$\frac{2}{3}\left\{\frac{3h^2+3hd+d^2}{2h+d}\right\}$	$\frac{6h^2+4hd+d^2}{6h+2d}$	$\frac{6h^2+8hd+3d^2}{6h+4d}$	$h+\frac{d^2}{16h}$

FIG. 2. *Equilibrium of floating bodies.*

10093.16640.4812/217.10000.11.22 Malby & Sons Lith.

Plate 152.

HYDRAULICS — 2.

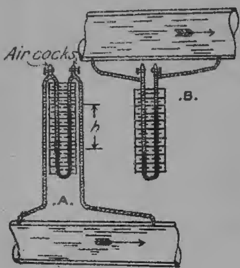

FIG. 1. *Manometer Tubes.*

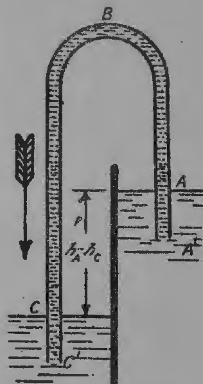

FIG. 2. *Siphon*

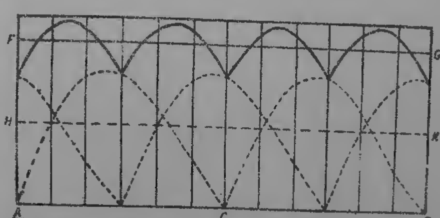

FIG. 3. —Curve for Pair of Double-Acting Pumps with Cranks at Right Angles.

16640 4871/317

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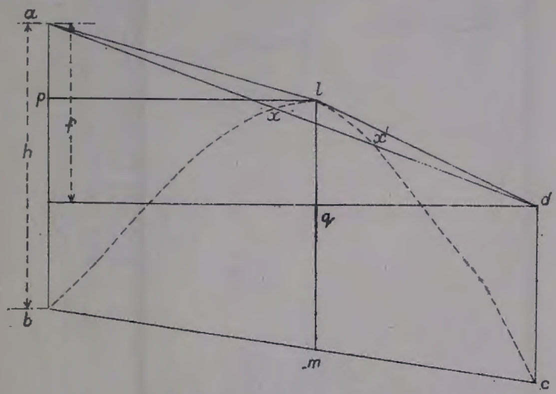

FIG. I. HYDRAULIC GRADIENT.

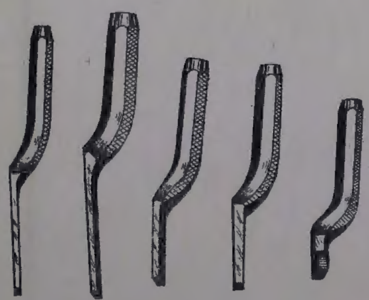

FIG. 2. SPECIAL SHAPED CAULKING TOOLS.

10038 - 18000 - 4612/217
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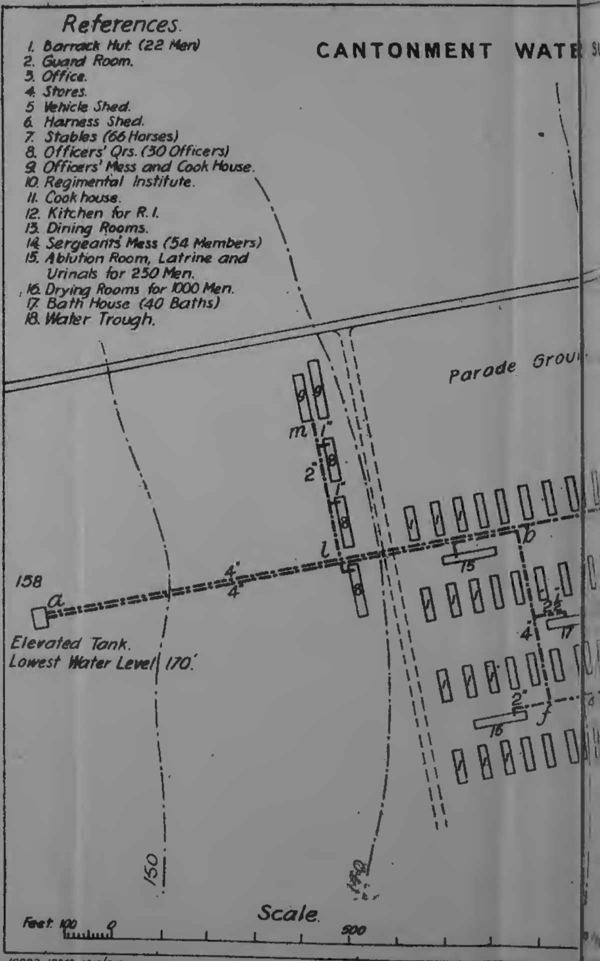
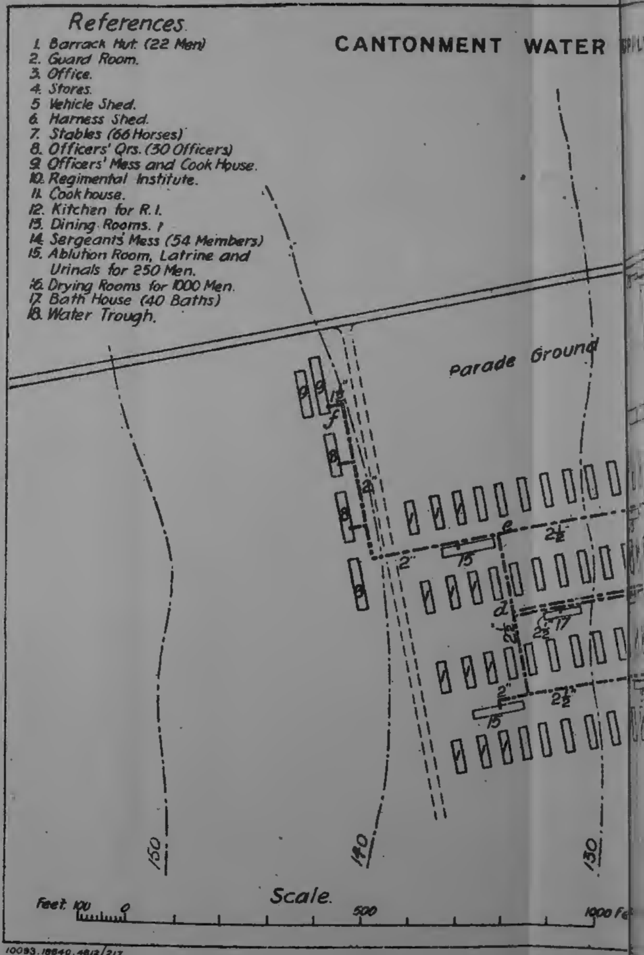


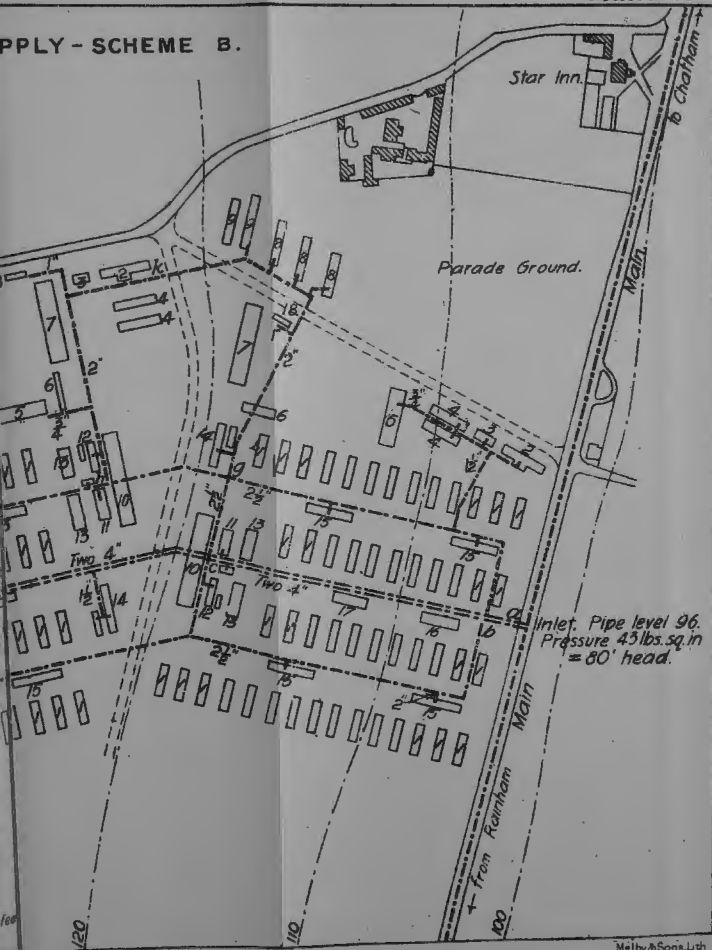
10093. 18640. 4812/217



10093.18840.4812/217

Plate 155.

PPLY - SCHEME B.



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PLUNGER PUMPS.

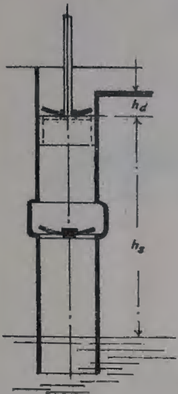


FIG.1. Bucket & lift pump

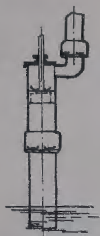


FIG.2. Single acting force pump

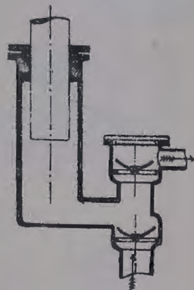


FIG.3. Single acting plunger pump

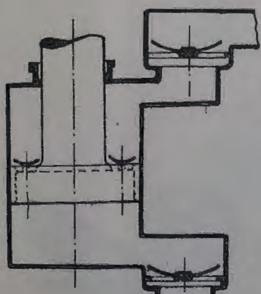


FIG.4. Bucket & plunger pump

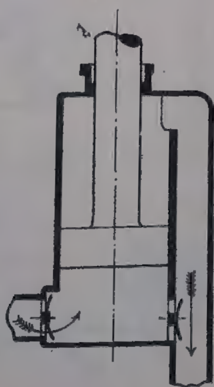


FIG.5 Piston & plunger pump

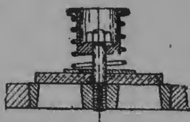
Reproduced from Gibson's "Hydraulics".

Malby & Sons Lith

Plate 157.

PUMP VALVES.

FIG. 1.

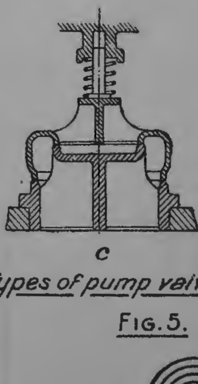


a

FIG. 2.

b

FIG. 3.



c

Types of pump valves.

FIG. 4.

FIG. 5.

The Gutermuth Valve .

10083.16840.4812/217 Reproduced from Gibson's "Hydraulics" Malby & Sons, Lith

CENTRIFUGAL PUMPS — I.

FIG. 1.

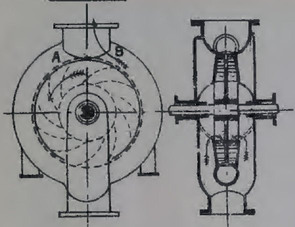


FIG. 2.

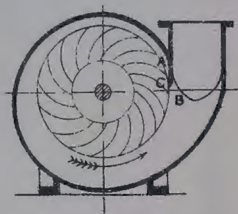


FIG. 3.

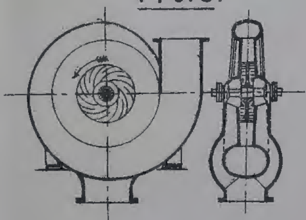


FIG. 4.

16693/18646/4812/217. *Reproduced from Gibson's "Hydraulics".*

Malby & Sons Lith.

Plate 159.

CENTRIFUGAL PUMPS-2.

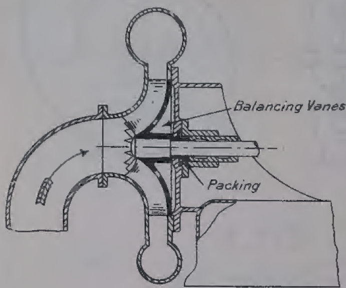


FIG.1.

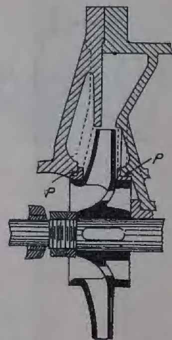


FIG.2.

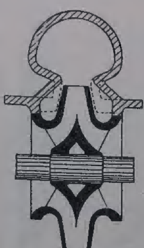


FIG.3.

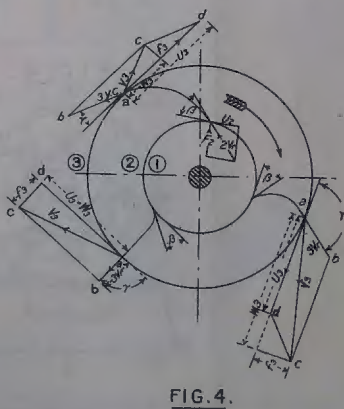
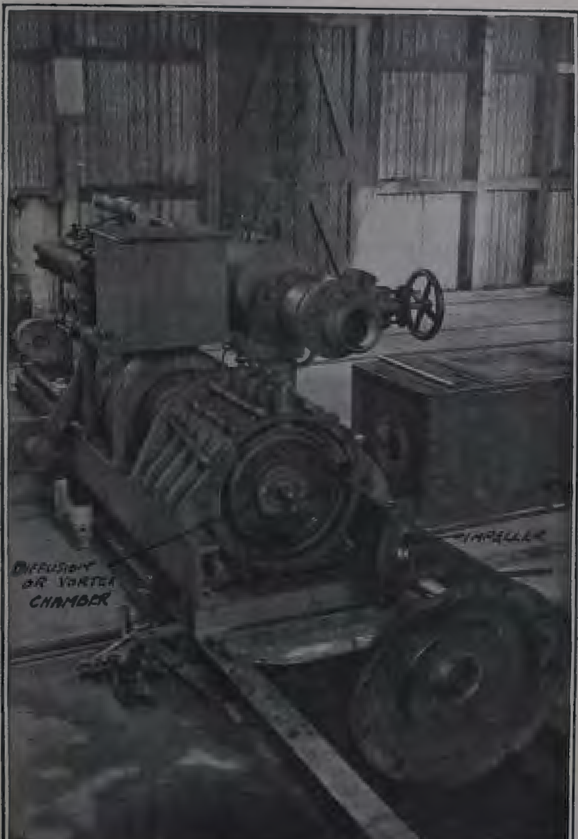


FIG.4.

10033.18640.4812/2/7. *Reproduced from Gibson's "Hydraulics".* Malby & Sons Lith.

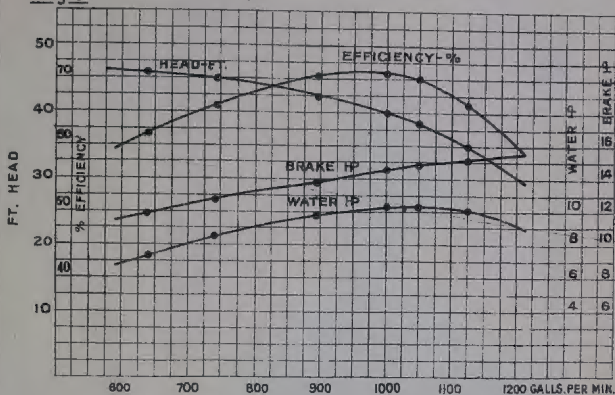
Plate 160.

DETAILS OF TURBINE PUMP



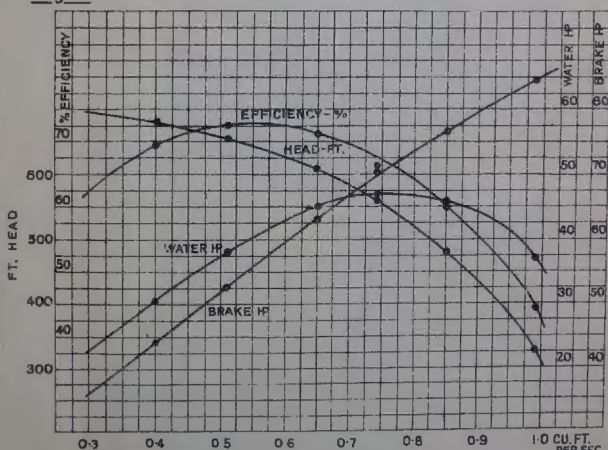
CHARACTERISTIC CURVES.

Fig. 1.



Characteristic Curves for Single Low-Lift Centrifugal Pump with Recurved Vanes.

Fig. 2.



Characteristic Curves from 4-Stage Quadruple High-Lift Pump with Radial Vanes.

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Horrocks' Testing Case for Chlorine Absorption.

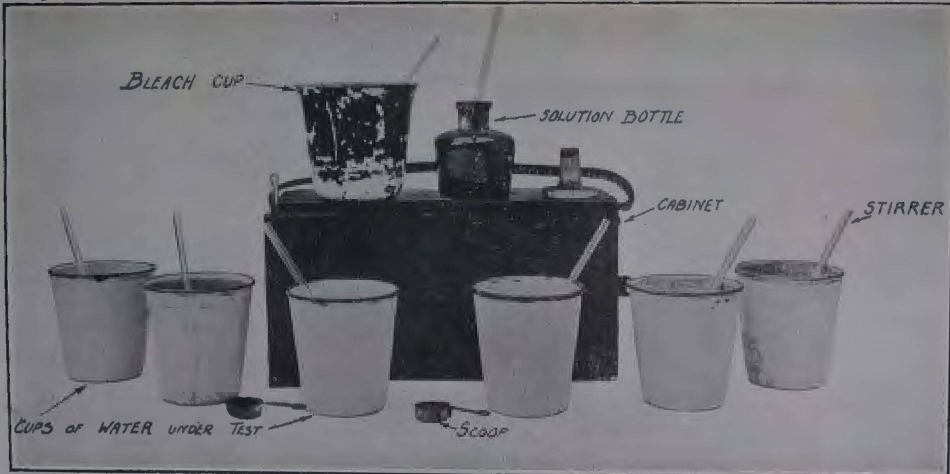
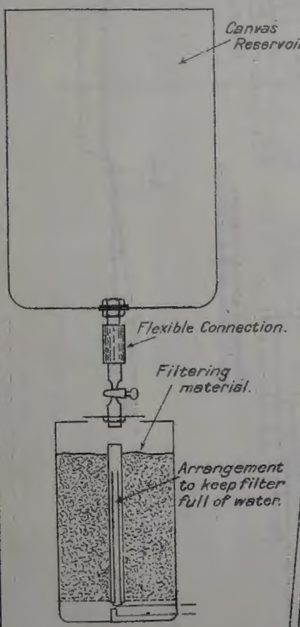


Plate 162.

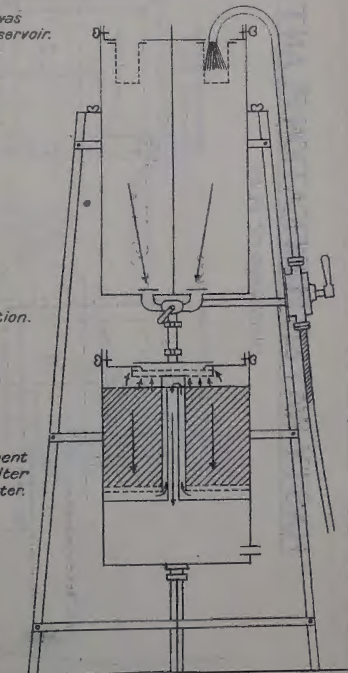
SMALL PORTABLE FILTERS.

FIG. I.



Coolie pack filter.

FIG. 2.



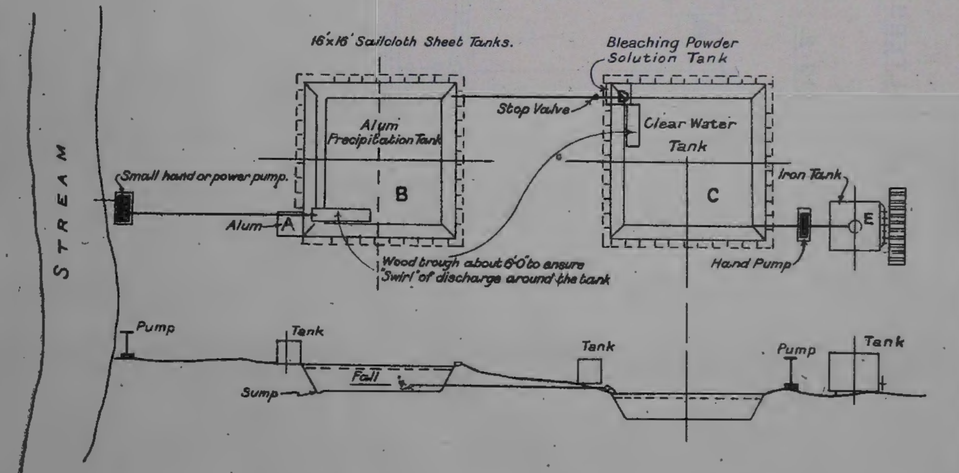
Mule pack filter.

Malby & Sons, Lith.

Plate 164.

HASTY WATER PURIFICATION PLANT

DIAGRAMMATIC PLAN



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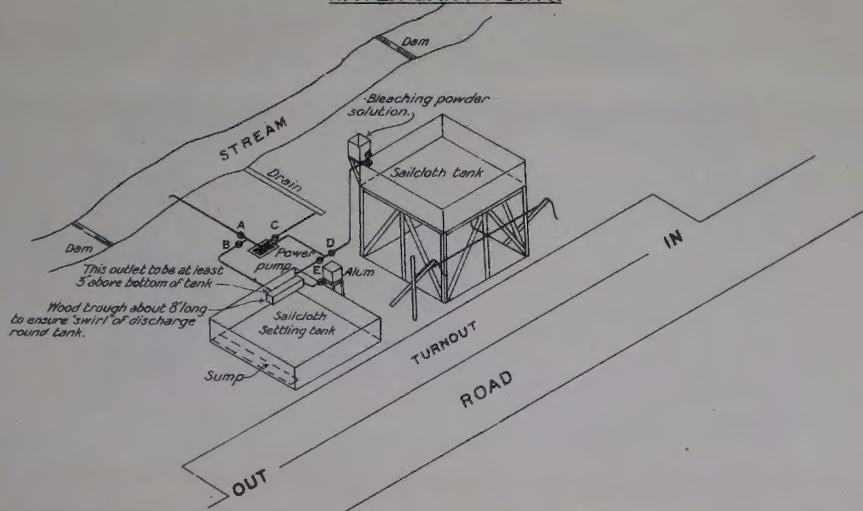
IMPROVISED WATER PURIFICATION PLANT COMBINED WITH WATER CART POINT.



10083.

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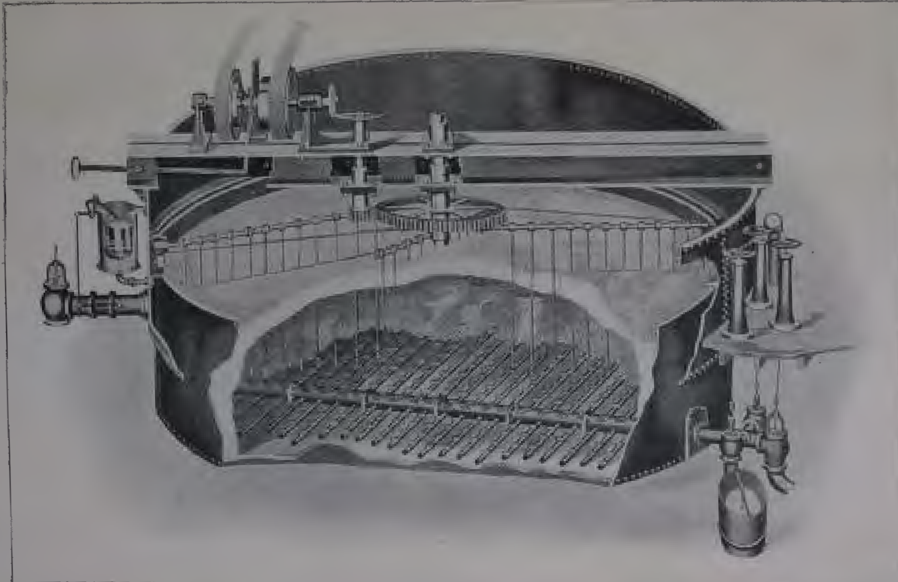
Plate 165.

JEWELL GRAVITY FILTER.



Reproduced by permission of the Jewell Export Filter Co., 8 Lendal, York.

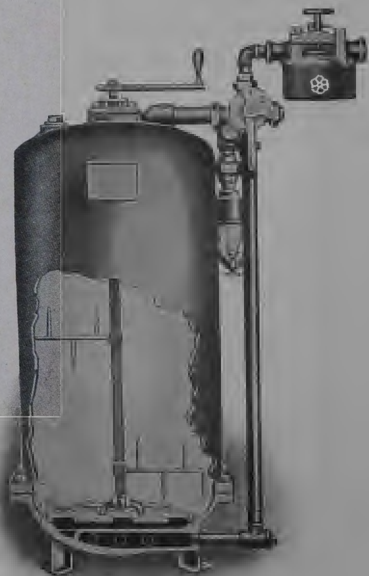
Plate 166.

Plate 167.

JEWELL PRESSURE FILTER.

(Household type.)

12″, 16″, and 20″ diameter.



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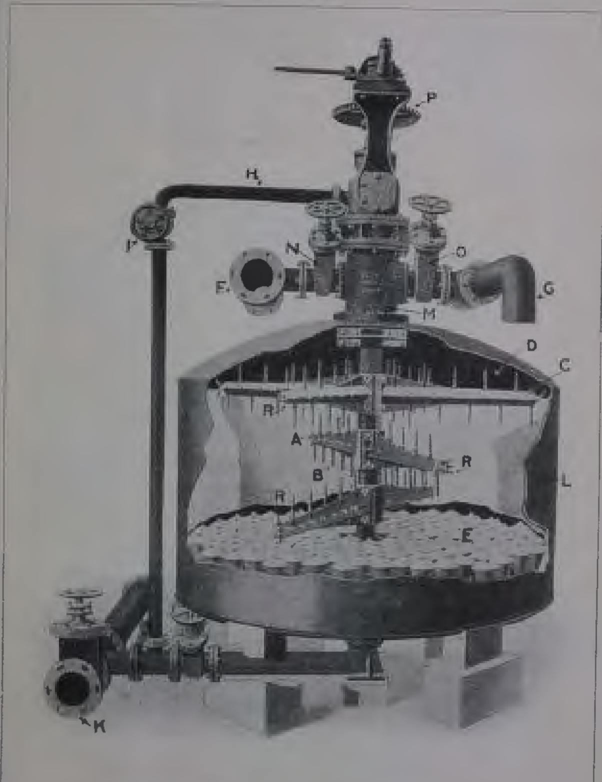
BELL FILTER.

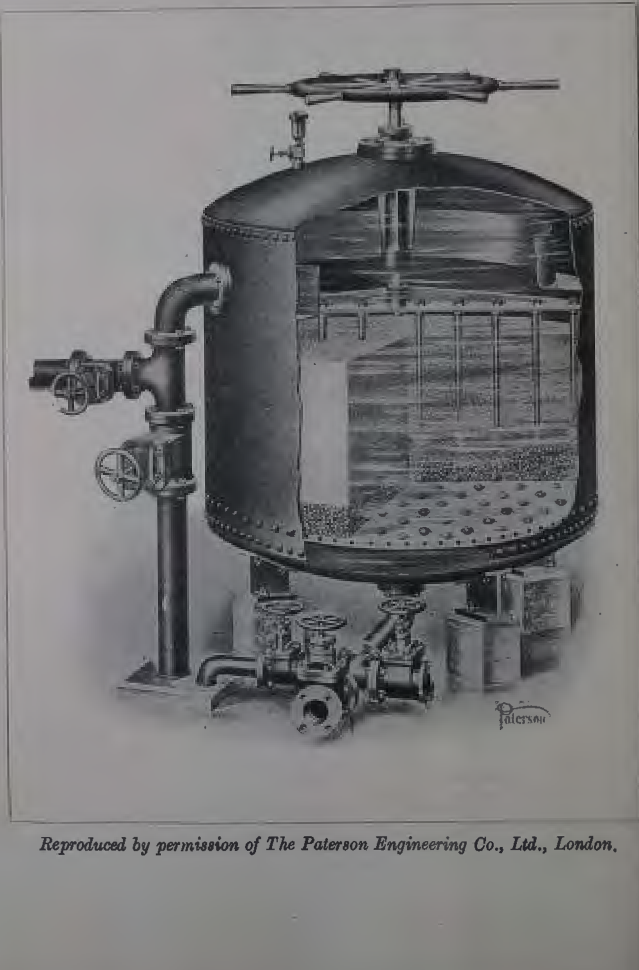


A—Valves in wash arms.
B—Rakes on wash arms.
C—Hydraulic hollow wash arms.
D—Hydraulic hollow shafts.
E—Perforated strainers.
F—Inlet pipe for dirty water.
G—Wash-out pipe for cleaning.
H—Top pipe.
I—Vertical wash valve.
K—Outlet for filtered water.
L—Steel filter shell.
M—Top block on shell.
N—Inlet valve for dirty water.
O—Washout valve.
P—Bevel wheels.
R—End rakes.

Reproduced by permission of Bell Bros. (Manchester), Ltd.

Plate 169.

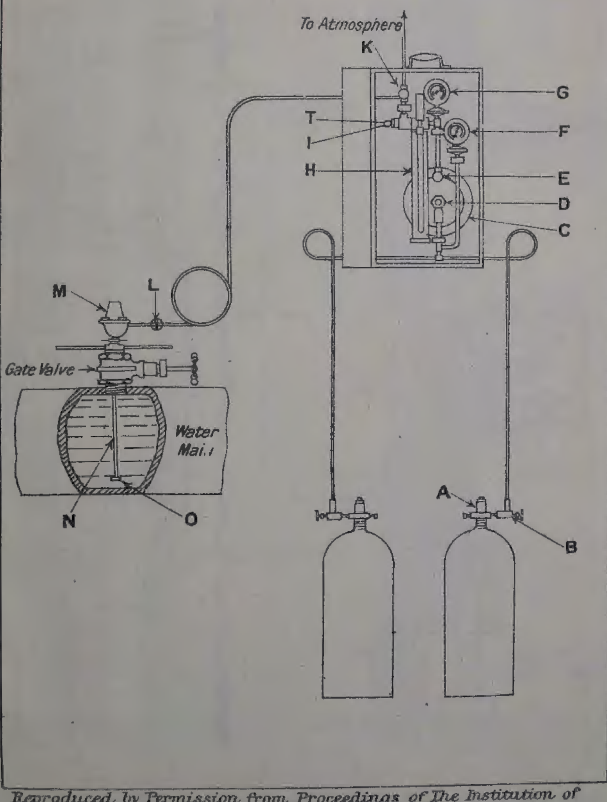
PATERSON FILTER.



Reproduced by permission of The Paterson Engineering Co., Ltd., London.

THE WALLACE-TIERNAN CHLORINATOR.

DIAGRAM OF APPARATUS.



Reproduced by Permission from Proceedings of The Institution of Mechanical Engineers, 1920, Page 1127, Fig 3, from a Paper on the "Sterilization of Water by Chlorine Gas", by Captain J. Stanley Arthur, O.B.E., B.Sc., A.I.C., R.A.M.C. (T.F.).

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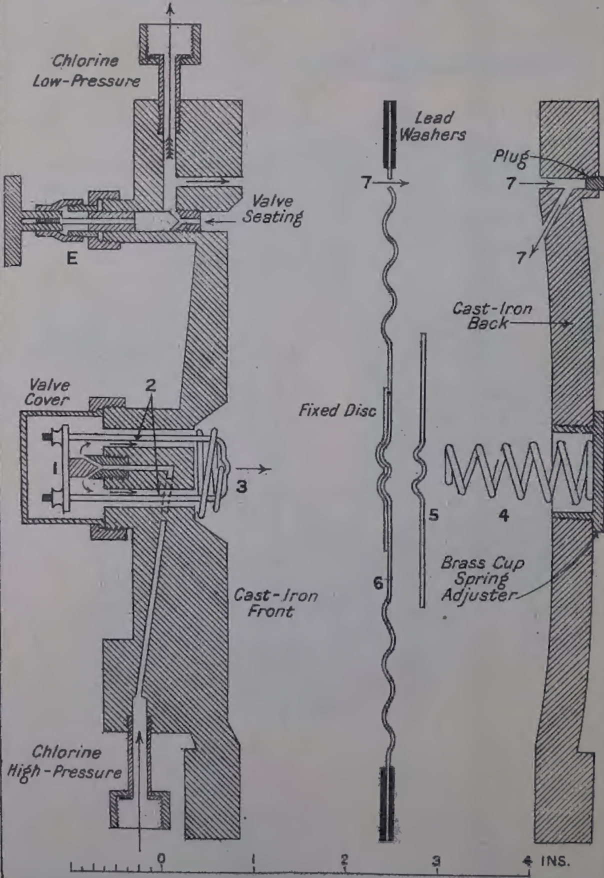
10093.

THE WALLACE-TIERNAN CHLORINATOR.

ENLARGED SECTION OF COMPENSATOR.

C. IN PL. 170.



Reproduced by Permission from Proceedings of The Institution of Mechanical Engineers 1920, Page 1127, Fig 4, from a Paper on the "Sterilization of Water by Chlorine Gas", by Captⁿ. J. Stanley Arthur, O.B.E., B.Sc., A.I.C., R.A.M.C. (T.F.).

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THE WALLACE-TIERNAN CHLORINATOR.

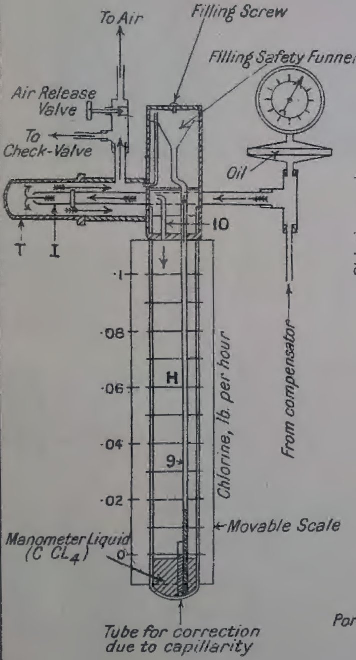


FIG. I. ORIFICE (I) AND MANOMETER (H)

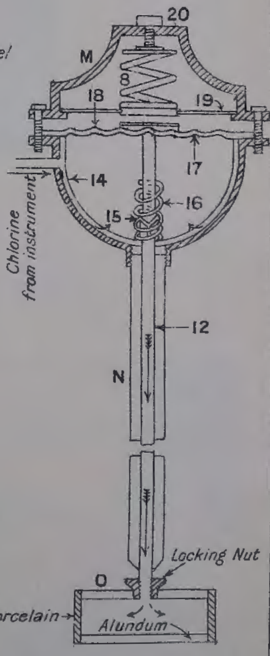
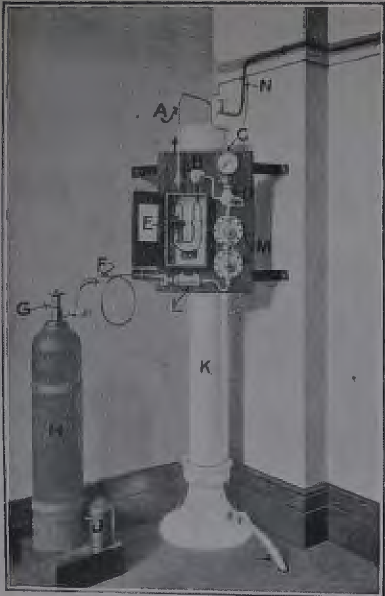


FIG. 2. CHECK-VALVE (M) AND DIFFUSOR. (O)

Paterson Chloronome.



Liquid Chlorine Dispenser.

A.—Chlorine supply pipe to absorption tower.

B.—Regulating valve.

C.—Chlorine pressure gauge.

D.—Stop valve.

E.—"Chloronome" or pulsating meter.

F.—Connecting tube.

G.—Cylinder stop valve.

H.—Chlorine cylinder.

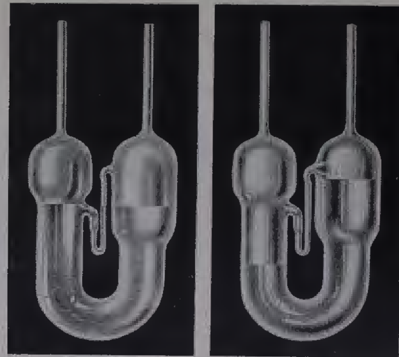
J.—Cylinder cap.

K.—Chlorine absorption tower.

L.—Filter.

M.—Pressure reducing valves.

N.—Water supply pipe to absorption tower.



(a) (b)

Chlorine Meter showing position of Liquid Piston.

(a) At commencement of stroke.
(b) At end of stroke.

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THE TURN-OVER FILTER.

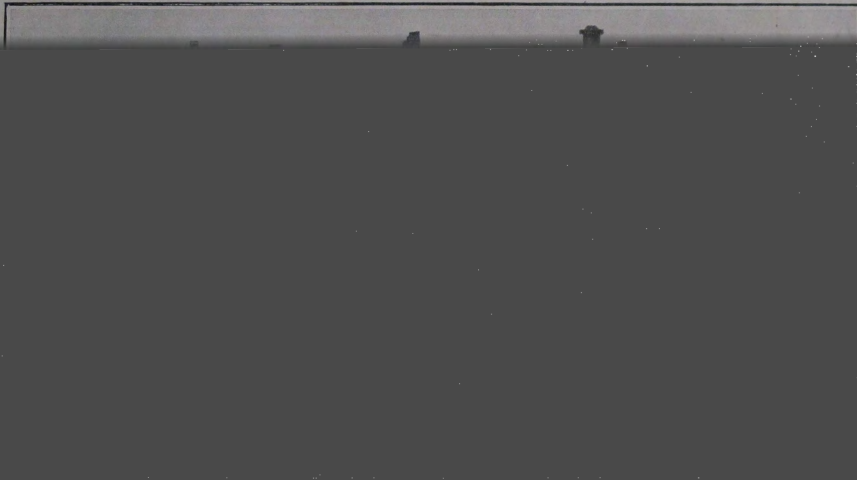
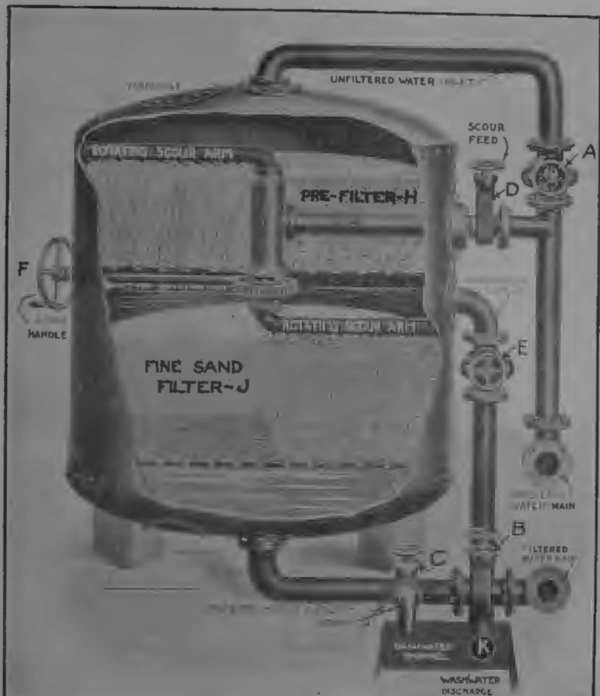


Plate 17

CANDY COMPOUND FILTER.



Valve A controls inlet of unfiltered water to the filter; valve B controls outlet of filtered water from the filter, also inlet of filtered water to filter for the upward wash; valve C is for emptying filter of water when required; valve D controls inlet of water to the hydraulic scour arms; valve E controls outlet of dirty wash water; the mouth of the wash water pipe is shown at K; F is the handle by which the scour arms are rotated; H is the coarse pre-filter resting on a perforated floor; J is the fine filter-bed resting on a floor furnished with special gun-metal nozzles.

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RAMSOME CONTINUOUS FILTER.

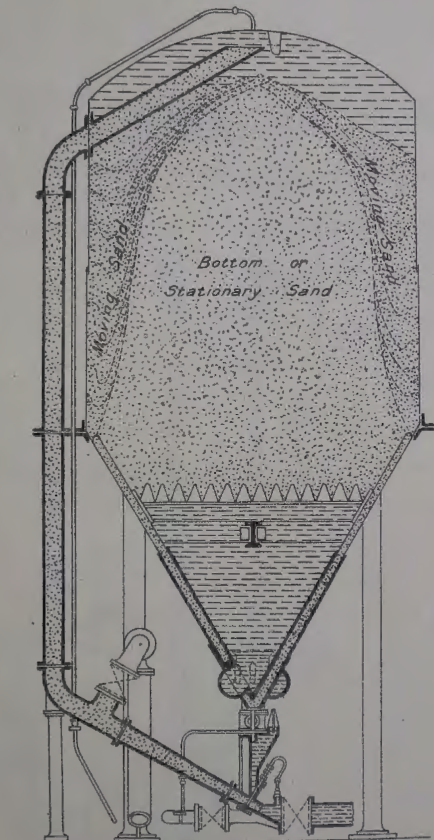

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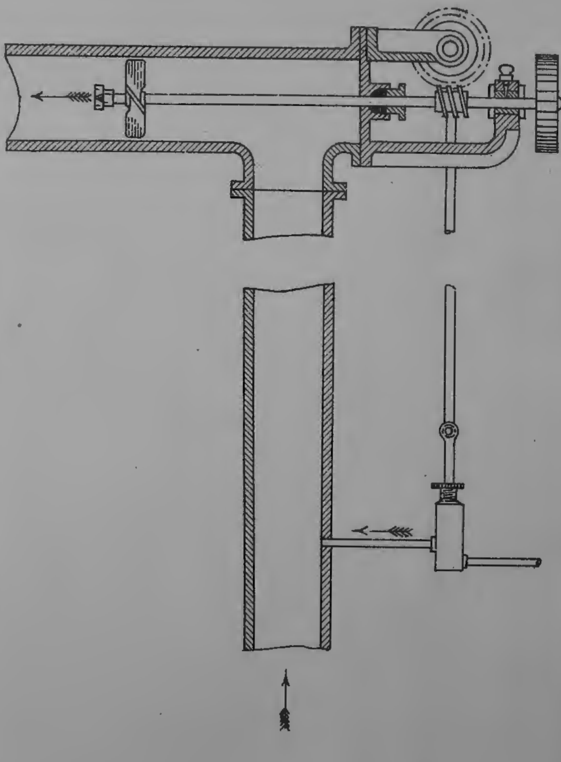
Plate 177.

TURBINE COAGULANT FEED.



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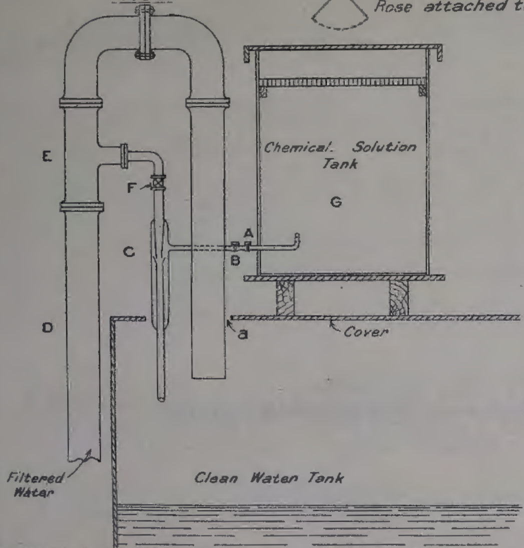
CHLORINATING APPARATUS.

FIG. 1.



A and B are Stop Cocks. a is a hole in the cover of the clean water reservoir of size suitable to allow the delivery pipe to pass, also the Filter Pump C. This is of the type sold by apparatus makers (Chemical) usually in glass, but can be obtained in metal. D is the pipe (usually 4") delivering the filtered water. E. is a T piece with a 2" side tube to which a 1" pipe fitted with a stop cock F. is bolted or screwed and to which the filter pump C is attached. The chemical Solution tank G. stands on the cover of the clean water tank.

FIG. 2.

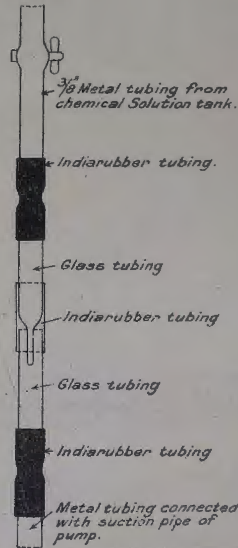


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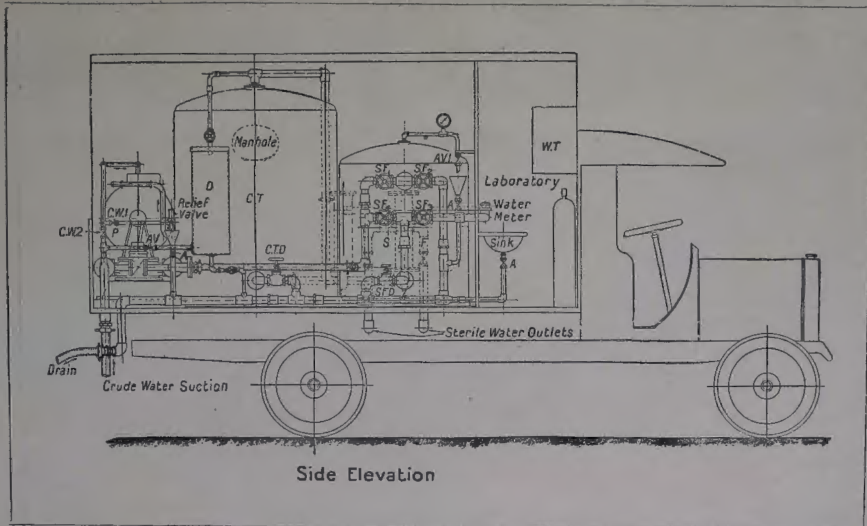
Plate 178.

STERILIZING LORRY. DIAGRAM.



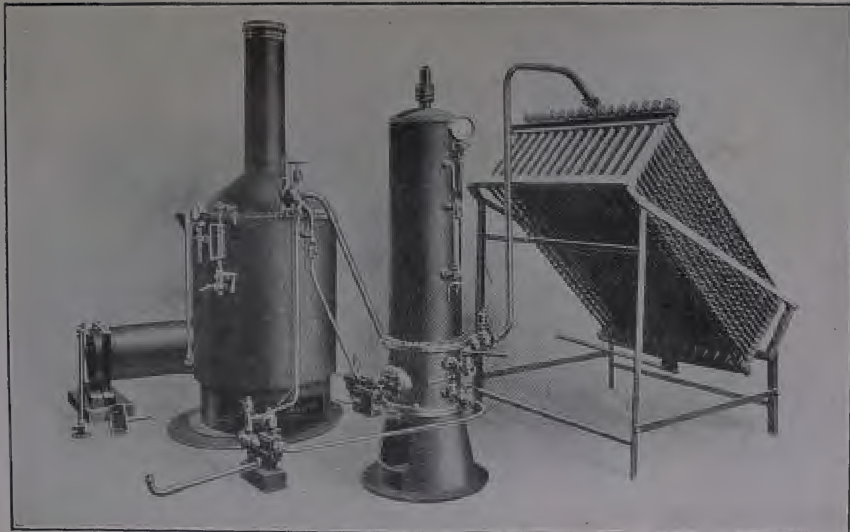
Reproduced by permission of United Water Softeners, Ltd., Kingsway, W.C. 2, who designed and constructed the equipment.

Plate 179.

STERILIZING LORRY READY FOR THE ROAD.

Reproduced by permission of United Water Softeners, Ltd., Kingsway, W.C. 2, who designed and constructed the equipment.

Combined Evaporator and Air Condenser (Row's Patent).



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